BS 7861-2:2009

BSI Standards Publication

Strata reinforcement support systems components used in coal mines –

Part 2: Specification for flexible systems for roof reinforcement

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Contents

List of tables

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 48, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI and came into effect on 31 October 2009. It was prepared by Subcommittee MRE/1/1, *Roof supports and strata reinforcements*, under the authority of Technical Committee MRE/1, *Mining mechanical equipment and machinery*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This part of BS 7861 supersedes BS 7861-2:1997, which is withdrawn.

Information about this document

Assessed capability. Users of this part of BS 7861 are advised to consider the desirability of quality system assessment and registration against the appropriate standard in the BS EN ISO 9000 series by an accredited third-party certification body.

Product certification/inspection/testing. Users of this part of BS 7861 are advised to consider the desirability of third-party certification/inspection/testing of product conformity with this part of BS 7861. Appropriate conformity attestation arrangements are described in BS EN ISO/IEC 17025. Users seeking assistance in identifying appropriate conformity assessment bodies or schemes may ask BSI to forward their enquiries to the relevant association.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Requirements are expressed in sentences in which the principal auxiliary verb is “shall”.

Where optional recommendations are included, they are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

In particular, attention is drawn to the following statutory regulations.

The Health and Safety at Work etc. Act 1974 [1]

The Chemicals (Hazard Information and Packaging for Supply) Regulations 2009 [2]

The Control of Substances Hazardous to Health Regulations 2002 [3]

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Introduction

This part of BS 7861 meets the need for specifying the quality and performance of components and systems used as flexible reinforcement in coal mines.

Flexible systems for roof reinforcement are formed from steel wire and are generally used to provide strata reinforcement in addition to that provided by conventional rigid rockbolts.

Flexible reinforcement can comprise wound strands, deformed strands or systems assembled from individual wires, which are grouted in place using resins, cementitious materials or a combination of such materials.

NOTE The various methods for performance testing are specified in Annexes A to L. Annex M gives notes on corrosion.

1 Scope

This part of BS 7861 specifies dimensional, material and performance requirements for flexible reinforcement systems used in coal mine roofs.

This standard does not cover the assembly or installation of these components to form a support system on site.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 1881-121, *Testing concrete – Part 121: Method for determination of static modulus of elasticity in compression*

BS 5896, *Specification for high tensile steel wire and strand for the prestressing of concrete*

BS 6319-1, *Testing of resin compositions for use in construction – Part 1: Method for preparation of test specimens*

BS 6319-2, *Testing of resin and polymer/cement compositions for use in construction – Part 2: Method for measurement of compressive strength*

BS EN 196-1:2005, *Methods of testing cement – Part 1: Determination of strength*

BS EN 1008:2002, *Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete*

BS EN 10016-4, *Non-alloy steel rods for drawing and/or cold rolling – Part 4: Specific requirements for rod for special applications*

BS EN 10244-2, *Steel wire and wire products – Non-ferrous metallic coatings on steel wire – Part 2: Zinc or zinc alloy coatings*

BS EN 10264-2, *Steel wire and wire products – Steel wire for ropes – Part 2: Cold drawn non alloy steel wire for ropes for general applications*

BS EN 10264-3, *Steel wire and wire products – Steel wire for ropes – Part 3: Round and shaped non alloyed steel wire for high duty applications*

BS EN 12385-10, *Steel wire ropes – Safety – Part 10: Spiral ropes for general structural applications*

BS EN 12390-1, *Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds*

BS EN 12390-3, *Testing hardened concrete – Part 3: Compressive strength of test specimens*

BS EN 12390-4, *Testing hardened concrete – Part 4: Compressive strength – Specification for testing machines*

BS EN ISO 7500-1:2004, *Metallic materials – Verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Verification and calibration of the force-measuring system*

BS EN ISO 15630-3:2002, *Steel for the reinforcement and prestressing of concrete – Test methods – Part 3: Prestressing steel*

3 Terms and definitions

For the purposes of this part of BS 7861, the following terms and definitions apply.

3.1 bond strength
load in a flexible reinforcement tendon/grout/rock system at which the system stiffness falls below 20 kN/mm, when measured by pull testing, for a given bond length

3.2 capsule loading tube
device used for inserting a resin capsule(s) and its retainer(s) to the distal end of the drilled hole to ensure effective bolt installation

3.3 captivation device
device located at the distal end of a post-grouted flexible reinforcement tendon for effectively retaining the tendon in the hole during and after installation, and during grouting

3.4 cementitious grout
pumpable mixture of cement binder, additives, fine filler and water that hardens after application to form an encapsulating material which provides a bond between the flexible reinforcement tendon and the strata

3.5 compacted strand
strand that has been drawn through a die, or compacted by other means

3.6 coupling assembly
assembly used to connect the proximal ends of two or more tendons

3.7 end fitting assembly
means of transferring load from the proximal end of the tendon to the mine roof surface

3.8 flexible reinforcement system
complete system of strata reinforcement for the roof or sides of roadways and other working places at a mine, comprising a flexible reinforcement tendon; resin or cementitious grout encapsulation, or a combination of both to achieve full encapsulation; and an end fitting assembly or a coupling assembly

NOTE The flexible reinforcement system could also contain a resin-retaining device, a grouting tube, a captivation device (distal end), and a bearing plate and tensioning or termination assembly.

3.9 flexible reinforcement tendon
flexible tendon of steel wire wound into plain strands, deformed strands or assemblies of individual wires, which is secured into the strata to resist ground movement

3.10 gel time
period during which a resin can be mixed with no appreciable change in viscosity, i.e. before it begins to turn from fluid to solid state

3.11 grouting tube
tube forming part of the flexible reinforcement system, through which grout flows during the grouting process, and which remains in situ during service

3.12 grouted systems

3.12.1 composite grouted system
flexible reinforcement system in which more than one type of grout is used for encapsulation, in a single installation

3.12.2 post-grouted system
flexible reinforcement system, in which the tendon is installed and anchored at the distal end, after which the annulus is filled with grout using a bottom-up or top-down grouting system

3.12.3 bottom-up grouting system
flexible reinforcement system in which grout is introduced at the bottom of the hole, feeds up to the top and displaces air down a breather tube to vent at roof level

NOTE This method necessitates a seal(s) at the proximal end of the hole. Full column encapsulation is indicated by the cessation of air bubbles/or a show of grout issuing from the breather.

3.12.4 top-down grouting system
flexible reinforcement system in which grout is introduced through a tube to the top of the hole and then, as it is forced down the annulus, displaces air to vent at the end fitting

NOTE No breather tube is required and full column encapsulation is indicated by grout showing at the end plate. This system requires a suitable grout to achieve a controlled feed down the annulus.

3.13 half-strength time
period after the setting time required for the resin to achieve a uniaxial compressive strength (UCS) of 40 MPa

NOTE This is determined by testing in accordance with Annex D.

