PRECAST CONCRETE
Materials, Manufacture, Properties and Usage

PRECAST CONCRETE

Materials, Manufacture, Properties and Usage

M.LEVITT
ARCS, BSc, DIC, PhD

Head—Materials Science Department,
John Laing Research and Development Limited,
Borehamwood, Hertfordshire, UK

APPLIED SCIENCE PUBLISHERS
LONDON and NEW JERSEY

This edition published in the Taylor & Francis e-Library, 2004.

APPLIED SCIENCE PUBLISHERS LTD
Ripple Road, Barking, Essex, England

APPLIED SCIENCE PUBLISHERS, INC
Englewood, New Jersey 07631, USA

British Library Cataloguing in Publication Data

Levitt, M.
Precast concrete.
1. Precast concrete
I. Title
691′·3 TA683·7

ISBN 0-203-49057-6 Master e-book ISBN

ISBN 0-203-79881-3 (Adobe eReader Format)
ISBN 0-85334-994-0 (Print Edition)

WITH 40 TABLES AND 109 ILLUSTRATIONS

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to John Laing Research and Development and The British Precast Concrete Federation Limited for their permission to publish this book. In particular the encouragement of Laing should be mentioned, with particular reference to assistance given by Cyril Hobbs, the Laing Group's Scientific Adviser, as well as the Precast Concrete Federation's declassification of a great deal of the originally restricted research data.

Gratitude is also expressed to the following precast concrete manufacturers who not only supplied illustrations, but many of whom also took upon themselves the task of checking the technical accuracy of many parts of the original manuscript.

Bardon Hill Quarries Limited
Beton Machinery Sales Limited
Dean Jesmond & Co.
ECC Quarries Limited
Forticrete Limited
Richard Lees Limited
Marshalls of Halifax
Redland Tiles Limited
Rocla Pipes Limited
Thermalite Limited

INTRODUCTION

This book is intended to meet the need for a general treatise on precast concrete, as the last relevant book on this subject was published in 1961. Since then there have been several publications dealing with particular parts of the subject which serve as useful back-up reading, but the precast concrete industry is complex and needs to be discussed in both general and particular terms over a large number of subject areas.

The book is aimed not only at people who have considerable experience but also at those new to the subject. Both of these groups of people will wish to extend their knowledge, either in their existing fields or new ones. Although high degrees of knowledge of mathematics, physics, chemistry and engineering are not required of the reader, it is assumed that he or she will have had two or three years of what may be loosely and internationally described as further education. Specifiers, manufacturers, contractors and teachers will all find something of use.

Engineering design and detailing are not covered in this book but details of materials, properties, manufacture and usage are discussed in as full a way as possible. Most of the data, although based upon UK experience, are equally applicable in other countries. Care has been taken to ensure that no matter what process, environment or materials are under consideration the reader will be able to abstract the data required to facilitate production and use of as good a quality product as possible.

The common factors in precast concrete products are aggregates, hydraulic cement and water, coupled with a technique for moulding these into a required shape. Although certain rules and guidelines can be laid down, technology can only be used part of the way, as 'know-how' and a large degree of 'alchemy' play important roles. One of the purposes of this book is to outline how far one can take the technology and when one needs to develop one's own experience. All that is asked of the reader is the same number of degrees of flexibility as there are variables relating to the properties of the final product. A rigid philosophy will not bear fruit, therefore, great care should be exercised to take a number in its context and not treat it as sacrosanct.

The reader should also bear in mind that imparting good practice information rarely breaches secrecy and will always result in a better image for the industry as a whole. Bad performance, whether due to design, materials and/or workmanship, is news that travels fast and even the innocent suffer in the aftermath. Since precast concrete is often one of the choices open to the specifier no one can be excused for promoting the alternatives through their own errors. Pride in the product is the aim and this is easy to achieve. Should any of the basic rules or guidelines be ignored one will find that there is only one rule and that is that the percentage number of rejects is inversely proportional to the control one has.

BIBLIOGRAPHY

H.G.CHILDE, *Concrete Products and Cast Stone,* Concrete Publications, London, Ninth Edition, 1961.

Architectural Precast Concrete, Prestressed Concrete Institute, Chicago, 1973.

J.G.RICHARDSON, *Formwork Construction and Practice,* Cement and Concrete Association, London, 1977.

CONTENTS

1

MOULDS AND MATERIALS

With the exception of admixtures and fly ash, all moulds and materials are discussed in this chapter. None of the factors listed can be considered in isolation since variation in one will often affect another. Mix design for various forms of precast manufacture is dealt with in Chapter 6. The purpose of this chapter is to acquaint the reader with all the starting variables. The background picture will then be fully understood before one proceeds to put these variables into a process, in order to produce a precast concrete product.

1.1 MOULDS

Moulds are basically means by which:

(a) concrete is kept to a required shape until it is strong enough to be demoulded, or
(b) concrete is moulded on a machine and retains that shape on virtually instant demoulding, or
(c) concrete is shaped immediately after casting using an additional or secondary mould acting on previously un-moulded surfaces.

In the sections that follow are outlined the types of moulding materials available and how they should be selected. Due to geographical and/or economic reasons one might be forced to a second or third choice, and this is acceptable provided that the persons responsible for this choice appreciate the limitations in use.

Notwithstanding all other factors, the one thing that all moulding techniques and moulds have in common are dimensions. Whether these be critical for structural, architectural and/or contractual reasons is a matter that causes quite a lot of argument. It is imperative that one appreciates the reasons for dimensions and what tolerances are permissible when combining the two fields of manufacture and installation.

The specification for the product should state strictly what is required, bearing in mind what is practical and how the product is to fit into the main construction. All too often precast products such as cladding are specified on a dimension such as:

$$A^{+x}_{-y}$$

where *A* is the target dimension often called the work size.

Two important points need to be borne in mind:

(a) Tolerance is an easy thing to find during construction but is a very difficult thing to lose. By this is meant that a product that is too large will generally cause more problems than a product that is too small, i.e. a joint can be filled with mortar, sealant, etc., when the product is nearer A-y but needs cutting back when there is too much A+x.
(b) Moulds tend to grow in size with continuous usage.

What all this means is that there are a large range of products where tolerances for a dimension of *A* are best specified as A-y.

Figure 1.1 shows how a joint can be designed to cater for resistance to arris damage and give apparent uniform joint thickness.

Fig. 1.1. Chamfered joint to cater for tolerances and arris damage.

Mould construction as well as mould materials play important roles in shape control. It cannot be stressed too strongly that any parts of the mould designed to be dismantled should be rigidly fixed at all times during the setting-out, casting and hardening process. Only in the case of products such as window-in-panel, culvert units, etc., should the internal moulding be slackened as soon as practicable in order to avoid the setting shrinkage of the concrete causing stress round the internal opening. Dismantleable mould parts should fit snugly together otherwise grout leakage will occur with subsequent risk of concrete flashings and honeycombing.

Sealant tapes and compressible seals are often ideal solutions to such problems. Sealant tapes are generally adhesive PVC tapes 10–25 mm wide which may be stuck along the joint. The compressible seals are adhesive-backed expanded soft plastics tape that may be placed inside the joint at corners, etc.

1.1.1 Steel moulds

Steel moulds, die-head and extruders are used in virtually all large production processes, whether machine-intensive or vibrated wet-cast labour-intensive large-scale production. Obviously the strength and abrasion resistance of steel makes it the best choice. However, no matter how resistant steel is to abrasion it does wear with use and a time comes when either refurbishing or replacement becomes necessary. It is up to the precaster to initiate a scheme for regularly checking the dimensions of the moulding system and to decide when action needs to be taken and the form it will take.

Concerning the shrinkage onto openings in a mould mentioned earlier, Fig. 1.2 illustrates a steel window-in-wall unit where the braces across the

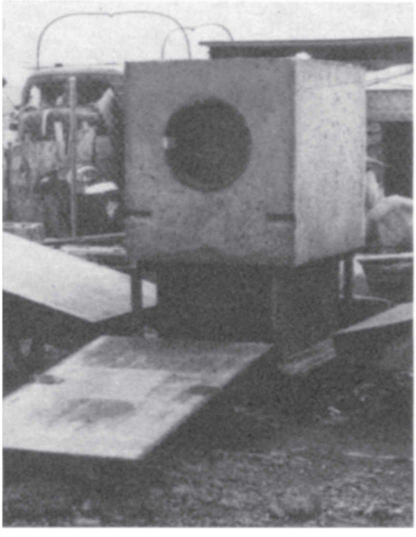

Fig. 1.2. Steel mould with collapsible internal moulding

window section may be released at 3–6 hours for temperate curing so as to allow the concrete to shrink as it sets without causing distress.

In machine-intensive processes the lifetime of a mould varies from months to years depending upon the attritional effect of the materials, the type of process and degree of maintenance. A steel mould for vibrated wet-cast processes can be used well over 1 000 times if proper care is exercised. When such moulds are put out of use for lengthy periods one of the best ways of protecting the moulding surface is to leave concrete in the mould until the mould is required for re-use. The alkalinity of the cement inhibits any rust formation. Protection of the outside of the mould is dealt with in the following sections.

Figure 1.3 illustrates a double beam mould where the two long sides are located by hydraulic jacks. Figure 1.4 shows a cess tank unit being demoulded. In all of such cases one is considering large-scale production products.

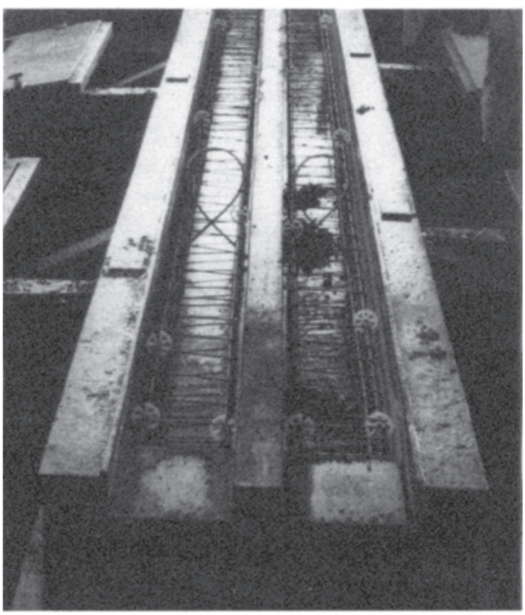

Fig. 1.3. Double beam mould with hydraulic ram sides.

1.1.2 Wooden moulds

Timber is the most versatile of moulding materials as it is relatively cheap compared to other choices and is easy to cut and shape. It is also

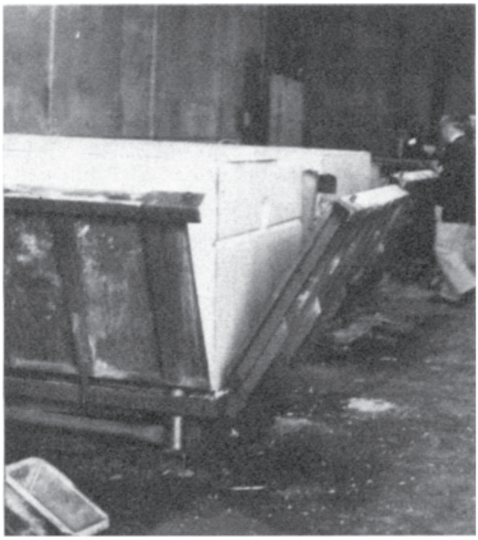

Fig. 1.4. Cess tank unit.

available in forms such as plywood and chipboard which have advantages and disadvantages compared to normal timber. The two basic types of wood available are softwood and hardwood and although many years ago hardwoods were about twice the price of softwoods, at the time of publication of this book their prices are quite close. Therefore, to obtain a greater number of uses of a mould coupled with dimensional stability it pays to use hardwood. Table 1.1 lists typical woods used for precast concrete mould manufacture.

TABLE 1.1
TYPICAL WOODS USED IN MOULD CONSTRUCTION

Softwoods	*Hardwoods*
Western Hemlock	African Mahogany
Douglas Fir	Afromosia
European Redwood	Sapele

The lifetime of a mould depends upon many factors, the most important being the paint used to protect it (discussed later). Generally the number of uses will vary from 20 to 100. However, timber has the advantage that it can be re-planed and re-furbished so that economic corrective measures can be taken when the mould goes outside tolerances.

When a wooden mould is taken out of use and stored for subsequent re-use, it should be stored in dry conditions and in such a way that distortion due to dead and/or live load is inhibited. All sides of the mould should be treated with a thin film of mould release agent to help preserve the timber. Oil-in-water emulsions or emulsifiable systems should not be used.

Most softwoods are not matured sufficiently to ensure against warping. There is a high risk of warping with moulds constructed in solid softwood timber. The more typical mould, as shown in Fig. 1.5, is made of plywood reinforced with softwood braces.

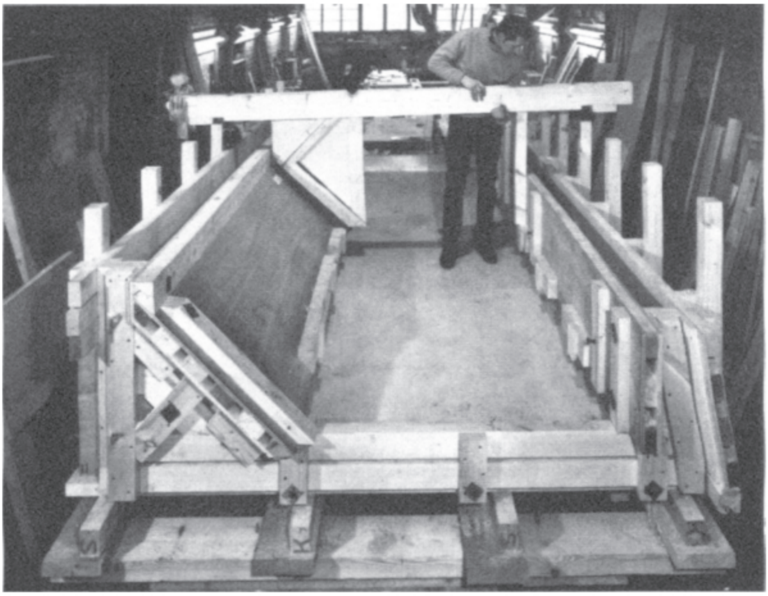

Fig. 1.5. Composite plywood mould.

1.1.3 Plastics moulds and linings

These types of moulds and mould linings come into their own when complex shapes and/or architectural profiled finishes are required. They can be considered in two basic plastics groups:

(a) Thermoset plastics, e.g. polyester resin reinforced with glass fibre (GRP), epoxide resin reinforced with glass fibre (GRE)
(b) Thermoplastics, e.g. polyethylene, polystyrene, polyvinyl chloride (PVC)

Type (a) moulds are suitable for such things as coffered floor units, garage and house panels, architectural concrete, frustrum cone flower pot units, etc., and when properly constructed and used have a lifetime of 200–1000 uses. Figure 1.6 illustrates a GRP-U-section gulley unit mould where the resin has a white silica flour filler to improve the abrasion resistance; the fibre-glass reinforcement can be seen on the outside.

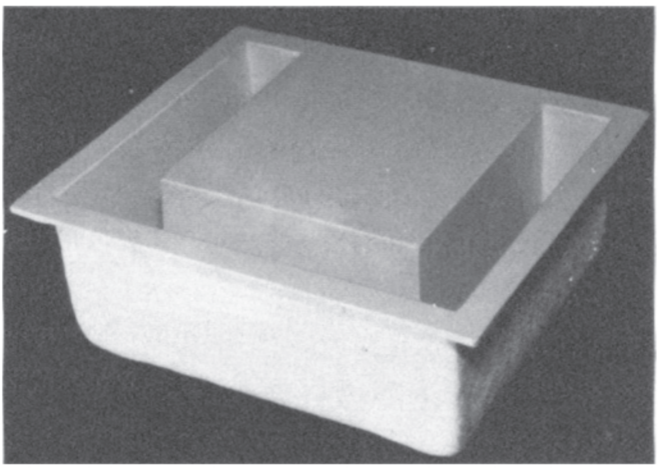

Fig. 1.6. GRP-U-section gulley unit mould.

Type (b) moulds are suitable as mould linings only, mainly because they come in sheet form and would suffer distortion if not supported. They can also be vacuum formed to give architectural shapes by heating the sheet over a vacuum tray with the required shape and applying the vacuum when the plastics soften. The lifetime of type (b) moulds is 10–50 uses depending on the aggregate attrition, vibration and other relevant factors.

Both types of mould require composite construction with other mould reinforcing materials in order to maintain the required geometry, for example:

(1) GRP panel (viz. garage) moulds need to have a plywood or

block-board base to prevent warping, sagging and creep. Steel or aluminium, channel or L-section edges are necessary at the lips to prevent damage.

(2) GRP large moulds need steel stays and edge protection and might also require welded steel anchor plates to accept clamp-on vibrators.
(3) PVS linings need to be rigidly supported by glueing, tacking or using PVC-lined plywood made during the wood production.
(4) Thermoplastics-lined steel sheets need to be fixed to a rigid external sub-frame with adequate soldiers and whalings (vertical and horizontal respectively) to prevent bowing beyond tolerance limits.

1.1.4 Aluminium moulds

The main use of these is in the roofing tile industry where they form the pallet for the extruded mortar ribbon. Their lifetime is many thousands of uses in this process. In the manufacture of other products, such as wall panels, paving units, etc., care should be exercised in two respects:

(1) The aluminium should be anodised or a couple of dummy casts run off to form an oxide coating before the mould is put into production.
(2) Reinforcement should not contact the mould otherwise there is the risk of galvanic action causing bubble formation on the mould and on the reinforcement, with loss in appearance and bond, respectively. Where this is unavoidable and the cement has 10 ppm of chromium or less a little potassium chromate solution (0·001% w/w cement) can be added to the mix.

Aluminium has twice the thermal expansion characteristics of steel or hardened concrete and should not be used as a mould construction material where the geometry is such that setting shrinkage and cooling of the warm or hot concrete can cause stress in the concrete with the risk of cracking.

1.1.5 Concrete moulds

These are not a common mould as they are cumbersome and difficult to use; however, no mould type in the previous four groups is capable of reaching the tolerance levels of production that a concrete mould can produce. One would normally talk about millimetres for other types of mould but for concrete one can work to fractions of such a unit. Such tolerances would be in order for tunnel lining units of circular section with rhomboid mating faces where, say, eight such units would make up a complete ring, with the last unit fixed in place acting as the locking piece.

The concrete mix used in the mould manufacture is best made of a flint gravel or volcanic rock coarse aggregate and a natural well-graded sand fines with a cement content of 350–400 kg/m^3 and an effective water cement ratio of 0·45 maximum. Accuracy in the mould manufacture is important but for such high tolerance units it is normal to make the mould slightly oversize and grind it to a template finish.

Concrete moulds, with proper care and treatment can be used many thousands of times.

1.2 MOULD TREATMENTS

Having gone into some detail concerning the types of mould materials the next logical discussion area concerns how to get the best use out of a mould. This is by mould protection, and is dealt with in two categories in the following sub-sections.

1.2.1 Mould paints

There are many different types of paint available and there is great deal of commercial literature where claims are often made concerning performance. It is, therefore, only logical to put the subject into perspective by making three salient rules:

(a) The paint system must be compatible with the substrate onto which it is to be applied.
(b) The paint shall always be pigmented as the pigment contributes more to the lifetime than the type of paint in which it is placed.
(c) Glossy smooth surfaces should never be used as they promote hydration staining (see Section 1.4). Table 1.2 exemplifies points (a) and (b) above and is based upon laboratory and works trials on production moulds with two-coat systems.

The resinous pines exemplify (a) in that chlorinated rubber is suitable whereas other types of paint fail early in use. The effect of pigmenting can be seen overall as a benefit. An added advantage of using a pigmented paint is that different colours can be used in successive coats, which not only facilitates painting but also helps observation of wear in the top coat with usage. The figure of 100+ for the pigmented epoxide or polyurethane on non-resinous wood was the maximum obtainable in the

TABLE 1.2
NUMBER OF USES TO NEAREST FIVE OF VARIOUS TREATED MOULDS OTHER THAN STEEL OR PLASTICS

Paint	*Mould or lining*	*Unpigmented*	*Pigmented*
Epoxide, polyurethane	Non-resinous wood	45	100+
	Hardboard	20	55
	Resinous pine	3	8
Chlorinated rubber	Non-resinous wood	20	30
	Hardboard	35	50
	Resinous pine	35	60
Cellulose, oil, shellac	Non-resinous wood	15	20
	Hardboard	10	20
	Resinous pine	1	5

precast factory, as the wood degraded with use. Another factory using pigmented epoxide paint on better handled moulds stated that up to 300 uses were being obtained.

It is additionally recommended that faces of the mould not used for concreting should also be protected by paint, although the quality of this paint need not be so good as that used on the casting faces. This helps to prolong the mould life as it inhibits water absorption and splintering.

In all, the general conclusion is that provided the paint is selected in type for the substrate to be treated and is pigmented the expensive paints of the catalysed type give the best performance. Obviously if one does not want a large number of uses then cheaper paints can be used; however, the economics of production demands that the maximum deployment be obtained of any material. It will be found, when the costing at the end of a production exercise is carried out, that the cheapest form of capitalisation is the dearest in the long run.

Of the moulds discussed in Sections 1.1.1–1.1.5, the only other type one might consider painting is the steel mould, although this is rarely necessary. Steel needs to be thoroughly degreased chemically or mechanically before painting, as Table 1.3 shows.

It may be seen that steel can be satisfactorily painted provided that all grease, mill scale and oil is removed by sand-blasting or emulsifiable cleaning compound which is scrubbed into the surface, then washed off with copious quantities of water. The phosphoric acid (10% solution) was

TABLE 1.3
NUMBER OF USES OF PAINTED STEEL MOULDS

Paint	*Steel preparation*	*No. of uses*
2 coats epoxide	None—new steel	4
2 coats epoxide	Sand-blasted—new steel	100+
1 coat phosphoric, 2 coats epoxide	Kerosene washed old mould	1
1 coat phosphoric, 2 coats epoxide	Emulsion cleaned old mould	100+

Note: The tests were discontinued after 20 weeks (100 uses) *as there was no sign of breakdown.*

applied to suppress any residual rust in the pores; the efficacy of this treatment can be judged by observing the surface turning a dull green when the acid dries. When handling this acid, care must be exercised to protect the hands, eyes and face, as it is far more dangerous than hydrochloric acid which has no oxidising effect on the skin.

Again, as with wooden moulds, protection of the non-concreting surfaces of steel moulds is achievable by coating with a mould release agent and/or by painting.

1.3 MOULD RELEASE AGENTS

Some form of release agent is necessary in most casting techniques except for moist mix design cast stone and several of the machine processes (see Chapter 6). Selection and use of release agent is important, otherwise one or more of the following problems will arise:

(a) The concrete will stick to the mould and suffer damage on demoulding.
(b) The surface will have a patchy or stained appearance.
(c) The agent may retard the set where it is too concentrated in parts of the mould, resulting in damage on demoulding.
(d) The surface may become too dusty and weak due to over-application.
(e) The agent may detrimentally affect the mould paint and lead to breakdown.
(f) The agent may promote rusting in steel or swelling in timber.

There are five basic groups of release agents:

(1) Non-emulsifiable machine oils.
(2) Emulsifiable oils giving oil-in-water phased systems (miscible with water).
(3) Mould creams from water-in-oil phases (immiscible with water).
(4) Metallic stearates and those of similar form and known as chemical release agents.
(5) Lanolin creams.

There is not a choice in all circumstances or countries between each one of these five types of release agent but whatever one selects or is forced to use, there is one basic rule that applies to all concrete compromises—do not use too little or too much or one or more of (a)–(f) will happen. A monomolecular layer of release agent is enough to ensure release but one is forced to use more than this due to the geometry of the mould. Ideal coverage rates range from 15 to $30m^2$/litre.

Airless spray application is one of the best methods of agent application but brush and rag applications are suitable provided not too much oil is used. Some systems can tolerate an over-application if the mould can be inverted and allowed to drain.

There are two points to note. First, some release agents in the (1) or (2) types can be carcinogenic and/or dermatitic and personal cleanliness and protection are essential. Second, fine air sprays giving a mist should be avoided as they can become airborne and be inhaled, and there is also the danger of fire or explosion.

Release agents of types (1) and (2) can be used provided that one is not particularly fussy about the appearance of the concrete or the effect of the oil on the mould or concrete. However, taking all the advantages and disadvantages into consideration, they should be avoided as the more expensive types of agents, (3), (4) and (5), tend to work out cheaper in the long run. The cost of the agent is the basic cost times the coverage rate, times a remedial work factor, and (3), (4) and (5) have better performance at 2–3 times the coverage rate one would need for good release with types (1) or (2) release agents. Type (5) agent tends to be mostly used for spun concrete products, such as horizontally manufactured pipes and lighting column posts, as it is extremely stable under spinning forces. It is not all that different in molecular form from the type (4) agents.

Having discussed these salient features, Table 1.4 gives advice regarding the use of agents on different types of mould when plain concrete is under consideration. For architectural and light-coloured concretes, types (3) or (4) should be used.

TABLE 1.4
SUITABLE RELEASE AGENTS FOR VARIOUS TYPES OF MOULD

Mould	*Agents*
Unpainted wood	(1), (3), (4)
Painted wood†	(1), (2), (3), (4)
Unpainted steel	(1), (3), (4), (5)
Thermoset plastics	(3), (4)
Thermoplastics	None or (3), (4)
Aluminium	(1), (2), (3), (4)
Concrete (painted)†	(3), (4)

†Some types of paint can be degraded by type (4) agents and trials are necessary when doubt exists.

Another aspect worthy of mention is that some admixtures do not take too kindly to certain types of release agent, and there is nothing better than undertaking a complete trial casting to ascertain that all the variables act independently. This helps to bring in such aspects as the cement chemistry, aggregate impurities, etc.

1.4 HYDRATION STAINING

Point (c) in Section 1.2.1 is worth a section by itself because this problem in so-called fair-faced concrete is quite troublesome from the architectural point of view. It manifests itself as dark shiny patches over the face of the smooth-moulded concrete which do not fade very much with time, and the effect is generally accompanied by difficulty due to sticking when stripping the mould. The patches are 3–10 mm deep and would involve expensive removal and matching making good.

This phenomenon is considered to be due to van der Waal's forces, in that when atoms become close they exhibit a strong attraction. Examples of this are microscope or diapositive mounting glasses which have to be slid apart instead of being pulled in tension. Also, smooth pure unoxidised copper faces can be joined together at room temperature to produce a bond stronger than any weld or solder. No matter what release agent is used, a smooth mirror-type mould tends to produce the effect of hydration staining, especially in the cases of:

(a) Brand new steel moulds which settle down after one or two uses.

(b) Polyurethane gloss lacquers.
(c) Smooth gel-coated glass reinforced polyester moulds.

The effect occurs no matter what release agent is used; the above three cases possibly suffer the effect the worst because of a better matching atom spacing fit between the mould or mould paint and the hydrating cement. The basic rule is never use a paint or a mould with a mirror-smooth finish—always finish with a matt surface.

1.5 CEMENTS

Since there are several books on cement it is not proposed to go into fundamental detail but to discuss those property aspects strictly relevant to precast concrete manufacture leaving mix design to Chapters 5 and 6.

1.5.1 Cement types

The most common cements used are ordinary and rapid-hardening Portland (including white), sulphate-resisting and high alumina cement. Universally the chemistries, performance, colours, etc., vary over quite a large range, but they all have to comply with a Standard such as BS, ASTM, DIN, NF, ON, etc., demanding minimum requirements. Provided that good practice is followed, cements are rarely a cause for concern as the user may refer to a Standard and manufacturers have Certificates of Test which relate to the purchase order. The first criterion in precast work is that the product should have a 'green strength' where it is virtually instantly demoulded and it should have a 6–18 hour handling and stacking strength. The second criterion is the old compromise in that there should not only be a minimum content for strength and durability needs (these two are not often related) but a maximum also in order to avoid too much shrinkage, exotherm and cost. Having said all this advice can now be given on various factors which can minimise later trouble-shooting.

1.5.2 Cement problems

(a) The specific surface (fineness) requirements of rapid hardening Portland cement (RHPC) are commonly met by the majority of ordinary Portland cements (OPC), and when one buys RHPC one generally obtains a cement much finer than required in the Standard. Although the setting times are similar, the initial hardening rate is faster for RHPC than for OPC and therefore handling strengths are improved. Against this one needs to assess the effect at 28 days old (often used as a specification) because any cement, admixture or process that accelerates the early strength often retards the later strength and vice versa.

(b) Disputes regarding cement performance in long-term casting projects are likely to arise, especially when triggered by poor or mediocre product or cube test results. Every delivery of cement should be appropriately sampled and stored in air-tight labelled containers with all the relevant information on the label or record sheet. In addition, one should identify what parts of the production are relevant to each cement delivery.

(c) Sulphate resisting Portland cement (SRPC) is often specified for concrete when resistance to sulphates is required with, all too often, the specifier and the manufacturer thinking that SRPC usage alone is the answer. However, resistance to sulphates or other aggressive chemicals is mainly a function of permeability, and mix design and workmanship are the main controllers of this property with type of cement being a secondary matter. In effect it is no use using SRPC unless care is taken with all the other variables.

(d) SRPC concretes are particularly susceptible to poor curing conditions and it is essential to ensure that the concrete does not lose water until it is at least 3 days old, and thereafter slowly.

(e) High alumina cement (HAC) has suffered a severe setback in concrete usage over the past years due to a combination of bad workmanship in mix design, poor design in not giving large enough bearing areas and poor deployment by usage in warm, damp conditions. However, the number of cases of poor-quality concrete products compared to the total number of units made is very small and there is no cause to denigrate this cement more than other types. Provided that the effective water/cement ratio is below 0·45 and the product is protected from the high early exotherm, and, when mature, not placed in hot damp conditions, then the cement can be used for precast concrete.

(f) For all cements good storage is critical to avoid airsetting with long storage; caking or hardening with damp storage can also occur. It is essential that cement be used in the order it is delivered. It is also essential to store cement on a stillage off the ground and keep the stock either indoors or, if outdoors, covered with a waterproof sheet in damp climates or a heat-reflective sheet in hot climates. These precautions avoid the cement becoming damp or hot and also inhibit ground moisture pick-up which, even in desert areas, is a night-time problem when condensation occurs. Bulk storage in silos needs to be such that old cement does not collect near the discharge point and air elutriation may be necessary to keep the silo contents mobile. Silos need to be either indoors, or, if outdoors, completely waterproof. In hot climates, silos benefit by a silver-coloured paint to reflect heat coupled with air circulation to disperse any heat build-up. In damp tropical conditions the use of hydrophobic cements assists storage life. These are cements blended or inter-ground with 0·05–0·2% of oleic and/or stearic acid type derivatives. Such cements have extended bag life but require more energy in mixing in order to break down the water-repellent layers of soap and metallic soap.

1.6 AGGREGATES

1.6.1 Aggregate types

These fall into two main types, each with several sub-groups:

Natural Aggregates:

- Flint
- Volcanic (granites, basalts, feldspars, etc.)
- Sandstone
- Limestone (sedimentary, oolitic, etc.)
- Marble (calcite)
- Barytes
- Natural sands (siliceous mainly, river, dune, wadi, marine)
- Perlite
- Vermiculite

Synthetic Aggregates:

- Sintered pulverised fuel ash
- Expanded shale
- Expanded slate
- Expanded clay
- Foamed slag
- Crushed bricks
- Calcined flint
- Iron
- Expanded plastics
- Reconstituted concrete

This list is quite extensive but may omit a few of the rarer aggregates.

The word 'gravel' has not been used in this list because the word, geologically, means a rounded angular shape and could refer to a flint or a limestone. As far as individual problems are concerned, these are dealt with a little later. The selection of aggregates for any particular precast concrete operation is a function of many factors of which economic availability and performance requirements are probably the most important. With many of the machine-intensive processes one might need to freight materials large distances just to satisfy the process requirements, even though suitable aggregates might be locally available for wet-cast processes.

1.6.2 Aggregate shape

The ideal shape of a coarse aggregate is rounded, angular and approximately cubic, this shape promotes optimum workability. The fine aggregate shape may be anything from rounded to angular, depending upon the precasting process. Naturally occurring flints from river beds, etc., tend to have this shape but other natural aggregates generally need to be crushed and screened or washed to produce suitable concreting materials. The efficacy of the crushing process controls the aggregate shape to a large extent and quarry-won materials, starting off as 150–300mm pieces, generally need to be processed through three or four crushing phases even though the same maximum aggregate size can be produced from a single crushing. Such a treatment as single crushing is likely to result in an aggregate with high flakiness (resulting in workability drawbacks) and a lot of dust (with high water demand and useless material for a large number of precast applications). With correct processing, it is possible to produce a crushed rock 'sand' with a grading suitable for precast work, although the workability water demand is slightly higher than for the rounded natural sand.

Of the synthetic aggregates, sintered pulverised fuel ash, expanded clay and plastics are rounded whereas the others are angular. Workability water demands tend to be higher for these angular materials than for the rounded ones but aggregate suction and water demand play significant roles. All these synthetic aggregates fall into special categories where lightweight, extra high density or architectural concrete is required. Crushed concrete, as an aggregate, is becoming a more economical material in some countries where a shortage of suitable natural aggregates has forced people to consider this as a secondary material. Crushed bricks (clay, calcium silicate) have been used in the past quite successfully and provided that the quality of the aggregate and concrete is acceptable, they are quite suitable. Calcined flint is mainly applicable to white architectural concrete work.

1.6.3 Aggregate grading

Coarse aggregates should normally be stored and used in the nominal single size category as this facilitates mix design, whereas for the 'all-in' and continuous maximum size gradings it becomes difficult to design for the tail-end effect on the fines. The principle of any grading process, with the exception of concrete blocks, is to ensure optimum pore space occupation and this is exemplified in tabular form. Table 1.5 illustrates typical gradings of suitable coarse aggregates.

TABLE 1.5
NOMINAL SINGLE SIZE COARSE AGGREGATES

Size	*Passing sieve*					
	63 *mm*	37·5 *mm*	20 *mm*	14 *mm*	10 *mm*	5 *mm*
63	85–100	0–30	0–5			
40	100	85–100	0–25	0–5		
20	100	100	85–100		0–25	0–5
10	100	100	100	100	85–100	0–25

Fine aggregates either lie in a specific range or outside; Table 1.6 shows suitable gradings for concreting sands. For crushed rock 'sands' the passing 150μm sieve maximum may be increased to 20%.

For structural vibrated concrete the silt, or passing 75μm sieve, content should not exceed 1% of total aggregate weight for coarse

TABLE 1.6
SUITABLE FINE AGGREGATE GRADINGS
(NATURAL SANDS)

Type	*Passing sieve*					
	5 *mm*	2·36 *mm*	1·18 *mm*	600 μm	300 μm	150 μm
1	90–100	60–95	30–70	15–34	5–20	0–10
2	90–100	75–100	55–90	35–59	8–30	0–10
3	90–100	85–100	75–100	60–79	12–40	0–10
4	95–100	95–100	90–100	80–100	15–50	0–15

natural aggregate, nor 3% for natural sands, nor 10% for rock fines (sands). However, for many precast processes, variations well outside these limits are permissible.

Some of the sand gradings shown in Table 1.7 are well outside the usual zones but they can still be used by blending with a 10 mm or 6 mm coarse all-in aggregate to produce an acceptable concreting sand.

Well-crushed rock fines tend to give similar percentages retained on each sieve. They are suitable for some precast concrete processes but are too fine for most applications. Again, by screening or washing out the dust they can be refined to give suitable materials.

TABLE 1.7
OTHER NATURAL SAND GRADINGS (NOT NECESSARILY TYPICAL)

Source	*Passing sieve*					
	5 *mm*	2·36 *mm*	1·18 *mm*	600 μm	300 μm	150 μm
UK—marine	100	100	100	92	8	2
Saudi—dune	100	100	100	89	45	19
Jordan—wadi	97	95	92	86	60	28

1.6.4 Aggregate problems

(a) Impurities in aggregates are world-wide problems where sulphates, chlorides, clay, silt, etc., need to be considered. Washing or, where water is expensive, spinning or heating coupled with careful pit or quarry selection are the answers, coupled with reference to standard or specification limit requirements. Sulphates in excess will retard setting times, chlorides will accelerate any corrosion risk, and clay and silt, when present above permissible limits, will promote high water demand and shrinkage during setting. As far as sulphates are concerned, most concretes can tolerate 5% as SO_3 based upon cement content. Since 2·5–3·0% is already present in cement then the maximum aggregate contribution acceptable is 2·0% w/w cement. Chlorides are a more contentious subject, but when expressed as anhydrous calcium chloride equivalent by weight of cement, a maximum of 0·5% w/w cement is acceptable provided no significant chloride-containing admixtures are used (e.g. A/C (aggregate/cement) =5/1 SO_3 in aggregate 0.3%. Aggregate sulphate w/w cement=1·5%. Assume cement SO_3 2·5%. Total SO_3=4·0%. A/C=5/1 Cl in aggregate 0·1% as $CaCl_2$. $CaCl_2$ w/w cement=0·5%.)

Clay and silt, as distinct from aggregate dust, may be present without harmful effects up to 3% w/w aggregate in natural sands. However, higher levels up to 10–15% are not harmful when high speed mixing is used forcing the collodial fines into a suspended filler state.

Pyrites and quicklime cause, respectively, staining and pop-outs, and repair work becomes necessary. Synthetic aggregates such as these should be allowed to weather for some days to allow these reactions to occur in the stockpile rather than in the concrete.

(b) Alkali aggregate reaction due to chert, opaline, etc., in siliceous materials and occluded clay in some limestones (dedolomitisation) is a world-wide problem. Long-term expansive reactions between the aggregate and the alkali in the cement (sodium and potassium) oxides is considered to be responsible, and reactive aggregates can be satisfactorily used provided cements of low alkali level are used.

A generally accepted maximum specification for low alkali cements is 0.6% expressed as equivalent Na_2O. When such cements are not available the aggregate needs to be tested to assess its suitability and there are three ASTM tests. Two of these tests are based upon solubility and on a gel pat assessment, and it is important to stress that positive results from these tests indicate reactivity but not necessarily a detrimental risk to the concrete. The third test is based upon mortar bar expansion and is the most meaningful; unfortunately it takes some months to produce a test result. This means that when one is considering a new source of aggregate one should assess the aggregate for alkali aggregate reaction early in the negotiations as all other test requirements are shorter term exercises.

The reaction needs moisture to assist the mechanisms involved and in dry situations reactive aggregates may be used with little distress being likely. Siliceous aggregates tend to have critical ranges of reactive materials usually in the 6–12% range by weight of total aggregate. This is probably the worst stress distribution with individual stress centres, whereas low levels are not enough to cause distress and high levels cause a monolithic overall expansion.

Fine reactive siliceous admixtures (e.g. trass, fly ash, etc.) help a little to suppress the reaction when the reactive materials are present in the fine fraction of the aggregate, but the only solution to the problem is a combined careful selection of cement and aggregate.

(c) Water demand of aggregates can vary between 0.5 and 20% depending upon pore structure. The speed at which aggregates in a nominally dry state take up water is also a critical factor. Many synthetic aggregates need to be pre-wetted prior to mixing with the cement and additional water. Some limestones and sandstones have a slower absorption rate, and workability requirements need to be met at the time the concrete is required for casting, not at the mixer stage as the vacuum effect of the aggregate sucks water out of the mix over the first 15–30 minutes. The later chapters will emphasise these effects more when the differences between total and effective water/cement ratios are discussed.

(d) High density concretes for radiation shielding produced from barytes or iron shot or similar aggregates are still being made. Barytes is a nominally inert material but careful selection is necessary because of the likelihood of lead and/or zinc and other impurities which significantly retard the setting and hardening of cement. Iron shot aggregate plays havoc with mixers and a slow speed annular or pan type mixer is best to use with low workability mixes so as to inhibit segregation during placing. With iron shot mixes consideration should be given to dry placing in the mould and grout filling by pumping using withdrawable grout tubes and tell-tale holes up the sides of the mould.

(e) Aggregate strength as determined by crushing, impact or 10% fines value tests is a significant factor in determining the maximum concrete strength potential. Care should be exercised in specifications not to specify strengths impossible for that aggregate, because no matter how much cement one adds, the limiting factor is the aggregate. As an example of this some limestones should not be specified at characteristic strengths above 40 N/mm^2, nor some sandstones above 50 N/mm^2.

(f) Aggregate variations affect physical, chemical and architectural properties and very few precasting projects can take in enough aggregate to cater for a complete contract. Having established that what is initially submitted for work is acceptable, not only should a large representative sample be retained in a labelled (full data) container but every subsequent delivery should be so sampled in large enough quantities for the requisite comparative tests to be undertaken at any time.

1.7 WATER

It has often been stated that water which is fit enough for drinking can be used for concrete but this is not always the case. Several Standards exist for water for concrete and the best answer to the question of the suitability of a source of water is to make the product with that water and see if it has the required properties. One manufacturer in the UK is known to make (unreinforced) concrete blocks from filtered sea water and apart from lime bloom has produced a reasonable product.

In most countries water is the cheapest ingredient of the mix and production bonuses paid on quantity rather than quality encourage the use of too much water. Machine-intensive processes generally will only accept a water content consistent with good mix design practice. The labour-intensive processes are different and in these one should only have enough water to achieve the minimum workability requirements.

1.8 REINFORCEMENT AND PRESTRESSING

Reinforcement is used for one or more of the following reasons:

(a) Structural (loading, fire, earthquake, etc.)
(b) Handling (to withstand stacking, transport and erection stresses)
(c) Shrinkage (to withstand differential stresses)

Certain reasons for reinforcement in concrete are not dealt with at length in the literature but are very relevant to precast work. Handling reinforcement is usually not well detailed and attracts a salutary, cursory wording in specifications, if any at all. Figure 1.7 illustrates a precast step construction in a prestressed, post-tensioned spiral staircase. The first batch of units delivered to site, in addition to the column steel, only had top cantilever rebars and failed during site handling where they were hoisted as single beams. The second batch handled well with the additional bottom steel but, as can be seen, failed when prestressed due to omission of the joint packing mortar.

Steel to counteract the effect of shrinkage in concrete is necessary in the top section of units such as exposed duct covers where the top face is subject to natural weathering and the bottom to continuous damp conditions. Precast units consisting of facing and backing mixes other than small paving slabs may also require the addition of shrinkage reinforcement depending upon geometry and conditions of usage.

1.8.1 Types of steel and problems

Mild, medium tensile, cold or hot rolled and high carbon drawn steel cover most of the types of steel used in precast work, with stainless steel

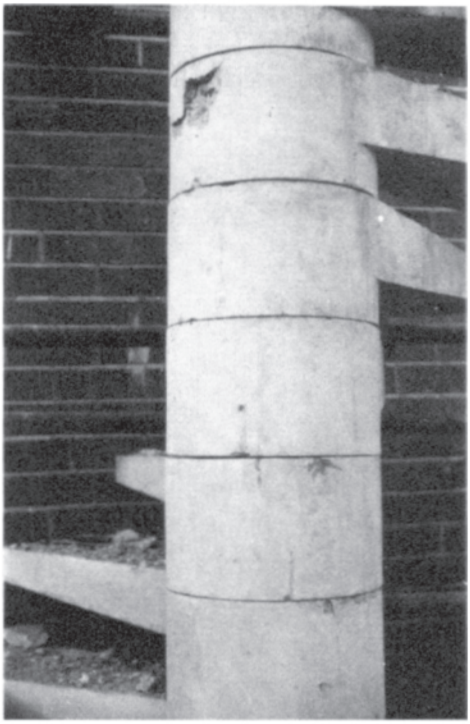

Fig. 1.7. Post-tensioned units with mortar omitted.

taking up a very small area of the market. Bond strength is the most important property and this is best achieved by allowing the steel to become slightly rusty before use; the bond obtained from new steel is generally good enough for bond requirements but improves with the mechanical key that a little rusting gives. It is important not to use steel with heavy rust and/or scale on the surface and such steel should be sand-blasted or similarly treated to remove the debris.

Steel with significant surface geometry has advantages in improved bond strength but disadvantage in welding and tying operations. Stainless steel has poor bonding characteristics and it is of benefit always to specify ribbed or heavily contoured sections.

Protection of steel is necessary for storage in humid and/or marine or chloride conditions or when used as reinforcement in exposed autoclaved aerated products. This can be achieved by galvanising, coating with a styrene-butadiene cement slurry or bitumen dipping, etc. Steel starter bars or any steel left protruding from a precast unit should be protected with a cold zinc coat, cement slurry or a styrene-butadiene cement slurry. This maintains the steel in a virtually pristine condition and stops rust wash downs onto the concrete.

There is a risk of gas evolution resulting in some loss of bond when galvanised steel is used in concrete where the cement is low in chromium. This is aggravated when a complete galvanic cell is set up as in the case of galvanised reinforcement traversing through holes in a steel mould. All white and some Portland cements will have chromium levels that result in this defect. The chromium in Portland cement can vary from 5 to 100 ppm and it has been observed that levels below 10 ppm are those where gassing occurs. The problem can be overcome either by adding a chromate solution to the mix to raise the Cr level to about 30–40 ppm or by treating the galvanised steel with a chromate solution. In the additive form 0·01% of potassium chromate (in solution) w/w cement would be sufficient, and for treatment a 1–5% solution may be used, preferably by dipping the complete cage of reinforcement in a tank. Brushing is not advisable.

Chromate solutions are not only highly poisonous but will promote dermatitis and skin cancer in personnel susceptible to the chemical. When mixing and dispensing the solution into the mixer, face protection and rubber gloves should be worn and any spillage onto the skin washed off immediately and affected clothing thoroughly washed. When handling treated galvanised steel, rubber gloves should be worn. In both cases the rubber gloves should be washed thoroughly before removal. Chromate solutions must not be discharged down mains drains, or into streams, rivers, etc., as they are poisonous to marine life.

Prestressing steel in single bar, wire or strand form should be accompanied by a manufacturer's certificate covering each bar or reel of wire or strand. All guide holes should have chamfered edges to prevent nicking (which can result in failure) and all beds should have restraining ropes, chains or similar at 5–10 m centres to hold failed wires in the bed. Personnel should never be in line with the prestressing operations and all anchors, blocks, etc., must be in good condition and clean. Cover to steel and its associated problems are discussed in Chapter 8.

1.8.2 'Reinforcing' fibres and meshes

Fibres and meshes made from steel, polypropylene, glass and carbon are in current use in many types of precast product. Their main applications are for concretes where thin sections, impact resistance or special thixotropic properties are required. Only carbon and steel fibres and meshes are true reinforcing materials as they have strengths and moduli in excess of concrete, whereas polypropylene and glass have moduli either lower or of the same order as concrete.

Apart from steel meshes, steel fibres have an application in specific products where a combination of high strength and impact resistance is required, viz. explosion-resistant units. However, the fibres require careful handling using steel-faced gloves, and slow addition to a working pan mixer otherwise the fibres tend to form balls or clots. Extra water and/or the use of workability admixtures is required to give an adequate workability, and compaction by vibration needs to be more energetic than for a conventional mix.

Polypropylene and the other plastics fibres being developed have the most promise, and give good impact resistance to products such as pipes, pontoons, etc., and stabilised high air content systems in architectural products such as the thixotropic Faircrete.

Glass fibres have had a chequered history since their use was taken up in the late sixties. From the thermodynamic point of view, the different heats of formation of calcium and sodium silicate indicate that the lifetime in a weathering situation will be limited. An optimistic picture can only be painted for zirconium glass fibre in cement matrices.

Until the manufacturers can produce a 100% zirconium glass or similar, not much future can be envisaged for the present glass fibres. Carbon fibre, at present, is extremely expensive but it is the most attractive of all the fibres with its exceedingly high strength, and good bond and corrosion-free properties. Its price might well be reduced with the development of new manufacturing processes but, even at its present price, it may still be applicable to some products. A watching brief needs to be kept on this material and other new developments.

One particular application that has not gained much, if any, acceptance is the use of plastics meshes as holding or handling reinforcement in the web parts of ribbed cladding panels. The web is usually only required for architectural reasons and its thickness is dictated by the steel reinforcement cover requirements. Plastics meshes with, for example, 50–100 mm square openings could be fixed under tension to the rebars in the ribs and the concrete placed through the section. Web thicknesses down to 20 mm should then be attainable.

1.9 REINFORCEMENT SPACERS

Spacers are designed to maintain the specified minimum cover between the steel reinforcement and the mould and may be made of a variety of materials, viz.:

(a) Concrete or mortar blocks with or without tie wires.
(b) Asbestos cement.
(c) Plastics, usually filled polyethylene or polyamide.
(d) Steel with end-leg protection.

They fall into two distinct types:

T1 Trestle: Horizontal bar support mainly (a), (b), (c), (d)
T2 Ring: Horizontal, vertical or angled bar support (b), (c)

A number of precautions may be listed. Durability aspects of spacers in concrete are covered in Chapter 8.

(1) Never use a trestle spacer in an angled or vertical position. It can rotate or dislodge under the action of vibration or the impact of concrete. Figure 1.8 shows a mould ready to receive concrete with clip-on trestle spacers on the bottom face as cast. Figure 1.9 illustrates usage of both types of spacer on horizontal and vertical surfaces plus conduits.

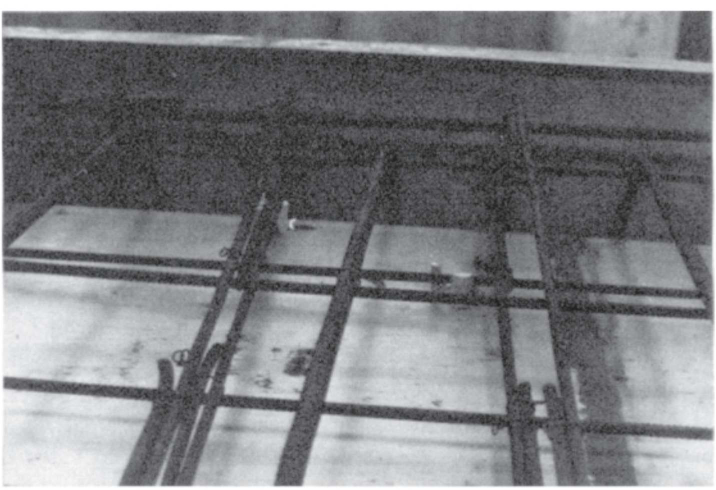

Fig. 1.8. Use of trestle spacers on horizontal base.

