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1984

Testing of resin compositions for use in construction —

Part 4: Method for measurement of bond strength (slant shear method)

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Committees responsible for this British Standard

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British Adhesive Manufacturers Association
British Plastics Federation
Cement and Concrete Association
Concrete Society
Construction Industry Research and Information Association
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment (Property Services Agency)
Department of the Environment (Transport and Road Research Laboratory)
Federation of Resin Formulators and Applicators Ltd.
Institution of Civil Engineers
Institution of Highway Engineers
Institution of Structural Engineers
Plastics and Rubber Institute
Society of Chemical Industry
Coopted expert

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Contents

Foreword

This Part of this British Standard has been prepared under the direction of the Civil Engineering and Building Structures Standards Committee. This Part describes a method for measurement of bond strength and is one of a series of Parts describing methods for measuring basic physical properties of resin based materials.

The compressive testing of concrete prisms having bonded scarf joints is a well established procedure for assessing bond strength. It has been used in one form or another over the past twenty years to assess such features as bonds in segmental construction and repairs. It has been variously referred to as a composite cylinder test, a combined compression and shear test and a slant shear test. The last of these terms has gained acceptance and has been adopted in this standard.

The use of this form of test does not seem to have become widespread, although a form of slant shear test using cylindrical specimens (the Arizona test) was published by the ASTM[1)] in 1978. In that instance the test was designed to measure the strength of the bond between two separately cast specimens and was of very limited use for the evaluation of crack injection systems. Like the other methods current at the time there were also other deficiencies, not least being the difficulty of casting specimens with two faces coming to a 30° angle.

This method of test is a further development of the earlier methods and has overcome the deficiencies previously apparent, allowing a better simulation of the situations in which resin compositions are used. Of particular importance is that it can be successfully used to evaluate crack repair materials and techniques. The committee acknowledges with gratitude the assistance given by Mr L Tabor during the preparation of this standard. It is anticipated that as a result of the publication of this method of test and as subsequent experience in its use is gained, knowledge of the behaviour of these materials and the ability to interpret the test results obtained will both increase.

This Part of BS 6319 should be read in conjunction with Part 1 which provides general information and describes a method for preparing test specimens.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 10, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

[1)] American Society for Testing and Materials. *Bond strength of epoxy-resin systems used with concrete.* ASTM C882-78.

0 Introduction

Most uses of resin compositions involve their application to hydraulic cement concrete and require the development of a strong adhesive bond between these two materials. The purpose of this test is to investigate the strength of that bond.

If the bond is loaded in compression little information will be obtained, since the only failure likely to occur as a direct result of the compressive stress would be compressive failure of one or other material. Prior failure of the bond line could only be an indirect effect resulting from shear stresses due to differences in the elastic responses of the two materials.

In most cases, if the bond is loaded in tension the result is a tensile failure of the hydraulic cement concrete, a mode in which this material is known to be weak. Hence, "pull-off" tests tend to be of little value since they most often measure only the tensile strength of the concrete, not of the bond.

When hydraulic cement concrete members are required to accommodate a tensile force, this is always achieved by the introduction of a tensile reinforcement, most commonly steel. The high tensile strength of the reinforcement is mobilized by way of shear stresses in the concrete. Shear stresses are also generated as a result of elastic response when concrete is loaded in compression. Thus it would appear that the shear properties of the adhesive bond are the most worthy of investigation if an indication of its useful strength is required.

The generation of pure shear stresses in the bond line between hydraulic cement concrete and a resin composition requires an elaborate set-up if turning moments and tensile stresses are to be avoided. A simpler approach is to apply a compressive load to a specimen taking the form of a composite prism with a bond line running diagonally through it. This method of investigation of the strength of an adhesive bond is known as a diagonal or slant shear bond test. It subjects the bond to a combination of shear and compressive stresses, the type of regime most likely to be encountered in concrete structures. The ratio of shear to compressive stress increases as the angle between the bond line and the vertical axis is reduced. An angle of 30° has been found to be the shallowest practicable angle at which a joint can be formed in a prism of modest dimensions.

The prism may be of hydraulic cement concrete with the resin composition forming a scarf joint between the two halves, or half the prism may be of hydraulic cement concrete and the other half of resin mortar or resin concrete, the interface forming the scarf joint.

Failure of the joint (at a stress of, say, x N/mm^2) before concrete failure occurs could be taken as an indication that the jointing composition and procedure employed would only give monolithic failure of a composite prism if the hydraulic cement concrete was of compressive strength x N/mm^2. To confirm this, or for any other declared reason, the test may be performed with a hydraulic cement concrete mix of any declared design.