3.14 resin grout
non-cementitious encapsulating material, which hardens after application, and is used to achieve a bond between the flexible reinforcement tendon and the strata

3.15 resin retainer
device used to anchor a resin capsule at the distal end of the hole prior to insertion of the strand

3.16 setting time

3.16.1 cementitious grout
period taken for the grout, when mixed to the manufacturer's instructions, to achieve a solid state

*NOTE See BS EN 196-3:2005, Clause **6**.*

3.16.2 resin grout
period following the gel time required for a resin to attain enough strength to resist the pull exerted on a resin encapsulated rockbolt when the rockbolt nut is tightened

[BS 7861-1:2007, **3.14**]

3.17 strand
product consisting of a number of wires spun together, the outer cover wires spun in the same direction and with the same lay length

3.18 system stiffness
stiffness of the flexible reinforcement tendon/grout/rock system for a given bond length over a specified load interval in load per unit displacement (kN/mm), when measured by pull testing

3.19 tensionable reinforcement system
flexible reinforcement system, which has:

a) a facility to anchor the distal end of the tendon, against which tension can subsequently be applied;

b) a proximal end fitting, which allows tension to be applied and retained;

c) the facility to ensure full column encapsulation with pre-tensioning

3.20 wire
product manufactured from one unit of wire rod by cold working

3.21 wire rod
hot rolled steel, delivered in coils, used for cold working treatment, such as wire drawing

4 Information and requirements to be agreed and documented

4.1 Information to be supplied by the purchaser

The following information to be supplied by the purchaser shall be fully documented. For compliance with the standard both the definitive requirements specified throughout the standard and the following documented items shall be satisfied.

a) The shape and dimensions of the wire and significant details of ribs, indentations or crimping (see **5.1.2**).

b) Whether zinc or zinc alloy coated wires are required (see **5.1.4**).

4.2 Items to be agreed

The following items to be agreed between the contracting parties are specified in the clauses referred to and shall be fully documented. For compliance with the standard both the definitive requirements specified throughout the standard and the following documented items shall be satisfied.

a) The shape and dimensions of the wire and significant details of ribs, indentations or crimping (see **5.1.2**).

b) Mass coating values for zinc or zinc alloy coated wires (see **5.1.4**).

c) The inspection and testing of round wires subsequently indented, crimped or formed (see **5.1.6**).

d) The values to which stress-relieved wound strand is to be inspected and tested (see **5.2**).

e) Whether non stress-relieved wound strand is to be supplied un-galvanized and/or with an indented, crimped or formed outer wire, and the values to which this is to be tested (see **5.2**).

f) The gel and setting times of mixed resin if other than as specified in Table 2 (see **7.6**).

4.3 Information to be supplied for system testing of tendons

The tendon supplier shall specify to the testing house:

a) the hole diameters and drill bit types to be used for system testing;

b) the cementitious grout and/or resin grout to be used for system testing; and

c) the official designation or product number for tendons supplied for testing.

Additionally, the tendon supplier shall provide the testing house with a summary of critical dimensions and tolerances for the tendons tested.

4.4 Information to be supplied to the user about tendons

The tendon supplier shall provide the following installation information to the user:

a) suitable installation hole diameters;

b) the drill bit types used for the system tests performed on the product;

c) resin grouts and/or cementitious grouts suitable for use with the tendon, based on the system tests performed on the product;

d) installation instructions, including deployment of captivation device;

e) maximum pre-tension load, if appropriate; and

f) safe handling and transport information.

5 Flexible reinforcement systems

5.1 Wire

5.1.1 Material

The wire rod shall be manufactured in accordance with BS EN 10016-4.

5.1.2 Wire form and types of deformation

The wire shall have a cross-sectional shape and size capable of completely enveloping a 4 mm diameter circle. It may be of any shape or dimension and may be plain, ribbed, indented or crimped, as specified by the purchaser (see Clause **4**).

5.1.3 Determination of wire size

Where the cross-sectional area (or diameter) of a wire is required it shall be determined as follows.

a) The cross-sectional area of a plain round wire shall be calculated from the average of two diameter measurements in perpendicular directions.

b) The cross-sectional area of an indented, crimped or formed wire shall be determined from the diameter of the plain round wire prior to indenting, crimping or forming operation.

In the case of shaped wire, or where it is necessary to measure the actual cross-sectional area (or determine the equivalent diameter) of an indented, crimped or formed wire, this shall be determined from the mass in accordance with BS 5896.

5.1.4 Wire condition

The wire shall be free from defects that would impair the performance of the flexible reinforcement.

Rusted wire shall not be used for the wire drawing process during tendon manufacture.

Products with rusted steel shall not be used in the production of wire, unless the rust is a thin film and the underlying steel surface appears smooth and unpitted to the naked eye.

Where zinc or zinc alloy coated wires are specified in the order for corrosion protection (see Annex M), manufacture, inspection and testing shall be in accordance with BS EN 10244-2. The mass coating shall be to values agreed between purchaser and manufacturer (see Clause **4**).

5.1.5 Welds

Wire may contain welds made before cold working, but shall not contain any welds made during or after cold working. There shall be not more than one such weld in any strand of a tendon assembly.

NOTE Strands that include a welded wire should achieve a breaking load of not less than 98% of the breaking strength of the strand.

5.1.6 Systems assembled from individual wires

Systems assembled from individual stress-relieved wires shall comprise wires manufactured, inspected and tested in accordance with BS 5896. Systems assembled from individual wires that are not stress-relieved shall comprise wires manufactured, inspected and tested in accordance with BS EN 10264-2 for plain wires or BS EN 10264-3 for shaped wires.

Round wires, which are subsequently indented, crimped or formed, shall be inspected and tested to values agreed between purchaser and manufacturer [see **4.2**c)].

5.2 Wound strand

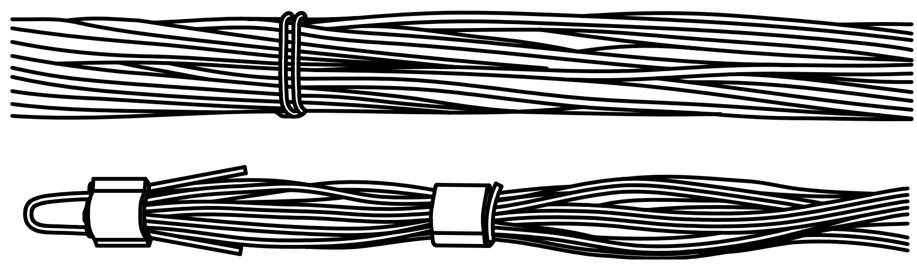
Wound strand which is to be given a stress-relieving heat treatment as the final manufacturing process (typically seven wires or less) shall be manufactured in accordance with BS 5896. The strand shall be inspected and tested in accordance with BS 5896 to values agreed between purchaser and manufacturer [see **4.2**d)].

Strand which is not to be given a stress-relieving heat treatment as the final manufacturing process (typically more than seven wires) shall be manufactured in accordance with BS EN 12385-10 but may, by agreement between purchaser and manufacturer, be supplied un-galvanized and/or with an indented, crimped or formed outer wire. The strand shall be inspected and tested in accordance with BS EN 12385-10 to values agreed between purchaser and manufacturer [see **4.2**e)].