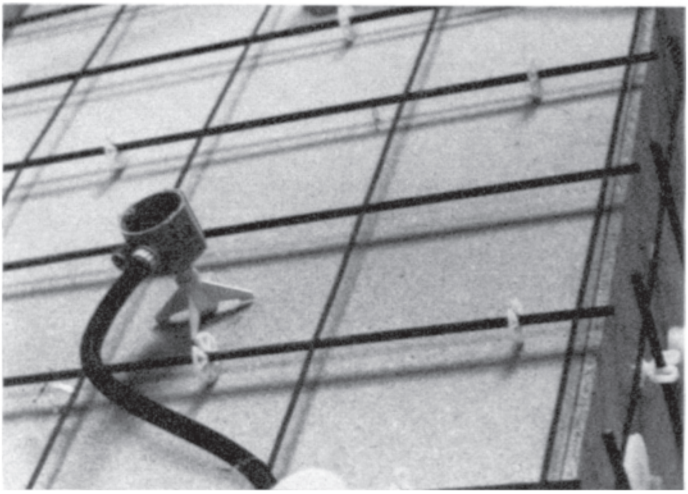

Fig. 1.9. Use of trestle and ring spacers.

(2) Never overload spacers onto soft mould materials nor overload plastics spacers onto hard formwork as they will, respectively, punch into the formwork or stand proud. In the former case the indentation in the formwork will recast as a protrusion in the next unit.
(3) Plastics spacers have about fifteen times the thermal expansion coefficient of concrete and should be pierced to at least 25% of their non-rebar area to permit the concrete to weave into the section and restrain movement, as shown in Figs. 1.10 and 1.11 as well as to provide optimum fire resistance. This inhibits thermal punching as shown in Figs. 1.12 and 1.13. Transverse cracking in thin sections (100 mm) is also inhibited.
(4) Mortar and concrete spacers should be neither too permeable nor too impervious. The very permeable types will promote steel corrosion and pick up release agent from the mould and show as unsightly marks. The highly impervious types will give poor bond, with the likelihood of water passage to the steel as shown in the broken concrete sample in Fig. 1.14. The medium, and optimum case, spacer permeability is shown in Fig. 1.15.
(5) Concrete spacers for use in architecturally faced units should be treated for exposure prior to use in the mould by the same method

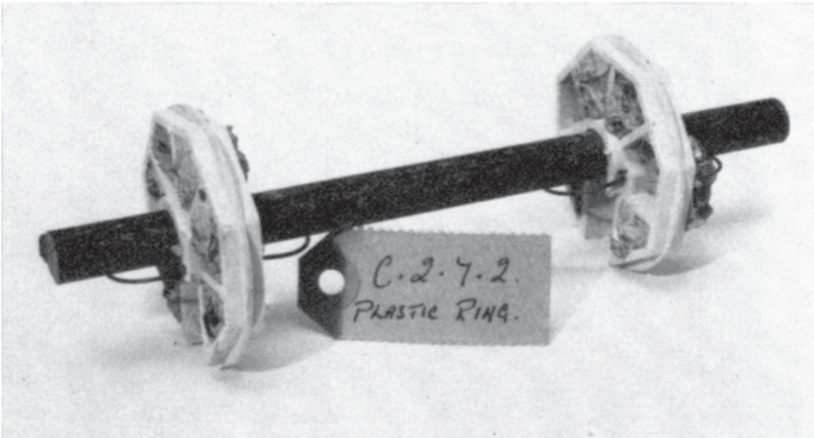

Fig. 1.10. Concrete interweaving plastics spacers.

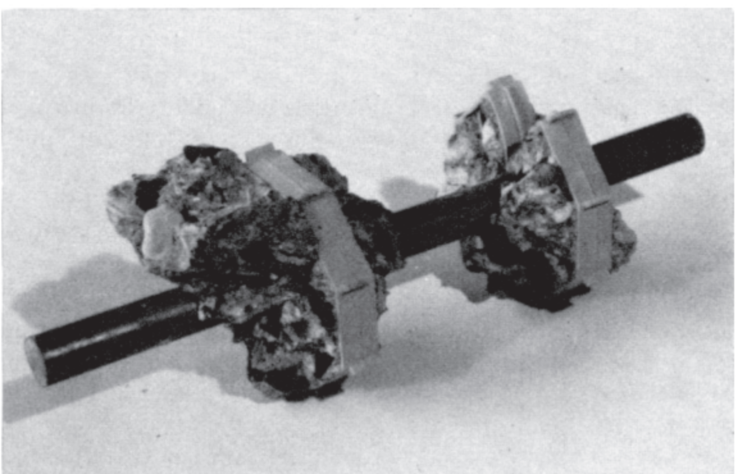

Fig. 1.11. Concrete interweaving plastics spacers.

as intended for the concrete, and should be made up of basically the same ingredients. For example, a washed-face spacer will read badly in a retarder finished surface.

(6) Plastics spacers should not be used in exposed aggregate finishes, especially those produced by sand- or grit-blasting. The highly elastic

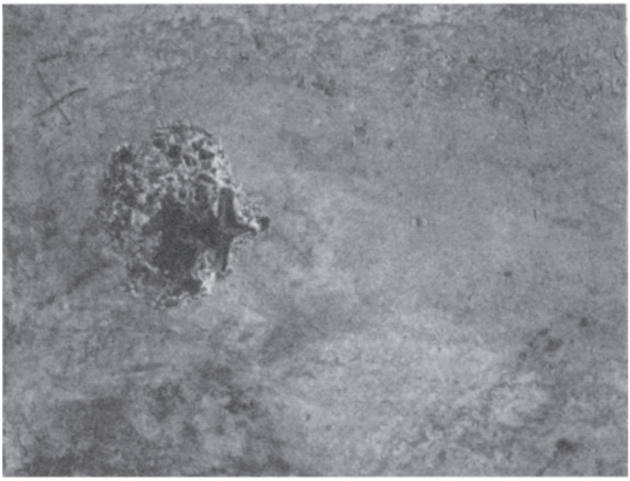

Fig. 1.12. Thermal spalling with plastics unpierced spacer.

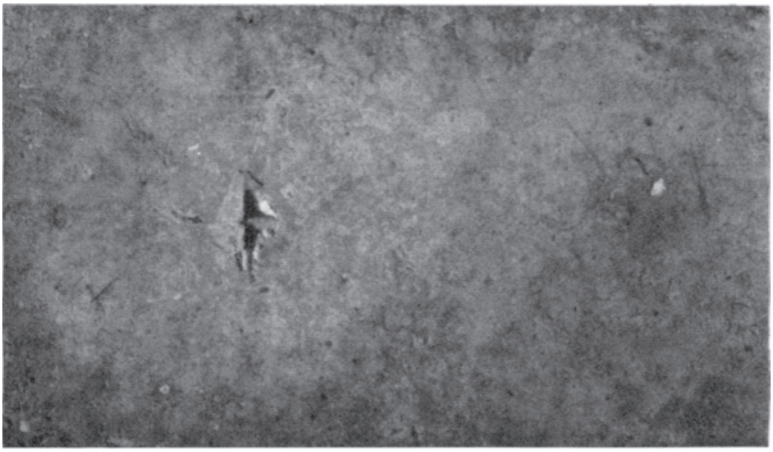

Fig. 1.13. Thermal spalling with plastics unpierced spacer.

plastics are very resistant to grit or sand and will be virtually unaffected by the treatment. In such units it is wiser to obtain the cover by suspending the reinforcement if concrete or asbestos spacers are unacceptable.

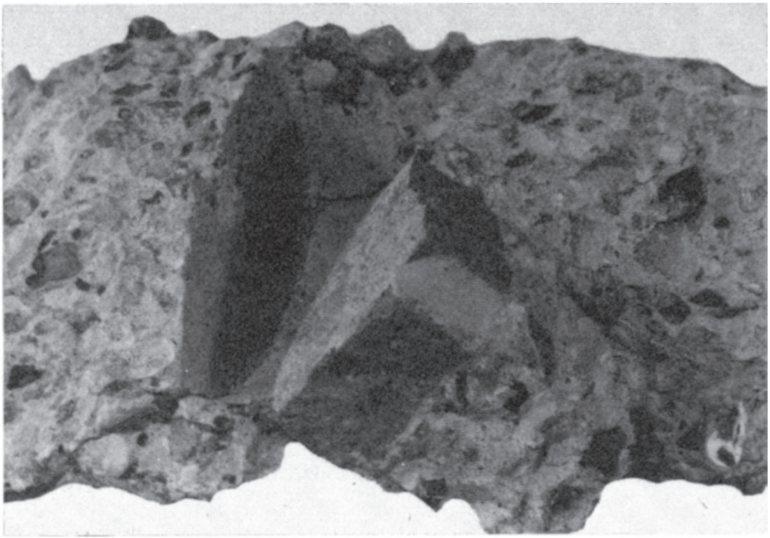

Fig. 1.14. Poor bond of mortar spacer to concrete.

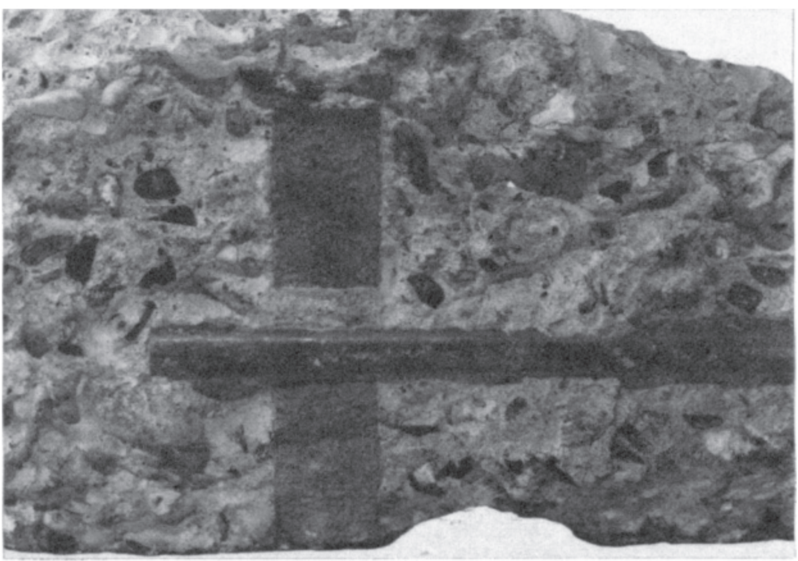

Fig. 1.15. Good quality well-bonded mortar spacer.

(7) Steel spacers should have slush-moulded or heat-fitted polyvinyl chloride or similar shoes and care should be exercised in storage and handling. They are more economical than other spacers at large covers but some types on the market cannot take very large loads and their legs become splayed.

1.10 FIXINGS, FITTINGS AND STACKER BLOCKS

A large variety of pieces of hardware go into the manufacture of many types of precast concrete units, in addition to spacers discussed in the previous section. Therefore, a few words of advice about how to avoid trouble would not be amiss.

1.10.1 Window fixings

These can be of wood or filled plastics and need to be reverse dovetailed into the concrete to provide a key. Wooden fixings should not be used if the unit is likely to be exposed to damp conditions before being built into the structure as the timber will swell and could crack the concrete. The filled plastics type is trouble-free and can be conveniently purchased in either bespoke sections or in long extruded bars that can be cut to the desired lengths. The risk with plastics spacers discussed in Section 1.9 (3) does not obtain for fixings because they have a free exposed face where movement can be accommodated.

1.10.2 Cladding fixings

A virtually infinite variety of pieces of hardware exist designed to hold precast units to the substrate frame, concrete, masonry, etc., and provided that the following points are borne in mind, trouble is unlikely to occur:

(a) A precast unit should never be rigidly fixed at two points as there is a risk that its differential movement compared to the substrate will cause distress.
(b) Precast units should be fixed at one position and restrained at another position.
(c) Cladding is better floor-hung rather than floor-supported. This makes it easier for the contractor and allows speedier fixing.
(d) Fixings should be:
    (i) Corrosion free.

(ii) Adjustable to cater for tolerances,
(iii) Strong enough for structural loads, wind pressure and also suction and restraint fixings,
(iv) Moveable to cater for differential movements,

(e) Dovetail fixings likely to slide too much during construction may be wedged with pieces of expanded plastics. Mortar or concrete should never be used otherwise (d) (iv) will obtain and trouble arise.

1.10.3 Stacker blocks

With architectural precast units being stacked either horizontally or near the vertical, stacker blocks should not only be at the minimum stress-promoting positions (e.g. fifth points in a uniform section unit) but also be dead in line with the other blocks. If a block is placed against a concrete surface at any age up to approximately 14 days old, a hydration staining mark will result. Stacker blocks used on such surfaces must be in minimal contact, and multi-domed plastics pads or similar approved geometry blocks are desirable.

BIBLIOGRAPHY

F.M.LEA, *The Chemistry of Cement and Concrete,* Arnold, London, 1970.
A.M.NEVILLE, *Properties of Concrete,* Pitmans, Bath UK, 1977.
US DEPARTMENT OF THE INTERIOR, *Concrete Manual,* USGPO, Washington, 1975.
ASTM, C227, C298 (and C586), C441.
M.LEVITT and M.HERBERT, Performance of spacers in reinforced concrete, *Civil Engineering,* Aug. 1970.
D.F.ORCHARD, *Concrete Technology, Vol.* 1 *Properties of Materials,* Applied Science Publishers, London, 1979.
D.F.ORCHARD, *Concrete Technology, Vol.* 3 *Properties and Testing of Aggregates,* Applied Science Publishers, London, 1979.
Galvanised Steel in Concrete, BRE Digest No. 109, Sept. 1969, Building Research Establishment, UK.

2

ADMIXTURES

This chapter covers the range of admixtures used in precast concrete products and mortars used with precast masonry. They are all used at relatively low concentrations (0·01–5% w/w cement) for the purpose of modifying the properties of the fresh and/or the hardened material. The chapter excludes additives such as ground blast furnace slag and pulverised fuel ash (fly ash), the latter being covered in Chapter 4. Pigments, although in the admixtures group, are covered in the next chapter.

It is often stated that well-designed, compacted and cured concrete should not need an admixture. However, when all the practical aspects of a situation are considered such dogmatism can seldom be justified. The author's opinion is that, with the complexity of castings, the chance to reduce water contents for the same workability, and with the many other advantages that admixtures can bestow, there are few cases where their non-use can be justified. However, one point that needs to be emphasised is that admixtures are used at relatively low concentrations and over or under dosage can lead to potentially disastrous results. Control of the basic ingredients of aggregate, cement and water must be strict because if there is any doubt about this there is no point in using admixtures. The admixtures are used to make good concrete products better, not to make poor or mediocre concrete good.

Having said all this, one can now proceed to discuss admixtures under performance headings.

2.1 ACCELERATORS

The purpose of these is to accelerate the setting and hardening rates of cement for the main purpose in precast work of getting a faster turnover rate in demoulding and stacking and faster delivery times. The most common and the cheapest accelerator is calcium chloride. Calcium formate, sodium nitrite and others are not so effective as calcium chloride and are extremely sensitive in their performance to the chemistry of the Portland cement. This is particularly noticeable with the C3A (tricalcium aluminate) content where the acceleration effect is less marked as the C3A content increases, especially above the 8% level. (See Table 2.4, later.)

Calcium chloride, largely due to abuse by either overdosing and/or use in poor or mediocre quality concretes, resulted in a ban in some countries on its use in concretes containing embedded metals. It is a pity that this ban also applies to precast concrete companies who used calcium chloride for over twenty years without a single performance claim ever being lodged. The admixture is still permitted in many countries for reinforced concrete, and in the countries where it is banned it is still permitted in concretes not containing embedded metals. Most countries, wisely, ban the use of chloride-containing admixtures (above a maximum level) in prestressed concrete.

The main overriding advantage of calcium chloride compared to other chemical accelerators is that it works exceedingly well in every type of Portland cement irrespective of the chemistry of the cement. On the other hand, the following disadvantages obtain.

2.1.1 Corrosion

At normal dosage rates of 0·5–1·5% equivalent anhydrous material by weight of cement it will promote corrosion in respect of:

(a) Accelerating the normal degradation of mediocre or poor quality concrete.
(b) Migrating with moisture in the concrete towards the colder face causing concentration gradients varying from, say 0·5 to 3·0%, from an original uniform 1·5%.
(c) Accelerating the speed and deepening the depth of the carbonate layer.

At excess concentrations, the pH becomes reduced below its average level of 12 and when it approaches 9 corrosion will set in if air can get to the steel as well. In addition, the hygroscopic nature of the material will allow corrosion to occur even if protected from the weather areas. The symbol ‘pH’ is a logarithmic term related to the hydrogen ion concentration in a solution. The value 7 refers to a neutral system, higher numbers are alkaline and lower numbers acidic solutions and the range is from 1 to 14.

At both concentrations, lime bloom (sometimes misquoted as efflorescence) will be promoted and the potential shrinkage of the concrete will be enhanced by 25–35%. This latter aspect is probably one of the most important associative factors in the use of calcium chloride because it becomes a crack-promoting factor, especially when the section is restricted by heavy reinforcement. In the vast majority of trouble-shooting works and site visits undertaken by the author where calcium chloride has been involved, cracking occurred before steel corrosion and not as a result of it. In effect, all such exercises should be carefully documented and dates and ages of defects recorded.

2.1.2 Retardation

Although this may appear a rather enigmatic subheading, a fault with calcium chloride (and other chlorides) when used at low concentrations is that severe retardation in early strength occurs at 'trigger' points in the concentration range 0·0005–0·05%anhydrous calcium chloride by weight of cement. These concentrations are likely to arise in practice from, for example:

(a) Using a mixer for a non-chloride mix without thorough washing from an earlier chloride-containing mix.
(b) Other admixtures containing trace chloride concentrations.
(c) Use of aggregates containing trace chloride concentrations.

The effect is believed to be due to an exothermic 'punch' at 10–12 hours from the time the water was added when the equivalent of 1 kW/m^3 can be emitted over a 20–30 minute period. The concrete, at this tender age, would suffer distress in the form of microcracking and aggregate/cement debonding. Table 2.1 illustrates this effect.

There is not a strict pattern, but the two trends of retardation at and below 0·1% and the decreasing defect with the higher water/cement (W/C) ratios can be seen. It is known to the author that this effect was almost certainly responsible for the in-works breakage of several large cladding units made from 'non-chloride' mixes following the earlier cold morning's chloride-containing castings. It is also interesting to note that the chloride level of 0·001% is close to the level obtained in typical tap water as equivalent calcium chloride. However, the chemical in tap water

TABLE 2.1
RATIO TO CONTROL STRENGTH FOR 24 HOUR OLD 4/1 MORTAR CYLINDERS

	Total W/C						
Anhydrous $CaCl_2$*/cement* (w/w)	*0·4*	*0·5*	*0·6*	*0·7*	*0·8*	*0·9*	*1·0*
1·0	2·1	1·6	3·5	2·1	2·5	1·6	1·7
0·5	1·8	1·4	3·1	1·8	2·2	1·9	1·4
0·1	1·5	1·5	2·6	1·6	2·0	1·5	1·2
0·05	2·0	1·6	2·9	1·6	1·8	1·3	1·1
0·01	0·9	1·3	1·8	1·1	1·7	1·9	2·0
0·005	0·6	0·5	0·8	0·9	0·8	1·0	1·7
0·001	0·7	0·5	0·8	0·6	0·7	0·7	0·5
0·0005	0·8	0·5	0·8	0·7	0·7	0·9	0·5

is generally sodium chloride and this has not been found to be as effective as calcium chloride in bringing about these retardations. One thing that these findings do indicate is the danger of inter-laboratory comparative testing with the same aggregates, cement, etc., unless distilled, de-ionised or identical waters are used in all cases.

The retardation effect is only regained in part at later ages as Table 2.2 shows. It can be seen that early accelerated strengths are not maintained at later ages. Chemical retarders act in the opposite way but, as already stated, this retardation effect is thought to be due to physical causes.

TABLE 2.2
24 HOUR AND LATER AGE COMPARATIVE STRENGTH FOR 4/1, 0.5 W/C MORTARS

	Age			
Anhydrous $CaCl_2$*/cement* (w/w)	*24 h*	*3 day*	*7 day*	*28 day*
1·0	1·6	1·5	1·3	1·1
0·5	1·4	1·4	1·3	1·0
0·1	1·5	1·4	1·2	1·0
0·05	1·6	1·4	1·3	1·1
0·01	1·3	1·2	1·2	0·9
0·005	0·5	0·5	0·6	0·7
0·001	0·5	0·6	0·6	0·6
0·0005	0·5	0·5	0·6	0·7

The admixtures should be obtained in liquor or solution stock form and dispensed into the mixer at the same time as the addition of the mixing water. Stock solutions may be made out of industrial flake and the amount required calculated from the solution SG (specific gravity) as in Table 2.3. The water requirement of the mix must be calculated to include for the water in the solution in total or effective W/C calculations.

TABLE 2.3
CONCENTRATION VERSUS SG OF $CaCl_2$ STOCK SOLUTIONS

w/v $CaCl_2$ (g/100 ml)	*SG*
0	1·00
10	1·04
20	1·08
30	1·13
40	1·17
50	1·22
60	1·26
70	1·31
80	1·35
90	1·40
100	1·44

A demand for non-chloride accelerators following the ban in some countries has existed since the middle sixties but substitutions by formates, citrates, nitrites, etc., cause problems, as mentioned earlier, because of their sensitivity to the tri-calcium aluminate level in the cement as Table 2.4 shows.

TABLE 2.4
COMPARATIVE CUBE STRENGTH TYPICAL COMPARISONS WITH CALCIUM FORMATE AT 1.0% w/w CEMENT

	Age			
C3A in cement (%)	*24 h*	*3 day*	*7 day*	*28 day*
14	1·0	1·1	1·0	1·0
9	1·4	1·4	1·3	1·3
3	1·9	1·8	1·6	1·5

It can be seen that the best results are obtained with a low C3A cement, and ordinary Portland cements with levels of C3A well under 10% and sulphate-resisting cements are the only types that will apparently benefit. The choice is between the use of plasticising and superplasticising admixtures as indirect accelerators (through reduction of the W/C) and the development of other economic accelerating chemicals.

2.2 PLASTICISERS

These are available in three forms:

(a) Normal—neither accelerating nor retarding
(b) Retarding
(c) Accelerating

They are usually based upon calcium lignosulphonate or carboxylic acid and plasticise by placing negative electrostatic charges on particle surfaces thus causing them to repel one another. As a group of admixtures they have the most promise in both the precast and *in situ* concrete industries because they enable one to reduce the W/C for the same workability as the control mix (indirect accelerator effect), to improve the workability for the same W/C as the control with the same ensuing strengths, or to have a mixture of both. In effect, this means an interim W/C with improved workability. Table 2.5 illustrates this effect.

TABLE 2.5
TYPICAL EFFECT OF PLASTICISING ADMIXTURE ON PROPERTIES OF A VIBRATED CONCRETE PRODUCT

W/C total	*Admixture w/w cement*	*Slump (mm)*	*Cube strengths in N/mm²*		
			24 h	*7 day*	*28 day*
0·50	0	50	15	35	45
0·50	0·2	150	13	35	48
0·40	0·2	50	20	45	60
0·45	0·2	100	17	40	55

The dosage rates vary from 100 to 1000 ml/50 kg cement and each type should be dispensed at the same time as the mixing water. As far as selection is concerned, much of this appears to be a function of the grading of the fine aggregate. The coarser sand mixes benefit more with the lignines, whereas the finer dune sands work better with the carboxylic derivatives. Some of the lignines have free sugar radicals left in them in the extraction process and these are largely responsible for the retardation. These are left in for the (b) type but removed for the (a) type, and, for the (c) type, not only removed but replaced by chloride or other accelerators.

The (a) and (b) types are the most commonly used in the precast industry, mainly in the wet-cast vibrated process, and their main applications are for indirect acceleration, workability and surface finish.

2.3 SUPER-PLASTICISERS

These are more vigorously acting agents based upon chemicals such as the naphthosulphonates and formaldehydes and work by the same electrostatic mechanism as described in Section 2.2 but with stronger dipole yet short-lived (30–60 minutes) forces. Their addition rates are rather higher than for plasticisers and range approximately from 200 to 2000 ml/50 kg depending upon the effect required. Their short active life is exemplified by the workability characteristics, which return to those of a no-admixture situation over 30–60 minutes depending mainly upon temperature. This makes them more applicable to precast rather than *in situ* work due to the shorter times between mixing and usage. In ready-mixed concrete work the admixture needs to be added to the mixer truck on site.

There are two ways in which these super-plasticisers can be used:

(a) By controlling the initial workability stringently before addition, to give a flowing concrete requiring minimum compactive effort coupled with little or no bleeding.
(b) By reducing the W/C for a vibratable type concrete workability.

System (a) is not only difficult to achieve but the mould work has to be designed to resist what is, in effect, a liquid with an SG of about 2.4. System (b) is far more attractive for precast work and is the only one that should be considered.

2.4 WATER REPELLENTS

These are hydrophobic capillary-lining materials in the form of metallic soaps such as calcium or aluminium stearate. They can be added to the mix at 0·5–2·0% w/w cement concentration in the form of the metallic soap, or can be added to wet concrete mixes at the mixer stage in the form of stearic acid, which will immediately react with the free lime to form the metallic soap which is the water repellent agent. In all forms the admixture comes as a fine low-bulk-density white powder. The main application is in hammer-compacted architectural units such as cast stone whose mediocre to high permeability needs to be compensated for to inhibit crazing, dirt formation and mould growth. An experiment on cast stone samples with calcium stearate concentrations from 0 to 2·0% w/w cement, weathering on a roof site for 10 years showed that the addition of the water repellent resulted in vastly improved durability. The control sample broke up due to frost and algae attack, the 0·1–0·5% concentrations showed slight dirtying and the 1·0–2·0% samples remained pristine. The admixtures have a particular application in pigmented concretes where they help to retain the colour.

Water repellents should never be used in a mix containing either plasticisers or super-plasticisers. The hydrophilic and hydrophobic effects will be in opposition and a very patchy product will result.

As far as the effects on strength are concerned the addition of stearates has a small retardation effect on the wet mix but improves the earth-moist mixes, probably due to retention of moisture in the low-water-content mix used. This is exemplified by the typical results shown in Table 2.6.

TABLE 2.6
CONTROL CUBE STRENGTH COMPARISONS FOR CALCIUM STEARATE ADMIXTURE

Mix	*Total W/C*	*Free W/C*	*24 h*	*7 day*	*28 day*	*Aggregates*
20 mm/ 350 cement	0·55	0·47	0·8	0·7	0·7	Granite/ sand
5 mm/ 400 cement	0·45	0·32	1·3	2·0	2·4	Limestone/ sand

2.5 AIR ENTRAINERS

Although air entrainment agents (AEA) are widely applied to *in situ* concretes, mainly for frost and de-icing chemical durability, they have a minimal application in precast work.

The admixture is in liquid form and based upon either the sodium salt of the vinsol resin or complex sulphonates or similar agents which are added at about 100–500 ml/50 kg of cement (depending upon the mix details and type of agent). They should impart to the mix a modified capillary structure by producing a stable fresh concrete system containing approximately uniformly sized and spaced bubbles, which act as safety valves in the freeze-thaw mechanisms. This improved resistance is alleged to obtain when de-icing chemicals are used, as well as when they are not, but the evidence (discussed in Chapter 8) casts doubt upon the benefits in the former case.

The only precast products that can benefit from proper air entrainment are wet cast vibrated units that are used in and around ground level, viz. paving slabs, kerbs, abutment units, flower pots, litter bins, etc. However, the vast majority of slabs and kerbs are made by machine-intensive methods where, due to their workability aiding effect, air-entrainment-agent-containing products will generally have less air in them than the control concretes.

Fresh concrete air content tests only reveal how much air there is in the mix and not how much is entrapped and entrained, and not the entrained form of air. A microscopic study or a standard freeze-thaw test is necessary to assess the performance of such concrete. About 5% of air v/v concrete is required and the efficiency is mainly a function of the cement content and the fine aggregate grading.

2.6 ANTI-MOISTURE MIGRATORS

This is not a common categorisation of admixtures, but is still a significant field bearing in mind that the admixtures considered in Sections 2.2, 2.3 and 2.4 do result in some anti-moisture benefits, but not enough to promote them as bedding and pointing mortar admixture for high suction substrates such as autoclaved aerated concrete, cast stone and/or for hot-weather working conditions where pointing has to be undertaken.

The most popular admixture is the same as the cellulose used for wall-papering. The common basic chemical is methyl ethyl cellulose used as a 0·5–1·0% w/v solution in the gauging liquid for the mortar. Such mortars are virtually unaffected by dry high suction surfaces and stay workable for a period up to about two hours even at temperatures as high as 40°C and at relative humidities down to 10%.

2.7 PRODUCT APPLICATIONS

With the foregoing discussion in mind, one can list the applications for the products/admixtures described in the preceding sections:

2.1 Vibrated reinforced and unreinforced concretes (reinforced units only if permitted by regulations).
2.2 (a) and (c) as 2.1 and pressed and extruded products.
2.2 (b) ready-mixed mortars delivered to site.
2.3 As 2.2.
2.4 Cast stone, coloured and architectural concretes without 2.2 and 2.3 present.
2.5 Vibrated roadside units.
2.6 Pointing and bedding mortars.

In addition to the point made that water repellents should not be used with plasticisers or super-plasticisers, other admixtures can be coupled provided that trial mixes and the hardened concrete properties are acceptable. A few 'nots' for guidance:

2.1 Do not use chlorides in prestressed work, formates in high C3A cements, nor with HAC or SRPC.
2.2 Do not add after the mixing water, and do not add too much mixing water.
2.3 Do not use stearic acid powder in earth-moist mixes nor with 2.2 types.
2.4 As 2.2, nor without a performance assessment.
2.5 Do not overdose (unlikely on a cost basis but disastrous if done).
2.6 Do not underdose.

BIBLIOGRAPHY

CI'80 International Conference, Admixtures Session, April 1980, London.

3

PIGMENTS

A pigment can be defined as ‘a fine dry powder, or aqueous suspension or slurry of the powder, inert to the ingredients of concrete, and intended to impart a specific colour to the product’. The words ‘intended to impart’ are the basis of this chapter which includes discussion on what pigments are, how they and their performance can be assessed and their practical deployment.

Pigments are available in a variety of particle shapes and sizes but the property they have in common is that they all have a minimum particle size smaller than the finest cement one would use, and rely on their smearing power over the cement and fine aggregate fractions to achieve coloration. Obviously the colours of the cement and the fine aggregate play important roles in determining the final colour of the concrete or mortar and are important in the selection of concrete ingredients. Colour is also affected by the type of formwork or mould materials, release agent, finishing treatment (if used) and curing conditions. To obtain uniform appearance of the product requires stringent controls of these variables.

Other variables associated with colour are discussed in detail later but one general aspect worth mentioning at this stage is ‘fading’ of pigments. By the definition given above there should be no such thing as fading. The staining power of a pigment can be masked by lime leaching over the pigment as well as by carbonation of that lime. In the cases of open-textured concretes and mortars, or when poor quality soft carbon blacks are used, pigments can be washed out by the weather. There is also some evidence that at high temperature (e.g. 40–60° C) and high humidity carbon becomes slowly oxidised.

3.1 TYPES OF PIGMENT

The most common types of pigment are the metallic oxides and hydroxides with those based upon iron furnishing yellow, brown, black and red colours and mixtures thereof. Chromic oxide and hydroxide give green colours, cobaltic oxide blue and titanium dioxide white colours. These oxide minimum levels are well above 90%; the remaining few per cent of materials are generally innocuous in nature. In the case of cobaltic oxides some sources of these pigments have traces of zinc and lead impurities and these can cause significant retardation in the setting and hardening times of cement and turn the concrete into a slate colour on weathering due to oxidation of these impurities. With cheaper and more reliable organic blue pigments available it is unlikely that cobalt blue pigments would be used to any great extent.

Organic pigments based upon copper complexes of phthalocyanine are now in use; they are available in blue or green colours. These pigments are very fine and hydrophobic and they are best used diluted with an inert filler such as fine silica in order to control the concentration and to endow the pigment with hydrophilic properties.

Carbon blacks are not long-lived as a rule as their colour can be easily masked by lime bloom oxidation and carbonation and they can also be washed away by rain. However, there are many sources of carbon black and if one has to use them the best sources are the industries associated with the manufacture of carbon for vehicle tyres. For black—and grey-coloured concrete, iron oxide pigments are more reliable and durable.

Natural pigments are available in a large range of colours and mineral forms, the most common of which are yellow ochre and ultramarine blue. Neither of these nor any of the other mineral pigments are suitable for colouring concrete and mortar. For example, yellow ochre has only about 20% iron oxide and the remainder is kaolin and other minerals which have masking effects. Ultramarine blue only maintains its colour in conditions of pH less than approximately 8, and when used in cementitious products only maintains a blue colour in the top carbonated layer.

3.2 PARTICLE PROPERTIES

Rather than compare specific surfaces as for hydraulic cements it is best to compare particle diameters, as this overrides the variable of specific gravity. As there are several different varieties of each colour available Table 3.1 picks out a few representative grades. Bulk densities are also given not only to show the danger of volume batching but also how different grades of the same colour have different properties. Additionally, water absorption is given as this value is of interest when making up pigment slurries or suspensions.

TABLE 3.1
PIGMENT PARTICLE PROPERTIES

Pigment	*Particle size (μm)*	*Bulk density (kg/m³)*	*Absorption (ml/100 g)*
Red iron oxide	0·1	900	35
Red iron oxide	0·7	1500	20
Yellow iron oxide†	0·2 × 0·3	800	50
Yellow iron oxide†	0·2 × 0·8	500	90
Black iron oxide	0·3	1100	33
Brown iron oxide‡	0·3–0·6	900	50
Brown iron oxide‡	0·1–0·2	1000	30
White titanium oxide	0·2	700	24
Green chromic oxide	0·3	1200	19
Carbon black	0·01	500	100
Green or blue phthalocyanine	0·01	500	N/A††

† The yellow iron oxide pigments are needle-shaped particles and this is why two particle dimensions are given; it can also be seen that they have a higher water demand than the other iron oxide pigments.
‡ Brown iron oxides have a larger range of particle sizes in them than the others.
†† The 'N/A' for the water absorption of the phthalocyanine pigments is because they are hydrophobic in their undiluted form and will not absorb water.

It is interesting to compare the figures with Portland cement where, depending upon the type of cement, the particle size (average) is about 5·0 μm and shows that pigments are ten times or more finer than the cement particle average size.

3.3 DISPENSING PIGMENTS

Bearing in mind that not only do bulk densities vary from pigment type to type, but also within a specific type the danger of volume batching dry pigment can be seen. Domestic-type scales are accurate enough and are quite suitable for concrete and mortar mixes whether they be weight or volume batched. Proprietary dispensing machines are available for pigment slurries or suspensions but in the case of suspensions the holding tank or container must be continuously agitated to prevent segregation. Additives may be used to help keep pigments suspended but these should not be the normal workability aids such as lignosulphonates and carboxylates used in concrete mixes, as their 'wetting' action is transferred to the concrete or mortar. This, in turn, allows the coloration effect of pigments to be more easily masked as lime can wet out the particles that much more easily.

3.4 PIGMENT CONCENTRATION

With all proportions on a cement weight basis the range of concentrations for the metallic oxide pigments can vary from 1 to 10%, with the range 3 to 6% being the most common. A great deal depends upon the architectural effect required as a 1 % level is that used for tinting, 5% for a definite colour and 10% for a deep shade. In the case of titanium oxide, this pigment is generally used with white cement and aggregate as the pigment has a very high tinting, and reflective power concentrations above 3% in sunny aspect situations can be uncomfortable to the eye.

The fine type of carbon black tabulated in Table 3.1 and the phthalocyanines, being much finer than the metallic oxides, are generally used at concentrations of 0·1–1·0%. Where the phthalocyanines are diluted, say, ten times with an inert filler, the concentration refers to the active pigment part of the diluent.

Slurries and suspensions are made up of pigment/water mixtures of ratios 1/1 to 1/10 by weight depending upon the pigment used. The dilution of the slurry or suspensions needs to be known accurately so that an automatic dispenser can be set to dispense the required quantity of active pigment material to the concrete mix. In addition, the automatic metering of water needs to be set at a lower level to take account of the water with the pigment. Some of the yellow iron oxide pigments cannot be used in slurry or suspension form for low water control concrete mixes as there would be too much water with the pigment.

3.5 ASSESSING PIGMENTS AND PRODUCTS

There are two distinct aspects to assessing pigments. First, one has a basic interest in quality control and reliability of supply of the material obtained. Second, having achieved a satisfactory state on the first count one wishes to know how consistent the manufactured product will be.

3.5.1 Testing pigments

The two Standards given in the Bibliography have smear tests, but whatever test is employed it is imperative to sample the acceptable product one is to use and to seal it in a dated, coded, air-tight container. In any later comparative test this is the sample that will be used as the control.

In the British test one uses either dry or hydrated-then-dried mixtures of cement and pigment which are squeezed between glass plates and compared against a white background. The German test uses a blend of barytes and pigment and two small pats of this (control and test) are laid side-by-side on white parchment paper then smeared with a square-ended spatula to give two parallel and touching coloured paths. In the writer's opinion a modified German test using the actual cement rather than the barytes is to be preferred. Not only is the comparison easier but there are two other advantages:

(a) If one cannot stock enough cement for a contract and a new batch has a different colour one can adjust the pigment type and/or concentration to suit.
(b) Where pigments are badly ground or poorly prepared the downward force used on the spatula is sufficient to cause streaking.

This streaking effect can be picked up with some carbons, and certainly is with the carbons in fly ash which, with the work put into the concrete by the mixer, tend to give a darker colour than one would predict.

3.5.2. Testing concrete colour

Both the desk-top 100mm square sample and the 300mm square hand-portable samples are misleading in the case of unpigmented materials, and for coloured concretes and mortars they seldom resemble the appearance of the full-size product.

Samples should always be made on a relatively large scale and should include all the variables that will occur in the production.

For example, in the case of a precast concrete panel all aspects of geometry, reinforcement, fittings, fixings and expanded plastics sandwiches should be included. Sandwich panels should be true sandwich units and not bridged as the different curing conditions and temperatures will result in different colours. In the case of brickwork or blockwork the bricks or block should be randomly selected from the supply and built up into a wall at least one metre square.

Since there are fundamental variations in depth, colour, shade and texture due to the many variables that go into concrete or mortar manufacture it is important that samples include these variations. With the best will in the world it is virtually impossible to produce consistent materials all the time and it is only fair to make this plain to the customer.

Having established what the samples are to be, at least one of the samples should be in the precast factory or on site (mortar) so that production can be visually checked against that control at all times.

3.6 PIGMENTING CONCRETE AND MORTAR

Here, two distinct aspects are discussed, namely the preparation of pigmented cements where these are used in preference to adding the pigment directly to the mix, and the manufacture, finishing and curing of materials.

3.6.1 Blending pigments

Producers of coloured concretes and mortars engaged in large amounts of work may well consider colouring the cement as this has two distinct advantages:

(a) The tinting power of a blended mix at a specific pigment concentration can be improved up to two-fold enabling savings of up to 50% of the pigment demand.
(b) A blending process lends itself easily to automated production where blended cements can be air-blown either into storage hoppers or directly into the mixer.
(c) Other admixtures can be blended into the cement at the same time as the pigment.

One of the most common blending tools is the rotary ball mill and, although this is an inexpensive piece of equipment, it is noisy and can take up to 30 minutes to blend and requires the use of ceramic liner and balls when light-coloured blends are being prepared. The more expensive air-elutriation plants can pay for themselves in a very short time as they are quiet, fast (effective blends can be prepared in a matter of 1–5 minutes) and require no modifications for light-coloured blends.

3.6.2 Manufacture of concretes and mortars

There are a number of guidelines to follow:

(a) Formwork or moulds should be of good quality and finish. High gloss paints and high gloss plastics linings should be avoided as they promote hydration staining and all finishes should be matt as discussed earlier.
(b) Mould release agents should be water-in-oil emulsion creams or chemical release agents. Ordinary mineral mould oils and oil-in-water emulsions promote streaking and staining.
(c) Pan-type mixes are preferred to tilting drums but whatever type of mixer is used it should be well maintained with blades properly set, and should be thoroughly cleaned at the ends of working periods or when there is a change in the mix requirements.
(d) As stated earlier pigments should always be weigh-batched or, with slurries and suspensions, weight or volume batched by approved dispenser. Accurate control of concentration is always important.
(e) Dry pigment or blended cement should be added with the nominally dry materials first and mixed for a minute or two. Suspensions and slurries should be added with the water after the dry mixing period.
(f) All concrete (or mortar) ingredients should preferably be weight batched; in the case of volume batching it is advantageous to know the bulk densities and moisture contents so that the proportions can be corrected from mix to mix.
(g) Compaction should be as effective as possible.
(h) Finishing tools may be of the conventional type but in the case of white or light-coloured concretes and mortars timber or acrylic tools are preferred as steel tools cause staining unless the steel is stainless.
(i) Consistent curing conditions are important to maintain a uniform colour and pigmented materials should not be subjected to extremes of conditions during the first few days. The use of membrane curing aids is of assistance if the environment cannot be controlled; polyethylene and similar types of covers are not recommended as they cause condensation and staining.
(j) Coloured concretes and mortars can be finished similarly to other

concretes except that blue phthalocyanine pigmented materials turn green permanently if etched with hydrochloric acid. Table 3.2 gives recommendations on materials, pigments and effects of etching and autoclaving.

TABLE 3.2
SELECTION OF MATERIALS FOR VARIOUS COLOURS OF CONCRETES

Colour Required	*Coarse Aggregate*	*Fine Aggregate*	*Cement*	*Pigment*	*Acid (HCl)*	*Autoclaving*
			For smooth-finished concretes			
White	White	White	White	2% TiO_2	None	None
Pink	Pink or white	White	White	1% Iron oxide	Darkens	Lightens
Red	Red or pink	Red	OPC	4% Iron oxide	None	Lightens
Black	Dark grey	Dark grey	OPC	5% Iron oxide	Lightens	Lightens
			For exposed-aggregate concretes			
Red on white	Red	White	White	2% TiO_2	None	None
Black on green	Dark grey	White or cream	White	4% Cr_2O_3	None	Lightens
White on black	White	Dark grey	OPC	5% Iron oxide	None	Lightens

3.7 PRACTICAL CONSIDERATIONS

(a) Lime bloom and carbonation, often misnamed as efflorescence, is one of the main drawbacks that causes problems with coloured concretes and mortars. By keeping the water content down to a low level, and by good compaction, mix design and curing, the incidence can be minimised. However, the use of an integral water-repellent admixture is recommended and 1% by weight of cement of stearic acid powder is generally sufficient for most concretes. For mortars a concentration of 1·5–2·0% is required and for earth-moist mix such as cast stone, concrete bricks and blocks, 1–2% by weight of cement of a metallic soap such as calcium or aluminium stearate should be used. Figures 3.1 and 3.2 show what happens to black pigmented (carbon) blocks due to poor mix design and curing. A practical roof application of iron oxide pigmented tiles and carbon-pigmented tiles on the same building showed that the iron oxide tiles had superior performance.

Fig. 3.1. Lime bloom masking black pigmented wet-cast blocks.

(b) Carbon black pigments have been discussed earlier but one consideration is the appearance of the mix which takes on an oily, viscous, low workability character even though none of these characteristics actually obtains. No more water should be added to these concretes or mortars than is necessary for the required pre-assessed workability.

(c) Autoclaving generally has a lightening effect on the colour and some colours are not suitable for use at autoclaving temperatures; the manufacturers will advise on this matter. To achieve the same colour for autoclaved products as for those cured at atmospheric pressure

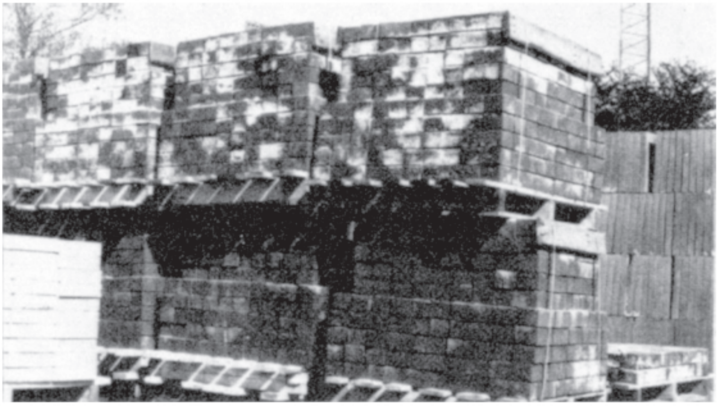

Fig. 3.2. Lime bloom on carbon-pigmented blocks.

and temperature the concentration needs to be increased from 10% to perhaps 50%.

(d) Protection of skin is necessary especially as pigment particles are easily air-borne. Although none of the pigments are toxic or poisonous they are irritants, and air extraction over mixes is a good method of keeping dust down to an acceptable level. When it comes to washing the skin, baby soaps are preferable to ordinary or liquid soap as their fine grain penetrates into the contours of the skin.

(e) Chlorides in the mix, either due to admixture or to impurities in the aggregates, will promote lime bloom and effect changes in the colour of the concrete or mortar. In iron-oxide-based pigments there will be a masking effect due to iron chloride formation, and in the phthalocyanine blue pigment there will be a green contribution due to conversion into the chlorinated form of pigment.

BIBLIOGRAPHY

BS 1014, *Pigments for concrete.*
DIN 55.913, *Pigments for colouring concrete.*

4

FLY ASH

This material, also known as pulverised fuel ash or PFA, is a by-product of electricity generation from pulverised coal firing. It is mainly of interest to those countries having this form of power production, but even in some of those countries it is not necessarily used everywhere because of transport costs.

It has a beneficial action in many applications in *in situ* concrete where its pozzolanic (long-term cementitious effect in the presence of lime and water) and exotherm control properties, as well as its ability to give ordinary Portland mixes an improved sulphate resistance, have been used to advantage. As far as precast concrete product properties are concerned these benefits are of little value because of early strength requirements, generally small sections being cast, and good compaction, respectively. What is of interest to the precaster are the following questions:

(a) Does the addition improve the early (0–10 minute old) handling properties?
(b) Does the addition improve the early strength (6–18 hours old)?
(c) Has the product better surface appearance and arrisses?
(d) How are other relevant properties affected?
(e) Does one get less wear and tear on machinery and plant?

This chapter divides into several parts, the first part dealing with a description of fly ash, and the remaining parts dealing with specific process studies of applications researched by the author. There is one matter to note before proceeding, however, and that is a criticism (constructive) of the terminology 'cement replacement'. Depending upon how one defines the control mix (the mix not containing fly ash) any addition of ash to the mix is a replacement of the cement and/or the aggregate. The only factor that is of interest is that of the concrete being economical to produce as a function of materials price, the total cost of production and the number of rejects.

4.1 PROPERTIES OF FLY ASH

Fly ash is a light slate grey to dark grey or brown powder extracted from the flue gases of a power station, usually by means of electrostatic precipitators. Its colour is governed mainly by the amount and particle size of the residual unburnt carbon, and secondly by the iron oxide.

Table 4.1 gives the reader an idea of the ranges of chemicals in fly ashes internationally, bearing in mind that sources, other than those specifically selected, can be modern, old or standby power stations.

TABLE 4.1
RANGES OF CHEMICAL MAKE-UPS OF FLY ASHES

Chemical	*Percentage range*
Silica (SiO_2)	28–51
Alumina (Al_2O_3)	12–34
Ferric oxide (Fe_2O_3)	4–26
Lime (CaO)	1–10
Magnesia (MgO)	0·5–2
Sulphate (SO_3)	0·2–3·6
Alkalis (R_2O)	1–5
Ignition loss—mainly carbon	1–32

The large ranges shown arise not only from the varying efficiencies of the boilers but also from the fact that a single power station may well rely upon supplies from more than one colliery and that there could be several seams being worked in each colliery. Apart from the sulphate and carbon contents, precast concrete product performance is luckily quite insensitive to the chemical make-up of the ash.

The first four chemicals, with the fluxing alkalis, form very small hollow glass balls, resulting in a low bulk density material. The presence of lime at high levels can result in cementitious properties and it is advisable to ensure that high-lime fly ashes are dry-stored otherwise they will slowly harden. The magnesia could cause expansive properties in the concrete if it is in the form of periclase. Although it is generally not in this form, Standards assume that it could cause trouble and specify limits.

The sulphate is one of the troublesome ingredients because concretes can generally tolerate a maximum sulphate level (SO_3) of about 5% by weight of cement. Since cement already has up to 3% as SO_3 from the gypsum used to retard the setting rate, the extra 2% or more needed to reach this can be easily obtained with an ash (2% SO_3)/cement ratio of 1/1 by weight. Such concretes can suffer from long-term internal sulphate attack even though all their other properties may be acceptable. This is shown in Fig. 4.1 in five-year-old kerbs.

Carbon is found as angular soft black particles which act as nominal voids and create a high water demand in the mix. Concrete colours tend to be darker than expected due to the carbon being ground finer in the mixer. Its presence is the reason why fly ashes cannot be used in light-coloured concretes. Carbon level is the factor leading to a loss of strength.

Particle size can vary from 200 to 800m^2/kg (Rigden or Blaine). Again, as for chemical composition, consistent material can generally only be obtained from a specified source. For *in situ* work the pozzolanic activity can be indicated by the passing 45 μm sieve but, as stated before, this is of little or no interest to the precaster. The acceptable range in precast processes is 300–600 m^2/kg; if the ash is too coarse it has a reduced beneficial effect on properties and if it is too fine it becomes difficult to disperse and mix.

The bulk density of fly ash can vary from 700 to 900 kg/m^3. Compared to Portland cement's range of 1300–1500 kg/m3 it can be seen that ash can result in dust nuisance and needs to be silo rather than bag handled and, in both cases, requires the installation of dust-extraction plant.

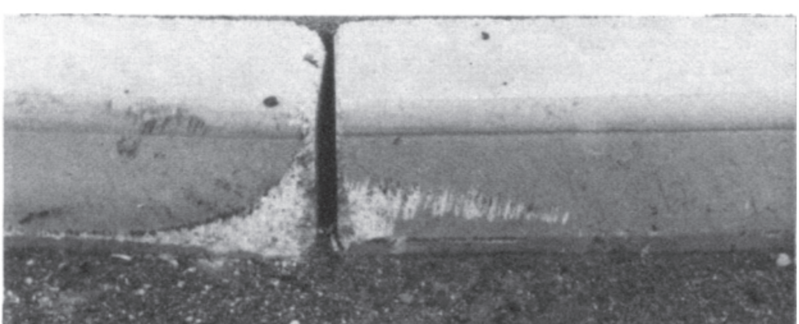

Fig. 4.1. Internal sulphate attack in kerb containing fly ash.

This bulk density figure means that a fully compacted fly ash concrete can have a higher denseness coupled with a lower density compared to a control concrete.

In the subsequent sections the following terminology is used:

F Fly ash (Specific ashes *F*1, *F*2 and *F*3 used in some tests)
C Ordinary Portland cement
A Aggregate total
W Water absorption at stated time (% on oven dry weight)
I Initial surface absorption at stated time (ml/m^2/s), *F*, *C* and *A* all on weight proportions.