The bond may be formed in a variety of ways to correspond to the variety of applications and circumstances for which resin compositions are used. These include the resin injection of cracks (for which a cracked or split test piece is required) and repair techniques using either resin based or hydraulic cement based mortars or concretes. To obviate the difficulties of compacting concretes or mortars into a 30° angle (or of producing a split running out of the concrete at such an acute angle) the test piece is a prism sawn from a larger plaque (see Figure 2). Thus any areas of difficulty are confined to the discarded pieces.

The slant shear bond test may be used not only to appraise the bond strength of materials but also to investigate the effect of concrete pre-treatments (e.g. acid etching) upon the bond strength. Appendices describe the preparation of composite test plaques representing the more typical constructions in which resin compositions are used. The principle of the test may be adopted for various other composite constructions, provided that full details are given in the test report. Similarly, the resin system may be applied, for instance, to damp hydraulic cement concrete, or be applied underwater, to investigate the effect of environmental conditions upon bond strength.

Where the purpose of testing is to provide basic data with which to compare the performance of resin compositions from different sources, it is recommended that these data are determined from tests using plaques made from the high-strength concrete mix described in **5.1.1**. It is important that the compressive strength of the concrete mix used is quoted against the slant shear bond strength of the resin composite. The compressive strength of the mortar or concrete used to prepare a built-up specimen should also be quoted.

1 Scope

This Part of BS 6319 describes a method of determining the slant shear bond strength of resin bonded prisms representing various composite constructions using the test procedure for compressive strength described in BS 6319-2.

Appendix A to Appendix C describe the preparation of composite test pieces (plaques) representing the following constructions:

a) cracked hydraulic cement concrete repaired by resin injection (see Appendix A);

b) hydraulic cement concrete with a resin composition topping or hydraulic cement concrete primed with a resin composition and built-up with a further layer of mortar or concrete (see Appendix B);

c) hardened hydraulic cement concrete bonded to hardened hydraulic cement concrete with a resin composition as, for example, when joining precast concrete units (see Appendix C).

Provision is made for the various conditions under which resin compositions may be applied, e.g. application of the resin composition to damp hydraulic cement concrete or application underwater.

A hydraulic cement concrete mix design is described in clause **5**. This mix design gives a high-strength concrete (compressive strength approximately 65 N/mm) so that the scarf joint may be subject to a considerable stress before the concrete fails. Other mixes may be used, according to the purpose of the test.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 6319 the definitions in BS 6319-1 apply together with the following.

2.1
compressive stress (nominal)

the compressive force (in N/mm^2) carried by the test piece (at any time during the compressive test) per unit area of original cross section measured normal to the principal axis

2.2
compressive strength

the maximum stress (in N/mm^2) carried by the test piece during a compressive test, at the time of failure

2.3
slant shear bond strength

the compressive strength (in N/mm^2) of a scarf-jointed test piece

3 Principle

The principle of this test is the compressive testing of a composite specimen in the form of a 2.7 : 1 aspect rectangular prism that is scarf jointed at 30° to its main axis. The joint is thus subjected to a combination of shear and compressive stresses, in a ratio 1.73 : 1. The result is simply expressed as the compressive strength of the composite prism and observation is made of the mode of failure.

Control specimens of materials used in the preparation of the plaque, including those used to build-up a half-plaque, are also prepared and tested in order to provide comparative information.

4 Apparatus

4.1 *Compression testing machine,* as described in BS 6319-2.

4.2 *Moulds*. Moulds for hydraulic cement concrete plaques shall comply with BS 6319-1 and shall be of a size to produce plaques having the dimensions specified in **5.2.1**.

NOTE 1 These moulds may be used to cast full-size plaques or may be stopped-down to enable half-size plaques to be cast. In the latter case the dimensions will be as shown in Figure 3 and the final size specified in **5.2.1** will be achieved by bonding together two half-plaques or by building-up a single half-plaque.

Moulds for control specimens of the hydraulic cement concrete used in the precast plaque(s) shall comply with BS 6319-1 and shall be of a size to produce prisms having the dimensions specified in **5.2.2**.

NOTE 2 These control specimens may be sawn from precast plaques. (See **5.1.3**.)

Moulds for control specimens of the mortar or concrete used to build-up a plaque (see Appendix B) shall comply with BS 6319-2, BS 1881-108 or BS 4551 according to the material being used.