5.3 Deformed strand

Plain strand may be bulbed, either by mechanical means or by unwinding and then rewinding the outer wires over a king wire spacer to form a bulb. These deformed strands can be used either singly or in pairs to form a flexible reinforcement tendon as shown in the examples given in Figure 1.

Figure 1 **Examples of use of deformed strands**



5.4 End fitting and coupling assemblies

5.4.1 End fitting assembly

Every reinforcement system shall include an end fitting assembly to provide support to the immediate roof. A tensionable reinforcement system shall include an end fitting assembly which can also provide and retain a preload to the tendon.

An end fitting assembly may be either yielding, i.e. allow controlled pull-through of the tendon, or non-yielding.

When tested in accordance with Annex A:

a) the average ultimate tensile strength (UTS) for the end fitting assembly of a single strand tendon shall be not less than 90% of the average UTS of the tendon determined in accordance with **5.5**;

b) the average UTS for the end fitting assembly of a double strand tendon shall be not less than 45% of the average UTS of the tendon determined in accordance with **5.5**.

5.4.2 Coupling assembly

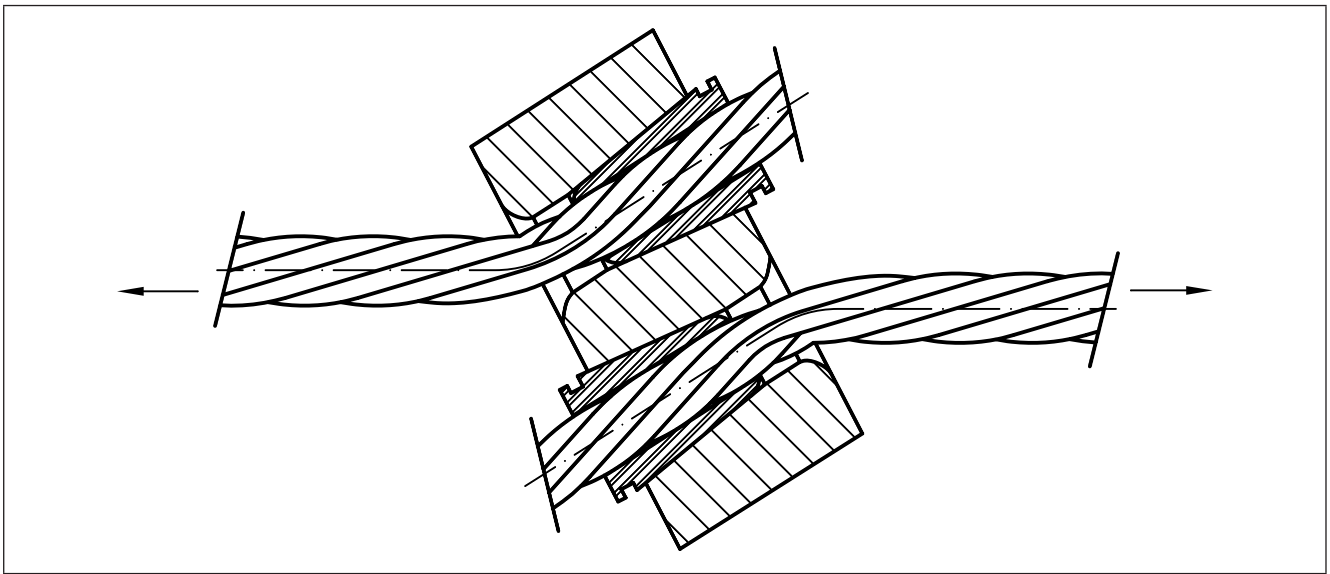
When tested in accordance with Annex A, the average maximum load of the coupling assembly shall be not less than 90% of the UTS of the tendon specified by the tendon supplier.

When tested in accordance with the intended application in terms of loading geometry and direction, the minimum maximum load of the coupling assembly shall be as declared by the supplier.

Each coupling assembly shall be marked with a unique indelible identification mark.

NOTE An example of a coupling assembly under load is shown in Figure 2.

Figure 2 **Example of a coupling assembly under load**



5.5 Mechanical performance of the tendon

When determined in accordance with Annex B:

a) for each test the 0.2% proof load shall be not less than 400 kN;

b) the UTS determined in accordance with Annex A shall be at least 15% greater than the 0.2% proof load on each tensile test; and

c) for each test the strain at maximum force shall be not less than 4% when corrected for constructional effects.

5.6 Post-grouted systems

Post-grouted flexible reinforcement systems shall be designed to achieve and indicate full column resin and/or grout encapsulation. They shall incorporate a captivation device designed to be effective over the manufacturer's range of hole diameters.

5.7 Tensionable tendon systems

5.7.1 Distal anchor

A tensionable tendon system shall incorporate a facility to anchor its distal end with a resin grout conforming to Clause **7**.

The resin-bonded length of the anchor shall be capable of withstanding a tensile load not less than the minimum UTS of the tendon as specified by its manufacturer. This may be calculated using the formula:

Minimum distal anchor bond length (mm) = 3 × UTS (kN).

*NOTE This is based on Clause **8**, which requires a bonded length of 450 mm to have a minimum system bond strength of 300 kN and a 2:1 in situ factor of safety (FOS).*

5.7.2 Proximal end fitting assembly including tensioning facilities

A tensionable tendon system shall incorporate a facility to allow the designed tension to be applied and retained. The proximal end fitting shall provide a means of applying tension in the tendon, such as attachment of a hydraulic tensioning kit, and a means of retaining this tension when the tensioning device is removed.

NOTE The manufacturer should specify the maximum designed pre-tension.

The proximal end fitting assembly shall incorporate a means of introducing resin and/or grout to fill the annulus after the tension has been applied, such that full encapsulation can be achieved. Tubes or ports within the end fitting may be used to achieve this. Any external tubes shall be such that the feed and return are not compromised during installation.

6 Cementitious grout

6.1 General

When tested in accordance with Annex C, the grout shall fully encapsulate the tendon in a pre-drilled hole.

Grout shall be supplied in a form in which it can be readily transported, mixed and pumped, in order fully to encapsulate a long tendon installed in a pre-drilled hole underground.

6.2 Storage life

The manufacturer shall specify the storage life and conditions.

6.3 Packaging

Containers shall be capable of withstanding transportation, handling and storage consistent with a mining environment. The containers shall be clearly marked with the following information:

a) net weight of grout;

b) the required water/solids ratio;

c) the volume of water (L) to be combined with the container net weight in order to achieve the required water/solids ratio;

d) date of manufacture;

e) batch referencing;

f) manufacturer and grout name;

g) the symbols, risk and safety phrases as required under the current legislation [2];

h) type of installation for which the grout is suitable, e.g. "bottom-up" or "top-down".

The actual weight of material shall be within ±1% of the quoted net weight.

NOTE Attention is drawn to the Chemical (Hazard Information and Packaging) Regulations 1995 [2].

6.4 Mechanical performance criteria

6.4.1 Uniaxial compressive strength (UCS)

When determined in accordance with Annex D, the UCS of the grout shall be greater than the minimum values in Table 1.