4.2 WET-PRESSED PRODUCTS

The process used here was the Fielding and Platt wet-pressed method where the initial water content of the mix is approximately halved under the action of pressure and taken out of the mix by a vacuum pressure box and a bottom filter.

In some of the works tests three ashes with the properties shown in Table 4.2 were selected. The mix used was a uniformly graded, nominally dry 20 mm granite down to dust and Table 4.3 shows the mixes used in the pressed kerbs.

Table 4.4 shows the 7 and 28 day flexural strengths in N/mm^2 working to a national standard minimum limit of 5 N/mm^2. Not only are the observed results recorded but they are also corrected for the financial gain bearing in mind that the mix becomes leaner in cement per unit

TABLE 4.2
PROPERTIES OF ASHES USED IN THE THREE ASH-WORKS TESTS

Station source	*Modern*† *F1*	*Old* *F2*	*Standby* *F3*
Specific surface (m^2/kg)	330	365	‡
Carbon content (C)	3·5	5·5	16·6
Sulphate content (SO_3)	0·8	1·2	1·8

† 'Modern' in 1963 when these ashes were sampled is no reflection on the later and improved boilers where a typical carbon content would be 1% or less.

‡ The standby ash could not be air-permeability tested as its high carbon content did not enable one to make a bed in the cell.

TABLE 4.3
WET-PRESSED PFA MIXES

A	*C*	*Initial water*	*F1/C*	*Carbon/C*	*F2/C*	*Carbon/C*	*F3/C*	*Carbon/C*
5·9	1·0	1·00	—	—	—	—	—	—
5·9	1·0	1·05	0·25	0·87	0·25	1·38	0·25	4·15
5·9	1·0	1·10	0·50	1·75	0·50	2·75	0·50	8·30
5·9	1·0	1·20	1·00	3·50	1·00	5·50	1·00	16·60
5·9	1·0	1·25	1·50	5·25	1·50	8·25	1·50	24·90
5·9	1·0	1·30	2·00	7·00	2·00	11·00	2·00	33·20

TABLE 4.4
OBSERVED AND COST-CORRECTED FLEXURAL STRENGTHS OF WET-PRESSED KERBS

F/C	*F1*		*F2*		*F3*	
	7 day	28 day	7 day	28 day	7 day	28 day
0	5·0	5·4	5·0	5·4	5·0	5·4
0·25	5·0(5·1)	5·7(5·8)	5·6(5·7)	6·0(6·2)	4·3(4·4)	4·8(4·9)
0·50	6·1(6·4)	5·2(5·5)	5·0(5·3)	5·2(5·5)	4·4(4·6)	3·8(4·0)
1·00	5·2(5·7)	5·5(6·1)	4·7(5·2)	4·7(5·2)	3·4(3·7)	4·1(4·5)
1·50	4·9(5·6)	4·7(5·4)	4·0(4·6)	4·0(4·6)	3·1(3·6)	3·7(4·3)
2·00	3·4(4·1)	4·1(4·9)	3·6(4·3)	3·6(4·3)	3·1(3·7)	2·8(3·4)

volume as the fly ash proportion increases. As a comparative exercise a 5·9/1·0/1·30/2·00 mix is about 20% cheaper than the control mix and the corrections are based on a 1% economy for every 0·1 *F/C* increment. By this form of correction of the results one gets an idea of how much it costs to obtain strength in the product. The cost-corrected results are given in brackets.

It can be seen that *F*3 detrimentally affects the strength at all loadings but that *F*1 and *F*2 have an initial benefit followed by a decrease in strength with increasing fly ash levels. The cost per unit strength numbers (given in parentheses) are interesting for *F*1 and *F*2 and indicate that up to or above equal cement weights fly ash concrete can produce economic and acceptable strengths.

When one plots on a graph strength against fly ash concentration one obtains a pattern of points through which the imaginative person can draw what he or she likes. However, when one plots the strengths against carbon/cement ratio using Table 4.3 one achieves an interesting shape of curve that predominates for virtually all precast machine processes of manufacture. Figure 4.2 illustrates this feature. Apart from observing a marginal improvement of the 28 day over the 7 day strengths it may be seen that the best fit curves show that there is an increase followed by a continuous decrease. At the equivalent of 4% carbon/cement one returns to the control 28 day strengths and all concentrations from 0 to 4% result in improved strengths without taking into account the additional cost-correction benefit factors. Since most fly ashes on the market (as at 1980) contain below 4% carbon, and the wet-press process becomes uneconomic at *F/C* greater than 1·0 due to the increased pressing time necessary, then it can be concluded that fly ash can do nothing but add strength to the product.

Samples of these kerbs were oven dried and submitted to the Initial Surface Absorption Test and the results are tabulated in Table 4.5 in ml/m^2/s. It is virtually impossible to cost-correct these so the tabulated results are those actually recorded. The same effects can be observed as

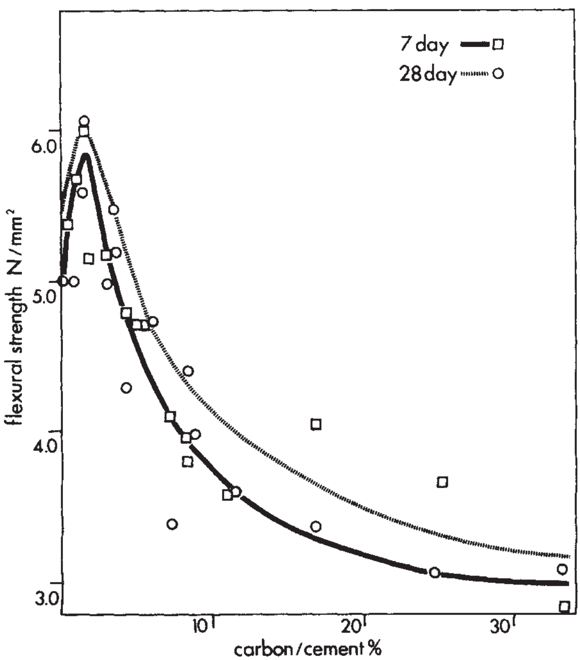

Fig. 4.2. 7 and 28 day wet-pressed kerb strengths versus carbon/cement.

TABLE 4.5
INITIAL SURFACE ABSORPTIONS FOR WET-PRESSED KERBS

F/C	*F1*			*F2*			*F3*		
	I 10 min	*I 30 min*	*I 60 min*	*I 10 min*	*I 30 min*	*I 60 min*	*I 10 min*	*I 30 min*	*I 60 min*
0	0·34	0·18	0·13	0·34	0·18	0·13	0·34	0·18	0·13
0·25	0·09	0·08	0·05	0·09	0·05	0·04	0·27	0·12	0·08
0·50	0·11	0·09	0·07	0·16	0·12	0·08	0·30	0·16	0·11
1·00	0·14	0·08	0·06	0·23	0·12	0·06	0·33	0·11	0·08
1·50	0·31	0·18	0·12	0·33	0·26	0·16	0·69	0·32	0·24
2·00	0·43	0·15	0·10	0·25	0·20	0·12	1·05	0·70	0·36

in Table 4.4 and in Fig. 4.2; in Fig. 4.3 these numbers are shown at 30 minute intervals plotted against carbon/cement ratio. It is again concluded that practical additions of fly ash to wet-pressed kerb mixes always result in an improved impermeability.

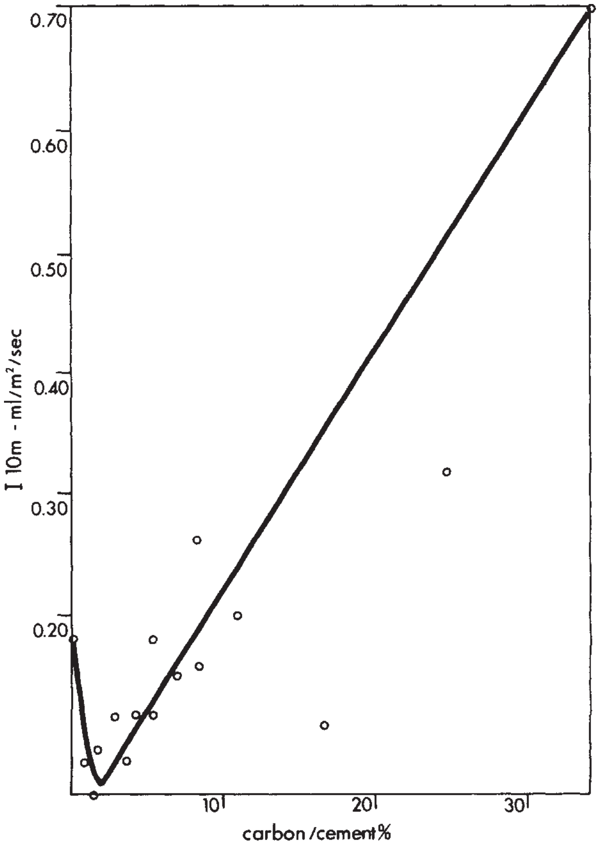

Fig. 4.3. *I* 10 min versus carbon/cement.

Frost resistance tests were conducted on 75×75×300 mm prisms sawn from these kerbs and immersed in water-filled sealed containers which were placed in an ethylene glycol tank and frost-cycled at the rate of one cycle every two hours from 20°C to–20°C, an extremely vicious test. It should be borne in mind that this test was based then (1963) on the USA tentative method of freeze-thaw testing before RILEM had begun their work. The average of pairs of samples' weight losses are recorded as percentages in Table 4.6.

TABLE 4.6
FREEZE-THAW PERCENTAGE WEIGHT LOSSES FOR WET-PRESSED KERBS (NUMBER OF CYCLES IN PARENTHESES)

F/C	*F1*		*F2*		*F3*	
age (days)	*29 (100)*	*60 (164)*	*29 (100)*	*60 (164)*	*29 (100)*	*60 (164)*
0	1·3	2·4	1·3	2·4	1·3	2·4
0·25	1·3	0·5	0·8	0·6	3·1	0·9
0·50	3·1	0·4	1·1	0·6	6·9	3·5
1·00	2·0	0·9	1·8	0·9	9·3	3·5
1·50	3·8	0·5	2·6	0·6	14·0	7·1
2·00	4·6	1·9	3·7	1·1	20·0	13·7

It can be seen that although this particular test is rather severe the results still have value, relatively speaking, in that the more mature 60 day old samples, apart from the controls, had better resistance than the 29 day old ones even when submitted to a larger number of freeze-thaw cycles. Some of this improved resistance could also be associated with improved elasticity and/or some pozzolanic effect. Again, a similar but not so distinct relationship is observed between freeze-thaw weight loss and carbon/cement ratio and is illustrated in Fig. 4.4.

Further tests were conducted on wet-pressed paving slabs with the mix designs to one part of cement shown in Table 4.7. The fly ashes used by these two precasters were known to be good-quality low-carbon materials (1–3% expected range) but no other details were made available at that time.

Table 4.8 shows the flexural or bending strength test results at various ages, all figures being in N/mm^2. These results have not been cost-corrected as in Table 4.4, but even without taking into account how much it costs to produce 1 N/mm^2 several conclusions can be drawn:

(a) The fly ash addition benefits the concrete containing the natural sand fines much more than the concrete containing basalt 5 mm down to dust as fines.
(b) Although there is a slight indication in the S-concretes that there is a contribution by the pozzolanic effect between 14 and 28 days this effect is much more significant in the L-mix concretes.
(c) Taking the 14 or 28 day strengths as the criteria determining when a

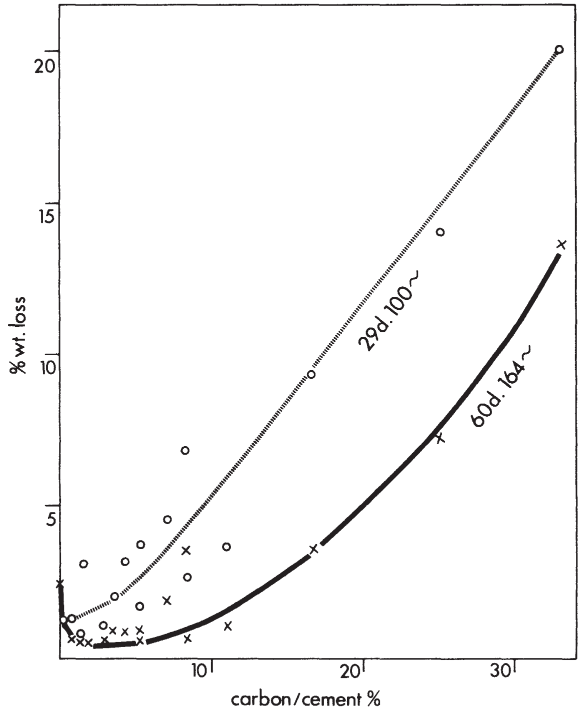

Fig. 4.4. Freeze-thaw % weight loss versus carbon/cement in wet-pressed kerbs.

TABLE 4.7
DETAILS OF WET-PRESSED PAVING SLAB MIXES

Ref.	*Mix*	*A*	*F*	*Initial water (estimate)*
S1	67% granite 10 mm	5·4	0	0·90
S2	33% basalt 5 mm down		0·10	0·93
S3	(very dusty)		0·20	0·96
S4			0·50	1·00
S5			0·75	1·03
S6			1·00	1·05
L1	80% granite 12 mm	5·0	0	0·85
L2	20% natural sand		0·25	0·88
L3			0·50	0·92
L4			0·75	0·96
L5			1·00	1·00

manufacturer would be likely to supply to a 7 N/mm^2 requirement, the dusty mixes need a slight enrichment with cement content to comply, whereas the L-concretes could tolerate a cement reduction if all other requirements were satisfied.

TABLE 4.8
FLEXURAL STRENGTHS OF WET-PRESSED PAVING SLABS

	Age				
Ref.	*7 day*	*14 day*	*4 week*	*7 week*	*18 week*
S1	6·8	6·7	7·3		
S2	6·3	6·6	7·3		
S3	6·8	7·3	7·0		
S4	6·7	6·4	6·7		
S5	6·1	6·7	7·5		
S6	5·8	6·0	7·0		
L1	6·6	6·2		7·9	9·2
L2	6·8	8·4		8·1	11·1
L3	6·9	8·3		9·3	9·1
L4	8·7	7·3		10·0	10·6
L5	7·0	8·0		10·0	10·6

It should be stressed at this point that paving slabs could well be required in light colours or pastel shades and fly ash might be unacceptable on this basis.

Further tests were undertaken on samples cut from these paving slabs and submitted to Initial Surface Absorption and Water Absorption tests and the results are shown in Table 4.9. The results relate to those in Table 4.8 where the filling and densifying effect is noticeable at all concentrations in the L-concretes but only at the lower fly ash concentrations in the S-concretes. However, none of the S-loadings of fly ash are sufficient to give cause for concern regarding the practical freeze-thaw or weathering resistance where *I*-maxima of 0·50, 0·30 and 0·20 at these terms are the suggested limits.

Surface shrinkage characteristics were investigated from 24 to 176 hours old drying in a room at 20±2°C and 45–50% relative humidity using a **DEMEC** strain gauge, and the results are recorded in units of 0·001% movement in Table 4.10. Assuming an exponential decay of the form:

$$S = S_F(1 - e^{-bt})$$

TABLE 4.9
INITIAL SURFACE AND WATER ABSORPTIONS OF WET-PRESSED PAVING SLABS

Ref.	*I 10 min*	*I 30 min*	*I 1 h*	*W 10 min*	*W 30 min*	*W 1 h*	*W 24 h*
S1	0·13	0·08	0·05	0·9	1·2	1·5	2·9
S2	0·07	0·05	0·03	1·8	2·6	3·2	4·8
S3	0·14	0·09	0·06	2·0	2·7	3·5	5·3
S4	0·17	0·16	0·10	2·0	3·0	3·7	5·4
S5	0·34	0·20	0·14	2·1	3·2	3·9	5·6
S6	0·35	0·16	0·12	2·0	3·0	3·7	5·6
L1	0·06	0·04	0·03	1·4	1·9	2·5	3·5
L2	0·02	0·02	0·01	1·0	1·7	2·0	3·1
L3	0·04	0·03	0·03	0·7	1·5	1·6	1·7
L4	0·04	0·03	0·02	1·2	2·1	2·8	3·5
L5	0·03	0·02	0·02	0·5	1·0	1·6	1·8

TABLE 4.10
OBSERVED AND PREDICTED SURFACE SHRINKAGES IN WET-PRESSED PAVING SLABS

	Observed				*Predicted*		
Ref.	*S 44 h*	*S 88 h*	*S 132 h*	*S 176 h*	*S 132 h*	*S 176 h*	SF
S1	35	48	51	49	53	55	56
S2	40	51	52	53	54	55	55
S3	43	52	52	56	54	54	54
S4	47	62	70	69	67	68	69
S5	27	38	41	44	43	45	46
S6	43	60	65	65	67	69	71
L1	44	53	56	59	55	55	55
L2	25	43	44	47	56	66	89
L3	35	46	46	50	49	51	51
L4	17	26	28	32	31	33	36
L5	27	40	41	40	46	49	52

where S is shrinkage at time t, and S_F is the final shrinkage, one can predict the longer term figures accurately as well as estimate the final value. At these drying conditions the concretes will probably dry down to the order of 3%v/v moisture content. Other imposed conditions would result in different end points.

These results not only reflect those of Tables 4.8 and 4.9 but also show something not picked up before now. With each result being the average of three samples some significance can be attached to the findings although the accuracy of recording is only to ±1. Both concretes were from two different factories and using different materials gave optimum drying shrinkage results at *F/C*=0·75 (S5 and L4). This is probably due to a combination of grading correction combined with pore-filling and pozzolanic effects.

Results from several other factories on wet-pressed products are available and they all substantiate the findings tabulated. The following conclusions are drawn:

1. Fly ash either has a beneficial effect or causes no property change in wet-pressed products, depending upon the mix being fines-deficient or not, respectively.
2. When benefits occur these are reflected in improved strength, impermeability and frost resistance.
3. Optimum benefits are obtained in the *F/C* range 0·50–1·00 with the 0·75 level being the most rewarding.

4.3 PNEUMATICALLY TAMPED PRODUCTS

In this section are described the experimental findings from a series of works-manufactured, laboratory-tested pneumatic-hammer-compacted precast concrete kerbs. The results may be related to any hand machine or mass machine process where earth-moist mix designs are compacted by pneumatic ramming.

The same ashes as described in Table 4.2 with the same loadings *F/C* as in Table 4.3 were used. The mix consisted of:

1	Rapid-hardening Portland cement
4·0	Natural sand, 3 mm downwards. Sharp and clean.
2·0	Granite 10 mm single size.
(all parts by weight)	

The mix, ash and water variations were as follows:

F/C	0	0·25	0·50	1·00	1·50	2·00
Total water	0·35	0·39	0·43	0·50	0·58	0·65

Table 4.11 lists the 14 day old flexural strengths in N/mm^2 in the style of Table 4.4.

TABLE 4.11
OBSERVED AND COST-CORRECTED FLEXURAL STRENGTHS OF PNEUMATICALLY TAMPED KERBS AT 14 DAYS OLD

F/C	*F1*	*F2*	*F3*
0	3·8	3·8	3·8
0·25	4·8(4·9)	4·1(4·2)	4·7(4·8)
0·50	5·0(5·3)	2·7(2·8)	4·2(4·4)
1·00	4·6(5·1)	3·9(4·3)	3·7(4·0)
1·50	4·0(4·6)	4·1(4·7)	2·6(3·0)
2·00	3·6(4·3)	3·1(3·7)	1·9(2·2)

It may be seen in Fig. 4.5 that the same pattern arises when one plots strength against carbon content but that the spread of results is larger than for the wet-pressed kerbs and that a beneficial effect for tamped kerbs obtains for carbon/cement up to 10%. The surfaces and arrisses of the instantly demoulded products were much more acceptable, and since the mix gets too impracticable to mix and compact at *F/C* much above 0·8, such products would benefit by using virtually any ash available. As with most closely controlled laboratory tests there is always an odd result and, from Chapter 2, this could be due to trace chlorides.

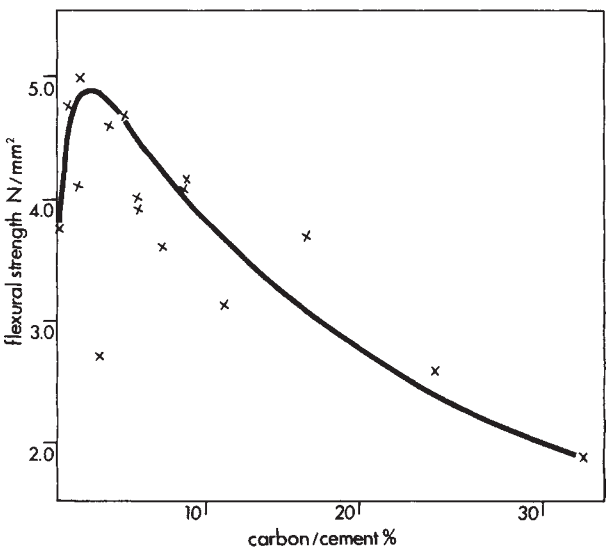

Fig. 4.5. 14 day pneumatically tamped kerb flexural strengths versus carbon/cement.

Initial surface absorption tests and freeze-thaw cycles as previously described were undertaken for 48 cycles from 60 to 64 days old and the results are shown in Table 4.12. The results reflect those of Table 4.11 to a small extent, but what is more interesting is the relationship between. *I* 10min and weight loss; this is approximately linear and with an *I* 10min of 0·50 (a tentative limit proposal) being equivalent to a 30% weight loss, this is an extremely severe freeze-thaw test.

The following conclusions are drawn:

1. Fly ashes with a range of carbon contents up to 10% may be used to advantage in tamped products provided there is no detriment to colour requirements.
2. The optimum *F/C* loading range is 0·5–1·0.
3. The maximum loading possible may be below 0·5 depending upon the method of tamping, type of machine and the raw materials.

4.4 EXTRUDED ROOFING TILES

Due to restriction in the permissible interference in a factory's mass production we could assess only one fly ash and *F2* was selected. The works mix was a 3/1 by weight sand/ordinary Portland cement mix with a sand grading:

Sieve No.	*Passing %*
1·18 mm	100
600 *μm*	95
300 *μm*	50
150 *μm*	5

The following *F/C* ratios and approximate total water contents were used:

F/C	0	0·25	0·37	0·50	0·63	0·75
Total water	0·28	0·32	0·34	0·36	0·38	0·40

Observed and cost-corrected-relative-to-control failing loads (flexure) are shown in Table 4.13. It can be seen that *F/C* over 0·37 detrimentally affects the 24 hour strength but this begins to sort itself out with the maturing following the steam (80% RH 36°C) curing and at 11 days old there is little to choose between them. With the particular sand used the pore-filling capability is better than with a finer or a continuously graded

TABLE 4.12
INITIAL SURFACE ABSORPTION AND FREEZE-THAW PERCENTAGE WEIGHT LOSSES IN TAMPED KERBS

F/C	*F1*				*F2*				*F3*			
	I 10 min	*I 30 min*	*I 60 min*	*Loss*	*I 10 min*	*I 30 min*	*I 60 min*	*Loss*	*I 10 min*	*I 30 min*	*I 60 min*	*Loss*
0	0·15	0·10	0·07	2·9	0·15	0·10	0·07	2·9	0·15	0·10	0·07	2·9
0·25	0·11	0·08	0·06	3·7	0·32	0·22	0·11	25·1	0·13	0·11	0·12	2·0
0·50	0·21	0·14	0·01	4·2	0·51	0·34	0·24	54·3	0·12	0·09	0·06	3·8
1·00	0·12	0·12	0·04	8·7	0·22	0·14	0·11	13·4	0·09	0·01	0·04	3·4
1·50	0·60	0·48	0·24	8·0	0·24	0·16	0·11	13·4	0·33	0·27	0·23	4·4
2·00	0·08	0·08	0·04	13·0	0·20	0·10	0·08	33·6	0·25	—	0·24	7·4

TABLE 4.13
OBSERVED AND COST-CORRECTED RELATIVE FLEXURAL STRENGTHS IN EXTRUDED ROOFING TILES

F/C	*24 h* *Obs. (Costed)*	*7 day* *Obs. (Costed)*	*11 day* *Obs. (Costed)*	*Carbon/ cement %*
0·25	1·07(1·10)	1·02(1·05)	1·08(1·11)	1·4
0·37	1·06(1·10)	0·87(0·91)	1·00(1·04)	2·0
0·50	0·83(0·88)	0·87(0·92)	0·95(1·00)	2·8
0·63	0·83(0·90)	0·97(0·95)	0·95(1·00)	3·5
0·75	0·69(0·75)	0·86(0·94)	1·10 + (Machine limit)	4·1

sand. Again, as for Sections 4.2 and 4.3, relative strength shows the same initial increase followed by a continuous decrease when plotted against carbon/cement for the 24 hour tests, as is shown in Fig 4.6.

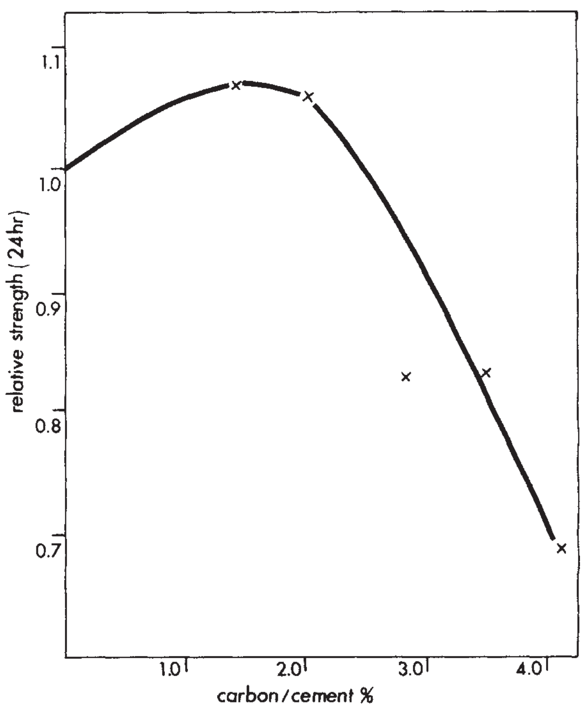

Fig. 4.6. 24 hour relative flexural strengths of extruded roofing tiles.

The improvements in strength are partly reflected in the Initial Surface Absorption Test results which are shown in Table 4.14. For this particular mix, fly ash and extrusion process it can be seen that the optimum *F/C* is about 0·4 even though the permeabilities at higher concentrations of ash are still better than the control. This shows that strength and permeability have little relationship where fly ash is concerned and that performance properties have to be assessed as individual exercises.

TABLE 4.14
INITIAL SURFACE ABSORPTIONS FOR EXTRUDED ROOFING TILES

F/C	*I 10 min*	*I 30 min*	*I 1 h*	*I 24 h*
0	0·58	0·31	0·17	0·14
0·25	0·40	0·19	0·12	†
0·37	0·10	0·09	0·06	0·01
0·50	0·26	0·15	0·09	†
0·63	0·15	0·11	0·07	†
0·75	0·23	0·19	0·11	†

† Below 0·01, which was the apparatus' minimum sensitivity.

The following general conclusions are drawn:

1. Provided that dark-coloured roofing tiles are to be extruded the addition of fly ash is beneficial.
2. The optimum *F/C* will lie in the range 0·3–0·6, depending on whether the sand is continuously graded or of coarser grade.
3. The assessment of performance should be based upon flexural strength as this goes past its maximum with increasing *F/C* even though the impermeability improves.

4.5 VIBRATED CONCRETE PRODUCTS

Using the same three ashes as described in Table 4.2, vibrated 100×100×500 mm concrete prisms were laboratory made and tested using a mix of:

4 10 mm flint gravel
2 natural sand
1 ordinary Portland cement

0·5+0·15 *F/C* water
(all parts by weight).

Units with *F/C*=1·0 or higher were impossible to demould at one day old so all samples were demoulded at 1–3 days old; the earliest age that they could be sensibly tested was 14 days old and the flexural strengths are shown in Table 4.15 in N/mm^2.

TABLE 4.15
14 DAY FLEXURAL STRENGTHS OF VIBRATED PRISMS

F/C	*F1*	*F2*	*F3*
0	4·1	4·1	4·1
0·25	3·2	3·7	1·4
0·50	2·6	1·6	1·0
1·00	3·0	1·5	0·8
1·50	3·4	1·4	0·9
2·00	0·4	0·8	0·9

Figure 4.7 illustrates this rapid decline in strength when the 14 day strength is plotted against carbon/cement ratio.

Initial surface absorption tests were undertaken at 28–35 days old on oven-dried half-prisms and the results are shown in Table 4.16.

A problem with honest reporting of results is that one often ends up with a series of numbers that defies any rational explanation. We know from the strength figures that vibrated concretes suffer early strength interference—a critical factor in precast work. Why *F*1 improved the impermeability, *F*2 made it worse and *F*3 worked in both directions is unknown. It could be related to some chemical reaction(s) not studied in this experiment.

However, the early strength of vibrated products is what interests the user, and in this respect vibrated concrete can only take a few per cent of ash and it is hardly economic to set up a second silo in a precast concrete factory to handle such a small usage.

It is concluded that fly ash has little or no application in vibrated wetcast concrete products except for autoclaved and heat cured processes.

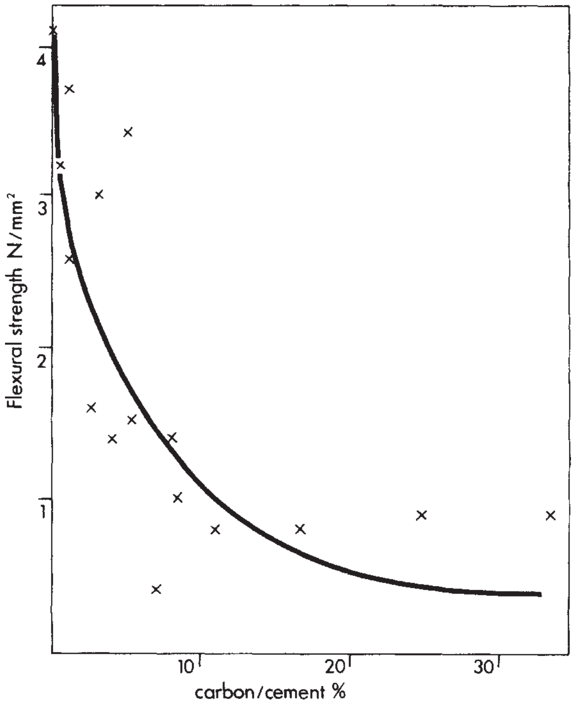

Fig. 4.7. 14 day flexural strength of vibrated concrete prisms.

TABLE 4.16
INITIAL SURFACE ABSORPTION FOR VIBRATED PRISMS

F/C	*F1*			*F2*			*F3*		
	I 10 min	*I 30 min*	*I 1 h*	*I 10 min*	*I 30 min*	*I 1 h*	*I 10 min*	*I 30 min*	*I 1 h*
0	0·60	0·25	0·14	0·60	0·25	0·14	0·60	0·25	0·14
0·25	0·09	0·09	0·04	0·72	0·31	0·12	0·35	0·30	0·26
0·50	0·04	0·02	0·02	1·00	0·60	0·40	2·25	2·00	1·65
1·00	0·09	0·04	0·03	0·85	0·56	0·45	0·93	0·71	0·42
1·50	0·12	0·06	0·05	0·77	0·74	0·39	1·25	0·72	0·68
2·00	0·11	0·06	0·04	1·50	1·00	0·85	3·25	3·50	2·00

4.6 OTHER PROCESSES OF MANUFACTURE

The last part of this chapter is based on visits to precast works and conversations with manufacturers, coupled with reports in the technical and trade literature. The author has no data on the properties of the products described but the fact that fly ash is and has been used in other processes points to a wider future than indicated in Sections 4.2–4.5.

4.6.1 Spun products

A significant proportion of pipes are made by spinning processes, as are most concrete lighting columns. The Chicago Fly Ash Company produced literature in the early sixties pointing out the advantages. One of the main difficulties in the spinning process is that the massive centrifugal forces that occur can cause segregation in the ingredients if the mix gets too wet. Fly ash has a stabilising effect and inhibits segregation. In addition, as these products are generally heat cured to accelerate the hardening rate with earlier release of the mould, the ash will have a contribution to make to the early strength.

4.6.2 Vibro-press products

These processes are those where the product is fully or intentionally partly compacted by the combination of vibration and pressure.

4.6.2.1 Vibro-press pipes

To the author's knowledge only one manufacturer has tried fly ash addition, with beneficial results in two basic respects:

(a) Faster compaction speeds through the ash acting as a workability aid
(b) Improved internal bore appearance and contours at the spigot and socket.

4.6.2.2. Blocks

This is a more widely appreciated application of fly ash in vibroprocesses and the main benefits are:

(a) Much improved 'green' strength (against palleting, vibration of ground, etc.).
(b) Improved appearance and arrisses.

Manufacturers using ash in block production need to limit the *F/C* to about 0·4 when the blocks are to be plastered as too much ash in the block makes this a difficult operation on site.

5

PRODUCTION— GENERAL CONSIDERATIONS

In dealing with the complex subject of production it was felt to be more convenient to discuss general aspects covering most of the considerations in any precast process in this chapter, and to describe the specific processes in the following chapter.

5.1 STAFF

Setting up any production process requires at least two people in managerial positions to be directly associated with that production. Problems can arise at any time, and hold-ups can be avoided if decisions are instant and accurate. Whether these people be works managers, chargehands, foremen or working (in the factory) directors is irrelevant. A minimum of two is always required in case one of them should fall sick or take a holiday.

The workers themselves need to be thoroughly trained in the particular process before supervision can be lowered to the minimum level (one supervisor to 6–10 workers). They should be educated to a level of full knowledge of what they are making and for what purpose it is intended and encouraged to make suggestions, in order to achieve a high degree of job satisfaction. Some machine-controlled processes are quality-controlled by the machine and payment can be based upon the number of units sold. Piece-work payment for vibrated wet-cast units and one or two of the machine processes is not advisable as such payment can result in high-water-content mixes with subsequent detriment in strength, durability, etc. The most important of the workers is the person in charge of the mixer, irrespective of whether he or she controls a console, levers and taps or anything else. All other workers rely on this person for a mix that will satisfy the process and property requirements.

Backing up this team should be one or two maintenance engineers with mechanical and/or electrical knowledge to carry out maintenance and ensure smooth running. In addition, one can have steel fixers for the manufacture of reinforcement cages and their placement in the moulds, as well as mould makers who are usually found in a carpenter's shop. The end of this chain is the storeman who will order and/or hold all the materials the factory needs.

Last, but by no means least, there is quality control; one or more persons should be responsible for materials, moulds, reinforcement accuracy and concrete testing. This is an essential part of the control in any process because it ensures that consistency of production is maintained throughout, coupled with the most economical use of manpower, materials and plant. It is also beneficial to have qualified technical staff to advise existing and potential clients and to visit sites to advise clients and avoid and/or deal with problems.

5.2 DOWN TIME

This is a common term and is defined as 'time spent by the operatives in the factory when products are not being made'. Precast factories visited by the author over a period of twenty-five years have ranged in appearance from pristine exhibition halls to demolition yards. The spending of half to one hour at the end of a working shift in a thorough cleaning down of all equipment and working and storage areas pays dividends in the following respects:

(a) Visitors to the factory will always be favourably impressed.
(b) Health and safety at work is maintained at a high level.
(c) Breakdowns and maintenance are kept minimal.
(d) Staff will know where all tools are kept, i.e. in an appointed place rather than scattered around.
(e) Staff will take a pride in their work.

These factors are not given in order of importance, and probably a few others could be included. Whilst concrete production is a dirty process there is no reason to let a works degenerate in appearance and efficiency. In addition, this down time should be viewed as an important part of the production, and the staff involved should be remunerated accordingly.

5.3 MATERIALS

Aggregates should either be stored on well-separated well-drained hard standings or in elevated bins, usually above the mixer level. In cold climates bin storage indoors or under heated conditions is necessary. Frozen aggregates may only be used if aggregates and hot water are placed in the mixer first and all the ice is melted before the addition of cement and any additional water required. In hot climates aggregates should be stored indoors or covered with heat-reflective sheets or reflective air-cooled bins. Some Portland cements are liable to flash setting at concreting temperatures of 40°C and above, and cooling in a hot climate can be as expensive as heating in a cold climate. Stocking and re-stocking requirements are a function of supply sources and usage rate. Stock should never be run too low as to be near the danger level, nor should re-stocking take place too early, as this is uneconomical.

Cement is delivered either in bags (50 kg normally, but one tonne bags are also available) or by bulk tanker. Bags should be stored on an elevated stillage so that the bags do not contact the ground. New deliveries should be stored likewise but not be used until the earlier delivery has been consumed. Outdoor storage of bags of cement should be dealt with as for aggregates. Silo storage of cements should also be as for aggregates in bins, except that cold weather precautions are not generally necessary. Bulk delivered cements can arrive fresh and hot and air elutriation of silos is advisable, especially in hot climates. All bins or silos should be of an approved and well-tried shape so as to avoid hold-ups or blockages at the dispensing end. All bulk aggregate and cement supply systems should also be equipped for sampling and testing.

Admixtures should be discharged into the mixer using an approved and calibrated dispenser, powders with the dry ingredients and liquids with the water.

5.4 MIXERS AND MIXING

Pan-type mixers as shown in Figure 5.1 are the best types to use for mixing concretes to the low workability requirements generally needed. This photograph also illustrates an elevated skip feed where the

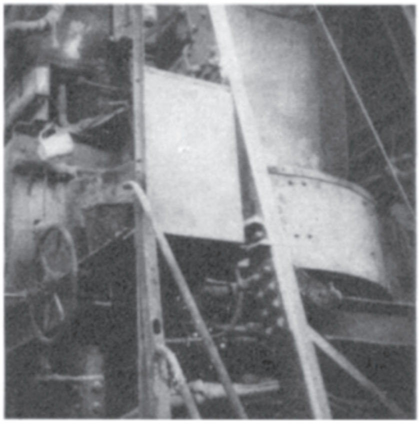

Fig. 5.1. Pan-type mixer.

aggregates and cement are loaded below the mixer level. Pan-type mixers may be any of the following approved types:

(a) Rotating pan—single star and stationary scraper(s)
(b) Rotating pan—double star and stationary scraper(s)
(c) Stationary pan—planetary mixer and scraper blades
(d) Stationary pan annulus ring—rotating mixers and scrapers.

Free-fall or 'coffee-pot' mixers are not so efficient but can still be used for mixes where slumps above 50mm are tolerable.

Control may range from the modern design as shown in Fig. 5.2, to the fully manual where someone will control all valves, taps, etc. In all cases accurate well-maintained weight-batching equipment is necessary, except in the case of ordinary vibro-press block productions where volume-batching is best. The moisture content of the aggregate together with its absorptive qualities need to be known so that mix adjustments can be made to acheive the same effective water/cement ratio each time. There are many devices available to control the water added to the mixer, working on mix electrical resistivity, or the aggregate resistivity, or the power consumption of the mixer. Each method has its advantages and disadvantages but the mix resistivity method has been found to be the most attractive, although it does not lend itself readily to the (c) and (d) type mixers. The mixer power consumption types of controllers are better for these mixers bearing in mind the adjustments required for different mixes, loads, etc.

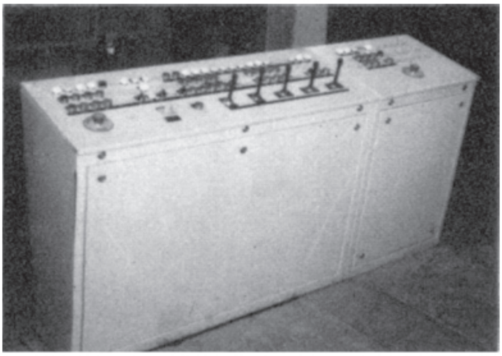

Fig. 5.2. Automatic control console.

5.5 REINFORCEMENT AND HARDWARE

Reinforcement cages are best made on a jig. This ensures accuracy of production and correct fitting into the mould. Where cross-overs are wire-tied rather than welded the tie should be turned into the concrete to face away from the cover zone. Steel fixers and carpenters can work better when a precast concrete product drawing is split up into the total geometry, the steelwork and the hardware as three separate entities. Fabricated cages should not be stored in such a fashion as to encourage deformation, rusting or damage.

Hardware items should be stored in labelled boxes or bins and be fixed to the rebar cage (viz. lifting sockets), or to the mould under the supervision of the carpenter, or in the mould (viz. spacers) under the supervision of the steel fixer or foreman. Positioning should be checked at all stages of production. Suspended cages may have their holding wires or bars removed only when the vibration has been completed. Through-tubes and dowels should be oiled and when the concrete is about 2–4 hours old, twisted a little each way in a rotary direction to break the bond.

Expanded plastics sheets, although not strictly hardware items, need careful handling in both full and part sandwich constructions. As they will float they need to be restrained by a top layer of reinforcement which is fixed in place when the mould is partly filled. The method of fixing this top layer of mesh to the bottom steel needs to be thought out at the design stage because there must be minimum delay in doing this.

Mosaic sheets, brick slips and other facings need to be firmly located and must not move under the action of concrete impact or vibration. Mosaic sheets may be glued down with a water-soluble glue, and slips, ceramic tiles and the like held in a template. It is also beneficial to trowel a mortar or mix onto the backs of these facing units and leave it for 1–3 hours before concreting, as this stabilises the face.

5.6 VIBRATORY EQUIPMENT

Energy needs to be put into concrete to enable compaction to be carried out and the normal way this energy is input is by vibration. There are three methods of causing this vibration:

(a) *Table*. Usually a static proprietary or bespoke piece of equipment where the mould and the concrete are taken to the table. Tables work by electromagnetic (no wearing parts) or eccentric mass vibration.
(b) *Clamp-on*. An eccentric mass motor that is portable and can be taken to the mould and fixed thereto.
(c) *Poker*. An eccentric mass inside a tube worked by an external drive. It is portable and can be taken to the mould.
(d) *Dropping table*. A low-frequency high-amplitude method of shock compaction.

The selection of the type of vibration to be used is a function of what is being made and how it is to be compacted. Whatever method is used there are a number of basic guidelines to observe, these are based upon research and experience.

1. Although vibratory equipment manufacturers often give the kilowattage or similar rating the most significant factor is the centrifugal force. This force will compact 1·5 times its level of the combined weight of concrete plus mould. An approximate equivalent for the power rating is that the wattage divided by four will be effective for that weight of mould plus concrete in kilogrammes (e.g. 4 kW per tonne combined weight.)
2. Vibrating tables should be vibro-insulated and moulds likely to bounce when empty should be clamped thereto. The equivalent

centrifugal force may be calculated from the amplitude and frequency measurements.

3. Moulds to which clamp-on vibrators are to be fixed should be vibro-insulated.
4. All moulds should be robust enough to be vibrated without distortion or flapping.
5. When two or more vibrators are to be used on or under the same mould they should be wired up to the same phase of the supply.
6. All vibratory equipment, motors, etc., should be protected from dirt, concrete, etc., but not in such a way as to interfere with their cooling by air.
7. Nut and bolt mould fittings should be of the locking type or fixed in a manner so as to prevent loosening under the action of vibration. It is possible for a nut to travel vertically up a threaded bolt whilst vibration is in progress.
8. Eccentric mass devices such as clamp-on and poker vibrators are high-wear-rate pieces of machinery and a sufficient supply of spares should always be kept.
9. Poker vibrators need plenty of room and full immersion to avoid overheating. There are very few products that can be so compacted but those that can be should have the largest diameter possible, as efficiency is a function not only of centrifugal force but also of diameter.
10. Low frequency vibration penetrates more than high frequency and selection of the type of vibrator is a function of maximum concrete dimension and surface finish requirements. To obtain the best of both worlds some concretes benefit by two different frequencies of vibrations, viz. a comparatively low frequency followed by a surfacing-improvement high frequency vibration.
11. Ear protection is necessary at all times as physiological damage can occur.
12. All electrical equipment should be powered by a maximum of 120V supply, except indoor vibrating tables or trestles which can work off up to a 240V or three-phase supply under closely supervised nominally dry conditions.
13. Re-vibration of concrete is beneficial if the concrete is re-vibratable and the cost of double handling moulds or vibrators is economical.
14. Properly designed concretes cannot be over-vibrated. The only time danger arises is when using high slump mixes with plasticisers or

super plasticisers present, when the minimum of vibration should be used.

5.7 MOULD EQUIPMENT

Having decided upon the method of production and type of mould to be used a regular mould checking routine should be initiated as outlined in Chapter 1. Many moulds are equipped with quick-release locks and these need to be kept clean and adjusted or replaced if they become worn. Bolts with damaged threads should be re-tapped or renewed and parts of the mould that are intended to move should be well-oiled at all times to prevent build up of concrete. Operatives should also be equipped with the correct tools for moulding and demoulding. All too often a defiant fixing is struck with a non-conformist type of tool, and this is why the standard 1 kg club hammer is often called a mould release agent. Damaging a mould can be an expensive exercise and if concrete is a little obstinate in leaving the mould the use of a hard rubber hammer working from the corners to the middle of each side will generally be encouragement enough. For large plane cast areas, especially those with smooth faces, the incorporation of greased air nipples and application of compressed air is often a good answer to sticking. Small moulds capable of being handled by two men can be lifted in the upside down position and dropped onto a hard rubber mat.

Machine-intensive processes have built-in mould boxes as a rule, but there is no reason to become blasé because one has a machine to do most of the work. The manufacturers of proprietary equipment will advise on a checking schedule and it does not pay to disregard this advice. Consistency and reliance on dimensions is a good selling factor. Slab machines (paving, kerbs, etc.) have their larger dimensions controlled by the mould boxes but their height as cast, a critical thickness in some applications, is controlled by a feed box. This box needs to be such as to discharge an accurate and consistent quantity of concrete into the mould.

In some precast processes tilting tables are used both to cast the concrete and lift the mould and concrete into the near-vertical position. The table needs to be locked into the vibration position during concreting and these locks must be well maintained. One should also remember to free the locks before cranage tilting, and a routine schedule of operations is part of the operatives' training.

5.8 PROPRIETARY PLANT

One can purchase highly modern plant for all operations in the precast industry. In the labour-intensive processes use of most of this plant generally stops at the mixer discharge point. In the machine-intensive processes this plant can continue to be used right through to the truck delivering the products to the site.

No matter what plant one is considering, as for vibration, a number of guidelines can be given.

1. Record cards should be kept for each piece of plant including at least the following information:
   (a) Date of purchase and date of commissioning
   (b) Manufacturer's or supplier's name, address and telephone number
   (c) Name and address and telephone number of manufacturer or servicing agency
   (d) Details of contractual service agreement
   (e) Date of last service and when the next is due
   (f) Date and details of any repair work or adjustments carried out by the works engineer
2. Avail oneself of any training facility afforded by the manufacturer or supplier.
3. Stock any spares the manufacturer or supplier advises.
4. Adhere to manufacturer's or supplier's works routine maintenance schedule.
5. Plant associated directly with concrete work, viz. mixer, bins, machine moulder, etc., should be subject to down-time cleaning and, if necessary, oiling, at the end of each working period.

5.9 HANDLING AND CRANAGE

Products may be manually, machine or truck handled and great care is necessary as the concrete is often in its so-called 'green' state. Again, one may enumerate several guidelines:

1. Tiles and paving slabs should be edge stacked to avoid scratching. Architectural products should be stored under cover; shrink (polythene) wrapping is not recommended as it promotes condensation and lime bloom.

2. Where specific lifting devices are intended to be used they should be used, and handling hardware should be designed carefully as shown in Figs. 5.3 and 5.4, and not treated as an afterthought as seen in Fig. 5.5.
3. Lifting cast-in devices should be integral with the reinforcement.
4. Metal items should be buffered against striking or rubbing against the concrete, crane chains may be bandaged, nylon slings, rubber separator pads, etc., may be used.
5. Crane wires should be carefully maintained and the strands regularly soaked in oil as they can rust from the inside and break when there is no sign of degradation on the outside.
6. Lifting positions should be as near to vertical as possible, when units are picked up at two or more positions on each a spreader beam should be used.
7. Take care on initial lifting and final stacking; the acceleration can instantaneously double the weight of the unit if too quick.
8. Large units such as cladding panels are best stacked and transported on A-frames with units securely fixed (without abrasive damage) to the frame.
9. Beams, planks and columns are best stored and transported flat with

Fig. 5.3. Rubber-faced scissor lift for paving slabs.

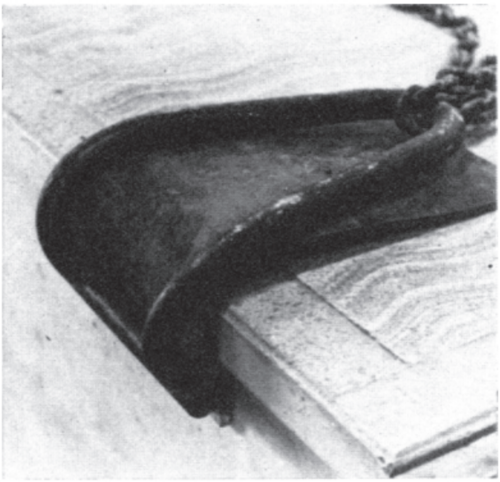

Fig. 5.4. Rubber-faced clip for lifting cess tank lids.

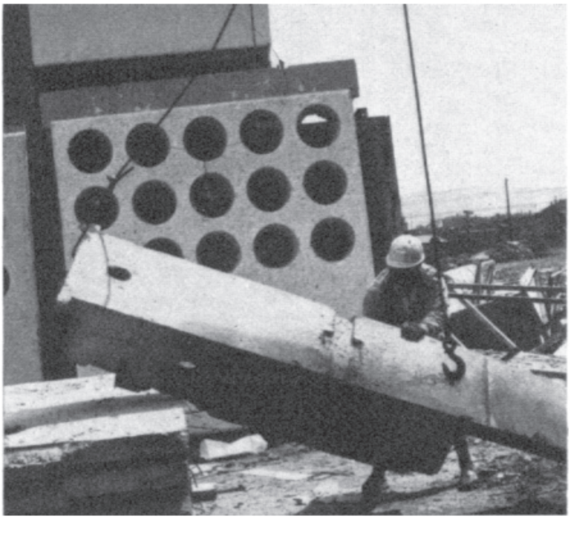

Fig. 5.5. Lifting by improvised means.

spares in line and at minimum stress points. Lifting instructions for column-handling on site should also be furnished to the contractor.