4.3 *Trapezoidal mild steel plates*, four, each having dimensions as shown in Figure 1, subject to a tolerance of ± 0.5 mm.

4.4 *Elastomeric pads*, two, each having plan dimensions 150 mm × 150 mm and a suitable thickness (see note). The plan dimensions shall be subject to a tolerance of ± 0.5 mm.

NOTE The characteristics of the elastomeric material selected need to be such as to ensure a relatively straight crack when splitting a plaque. 10 mm thick reinforced rubber sheet as used in convey or belting has been found to be suitable, as has 6 mm thick unrein-forced polyurethane elastomer sheet of 90 Shore A hardness.

4.5 *Abrasive saw*, suitably mounted and capable of producing clean vertical cuts through the 55 mm thickness of the concrete plaque.

5 Test specimens

5.1 Preparation of specimens

5.1.1 *Preparation of concrete plaques.* The plaques shall be cast from a high-strength concrete mix of the following composition, or of any other declared composition (see item g) of clause **8**).

NOTE 1 See final paragraph of clause **0**.

Constituent	Parts by mass
Ordinary Portland cement, complying with BS 12	1.0
Coarse aggregate, saturated, surface dry complying with BS 4550-4	2.0
Medium-grade sand, saturated, surface dry, complying with BS 882, BS 1201	1.6
Water/cement ratio	0.4

Each plaque shall be cast either as one unit or as two equally-sized portions (see Figure 3), as appropriate to the composite construction to be tested (see Appendix A to Appendix C).

Hydraulic cement concrete plaques shall be cast and subsequently demoulded and cured, for a total of 28 days, by the method described in BS 1881-111 before any further conditioning that is required.

NOTE 2 Additional plaques may be cast for preparing control specimens (see **5.1.3**).

Prepare composite test plaques by the appropriate method described in the appendices of this standard or by any other declared method (see clause **8**).

5.1.2 *Preparation of test specimens from composite plaques for the slant shear bond test.* After the resin has cured saw the plaque into three sections, so that in the middle section the repair joint or interface bisects the prism at a nominal angle of 30° and runs out of the prism on two opposite long sides, clear of the top and bottom (see Figure 2).

Discard the outer sections of the sawn plaque and use the middle section as the test prism. If this operation is carried out before the end of the full resin curing period, return the test prism to its curing environment as soon as possible. If water cooling is employed for sawing a prism from a composite plaque otherwise being cured in a dry environment, allow the prism to dry before testing it.

5.1.3 *Preparation of control specimens.* Control specimens of the hydraulic cement concrete used in the plaque(s) prepared in accordance with **5.1.1** shall be of the same overall dimensions as the composite test specimens and shall either be sawn from further plaques of the same mix used to prepare the plaques for those specimens, or be cast from the same mix as used to prepare the plaques for those specimens and conditioned as specified in **5.1.1**.

Control specimens of the mortar or concrete used to make built-up specimens shall be cast from the same mix used to prepare the plaque and shall be cast as described in BS 6319-2, BS 1881-108 or BS 4551, according to the material being used.

Control specimens shall be conditioned in the same manner as the composite plaques.

5.2 Dimensions of specimens

5.2.1 ***Specimens for slant shear bond test***

5.2.1.1 *General.* Composite test specimens shall be right true prisms having dimensions 55 mm × 55 mm × 150 mm sawn from plaques having dimensions 55 mm × 150 mm × 150 mm subject to a tolerance of ± 0.5 mm on all cast faces and + 0, – 5 mm on the sawn width (of the test specimen) (see Figure 1 and Figure 2 for details of measurements and orientation of casting).

5.2.1.2 *Squareness.* The surface of each sawn face of the composite test specimen shall lie between two parallel planes 0.5 mm apart which are perpendicular to the adjacent cast faces.

5.2.1.3 *Parallelism.* One end face of the composite test specimen shall lie between two parallel planes 0.25 mm apart, parallel to the other end face. If correction is required this shall be achieved by grinding, or by capping the prism as described in Appendix D.

5.2.2 *Control specimens.* Control specimens of the hydraulic cement concrete used in the precast plaque(s) shall be right true prisms having dimensions 55 mm × 55 mm × 150 mm subject to a tolerance of + 0, – 5 mm on the width and ± 0.5 mm on all other dimensions, and shall comply with **5.2.1.2** and **5.2.1.3**.