Table 1 **Uniaxial compressive strength**

Curing period Days	**Minimum UCS** N/mm^2
1	30
3	50
7	60
14	70
28	80

6.4.2 Elastic modulus

When determined in accordance with Annex E, the elastic modulus of the grout shall be greater than 15.5 GPa.

6.4.3 Expansion

When tested in accordance with Annex F, the grout shall demonstrate a minimum positive expansion after setting of 0.01%.

6.5 Mixing water quality

Water used to mix grout shall conform to BS EN 1008:2002, Clause **4**. The chloride content of mixing water shall be a maximum of 500 mg/L as specified for pre-stressed concrete and grout in BS EN 1008:2002, Table 2.

7 Resin grout

7.1 Capsules

Resins shall be supplied in capsule form and shall be such as to achieve full column bonding when used with non post-grouted flexible reinforcement systems.

7.2 Capsule material

The capsules shall contain a filled polyester resin and a catalyst in separate compartments within a frangible sheath.

7.3 Capsule size

Capsules shall be of a diameter and length suitable to the combination of tendon size (diameter and length) and hole diameter, so that, when adequately mixed, the required length of encapsulation of the tendon is achieved. Capsule tolerances shall be ±0.5 mm on diameter and $^{+10}_{-5}$ mm on length when measured between the crimped ends.

7.4 Shelf life of resins

Resins shall be such that, when stored in accordance with the manufacturer's instructions, they retain sufficient rigidity to enable insertion using a capsule loading tube and resin retainer, and continue to conform to **7.6** and **7.7**.

7.5 Packaging of capsules

7.5.1 Capsules shall be so packaged that they are capable of withstanding transport, handling and storage in a mining environment.

7.5.2 The package shall be of a suitable size, shape and weight for manual handling.

7.5.3 The following information shall be displayed on all packages.

a) Manufacturer's name.

b) Type of resin.

c) Size of capsule.

d) Quantity of capsules.

e) Colour code as specified in Table 2.

f) Gel and setting time at 27 °C.

g) Shelf life and storage conditions.

h) Date of manufacture.

i) Weight.

j) Batch or time reference.

k) Manufacturer's identification.

l) The symbols, risk and safety phrases as required under the current legislation [2].

m) Installation procedure.

NOTE Attention is drawn to the Control of Substances Hazardous to Health Regulations 2002 [3].

7.6 Gel, setting and half-strength times of resins

The gel and setting times of the mixed resin, tested at a temperature of 27 °C, shall be as specified in Table 2 or as otherwise agreed between the purchaser and the manufacturer to suit particular reinforcement systems [see **4.2**f)].

The manufacturer shall provide information indicating gel, setting and half-strength times within a temperature range of 20 °C to 35 °C.

Table 2 **Gel, setting and half-strength times for mixed resins**

Resin type (Colour)	**Gel times** s	**Setting times** s	**Half-strength times** min
Fast set (red)	13–18	7–10	2.5
Medium set (yellow)	40–55	10–15	3
Slow set (green)	70–200	30–50	12
Ultra slow set (blue)	270–330	80–140	13

NOTE Times are cumulative, i.e. the setting time starts after the gel time (as tabulated) has passed; similarly, the half-strength time starts after the setting time (as tabulated) has passed.

7.7 Mechanical performance criteria for resins

7.7.1 Uniaxial compressive strength (UCS)

When tested in accordance with Annex G, the UCS of the resin shall be greater than 80 MPa.

7.7.2 Elastic modulus

When tested in accordance with Annex H, the elastic modulus of the resin shall be greater than 11 GPa.

7.7.3 Resistance to creep

When tested in accordance with Annex I, the creep of the resin shall be not more than 0.12%.

7.7.4 Re-testing of resin

All resin shall be re-tested if there is a change in constituents or a change in the production process.

8 System performance

8.1 Tests

Flexible reinforcement system performance tests specified in **8.2** and **8.3** shall be conducted using the grouts, resins and hole sizes recommended for use with a tendon by the tendon manufacturer.

8.2 Bond strength and system stiffness

8.2.1 Resin grouted systems

When tested in accordance with Annex J, the minimum system bond strength of a resin grouted system shall be 300 kN, and the minimum system stiffness shall be 150 kN/mm, measured between loads of 100 kN and 200 kN.

8.2.2 Cementitious grouted systems

When tested in accordance with Annex K, the minimum system bond strength of a cementitious grouted system shall be 400 kN, and the minimum system stiffness shall be 95 kN/mm, measured between loads of 150 kN and 300 kN.

8.2.3 Composite systems

Any section of a system that is resin grouted shall conform to **8.2.1** and any section that is cementitious grouted shall conform to **8.2.2**.

8.3 Shear strength

8.3.1 Resin grouted systems

When tested in accordance with Annex L, the shear strength of a resin grouted system shall be greater than 325 kN.

8.3.2 Cementitious grouted systems

When tested in accordance with Annex L, the shear strength of a cement grouted system shall be greater than 380 kN.

8.3.3 Composite systems

Any section of a system that is resin grouted shall conform to **8.3.1** and any section that is cementitious grouted shall conform to **8.3.2**.

8.4 System pumping for cementitious grouts

8.4.1 System designed for bottom-up grouting

When tested in accordance with:

- **C.2**, the grout shall fully encapsulate the tendon;
- Annex D, the grout UCS after 28 days curing shall conform to **6.4.1**.

8.4.2 System designed for top-down grouting

When tested in accordance with:

- **C.3**, the grout shall fully encapsulate the tendon;
- Annex D, the grout UCS after 28 days curing shall conform to **6.4.1**.

9 Mechanical performance criteria

Type tests shall demonstrate that the mechanical performance specified in **5.4.1**, **5.4.2**, **5.5**, **6.4.1**, **6.4.2**, **6.4.3**, **7.7.1**, **7.7.2**, **7.7.3**, **8.2** and **8.3** can be achieved. The tests specified in **5.4.1** and **6.4.2** should be performed on a routine basis.

Annex A (normative) Tensile testing of end fitting/coupling assemblies

A.1 Principle

The maximum load, deflection and mode of failure are determined in the laboratory by tensile testing.

A.2 Apparatus

A.2.1 *Tensile test machine*, calibrated in accordance with BS EN ISO 7500-1:2004, Class 1 and having an autographic recording facility or other means of providing a load/extension graph.

A.2.2 *Test appratus*, capable of imparting the required test load to the end fitting/coupling assemblies without significant deflection of the apparatus (see Figure A.1 and Figure A.2).

A.3 Procedure

A.3.1 Sample size

Use three specimen end fitting/coupling assemblies for each test.

A.3.2 Test method

Centralize the end fitting/coupling assembly over the backing plate and ensure that all components are correctly seated or secured in accordance with the supplier's specified procedure.

Apply a gradually increasing load (**A.2.2**), avoiding shock loading, and record the corresponding extension values (**A.2.1**).

Discontinue the test following failure of the end fitting assembly, i.e. the point at which nominal load reduction occurs (approximately 5 kN, which is associated with a yielding component, a strand wire breakage generally near to the wedge), or when strand draw-in exceeds 15 mm.