10. Pipes are best stored horizontally with end-wedges at the end of each row. Uniform pipes may be stacked on top of each other, from 2 to 10 rows high depending upon diameter. Flat bottomed and socketed pipes are best stored and transported with intermediate wooden planks between each row. Works handling and site off-loading may be by modified fork lift truck, but they are best trenched using a hairclip canvas-protected single U-fork.
11. Green pipes made in the vibro-press process are handled by specially adapted trucks either by picking up the demoulded pipe by the bottom support ring or by picking up the outside mould. Factory floors must be kept absolutely clean to avoid any bumps, and the truck is best driven by propane or electricity rather than diesel or petrol so as to make for a smoother ride.
12. Cranes and overhead gear should be capable of coping with the maximum load that can be made in the works, even though normal production is well below this level. One never knows what one will be called upon to make in the future, and it may be necessary to lift a tilting table as well.
13. Always specify lifting positions and always mark ‘top’ when there is a likelihood of something being lifted or constructed upside down (e.g. lintels).
14. Always observe safety regulations and train all operatives to follow a safe and efficient routine.

BIBLIOGRAPHY

J.J.KOLLEK, The external vibration of concrete, *Civil Engineering*, March 1959.

J.J.KOLLEK, The internal vibration of concrete, *Civil Engineering*, November 1959.

M.LEVITT, An appreciation of the Hydrobot, *Civil Engineering*, January 1964.

6

PRODUCTION—SPECIFIC PROCESSES

This chapter should attract considerable attention and the dogmatic reader will search for numbers to use and specify. If this is the reader's philosophy the author suggests that this chapter should be given a miss because technology, 'alchemy' and 'know-how' all play important roles in production, and the intention of this part of the book is to indicate where the target-range is and what the boundary conditions are. Concrete production, *in situ* or precast, is not a case of working to maximum and/or minimum limits in any respect; it is a case of working within a range of ideas where there is a maximum and a minimum for each variable at one's disposal. The 'know-how' is knowing where these limits are and the 'alchemy' the kitchen routine of ringing the correct changes to get the materials to produce what one wants from the plant one has.

The technology is relatively simple because although strength is specified at a specific age or at delivery the early handling or durability requirements for precast concrete generally result in the specified strength being achieved before it is required. Three things control the performance of concrete:

Design
Materials
Workmanship

Materials are seldom the cause of faulty products and even when marginal or suspect materials are used any potential trouble can more often than not be designed out by careful thought.

Before dealing with specifics a general comment about mix design should be included so that the numbers suggested as bases for design are understood. Many times a minimum cement content is specified (e.g. 350 kg/m^3) and this is easy to understand and implement. It is when the maximum water/cement ratio (W/C) is specified that confusion arises because there are two water/cement ratios in mix design:

Total water/cement ratio
Effective or free water/cement ratio

The second term is the only meaningful one because the difference between the two ratios is the extra water to make the aggregates workable and this is a highly variable factor depending on shape, absorption, etc. An example is a mix specified as:

	Dry weights	*Aggregate absorption*	*Actual moisture*
300kg granite 12mm clean		0·4%	0
150kg sand		1·0%	3·0%
100kg cement			
40kg effective water			

The granite needs 1·2 kg water to cater for its absorption. The sand has 3·0 kg excess water in it, (3·0%–1·0%)×150kg.

The mix design would be:

	Batch weight (kg)	*Water requirement (kg)*
Granite	300	1·4
Sand	154·5	–3·0
Cement	100	
Water	40+1·4–3·0=38·4	= Added water
	40	= Effective or free water
	40+1·4+1·5=42·9	= Total water

Admittedly one would not work to such accurate batch weights in a precast works but it can be seen that a significant difference exists between the 0·40 and 0·43 effective and total water/cement ratios. With absorptive aggregates this difference becomes greater and in some mix designs it is possible for the total W/C to be two or three times larger than the-effective ratio. This may be exemplified by the mix design for a lightweight aggregate concrete mix (aggregates all nominally dry):

	Batch weight (kg)	*Water requirement (kg)*
10mm	600	30
5mm down	400	20
Cement	100	40

Water	40+20+30= 90 =	Added or total water
	40 =	Effective or free water

The two W/C ratios are 0·40 and 0·90.

6.1 GENERAL PRECAST WET-CAST PRODUCTION

Products in this category are compacted by table, clamp-on or poker vibration where there is no requirement for architectural usage, for instance beams, columns, fenceposts, manhole covers, tanks, struts, cills, coping, access pipes, etc.

Selection of materials, moulds and methods of vibration have all been discussed earlier and accelerated curing is dealt with in the next chapter.

6.1.1 Mix design

Coarse aggregate should be used—20mm down to 10mm maximum depending on section, with maximum size such that 2·5 times this size is the minimum spacing between the reinforcement bars or between the bars and the mould sides, whichever is the smaller.

If the aggregate maximum size is 20 mm clean then 10 mm clean will also be used unless the aggregate is a 20–5 mm all-in type. Where the product is to be exposed to marine conditions, or sandstorms, or other high wear situations, gap-grading is preferred (i.e. 20 mm or 10mm clean only with sand) as the intermediate-sized stones tend to be the first to be pulled out of the matrix. The fine aggregate may consist of a clean natural sand or crushed rock fines washed or spun to simulate a natural sand grading. Single-sized sands and dusty crushed rock fines should be avoided.

The purpose of the exercise is to fill up the voids with a graded system of particles in order to keep the cement and water demands down to minima.

The coarse/fines ratio will vary from 2·3 to 1·7, depending upon finer or coarser 'sands' being used. The ratio of two coarse aggregates (20 mm and 10 mm) will vary from 2·2 to 1·3 depending upon particle shape and the product being made.

Cement and admixture selection depends upon product, climate, etc., with the following being typical:

Cold climate
Cement: OPC, RHPC, SRC

Admixture: AEA, plasticiser, or super-plasticiser, or accelerator, or combined.

Temperate climate

Cement: OPC, RHPC, SRC

Admixture: AEA, plasticiser, or super-plasticiser, or combined.

Hot climate

Cement: OPC, LH or Pozzolanic PC, SRC

Admixture: Retarding plasticiser or plasticiser.

Note that air entraining agents would only be used in vibrated wetcast products intended for road-side use or in permanently damp conditions where freezing may occur.

Cement contents vary from 300 to 450 kg/m^3 for most products, depending upon durability and strength requirements. Free W/C will vary from 0·45 to 0·30. The 300/0·45 type mix would be used for products such as cess tanks, the only performance requirements being fluid-holding capability and resistance to ground acids. A 350/0·42 type concrete is shown in Fig. 6.1 for access chambers. The richer concretes such as 400–450/0·40–0·30 are shown in Figs. 6.2 and 6.3 where extra-high early

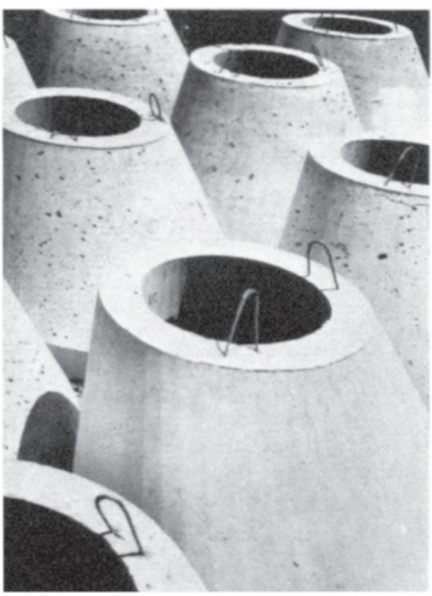

Fig. 6.1. Wet-cast access chambers.

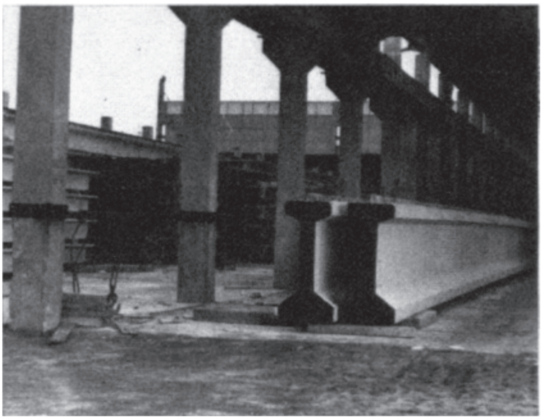

Fig. 6.2. Wet-cast prestressed beams.

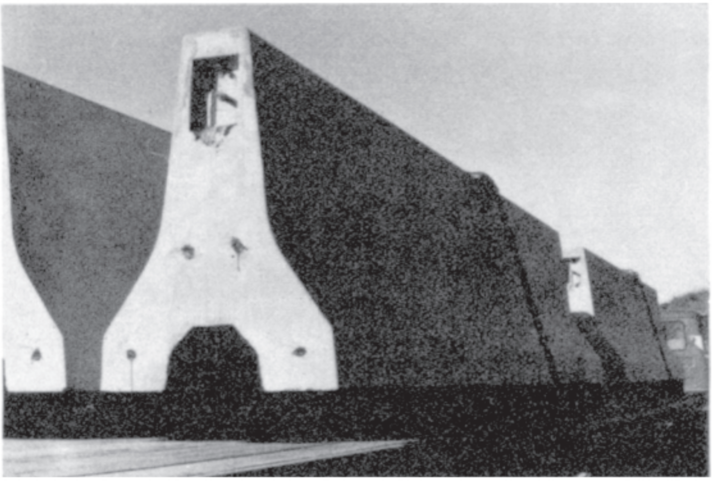

Fig. 6.3. Wet-cast prestressed beams.

strengths are obtained by the combination of relatively high cement contents coupled with heat curing. The blowholes, honeycombing and occasional small cracks seen in Fig. 6.1 sometimes cause worries about durability. The cracks and honeycombing result in no risk provided that they do not allow corrosion of the reinforcement to occur. Blowholes in wet-cast concrete are to be expected with good quality concrete which has an appearance, ex-mould, inversely proportional to its quality. The unit with a smoother appearance in Fig. 6.1 would have been made from a wetter mix than the others and will have a lower strength and durability. If the client wants a good finish for vibrated wet-cast units he has to be prepared to pay for the use of high quality moulds, release agents and the extra labour of surface-finishing techniques.

6.1.2 Compaction and curing

Whatever method of compaction is used the mould should be vibrating before dispensing the concrete into it, and the concrete should be discharged at one place, preferably the middle of the mould, and allowed to flow outwards under the action of vibration. Placing concrete at two separate positions and allowing the masses to flow towards each other results in a seam appearing at the junction.

Usually at least two minutes continuous vibration is required at the end of the vibration/filling period in order to disperse excess air. One should only use the observation of displaced air as a criterion for the centre of a top concrete face as mould sides can 'pump' on occasions and take air in as well as displacing it. After vibration the top should be finished off with a trowel, sliding bar or other means. The appearance of a sheet of water on this face after trowelling is not a defect.

In the curing regime the concrete should not be allowed to dry out too quickly. If factory conditions are such that rapid drying can occur the trowelled face should be covered. Spraying with water is not recommended unless it be continuously applied, as green concrete will surface crack under the action of wetting and drying cycles. The demoulding age will vary from 3 to 48 hours depending upon the type of unit being made and other conditions. Again the demoulded surfaces should not be subjected to extremes of humidity, wind or temperature differentials. The means of protection are functions of the type of product and local conditions, but there are a variety of methods available if the unit cannot be kept inside a building. For instance, covers, cloches and membrane-curing compounds are a few of the choices of protective measures.

Another curing aspect that often gets overlooked is relevant to thin panels, pipes, etc., where differential solar thermals can be set up in the stacking yard between the time the units are made and the time they are delivered into the construction. The effects manifest themselves by curving creep in thin panels, cracking in pipes and delamination of surface applied finishes. Such products are best stacked with their long axis in an east-west direction as this minimises thermal differentials.

6.2 WET-CAST VISUAL CONCRETE

The word 'visual' refers to all concrete products where there is an architectural specification regarding the intended appearance. Although all concretes are visual in the literal sense of the word the connotation here is that precast visual concrete is that which is subject to architectural inspection and approval.

6.2.1 Mix designs

Coarse aggregate maximum size may be up to 20mm with the same proviso as in Section 6.1.1 regarding rebar and cover spacing but there are two variations.

(a) The intermediate size can be omitted for exposed aggregate work (i.e. no 10 mm) to give a gap-graded mix unless the unit has smooth as well as exposed-aggregate areas to its face. This precaution avoids the risk of aggregate transparency where the pieces of aggregate can be 'read' through the surface where the mix is gap-graded.

(b) In units with sloping sides and window or door openings where filling requires the concrete to run down a slope the aggregate maximum size should be 12mm for rounded materials and 10mm for angular stones. Larger aggregate mixes will hold up on the lateral rebars and the mix will roll across, leaving mortar on the face at that point and a concentration of stones away from the steel.

Fine aggregates should be as in Section 6.1.1, and it should be remembered that using crushed rock fines without preparation will result in high total water/cement ratios with subsequent detriment to properties. If this is unavoidable one should try to use a rounded sand as an additional fine aggregate to improve the workability and lower the water demand. Plasticisers or super-plasticisers will also be necessary.

Coarse/fines ratios should be 2·5–1·7; the range is larger than in Section 6.1.1 because in exposed-aggregate concrete work one wants the coarse material to read out strongly on the face compared to the fines. It does not help to exceed the 2·5 ratio because the mix becomes fines-deficient and although the concrete can look attractive from a few metres away, as in Fig. 6.4, Fig. 6.5 shows the problem that occurs in close-up, where the 'hunger' can be easily seen.

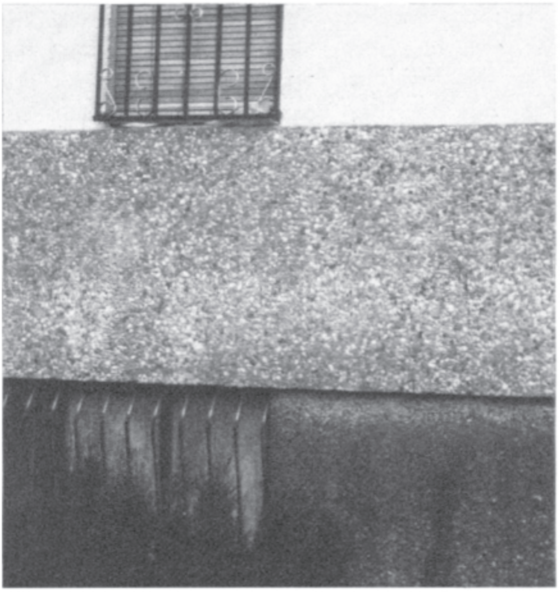

Fig. 6.4. High coarse/fines ratio in exposed aggregate work.

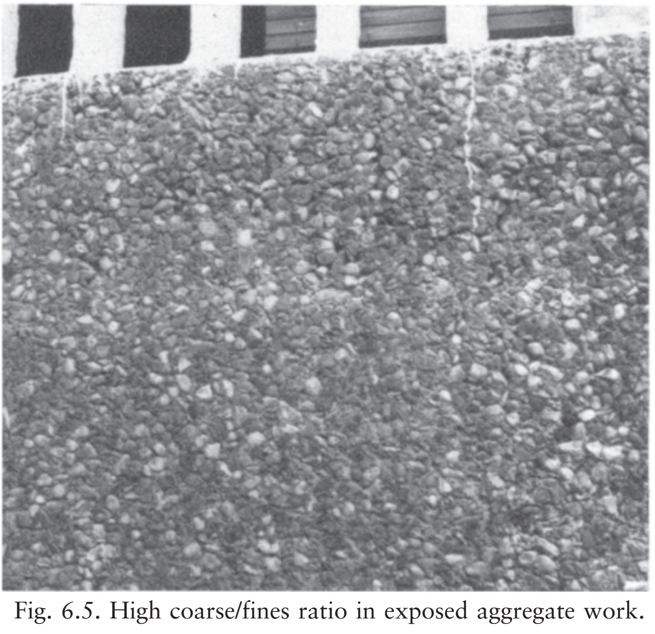

Fig. 6.5. High coarse/fines ratio in exposed aggregate work.

Cements and admixtures are as in Section 6.1.1 but one must bear in mind that, in addition, white and coloured cements may be used. However, for all other design purposes these cements will comply with the relevant Standard for Portland cement. In addition, pigmented products should also contain a water-repellent admixture and no plasticiser or super-plasticiser should be used for the reasons already discussed in Chapter 2.

Cement contents will vary from 350 to 500 kg/m^3, again, depending upon durability requirements. Higher cement contents than for the ordinary wet-cast products are required in order to minimise works damage and reduce rejects. Visual concrete products are more often delicate units with complex shapes that cause difficulties in manufacture, handling, transport and installation. Since large, complex, visual precast units can cost the equivalent of up to 0·5 kg of gold to make and market one can see the care that is necessary.

Effective or free W/C vary from 0·43–0·30 for this range of cement contents. The cement content required is basically a function of the smallest dimension of the unit and the age and maturity of the unit when it is to be handled and its durability requirement.

6.2.2 Compaction and curing

This is exactly as in Section 6.1.2 with the added proviso that more stringent care is required in the control of temperature differentials than is the case for ordinary wet-cast units. In addition, light coloured concretes, especially those made with white cement, stain under the action of steel finishing tools. Timber, acrylic or rubber-faced tools are better than steel tools in this respect.

6.2.3 Surface finishes

It is advisable to repeat here two extremely important points:

(a) It is virtually impossible to make all units identical in appearance
(b) Any sample(s) should be as near to full size as possible and include all the variables of production and reflect the range of finishes that will occur in the production.

6.2.3.1 Ex-mould

This does not matter for units which are to be covered or will not form more than a small area of the facade as shown in Fig. 6.6, but ex-mould finishes have the following problems:

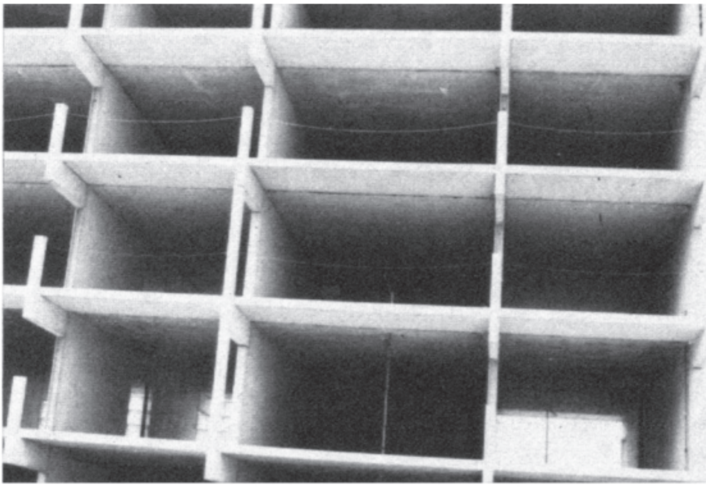

Fig. 6.6. Precast frame with visual concrete balcony columns.

(a) They are the most difficult to produce consistently.
(b) The laitance is the most permeable part of the unit and gets dirty quickly.
(c) They tend to craze (architectural surface hairline cracking).
(d) They will contrast badly with non-uniform weathering and detailing faults.

The best thing to do with these so-called fair-faced concretes in any areas other than desert ones is to get rid of the laitance surface by any approved method, such as grit-blasting. In most of the world natural weathering will remove this skin with time; in windy desert areas sand attrition will do this more quickly.

6.2.3.2 Surface-applied exposed aggregate

The advantage of this method is that one gets what one can see and one can use large sized stones in the surface. The mould is filled and compacted to within a few millimetres of the top and the stones are placed by hand or broadcast by machine and trowelled or rolled into the surface. A lot of expertise is required and the hand process is time-consuming. After the trowelling or rolling-in, the unit is subjected to a wash-off, sand-blast or other suitable technique to expose the aggregate.

6.2.3.3 Wash-off

This is a face-up technique where some time between the initial and final set of the cement (within a matter of hours) the unit is tilted in its mould and washed and brushed, working downwards. One can see the finish one gets at the time of preparation. For large panels a hollow-handled stiff broom with water feeding to a spray pipe in the bristles enables the operative to reach quite high, holding the broom with both hands. For this process one always brushes from the top or furthest point downwards, avoiding the use of high pressure jets which can easily blast holes into the concrete.

6.2.3.4 Surface retarder

This is probably one of the most popular methods because of its versatility. The mould is treated with a surface retarder, according to the manufacturers' instructions, which is selected to give a specific retardation into the surface concrete. The retarder acts on the cement so that for large-sized-aggregate concrete a given retarder will retard deeper than for a smaller aggregate, as there is more retarder per unit area of cement at the mould face. Solvent-based retarders are preferred because they dry off quickly and are activated by the lime in the cement. When the unit is demoulded the retarded surface should be brushed, washed or blasted immediately as the retarder loses its potency when exposed to air. The cleaning of the mould is of secondary importance in the order of action.

The performance of a retarder is sensitive to different types of aggregates as well as different cements. It is essential that each application be assessed by a practical trial, preferably on a full-sized unit.

6.2.3.5 Blasting

As early as possible after demoulding, the face to be exposed is subject to blasting with sand or flint. This operation is carried out by a person wearing full protective gear with an air-pressurised helmet. There is thought to be a silicosis risk with the grit or sand debris and it is, therefore, best to carry out the work in an enclosure so that all dust is contained.

6.2.3.6 High pressure water

Again, as in Section 6.2.3.5, this is a process carried out when the concrete is about 14–20 hours old, as both processes become quite slow when the concrete gains in strength. Multiple high pressure water jets are played out of ceramic nozzles onto the concrete and these cut into the surface. The ceramic nozzles are necessary because of the high wear effect of the water on metals. Although there is no dust risk in this method a lot of sludge needs to be collected and disposed of. There is little danger in dropping a grit or sand blaster as the soft-rubber clothing encasing the operative allows the grit to bounce off. However, in high pressure water jet work the gun must be equipped with a 'dead-man's handle' as it can do considerable damage to operatives. The process needs to be contained inside an enclosure so that no personnel, apart from the operative, are involved.

6.2.3.7 Tooling

This is carried out at not less than 2 weeks old, and tools such as point chisels, needle guns and bush hammers chip away at the surface exposing and bruising the aggregate. Such exposure should never be extended to an arris otherwise spalling will occur; visual concrete produced by these tools should be 20 mm minimum clear of all arrisses.

6.2.3.8 Aggregate transfer

This is an uncommon method because of its high labour intensity and the cost of materials and storage. Onto sheets of pegboard cut to mould panel size is trowelled a sand/cellulose mortar and the stones are hand-placed into the mortar with not more than one third embedded. When the mortar dries out the panels are stored in racks ready for later use. They are then placed in the mould, well supported, and ordinary concrete to the required matrix colour is placed against the sheets. When the unit is demoulded the pegboard comes away leaving the aggregate transferred into the concrete. The cellulose mortar is then washed and brushed away leaving the aggregate visible.

6.2.3.9 Flaming

In this method a gas/air multijet is traversed over the face of the concrete and causes the concrete to break up by calcining and expanding any flint present. The depth of exposure is controlled by the heat applied and the speed of traverse. This method does not work for most volcanic rocks and has no exposing effect on limestone and sandstone concretes where it only dehydrates and weathers the surface.

6.2.4 Selection

Whatever method is used a lot depends on the architect's intention, for example an alternating two-tone scheme or a monolithic facade as in Fig.

6.7 Each method has its advantages and disadvantages but without a doubt surface retarder and blasting are the most versatile. There is, however, one overriding rule.

Fig. 6.7. Monolithic facade.

Do not leave aggregate overexposed as in Fig. 6.8, always ensure at least 65% of the aggregate volume is matrix-embedded as in Fig.6.9. Also, remember a vertically cast face will have a different appearance from a horizontally cast face due to the aggregate orientation under vibration.

6.2.5 Applied finishes

This refers to special finishes such as brick-slip, tiles, mosaic, etc., which can either be cast in the mould or applied to the finished concrete surface later, in the works or on the building. Facing systems with good modular co-ordination are required because everything has to fit properly either in the mould, or to the face or in a locating template.

6.2.5.1 Mosaics

These should be carefully located in the mould and their stability under vibration can be ensured by using a little water-soluble glue between their paper face and the mould base. The mortar that is usually trowelled into the backs of the mosaic prior to the main concrete should be left for 1–2 hours to set up a little. Some mosaics are sold net-backed rather than

Fig. 6.8. Over-exposed aggregate finish.

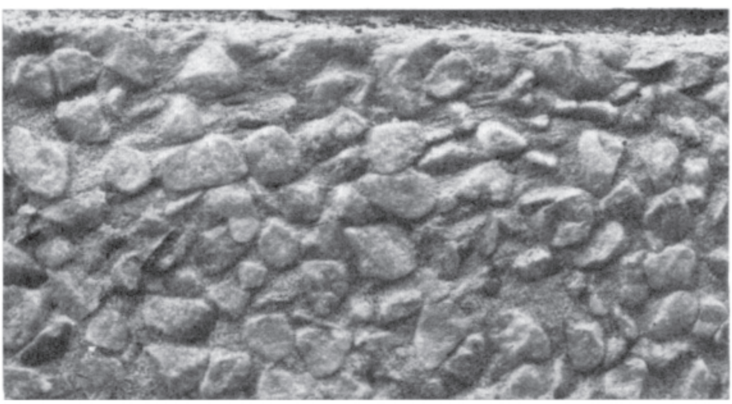

Fig. 6.9. Properly exposed depth.

paper faced and these are known to cause trouble due to bond interference and are not recommended. When selecting and applying mosaics one should always ensure that the glue used is of a slowly water-soluble variety in order to inhibit dislodgement in the mould under vibration. Mosaics should never be taken to the edge of a unit where they can weather badly as in Fig. 6.10 which shows the tesserae becoming dislodged.

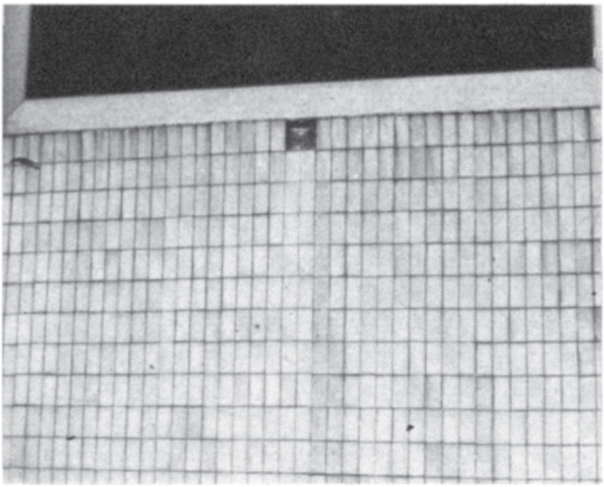

Fig. 6.10. Tesserae dislodgement from badly detailed mosaic panel.

When post-applying mosaics the surface of the concrete must be tooled or grit blasted to remove the weak laitance. The concrete should be wetted and the concrete and the backs of the mosaic brushed with a styrene-butadiene rubber, or acrylic or similar approved polymer/cement slurry, then a mortar mix with the same polymer in it should be immediately applied to the concrete and the sheets of mosaic trowelled and worked into place. When the mortar has set a scrub and brush with water will remove the paper.

6.2.5.2 Slips and tiles

In the precast operation it is best to make up a template of wood, rubber or similar material to hold the units firmly in place whilst the concrete is being placed and compacted. The fillets of the template should be a tight fit so as to inhibit grout leakage. It is generally best to back up the slips or tiles with a hand-applied mortar and leave that to go off a little before proceeding with the remaining concrete. This leaves the job of pointing up afterwards, but this will tend to produce a better finish as shown in Fig. 6.11. The darker patch at the bottom of this tiled facade is the reflection of the buildings on the other side of the road and not due to any other effect.

For post-application, the slips or tiles should be treated as for mosaics. The preparation of the mosaics or slips is vital when they are cast with

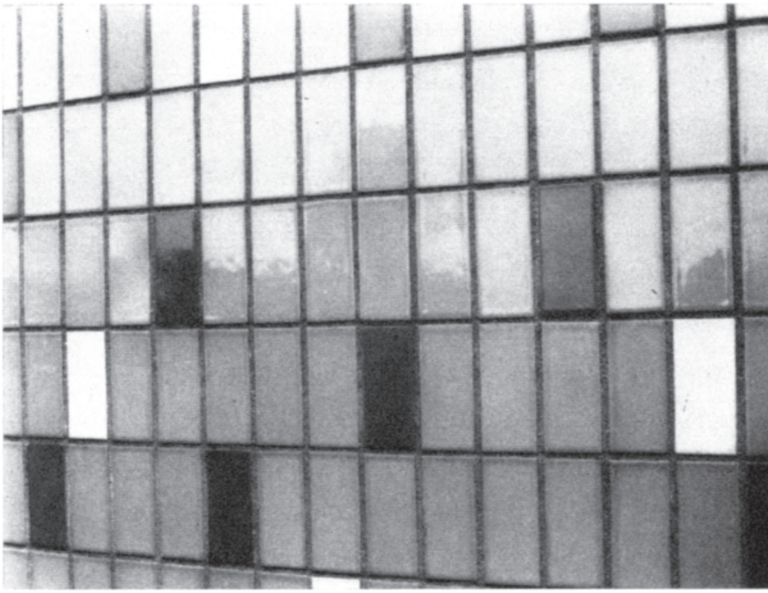

Fig. 6.11. Tile-faced pointed facade.

the product, and the preparation of the concrete is vital when they are post-applied.

6.2.5.3 Faircrete

To the trowelled face of a thixotropic concrete containing fibrillated polypropylene fibres and about 20% air, a chipfoam mat is pressed or rolled giving a finish as shown in Fig. 6.12. This is a patented Laing R+D process.

6.3 VERTICAL PIPES

In this process an inside and outside mould are placed together with clamp-on vibration fixed to the inside mould usually. The assembly is placed on a supporting ring and the reinforcement cage with its spacers (only for reinforced pipes of course) is placed inside. Concrete is fed in with the vibration running, and when the mould is filled a circular plate descends onto the top of the concrete and applies pressure, sometimes coupled with a slight rotary action, whilst the vibration continues and

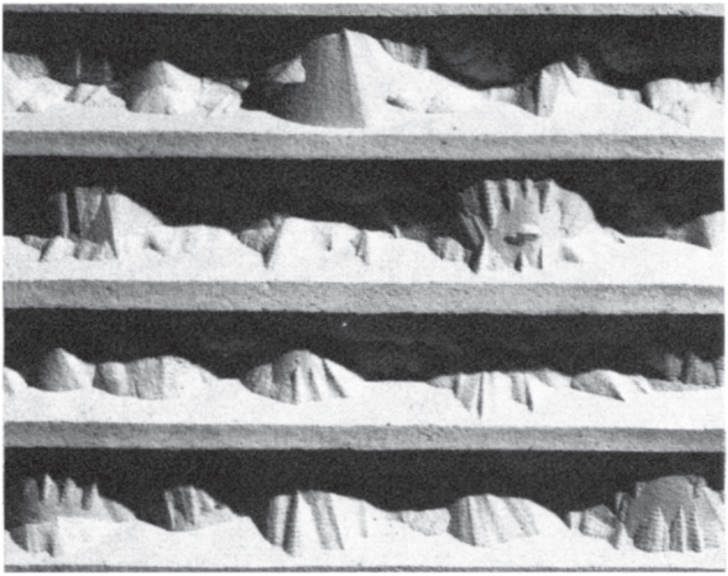

Fig. 6.12. Faircrete.

contours the spigot. The inside mould is drawn into an underground chamber and the outside either lifts above the bed or, for the larger diameters and lengths, stays on the concrete for a few minutes until it is transported away from the machine and subsequently demoulded.

Diameters can vary from 0·2 to 2·0 m and heights can go up to 4m; wall thicknesses vary from 25mm upwards depending upon requirements. Production rate depends upon size and varies from 20 per hour to 5 per hour. Figure 6.13 shows a small pipe being moulded with a pressure ring on top. Figure 6.14 illustrates the type of vibro-press pipe that can be moved across the factory floor without the outside mould for support when using a propane gas trolley. Figure 6.15 shows the type of vibro-press pipe that requires outside mould support because of the overhead lifting technique used.

6.3.1 Mix design

Coarse aggregate is normally a 10–14 mm clean angular crushed rock but it can go up to 20 mm or down to 6 mm depending upon wall thickness. Fine aggregate is usually a not-too-fine clean sharp sand. The coarse/fines ratio is about 2/1.

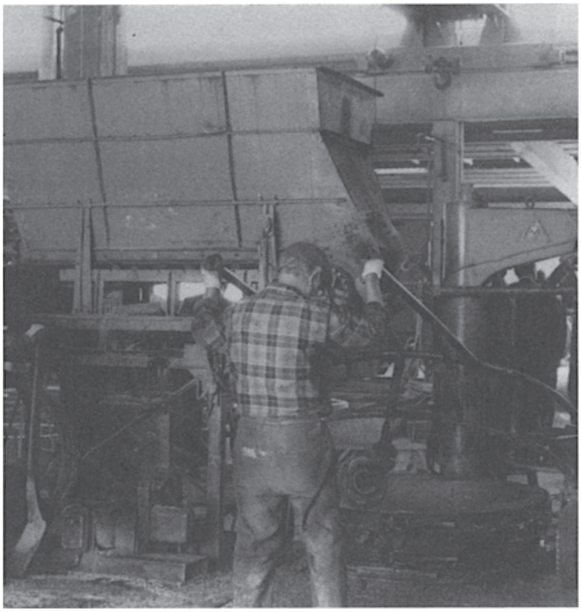

Fig. 6.13. Moulding a small diameter pipe.

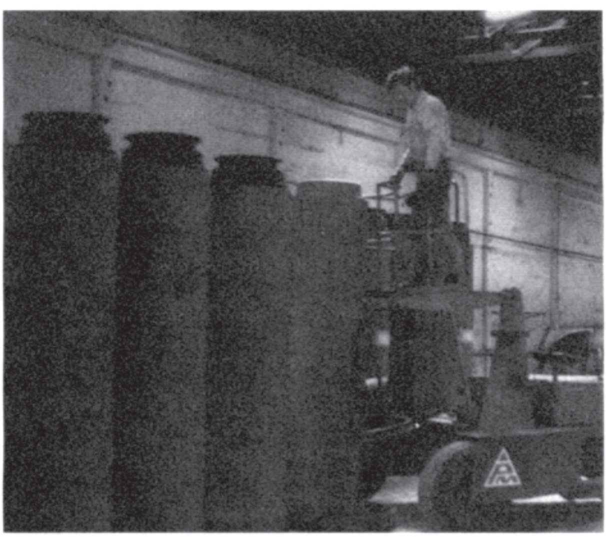

Fig. 6.14. Pipe movement without outer mould support.

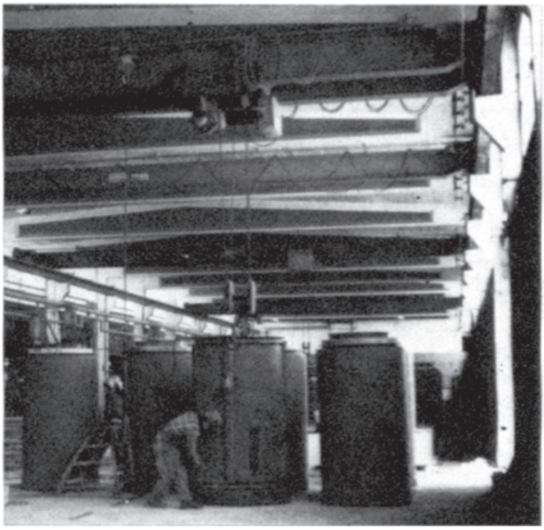

Fig. 6.15. Pipe movement with outer mould support.

Cements will be OPC, RHPC, or SRPC and their content will vary from 350 to 450kg/m^3 with a corresponding effective W/C from 0·40 to 0·30. The actual numbers selected are a function of length, diameter, wall thickness and mode of transport.from machine to demoulding area.

Admixtures are not normally used as very early handling strength is the important factor. Additives or mix moderators such as fly ash have been found to be useful as they assist in the compaction process and promote high early fresh concrete strengths.

Normally these units are cured in the factory air and in addition to the comments made in Chapter 5 regarding draughts, rapid changes in temperature, etc., it is important to remember that pipes made with SRPC must be held in damp conditions for the first few days of their life.

6.4 VIBRO-PRESS PRODUCTION

Low free water/cement ratio mixes are the types that cannot be compacted other than by a combination of vibration and pressure (vibropress), or by extremely high pressure, or by high energy vibration alone. The sort of mix referred to here is known as ‘earth-moist’ and has the property of leaving one's hand nominally unmarked when handled. Sometimes the term 'semi-dry' is applied in description but since 'semi' means half and 'dry' means arid and completely destitute of moisture its usage is not encouraged, since, logically, one cannot make concrete with a water content of half of nothing. The principle underlying compaction by the two processes described in this section is that pressure alone will only compact the top of the concrete. Vibration alone will result in a little compaction at the bottom of the section. Under the action of both forms of energy the vibrating particles move under pressure to take up their most compacted position, and the effect of vibro-press is orders of magnitude higher in compactive capacity than either vibration or pressure on their own.

It does not matter whether the mould vibrates and the pressure plate(s) just press or the mould remains static and the pressure plate(s) vibrate provided the vibrational energy is transferred to the concrete whilst the pressure is being applied. The overall advantages of the process are:

(a) One can work at lower free W/C ratios than with other methods with subsequent property benefits.
(b) One can normally get instant re-use of the mould.
(c) Any making good required can be carried out on the fresh concrete.

The disadvantages are:

(1) The product is exposed to the risk of damage during the first few hours of its life.
(2) Specific care is needed in curing as drying conditions can powder the surface and dehydrate the cement.

6.4.1 Concrete blocks

This is a special application of the vibro-press process because it is used to compact the concrete only partially, not fully.

The reasons for partial compaction are:

(a) Thermal insulation, as the K-value decreases with density.
(b) Greater volume production per unit weight of concrete.
(c) Better bond for plaster and renderings.
(d) Better impact sound resistance when blocks are used as floor infill units.

In a few instances, such as road paving blocks and fair-faced units, vibropress blocks are produced to virtually full compaction, mainly for durability. The only difference between this and the partial compaction method is that in the latter process the heads of the machine are only allowed to descend a given distance into the mould box whereas in the former method they descend until refusal.

There are four world-wide methods of concrete block production and the descriptions that follow exclude autoclaved aerated block and panel production which are covered in Section 6.8.

6.4.1.1 Hand-manufacture

This is a one-off process where the mould box sits on a wooden or similar pallet and a hinged press head plate fits into the top of the box. The mix is placed inside the box and the head is banged onto the concrete several times. This is, in effect, a combination of pressure and high-amplitude low-frequency vibration. It is essential that the hand-placed mix fills the box to the top as the degree of compaction is directly proportional to the ratio of the uncompacted/compacted volumes since the descent depth is not adjustable.

Apart from the mixer requirement, the plant capitalisation is extremely low, and this type of process lends itself to use in developing countries where small quantities of block production are required at various locations.

Mix design is very much a function of local materials and specifications (if any). A typical mix might be:

6 volumes 10 or 15 mm stone down to dust
1 volume cement
Water/cement ratio 0·4 free, approximately

6.4.1.2 Pallet machine

In this process a multiple mould is filled by a hopper and the top of the mould box is trowelled level, with excess concrete either wasted or returned to the hopper. The heads descend into the box and the blocks are compacted to the required density. The mould box sits on a pallet, and after the partial compaction the mould box and the heads lift up and the newly cast blocks sitting on the pallet are taken off on a roller conveyor or ropeway into storage or steam curing. The advantage of the process is that, within a factory of relatively small size, the mixer, plant and block machine together with the conveyors, rackers and curing can all be situated in a relatively small floor space, all under covered conditions. Figure 6.16 illustrates such a machine where, depending upon block size,

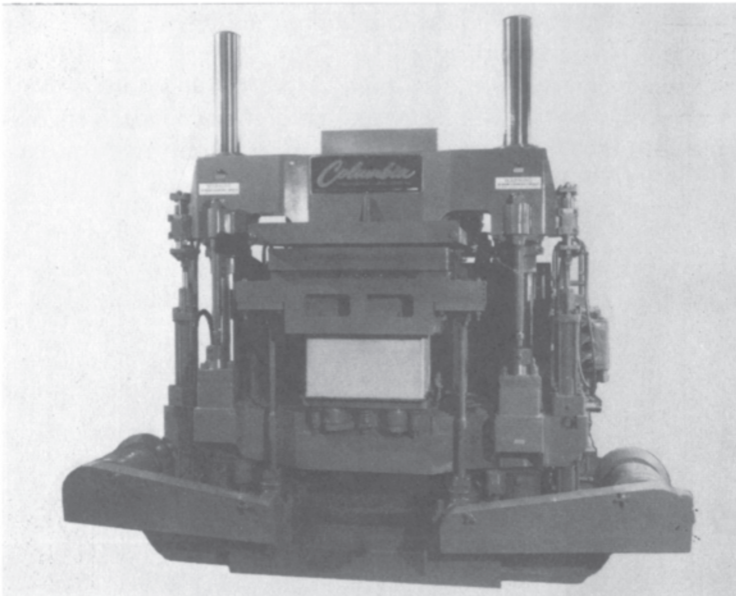

Fig. 6.16. Pallet block machine.

machines are capable of producing anything from a 6-drop to a 72-drop at every cycle, with a cycle taking from 10 to 20 seconds.

Blocks need to have a zero-age strength in order to withstand the vibrations and movements that they undergo between the time they leave the machine to the time they become hard.

Typical volume/volume mix designs are shown in Table 6.1.

6.4.1.3 Egg-laying machine

As its name implies this machine lays blocks directly onto the ground.

TABLE 6.1
MIX DESIGNS (v/v) FOR BLOCK MIXES FOR A 10 N/mm² STRENGTH

Type	*100 mm solid*	*150 mm hollow*	*100 mm fair-faced*
Coarse aggregate	5	3	2
Fine aggregate	3	5	4
Cement	1	1	1
Free W/C	0·40	0·40	0·42

The machine is mobile, with the feed hopper, mould box and heads all in the one unit, as shown in Fig. 6.17.

The machine locates at a fixed point, lays its blocks, then moves onto the next position. No racking, steam curing or convenient storage is possible until the blocks are strong enough to be scissored together and

Fig. 6.17. Egg-layer block machine.

lifted. It is a less capital intensive process than the pallet machine (Section 6.4.1.2) but has several disadvantages:

(a) The blocks need a huge covered area if they are to be cured under consistent conditions but they are generally made outdoors and subject to a variety of weathers, many of them not very congenial to good curing practice.
(b) A feed hopper has to travel between the mixer plant and the machine at frequent intervals to keep it topped up with concrete.
(c) The ground onto which the blocks are laid needs to be scrupulously clean. Any debris left lying around onto which a block is laid can cause the block to split.

6.4.1.4 General

Both the pallet machine and the egg-laying machine require an accurate and consistent mould box fill. Any variation across the box will be reflected in the properties of the blocks produced out of each of the multiple moulds.

6.4.1.5 Pallet/egg-laying machine

This machine combines the features of the two preceding machines and is generally used for making small fully compacted units such as the interlocking road blocks, also known as interpave. The machine is mobile and is indexed both in horizontal and vertical directions by a photocell control system. The blocks are compacted onto a metal pallet in the machine and these are then slid off the pallet onto the floor or onto the layer of previous blocks with sprinkled-sand parting the layers. The machine will drop something like 32 units at a time and build up stacks about 1 m high all in one row in the factory. The following day a clamping machine will close up the stack and it will be banded with steel tape, and either delivered in that form to site or as loose units. When the machine has filled up one lane in the works it will be moved along to the next lane and the process repeated.

Figure 6.18 shows the machine being fed and Fig. 6.19 shows blocks being laid onto a roller conveyor.

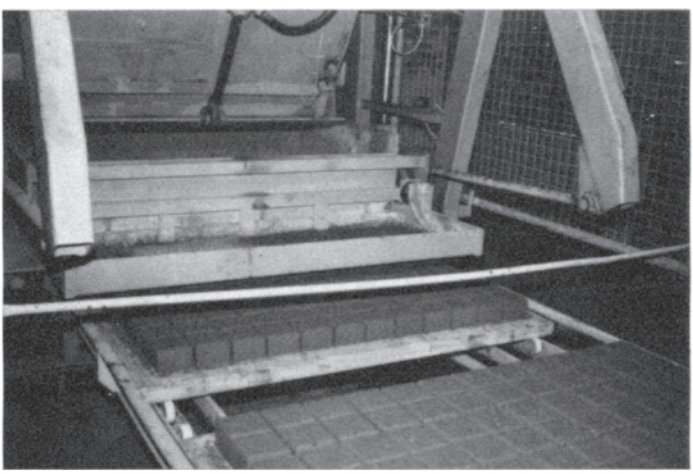

Fig. 6.18. Pallet/egg-layer being filled with concrete.

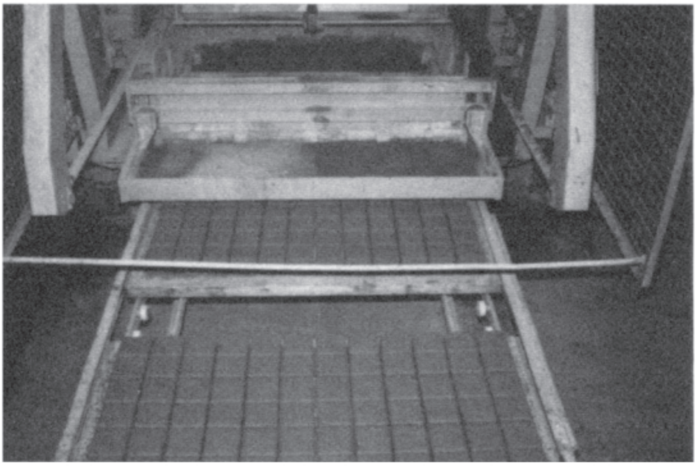

Fig. 6.19. Pallet/egg-layer in action.

Blocks may be loose-loaded into a truck for delivery to site; breakages, surprisingly, are quite few. Figure 6.20 illustrates one pattern of interlocking blocks being laid on a site. It may be seen that these blocks are delivered on pallets.

Mix designs need to be more stringent for durability, especially against

Fig. 6.20. Interlocking blocks being laid on site.

the risks of freezing and thawing and the use of de-icing chemicals. A typical mix design could be:

2·7 parts of 10 mm hard stone or crushed rock
1·5 parts of natural sand or sand-graded crushed rock fines
1·0 parts of cement
0·33 free W/C
(All parts by weight)

6.4.2 Cast stone

This term is mainly used in the UK and refers to a range of vibro-press products made to resemble natural stone. The art began in about 1850 and reached peaks of production about 1900 and 1960 but, unfortunately, declined to a low level in the seventies due to economic cut-backs affecting the more exotic processes before the general production methods. Other countries have their own terminologies for architectural, synthetic, reconstructed or reconstituted stone but, unless one is referring to the substitutional natural stone products, these other terminologies are excluded from this section. The German word 'Betonstein' is an example of a general word used to mean anything from a terrazzo, smooth fair-face finish to cast stone products.

Products can vary in size from storey-height structural units, to medium size units as shown in Fig. 6.21, down to garden ornaments as illustrated in Fig. 6.22. Production is labour-intensive in that the

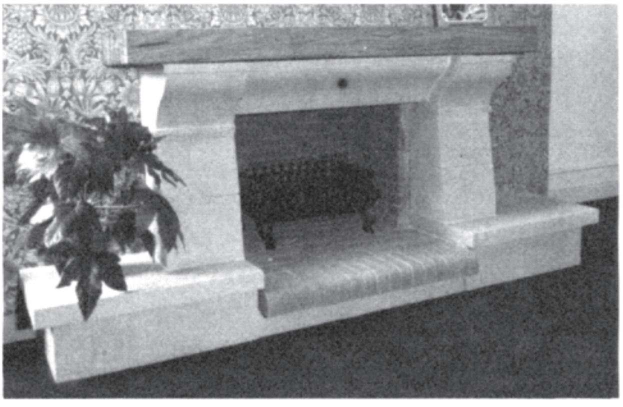

Fig. 6.21. Medium-sized cast stone units.

Fig. 6.22. Cast stone garden ware.

vibro-press work is undertaken by a person holding a pneumatic hammer and compacting an earth-moist mix into a mould. In this respect storey-height units should not really be made by this process, as difficulty will be experienced in production, with personnel having to stand on the mix whilst compacting it.

Before describing mix design, crazing should be mentioned. This is more likely in cast stone than other products as they often contain white cement, and this has a larger movement under wetting and drying cycles than grey cement. However, in all other respects except colour, it is virtually identical in performance. Crazing is an aesthetic non-structural surface map cracking pattern with 'square' dimensions from 5 to 100 mm. In the larger size pattern it is dirt-occluding and unsightly but it generally has a trend to autogenous healing (calcite formation in the craze cracks) after a few years. The finer patterns of crazing relate more to wet-cast units than to earth-moist mix design units, where the water content is too high and a laitance is driven to the surface. Most manufacturers of cast stone use a facing mix at least 20 mm thick followed by a backing mix which is made of cheaper local aggregate and grey cement and contains the reinforcement. The facing mix consists of crushed stone fines mixed with a rounded similar coloured sand to give the mix an improved workability. It is in the design and mixture of these two facing aggregates that crazing can be inhibited or encouraged. The susceptibility to crazing can be determined by consecutive wetting and drying cycles carried out at decreasing relative humidities using carbon-containing water to emphasise the crazing.

In the mixture of crushed rock and natural sand both the following conditions need to obtain:

(1) The natural sand should constitute at least 25% of the total aggregate.
(2) Not more than 5% of the sand should pass a 150μm sieve.

The grading of the crushed rock is irrelevant in this respect.

A typical process would be as follows. Into the clean, robust (usually timber) unoiled mould the facing mix is placed and pneumatically hammered into place to a depth of at least 20 mm at all points. The back of this is mechanically tooled with a nail-comb or similar tool and the backing mix is hammered onto the top of this keyed face to give a build up of at least 20 mm. Reinforcement is placed in position and the remaining backing compacted in 40–50 mm layers without mechanical keying between layers until the top face of the mould is reached. The product is then floated smooth using some of the facing mix if required to obtain a good face. The product and the mould are then carefully inverted onto a prepared pallet and the mould carefully stripped. Any repair work can be undertaken immediately and personnel should keep well clear of the unit until it has hardened. No specific curing is necessary as the facing mix design ensures little loss of water due to the presence of the admixture.

The gradings given in Table 6.2 would be considered suitable.