Control specimens of the mortar or concrete used to make built-up specimens shall be cubes of the size specified in BS 6319-2, BS 1881-108 or BS 4551 according to the material being used.

6 Procedure

6.1 Sample. For each prescribed set of test conditions, a minimum of four composite test specimens and a minimum of four control specimens of each mortar or concrete used in the composite test specimens shall be tested.

6.2 Measurement. The cross-sectional dimensions of each specimen shall be measured to the nearest 0.5 mm and recorded.

6.3 Testing

6.3.1 *Temperature.* The compressive testing of specimens shall be carried out at 20 ± 1 °C or at any other declared temperature (see clause **8**). The composite test specimens shall be maintained at the test temperature conditions for not less than 16 h before testing commences.

6.3.2 *Placing and loading.* The composite test specimens and the control specimens in the form of prisms shall be positioned and loaded as described in BS 6319-2. The load shall be applied in a direction parallel to the principal axis of the specimen.

Control specimens in the form of cubes shall be tested as described in BS 6319-2, BS 1881-116 or BS 4551, according to the material from which the specimen is made.

7 Calculation

Calculate the compressive strength of each composite test specimen by dividing the load at failure by the cross-sectional area. Also calculate the mean compressive strength for a minimum of four composite test specimens. Express the values to the nearest 1.0 N/mm^2, and report them as slant shear bond strengths.

NOTE The test results are expressed in terms of the compressive strength of the composite prism since this is then easily related to conventional concrete appraisal and design procedures. If the actual shear and compressive stresses are required they are obtained by multiplying the result by ($\sin 30° \cos 30°$) and $\sin^2 30°$ respectively.

Calculate the compressive strength of each control specimen by dividing the load at failure by the cross-sectional area. Also calculate the mean compressive strength for a minimum of four control specimens of the material used in the plaque and, where appropriate, of a minimum of four control specimens of the material used to build-up the composite test specimen (excluding any materials used to cap the ends of specimens). Express the values to the nearest 1.0 N/mm^2.

8 Test report

The following information shall be included in the test report:

a) date and site of sample preparation;

b) date of test;

c) ambient conditions during the preparation and testing of the specimens, and the curing regime adopted including details of conditioning;

d) the age of the hydraulic cement concrete plaque and of the resin bonded scarf joint when tested;

e) a complete identification of the material tested including type, source, manufacturer's code numbers and history;

f) the method of repair or bonding used (crack injection, mortar build-up, etc.);

g) the mix design of the hydraulic cement concrete used;

h) in the case of built-up specimens, the mix design of the material used to build-up the half-plaque;

i) the condition of the concrete face and any pre-treatment used (i.e. "off the mould", riven, acid etched, etc.);

j) full details of any priming system used;

k) if appropriate, method of injection of the resin composition (gravity or forced feed) and final pressure;

l) cross-sectional dimensions of each composite test specimen;

m) cross-sectional dimensions of each control specimen;

n) slant shear bond strength and mode of failure (whether at or near joint or by failure in hydraulic cement concrete or resin composition) of each composite test specimen;

o) mean slant shear bond strength of the composite test specimens (see also clause **0**);

p) compressive strength of each control specimen;

q) mean compressive strength of the control specimens (see also clause **0**);

NOTE Two values will be required for built-up specimens.

r) type of test machine used.

Appendix A Crack repair by resin injection

A.1 Preparation of plaque for repair. Split a single 150 mm × 150 mm × 55 mm hydraulic cement concrete plaque, prepared in accordance with clause **5**, using the procedure described in Appendix E. Take care to keep the two halves in plane.

NOTE 1 This will normally give a crack width of the order of 0.2 mm to 0.5 mm. If it is desired to investigate the performance of the resin composition in repairing wider cracks, the two halves of the plaque may be further separated; this fact then needs to be stated in the test report

Prepare the two ends of the crack, i.e. at the 55 mm faces, for resin injection by the procedure recommended by the material supplier.

NOTE 2 This may involve bonding metal or plastic tubes over the crack for use as inlet and outlet ports, or leaving a short length of crack unsealed if the injection nozzle is to be applied direct to the concrete.

Seal the remainder of the periphery of the crack by the method recommended by the material supplier.

Before injection of the resin composition, condition the split plaque in the environment under which the injection of the resin is to proceed. If the repair is to be carried out on dry concrete, allow the split plaque to dry in air for a period of not less than 16 h. If the repair is to be carried out on wet or damp concrete, force water through the crack to displace all trapped air and then totally immerse the split plaque in lime-saturated water for a period of not less than 48 h.