A.4 Results

A.4.1 Prepare load/extension graph(s) (**A.2.1**) showing the load/deflection of the whole assembly, any yielding components and any strand draw-in.

A.4.2 Record the following results:

a) maximum load;

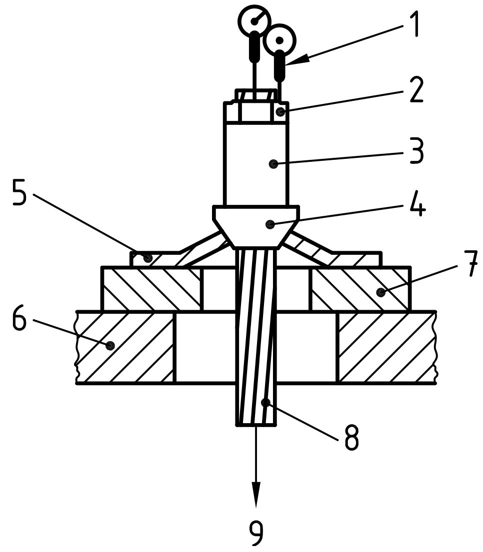
b) deflection of any yielding components immediately prior to failure;

c) strand draw-in, i.e. relative movement between strand and barrel;

d) mode of failure.

Derive the average values of yield load and UTS from the test results of the three specimens.

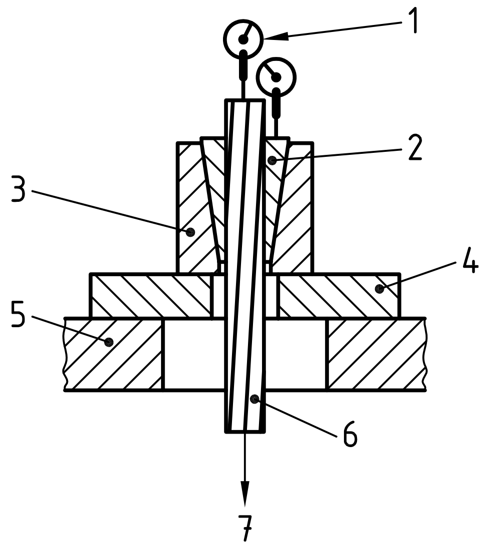
Figure A.1 **Typical end fitting/coupling assembly with a yielding plate**



Key

1 Dial gauges
2 Drive nut
3 Swaged end
4 Conical seat
5 Steel domed washer plate
6 Testing machine platen
7 Backing plate with a hole diameter of (d+2.5w) where d is the largest diameter of the conical seat and w is the thickness of the dome washer plate in mm
8 Tendon
9 Applied load

Figure A.2 **Typical end fitting without yielding plate**



Key

1 Dial gauges
2 Wedge
3 Barrel
4 Backing plate
5 Testing machine platen
6 Tendon
7 Applied load

Annex B (normative) Determination of 0.2% proof load and strain at maximum load in tendons

B.1 Principle

The load-strain behaviour of a flexible reinforcement tendon in uniaxial tension is influenced by both the properties of the steel wires and the construction of the tendon. This is particularly the case for mechanically deformed strands containing bulbs. This annex describes the interpretation of the test records for these products.

B.2 Tensile test procedure

Carry out five tensile tests in accordance with BS EN ISO 15630-3:2002, using an extensometer with a minimum gauge length of 500 mm or two times the lay length of the strand, whichever is the greater. Record the load-strain trace. An example of a typical load-strain trace is shown in Figure B.1.

B.3 Analysis

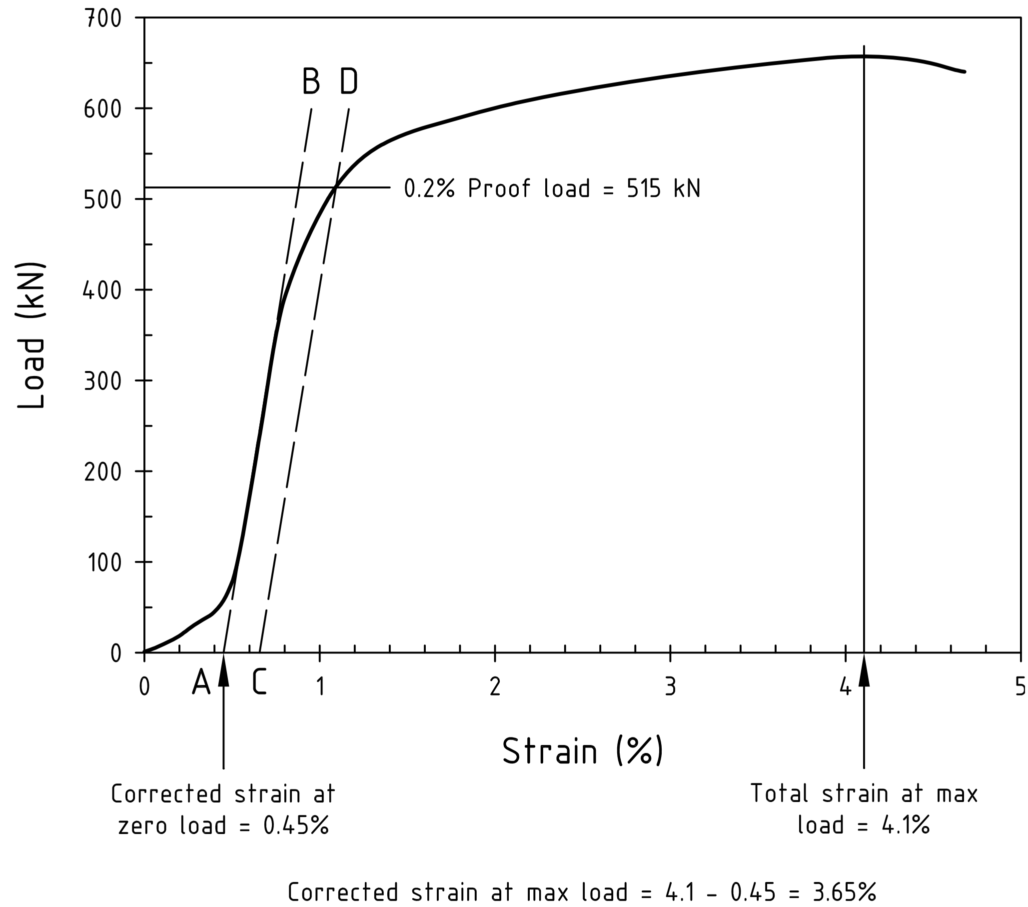
B.3.1 Determination of 0.2% proof load

Construct a tangent on the load-strain trace to the point of maximum gradient above 10% of maximum load (line AB on Figure B.1). Construct a second line parallel to the first, offset by 0.2% on the strain axis (line CD on Figure B.1). The load at which this second line intercepts the load-strain trace is the 0.2% proof load.

B.3.2 Determination of strain at maximum load

Construct a tangent on the load-strain trace to the point of maximum gradient above 10% of maximum load (line AB on Figure B.1), and extending down to intercept the strain axis. This gives an effective value of strain at zero loads without the effect of the tightening of bulbs in the strand. Subtract the effective strain at zero loads from the measured strain at maximum load to give a corrected strain at maximum load.