TABLE 6·2
SUITABLE GRADINGS FOR CAST STONE MANUFACTURE

% passing	*Facing crushed rock*	*Facing sand*	*Backing coarse*	*Backing sand*
10	100	100	100	100
5	100	100	60	100
2·36	100	100	10	100
1·18	80	100	0	95
600	60	80		70
300	40	2		30
150	20	1		10
75	10	0		2

The following mix designs would suit the production of a cast stone design to simulate natural limestone rock:

Facing mix

3 Crushed rock
1 Facing sand
1 White cement
1·0% Calcium or aluminium stearate w/w cement (see Chapter 2)
0·33 free W/C

Backing mix

3 Backing coarse
1·5 Backing sand
1 OPC
0·32 free W/C
(all parts by weight)

A similar approach may be made to simulating granite and basaltic types of natural stone except that a grey or pigmented white or pigmented grey cement may be required together with another natural sand. Cast stone sandstone is the odd one out as most of the sandstones used for natural stone work do not crush to give very good aggregates. In these cases it is best to use crushed rock fines (limestone or of volcanic origin) together with a suitable sand and coloured cement or pigment with white cement.

National and international laws may well apply when describing the product and it is always best to use the 'cast stone' terminology as this permits the manufacturer full licence in materials selection. The terms 'reconstituted' and 'reconstructed' can be construed to imply that the name stone in the product description is the sole aggregate used in the facing mix. Such would not only result in a poor mix design having no natural sand to assist workability but also in the possible use of a low quality aggregate.

6.5 SPUN CONCRETE PRODUCTION

This process is used for the production of lighting column standards and pipes. The outer section mould is spun on rollers and the mix is fed in by conveyor belt, pump or manually and the centrifugal force of the spinning compacts the concrete against the side of the mould. It has the advantages over the vibro-press process that the unit can be heavily reinforced without compaction or concrete flow interference, and also be prestressed laterally with pretension wires anchored to the mould lips, as well as being able to take circumferential post-tensioning later on. Its main process disadvantage is that the mould is in use for 4–18 hours whilst heat curing so as to obtain enough strength for demoulding either reinforced or pretensioned pipes.

Spinning speeds vary depending upon diameter, wall thickness, etc., but a typical l·5m diameter×2·0 m long pipe would be spun at about 2cps (cycles per second) during the filling process and this would be increased to 5–10cps during the compaction process over a period of 10–15 minutes. Concrete is generally fed in, in 35–40 mm thick layers to assist in aggregate distribution across the wall thickness.

Selection of concreting materials and mix design require stringent control because if these variables are not within specific limits the high centrifugal forces will cause the mix to segregate. Any segregation that occurs results in the medium density aggregate migrating to the outside, the low density water towards the middle of the pipe wall section and the high density cement to the inside face. The reason why the cement is least affected by the force, even with its high density, is because of its small particle size. In such a material Brownian forces are operative and not the normal Newtonian ones. The cement, therefore, must not be too fine, and coarse ground grades with specific surfaces in the range 200–300 m^2/kg are preferred. Having established that the right sort of cement is available, one uses a clean angular crushed rock aggregate, such as granite, basalt, dolomite or similar, together with a sharp uniformly graded natural sand. The last variable to control is the free water/cement ratio which must be high enough to satisfy the cement hydration and curing requirements but not high enough to encourage segregation. A typical mix design suitable for spun concrete would be:

3·0	Clean 10mm crushed rock
1·5	Sharp concreting sand
1·0	OPC-CGPC (coarse ground) or SRPC
0·33	free W/C

(all parts by weight)

Fly ash has been found to be beneficial in inhibiting segregation when the mix is prone to this effect. Additions of 20–40% w/w cement are typical. If fly ash is not available pozzolana and pozzolanic cements (commonly used for hot weather work) as a full or part substitute for the

OPC-CGPC could well be beneficial. This would permit higher free W/C without segregation, as well as tolerating the finer range of OPC particle size or even RHPC.

Where spun pipes are post-tensioned it is necessary to spray a mortar or grout onto the pipe to protect the steel from corrosion. Mixes of 1/1 sand/cement sprayed or gunned onto a thickness of 25–50 mm have given good performance, but the presence of a polymer admixture would enable one to use thinner coats with the same performance and with less risk of coating damage during handling, transport and laying.

Spun lighting columns are generally prestressed along their length so as to give strength and impact resistance. The junction with the lamp bracket at the top of the column be it concrete, metal or plastics, needs special attention. Under the action of impact from a vehicle the inertia of the bracket acts against the whip effect at the top of the column and concrete break-out can occur unless additional reinforcement is placed at that point to restrain the concrete.

Figure 6.23 shows a reinforced pipe ready to receive concrete, Fig. 6.24 concrete being fed into the mould by a retractable conveyor belt, and Fig. 6.25 the invert finish technique.

6.6 HYDRAULICALLY PRESSED PRODUCTS

In the three basic processes described in this section very high pressures are applied to concrete mixes to:

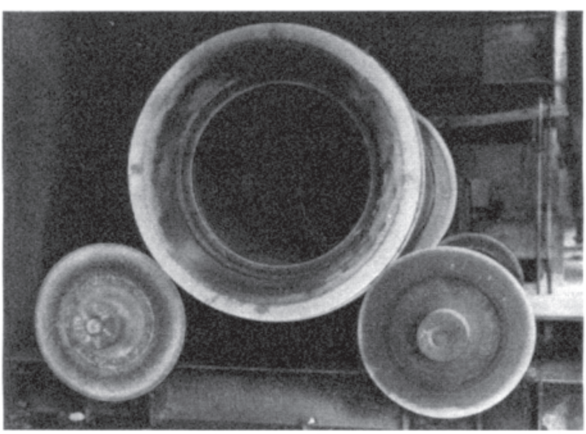

Fig. 6.23. Spun pipe mould ready to receive concrete.

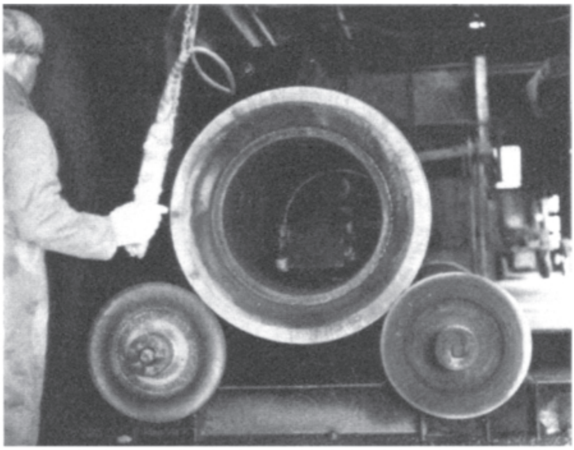

Fig. 6.24. Concrete being fed into spinning pipe mould.

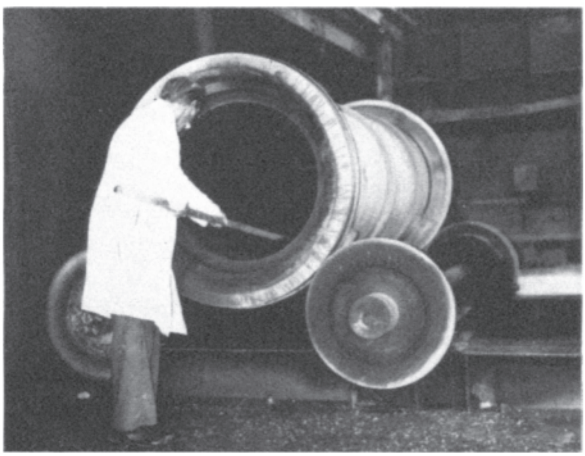

Fig. 6.25. Finishing invert of spun pipe.

(a) Press the excess water out of the mix.
(b) Compact an earth-moist mix without vibration.
(c) Compact together a vibratable facing mix with an earth-moist backing mix to diffuse the two together.

Products covered in these processes are:

(a) Paving slabs, kerbs, channels and edging.

(b) Bricks and special paving slabs.
(c) Floor tiles and faced paving slabs.

6.6.1 Wet-pressed products

The press table is either a three-stage turntable or a single-stage reciprocal but the method is the same in both machines. Under the base of the mould is an ejector jack and on the base sits a perforated metal plate or a metal gauze. Onto this is placed a sheet of paper which acts as a filter and then a very wet concrete mix is metered by secondary hopper onto the paper and fills the mould. On top of this another sheet of paper is placed and a press head, sometimes in the form of a vacuum box with a perforated face, applies a pressure of up to 400 tonnes and the excess water is pressed out through the paper and sucked through the vacuum press head or pressed out of the top paper. The press returns to its rest position and the ejector jack raises the product above the table plane, a vacuum pad then picks the unit up and the paper is either left on until the product is hard or blown off whilst the product is being lifted. The vacuum pad then takes the product away from the machine and, in modern plants, turns through ninety degrees and deposits the unit on its edge onto a pallet next to its neighbours.

In the turntable machine the three stages are filling, pressing and ejection, and in the reciprocating single stage machine all three processes are carried out with a single mould. Although both machines lend themselves to mass production, with the three-stage being about twice as fast as the single-stage machine, the latter has the advantage that for changes of unit type production, only one mould box and one head need to be changed instead of three mould boxes and one head for the three-stage machine.

Accurate metering of concrete volumes or weights is essential to ensure a consistent thickness of product. Figure 6.26 illustrates a motor-driven conveyor feeding a microswitch-balanced secondary hopper which trips off the conveyor when it has had its predesignated fill of concrete. The workability of the mix is shown in Fig. 6.27 where the feed hopper is being fed from the main hopper, and in Fig. 6.28, where it is being fed into the mould box. Figure 6.29 shows a single-stage press mould being fed with concrete. Figure 6.30 shows the complete set-up of a three-stage turntable machine. Figure 6.31 illustrates a typical soft foam rubber-edged vacuum lift plate as used for paving slabs. Figure 6.32 shows vertical slab stacking with immediate removal of paper whereas Fig. 6.33 shows paper being removed from hardened concrete kerbs at about one day old.

Mix design is always a function of the concreting materials available

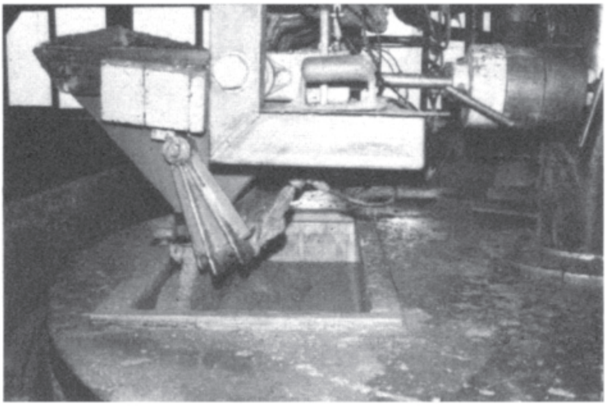

Fig. 6.26. Feedhopper for wet-pressed product.

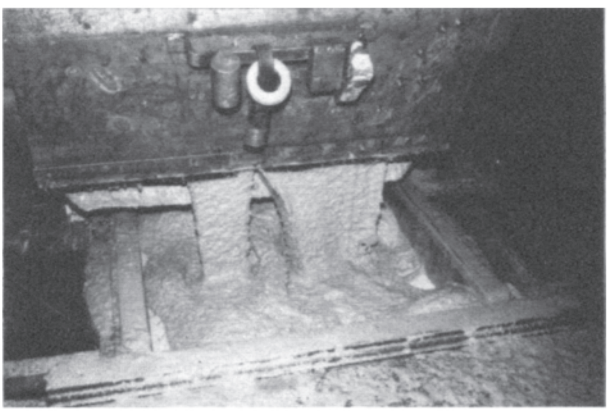

Fig. 6.27. Secondary hopper feed.

and the performance requirements, and the only common factor is that this process should not use natural gravel and sand mixes unless the gravel is crushed to give a crushed rock aggregate grading. The press process requires an interlock between the aggregate particles, the presence of fine material to fill the voids and the presence of a fine rounded material such as natural sand or fly ash to aid workability. Normally, crushed rock mixes including the fines and dust portion are used together with natural sand and/or fly ash. The aggregate must not contain too much dust (often called flour) and the cement used should not exceed about $350 m^2/kg$ in fineness. If either or both of these occur

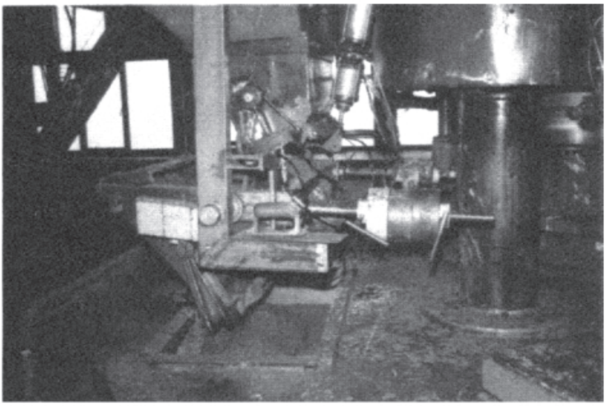

Fig. 6.28. Feed of concrete into wet press mould box.

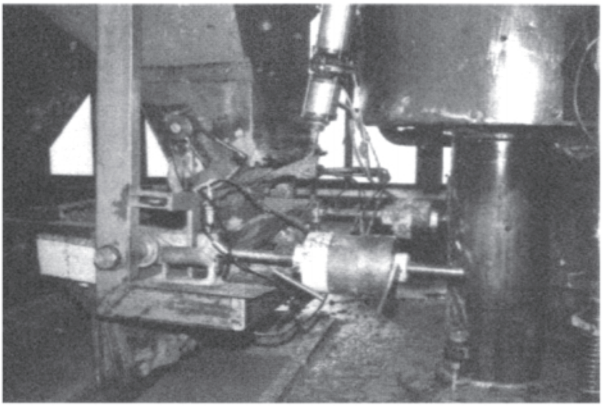

Fig. 6.29. Single-stage press being fed with concrete.

the process can be delayed as there is a risk of ‘shutting off’ the top and the bottom of the unit under pressure and not allowing the water in the middle to egress. This results in what is known industrially as ‘soft-centres’, but can be avoided by extending the pressing time or, more effectively, by changing the aggregate proportions in the mix.

Admixtures such as air-entrainers and workability aids have no effect on the pressing process or properties and should not be used.

Typical and suitable gradings of the fine materials suitable for production are as given in Table 6.3. Suitable mix designs are listed in Table 6.4.

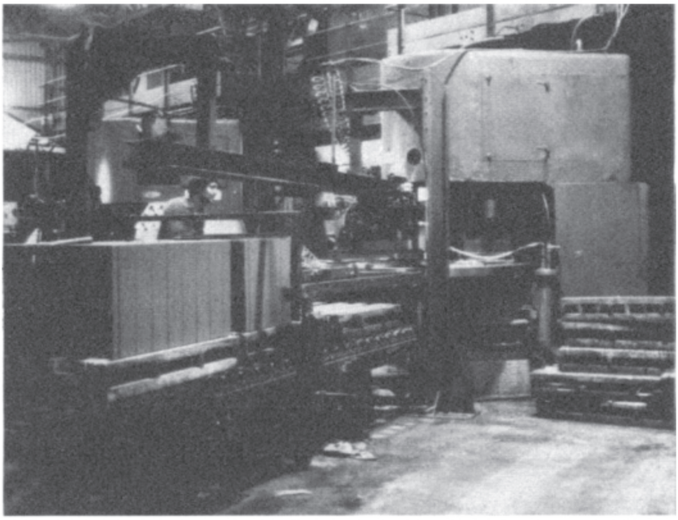

Fig. 6.30. Three-stage wet press machine.

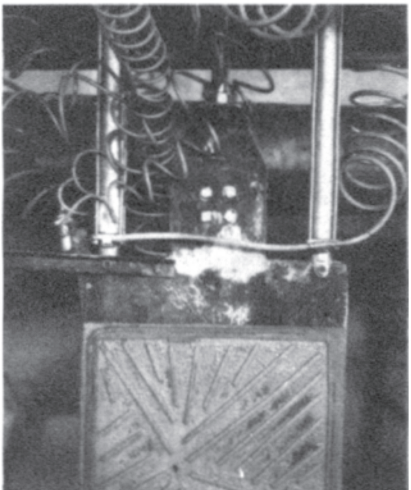

Fig. 6.31. Vacuum lift plate.

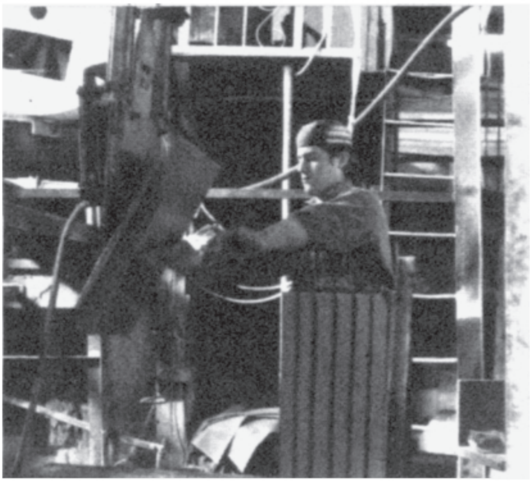

Fig. 6.32. Vertical stacking of slabs with immediate removal of paper.

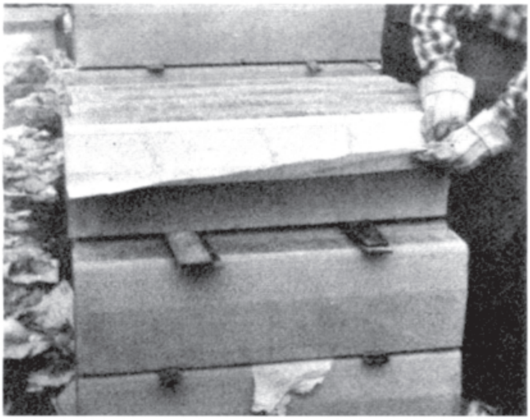

Fig. 6.33. Removal of paper from hardened wet-pressed kerbs.

All parts are by weight to one part of cement. When coloured slabs are being made the mix should contain 1% w/w cement of stearic acid.

Production rate is controlled by the slowest part of the process, normally the pressing time, and it is essential that the rate does not become as quick as the machine can press but is experimentally adjusted to the fastest speed commensurate with the best product. A typical press

TABLE 6.3
FINE AGGREGATE GRADINGS FOR WET-PRESS PRODUCTION

Passing sieve no.	*Crushed rock*	*Natural sand*
5	70–100	90–100
2·36	50–100	80–100
1·18	40–90	70–90
600	30–80	50–90
300	25–50	20–60
150	15–30	10–40
75	5–15	5–15

TABLE 6.4
SOME TYPICAL MIX DESIGNS FOR WET-PRESSED PRODUCTS

Aggregate	*Kerb*	*Kerb*	*Slab*	*Slab*
20 mm	1·5	2·0		
6 or 10 mm	2·0	2·0	2·0	2·5
5 mm down	2·5	2·5	2·5	2·5
Natural sand	0·5		0·5	
PFA		0·5		0·5
Initial free W/C	0·80	0·86	0·70	0·80
Final free W/C	0·40	0·43	0·35	0·40

cycle would be a 2 second build-up followed by a 6–10 second hold followed by a 1 second pressure removal. Thick sections need a longer build-up than thin ones to avoid soft centres and also need a longer hold-time as there is more excess water to remove. Turntable production rates vary from 2 to 6 cycles per minute depending upon what is being made.The paper selected for the bottom filter plate needs to be of good finish, and it is best to remove it whilt the concrete is fresh rather than risk sticking, which can occur if it is left until the concrete has hardened. Retarder-impregnated paper is left on until the following day then the product may be scrubbed to give a visual concrete with exposed aggregate finish. Proprietary machines are available for this work.Aggregate exposure could be undertaken with fine water jets on the freshly moulded face for the earth-moist process, but the author knows of no one using this technique for wet-pressed products. Excess water from the press or other processes herein described may be re-used if it is kept agitated and mixed with some fresh water just before dispensing.

6.6.2 Earth-moist pressed products

The press table used for special paving slabs is usually a four-stage or sometimes a five-stage machine. Underneath each base plate, which is of solid steel or hard rubber, is an ejector jack. In the five-stage press a very workable facing mix is placed in the box first and undergoes a vibration to spread the mix. In the next stage, the first in the four-stage press, the earth-moist mix is placed in the box. The turntable then swings under a 500–600 tonne press head and the concrete is compacted. At the eject stage the paving slab is slid onto a tilting plate with a bottom shelf and carried to the storage pallet where it is stored on its edge as for wet-pressed unit production (Section 6.6.1). The surface of these concretes is too open-textured to be vacuum lifted. In the five-stage process there is interdiffusion between the facing and backing mixes with a pseudo-vacuum concrete effect occurring. Figure 6.34 illustrates a four-stage press making 300×600 mm slabs which are aggregate-exposed by waterspray immediately on demoulding as seen in Fig. 6.35 and edge-stacked on pallets as in Fig. 6.36.

The concrete brick process as shown in Fig. 6.37 makes plain or frogged bricks, usually frog- or face-down. The press is basically single-stage, as seen here, but multi-stage units are also common. The feed, press (up to 15 N/mm^2) and eject stages are similar to the above

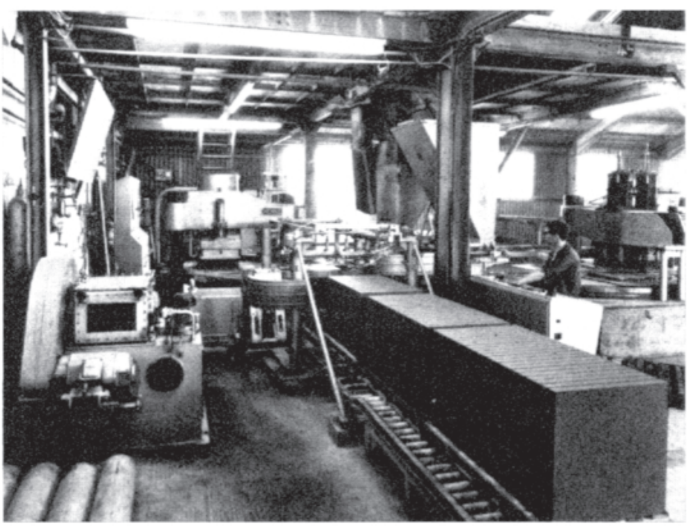

Fig. 6.34. Four-stage earth-moist press.

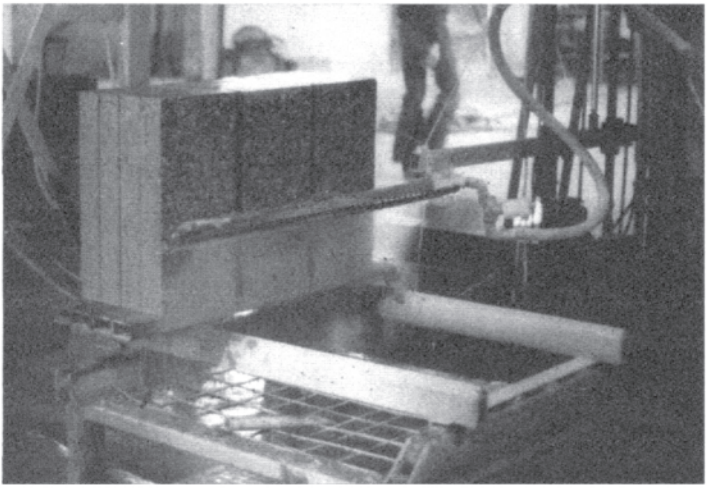

Fig. 6.35. Immediate aggregate exposure by water-spray.

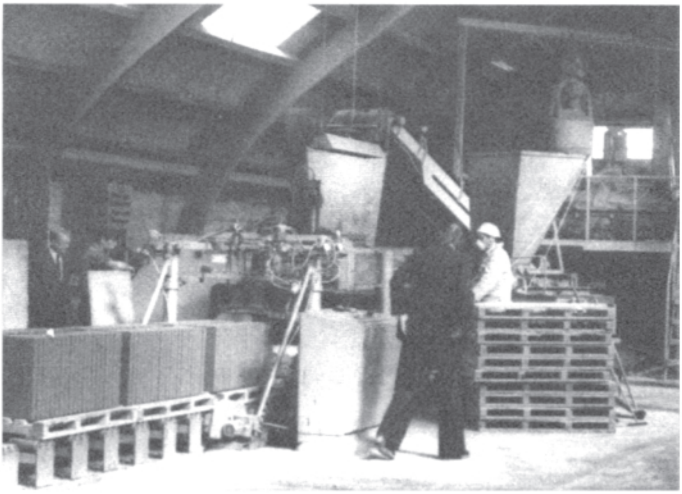

Fig. 6.36. Edge-stacking of earth-moist mix paving slabs.

processes and the feed pallet is withdrawn when it deposits its drop onto the main pallet. In the multi-stage rotary press the mould is filled in the feed pan, the table rotates and the bricks are then pressed up to 200 tonnes pressure. After a further rotation they are ejected and manually or machine stacked. Curing on pallets is in air or by low pressure steam.

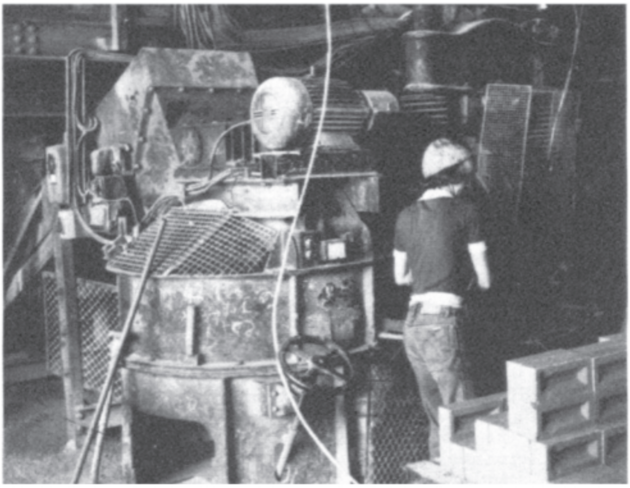

Fig. 6.37. Earth-moist mix brick press.

Mix design is very dependent on machine characteristics in that materials may not always be suitable—particularly with respect to sand grading, whether it be a natural sand or crushed rock fines. The requirement for interlock and workability as discussed in Section 6.6.1 is relevant.

Suitable gradings for fine materials are shown in Table 6.5, with suitable mix designs as shown in Table 6.6 (all parts by weight to one part of cement (ordinary, rapid or sulphate-resisting)).

TABLE 6.5
FINE AGGREGATE GRADINGS FOR EARTH-MOIST PRESS PRODUCTION

Passing sieve no.	*Crushed rock*	*Natural sand*
5	70–100	90–100
2·36	50–90	80–100
1·18	40–60	70–90
600	30–50	50–80
300	20–30	20–60
150	0–10	10–30
75	0–5	0–10

TABLE 6.6
SUITABLE EARTH-MOIST MIX DESIGNS FOR SLABS AND BRICKS

Aggregate	*Slab*	*Brick*
6 mm crushed rock	3·0	—
Natural sand or rock sand	1·5	10·0
Free W/C	0·32	0·45

It is essential in the paving slab process that aggregate selection results in a low dust level crushed rock, otherwise the total W/C would need to be increased for workability; and when mixes become too dusty they are difficult to press. The sand grading requirements rule out the vast majority of the single-sized sands except those that predominate in the 600–300 sieve range; a good quality concreting sand is usually the best choice. The press can produce triangular, circular, hexagonal, etc., shapes, as well as faced concretes; but there are difficulties in stacking some of these geometries on edge and some shapes have to be stored flat. The mould box at the filling stage needs trowelling off to ensure a uniform fill otherwise a density gradient will result. Pressure build-up and holding time is not so critical as in Section 6.6.1, but a normal cycle would be about 25 seconds with about 10–15 seconds in the pressing stage.

In the brick process a 4- or 8-drop would take place about every 15 seconds.

6.6.3 Wet and earth-moist mix presses

In the production of floor tiles the wet and earth-moist mix mentioned for the five-stage process (Section 6.6.2) is the principal mode of manufacture. The turntable press is a four-, six- or eight-stage turntable with either single or separate presses. Of the stages only four are used in any one press cycle, namely, backing fill, facing fill, press (up to 15 N/mm^2) and eject. The backing is the earth-moist mix, and the facing the wet mix, and the two are interdiffused by interface cement and water migration. The backing mix is a mortar and the facing mix what the client requires for a finish. In terrazzo work large pieces of aggregate are hand-placed in the cement mortar with large facets horizontal. Even with tiles of 300×300×25 mm size it is possible to use 40 mm marble pieces with a 10 mm thickness in the 12 mm facing depth. After pressing and ejecting the tile is slid onto a pallet and stored flat. When the tile has hardened sufficiently it is submitted to 2–5 grinding and polishing stages to achieve the desired finish. One can see that even with a machine-intensive process there is a part that is labour-intensive, but with experienced labour the facing aggregate spread can be completed in 5–10 seconds. Press time is 10–15 seconds and this is the time of each tile production cycle.

Table 6.7 outlines typical mix designs for two types of terrazzo-faced tiles. It should be noted that both these facing mixes contain no fine aggregate but tiles can be made with a 2/1 coarse/fines if that effect is required in the finish.

TABLE 6.7
MIX DESIGNS FOR WET/EARTH-MOIST MIXES FOR TERRAZZO TILES

Aggregate	*Tile 1*	*Tile 2*	*Part*
40 mm marble slips	3·0		Facing
White cement	1·0		Facing
10 mm quartzite		3·0	Facing
Pigmented cement		1·0	Facing
Concreting sand	3·0	3·0	Backing
OPC or RHPC	1·0	1·0	Backing
Free W/C initial	0·4	0·4	Facing
Free W/C final	0·3	0·3	Facing
Free W/C initial	0·2	0·2	Backing
Free W/C final	0·3	0·3	Backing

All parts by weight

6.7 EXTRUDED AND SLIP FORM PRODUCTION

The dividing line between these two types of process is rather tenuous and as they are both used in the manufacture of prestressed pretensioned floor planks and wall panels they are dealt with together in this section.

6.7.1 Roofing tiles

Mortar made of a specially selected graded sand at 3/1 A/C with OPC or RHPC and a free W/C of about 0·28 is fed into a hopper at the bottom of which is a rotating vaned roller. This pushes the partially compacted mix into a tapered box at the end of which is a high speed rotating vaned roller which extrudes the compacted mix through a die of the same shape as the tile. This ribbon of mortar is fed onto a train of oiled aluminium pallets of similar shape on a ropeway traversing at the same speed as the mortar ribbon. A guillotine cuts the ribbon at pallet joints and, if required, coloured sand is sprayed onto the surface and the excess blown off. The tiles are then roped away and fed into steam curing chambers. When the tiles are hard the pallets are re-fed onto the ropeway and automatically demoulded by side wheels; the tile is then fed into storage and the pallet continues down the feed side of the ropeway where it is automatically oiled and stacked for feeding into the machine again. Production rate is about one per second but the duplex machines produce at twice this rate. Figure 6.38 shows a view of the works with the

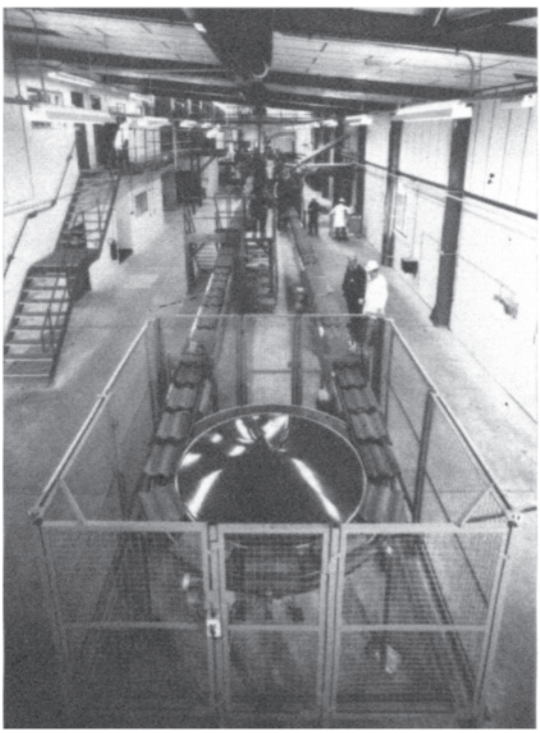

Fig. 6.38. Roofing tile production.

tiles leaving the machine and heading towards steam curing. Figure 6.39 shows tiles being fed into the steam chambers.

Fig. 6.39. Roofing tile steam curing chambers.

6.7.2 Extruded planks and panels

There are two basic methods of production but both work on the same principle. In the first a number of augers inside the machine under the feed box push the concrete through a rectangular die over which a couple of high frequency clamp-on vibrators provide the final compaction and finish. This is illustrated in Fig. 6.40. The machine traverses along the bed where the pretensioned strands are already under tension and traverse through the machine. The augers result in the round holes that one sees in these products. The beds are then subjected to heat curing and when the concrete reaches the required transfer stress the units are either cut semi-automatically as shown in Fig. 6.41, or fed out into the yard and where they can be cut manually as seen in Fig. 6.42.

In the second method recoverable coarse aggregate is fed through dies at the same time as the auger-pressurised concrete. This enables one to

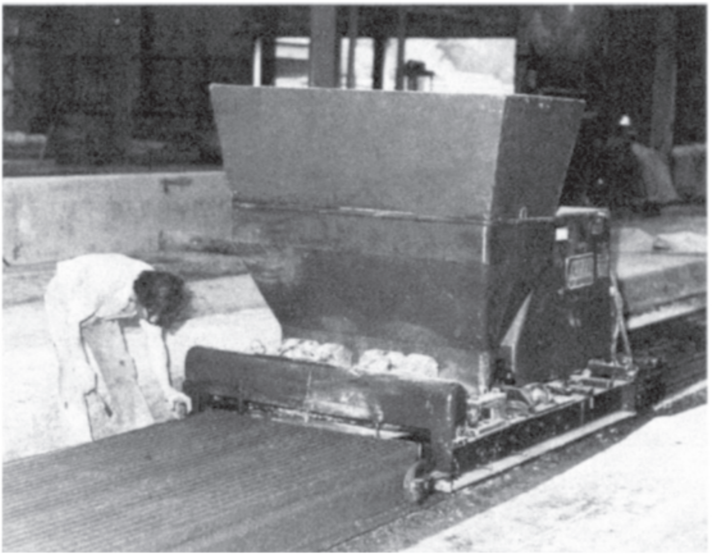

Fig. 6.40. Extruded Spiroll plank production.

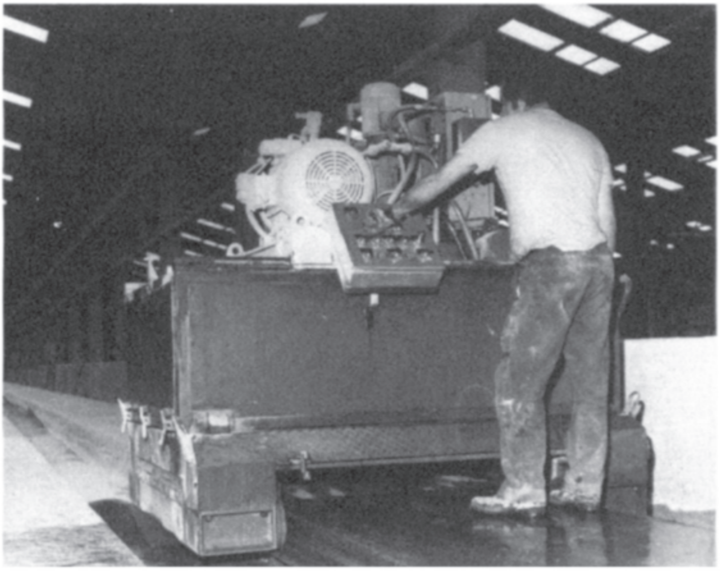

Fig. 6.41. Semi-automatic plank cutter.

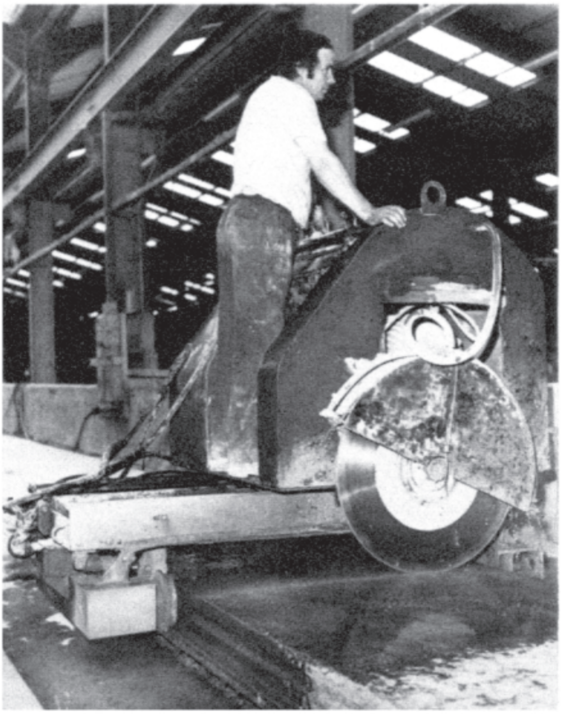

Fig. 6.42. Manually operated plank cutter.

achieve different-shaped voids in the production of exposed-aggregate prestressed cladding panels, illustrated in Fig. 6.43. In this case the bed is partitioned so that cutting is unnecessary and units are demoulded from their end plates as shown in Fig. 6.44 and the strands or wires are cut. Prestressing also takes place across window openings without any ill effect on transfer of prestress. Production by this method is also subject to heat curing as a rule in order to achieve economic transfer times.

Mix design is typified by a mix of:

3·0	10 mm coarse aggregate
1·5	Medium fineness concreting sand
1·0	OPC or RHPC
0·38	Free W/C
	(all parts by weight)

The process is rather sensitive to variations in the fine aggregate grading

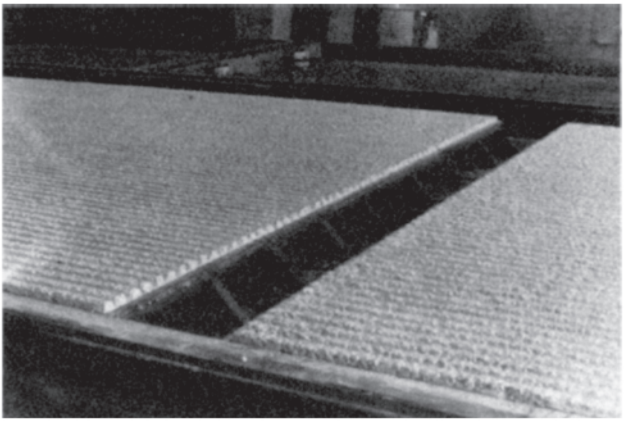

Fig. 6.43. Prestressed extruded wall units.

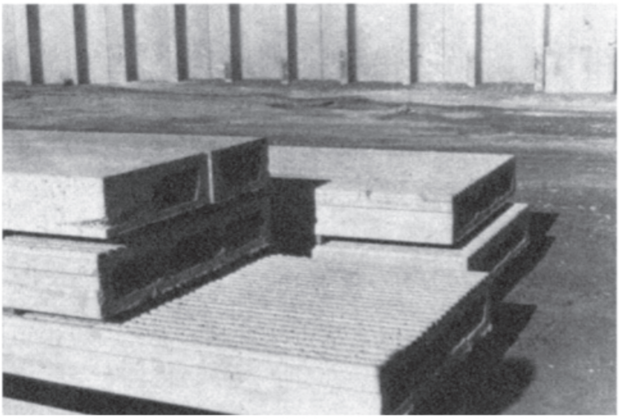

Fig. 6.44. Prestressed extruded wall units.

and free W/C and production of a consistent product is only possible if these two factors are subject to (probably) the most rigid form of materials control of any of the processes discussed in this chapter. The top face as cast of these units is likely to have fissures and permeable particles or 'holes' if care is not taken, and a lot of water, turning into high alkaline liquid, can be trapped on site without proper precautions. Holes in the soffits to allow drainage are generally a good idea where this risk obtains.

6.7.3 Slip-formed planks and panels

Vigorously vibrated concrete being forced under a moving die plate is the basis of this process, illustrated in Fig. 6.45, where three runs of prestressed units are being made with the one pass. The system lends itself to the manufacture of reinforced units, whereas this is not an easy matter for the methods described in Section 6.7.2.

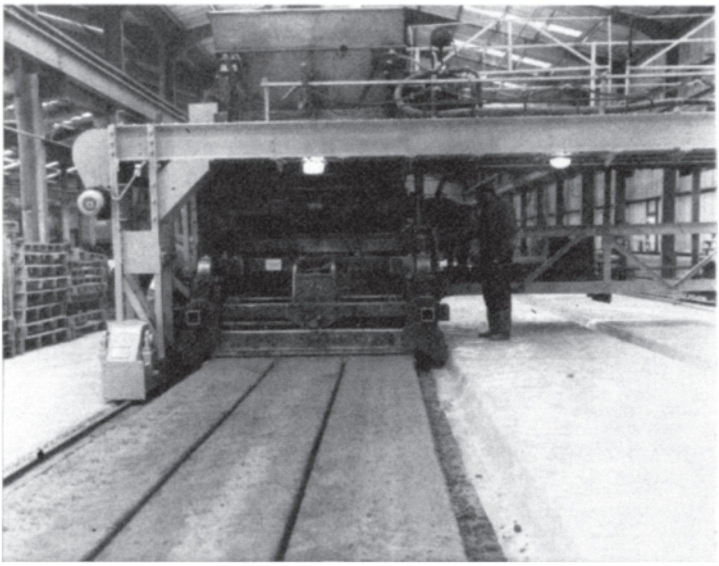

Fig. 6.45. Slip-formed Tembo prestressed plank production.

Mix design, curing and cutting is identical to that in Section 6.7.2, but the mix design is not so sensitive to the sand grading and a better top finish is obtained. In addition, virtually any shape of void may be made. In both the processes described in Sections 6.7.2 and 6.7.3 the concrete is generally so well compacted that the operative can stand on the newly finished surface without harming it, provided the void lines are avoided.

6.8 AUTOCLAVED AERATED CONCRETE PRODUCTION

Autoclaved aerated and aerated concrete are dealt with at length in several chapters in the book by Short and Kinniburgh (see Bibliography) and it is not proposed to go into the process in great detail here.

Autoclaved aerated precast concrete products are strictly aerated mortars with most of the ingredients well under 100μm mesh in size. Aeration is normally achieved by using an aluminium powder which reacts with free lime and water to form discrete hydrogen bubbles in the matrix. Since aerated concretes are weak this has to be accepted for *in situ* work, but for precast work, by submission of the aerated material to a high pressure and temperature (e.g. 11–15 bar at 180–210°C for 10–18 hours) an autoclave-induced chemical reaction occurs resulting in the formation of mono-calcium silicate.

The basic ingredients are:

(1) Silica sand ground to cement fineness or fly ash.
(2) Portland cement and/or hydrated lime.
(3) Aluminium powder.
(4) Water.
(5) Wetting, lime solubility promotion, cell stabilisation and reaction initiation admixtures.

Practice varies from factory to factory and one process would be to mix the ingredients up and pour them into a mould and allow the mix to foam and rise. The block is allowed to take on a little 'green' strength either by waiting for some hours or by accelerated heat curing, and then it is cut with wires into block-size units or to the size of the beam or panel. Depending on the block size the wires will cut in two or all three of the orthogonal directions. The cut block is then bogey-fed into the autoclave and at the end of this may be stacked or delivered, as the full potential strength has been obtained. The hydrogen forming the bubbles is not a fire or explosive hazard as it is replaced very quickly with air in the natural diffusion process.

In the case of reinforced units the rebars require coating protection to prevent corrosion and a bitumen mineral-filled coating is often used, with the designer taking into account the reduced bond strength. Polymer grouts would appear to have a high promise as total coatings; one manufacturer uses a latex slurry layer as undercoat prior to the bitumen.

Even though this process results in a viable method of producing an aerated product with a selected oven-dry density from 500 to 1000 kg/m^3 the production is extremely specialised. It is not for the inexperienced because, apart from the expensive capitalisation, the combined disciplines of chemistry, physics and engineering are required.

To exemplify production in a particular factory, Fig. 6.46 shows filled

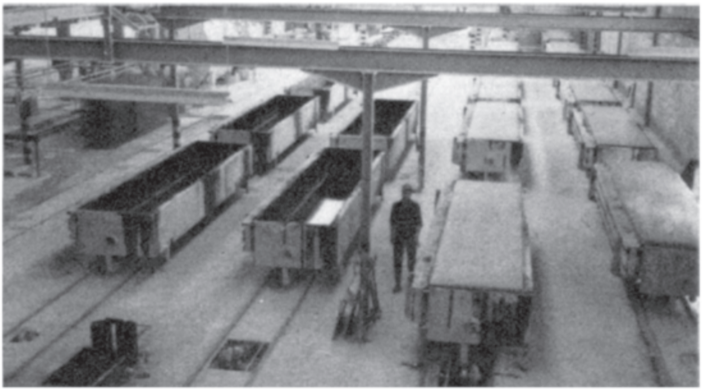

Fig. 6.46. Filled and unfilled autoclave moulds.

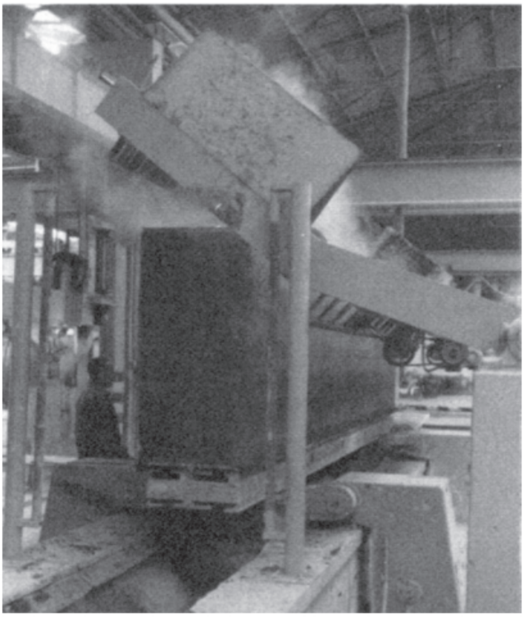

Fig. 6.47. One of the cutting stages of 'green' blocks.

and unfilled moulds with the filled moulds already foamed above the mould tops. A trimming machine then removes excess material from a block standing on a casting side; a débris return trench with conveyor underneath feeds back to the mixer. Figure 6.47 shows one of the cutting phases and Fig. 6.48 the autoclaves with blocks being loaded. The wire cut lines are practically invisible but the whole separates easily into the individual blocks. Figure 6.49 shows a typical block and an enlarged view of the aeration.

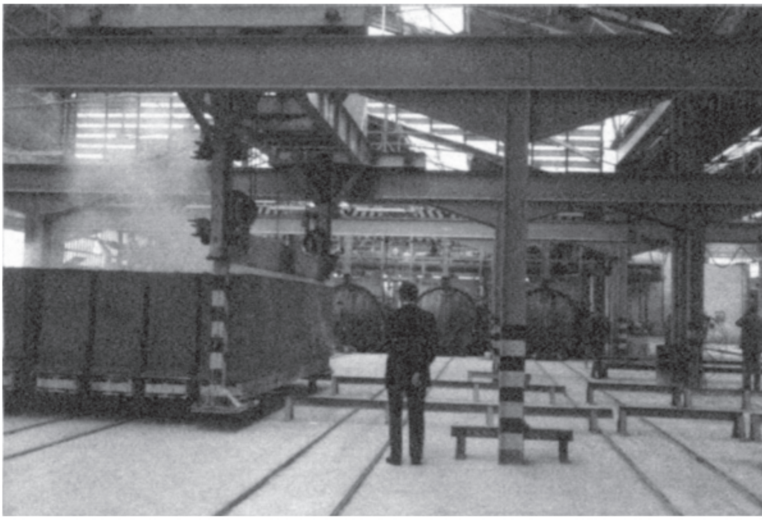

Fig. 6.48. Autoclaves and aerated blocks ready for loading.

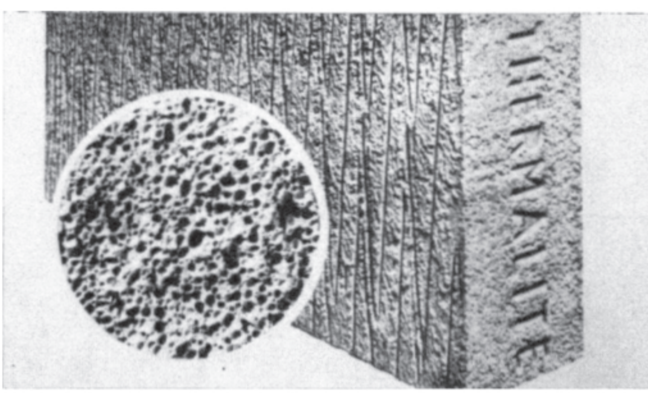

Fig. 6.49. Typical autoclaved aerated block.

6.9 ROTARY PIPE COMPACTION

6.9.1 Roller suspension

The system known as the roller suspension system is Australian in origin. It has been used for many years to produce reinforced sewerage and drainage pipes and also high pressure mains water pipes.

The mould is suspended on the roller, the roller then being driven and rotating the mould through contact with the mould end rings. Concrete is then fed by conveyor into the rolling mould as shown in Fig. 6.50.

The rolling action of the mould does provide some centrifugal force to the concrete, but it is the weight of the concrete and mould acting on the roller surface, together with incidental vibration, that produces the main compaction forces, which are considerable.

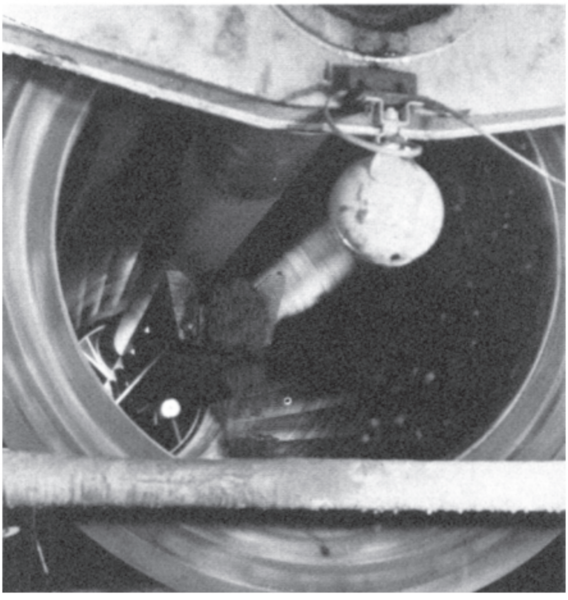

Fig. 6.50. Roller compaction of pipes.

Pipes may be heavily reinforced because there is no inside mould; they may be, and often are, prestressed laterally and/or circumferentially.