If the resin composition is to be evaluated for the repair of damp concrete, remove the split plaque from the water at the end of the conditioning period and allow it to drain for 30 min before proceeding to the injection of the resin composition. In the absence of specific requirements, condition the split plaque as specified in clause **4** of BS 6319-1:1983.

If further preparation of the surfaces of the crack is required for a specific purpose this shall be declared in the test report.

If the resin composition is to be evaluated for under-water repair, the injection of the resin composition shall be carried out either with the split plaque submerged in the conditioning tank, or by the following sequence of operations. Temporarily seal the outlet port. Remove the split plaque from the water and immediately connect the resin supply tube to the inlet port. Remove the temporary seal from the outlet port, and inject the resin composition immediately.

A.2 Injection of the resin composition. Support the plaque with its principal axis vertical. The lower end of the crack shall be the entry port for the resin injection. Condition and mix the resin composition in accordance with clause **4** of BS 6319-1:1983. Introduce the resin composition into the crack via the entry port by the method stated in the manufacturer's instructions. In the absence of specific instructions inject the resin from a mastic gun, grease gun or peristaltic pump or similar device. Maintain the flow of the resin composition until all air (or water) has been displaced from the crack and the resin is freely flowing from the discharge port. Seal the discharge port. If required by the manufacturer's instructions, raise the pressure of the resin composition within the crack by further pumping. Seal the inlet port.

Return the injected plaque to its conditioning environment for a further 7 days before proceeding as described in **5.1.2**, unless an alternative period is specified by the resin composition manufacturer.

Appendix B Repair by building-up with resin based or hydraulic cement based mortar or concrete

Prepare in accordance with clause **5** a hardened hydraulic cement concrete unit in the form of a trapezoidal half-plaque as shown in Figure 3. Cast this with the long face "off the mould" or as the upper cast face according to the requirements of the process under investigation, or alternatively split a full-size plaque into two by the method described in Appendix E to give a riven face against which to apply the resin composition.

NOTE With some aggregates, including those described in **5.1.1**, this may give a good simulation of a scabbled surface.

Before building-up the half-plaque, condition it in the environment under which the repair is to proceed. If the repair is to be carried out on dry concrete, allow the half-plaque to dry in air for a period of not less than 16 h. If the repair is to be carried out on wet or damp concrete, totally immerse the half-plaque in lime-saturated water for a period of not less than 48 h. In the absence of specific requirements condition the half-plaque as specified in clause **4** of BS 6319-1:1983.

If pre-treatment is specified in the instructions of the supplier of the resin composition, pre-treat the long face of the concrete unit, for example by acid etching or grit blasting. If the instructions of the manufacturer of the resin composition require the use of a resin primer before the application of a resin mortar or resin concrete, apply resin primer in accordance with the manufacturer's instructions, the resin primer being prepared in accordance with clause **4** of BS 6319-1:1983. Work the primer into the concrete surface by the method given in the instructions of the manufacturer of the resin composition, or otherwise with a stiff-bristled brush.

Place the trapezoidal half-plaque on its base (see Figure 3) in the 150 mm × 150 mm × 55 mm mould (see **4.2**) and fill the mould with the mortar or concrete under test to prepare a full-sized plaque. For resin mortars and concretes, conditioning of mould and materials, filling of the mould, and subsequent curing shall be in accordance with BS 6319-1. For hydraulic cement concrete the procedures given in BS 1881-111 shall be followed.

Appendix C Bonding of precast hydraulic cement concrete units with a resin composition

Prepare in accordance with clause **5** a hydraulic cement concrete plaque as shown in Figure 3, but cast the plaque as two identical trapezoidal halves. The faces to be bonded shall be either "off the mould" or "upper faces as cast" according to the condition being investigated.

Before bonding the half-plaques condition them in the environment under which the bonding is to proceed. If the bonding is to be carried out on dry concrete, allow the half-plaques to dry in air for a period of not less than 16 h. If the bonding is to be carried out on wet or damp concrete, totally immerse the half-plaques in lime-saturated water for a period of not less than 48 h. In the absence of specific requirements, condition the half-plaques as specified in clause **4** of BS 6319-1:1983.