Figure B.1 **Example of load-strain trace**



Annex C (normative) Grout encapsulation tests

C.1 Overall principle

The ability to achieve complete encapsulation of a flexible reinforcement system (tendon or grout) is determined in the laboratory by grouting a vertical installation of the tendon, using a clear tube to simulate the installation hole and allow viewing of the encapsulation process.

C.2 Bottom-up grouting

C.2.1 Principle

The ability of a bottom-up flexible reinforcement system to consistently achieve full encapsulation is verified.

C.2.2 Apparatus

NOTE A suitable test arrangement is shown in Figure C.1.

C.2.2.1 *Flexible reinforcement tendon*, of the manufacturer's maximum recommended length for vertical installation using standard pumping equipment, installed in a clear rigid tube with an internal diameter equal to the manufacturer's recommended installation hole diameter ±1 mm.

C.2.2.2 *Grouting tube,* either of continuous length or made up from several pieces with made-for-purpose sockets allowing a smooth joint and bonded with a suitable proprietary cement, with:

a) a minimum wall thickness of 2 mm;

b) one end capped with a made-for-purpose end fitting, again bonded with a suitable proprietary cement;

c) airtight joints.

NOTE It is important that the wall thickness and construction of the tube and all ancillary components are selected taking full account of the pressures that could be generated during the test.

C.2.2.3 *Flexible breather and grouting tubes*, if required by the system design, conforming to the recommendations of the tendon manufacturer.

C.2.2.4 *Means of supporting the assembled test tendon and tube in a vertical position*, such as a structure attached to the side of a building, a scaffolding tower, a support pole erected into the vertical position via a pivoting bracket, or other suitable arrangement.

C.2.2.5 *Mixing and pumping equipment*, from the range typically used and accepted for underground use in coal mines, or as recommended by the manufacturer (see Figure C.1). If pneumatically operated, an adequate supply of compressed air (consult the manufacturer's literature) is necessary, connected with suitable low-restriction hosing and couplings.

C.2.2.6 *25 mm bore hose for grouting*, not less than 10 m long and fitted with a suitable connector at one end for connection to the pump, and a means of connection to the grouting tube at the other.

C.2.2.7 *T-piece arrangement at the pump outlet*, with associated valves, couplings and an additional hose to relieve the pressure at the pump after grouting and deliver excess grout or flushings to a suitable container.

C.2.2.8 *Sufficient grout* for efficient operation of the mixing equipment, full encapsulation of the test tendon, and filling of grout sample moulds (**C.2.3.3** and **C.3.3.3**).

C.2.2.9 *Digital scale*, calibrated using equipment with calibration traceable to national standards.

C.2.2.10 *Means of recording the pumping operation*, ideally a video camera.

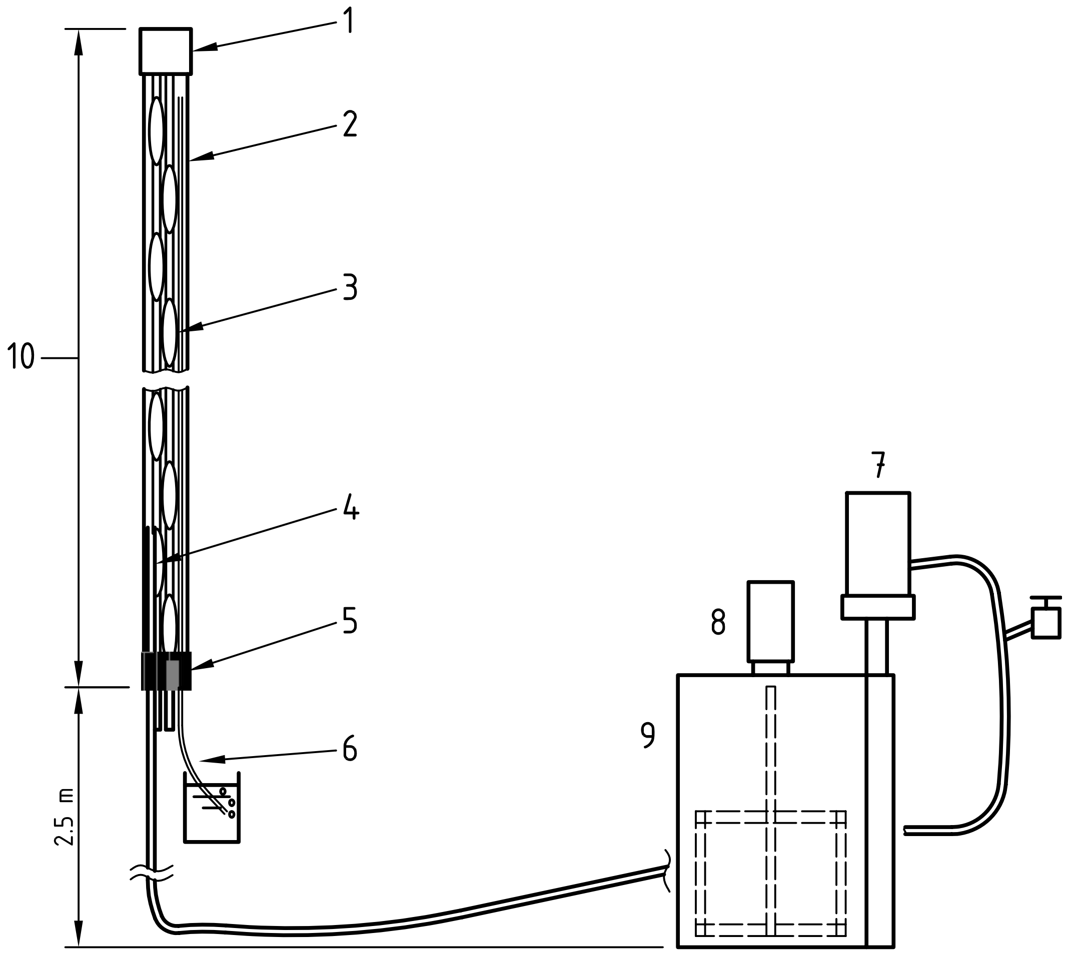
C.2.2.11 *Water for mixing.*

C.2.2.12 *Water container*.

C.2.2.13 *PVC or other tape,* suitable for securing a breather or grouting tube to the tendon or for forming a seal around the joint between tube and tendon.

C.2.2.14 *Camera for photographing sections* (see **C.2.4**).

Figure C.1 **Example arrangement for grout encapsulation test: bottom-up grouting**



Key

1	End cap	6	Breather immersed in water container
2	Clear tube	7	Grout pump
3	Cable bolt	8	Mixer motor
4	Grouting tube 0.5 mm into clear tube	9	Mixing tank
5	Seal	10	Manufacturer's maximum recommended pumped column length

C.2.3 Preparation of the test tendon and grout

C.2.3.1 Preparation of the tendon

Assemble the tube components and bond together. Fit the breather tube and grouting tube (if required by the system design) (**C.2.2.2**) to the tendon (**C.2.2.1**), and secure using PVC or other suitable tape (**C.2.2.13**). Ensure sufficient tubing extends beyond the proximal end of the tendon for immersion in water (breather) and connection to the grout hose (**C.2.2.6**). The test tendon can be anchored either at the top of the tube using, for example, mixed encapsulated resin, and/or at the bottom using a seal and clips/tape. Seal the test assembly at the proximal end with a surgical sock filled with pre-mixed grout, as is typically practised underground, or by some other suitable means.