The mix design is very similar to the vibro-press pipes with a typical mix being:

3·0 Coarse aggregate (up to 12 mm)
1·5 Concreting sand
1·0 OPC or RHPC or SRPC
0·30 Free W/C maximum
(all parts by weight)

6.9.2 Vertical rotary pipes

In this method, which is not as popular as it used to be, the inner mould is a rotating barrel with vanes brushing between it and the stationary outer mould. The mix is fed down the side of the barrel, and as the mix becomes trapped and compacted under the vanes due to their design and the weight of the barrel, it travels upwards. Although good quality concrete can be made it is difficult to reinforce these units as the operation has to be interrupted by withdrawing the barrel and dropping a steel hoop into place then continuing the process.

The mix design is as in Section 6.8.1 except that when land drainage pipes are made a more typical mix would be:

2·0 Coarse aggregate
4·0 Single sized sand
1·0 OPC
0·35 Free W/C
(all parts by weight)

BIBLIOGRAPHY

J.G.RICHARDSON, *Precast Concrete Production*, Applied Science Publishers, London, 1973.
Architectural Precast Concrete, PCI, Chicago, 1973.
M.T.GAGE, *Guide to Exposed Concrete Finishes*, Architectural Press/C & CA, London, 1970.
J.G.WILSON, *Exposed Concrete Finishes*, Vol. 1, C.R. Books, London, 1962.
J.G.WILSON, *Exposed Concrete Finishes*, Vol. 2, C.R. Books, London, 1964.
Recommendations for the Production of High Quality Surface Finishes, C & CA Technical Advisory Series, London, 1967.
A.SHORT and W.KINNIBURGH, *Lightweight Concrete*, Third edition, Applied Science Publishers, London, 1978.

7

ACCELERATED CURING

This chapter integrates the experience of Laing R+D and the British Precast Concrete Federation (BPCF) on the subject of heat curing; the purpose is to produce a background of guidelines for the practitioner wishing to produce high-early-strength concrete using heat as the accelerator. It is not the purpose of the exercise to summarise each of the reports; data has been abstracted where particular points need to be made.

When cement hydrates its speed of reaction is mainly a function of the starting temperature of the system and the curing regime. Hydration is accompanied by exotherm so the concrete tends to warm up as hydration progresses. What this means is that a cold-starting concrete, say 5°C, warms up and gains strength slowly; a warm-starting concrete, say 25°C, warms up and gains strength more quickly; and a concrete starting at, say 40°C, can be handled within a few hours. Any method of accelerating the early strength of concrete is known to detract from the 28-day strength—the usual specification age for concrete cube strength. However, this decrease, more often than not, is within the range of the ± 10% variation one obtains. What is really significant is that heat curing is carried out to obtain a high early strength, and 28 day strength specifications are generally exceeded by an excess one does not require. Research data obtained from both industrial and laboratory processes show that, although there is a decrease in the 28 day cube strength, at 3–6 months old the strength is equivalent to that of the normal-cured concrete.

Flexural strength at 4–24 hours old is the practical consideration as concrete is subject to bending during demoulding and handling. If, for example, one aimed at and achieved a minimum 16 hour flexural strength of 3 N/mm^2 the cube strength at that time would be about 15 N/mm^2 and about 45 N/mm^2 at 28 days old.

Published data is rather sparse on the subject and the main references that come to mind are those by Saul, Thompson and Sadgrove, and CP 110 (see Bibliography). The recommendations given in the Code of Practice CP 110 summarise the main recommendations of Saul and others by stating that the ultimate strength is not likely to be adversely affected provided:

(a) the rate of temperature rise during the first three hours does not exceed 15°C/hour,
(b) thereafter, the rate of rise or fall of temperature does not exceed 35°C/hour,
(c) the temperature of the concrete does not exceed 80°C.

After discussing maturity based upon a –10°C reference zero the Code then states The strength of concrete subjected to accelerated curing for periods up to about 24 hours may well be appreciably greater than the value estimated in this way (the maturity law on –10°C base) and a base of 0°C should be taken'. This obviously means that a new series of maturity curves need to be drawn based upon the new origin.

Although these guidelines are well-intended they omit many of the main requirements and are misleading in that they might be right in one particular case, too lax or too severe in others. Each heat curing regime must be considered as a separate exercise and logic applied in establishing the necessary boundary conditions. Having said this one can now proceed and discuss all the relevant variables in order to arrive at guidelines.

7.1 FORMWORK MATERIALS

Moulds or formwork may be made from timber metal, plastics or composites and the choice is governed by the shape and size of the concrete being cast and the number of units to be cast out of each mould. The ability of a mould or formwork to insulate the concrete thermally is rarely or even partially used as an accelerating technique. Wood 25 mm thick has a thermal resistance equivalent to about 500 mm of solid brick and most of the cement exotherm in timber-shuttered concrete is lost through the exposed face, especially when there is protruding reinforcement. Metal and plastics moulds have thin walls and rely for their stress resistance either on the use of whalings and soldiers or on a shape factor. Their heat loss through the formwork due to radiation and convection is very high, especially in windy conditions. Improvement in the performance in exposed conditions can be achieved by lining the exterior of the formwork and covering the exposed face with expanded plastics. Formwork of metallic or plastics construction used under cover (e.g. a precast concrete factory) can have its thermal insulation properties improved by painting the outside with aluminium or silver paint. In such a case most of the formwork heat loss is due to radiation and this will be reduced; heat losses due to convection will be small. The free face of the concrete will still need insulation with expanded plastics.

Hollow steel moulds with external thermal insulation have been found useful for accelerated curing with hot water or air being passed through the cavity. This system has been successfully used in the 'Sectra' system of housing construction, where demoulding and cranage was achieved at 15 hours old just using warm concrete, insulated form and no externally applied heat. Heated mould systems for timber and glass-reinforced plastics (GRP) may either be made by oneself or purchased as proprietary systems in the form of electrical heating grids. Materials such as 'Mhoglas' and 'Eislerfoil' can be fixed to electrically insulated sheets with protruding bus-bars connected to a low-voltage high-current supply. Care must be exercised in mould construction bearing in mind that the formwork is going to get hot and one side could well be hotter than the other. Additional mould reinforcement or modified design is required to avoid warping.

Another aspect that needs careful attention is differential thermal expansion between the formwork and the concrete. This is not so much of a problem in the heating stage when the concrete is fairly plastic as it is in the cooling stage. Changes in geometry of the concrete such as nibs and aprons or across windows or doorways can act as stress raisers. Steel, having the same order of thermal movement as concrete, should be used in these instances. Aluminium has a higher expansion coefficient than concrete, and concrete has a higher coefficient than timber along the grain. Plastics move about fifteen times as much as concrete and should only be used for simple rectangular sections.

The type of aggregate used can help to counteract cracking brought about by these means and a change from flint gravel to limestone resulted in a significant improvement in one of the Jespersen factories. The original cracking trouble could have been partly due to the mould/concrete thermal differentials and partly due to differentials in the temperature gradient in the concrete from the surface to the centre of the section. For example, limestone concrete has a lower coefficient of thermal expansion and a lower modulus of elasticity than a flint gravel concrete, and both these factors will result in reduced stresses.

7.2 RELEASE AGENTS AND RETARDERS

Release agents for heat-cured concrete moulds and formwork need to have the following properties:

(a) Ease of application by brush, spray or roller.
(b) Good wetting ability with no tendency to globulation.
(c) Non-toxic, non-dermatitic and non-carcinogenic.
(d) No effect on the mould or formwork or lining other than its release properties.
(e) Non-corrosive to metalwork.
(f) Give easy release.
(g) Produce a finish with acceptable coloration changes and blowholes (size and distribution),
(h) Retain all these properties at elevated temperatures.

The recommendations of the Cement and Concrete Association concerning mould oils were produced before the impact of the chemical release agents on the market. Although, on a materials cost comparison, these are expensive compared to mineral oils and emulsified systems they work out more cheaply on a total cost basis. Savings are made on coverage rates, ease of demoulding and improved finishes. Chemical release agents have none of the risks outlined in (c) above; when trouble such as dermatitis occurs with the use of mineral oils it persists for a long time, and personnel should be checked for a personal or family history of this trouble before being allowed to come into contact with conventional oils in any form.

In spite of what is recommended by the Cement and Concrete Association, experience at one factory showed that not all proprietary compounds of the mineral oil type are suitable for steel moulds, and ringing the changes between manufacturers improved the performance. Performance and cost comparisons between products should be made on observations of (a)-(h) above, coupled with the total materials plus labour cost.

Curing at high temperatures can cause physical and/or chemical changes in the release agent. Straight and emulsified mineral oils as well as vegetable oils become less viscous and are prone to globulation as the temperature increases. Run-downs on a vertical face due to streaking of the oil will appear as defects on the struck concrete. Emulsified systems can suffer segregation or evaporation of their water with resultant defects in the finish.

Chemical release agents lose their volatile solvent at ordinary casting temperatures and leave a hard waxy film, resistant to both rain and the scouring effect of fresh concrete being introduced into the section. High temperature usage only causes the solvent to volatilise more quickly and has no effect on the base material—normally a fatty acid.

Retarders are used for exposed aggregate finishes either for architectural or structural (viz. daywork joints) reasons. The cheaper varieties are water-solvent types and cause a lot of defects; the more expensive types are aromatic-solvent-based and spread to leave a hard waxy film after solvent volatilisation. As with the chemical release agents the film is resistant to scouring and rain and only activates and retards when it comes into contact with the lime from the cement. Retarders should be those specifically tailor-made for hot concrete work.

7.3 CONCRETING MATERIALS

7.3.1 Aggregates

Aggregates may be either natural or synthetic or mixtures thereof, the choice being governed by a number of factors all outside the scope of this study. However, bearing in mind that a cubic metre of natural aggregate concrete contains about 2000 kg aggregate and lightweight aggregate about 1200 kg, the exotherm from the same cement content will result in a higher concrete temperature for the lightweight material as there is a lower total thermal capacity (weight×specific heat). Other factors such as differential thermal expansions, elasticities, etc., also feature strongly in the behaviour. As mentioned earlier it was observed that a change from flint gravel to a limestone concrete caused less cracking in the finished product. One can understand this by comparing the aggregate and concrete properties:

	Thermal expansions/°C×10^5			
Aggregate	Limestone	0·45	Flint gravel	1·1
Concrete	Limestone	0·74	Flint gravel	1·3

The following typical data illustrate the importance of both the *E*-values

(Young's modulus) and the value of the ultimate tensile strain of three different sorts of concrete:

Type of aggregate	*Flint gravel*	*Limestone*	*Lytag*	*Units*
28 day cube strength	55	40	30	N/mm^2
28 day flexural strength	6	5	4	N/mm^2
E-value	45	30	25	kN/mm^2
Ultimate tensile strain	110	130	160	μs

Thus the resistance to cracking under a flexural strain effect is inversely proportional to the compressive strength.

The flexural stress/strain curve for these concretes is steeper (higher *E*-value) for the stronger concretes and, therefore, a compromise in design is necessary in most cases. In effect one needs to aim at a minimum strength value for demoulding and handling purposes (and the specification); but to aim too far in excess of this level is inadvisable both for the aforementioned properties and for the sake of material economy.

The thermal conductivity of the aggregate reflects itself in the same property of the concrete from which it has been made. A flint gravel, granite, basalt, etc., aggregate concrete will result in better heat flow and lower temperature gradients than, in sequence, a sandstone or limestone then lightweight aggregate concretes. On the other hand it has been shown that these latter aggregates can tolerate more differential stress so that one can expect similar stress systems throughout the whole spectrum of aggregates. It is rather fortunate that aggregates that promote high temperature gradients through a section are also those that give a lower *E*-value to the matrix. The change mentioned earlier referred to the 'Sectra' limestone aggregate, and indicates that one gains more in *E*-value than one loses in the ultimate stress.

7.3.2 Cements

The speed of hydration of cement, apart from the effect of temperatures, is also dependent upon the particle size and the chemical composition. About 30% of the cost of cement production is taken up with grinding costs and, in order to save energy, there is, at present, a tendency for cements to become coarse ground. Although the present OPC still complies with the BS 12 minimum specific surface of 215 m^2/kg the older supply range of about 330 m^2/kg is now nearer 280 m^2/kg. In the case of RHPC the changed figures are typically from 410 to 360 m^2/kg, which is still in excess of the 320 required minimum.

This means that both the precaster and the contractor will be getting lower early strengths than before, all other things being equal. In order to restore the early strength requirement either more cement will be required, water-reducing admixtures or accelerators used, or accelerated curing employed. The use of the cement exotherm becomes an attractive proposition if one cannot use admixtures, and the importance of the contribution of cement can be visualised when one considers that 1 g of cement gives out about 600 J of heat over its full hydration. This means that 600 g of cement hydrating in 1 kg of water, all fully thermally insulated, will boil the water.

Over about the first 18 hours of hydration the total exotherm would be about 100 J. Let us now consider the effect of this in a mix consisting of 2000 kg aggregate, 400 kg cement, 200 kg water at 30°C

Taking the specific heats (those necessary to raise the temperature by 1°C) of both the cement and the aggregate as 0·84 J/g and of water as 4·2 J/g, the average specific heat of the system may be calculated on weight proportions:

$$\frac{2\ (\text{water}) \times 4{\cdot}2 + 24\ (\text{aggregate and cement}) \times 0{\cdot}84}{26} = 1{\cdot}1\ \text{J/g}$$

Since mass×temperature change×specific heat=heat given out or absorbed

$$2{\cdot}6\times10^{6}\ (\text{total weight in g})\times T\times1.1=4\times10^{5}\ (\text{cement})\times100\ (\text{exotherm})$$

This gives T=15°C approximately, and, if it is under ideal insulating conditions, a final concrete temperature of 45°C (30+15).

It can be seen from this simple calculation how important a factor the cement exotherm is in promoting an accelerated curing condition. If one had a zero efficiency thermal insulation and put this amount of heat (40×10^{6}J) into the system, to get to 45°C one would need other forms of energy. If electrical heat was to be used this would be equivalent to about 3 kWh; heating by steam, oil or air would be cheaper. However, these costs ignore the heating efficiency and the cost of plant, heaters, controls, etc.

7.3.3 Mixing water

Cement only requires a W/C of 0·23 to ensure full hydration; concrete mixes have to contain more than this in order to wet out the aggregate surfaces and achieve workability. Excess water is well known for the detrimental effects it has on the concrete properties. However, it can be seen in the calculation in Section 7.3.2 that water has five times the specific heat of any of the other main concrete ingredients. A kilogram of water at 50°C has five times the amount of available heat as the same weight of aggregate or cement at the same temperature. Therefore, one of the most efficient ways of getting heat into a concrete mix is to use hot water. The danger of flash setting a batch of fresh concrete obtains for some Portland cements but not for others, it is more a function of the cement than the temperature of the mix. Cements which are prone to false set at normal temperatures are likely to be prone to flash set at elevated temperatures. The risk can be minimised by selection of a cement not prone to this behaviour, when water up to 100°C can be added to the aggregates first and the cement then added as the last ingredient. Experiments have been successfully undertaken on the production of a precast concrete coffered garage panel with water at 80°C and, due to using heated aggregates, a final mix temperature of 95°C. Units were stripped at 3 hours old and lifted and a section treated with retarders had its aggregate exposed.

The first mix run through at the start of the day in a hot concrete process loses a lot of heat to the mixer and ancillary plant, and steps can be taken to overcome this effect. Hot water can be run through the system but this is rather messy. A small quantity of methylated spirits placed in the mixer and set alight heats up the pan and mixer blades very quickly. Petrol or diesel fuel should not be used as deposits of carbon form when they burn. Normal precautions should be taken whilst using this highly inflammable liquid and adequate ventilation ensured to get rid of the combustion gases.

Water may be heated in advance of concrete production using cheap off-peak electricity and can be stored in insulated tanks. The steam heating of aggregates observed in a Danish Jespersen factory used both in summer (aggregates heated to 43°C) and winter (heated to 15°C) was not an efficient way of getting heat into the system and is only considered necessary as a winter measure when there is ice in the aggregate.

7.3.4 Admixtures

Although water-reducing admixtures are, in effect, indirect accelerators this application is not within the terms of reference of this chapter. However, what must be borne in mind is that because an admixture behaves in a certain way at 5–25°C it must not be assumed that it will perform similarly outside this temperature range. Recent research illustrates the danger of this assumption when the use of a retarding admixture in heat-cured concrete was found to improve both the early stripping strength and the 28 day value. Where an admixture is intended for use at elevated temperatures (or, for that matter, at very low temperatures) its performance should be studied under, as near as possible, conditions identical to the intended usage.

7.4 CURING METHODS

In the various methods outlined below the aspects discussed in the previous sections must not be forgotten. It must be stressed that it is very uneconomic to use an extremely efficient method for heating up concrete then to lose a lot of the heat due to faulty insulation. Once one gets the cement to react at a high temperature the reaction must be kept in its accelerated state to achieve the rapid turnover of production required. Which of the methods one selects depends upon what is being made, how many castings are needed, the sources of energy, facilities on site or in the factory, etc.

Whichever accelerated curing method is used two important properties of the system must be known, controlled and monitored:

(a) Temperature of the concrete and gradients.
(b) Humidity of the atmosphere adjoining free faces.

The first is obviously important as it relates directly to the strength at early ages and the likelihood of cracking. The second is not so much appreciated but a commonsense approach tells one that if the humidity is too low the surface will be permeable due to too rapid a drying rate with the possibility of under-hydration at the surface. Too high a humidity will cause sweating, pooling of water and unsightly effects such as lime bloom (often mis-named efflorescence).

7.4.1 Steam

Steam, or, more correctly, hot water vapour is the commonest and generally the cheapest way of applying external heat to concrete. Sometimes the steam may be recirculated after re-cycling the condensate but more often than not it is wasted to the atmosphere. Steam may be:

(a) Passed through openings into insulated curing chambers.
(b) Passed out through perforated pipes under cloches covering the moulds.

(c) Passed through hollow moulds.
(d) Passed through underfloor pipes in contact with the mould steel base plates.

A relatively new way of producing steam is to pass hot oil from an oil heater in pipes passing through troughs of water under the concrete in steam chambers or cloches. The steam formed passes its heat to the metal moulds and the condensate runs back into the troughs. Capitalisation costs on this system are more expensive than on steam boilers but can be written off at any early stage due to the low maintenance costs and the longer life expectancy of the oil boiler.

7.4.2 Steam injection

This process was publicised in the late sixties as being the answer to a lot of the practical problems associated with other forms of heat curing as well as being said to get over the detrimental effect on the 28 day strength. The system is that the live steam (about 105°C, 2–3 bar pressure) is pumped into the mixer and the latent heat of the live steam passes its heat to the mix and the condensate increases the W/C ratio to the design level. The principle is ideal in theory but poor in practice. The initial water content of the mix must be so selected that:

(a) The thermal conductivity of the mix is high enough to conduct the heat.
(b) The mix does not finish up too wet.
(c) The mix does not take too long to reach an optimum state.

Under strict laboratory-controlled conditions it has been found that a mix at 60–80°C can be produced in 5 minutes. If the initial W/C is wrong one ends up with a situation where the mix is either too wet at the right temperature or too hot at too low a water content. Mixing times up to 20 minutes have been found necessary when the aforementioned errors in mix design occur.

The 'hot concrete' system originated in Denmark and, at one of the originator's factories it was observed that small precast units were still being subsequently conventionally steam cured; only the very large units had enough thermal inertia to result in a reasonable curing cycle.

As far as practical site or precast works usage is concerned the system would be recommended only if very strict control obtained and there was no way of heating the water and/or aggregates. Conventional pan-type mixes can be modified to take steam injection and there is a proprietary mixer available designed for steam-injected concrete manufacture.

7.4.3 Electrical

Before discussing the practical and proprietary systems in use it is a good idea to dispense with some of the myths concerning direct-passage, electrically heating rebars or prestressing tendons. Most of these ideas materialised in the late fifties, but were thought up by people with little or no practical concrete experience. All such methods require a lot of power in the form of a low-voltage high-current supply and a heavy duty expensive transformer is the first requirement. Heavy duty cables and scrupulously clean connections are essential. Even if these conditions are achieved the passage of electricity along the reinforcing or prestressing never results in uniform distribution of heat. Stress raisers can be formed, the heat will try to pass through the concrete radially from the steel and the concrete surrounding the immediate vicinity of the steel hydrates and dries quickly. The wetness required for good thermal conductivity is not there as the water, both that required for cement hydration and the normal excess, migrates to the colder peripheral zones. There is also a danger in that over-heated prestressing wires or cables can lose some of their high tensile properties. Such methods of heating should not be considered.

A laboratory trial on a semi-electrically-insulated cube mould was undertaken by passing the current between opposite steel sides through the concrete. High early strengths were achieved but the supply had to be switched on and off to prevent over-heating. This method, although not very practical, is preferable to direct passage of current through the steel rebars or prestressing wires, but, again, a low-voltage high-current supply is required with all its attendant disadvantages.

However, there are other electrical methods that are practical and economic but these require different skills at work to those normally employed. Any systems using electricity require a high degree of knowledge of the system selected coupled with an awareness of the wiring by all working on the concrete.

Standard production units can avail themselves of proprietary systems of steel, timber or GRP formwork where electrically heated grids are built into the face. Alternatively, especially for non-standard sections or for cases where one wants part of the concrete to accelerate in strength gain more than the rest, disposable heating wires may be cast into the section. Not only have these electrical methods been proven to be economic but they also lend themselves to a thermo-control system more readily than steam methods.

7.4.4 Cement exotherm

This aspect has been fully discussed in Section 7.3.2; high early strengths can be achieved provided that the mould is well insulated and the free concrete face is covered with an insulator such as expanded polystyrene. Timber moulds are preferred for this sort of work but if steel moulds are used they must be insulated externally. Use was made of the cement exotherm in 'Sectra' construction, with the fresh concrete starting at 30°C. The free-face insulation was temporarily removed whilst power floating was undertaken. The units were stripped and handled satisfactorily at 15 hours with no significant deflexions being observed.

7.4.5 Others

Laboratory trials have been undertaken on autoclaving, very high steam pressure and, also, high temperature curing—all experiments being on cubes. Demoulding and testing by crushing was carried out at 2 hours old with good results. With larger units autoclaving would be a commercially viable proposition but the required production rate would have to be large to justify the expenditure on plant.

There have also been some trials on the use of infra-red and microwave methods of curing, but the former method only heats the surface and the microwave method requires expensive plant and is difficult to control because of its sensitivity to moisture content and gradients. It is felt that neither of these two methods would be viable for large precast units or *in situ* castings.

7.5 THE CURING CYCLE

This aspect is the most important part of any heat-accelerated system and the cycle one uses can either benefit or ruin a process. In selecting a curing cycle it should be borne in mind that concrete can stand a lot of temperature abuse whilst in its fresh plastic state. Therefore, one should concentrate on ringing the changes in the maximum temperature, the gradient through the section, the cooling rate and the conditioning throughout until the best conditions are found.

The exotherm of the cement, coupled (if also used) with the applied heat, will normally result in a temperature gradient across a section. The gradient from the walls of the section to the middle can either be positive or negative depending upon which method of acceleration is being used.

One establishes what can be tolerated by experience, and should not follow similar applications elsewhere too closely because the conditions are never identical. Excess temperature gradient is the common pitfall for accelerating curing techniques and once the maximum tolerance has been established the remainder of the exercise is relatively easy. The most important thing to bear in mind is that every application of accelerated curing is an individual one and it is best to develop it oneself using the guidelines given in Section 7.7, allowing for the particular conditions involved.

The discussion will now examine the criteria concerning heating rates, holding times and cooling rates coupled with the conditioning atmosphere.

First, concerning heating rates, there is a body of opinion supporting the theory that it benefits the ultimate properties to hold the concrete at ambient temperature for 1–3 hours before commencing to heat it. Experience in both Jespersen systems and in laboratory experiments indicates that this is not so. It is logical to assume that if one intends to apply heat one should do so as soon as possible whilst the concrete can be heated in its plastic stage. If the concrete has begun to set and heat is then applied, thermal stresses could arise if the heating rate became too fast. The concrete, immediately after compaction and finishing, may be heated at rates up to 20°C/hour to its maximum temperature position (compared with 15°C/hour in CP 110). A lower rate of 10–15°C/hour has been found necessary for lightweight aggregate concretes as they have a lower thermal conductivity, and too fast a heating rate caused a hard surface concrete with soft centres to form.

Once enough heat has been applied, the heating source should be either turned off or moderated; this stage is normally reached when the maximum temperature recorded in the concrete is 5–15°C below the maximum required. The cement exotherm takes over for the last 1–2 hours of the heating cycle and the design level is achieved. Relatively thin sections of concrete would have the heating moderated at about 5°C below the design maximum, whereas thicker sections would have the temperature moderated (viz. above 100 mm thick) at about 15°C difference. Thick sections have more cement reacting in them and have a higher thermal inertia and need a stricter control than thinner sectioned concrete.

The maximum design curing temperature is the second consideration and can safely be taken as high as 90°C depending upon the section size and geometry of the concrete being cast. The maximum may need to be reduced to 70–80°C when units with, for example, doorways, windows, return ledges, etc., are being cast. The time for which the maximum temperature is held is a function of the required strength and casting cycle time required. For overnight casting a holding time of 7–10 hours is of the right order, and for most curing cycles the maximum holding time constitutes about half the time of the total curing cycle.

Cooling rates are critical. To take a unit with a concrete surface temperature of, say, 80°C and place it outside in the cold can cause defects. Depending upon the unit being cast, cooling rates should generally lie in the range 10–20°C/hour, and temperature gradients should be 50–150°C/metre. In rapid cooling of a Jespersen precast unit with an A/C of 6·5, a centre temperature of 90°C, and a surface temperature of 35°C, cracking was induced. For a 150mm thick unit this is a temperature gradient of over 600°C/metre. It should also be borne in mind that moisture evaporates very quickly from a hot surface and the durability to weathering and atmosphere will be detrimentally affected. The mould or formwork together with the top face cover should be kept on as long as possible and, when stripped, the concrete should be covered with a membrane-curing compound, plastics sheet or wet hessian. Care should be taken in the latter two cases to avoid sweating and the subsequent unsightly lime bloom. The use of plastics covers outdoors can result in a greenhouse effect and hessian, kept wet, is preferable. The prime aim is to get the temperature of the concrete down to the ambient without causing distress.

Throughout all these temperature control and monitoring processes it is essential to control the relative humidity where a free face of concrete is exposed to the heat during the curing. Too rapid an evaporation rate at a low humidity will cause the surface to dry out and produce a concrete which has a permeable, poorly cured surface with a relatively poor durability; too wet an atmosphere will cause lime bloom, streaking and accelerated corrosion of fittings and formwork. Ideally, the relative humidity should be kept in the range 75–90%.

Maturity expressed as the product of temperature (above 0°C in these exercises) and time (in hours) can only be related to strength or any other property when the curing cycle details are known. For example a 1000°C hour maturity based upon a maximum temperature of 80°C will give different and higher early strengths and lower 28 day strengths than the same maturity from a maximum temperature of 60°C. All this accentuates the need for the designer to work out the best cycle for his own particular requirements. The guidelines given in Section 7.7 coupled with the practical need for a minimum demoulding strength at 28 days old are all that the designer needs to know.

7.6 TESTING AND INSTRUMENTATION

The relation between compressive and flexural strengths has been discussed in Section 7.3 and, although the flexural strength is the more critical in demoulding, handling, etc., it is the cube strength that is in the specification. If one is using cube strength as a guide there is a bonus for concrete 6–48 hours old as the ratio of these two strengths is 1/5–1/7 whereas at later ages the ratio is 1/8–1/11. Type tests, such as in cubes, are preferably carried out in a Temperature Matching Curing Bath (TMCB) coupled to thermocouples in the critical strength part of the concrete. Cube moulds kept in the same curing conditions as the larger products seldom give a correct indication of strength. In Jespersen system casting, large differences were observed for both cube and cylinder moulded concrete test specimens compared to their large neighbours.

Non-destructive testing with a rebound hammer such as the Schmidt Hammer has been found to be one of the most useful in accelerated cured concretes. One needs to set up one's own calibration curve using cubes cured in the TMCB. The ultrasonic method of measuring pulse velocity is not very good unless one is looking for hidden defects or studying the depths of cracks observable on the surface.

Proof tests up to a design, not a failure, load are the best that one can do, as the assessment is on the actual unit cast. A large test area and loading frame are required and there is no need to take the test to failure unless it has been decided who is to pay for the unit.

Temperature monitoring is easily carried out with cast-in thermocouples wired to a selector switch, multipoint recorder or similar device. The use of temperature monitoring in the trial runs is to establish:

(a) The maximum temperature and holding time
(b) Temperature gradients
(c) Likely hot or cold spots

The curing atmosphere needs to be monitored for temperature and humidity as the temperature relates directly to the temperature of the concrete and the humidity relates to the surface characteristics of any free concrete faces. One can programme the cycle on a temperature/time switch with feedback from the concrete thermocouples into the temperature control. The humidity would be held in a reasonable range by the use of humidifiers or condensers.

At Laing a computer service is in use where, knowing the type of cement, mix design, section geometry and concrete starting temperature both temperature during early hydration and early strengths can be predicted with a reasonable degree of accuracy.

7.7 GUIDELINES

These guidlines have been set out as a series of general rules and a table (Table 7.1) of the typical cube strength relativities under different curing regimes. The tabular data is purely for guidance and the strengths used for comparison purposes solely. The strengths obtained may obtain in particular cases but should not be taken as exact guides.

7.7.1 General Rules

A. Where free concrete faces are exposed to the accelerated curing atmosphere, maintain the relative humidity in the range 75–90% throughout the cycle.

B. Start with the concrete as warm as possible and ensure that all plant is warm at the start of concreting. Where hot water is used this should be added and mixed into the aggregates and the cement added as the final ingredient.

C. If the cement exotherm method of acceleration is to be used the formwork should be suitably insulated. In all cases the free face should be covered with a material such as expanded polystyrene sheet.

D. When heat is applied, start the heating as soon as the concrete is cast with the maximum temperature rise of 20°C/hour over the first 2 hours at least. Use lower heating rates for lightweight aggregate concrete.

E. Hold maximum temperature no longer than required to allow for the optimum cooling period.

F. The maximum temperature of concrete may be as high as 90°C but needs to be decreased when the materials or geometry demand it.

G. Cool at rates of 10–20°C/hour and temperature gradients up to 150°C/metre maximum.

H. Use chemical self-hardening mould release agents rather than the cheaper mineral or emulsion oils.

TABLE 7.1
CURING CYCLE COMPARISONS

Start temp. (°C)	*Heat (h)*	*Temp. (°C)*	*Hold (h)*	*Hold temp. (°C)*	*Cool (h)*	*Final temp. (°C)*	*Maturity, heat (°C h)*	*Maturity, hold (°C h)*	*Maturity, cool (°C h)*	*Maturity to 24 h (°C h)*	*Maturity total (°C h)*	*Cube strengths 24 h (N/mm²)*	*Cube strengths 28 day (N/mm²)*
10	4	25	12	30	2	20	70	360	50	110	600	4	45
10	6	35	10	40	3	25	135	400	100	135	770	7	43
10	8	50	8	55	4	30	240	440	170	100	950	10	42
20	4	40	12	45	3	25	120	540	80	110	850	10	42
20	6	50	10	55	4	30	210	550	170	100	1030	14	39
20	8	45	8	70	5	35	340	560	250	80	1230	18	36
30	4	55	12	60	4	30	170	720	180	100	1170	15	37
30	6	65	10	70	5	35	290	700	260	80	1330	20	34
30	8	80	8	90	6	40	440	720	390	80	1630	25	33
40	4	70	12	75	5	35	220	900	280	80	1480	20	35
40	6	80	10	90	6	40	360	900	390	60	1710	25	33
40	8	95	8	105	7	50	540	840	540	40	1960	10	15

I. Surface retarders should be volatile solvent-based compounds and designed for hot concrete work.
J. Assess admixtures under the proposed curing cycle and do not be misled by data based upon normal temperature work.
K. Be careful of products which have protruding ribs, or units with windows or doors in them. These should be cast in steel formwork as its thermal characteristics are similar to concrete as regards temperature movement.
L. Be prepared for changes in raw material supply—regular testing should be combined with the constant monitoring.

7.7.2 Relativity of compressive strengths

The data are abstracted from Laing R+D and factory research, with interpolation and extrapolation, and are shown in Table 7.1.

It is assumed that the same mix is used throughout and, therefore, the comparisons are between the different cycles.

It may be seen that:

(a) Maturity relates to the early strength (24 hour) but not the 28 day strength.
(b) Maturities up to 1500°C hour at 24 hours old based upon 0°C as the zero may be employed without detrimental effects upon the maximum temperature and the early and late strengths.
(c) Exceeding 90°C concrete temperature causes loss in both the 24 hour and 28 day strengths due to the concrete becoming too hot and losing water.
(d) Increasing early strength by accelerated curing can result in decreases of up to 25% of the 28 day strength.

BIBLIOGRAPHY

A.G.A.SAUL, *Principles underlying the steam curing of concrete at atmospheric pressure*, Research Note Rp. 3 (12/50), Cement and Concrete Association, 1950.

M.S.THOMPSON, *The heat treatment of Jespersen concrete*, Jespersen Congress, Fredensborg, 1966.

CP 110, *The structural use of concrete*, Pt. 1, Materials and workmanship, BSI, 1972.

B.SADGROVE, Technical Note No. 12, Construction Industry Research and Information Association, UK, 1970.

8

PROPERTIES AND PERFORMANCE

Since any single property will relate to one or more performance characteristic and vice versa it has been decided to place the whole in the one chapter even though the exercise proves rather extensive. In this respect caution should be exercised that single characteristics and properties are not read out of context. It was emphasised earlier that 'getting everything right' results from a combination of technical 'know-how' and the 'alchemistic' art of getting all the variables within specified boundary conditions. A superlative attainment in a property often lets a performance characteristic go adrift.

In the following sections, properties and performance of precast concrete products are discussed in the fullest way possible. A lot of what follows is basic common sense but needs to be considered in detail as all too often a particular property or performance attracts too much consideration and other aspects become overlooked.

8.1 STRENGTH

This is probably the property that attracts attention most commonly, yet is the least necessary to worry about because the high early handling strengths required in precast production virtually always guarantee that all but the most severe specifications will be attained. Precast products are more reliable than their *in situ* relatives because the product, *per se,* is generally what is subjected to test (proof test) and not a cube or cylinder made from the same mix (type test). Even large units such as panels, beams and columns can be subjected to proof load tests without taking them to destruction. On the other hand low-cost products such as bricks, blocks, paving slabs, kerbs, tiles and small diameter pipes can be tested to destruction, as their value is small compared to the test cost.

International Standards commonly specify bending tests, and only in the case of type testing does cube or cylinder crushing or splitting come into the picture, and only for bricks and most blocks are proof compressive tests specified. Taking this view to a logical extreme, what compressive strength means by itself is that if, for an example, one had a 40 N/mm^2 concrete in a construction under pure compression it could support 1 km of concrete. This is why flexural strength testing is commonly specified; because it relates more closely to handling and structural requirements than taking a compressive strength figure and dividing by ten or some other factor that is thought to relate to a flexural, shear and tensile property.

Proof strength tests, be they flexural or compressive, are obviously those which provide one with meaningful numbers. Provided that the test is undertaken strictly (implicitly) to the required National or International Standard the producer can build up basic data on which simple numerical or statistical control systems can be devised. Whether these be based upon the occasional single strength test (e.g. cladding units) or daily or weekly tests (e.g. blocks) is irrelevant. One obtains an immediate piece of data which tells the manufacturer, for example, whether:

(a) The product complies or not with the specification.
(b) The product strength relates or does not relate to the cube or cylinder strengths.
(c) There is a variation that relates to the supply of one or more of the materials in use.
(d) There is a variation that relates to some change in works plant and/or personnel.
(e) There is a variation that relates to one production shop compared to another.
(f) There is a variation that relates to changes in the curing régime.

Type tests such as those on cubes and cylinders are different. Only if the mould used is within the specified tolerances, and the concrete made to the relevant specification and cured identically to the product does one get a result that will be the same as that from the concrete. In the vast majority of cases the cube or cylinder strength gives a value that can be best described as a potential strength, i.e. if one obtains a particular cube or cylinder strength one can get the same product strength. Questionable cube or cylinder results, usually low ones, should not cause panic as they often do in *in situ* work, since there are so many things that can be done wrongly in the manufacture and testing of a type sample. It is imperative to examine the moulds, method of manufacture and the testing procedure before deciding that there is a case for testing the product.

There is a tendency in many countries to move away from type testing to proof testing and Fig. 8.1 typifies computer-controlled testing used daily either for proof-load or destructive testing of prestressed extruded floor planks. This particular precast concrete manufacturer has both his works and laboratory subjected to quarterly national inspection for approval for registration as one of assessed capability. Admittedly the cost of having such a facility is high; but it is considered that this will be the norm by the end of the century, in that product control specifications will be such that production will have to be more consistent and that the level of rejects will need to be less than that presently permitted or countenanced.

Relationships between strength and density, durability and other performance characteristics have been researched and written about in too large a number of articles and books to be abstracted in this book. If one can answer the simple question of 'why is the strength specification x?' in all honesty, then one has gone a long way to understanding what

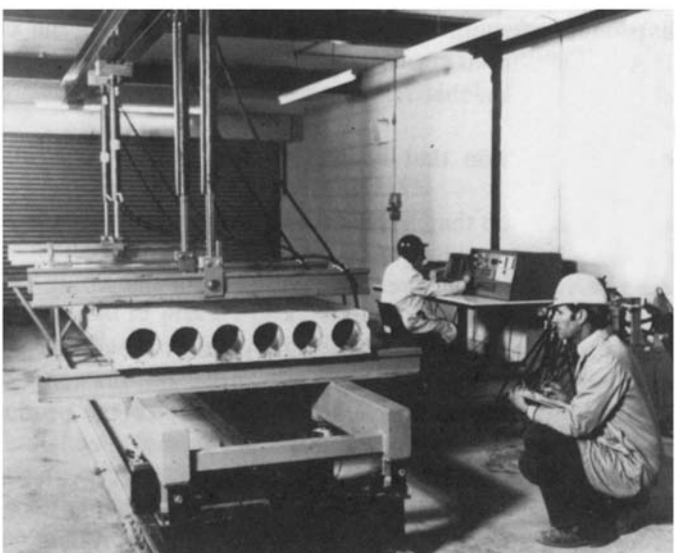

Fig. 8.1. Computer-controlled testing of prestressed extruded floor planks.

the subject is all about and need not consider the strength figures as individual absolutes. Density only relates to strength provided that aggregate and cement specific gravities always remain the same, but they vary by slight amounts, batch to batch, and the variations reflected in the concrete density are not sensitive enough to relate to strength differences. Probably denseness rather than density would show a better relationship but there is no practically acceptable way of measuring this. Strength, *per se,* relates either directly or inversely to many other properties that could well be relevant to the performance of the product, viz. (respectively) ultimate stress and durability to weathering on the one hand and impact resistance and ultimate strain capacity on the other hand. This points to other than economic reasons for aiming for a strength range rather than a minimum or characteristic value. As the reader has been advised earlier in this book, concrete will be made and perform well if one accepts the boundary conditions and the resultant compromises.

Non-destructive testing has been in vogue for many years. In such testing it is essential to bear in mind that findings are indicative rather than conclusive. Rebound Hammer or Schlerometer tests are the best established for strength determination. The accuracy is only approximate for an unknown concrete but particular calibrations for cubes or cylinders up to 3 months old give much more accurate comparisons for that particular concrete. The type sample can be tested whilst it is under a slight load in the testing machine. The use of the rebound hammer without a calibration for the specific concrete can give a poor idea of strength. The results need to be quantified by either testing that product or a core cut from it. The ultrasonic pulse velocity test is only suitable for studying product concrete consistency, discontinuities, cracks and crack depths and is not reliable for strength determination other than determining Poisson's ratio and/or *E*-value (Young's modulus) to a reasonable accuracy. Concerning the pull-out tests, quite a lot has been published but none of the evidence gives grounds for confidence. The behaviour of an expanding bolt driven into a hole is very sensitive to aggregate shape and size and the correlations produced are not as good as the rebound hammer in use on an unknown concrete.

8.2 IMPERMEABILITY

This is probably the most important property of concrete because on it depend the majority of durability risks and aesthetic aspects. Yet it only receives the minimum of attention in Codes and Standards, largely because of a general philosophy that there is a relationship between strength and impermeability. Such a relationship might well hold for the odd example but it is best to treat this as a concrete property in its own right.

Before proceeding into detailed discussion 'porosity' should be briefly discussed, and this is the last time this word will be mentioned. A porous material is one which has pores in it; these pores may be isolated or connected. In the latter case the porous material becomes a permeable one. This, in effect, means that a porous material may be completely impermeable. Since any concrete has an interconnected capillary and pore structure it is permeable and its resistance to a large number of durability hazards may be measured by its impermeability. There are three basic test methods for determining this property.

8.2.1 Initial Surface Absorption Test (ISAT)

This is not a true permeability test as it measures the rate at which water goes into concrete at a given time from the start of the test. It only becomes a true permeability test when either the test is carried on for a long while or the concrete is very permeable or thin in section, such that water egresses out of the other side. Nevertheless it has been proven to give results related to natural weathering, freeze-thaw attack and marine exposure and is specified in a UK method of test as well as in the Standard for Cast Stone. It has also been invoked in contractual documents for both precast visual concrete as well as 'fair-faced' *in situ* work. What the test picks out as a number is the combined effect of materials, manufacture and curing; no other test is known to be able to do all this at the one time.

The mechanism of a fluid travelling into and through the tortuous capillary structure that makes up concrete can be derived from the Poiseuille equation for a liquid travelling through a single capillary tube (cgs units):

$$\frac{dv}{dt} = \frac{\pi \, Pr \, 4}{8 \, L\eta} \qquad (1)$$

where dv/dt is the volume flow rate, P is the applied pressure, r is the capillary radius, L is the capillary length, and η is the viscosity.

When the ISAT is undertaken P is the applied pressure of a 200 mm head of water; the depth of ingress and the capillary attraction pressure are given by (cgs units):

$$\gamma = \tfrac{1}{2} \, rdhg \qquad (2)$$

where γ is the surface tension, d is the density of the liquid, h is the capillary suction height, and g is the acceleration due to gravity.

Since the average capillary size in concrete is of the order of a few micrometres it can be seen that once one wets the surface of concrete the attractive pressure is in metres, h in eqn. (2) becomes the predominant part of P in eqn. (1) and can be assumed to be fairly constant along with r and η.

This gives
$$\frac{dv}{dt} = \frac{b}{L} \quad (3)$$

where b is a constant. Since L is proportional to the volume of water in the capillary the equation can be integrated and substituted giving:

$$\frac{dv}{dt} = at^{-0\cdot 5} \quad (4)$$

i.e. for a single capillary tube permeability will decrease as the inverse of the root of the time. It has been found that most concretes follow the rule where:

$$\frac{dv}{dt} = at^{-n} \quad (5)$$

where n is constant for one concrete but varies from concrete type to type in the range 0·3–0·7. The 0·3 is a slow decay and is indicative of a cleaning or a flushing process one can associate with a deficiency in very fine particles. The 0·7 is a rapid decay and indicates a silting up and capillary blocking process.

Open-textured and honeycombed concretes cannot be tested by this method but the vast majority of precast products can be so tested. The apparatus is simple to make and use and requires about 10 hours assorted testing for training. The cap containing the water with reservoir and capillary tube feeds may be clamped to a product as shown in Fig. 8.2 or stuck to the product on the building as shown in Fig. 8.3. Apart from a grease or modelling clay seal mark on the concrete, and the fact that one cannot test in the same place twice, the test is non-destructive.

8.2.2 Absorption Test (AT)

In this test either the whole precast unit or a sample cut from it is oven-dried, cooled and placed in water for a specified time and its percentage weight gain measured and recorded. The test is very simple but has several drawbacks:

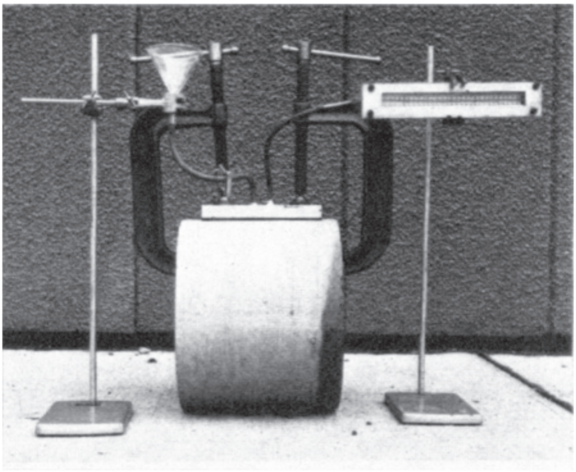

Fig. 8.2. ISAT on a pipe.

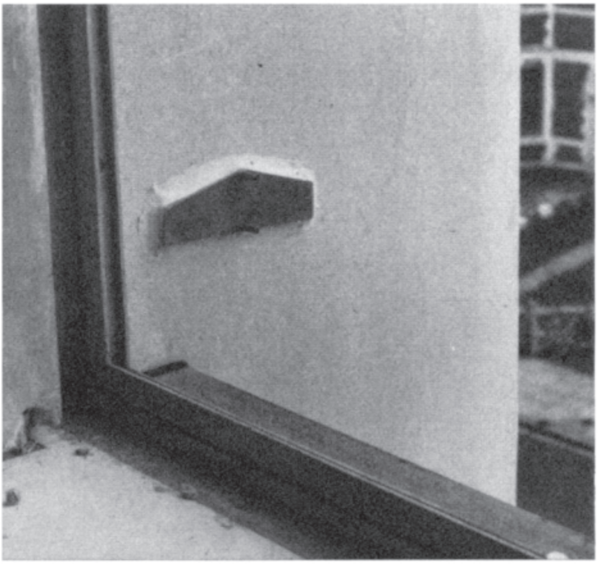

Fig. 8.3. ISAT on a precast mullion.

(a) The cut sample weighs 1–2 kg and the accuracy of weighing is 1 or 2g and thus the closest one can record is 0·1%. A 30 minute figure can range from 1·5 to 4·5% from the best to the worst of the concretes subject to this sort of specification, and one has to draw a line somewhere within these 30 increments.
(b) The sample preparation requires sawing and the water lubricant accompanying this will have beneficial additional hydration and curing properties.
(c) Few Standards specify the depth of immersion and the highest results are obtained with the top face of the sample almost flush with the surface, thus letting air escape. High-depth immersion causes an air pocket to be trapped which is extremely difficult to displace.
(d) Some Standards specify a 24 hour immersion or a 0·5–1·0 hour boiling water immersion. The 24 hour test produces a rather meaningless figure which does not relate to performance, and the boiling water test can produce highly variable results within a batch of replicate samples.
(e) Short-term tests taken at, say, 5–10 minutes from the start give widespread results because at this time dry concrete is picking up water rapidly and a few seconds deviation either side of the specification time can upset the result.
(f) The sample, on removal from the water, has to have the excess water removed from the surface with, preferably, a damp rag. This can also affect the result depending upon how damp the rag is and how long one takes.
(g) Some people argue that concrete dried at 105°C is not the same as the original concrete less its free water because there will be an effect on the cement gel. The author takes no stand on this issue; suffice it to say that if the result is relative to a standard specified figure, where a particular concrete dried at 105°C will generally give the same absorption, then this is probably good enough.

If an absorption test is to be in a specification it should refer to a 0·5–1·0 hour figure and be quite specific regarding the method of preparation of the sample throughout the test regime.

8.2.3 High pressure water test (HPWT)

This is often undertaken as an academic test or exercise, as there are few laboratories equipped to do it, and the results relate to a cement gel permeability or D'Arcy coefficient. Tests undertaken at pressures of the order of several atmospheres would be liable to break down capillary wall and pore structures that never would have been affected by the worst of durability risks. It would only be for the rare cases of precast concrete products used in deep-water-retaining structures or at great depths in the sea or lakes that the test data would possibly relate to a performance criterion. Even so a pressure of a maximum of 10 atmospheres would represent most of these risks. A study of the effect of the pore structure of concrete by high pressure fluids would make for a long and interesting programme.

8.3 AESTHETICS

Appearance, architectural impact, visual effect, or whatever term one wants to use are all subjective matters, but they are the bases for no end of arguments in visual concrete contracts as well as with other contracts where one would think the appearance did not matter, e.g. pipes, kerbs, etc. In order to try to introduce a little scientific understanding a number of sub-sections have been drawn up in an attempt to explain the various factors in as coherent a fashion as possible.

8.3.1 Surface appearance

It is in all parties' interests to produce samples reflecting all the variables likely to be encountered in the manufacture. This will enable one to establish boundary conditions as to what are the upper and lower limits on, for example (all on a unit-to-unit and within-unit basis):

(a) Colour variation.
(b) Blowhole size and distribution.
(c) Aggregate depth of exposure for exposed aggregate.
(d) Aggregate spacing.
(e) Aggregate colour and distribution.

The manufacturer should not mislead either himself or the client or his representative in producing samples that he stands no chance of achieving in the full-sized units.

Having achieved an acceptable product on site or on the structure the keen eye will still be able to pick out some variations which, although acceptably within the agreed sample variations, might still give cause for aesthetic concern. It cannot be stressed too strongly that new products on a structure should never have any treatment undertaken on the faces unless it is absolutely essential. After 3–6 months on site concrete loses its newness of look and tones in to an acceptable appearance. If one wants to record the weathering performance of the surface of the concrete it should be done at night time under standard photographic flash conditions and positions. This avoids day-time comparisons during which sun, cloud, rain and shadow effects can give a dubious standard of photograph.

It should be borne in mind that once concrete products are built into a structure there are numerous factors that can cause changes in appearance, and the science of detailing a construction coupled with a knowledge of the environment will jointly help in achieving a pleasing construction. The following are a few of the factors that affect the weathering appearance:

(a) Run-down of rain and dirt.
(b) Elevation to rain, shade, sun, wind, etc.
(c) Micro-meteorological local effects due to height, adjoining buildings, and, particularly, geometry of construction.
(d) Lime bloom on the surface.
(e) Discoloration due to other building components.

With a lot of thought and commonsense virtually all these problems can be overcome, with the proviso that the designer must also work within strict boundary conditions. The following recommendations are intended as a set of guidelines:

1. Avoid fair-faced or smooth concrete faces wherever possible. These are the most difficult to make consistently and the easiest on which to see variations.
2. If such a finish is required the specifier should realise that the use of top quality moulds, release agents, materials storage and works control in manufacture and curing will have to be paid for.
3. Visual concrete should be either exposed aggregate or profiled finish.
4. Where it is exposed aggregate, the aggregate should have at least 65% of its volume in the mortar matrix.
5. Where it is profiled a vertical accentuation is the most beneficial, as the staining and dirtying occurs within the shadows.
6. Avoid designing flush facades of window and concrete. Concrete exudes alkali and lime and unless the facade is designed to shed water away from the glass, etching will occur.