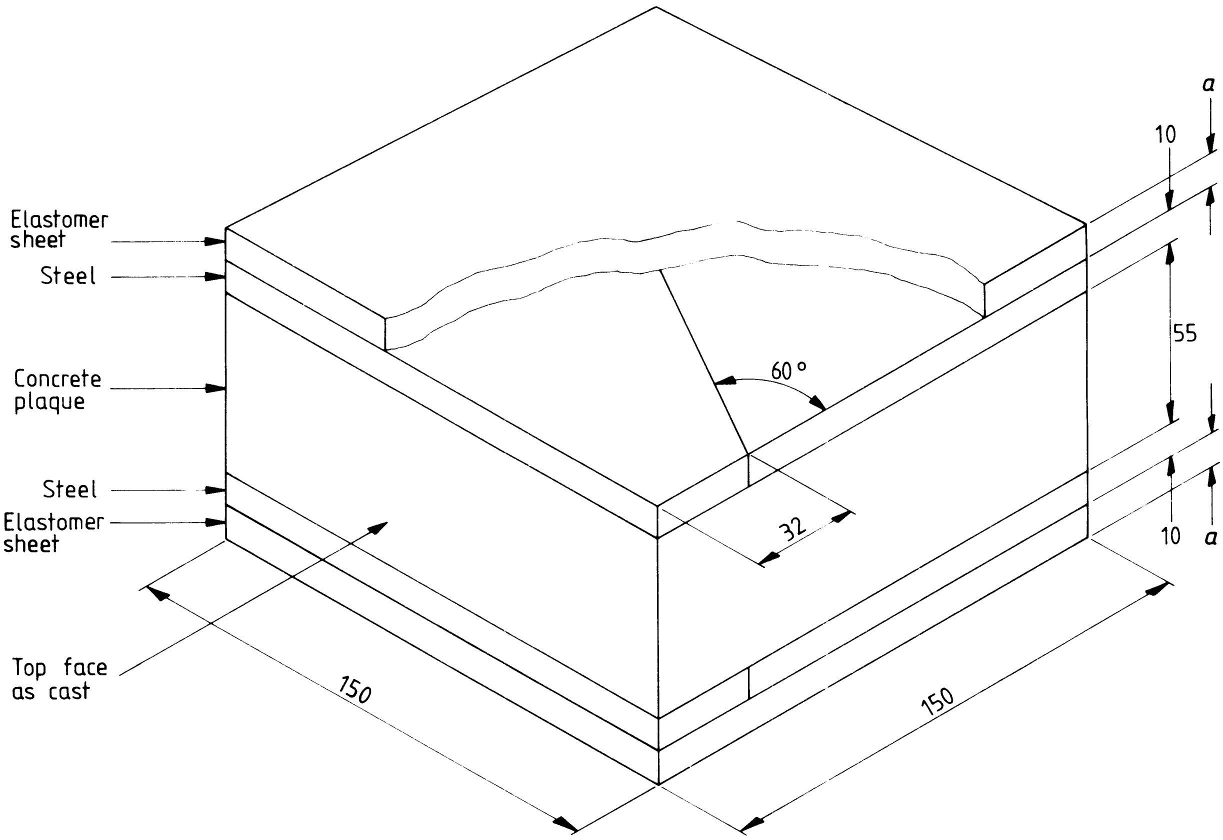
Prepare the concrete surface in accordance with the instructions of the supplier of the resin composition. Mix and apply the resin composition in accordance with the supplier's instructions. When the two halves are brought together take care to keep them in plane; jigs and clamps may be necessary. Leave the bonded plaque undisturbed until the resin has hardened.

Appendix D Procedure for capping test specimens

Separate a 150 mm cube mould complying with BS 1881-108 from its base plate using accurate spacers between the baseplate and the sides of the mould (6 mm float glass is suitable). Apply a release agent to all surfaces of the mould. Apply a finely-filled polyester composition (as used for concrete repair) to both end faces of the prism in slightly domed layers about 5 mm thick. Offer this up to the mould, fitting one of the long arrises snugly into a corner of the mould. Lower the prism carefully, keeping the arris in firm contact with the mould, squeezing out the compound on the bottom face until uniformly bedded. Lightly clamp or support the prism in this position and then squeeze out the excess compound on the top face by carefully pressing a 6 mm float glass plate coated with release agent on top until this is in firm contact with the machined top flanges of the mould. Carefully remove excess compound and leave the prism undisturbed until the capping has hardened.