Raise the test assembly to the vertical using a means of support described in **C.2.2.4**. Ensure that the test tendon is straight to within 100 mm of the notional vertical axis of the test assembly and the proximal end of the test tendon is approximately 2.5 m above ground level.

C.2.3.2 Preparation of the grout

Store the grout (**C.2.2.8**) at a temperature of (20 ±1) °C. Water for mixing (**C.2.2.11**) should also be at this temperature as a result of storage or blending. Weigh the components (water and grout) in the proportions recommended by the manufacturer's water-to-solids ratio, using the digital scale (**C.2.2.9**).

C.2.3.3 Test method

Ensure that the test tendon is securely in position. If a grout seal has been used, allow this to cure for at least 6 h. Immerse the breather tube (**C.2.2.3**) outlet in a container of clear water (**C.2.2.12**).

Pour the water for grout mixing into the mixing tank (**C.2.2.5**), having first established that the tank is clean and empty. Add the grout in increments while using a suitable rotational speed for the mixing paddle. Once all the grout has been added, continue to mix for the period recommended by the grout manufacturer prior to grouting. Continue mixing throughout the grouting operation. Having established that the grout hose (**C.2.2.6**) is clear of water and contaminants (by, for example, blowing through with compressed air), connect the hose to the pump outlet, direct the other end to the mixing tank, and commence pumping to establish a return flow to the tank. Observe the flow to establish that it is continuous, free of air voids and appears to be consistent with the pump manufacturer's quoted flow rates.

NOTE Flow can be checked by filling a known volume and timing the event.

Stop the pump (**C.2.2.5**), and connect the grout hose securely to the grouting tube (**C.2.2.2**).

Start the pumping operation and record events (**C.2.2.10**).

Terminate the test when:

a) full encapsulation is achieved, as indicated by either:
   - a show of grout at the breather tube outlet if a breather tube with a bore of 7 mm or more is used; or
   - a cessation of bubbles at the breather tube outlet; or

b) full encapsulation is prevented by, for example, pump stall or leakage.

Depressurize the circuit by opening the secondary line at the pump outlet and then disconnect the hose from the test assembly. Use the grout hose to fill three moulds with the remaining grout for UCS measurements in accordance with Annex D.

C.2.4 Results

Leave the test tendon in position for at least 12 h to allow the grout to cure. Lower the tendon to the ground and remove any supports. Photograph (**C.2.2.14**) the tendon in approximately 1 m long segments in order to have a record of the encapsulation. Inspect the test tendon and confirm that full encapsulation has been achieved or otherwise. Inspect for any voids in the encapsulation and note their positions. Section the tendon at points where possible voids have been noted, or at four points equally spaced along the tendon. Photograph the sections.

Conduct five tests. For a candidate system to be acceptable, all tests have to be completed satisfactorily.

C.3 Top-down grouting

C.3.1 Principle

The ability of a top-down flexible reinforcement system to consistently achieve full encapsulation is verified.

C.3.2 Apparatus

As in **C.2.2**, except that the grouting tube (**C.2.2.2**) may be either integrated into the tendon structure (internal) or attached along the length of the tendon (**C.2.2.1**) (external). The exact positioning of an external grouting tube should be determined using the manufacturer's specification.

NOTE A suitable test arrangement is shown in Figure C.2.