7. Plug scaffolding in wet and/or windy climates as rust or organic residue can blow through the tubes and stain the face.
8. Protect concrete against *in situ* concrete run-downs, bitumen spillage and sealants, etc.

8.3.2. Staining agencies

In addition to rust, bitumen and organic residues concrete is subject to other staining sources such as copper, aluminium, zinc and algae or lichen growth. Most chemical stains can be removed, or mostly removed, by standard chemical treatments, and this includes graffiti. The organic growth of algae, moss and lichen is a different matter and although they can be removed the conditions that caused their growth in the first place are likely to remain. Such growth generally relates to a mediocre quality concrete and, having removed the growth by one of the approved methods the concrete should be treated with a silicone, acrylic, polyurethane or similar treatment that keeps the moisture out but still permits the concrete to breathe. It is considered that painting precast concrete products should not be necessary. Such a need points towards a lack of thought somewhere in the design, workmanship and/or choice of materials. The only paint application should be where the product needs to resist an environment where even the best of concretes would degrade, viz. settlement tanks, acid vats, railway inspection pits, etc. The architectural use of paint means that the concrete is not being used in its own right.

Assuming various mistakes have been made in the construction, and that stain removal is required, the following abstracts from the literature (see Bibliography) describe methods of removing stains.

8.3.2.1 Rust stains

Dissolve 1 part of sodium citrate in 6 parts of lukewarm water and add 7 parts of lime-free glycerine. After mixing thoroughly, take a small quantity of whiting or kieselguhr and moisten it with the solution to form a thick paste. Spread the paste onto the stain with a trowel and scrape it off when it has dried out. The treatment is repeated until the stain has gone, and the surface should then be washed thoroughly with clean water.

If this method does not procure the desired result the following treatment is usually effective. Dip some cotton wool in the sodium and water solution already described (without the glycerine) and place this on the stain, leaving it there for about half an hour. Make a stiff paste of whiting or kieselguhr and water. Take a flat slice of this on a float or trowel, sprinkle some hydrosulphite crystals over it, moisten it with a little water, and (after removing the cotton wool) press the paste onto the stain, leaving it there for about an hour. The process may be repeated if necessary, but in most cases one application is sufficient. When the stain is removed, wash the surface thoroughly with clean water.

8.32.2 Tobacco stains

Dissolve 1 kg of tri-sodium phosphate in 8 litres of water. Then, in a separate vessel, make a stiff smooth paste of about 300 g of chloride of lime and water, taking care that no clots are left in this mix. Pour the tri-sodium phosphate solution onto the chloride of lime paste and stir well until both are thoroughly mixed. Allow the chloride of lime to settle at the bottom. Draw off the clear liquid and dilute it with equal parts of water. Make a stiff smooth paste of this and powdered talc, and apply in the same way as described under rust stains. Stains caused by urine can be removed by the same method.

8.3.2.3 Smoke stains

Make a smooth stiff paste of tri-chlorethylene and powdered talc, apply it to the stain as already described, and cover it with a piece of glass or other non-absorbent material, since the tri-chlorethylene evaporates very quickly. If after several applications it is found that no further improvement is apparent and that a slight stain is still left, remove every trace of the paste, allow the surface to dry thoroughly, and then use the method described in Section 8.3.2.2. Care should be taken when working with tri-chlorethylene as the fumes, if inhaled for some time, act like chloroform. If the mixing is done in a room, provision should therefore be made for a constant current of fresh air.

8.3.2.4 Copper and bronze stains

It is often found that the cast stone bases of monuments and statues are disfigured by green or brown stains. Stains of this type can be removed by the following method. Mix 1 part of ammonia with 10 parts of water. Then thoroughly mix 1 kg of powdered talc and 250 g of ammonium chloride in their dry state. Make a smooth stiff paste of these mixtures, and spread this over the stain at least 10 mm thick. Allow the paste to dry out, scrape off, and wash the surface with clean water. Repeat the application if necessary.

8.3.2.5 Ink stains

Dissolve 250 g of chloride of lime in 2·5 litres of water. Allow the solution to stand for 24 hours or until the chloride of lime has settled at the bottom. Pour off the clear fluid and strain it through several thicknesses of clean cloth. Add to it 15 g of 24% acetic acid. Soak a piece of flannel in this, place it on the stain, and cover it with a piece of plate glass, slate, or other impervious substance. If the stain has not disppeared when the paste has dried out, the application should be repeated.

8.3.2.6 Mineral oil stains

Make a smooth stiff paste with powdered talc and tri-chlorethylene as described in Section 8.3.2.3 and apply in the same way.

8.3.2.7 Stains from linseed oil, palm oil or animal fat

Proceed as described in Section 8.3.2.6. If, after repeated applications, the stain is still visible to some extent, apply the ammonia paste described in Section 8.3.2.4 and repeat this until the stain has gone. Then wash the surface with soap and water, and finally with clean water. If any trace of the stain is still left use the following method. Mix thoroughly 50 g of tri-sodium phosphate, 35 g of sodium perborate, and 150 g of powdered talc in their dry state. Dissolve 500 g of soft soap in 2·5 litres of very hot water, pour this solution onto the dry mix, and stir thoroughly. This will make a stiff paste. Trowel some of this paste onto the stain, leave it there until it has dried out, and then carefully remove it. Soak a piece of flannel in a mixture of equal parts of acetone and amyl acetate and place it over the stain. Cover with a piece of plate glass to prevent quick evaporation. The procedure may be repeated if necessary, always thoroughly drying the surface before repeating the application.

8.3.2.8 Bitumen and asphalt stains

Make sure up a poultice of powdered talc and petroleum spirit or tri-chlorethylene and leave on the stain for at least 10 minutes. Repeated applications will be necessary. It sometimes helps to freeze the surface of the affected area first with ice or solid carbon dioxide so that thick deposits may be mechanically removed before using poultices.

8.3.2.9 Timber stains, algal and fungal growths

Make up a 10–20% solution of household bleach and brush into the surface. Timber stained areas may be washed after a few minutes but organic growth areas so treated should be left for a few days before cleaning and scrubbing the surface.

8.4 SITE HANDLING AND USAGE

With a good deal of sense 90% of the site problems that occur with precast products could be avoided, and the bad name that good quality products acquire through no fault of their own would not obtain. Based upon his personal experience the author has set out a number of guidelines relating to various products.

8.4.1 General site conditions

Site conditions can vary from tidy to uncomfortable. Good access and site roads or stabilised soil tracks are necessary for transport, site accommodations and storage. If all precasters put a little contractual clause in their quotation and delivery note to the effect 'delivered to site and unloaded on good hard standing' it would place the responsibility where it should be. If a contractor is operating under bad conditions the full responsibility for damage occurring during the site access of the precast concrete manufacturers' transport, and during loading or storage on site, will rest on the contractor. The amount of damage and wastage that occurs on building sites is still far too high and it has been calculated for the UK that this daily level is equivalent to building at least two houses in total value.

A site schedule of plans of operations should indicate, *inter alia:*

(a) When products are to be delivered.
(b) Where they will be stored and how.
(c) When they will be used in the construction.
(d) When cranage will be required to offload delivery trucks.
(e) When cranage will be required to place units in the construction.
(f) What spreaders, loops and lifting devices will be required.
(g) What form of site sub-transport will be required for non-cranage journeys from the stockpile.

8.4.2 Structural beams, columns, planks

Reinforced units will generally be delivered on a wooden stillage with the fillets placed at fifth points (for uniform section) and dead in line with each other in the vertical direction. Chain or rope restraint will generally be necessary to stop the units bouncing, and chains or other metal devices should be bandaged or similarly covered where they contact an edge in order to inhibit rubbing or spalling, and not as in Fig. 8.4. Units should be stored on site on a good hard standing with supporting fillets as above. Lifting should be undertaken using a spreader beam so that the lifting loops are vertical. For columns, normally delivered as beams, one has to turn these into the vertical position and lift from the top end. Foamed rubber mats, mattresses, etc., may be used to protect the lower end as it rotates through the ninety degrees.

Prestressed units are generally picked up from their ends, and as most of these are hollow, inserts may be placed in the holes and trucks off-loaded onto site. It is more often than not best to stock these on fillets at their ends so that sufficient clearance for the lifting loops is available. Such units are generally delivered flat in concrete to concrete contact. Restraint for transporting is as for reinforced concrete units. Special care is necessary with extruded concrete planks when the impermeability of the top face as cast is in question. If these top faces allow water ingress, the products, both when transported and when stored on site should be protected, and the minimum of water allowed onto them during the construction. It is also of benefit to have holes drilled into the voids at the soffit lowest points to permit drainage.

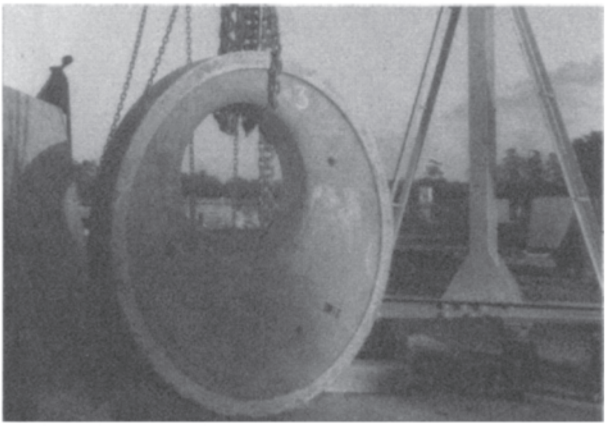

Fig. 8.4. Lifting with unprotected chains.

8.4.3 Cladding panels

Visual concrete units need all the care they can be given; even with the best site planning, as shown in Fig. 8.5, damage can occur as seen in Fig. 8.6. Flat transport should be avoided as vibration damage and batten staining can result. Units are best transported and stored on tailor-made A-frames taking care that all restraint chains, ropes, shackles, etc., are protected at chafing positions. The storage site selected should be well clear of all roads, splash zones, etc., and be within easy and capable reach of the crane, be it a mobile, rail or tower type.

Spreader beams should always be used. Lifting and cast-in sockets should be plugged and well-oiled to avoid water pockets and staining. When units are leant one against the next, proprietary spacer blocks or corrugated plastic padding may be used to allow visual faces to breathe and avoid staining. Allow for low bridges in the planned transportation route.

All fixings, be they support or restraint, should be detailed well beforehand and torque spanners and other fixing tools should be readily available. Where there is a choice of the way cladding is to be fixed to a frame, it is contractually easier to select floor-hung rather than floor-supported units. Allowance should always be made for moisture and thermal movements relative to the temperature of the relatively inert

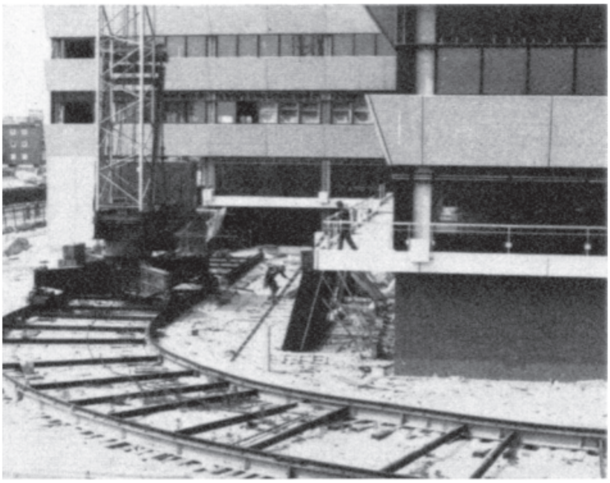

Fig. 8.5. Cladding construction.

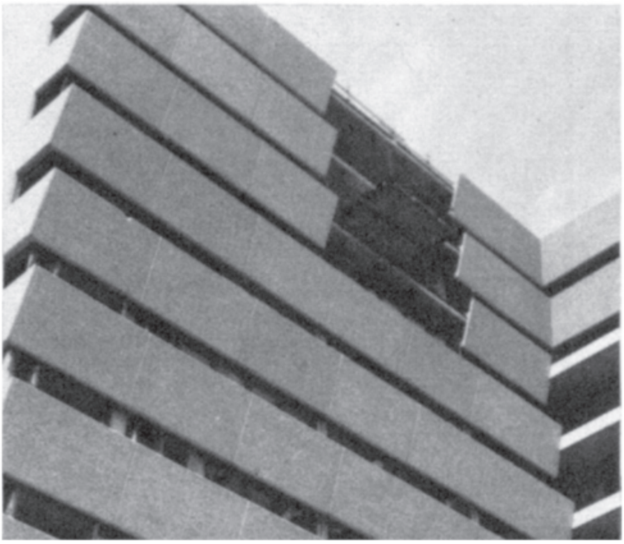

Fig. 8.6. Cladding on site showing spall damage to panel.

material of the main construction. Compressible jointing materials may be used in horizontal joints quite easily but pre-placed materials of this nature can cause difficulties in-vertical joints. Although soft to finger pressure, a joint 1–3 m high or higher requires a lot of pressure to close it up to the design position and the method used to achieve this horizontal movement can result in damage to the panel.

8.4.4 Cast stone, floor tiles and delicate units

These are best packed in crates with straw packing or similar. When straw is used the wheat variety is preferred to corn, maize or barley as it has less staining capacity. Truck loads should be covered to protect the products from rain and dirt and it is also best to put them under cover on site without using polyethylene drapes as these encourage condensation and lime bloom. Cast stone products should not contact the soil as they will attract moisture and dirt by capillary action. Other site protection requirements should be as described in Section 8.4.3.

8.4.5 Kerb and channel

Products of this nature are best transported flat in contact with each other. They may be transported as individual units or polyethylene shrink-wrapped or steel taped into groups. In the latter two cases they are best transported on returnable wooden pallets so that movement by fork lift truck or crane scissors on site is made easy.

The deployment on site is where the main troubles arise and if the following recommendations are followed defects will be minimal:

(a) Bedding and backing of kerbs should be with concrete of the specified depth and width with a characteristic strength of 25 N/mm^2 as a minimum. Figure 8.7 shows what happens to kerbs if they are not bedded properly.
(b) The joint width should be that of a trowel blade and left unfilled. Butt jointing causes stress raisers as shown in Figs. 8.8 and 8.9, as do

Fig. 8.7. Badly bedded kerbs.

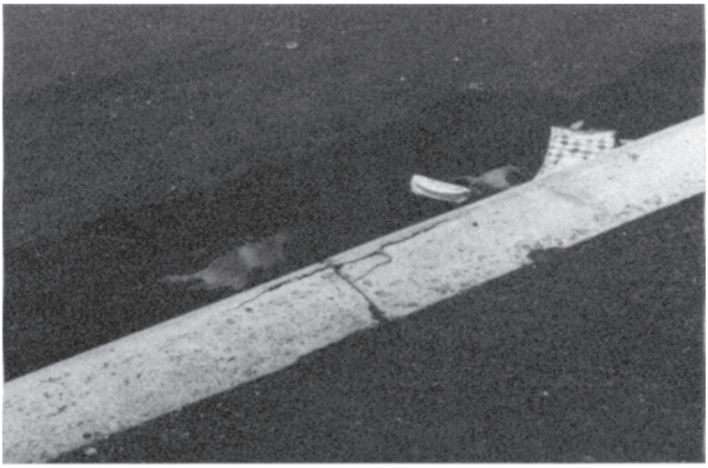

Fig. 8.8. Stress raiser in butt jointing of kerb.

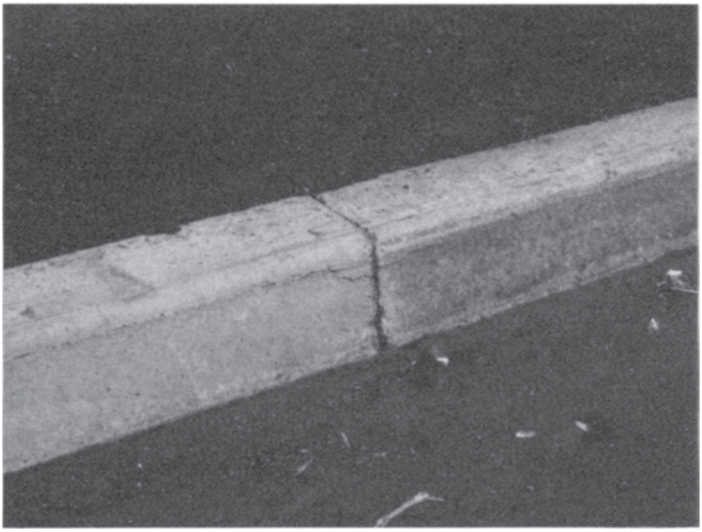

Fig. 8.9. Stress raiser in butt jointing of kerb.

wide joints which allow stones to become trapped. Figure 8.7 also shows this manifesting itself through delamination.

(c) Lateral movement joints in a concrete road should be continued through the kerb joint and haunching so that each section of road and kerb can move as an individual section.
(d) Kerbs laid on a steeply sloping road should be restrained by concreted-in mini-piles driven into the ground at 5–15m spacing. This prevents the kerbs creeping down the hill.
(e) Kerbs not made by hydraulic pressure or extrusion, viz. gulleys, garage drive entrances, etc., should be vibrated and air entrained.

8.4.6 Paving slabs

These are best transported and stored on their edges. Where shrink-wrapped or taped they can be treated as for kerbs. Maintenance is kept minimal if:

(a) The sub-base is dry-lean concrete or roller compacted cement-stabilised soil.
(b) The bedding is a weak but full-fill sand/cement mortar.
(c) Joints are 5–10 mm wide and full-filled with a 3/1–4/1 mortar before offering up the next slab.

(d) Expanses such as patios have control joints to take up movement so that the expanse is divided up into 10–15 m squares.
(e) Slabs used on inverted roofs are made to strict thickness and twist tolerances and located on supports round their periphery to avoid rocking under pedestrian or wheeled traffic. Joints will generally be left open to allow for drainage.

8.4.7 Pipes

Truck carriage will generally be with the pipes in the orientation as laid. Particular geometries such as spigot and socket pipes and flat-based pipes may need wooden or similar plank packers between rows. On arrival on site they should not be pushed or rolled off the back of the truck onto the ground. Cranage with special lifting devices will be necessary and if stored on site they should be stacked in a similar way to their stacking on the truck, ensuring edge wedging is used if necessary.

In the trench the shoring should allow for the length of the pipe to be placed and a prepared base of concrete or gravel should be ready to receive the pipe.

When jointed and laid, backfilling should proceed by careful filling with stones to cover the pipe run, before filling up with the spoil Heavy impact should be avoided at all times. Pipe joints should be lubricated with clay or bentonite before fitting O-rings or baffle joints, and care should be taken to avoid distortion when offering the next pipe to the run. Mortar-jointed pipes should be mortared on the receiving joint first before offering up the next pipe, and excess mortar cleaned away.

8.4.8 Blocks

These may be transported in the as-laid position, either as individual units or in wrapped stacks as for kerbs and slabs, in which case they may be treated likewise. Storage on site should be on a good hard standing and stacks should not be dangerously high. Visual concrete blocks should be protected on site as for cladding.

When building blocks into masonry an appropriate building code should be observed. This will give the builder complete guidance on the type of mortar, positions of control joints, fixing ties and frame restraint. Proper construction not only ensures good performance from the structural or aesthetic viewpoints, but also for the functions of sound insulation and fire resistance.

8.4.9 Roof tiles

These are best transported and stored on edge and even if shrink-wrapped they generally involve a manual handling operation. Storage on site should be on concrete or protected hard standing to avoid staining from the ground. Tiles may be stacked row on row, but these should not be more than 4 rows high on site; and the tilting of the tiles in each row should be as a run resting against a rigid support or a split row with two runs of the tiles sloping in opposite directions. In the latter case the tiles should be removed fairly equally from either end as required so that the horizontal opposing force components are more or less equal.

8.5 DURABILITY

This is a word that means many different things to different people but may be simply defined as 'the ability of being able to perform in the manner expected under the expected conditions and predicted lifetime'. No matter what material one talks about it can be seen that the word 'durability' and, in particular, the phrase 'durable concrete', have no meaning unless one qualifies the situation. Since there are about a dozen variables either inherent in the concrete itself or its environment or the combination of them both it is best to deal with each of these as a separate entity. Their order of presentation is such that the in-concrete durability hazards are dealt with first and the environmental ones later.

8.5.1 Permeability

The very nature of concrete results in a product that has a capillary and pore structure and this can vary from well under 1% v/v to well over 20% v/v depending upon the concrete product under consideration. Whether this property be measured by an Initial Surface Absorption Test or an Absorption Test (see BS 1881, Pt. 5) is irrelevant so long as one has a meaningful number to use as a quality index. The strength of concrete is only relevant to structural and handling requirements and relates but little to most of the durability risks. This subject will come up again in many of the following discussions and the only point that needs to be made here is that one should not specify a value unless one understands the relationships between permeability and the stated risk. In addition one should never specify strength as any durability criterion when all-embracing relationships are impossible to prove.

8.5.2 Corrosion of reinforcement

This is generally a combined effect of the concrete and its environment, but achieving durability in the form of corrosion resistance is basically a function of the concrete. Books, articles and papers abound on the subject and rather than summarise all these, a few words based on experience together with some abstracts from other works should be found helpful.

For corrosion to occur three conditions must all obtain:

(a) The pH round the steel must be less than 9 so as to depassivate the surface.
(b) There must be moisture present.
(c) There must be oxygen present.

The (a) is generally dealt with in Codes and Standards by specifying a minimum cover; but cover is treated reverently by too many people. With weathering, the surface of concrete carbonates or de-alkalinises and this can reach into the concrete to an asymptotic depth of 0·2–3·0 mm after 20 years exposure for impermeable grades of concrete, 2·0–30·0 mm for mediocre concretes, and through the complete section for very permeable concretes. In this carbonated or de-alkalinised zone the pH drops from its usual 11–12 down to 8–9 and if air can get into the system as well as moisture, steel (other than stainless or protected) will commence to rust.

Many contractual disputes arise when the cover achieved is below that specified, and the subject needs to be reviewed objectively. The very act of specifying a cover (10, 20, 25, 30, 50 mm, etc.) is tantamount to an admission that the concrete will carbonate to that depth at the end of its lifetime and the concrete will commence to decompose. In effect, one can logically sum up the whole discussion on cover by concluding that cover specifications are all fatal date deferments.

Deep covers and large-sized bars are unnecessary except from the point of view of fire-resistance which is discussed later. Reinforced concrete is designed to permit the concrete to crack in the tensile zone with the load being taken up by bond transfer onto the steel. When concrete suffers a particular tensile strain the cracking pattern will be a few large cracks for the deep cover concretes but a large number of finer cracks for the small cover concretes. From the viewpoint of corrosion durability one should ask what sort of cracking can be tolerated. With the combined effect of finer cracking coupled with higher stress ratings it would seem only logical to keep the cover down to the minimum. With these factors pushing one way and the risk of carbonation or dealkalinisation pushing the other way a compromise has to be reached.

Enough evidence has been published on the long term corrosion durability of low cover, low permeability concrete to prove beyond any reasonable doubt that there are only two choices open:

(1) If one specifies a meaningful permeability limit the minimum cover may be 5mm.
(2) If one does not and the concrete is of a mediocre or poor quality then one can get about 1 year of lifetime for every 1 mm of cover before corrosion starts.

Any cracking that occurs in reinforced concrete helps conditions (a), (b) or (c), above, to obtain, and whether this is due to stress raisers or loading cracks (in that order of likelihood) is immaterial.

Concrete containing chlorides (admixture, aggregates or marine exposure) will have a depressed pH value when the level of chloride becomes high enough. Corrosion will ensue if (b) or (c) obtain as well as (a). This is why concrete used in a marine application only tends to corrode in the tidal and splash zones. Concrete under water will often retain its corrosion durability for decades as the oxygen in water decreases with increasing depth.

Some discussion of calcium chloride would not come amiss. This can seldom be blamed as the sole cause of degradation since the vast majority of cases are due to combinations of chloride, mediocre or poor quality cover and misplaced cover to steel. Since chloride is known to accelerate corrosion in circumstances favourable to corrosion, it can be argued that all reinforced concrete should contain calcium chloride so that if it is going to degrade it will degrade during the time that the architect's, engineer's, contractor's and precaster's names are all relatively fresh in people's minds. There are quite a few constructions built in the fifties that contain calcium chloride that have never given cause for concern.

A final word about mixed metals or alloys is necessary, because different metals or alloys in contact in concrete where moisture is present can set up galvanic corrosion. This should be avoided. Materials and hardware such as steel, galvanised or zinc-coated steel, phosphor or manganese bronze, and copper or brass can set up corrosion when paired together.

8.5.3 Corrosion and reinforcement spacers

The author published the results of some studies on spacers in 1970 and can now add, in this book, the findings after ten years weathering. Briefly, in the original work, concrete prisms of 75×75×225 mm size were made from a mix of:

1·0	OPC
1·5	Medium concreting sand
3·0	10 mm flint gravel
0·45	Total water (0·40 free)

(all parts by weight)

To a 12 mm diameter mild steel smooth bar three mild steel plates of 50×40×3 mm size were welded. This load plate is shown at the bottom of Fig. 8.10 and was designed to take four spacers along its length, but as

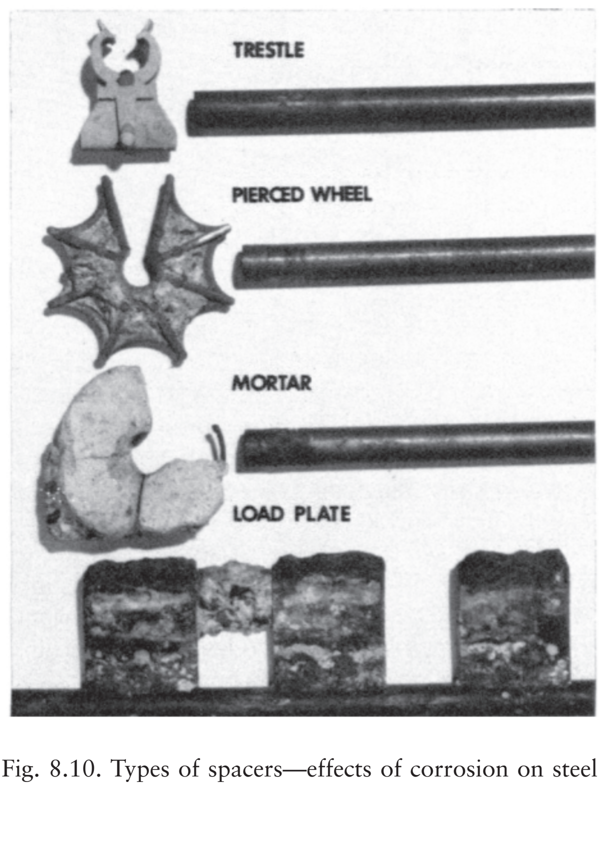

Fig. 8.10. Types of spacers—effects of corrosion on steel.

this promoted early lateral cracking the experimental procedure was changed to two spacers per bar, one at each end.

Figure 8.10 shows typical examples of three of the spacers used in the tests and Fig. 8.11 shows an example of the condition of the trestle spacer samples after 10 years weathering. The spalling has already been described in Chapter 1, and the thin section cracking risk is seen to have caused transverse cracking up to 1 mm wide at the surface, all spacers having 25 mm cover.

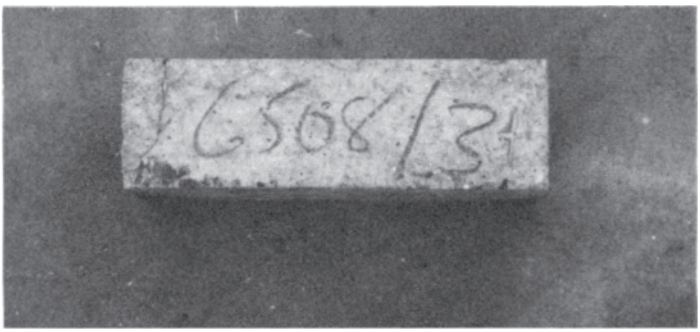

Fig. 8.11. Trestle spacer sample after 10 years weathering.

Before discussing the spacers it is interesting to have a look at the concrete encrusted load plate removed from one of the samples. The plate was so designed that whilst the concrete was fresh the three plates stood proud of the trowelled face and were loaded to simulate a considerable weight of reinforcement on the two spacers. The piece of concrete left between two of the plates has, as its top, the top trowelled face. It may be seen in Fig. 8.12 that most of the protruding 12 mm has corroded away but the exposed steel has only rusted down its sides into the concrete section—just a few millimetres in ten years! There was no spalling in any of the dozens of samples so exposed because the rusting steel has a free face out of which the corrosion product can expand and escape. This means that if one wanted a lifetime of ten years for a sacrifice of a few millimetres of steel the reinforcement can be on the surface. Only in some types of hardened steel might pitting corrosion result in too high a risk in such a situation.

The spacers and the effects of corrosion show that for plastics, although piercing relates to spalling and fire resistance, the actual design

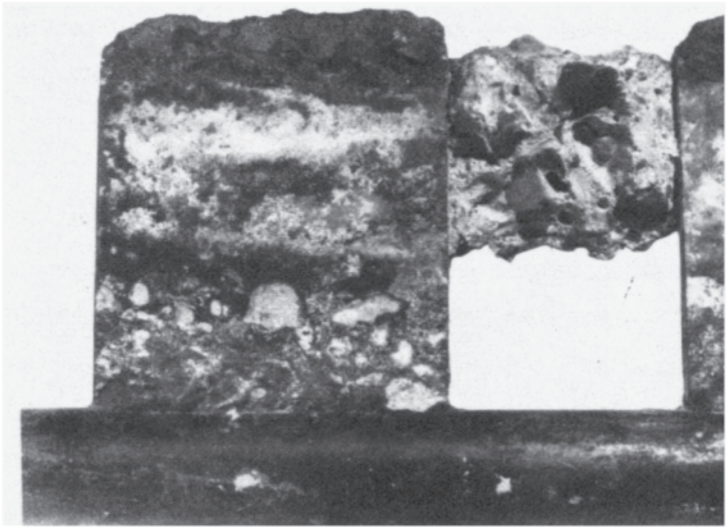

Fig. 8.12. Loading plate.

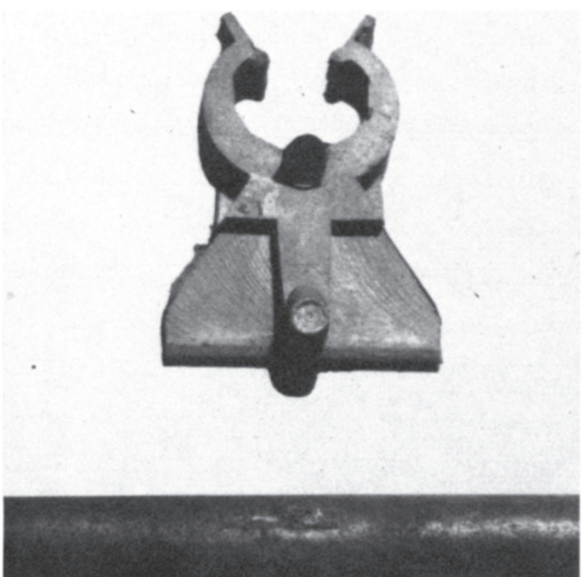

Fig. 8.13. Trestle spacer.

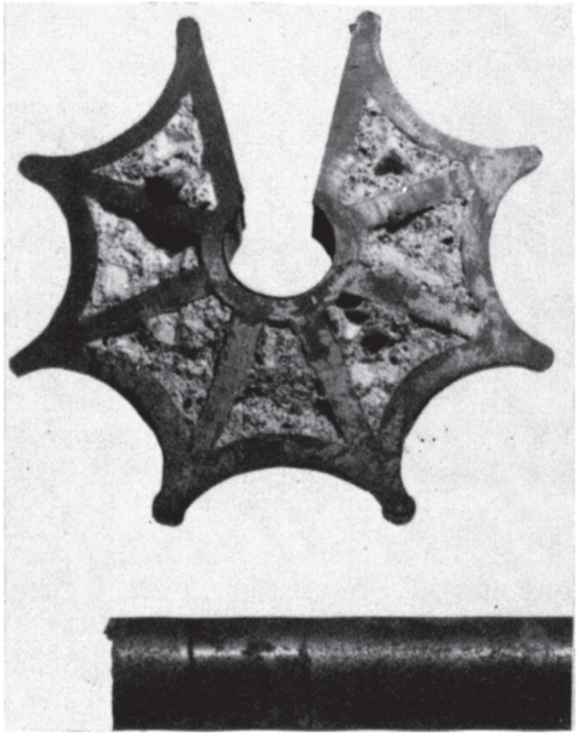

Fig.8.14. Peirced wheel spacer

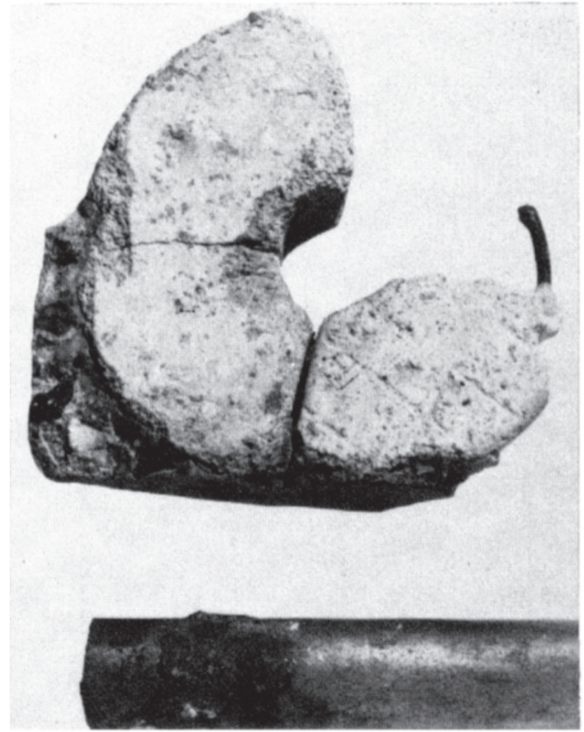

Fig.8.15. Mortar ring spacer

of the spacer is the main factor in its corrosion risk. Figures 8.13–8.15 are enlargements of the spacers in Fig. 8.10 and show that:

(a) The steps in the trestle spacer stop water ingress. The line of corrosion mates up with the tops of the clips and indicates that the main passages for moisture are up the thin edges and round the shoulders to the top of the spacer.
(b) The lack of steps in the pierced wheel spacer results in significantly more corrosion, but certainly not enough to cause worry after ten years. The depth of pitting was 0·1–0·2 mm.
(c) The mortar spacer, although well bonded, exhibited heavy corrosion on the steel 0·5–20 mm deep, this was due to the relatively high permeability of the spacer.

This points to two basic design requirements in plastics spacers:

(1) Piercing for bonding, thermal differential and fire resistance requirements.
(2) Steps or water stops to break up any continuous planes of plastics between the outside and the steel. There are also two requirements for mortar or asbestos spacers:
    (i) they should not be so permeable as to allow water ingress through their matrix to the steel;
    (ii) they should not be so impermeable as to result in poor bond between themselves and the surrounding concrete.

8.5.4 Alkali-aggregate reaction

The alkali in cement is generally expressed as the equivalent Na_2O content and it is the sum of the Na_2O molecular equivalents of the actual Na_2O and the K_2O. To speak of alkali-aggregate reaction as though it is an unusual and bad thing is wrong, because the alkalis in cement are always reactive with aggregates irrespective of the kind of aggregate. Durability only comes into question when the combination of the aggregates and cement results in a long-term expansive reaction that disrupts the concrete.

There are two basic reactive systems:

(a) Alkali-silicate. Here, siliceous aggregates can contain minerals such as opaline and chert which are known to have highly expansive products of reaction.
(b) Alkali-carbonate. This process is believed to be one where the aggregate particle fissures and allows moisture into the particle,

where there is an occlusion of dry clay which then commences to swell. The term 'dedolomitisation' has been used in this context.

Both reactions require moisture but their speeds of causing distress are different in that (a) tends to manifest itself after some years of weathering whereas (b) often shows up in the form of cracking in as short a period as one or two years. The cracking is random map-cracking in appearance with distances of 10–150 mm across each 'square'. The crack widths can vary in size from 0·1 to 5·0 mm, and sometimes the air-hardened exuding reactive gel can be seen at the top of the cracks. The defect is more often than not a Standard hazard in that not only does the concrete lose its integrity but also the cracking is wide and deep enough to permit ingress of water to the reinforcement or prestressing.

There are three matters to consider in locations where this risk is known or thought to exist:

(1) Testing to assess the risk.
(2) Mix design to accommodate it.
(3) What to do about concrete showing this trouble.

Concerning (1) most countries tend to invoke the ASTM Specifications, and of the four tests in this list, two of them, the gel-pat and the chemical solubility Standards only tell one that there is a significant reaction that can be labelled as 'deleterious', 'potentially deleterious' or 'innocuous'. Those Standards are quite explicit in stating that the mortar bar expansion test must be undertaken when the warning is received in either or both of the other two tests. These two tests can be completed and reported in a matter of 2–3 days; but the mortar bar test takes 3–6 months to produce a meaningful result, and it is not an easy test to accelerate or a predictable enough one to extrapolate. This means that tests should be undertaken with unknown aggregate with this potential danger well in advance of any contract work, be it precasting or *in situ*. This warning against using the gel-pat and/or solubility tests as go/not go criteria cannot be stressed too strongly. On at least two occasions Laing R+D has been involved with the use of Middle East aggregates that behaved abominably in the first two ASTM tests but showed little or no expansion in the mortar bar tests.

Regarding point (2), specifications often invoke the use of low alkali cement with an equivalent Na_2O maximum of 0·6%. From this point of view it pays to compare the differences in mortar bar expansion behaviour for a range of Na_2O cements, because even at the level of 0·6% the first two ASTM tests can show up as strongly positive. The alternatives or additional steps that can be taken to inhibit the reaction are:

(a) Use a cement with an equivalent Na_2O maximum of 0·6%.
(b) Geologically examine aggregates from a suspect source and identify acceptable seams in a quarry or areas of a pit, wadi, dune or sea bed.
(c) Accept higher aggregate costs, and transport known good quality materials larger distances.

Additives such as PFA, pozzolana, trass and other siliceous materials will be of little help as they do not help to depress the number of sodium ions in the solution. Admixtures such as water-reducing plasticisers or water repellents would be of help, and they will make a good quality concrete even better. The most important things, in addition to mix design, are compaction and curing. Providing the concrete has a low permeability the amount of moisture that can ingress is limited.

The defect will come under the eye of the repair or remedial specialist and point (3) only requires attention in countries that have reasonable amounts of rainfall or high humidities. In effect, reactive expansive aggregates can be used in arid climes and result in a long lifetime of the concrete because there is not enough moisture around, apart from a few weeks rainy period, to cause any distress. When it comes to considering remedial action there would seem to be only two alternatives open:

(a) Having repaired the cracks, spalls, etc., surface treat the concrete with a completely impermeable surface treatment (viz. chlorinated rubber, pitch/polyurethane) *provided* that there is no risk of suppression of water in the concrete trying to get out.
(b) Remove the defective concrete *in toto* and replace with good quality concrete.

Most of the experience with alkali-aggregate reaction is that the defect manifests itself after the steel has corroded and the concrete has cracked or spalled and it is rare for one to find a construction where this is the sole cause of trouble.

8.5.5 Moisture movement

This is the penultimate of the in-concrete durability properties that needs to be considered. Mature concrete is not a static material and it responds to the natural variations in conditions in which it is placed. It expands when it gets wet and shrinks when it dries in a largely reversible fashion, apart from slight additional cement hydration and surface carbonation. Most of this movement is due to the capillary and gel pore structure of the cement paste and this is restricted by the aggregate dilution.

Any trouble will manifest itself in the drying cycle(s) because concrete is weaker in tension than in compression. It will take the form of 'bracelet-cracks'—a number of approximately equidistant cracks at right angles to the longest axis of the concrete. Crack widths will vary from 0·1 to 1·0 mm and can constitute a structural and corrosion risk depending upon the sort of product and where it is in the construction. The vast majority of the cases examined by the author have been non-structural and non-corrosion risks.

Mix design, compaction and curing all play strong roles in helping to minimise this risk of drying shrinkage cracking. Wetting expansion and drying shrinkage are the two components of moisture movement. The aggregate needs to be selected and subjected to an agreed test to assess its suitability. The concrete needs to be well designed and compacted to inhibit the amount and speed of moisture ingress and egress. Curing is important so as to ensure that the structure of the concrete is as monolithic as possible right up to the surface, otherwise differential moisture stress will be encouraged.

The second aspect to consider is design. Moisture movement of concrete cannot be reduced to zero, no matter how well one makes the concrete product; in the case of the partially compacted products such as blocks, moisture will have a relatively easy passage. Concrete constructions always need to be 'picture framed' so that movements can be designed for in specific plan or elevation areas. Blockwork and brickwork needs horizontal and vertical control joints, cladding requires isolation from the main frame, kerbs and paving have already been discussed.

The third and most contentious matter is testing, and it is the author's opinion that the National Standards that exist as at 1980, be they for aggregates, precast products or *in situ* concrete, leave a lot to be desired. Testing conditions vary from submission to high temperatures and low humidities (starting off with a nominally saturated sample) for a few weeks, to submission of an as-received sample to a medium relative humidity for some months. The aim of any test is to obtain a meaningful and quick answer useful to the manufacturer and the designer of the construction. Quite simply all one needs to do is to dry the concrete from its wettest expected level down to its driest expected level and measure the shrinkage. Most of the National Standards with moisture movement tests tend to be rather time-consuming. It is to be hoped that in the not too distant future a more practical International test will evolve.

Tests are normally undertaken on cast or cut prisms either with reference points cast in with the concrete or stuck on afterwards. A useful on-site test is the DEMEC surface strain gauge, which also reads to the 10 microstrain accuracy of the specified Standard tests. This is illustrated in Fig. 8.16. The equipment reads off surface reference points, which is more relevant to where the main shrinkage effects occur.

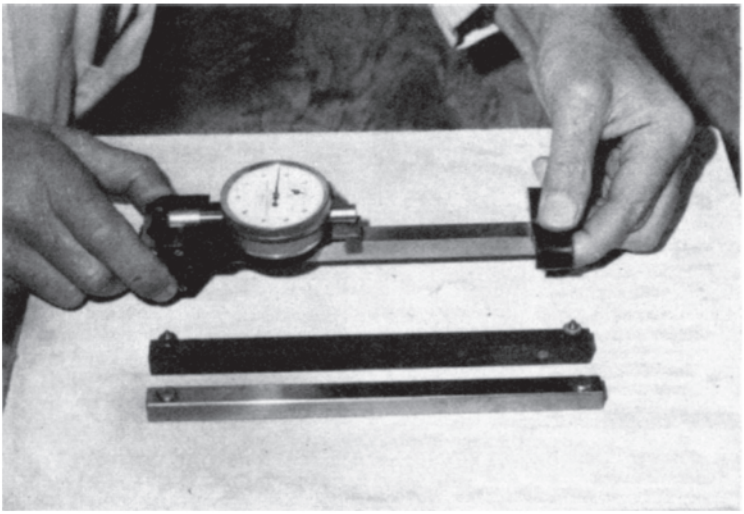

Fig. 8.16. DEMEC strain gauge with calibration and setting out bars.

8.5.6 Thermal movement

This is the last of the in-concrete properties, but is certainly not the least important, as concrete has a linear coefficient of thermal expansion somewhere in the range $(5\text{–}15)\times10^{-6}$/°C. When concrete is in a wet climate and drying due to solar radiation occurs, one has the opposing effects of drying shrinkage and thermal expansion. Usually the thermal response is faster than the moisture and encompasses a larger range. For example, a typical moisture movement range for concrete would be about 0·03%. If the coefficient of thermal expansion was a typical 10^{-5}/°C this moisture range of movement is equivalent to a 30°C movement. Depending upon the country, elevation, colour and texture, concrete has a much larger temperature movement than moisture movement. The position of the concrete affects where this range lies. Typical examples of the range could be:

Country	*Surface of concrete*	*Max.*	*Min.*	*Range*
UK	Smooth grey	50	–10	60
UK	Exposed aggregate black	85	–15	100
Iran	Smooth white	70	0	70
Iran	Smooth black	95	–5	100

It may be seen that these ranges are 2–3 times the equivalent expectancy of moisture movement. Not only do these numbers indicate that when fitting a lot of concrete units together movements up to 1 mm/1 m should be allowed, but that attention needs to be paid to the expected expansion of units fitted in winter, and vice versa for those fitted in summer. Mention has also been made in an earlier chapter of the effects of differential thermals on thin or slender-walled units which can creep and/or crack under the strains created. The same recommendation applies—stack such units with their longest axis East-West.

8.5.7 Natural weathering

It is not the intention in this short section to teach the architect or designer their jobs but to qualify some of the earlier comments in this book. How concrete behaves under natural weathering is a function of many things and the only universal factor is that it generally will not retain its as-delivered appearance for more than a few months. Natural weathering tends to lighten the appearance of concrete when it is grey or one of the darker colours. The pastel shades of concrete as well as white tend to darken slightly. Ignoring the effects of dust storms, industrial environment, etc., and only considering wind, rain and sunshine the following can be expected:

(a) On a sheltered elevation there will be a toning down of the appearance and some occlusion by dust.
(b) On an exposed situation the surface will become matt or even aggregate-exposed, depending upon the quality of the concrete and the severity of the exposure.

In addition to these factors the following effects need to be considered:

(1) Rain or high humidity causing lime bloom.
(2) Badly detailed facade directing rain down part of the unit.
(3) Mortar or sealant staining the joint face.
(4) Metal oxides from steel or aluminium, or organic stains from timber.

Most of the troubles can be avoided by sound commonsense and if a visual concrete is required it is generally preferred to opt for either exposed aggregate or a profiled finish with a vertical ascent.

8.5.8 Freeze-thaw cycling and de-icing chemicals

Concrete, being a permeable material, is subject to becoming wet in most countries in the world. Where these countries have cold winters certain qualities of concrete are subject to degradation, either due to weather-imposed freeze-thaw cycles and/or those induced by the application of de-icing chemicals.

The mechanisms of the effects of freezing and thawing on wet concrete have been discussed and written about for many years and by the early seventies there emerged a general consensus of opinion. Although water expands when it turns into ice this cannot be the major damage mechanism since identical damage can be induced by freezing concrete in benzene which does not expand when it solidifies. The first factor that has been established is that the concrete needs to be saturated to a minimum percentage of its total capability before freezing becomes a likely cause of damage. This minimum is specific for a specific concrete and is known as the Critical Saturation Factor for that concrete. For most concretes it generally lies in the range 80–90%. For example, a concrete with a total free water capacity of 10% could be at risk if it had 8% of water in it when freezing occurred. A very permeable concrete cannot hold enough water, nor a reasonably low permeability concrete take enough water in for either to be at risk. Although this ignores other durability hazards for the very permeable concrete it means that concretes within a certain range of absorptive qualities are at risk whereas those both above and below this range are not.

When wet concrete is subject to freezing an ice phase forms at the cold face. Since ice has a much lower saturated vapour pressure than water, the non-equilibrium of the system is adjusted by water moving towards the ice face to equilibrate the pressure. This water is within a sealed system and the pressures exerted cause a supercooling with water still in the form of water below 0°C This supercooled water will line the pores and capillary walls; and only when the concrete is too wet, so that it cannot find an accommodating location, does pressure rise and disruption occur. As the temperature increases the pressure drops and the supercooled water turns into ice briefly, and this assists the disruption by causing cracks in the matrix.

The defect manifests itself by a sudden drop in the *E*-value and dilation. In the International Test Methods proposed by RILEM, either the *E*-value, or dilation, or strength comparisons with the unfrozen control samples is used as one of the tests. In the other test Critical Saturation is calculated by simple freeze-thaw cycles on samples of concrete containing increasing amounts of water. At the same time, partner concrete samples are subjected to a zero head capillary rise absorption test to ascertain if that concrete is at risk through absorbing too much water.

It is important not to use weight loss as an indication of freeze-thaw damage where de-icing chemicals are not used, as changes in *E*-value and dilation can occur without any visible sign of distress. When cracking eventually results it is a partly random map cracking but with a tendency for the major cracks to parallel the long axis of the concrete. A slate blue/grey discolouration is often visible at the tops of the cracks. Figure 8.17 shows a kerb just beginning to show frost damage. When such is observed usually all units made from that concrete have a short lifetime ahead of them and it is best to replace them all. Architecturally patterned solutions of the problem, as seen in Fig. 8.18, are only part of the work that needs to be undertaken.

Since one does not want a high permeability product because of its relatively low strength, the way to achieve a frost-resistant concrete is to make it so that under the worst weather conditions it will always be below its Critical Saturation Factor when freezing occurs. In wet-cast vibrated products, a small part of the precast industry's roadside unit

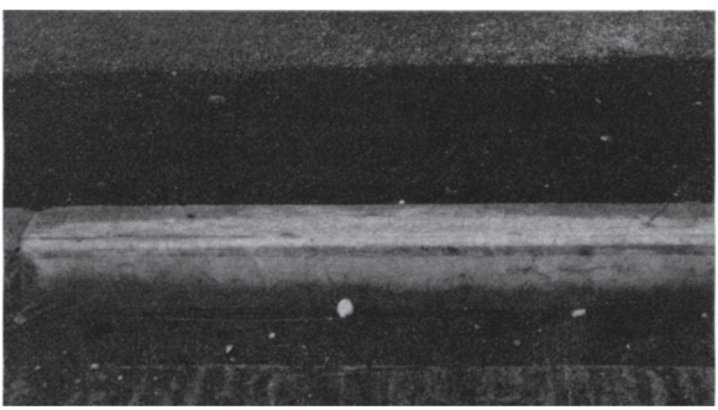

Fig. 8.17. First signs of frost damage on kerb.

Fig. 8.18. Defective kerbs with only partial replacement.

manufacture, the solution is a simple one and that is to air-entrain. It is essential that when this is done the concrete is checked either by one of the aforementioned freeze-thaw tests or by microscopic scan to ensure that the air is:

(a) the correct level,
(b) the best bubble size,
(c) the optimum bubble spacing.

The reason why such concretes behave well is that water cannot get from a capillary tube into one of these bubbles due to the surface tensions and therefore the concrete is full of plenty of 'safety valves' that can accommodate supercooled water and ice and the concrete never gets near to its Critical Saturation. The Initial Surface Absorption Test is useful in observing this waterlock effect as the following typical readings in m1/ m^2/s show:

	10 min	*30 min*	*1h*
Non-air-entrained	0·50	0·30	0·20
Air-entrained	0·40	0·05	0·01

The air-entrained concrete does not behave like a Poiseuille capillary model.