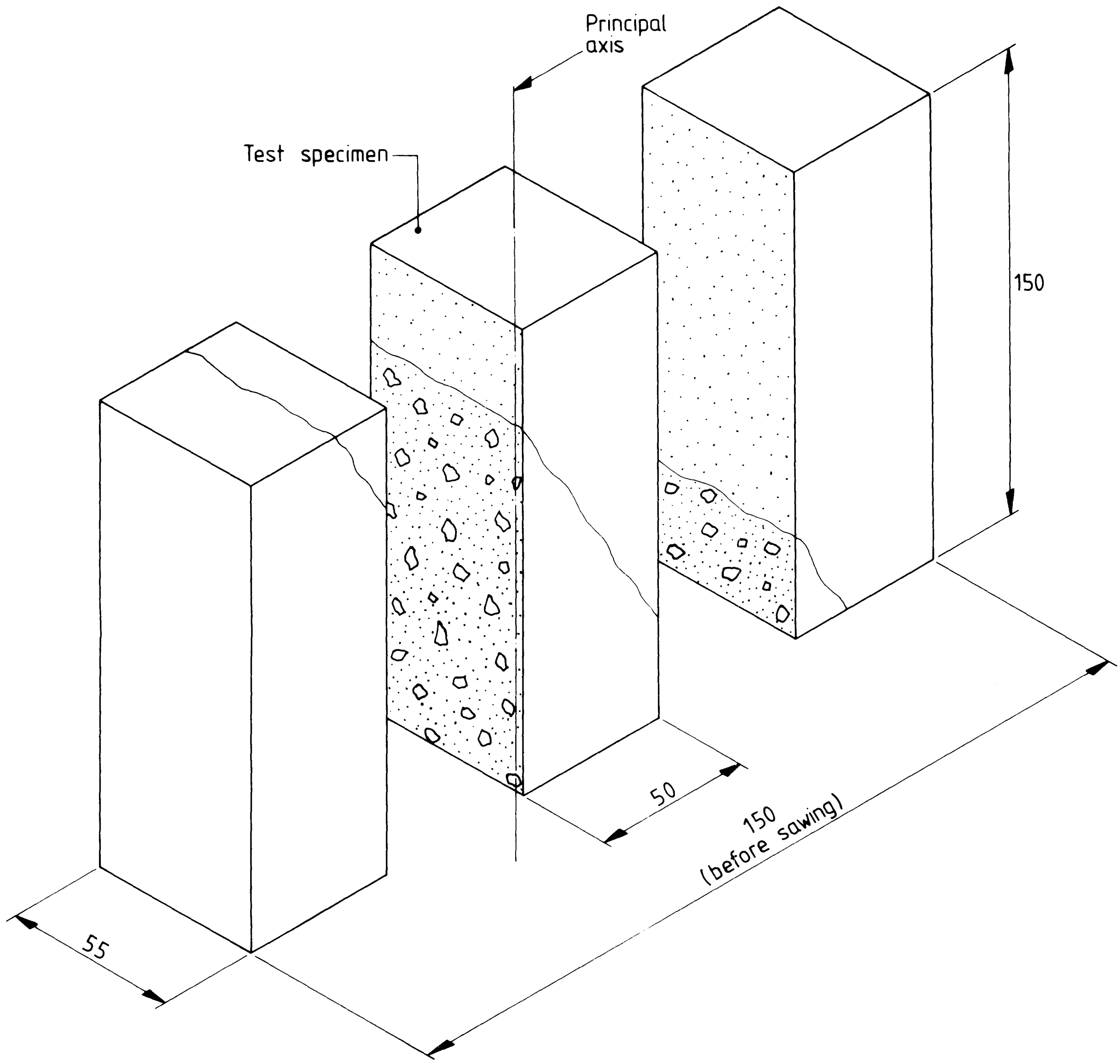
Appendix E Plaque splitting

Assemble the hydraulic cement concrete plaque with the trapezoidal plates and elastomeric pads as shown in Figure 1. Place this assembly between the platens of a hydraulic press and apply load evenly and smoothly until the plaque fractures. Release the load and remove the assembly carefully from the press. If required for resin injection, hold the two halves of the plaque lightly together, to prevent loss of any debris from the crack. This may be done by lightly clamping the plaque, or by fitting a stout rubber band round the plaque before splitting. After removal of the top elastomeric pad and steel plates the plaque is ready for use as a test piece.



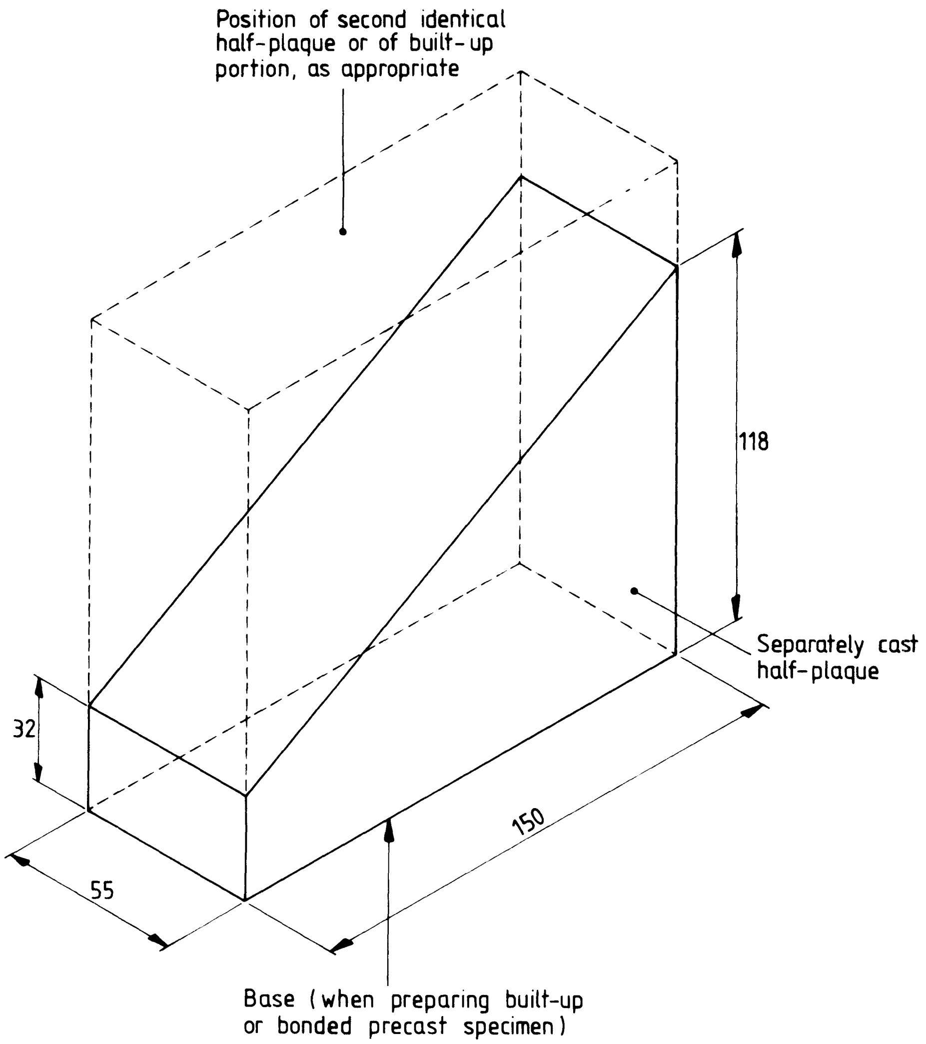
NOTE Thickness of elastomer sheet, *a*, to be in accordance with **4.4**.
Linear dimensions are in millimetres.

Figure 1 — Assembly for splitting concrete plaque at controlled angle



Dimensions are in millimetres.

Figure 2 — Plaque sawn to produce test prism



Dimensions are in millimetres.

Figure 3 — Dimensions of cast half-plaques used for preparation of built-up or bonded test specimens

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Publications referred to

BS 12, *Specification for ordinary and rapid-hardening Portland cement.*
BS 882, *Aggregates from natural sources for concrete.*
BS 1610, *Methods for the load verification of testing machines.*
BS 1881, *Testing concrete.*
BS 1881-108, *Method for making cubes from fresh concrete.*
BS 1881-111, *Method for normal curing of test specimens (20° method).*
BS 1881-115, *Compression testing machines for concrete.*
BS 1881-116, *Method for determination of compressive strength of concrete cubes.*
BS 4550, *Methods of testing cement.*
BS 4550-4, *Standard coarse aggregate for concrete cubes.*
BS 4551, *Methods of testing mortars, screeds and plasters.*
BS 6319, *Methods of test for resin compositions for use in construction.*
BS 6319-1, *Method for preparation of test specimens.*
BS 6319-2, *Method for measurement of compressive strength.*
ASTM C882-78, *Bond strength of epoxy-resin systems used with concrete.*

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