The problem with concretes such as hydraulically pressed, pressure/vibration, extruded, etc., is how to achieve the same resistance when it is not possible to entrain air. The answer lies in having enough cement or cement plus filler (e.g. PFA) to achieve the lowest possible economic absorptive factor. The level required of cement or cement plus filler needs to be of the order of 350 kg/m^3 minimum. Although 300 kg/m^3 will give enough strength for other requirements the concrete will not have a low enough permeability. This illustrates earlier discussion in this book showing that a particular durability hazard demands more than the strength requirement specification.

De-icing chemicals are used to free concrete of snow and ice as well as to inhibit ice formation. Sodium chloride or calcium chloride are generally used, whereas in airport areas the de-icing and anti-frost chemicals used are urea or glycol derivatives so as not to encourage corrosion of the aircraft. Although all these chemicals depress the freezing point and remain in the concrete for a considerable time they have several disadvantages.

The chlorides are endothermic in solution and can freeze cold, wet concrete without the temperature dropping below freezing point, and therefore salt being moved by traffic can cause freeze-thaw cycling by itself. The chlorides will also impregnate mediocre or poor quality concrete and encourage corrosion of the steel if there is any there. The organic chemicals not only depress the freezing point but are chemically reactive with the lime and will slowly soften the surface. All of them will encourage higher moisture contents in the concrete because there is less area for evaporation to occur; and they are all hygroscopic, especially the chlorides, and therefore the concrete will be moved towards critical saturation if it is not already there.

The RICEM test involves observation of the change of surface, as deicing salts and chemicals cause surface spalling as shown in Fig. 8.19 for kerbs and Fig. 8.20 and 8.21 for paving slabs. The sample is ponded with a 3% solution of the salt or organic chemical and subjected to freeze-thaw cycles. The damage is recorded as the weight loss per unit area, percentage area spalled, or by a visual 'mild', 'medium' or 'gross' notation.

Again air-entrainment helps for vibrated products, but for other products the solution appears to be a combination of minimum cement content with a maximum *E*-value. It would seem that it is best to work with a cement content in the range 360–400 kg/m^3 and thus avoid

Fig. 8.19. De-icing salt surface spalling—kerbs.

Fig. 8.20. De-icing salt spalling—paving slab.

Fig. 8.21. De-icing salt spalling—paving slab.

making the concrete too brittle, otherwise its ultimate tensile strain will be too low when internal pressures arise.

8.5.9 Sulphate-bearing grounds and other sources

Sulphates can exist in clays and sands in the form of magnesium, sodium, potassium and calcium; and although their solubilities range from high to low they can all get into solution once what was already there has attacked the concrete. The risk component of the cement is the tri-calcium aluminate phase of the cement which forms ettringite under the action of sulphate (calcium aluminosulphate) and expands.

If there is:

(a) ingress of sulphate into the concrete,
(b) enough C3A to permit the attack,
(c) nowhere for the expansion products to expand,

then trouble can occur. The situation is similar to frost resistance, but in this case the highly absorptive concrete (viz. blocks) has plenty of room for sulphate to expand whereas the low permeability concrete will not allow enough sulphates in to cause distress. In effect, concretes within a range of absorptive properties are those subject to this risk whereas those both above and below are not. Obviously, it pays to be below for reinforced concretes so as to reduce the corrosion risk. In (a) the ingress will only be high enough to be a risk if the concrete is designed, manufactured or cured badly, and strict control of cement content and free water cement ratio is essential. One would use (b) by selecting a sulphate-resisting cement which has a virtually zero level of C3A, but only if (a) was strictly observed. SRC is no solution to the resistance-to-sulphate problems when concrete is not properly made. The intermediate-permeability concretes are those categorised by (c), and even with sulphates from clay brickwork, expansion can occur as shown in Fig. 8.22. This particular fault could have been avoided by better design.

Fig. 8.22. Sulphate attack on concrete coping causing expansion.

It is a pity that as at the end of 1980 no international test for sulphate resistance exists.

8.5.10 Chloride environments

Several areas in the world contain sodium chloride in the ground; this is very often accompanied by sulphates. Apart from there being less water around the exposure is similar to concrete in sea water. Two types of degradation occur. The first is not dissimilar to sulphate attack, where the C3A is converted into tri-calcium alumino chloride. This is accompanied by some expansion but is nowhere near as severe as with ettringite formation. The second is of greater consequence and that is chloride in solution penetrating as deep as the reinforcement, lowering the pH, and setting up either direct corrosion if the water has enough oxygen in it, or galvanic differential degradation if chloride gradients exist from one part of the reinforcement to the next. Provided that the concrete is as impervious as possible and has no cracks in it permitting passage to the steel then a long lifetime can be predicted. If the concrete is mediocre or poor in impermeability it does not matter how much cover one has because the steel will eventually corrode. Most of the risk exists in salt-bearing grounds which are either damp or wet, or in marine environments such as splash and tidal zones where there is plenty of oxygen in the water. The selection of a low C3A cement helps to improve the, performance but, in the writer's opinion, it only makes good quality concrete better and not poor or bad quality concrete good. Good quality concrete with as little as 10 mm cover has been observed to perform well in a tidal zone for over 30 years without any distress.

8.5.11 Industrial and agricultural fluids

Questions are often asked such as 'What is the pH of the acid?' since acid environments are those that are of most concern with an alkaline material such as concrete. A pH value from below the neutral figure of 7 down to the highly acid level of 1 only represents the logarithm of the inverse number of hydrogen ions. It gives no information on the presence of water, which is essential to create a reactive situation, nor does it tell one what the reaction product is and the form it takes.

To illustrate the first point it is possible to fill up a concrete tank with concentrated sulphuric acid (less than 1% water) without harming the concrete. There are several other low-water-content acids from non-acid-gas systems that behave similarly. All in dilute form will attack concrete in a slight or gross fashion depending upon the reaction product. If the reaction product is a soft friable salt it will break away with the debonded aggregate to expose new surfaces to the acid. If, on the other hand, the reaction product is a strong pore-blocking impervious salt it will react for a short period then stop. Citric acid is an example of this latter mechanism, and orthophosphoric acid and fluoric acid can behave similarly. That is why they are safe (to the masonry) stone and concrete cleaning media as their reactions tend to be confined to the surface. Many years ago the Ocrat system of subjecting permeable concrete to HF gas gave remarkable results in improved impermeability and acid resistance, but it did not become very popular for fairly obvious reasons.

It is interesting to consider at this point that if some acids make concrete resistant to themselves, this could be a viable way of treating concrete to make it resistant to other acids.

However, what this all means is that the following points have to be considered in deciding whether concrete will be able to resist sufficiently in its own right or whether some protection will be necessary:

(1) The permeability of the concrete.
(2) Reactions with the cement phase.
(3) Reactions with the aggregate phases.
(4) Acid availability (it could all be used up without replenishment).
(5) Water content of the acid.
(6) pH of the acid.
(7) Form and type of product salt of the reaction (salt being used in its chemical meaning).

Each particular case must be considered as an individual one and no general rules drawn.

Consider some typical examples:

(a) For sulphurous-containing effluent travelling down a pipeline good quality concrete will serve well provided that the air space above the effluent is well ventilated and, preferentially, limestone aggregate is used. The slight solubility of this aggregate results in a more even erosion over the years, whereas a flint or volcanic-origin aggregate will dislodge as the cement around it becomes eaten away.
(b) For aqueous systems such as hydrochloric, sulphuric and nitric the concrete will require a protective coating such as pitch/polyurethane if the acid strength is high.
(c) Agricultural source acids are extremely vicious at much lower concentrations than the inorganic acids, and if the concrete is not of an exceptionally low permeability it will need treatment to protect it from acids such as lactic, butyric and acetic.

To exemplify (c) even the hydraulically pressed slabs used in post-tensioned grass silos are eroded by 2–3% solutions of these acids as shown in Figs. 8.23 and 8.24. Luckily these concretes are not reinforced and the acids have little effect on the external prestressing bars. The doorways used in these constructions, a line of vertical openings up the side, are wet cast vibrated units and they have been known to last only one season if the quality of the concrete is mediocre or poor.

The permeability of the concrete is best controlled by the cement

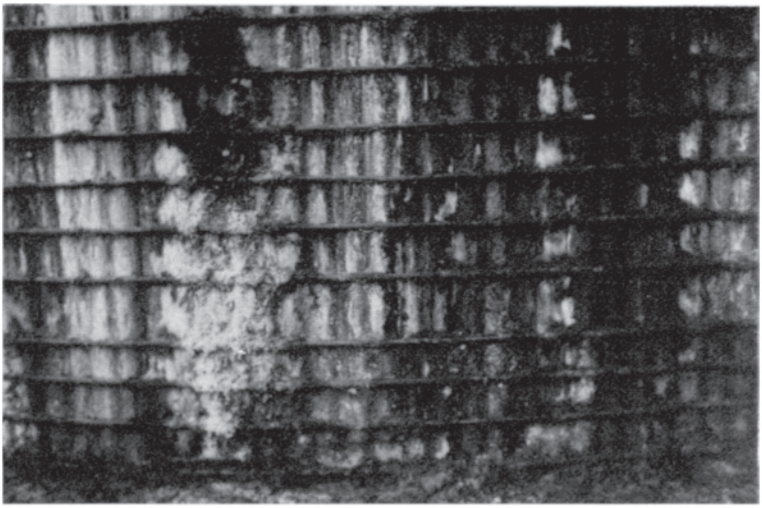

Fig. 8.23. Joint leaks in concrete grass silo showing corrosion products and aggregate exposure.

Fig. 8.24. Effect of grass silo acid on concrete surface.

content, which should be in the range 350–420 kg/m^3, as well as by the compaction and the curing. Air-entrainment in acidic environments has been observed to lower the resistance. Acid systems have lower saturated vapour pressures than water, and not only penetrate into air-entrained concrete fairly easily, but in their general degradation process they have less concrete to react with per unit area or volume.

Anaerobic bacteriological effects in sewers and similar environments give rise to hydrogen sulphide, sulphurous and sulphuric acids. In severe situations concrete needs protection with a pitch/polyurethane paint or similar. It is essential in all situations such as these that the areas be well-ventilated, as the harmful bacteria are killed by oxygen.

Alkalis are not normally a risk except for concentrated ammoniacal solutions when replacement reactions in the cement can occur. Soluble nitrates and nitrites in alkaline form also dissolve out some of the cement, and protective measures as for acids are required.

8.5.12 Impact

This is a largely ignored property but is still important enough to attract the designer's attention for such things as pipes, pontoons, tunnel units, etc. The absorption of impact energy is largely a function of the *E*-value.

Concretes or mortars will crack or shatter under impact but their performance can be dramatically improved by fibre 'reinforcement' which absorbs and distributes the energy through micro—rather than macro-cracking. The *E*-value importance shows that the strength, which is related to *E*, should be kept within a compromise range. For precast handling and delivery requirements a characteristic strength of about 30 N/mm^2 would be necessary; if the manufacturer aimed at a higher strength and a few of the products reached 60 N/mm^2 there would be quite a lot of damage to them by the time they reached the site.

There is no International test available as at 1980 for impact to concrete although one can conceive many tests of one's own. All that can be recommended is that any test one designs should simulate the impact durability risk liable in the construction. There is a lot of difference between 1000 t travelling at 0·1km/h and 10 g travelling at 1500 km/h.

8.5.13 Wear

Although there are a few National Standards there has been little progress, as at 1980, towards producing an International wear test for concretes and mortars, even though this is an extremely important property, e.g. for paving slabs, inside pipes, marine and coastal products, etc. Wear directly relates to hardness and therefore the stronger the concrete the harder it is. The hardness is made up of two factors—the aggregate and the cement. The cement will generally wear away before most aggregates except limestone and sandstone, so, in addition to the control of the free W/C the selection of aggregate is important. As stated earlier the best mix design to select is one based upon gap-grading. The cement will wear away first leaving a range of sizes of aggregate particles exposed. Since the intermediate size (7–13 mm) tend to come out first it is best to gap these out of the mix and allow the coarser particles to become close-packed.

For industrial wear it is also of benefit to measure changes in friction of the surface as wear continues, viz. a wet or dry test as appropriate to the use. Some surfaces tend to become polished under wear, and this is an added risk.

Wear also relates to softness when one is considering plastics materials, and at this point the reader may recollect that plastics spacers will stand proud of a grit or sand blasted surface. In effect materials in the intermediate range of hardnesses are those prone to the higher wear rates. A wear experiment was undertaken on a cam-driven rocking pipe. The pipe had strips of different paints on the inside face and 100 steel balls of 12 mm diameter traversed up and down the paint at the rate of one cycle every 10 seconds approximately. At the end of a day's 2000 cycles the pipe was examined and rotated to test the next paint. After the test it was found that the unpainted area had become exposed aggregate. The epoxide, linseed oil and cellulose paints had disappeared and the aggregate was partly exposed. The chlorinated rubber paint had almost worn away just showing the aggregate and the pitch/epoxide was as new. At the time of this experiment (1960) pitch/polyurethane paints were not available but at 1980 the experience gained indicates that it has superior performance.

8.6 THERMAL PROPERTIES

Concrete is often called upon, either by itself or as a composite with other materials and/or air spaces, to confer specified thermal properties to a construction. The aspects under main consideration are thermal conductivity, thermal inertia and fire resistance. Thermal expansion has been dealt with earlier and fire resistance is discussed in the next section. Thermal properties are not durability subjects and fall within the province of the designer and heating engineer, since failure to comply with a requirement is not at variance with the 'perform in the manner expected' part of our durability definition. Most of this discussion will concern the conductivity and inertia theories but some physics and mathematics needs to be introduced so that the reader can understand what it is all about and then go on and do his or her own calculations.

Movement of heat energy is either by:

(a) Molecular vibrations in a solid or fluid where heat is passed through by molecular excitations from the adjoining molecules. Obviously the closer packed the molecules are the easier it is to pass heat through the material. This is why a solid conducts heat better than a liquid which, in turn, conducts heat better than a gas. This property of a solid or fluid is known as the thermal conductivity and is given the symbol k in units of watts per metre °C. It can be obtained from first principles by considering the amount of heat Q in joules flowing through a rectangular block of area A (m^2) in time t (s) over thickness d (m) with a temperature gradient of $(T_2 - T_1)$ (°C). With Q proportional to all variables, except for an inverse proportionality to d, the constant k of conductivity produces on equality:

$$Q = \frac{kAt\,(T_2 - T_1)}{d} \text{ joules or watts (W) per second}$$

(b) Radiation wave energy in a vacuum or in a gas. This is a wave energy in the infra-red range which will only convert into heat when the wave energy strikes a molecular system. The sun's rays will warm up loose molecular packed air much slower than they will warm up the face of concrete. When wave energy converts into heat energy and vice versa a resistance needs to be overcome. This is defined as a surface resistance factor and varies for different places in the construction.

In order to assess the total performance of a concrete unit, construction or composite component all one has to do is to find the thermal transmittance or U-value. The k-value for oven-dry concrete varies from about 0·2 to 1·2 from the lowest to highest precast concrete densities. Each particular value can be doubled by saturating the concrete. Therefore, for calculation purposes one needs to either refer to an accepted k-value or determine it oneself by an approved Standard. Having obtained that value one must then multiply it by a factor to represent a typical moisture content (v/v) in the construction. In practice the material will exhibit a range of values depending mainly on the moisture content. When the k-value for design purposes is agreed and selected one then calculates d/k as the resistance of the 'solid' material (m^2 °C/W).

Surface resistances offer easy design figures for cavities (0·175) and inside surfaces (0·125), but the external resistance can vary from about 0·02 to 2·00 depending upon the colour, reflectance, surface texture and exposure. One can take 0·05 as a typical design figure for calculation purposes. Having obtained all the resistances one then adds them all up, inverts the answer, and this is the U-value in W/m^2 °C, also known as the Thermal Transmittance.

Example 1

Single leaf wall, 100 mm thick, k=1·0 W/m °C.

$$\text{Sum of resistances} = 0{\cdot}125 \text{ (internal surface) } + \frac{0{\cdot}1}{1{\cdot}0} \text{ (solid material)} + 0{\cdot}05 \text{ (external surface)}$$

$$= 0{\cdot}275 \text{ m}^2\ {}^\circ\text{C/W}$$

Therefore U = 3·64 W/m^2 °C

Note that the two surfaces have a total resistance higher than the solid wall.

Example 2

Outer leaf, 150 mm thick, k=1·0 W/m °C

Cavity, 50 mm wide (resistance=0·175 for cavities wider than 10 mm)

Inner leaf, 100 mm thick, k=0·33 W/m °C

$$\text{Sum of resistance} = 0{\cdot}350 \text{ (surfaces plus cavity)} + \frac{0{\cdot}15}{1{\cdot}0}\text{(outer)} + \frac{0{\cdot}1}{0{\cdot}33}\text{(inner)}$$

$$= 0{\cdot}80 \text{ m}^2\ {}^\circ\text{C/W}$$

Therefore U = 1·25 W/m^2 °C.

Example 3

As example 2 but with 50 mm expanded plastics, k=0·025 in cavity

$$\text{Sum of resistances} = 0{\cdot}175 \text{ (surfaces)} + \frac{0{\cdot}15}{1{\cdot}0} + \frac{0{\cdot}050}{0{\cdot}025} + \frac{0{\cdot}1}{0{\cdot}33}$$

$$= 2{\cdot}625 \text{ m}^2\ {}^\circ\text{C/W}$$

Therefore U = 0·38 W/m^2 °C

Note that the plastics incorporation more than trebles the resistance.

Example 4
Part sandwich cladding panel 150 mm thick with 50 mm cast-in expanded plastics panel taking up 80% of area. k=1·0 for concrete, 0·025 for expanded plastics.

$$\text{Resistance of concrete} = 0{\cdot}175 + \frac{0{\cdot}150}{1{\cdot}0} = 0{\cdot}325\ \text{m}^2\ {}^\circ\text{C/W}$$

Solid section: U (solid)=3·08 W/m^2 °C

$$\text{Resistance of sandwich} = 0{\cdot}175 + \frac{0{\cdot}100}{1{\cdot}0} + \frac{0{\cdot}050}{0{\cdot}025} = 2{\cdot}275\ \text{m}^2\ {}^\circ\text{C/W}.$$

Concrete and plastics: U (sandwich)=0·44
On an area proportionality

U (panel)=0·44×0·8+3·08×0·2=0·97 W/m2 °C.

It may be seen that it is quite easy to undertake one's own calculations, and reference to various handbooks, Codes, etc., will usually furnish one with conductivity and resistance figures one can use to produce standard calculations. However, the conductivity of concrete is often measured by a guarded hot plate method with specimens in contact with both cold and hot plates. The moisture distribution that arises in this method does not resemble that of concrete with both faces ventilated and a full or half-scale test for conductance or transmittance is preferred as the conditions are more realistic.

The thermal inertia aspect is the 'heat sink' concept where the latent heat inside a solid material or the heat required to warm it up to that temperature is a product of its mass, specific heat and temperature. This is to say that any enclosure which one intends to maintain at a specified temperature will need less 'ons' and 'offs' of the controlling mechanism if there is thermal inertia on the inside face of the enclosure (room, office, factory, etc.). For a specific U-value with a lightweight concrete internal and heavy concrete external leaf the switchgear will have more work to do in the control of temperature than if the wall had been built the other way around. An added advantage of having the lighter material externally is that the moisture content effect on exposed concrete will increase the overall U-value much more for the dense concrete outer leaf construction than for its reverse, when typical k-values are respectively 1·2, 0·3 and 0·36, 1·0.

8.7 SOUND

Transmission of sound is a sinusoidal compression/vacuum mechanism in both solids and fluids and its speed is related directly to the density of the medium. Its molecular property compared to the molecular and wave energy heat forms is the reason why sound cannot travel in a vacuum whereas heat can.

There are two main sources of sound:

(a) Machinery, instruments, voices, etc.
(b) Impact

In (a) the sound source will transmit a noise through air. The frequency (frequencies) will be a function of the noise source and can be a single frequency (musical note) or a mixture anywhere in the human audible range of about 10 Hz to 5000 Hz (1Hz (Hertz)=1 cycle per second). No matter through what medium sound travels the frequency or frequencies remain(s) unchanged. The low frequency sounds are much more in sympathy and resonance with the properties of solid materials and are more difficult to obstruct than the higher frequencies. This is why when one is on the other side of a wall from a record player playing a number of instruments the noise of drums, cellos and bass guitars will be heard much more easily than violins, flutes, etc. The amplitude is measured in decibel units, with the symbol dBA for decibels, and is the height of the sinusoidal curve that represents a sound wave. Since sound is absorbed as it passes through a material the amplitude will decrease with each cycle, and this is the reason why low frequency noise has an easier passage as it has less cycles per unit path length for dampening to occur than does a high frequency noise. When one plots dBA reduction against frequency one therefore achieves a steadily increasing set of numbers with, perhaps, one or two narrow deep troughs at the low frequency end where the material has resonance with the sound and could ‘flap’.

In (b), the impact of one solid body striking another will generate a sound wave as both materials are brought into instantaneous compression at their interfaces. The frequency (usually a single note) will be a function of the actual materials. The amplitude will relate directly to the compressibility of the molecular systems, and if one of them is open-textured and/or soft and/or weak the sound will be transformed into a miniscule quantity of frictional surface heat with little or no sound being generated. What this means is that for concrete the weaker and more open-textured it is the better will be its resistance to impact sound sources. For suspended floors a compromise in design is required and this is the reason why a considerable number of floor constructions are undertaken with a prestressed beam and lightweight block infill design. In effect if impact is a risk one needs something soft in the way of impact and if airborne sound is a risk one needs a minimum weight per unit area in the path of the sound.

Cavity construction of a given weight per unit area will have a higher insulation than the same weight in the form of a single leaf, as sound has to overcome a resistance (like heat) when it enters or leaves a surface. A cavity construction filled up with expanded plastics will have a vastly improved thermal resistance, but its sound resistance will decrease as it has lost two surfaces and substituted a mixture of air voids and solid plastics in that space.

Considering surface condition and absorption and emission of sound: as with heat, all good absorbers are good emitters and expanded plastic tiles, for example, stuck onto the soffit of a suspended floor transfer impact noises easily into the space below whereas a smooth, hard, highly (sound) reflective surface will not. Compromises are always required as one does not want a space full of echoes from the internal sound sources, nor does one want to have high emissions from other sources.

Putting meanings to the numbers might make it easier for the reader to understand. First of all with frequency an average musical sound would be middle C with a frequency of 250 Hz. As one goes down or up an octave the frequency halves or doubles, respectively, so that an average piano will traverse from about 30 Hz to 3000 Hz. Decibel amplitude is a sound pressure measured on a logarithmic scale with 10dBA equal to about 2×10^{-5}N/m^2, a very low pressure. An increase by an increment of 10dBA increases the energy level by a factor of 10; i.e. 20dBA is about 2×10^{-4}N/m^2, and so on. Equivalents in real terms are:

Less than 10	An eerie silence
10–20	Birds in a garden
20–40	Conversation
40–50	In a theatre
50–70	Radio or television in a room
70–90	Disco or loud concert
90–100	Pneumatic drill at 1–2 m distance
100–120	Jet aircraft 20m from engine—physiological damage
120 +	Damage to ears or death

30 dBA is the ideal maximum for most premises, and with an average reduction of 50 dBA in an external wall only noises about 80 dBA would cause discomfort.

BIBLIOGRAPHY

J.D.RADFORD and D.B.RICHARDSON, *The Management of Production,* Pitman, Bath UK, 1972.

A.M.NEVILLE, *Properties of Concrete,* Pitman, Bath UK, 1977.

J.J.KOLLEK, Using the Schmidt rebound hammer, *Concrete,* **2**, 1968.

M.LEVITT, The ISAT—A non-destructive test for the durability of concrete, *British Journal for Non-destructive Tests,* **13**, 1965, 4.

British Standard 4408, Pt. 5, *Measurement of UPV in concrete.*

British Standard 1881, Pt. 5, *Methods of measuring concrete for properties other than strength.*

British Standard 1217, *Cast stone.*

CEMENT and CONCRETE ASSOCIATION, Advisory Note, *Chemical methods of removing stains from concrete,* No. 13, London, 1968.

R.E.BAUMGARTEN, Removing stains from concrete, *Concrete Building,* March 1937.

ASTM C227, *Potential alkali reactivity of cement aggregate combinations by mortar bar method.*

ASTM C289, *Potential alkali reactivity of aggregates in Portland cement concrete, test.*

ASTM C441, *Potential alkali reactivity in Portland cement mixtures measuring expansion control effectiveness of mineral admixtures, test.*

ASTM C586, *Potential alkali reactivity of carbonated rocks for concrete aggregates by rock cylinder method.*

M.LEVITT and M.HERBERT, Performance of spacers in reinforced concrete, *Civil Engineering,* August 1970.

British Standard 4408, Pt. 2, *Strain gauges for concrete investigations.*

M.LEVITT, An introduction to RILEM methods of testing resistance of concrete to freezing and thawing and the international co-operative tests on the critical degree of saturation methods, *Materials and Structures,* No. 58, July/August 1977.

RILEM methods of carrying out and reporting freeze/thaw tests on concrete without de-icing chemicals, *Materials and Structures,* No. 58, July/August 1977.

RILEM methods of carrying out and reporting freeze/thaw tests on concrete with de-icing chemicals, *Materials and Structures,* No. 58, July/August 1977.

RILEM tentative method. The critical degree of saturation. Methods of assessing the freeze/thaw resistance of concrete, *Materials and Structures,* No. 58, July/August 1977.

G.FAGERLUND, Critical degree of saturation. A method for estimating the frost resistance of construction materials, *Materials and Structures,* No. 25, September/October 1971.

T.C.POWERS and R.A.HELMUTH, Theory of volume changes in hardened Portland cement paste during freezing, *Highway Research Board,* **32**, 1953, 285.
H.BLAKEY, Letter to the Editor, Mulberry Harbour, *Concrete,* December 1973.
M.LEVITT, J.J.WILLIAMSON and C.H.LEACH, Factors affecting the sound insulation of lightweight aggregate concrete block walls, *Precast Concrete,* March 1971.
D.F.ORCHARD, *Concrete Technology,* Applied Science Publishers, London, Vol. 3: Practice, 1979.

9

QUALITY ASSURANCE

9.1 GENERAL

This chapter, although a relatively short one, deserves an individual place in this book because at the time of writing schemes are already operational in the industrialised countries of the world which enable Companies, Test Houses and the like to be registered under a National Quality Assurance Scheme. The schemes embrace all industries and laboratories and not only guarantee a minimum standard of quality in product or service but also encourage International trade in these two items. Developing countries will only be developing for a limited number of years, and the scheme will spread and it is in all parties' interests to encourage such spread.

The term 'Quality Assurance' is not to be confused with 'Quality Control' which is only a part of assurance, because Quality Assurance needs to be what its name means—an assurance that every assessment of capability has been undertaken. Since the Quality Assurance that any part offers has to be assessed, the assessors must be under the jurisdiction of an independent National or International body who can use their own staff or approved external assessors. The business is not a simple one because Quality Assurance in precast concrete manufacture and/or testing involves:

1. Regular inspections of the premises (Assessors).
2. Interviewing personnel responsible for the various activities (Assessors).
3. Examination of all procedures in the manufacture and/or testing (Assessors and Company).
4. Keeping Record Cards on all machinery, equipment, etc. (Company and Assessors). (See Chapter 5.)
5. Calibration of all test equipment (Company with Assessors checking).

6. Documentation of input of all materials (Company with Assessors checking).
7. Documentation of output of all products (Company with Assessors checking).
8. Documentation of all test data (Company with Assessors checking).
9. Setting up calibration and maintenance schedules for all facilities in use (Company).
10. Maintenance of customer confidentiality, health and safety (Company).

A lot of people would tend to call No. 8 either Quality Control or Quality Assurance; but it may be seen from this list that Quality Assurance involves a number of items. Since most items except No. 8 have been discussed at length in the preceding chapters we can dwell for a while on the achievement of Quality Control. This depends upon all responsible parties having undergone the requisite training and having had the necessary experience.

9.2 QUALITY CONTROL

Quality control involves something being done to a product, process or service that, with one exception, produces certification at the end of the operation. The only time that quality control does not result in certification is in the control of aesthetics, where approved samples, drawings, photographs or similar schemes have to be used for a visual comparison resulting in a 'go/not go' result. The resulting number may be a strength, dimension, deviation from a plane or line, absorption figure, etc. and for quality control these numbers, as they accumulate with time, have to be of service. Too many people collect numbers just for the sake of it, or for publicity, or out of conscientiousness; but there are many other things that can be done that will always benefit the manufacturer. It has been stated several times already that successful production is the control of all the variables at one's disposal coupled with technical knowledge, 'know-how' and 'alchemy', and if one does not know what the variables are doing at any one time control is lost. One can list the factors and control variables one would use in precast manufacture bearing in mind that all materials data need to be backed up by proper sampling and retention of approved materials in sealed and labelled containers. If this is not done the precaster has no recourse against the supplier.

The following list outlines most of the main factors in a quality control procedure.

Aggregates: Grading, moisture content, colour (for visual concrete), impurities, etc.
Cement: Manufacturer's certificate (out house), specific surface, setting times, expansion, colour.
Water: Chemical analysis if not mains water or cube tests using standard sand and cement.
Pigments: Colour, staining power, fastness.
Admixtures: Workability, setting time, strength.
Additives: Fineness, impurities, setting time.
Dimensions: Deviations plus and minus from work size in x, y and z.
Planeness: Deviations from specific straight edge across adjacent and diagonal corners.
Twist: Deviations from parallel of supposedly parallel sides.
Strength: Observed cube, cylinder or product strengths or failing loads.
Absorption: Absorption or Initial Surface Absorption Tests at specified ages and times.
Permeability: Rate of flow through or drop in water level in a specific test.

Go/not go tests can be given a 1/0 numbering which could apply to:

Strength: Proof loading tests.
Permeability: Hydraulic proof tests.
Visual: Architectural requirement.

At all times one must have at one's disposal a full list of the materials variables because one of the most difficult things to undertake is to nominate which variable(s) is/are responsible for an observed deviation from the expected and planned performance. Probably the best way of dealing with the problems that are likely to arise is to give examples of a few systems of Quality Control that could well obtain in precast concrete operations.

Example 1: Dimensions of cladding unit ex-mould No. 3 where specifications are:

x=3015+0–10
y=2550+0–10
z=150+3–3
(all in mm)

Cast No.	*x*	*y*	*z*
37	3013	2545	150
38	3013	2545	152
39	3014	2545	151
40	3014	2546	153
41	3015	2546	152

(all averages of 4 individual readings)

These results give three pieces of information, two of them requiring early action:

(a) The mould is wearing on its long x-axis and needs re-adjustment immediately.
(b) The *y*-dimension is growing slowly and if cast No. 1 was on 2540 mm at about Cast No. 80 it will need re-adjustment.
(c) The *z*-deviations indicate that the finishing and trowelling operations need tightening up, especially if thickness is critical in the construction. There is a tendency to overfill the mould—a materials wastage.

Example 2: Two nominally identical production lines producing paving slabs with flexural 7 day strengths:

Day of casting no.	*Line 1*	*Line 2*	
10	5·5	5·5	
11	5·6	5·5	
12	5·5	5·7	
13	5·7	5·2	
14	5·6	5·3	
15	5·0	4·9	
16	5·1	5·1	
17	5·5	5·6	Works specification 5·5 minmum

(average over 3 slabs)

In this example we can pick out trends and make comparisons:

(a) On casting days numbers 13 and 14 something went wrong on Line 2 which one would need to identify as under-thickness, change of personnel, machine fault, etc.
(b) On casting days numbers 15 and 16 there was a drop in both Lines' strength which would point to a materials rather than a personnel or machine fault. An investigation of the materials deliveries in use at that time would need to be undertaken.

Example 3: Initial surface absorption test on visual concrete with maximum specification limits of 0·25 at 10 minutes, 0·15 at 30 minutes, 0·10 at 1 hour (all in $m1/m^2/s$).

All tests were undertaken at 14–28 days old on units covered for the previous 3 days.

Day of casting no.	*10 min*	*30 min*	*1 h*
1	0·20	0·12	0·09
2	0·10	0·07	0·05
3	0·13	0·08	0·06
4	0·09	0·06	0·04
5	0·37	0·20	0·16
6	0·09	0·07	0·05

One would need to look at the curing conditions on day number 6 that affected the curing of the day number 5 cast.

Example 4: Statistical control of concrete block production from a single machine producing, with intent a block of 7·0 N/mm^2 nominal strength at the time of delivery. With this criterion a cumulative set of figures can be set up based upon 10 blocks/day testing:

Average of 10 blocks $\geqq$ 0.9 × specified strength + 0.62 × standard deviation

Day no.	*Average of 10*	*Standard deviation (σ)*	*0·9×7·0 +0·62 σ*	*Accept/ reject*
51	7·4	0·5	6·61	A
52	7·3	0·6	6·67	A
53	7·1	0·8	6·80	A
54	7·0	1·0	6·92	A
55	6·9	1·0	6·92	R
56	6·8	0·5	6·61	A
57	7·2	1·8	7·42	R

Thus with control of variability it is not possible to produce a lower average strength than the 7 N/mm^2 specification; but the converse holds in that a higher average strength sample with variability will fail. This is a sensible way of looking at blocks since a large number of units go to make up the whole, but there may be one or two in a critical part of the construction and this control method guards against rogues. Another advantage of the system is that cumulative statistical exercises may be undertaken on a Cusum (averages or standard deviations) to determine if there are trends in control. The reader might like to carry out the exercise of drawing his or her own inferences about trends and Quality Control from these figures.

9.3 RECORDING

Documentation of data, events, etc., is the most important part of Quality because the discipline rests on records. Standards and Codes should be rigidly observed in such matters as 'Reporting of Results', and whether one is dealing with a Record Card referring to a piece of manufacturing plant or a Certificate referring to a test it is best to have too much rather than too little information.

Consider the case of cube testing in a prestressed concrete works where one would need at least the following information:

(1) Concrete sampled from production line, shop or shed No…
(2) Concrete sampled…minutes after mixing at time…h.
(3) Size of cubes…mm.
(4) Reference numbers on cubes…
(5) Conditioning of curing up to demoulding…(temperature, covered, etc.)
(6) Condition of curing up to test…(temperature, water, etc.)
(7) Date of manufacture…
(8) Method of compaction…
(9) Date…and age…of test.
(10) Cube sizes (check) (Orthogonals)
x=… y=… z=…
x=… y=… z=…
x=… y=… z=…
(11) Failing loads .... kN.
(12) Failing stresses .... on nominal size (N/mm^2).
(13) Mode of failure, normal, split or spall ....
(14) Retention for further inspection or analysis……
(15) Aggregate maximum size, cement content, W/C or slump or compacting factor…
(16) Specification requirements…

It may be seen that for such an apparently simple thing as cube testing quite a lot of information needs to be recorded. Luckily, enough guidance is given in the respective Standards and Codes generally to tell one how information should be recorded and what needs to be recorded. However, it does no harm to ask oneself questions all the time to ensure that one has all the answers to all the questions likely to be asked. A classic example of a Standard that did not say enough was one dealing with cantilever tests on prestressed precast concrete columns where the specification stated that after the load was removed there should be immediate recovery of at least 85% of that deflexion. The simple way of measuring this is to mark the end of the column with a piece of wire or wood which abuts a fixed vertical scale. One testing organisation, since the Standard did not state how this should be measured, set up a travelling microscope on the clamped end of the column focused on a cross-wire fixed to the loaded end. The consistent recorded failure of the columns was traced to the microscope which tilted on the opening and closing crack under its three legs.

There are three reasons for failure to comply with a Standard:

The product
The product plus test procedure
The test procedure

An organisation which sets out to record test data in a thorough and comprehensive manner is one unlikely to have a slovenly test procedure. The moral of all this is never to stop asking questions of others and yourself; if you have not got the answers (and honest ones) to all the questions then Quality Control in particular and Quality Assurance in general will be in question.

10

REPAIRS

10.1 GENERAL

There have been quite a number of books, articles, seminars and conferences on repairing concrete and the purpose of this chapter is not to abstract the known data but to describe the author's personal experience, ranging from laboratory testing through to precast works repair and culminating in management of repair contracts. The author avoids the temptation to divide repairs up into so-called structural and non-structural categories as the division between them is tenuous to the point of invisibility. There are some structural aspects to even the smallest repair. If one needs to divide repairs up into categories one could use the following two groups, as each relates to separate forms of damage.

A. Design and detailing faults—random cracking, spalling
B. Workmanship and materials faults—regular patterns of cracking or spalling

Even so, these two groups are not always distinct (e.g. badly designed plastics rebar spacers) but the categorisation suggested assists in the pathology of the subject.

When concrete shows distress or does not perform in the way expected of it there are a series of activities required:

(a) Identify fault(s) causing the trouble
(b) Determine whether or not the fault(s) causing the trouble (A, above) can be removed.

— —

(c) Prepare repair specifications for each of the defects, catering for A if the fault(s) cannot be removed.

(d) For work on constructions set out suitable data record sheets for survey.
(e) Complete survey and prepare programme including Bill of Quantities.
(f) Appoint repair company by Tender or Nomination then undertake work.

However, one must not lose sight of the fundamental decision required between steps (b) and (c) accented by the dashed line, the decision lying in the question 'is it repairable or should it be removed and replaced?'.

The philosophy that repair is only applicable to damaged areas is short-sighted. A more sensible approach is to deal with both damaged and undamaged areas to cover the B situation. In effect (a)–(f) will still apply but (c) will be extended to cover apparently sound concrete as well. To exemplify this, take the case of corrosion of reinforcement where the cover of 5 mm to the steel in places has led to spalling in a concrete that has a mediocre or poor permeability at 10 years. Having decided how to deal with the corroding and spalled areas one would also have to specify treatment for areas where there is a latent corrosion risk.

Having decided what needs to be repaired one has a vast number of proprietary materials to choose from, and one needs to select on the basis of the following criteria:

(1) Bond to substrate.
(2) Differential movements.
(3) Durability risks.
(4) Architectural weathering and appearance.

10.2 AVAILABLE MATERIALS FOR REPAIRS

These fall into three groups:

(1) Thermoset plastics such as polyester, epoxide, etc. These are catalysed systems consisting of two or more packs which, when mixed together, cross-link and harden to form a giant single molecule.
(2) Thermoplastics such as styrene-butadiene rubber (SBR), polyvinyl (PVA), acrylic (A), and versatate (V), etc. These are aqueous emulsions which are miscible into Portland cement mortars and concretes and achieve the requisite properties by film formation.

(3) Impregnates and surface treatments such as the silicates, silanes, silicones, stearates, acrylics, polyurethanes, etc. These are the types of materials one would use for invisible latent defect remedial work.

Table 10.1 compares properties between (1), (2) and a control mortar or concrete (0).

TABLE 10.1
COMPARISON OF PHYSICAL PROPERTIES OF MORTARS AND CONCRETES, ETC.

Property	*(0)*	*(1)*	*(2)*
Compressive strength, N/mm^2	20–70	50–120	20–80
E, kN/mm^2	20–30	1–20	1–30
Flexural strength	2–5	25–30	5–15
Tensile strength	1–4	10–20	2–10
% break elongation	0	0–15	0–20
Thermal coefficient of expansion, 10^{-6}	7–12	25–35	10–20
7 day water absorption	5–15	0–1	0·1–0·5
Maximum service temp., °C	300+	40–80	300+
Strength developed at 20°C	1–4 weeks	2–48 hours	1–7 days

10.3 PREPARATION

The most important part of any repair operation, having decided to go ahead with the work, is the preparation to receive (1), (2) or (3) above and it is probably best to list these as separate items.

(a) Exposed steel reinforcement or visible corrosion on surface: Hack away all round area and behind corroding bar to expose full steel periphery. Either remove steel if it performs no useful surface or clean off all loose rust all round the section.
Ensure that all unsound concrete has been removed. Apply a slurry of a (2) or aqueous (3) mixed with cement to the steel and allow to harden.

(b) Spalled areas: Hack away all unsound concrete finishing with a turret or dovetail contour at the original face—avoid feather edging. Fix dowels into all lower part spalls too, support the added reinforcement holding the repair.

(c) Pop-outs, due to pyrites, quicklime, etc.: Hack out all pop-outs down to sound concrete. Examine all the surface carefully as dormant pop-outs could be showing as star-cracking which should be treated in the same fashion.

(d) Cracked reinforced units: Wire brush surface at crack zone and blow all dust clear, then place in warm dry area if possible.

(e) Broken unreinforced units: Clean and dry faces and support to give original line ready for repair.

(f) Faces to receive render: Scabble, bush hammer or similar to remove all unsound material.

(g) Face to receive impregnant: Wash or steam clean following, if necessary, a wire brushing or similar cleaning process.

10.4 REPAIR EXAMPLES

A. Lowcover, permeable concrete, spalling and corrosion.

Preparation	(a) (b)	(f)
Repair	(2) Mortar	(2) Mortar

B. High permeability concrete, no corrosion, cover acceptable.

Preparation	(g)
Repair	(3)

C. As B but cover too low to be acceptable.

Preparation	(f)
Repair	(2) Mortar

D. Broken beam intended for post-tensioning.

Preparation	(e)
Repair	(1) Mortar

See Fig. 10.1, the duct holes were protected from polyester mortar ingression using expanded polystyrene plugs which were easily pierced by the prestressing cables.

E. Cracked (accidentally) reinforced concrete unit

Preparation (d)

Repair (1)

Figure 10.2 illustrates a beam that was cracked and repaired (black line) then re-loaded, re-cracked and re-repaired (invisibly) on line 'IR'. The two dark line areas over the face are where the load was applied. The invisible repair was obtained by cutting out a channel round the crack and filling in with a (2) mortar.

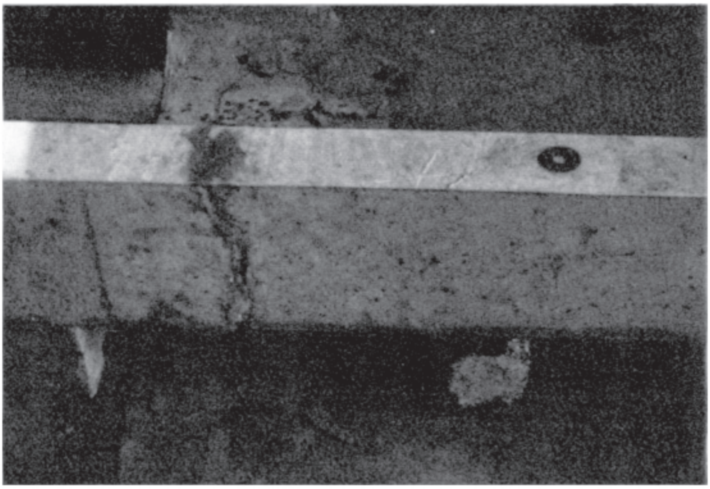

Fig. 10.1. Broken beam for post-tensioning repair.

Fig. 10.2. Cracked and re-cracked reinforced concrete beam repaired twice.

F. Spalled apron of cladding unit in structure.

Preparation	(b)
Repair	(2), or (0) if it has a minimum dimension of 25mm

G. Pop-outs

Preparation	(c)
Repair	(1) or (2), both in mortar form

Architectural matching of a reasonable level of acceptability is possible by finishing off any repair with a (2) or (0) finish but it is not possible to achieve identity. When (2) systems are used right up to face one would need to indulge in 'alchemy' in the laboratory, works or site with varying aggregates and cements to achieve the best match.

10.5 FIRE-RESISTANCE OF THERMOSET REPAIRS

The penultimate entry in the middle column of Table 10.1 shows that there is a fire risk. The author has published an article showing that this can be catered for and the report is abstracted in this section.

A laboratory furnace was constructed to follow the temperature requirement of BS 478 of 900°C in 1 hour, 1050°C in 2 hours, etc. On the roof of the furnace were placed epoxide and polyester butt-jointed and 25 mm mortar-jointed beams. Some of the 25 mm jointed beams had a 25 mm deep limestone-mortar-filled rebate. All concrete units were 150 ×100 mm in section with the 100 mm wide face being exposed to the fire. Cover to the prestressing wires was 50 mm in all cases. Figure 10.3 illustrates a butt-jointed 2 hour failure where it was found that polyester resin-bounded units sagged under load after 1 hour with 6 mm resin degradation depth. For epoxide butt-jointed samples the figures were 30 minutes and 12 mm showing that polyesters have a better fire-resistance than epoxides, although both are short times. The concrete had also degraded past the steel and the prestress was lost at 1 hour in both cases with steel temperatures above 550°C. The 25 mm butt-jointed units hogged as the resin softened in the 0–50 minute period then sagged at 50–80 minutes, and failure occurred at 2 hours for both types of resin mortar. The mortar had degraded 75 mm deep for the polyester and 10 mm deep for the epoxide mortar, the last-named failed sample being shown in Fig. 10.4.

When the joint was recessed as shown in Fig. 10.5 and subsequently filled with a limestone mortar, loss of integrity was observed after 2 hours of fire and the unit shown in Fig. 10.6 performed as though there was no joint present.

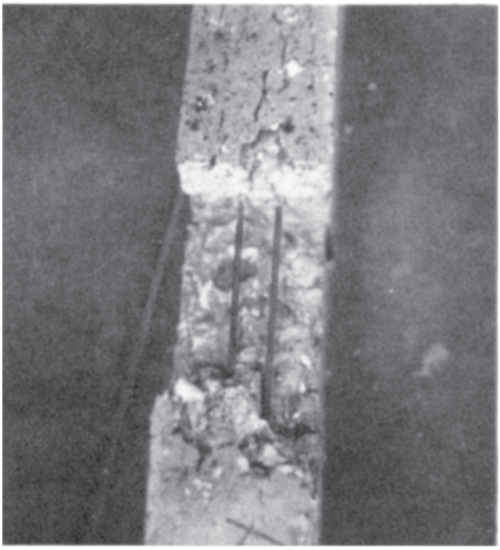

Fig. 10.3. Butt-jointed 2 hour fire test—failure 1 hour.

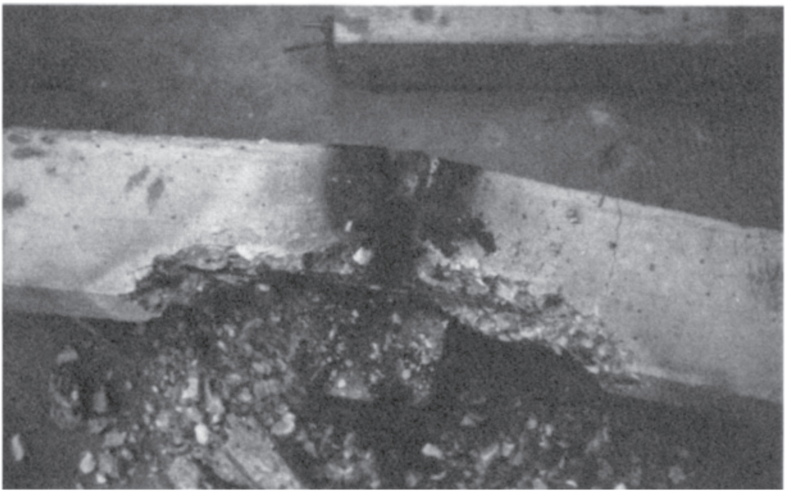

Fig. 10.4. 2 hour fire test on epoxide-mortar 25 mm jointed prestressed unit.

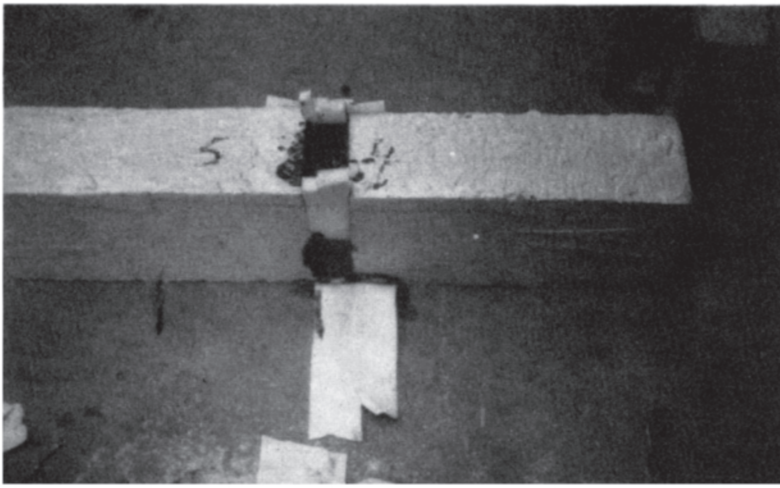

Fig. 10.5. Rebating a mortar joint.

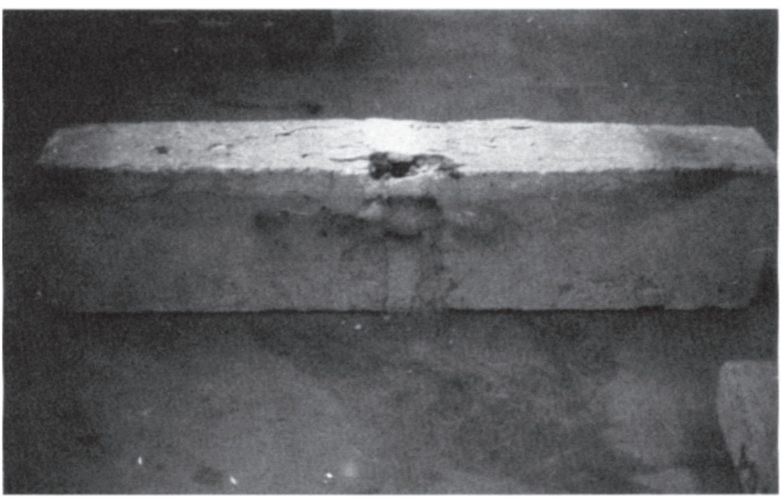

Fig. 10.6. 2 hour fire test on limestone-mortar-pointed resin-mortar joint.

10.6 TESTING

The following tests may be used for assessing the performance of joints:

1. Loading.
2. Pull-offs on isolated squares, rectangles or circles.
3. Abrasion.
4. Impact.
5. Initial surface absorption.
6. Fire.
7. Integrity after submission to various aggressive fluids.
8. Elasticity.
9. Thermal expansion.
10. Shear or torque.

BIBLIOGRAPHY

S.CHAMPION, Failure and repair of concrete structures, *Contractors Record,* Wiley, New York, 1961.

P.H.PERKINS, *Concrete Structures, Repair, Water-Proofing Protection,* Applied Science, London, 1976.

M.LEVITT. The use of adhesives in the bonding repair of precast products, *Civil Engineering,* March/April, 1961.

M.LEVITT, *The fire-resistance of resin-jointed concrete,* Conference on Plastics in Building Structures, London, June 1965, The Plastics Institute.