C.3.3 Preparation of the test tendon and grout

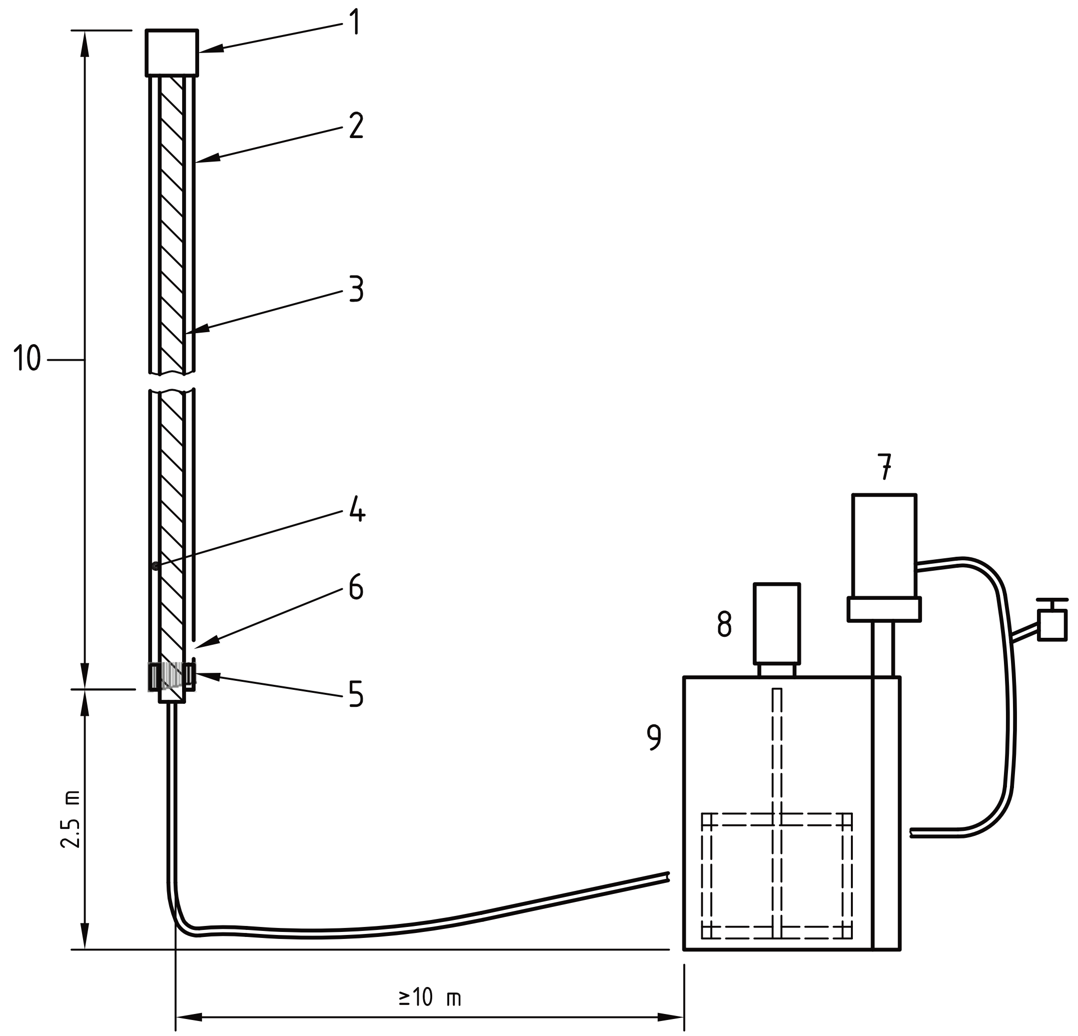
C.3.3.1 Preparation of the tendon

Assemble the tube components and bond together. Fit the grouting tube (if required by the system design) (**C.2.2.2**) to the tendon (**C.2.2.1**), and secure using PVC or other suitable tape (**C.2.2.13**). Ensure that the grouting tube arrangement conforms to the manufacturer's recommendation and is not blocked during assembly and anchorage. Ensure sufficient tubing extends beyond the proximal end of the tendon for connection to the grout hose. The tendon can be anchored either at the top of the tube using, for example, mixed encapsulated resin, and/or at the bottom using a combination of a seal and clips/tape. Seal the test tendon at the proximal end. This arrangement will depend upon whether an end plate is used to complete the installation. If not, a tape seal around the joint between tube and tendon will probably be effective.

Raise the test tendon to the vertical using a means of support as described in **C.2.2.4**.

Ensure that the test tendon is straight to within 100 mm of the notional vertical axis of the test assembly. The proximal end of the test tendon should be approximately 2.5 m above ground level. Provide a means of egress of air at the proximal end via an end plate or a 6 mm hole drilled in the tube just above the seal.

Figure C.2 **Example arrangement for grout encapsulation test: top-down grouting**



Key

1	End cap	6	Breather hole
2	Clear tube	7	Grout pump
3	Flexible reinforcement tendon	8	Mixer motor
4	Grouting tube	9	Mixing tank
5	Seal	10	Manufacturer's maximum recommended pumped column length

C.3.3.2 Preparation of the grout

Prepare the grout in accordance with **C.2.3.2**.

C.3.3.3 Test method

Ensure that the test tendon is securely in position. Pour the water for grout mixing (**C.2.2.11**) into the mixing tank (**C.2.2.5**), having first established that the tank is clean and empty. Add the grout in increments while using a mixing paddle at a suitable rotational speed. Once all the grout has been added, mix for the period recommended by the grout manufacturer. Continue mixing throughout the grouting operation. Having established that the grout hose is clear of water and contaminants (by, for example, blowing through with compressed air), connect the hose to the pump outlet, direct the other end to the mixing tank, and commence pumping to establish a return flow to the tank. Observe the flow to establish that it is continuous, free of air voids and appears to be consistent with the pump manufacturer's quoted flow rates.

NOTE Flow can be checked by filling a known volume and timing the event.

Stop the pump, and attach the grout hose securely to the test tendon using a proprietary lance, grouting tube or other suitable fitting.

Start the pumping operation and record events (**C.2.2.10**).

Terminate the test when grout issues from the breather hole, or full encapsulation is prevented by, for example, pump stall.

Depressurize the circuit by opening the secondary line at the pump outlet and then disconnect the hose from the test assembly. Use the grout hose to fill three moulds with the remaining grout for density and UCS measurements in accordance with Annex D.

C.3.4 Results

Inspect the tendon and record the results in accordance with **C.2.4**.

Annex D (normative) Determination of uniaxial compressive strength (UCS) of cementitious grout

D.1 Principle

The UCS of cementitious grout is determined by subjecting specimens of a defined geometry to a compressive force until failure occurs. Measurement of the compressive force is used to calculate the uniaxial compressive strength, in N/mm^2.

D.2 Apparatus

D.2.1 *Testing machine and auxiliary platens*, conforming to BS EN 12390-4.

D.2.2 *Grout mixer*, conforming to BS EN 196-1:2005, **4.4**.

D.2.3 *Moulds for 100 mm cubes conforming to BS EN 12390-1*, for reference testing.

D.2.4 *Sufficient grout* for filling of grout sample moulds.

D.3 Preparation of test specimens

Mix the grout (**D.2.4**) according to the manufacturer's instructions, using the grout mixer (**D.2.2**).

Prepare all specimens from the same batch of material at (20 ±1) °C. For reference testing, cast at least 15 specimens without compaction. Cover the moulds (**D.2.3**) with steel plates to restrain any plastic expansion.

D.4 Test method

Test three specimens in accordance with BS EN 12390-3 at a temperature of (20 ±1) °C after each curing period of 1, 3, 7, 14 and 28 days (see Table 1).

D.5 Results

Calculate the UCS of each specimen to the nearest 0.5 N/mm^2 as follows:

UCS = *L*/CSA

where:

L is the maximum load in N;

CSA is the cross-sectional area in mm^2.

The UCS of the grout for a specified curing period is the mean of the three individual UCS values. No individual value is to fall below that specified in Table 1.

Annex E (normative) Determination of the elastic modulus of grout

E.1 Principle

A specimen having an aspect ratio of not less than two and not greater than four is subjected to a controlled axial compressive load, relating the compressive stress to the longitudinal strain induced by that stress.

E.2 Apparatus

E.2.1 *Testing machine*, of sufficient capacity and conforming to BS EN 12390-4, capable of applying load at a rate required in **E.4**.

E.2.2 *Grout mixer*, conforming to BS EN 196-1:2005, **4.4**.

E.2.3 *Spacing blocks conforming to BS EN 12390-4,* if necessary, between the specimen and the platen.

E.2.4 *Moulds conforming to BS EN 12390-1,* for reference testing.

E.2.5 *Sufficient grout* for filling of grout sample moulds.

E.2.6 *Robust, stable measuring devices*, capable of determining:

a) the average of two axial strain measurements, equally spaced, for each increment of load, and having a strain sensitivity of the order of 5×10^{-6};

b) axial strain to an accuracy of 2% of the reading and to a precision of 0.2% of full scale.

NOTE Examples are electrical resistance strain gauges and linear variable differential transformers (LVDTs), dial micrometers, compressometers and optical devices.

If electrical resistance strain gauges are used, the length of the gauges over which axial strains are determined should be at least 20 mm and the gauges should not encroach within 15 mm of the specimen ends.

If dial micrometers or LVDTs are used for measuring axial deformation, these devices have to be graduated to read in 0.002 mm units and be accurate within 0.002 mm in any 0.02 mm range and within 0.005 mm in any 0.25 mm range. The dial micrometer or LVDTs should not encroach within 15 mm of the specimen ends.

E.3 Preparation of test specimens

For reference testing, mix the grout in accordance with the manufacturer's instructions. Proceed in accordance with BS 1881-121.

Prepare three samples and allow to cure for 14 days.

E.4 Test method

Conduct reference testing at a temperature of (20 ±1) °C.

Place the test sample in the testing machine (**E.2.1**) such that the load is applied normally to the prepared top and bottom surfaces of the specimen.

Apply a continuous load at a constant stress rate within the range 0.5 $N/mm^2 \cdot s$ to 1.0 $N/mm^2 \cdot s$.

With the load increasing, and without interrupting the loading cycle, record the strain (**E.2.6**) at loads corresponding to 10% and 50% of the estimated UCS.

On reaching the 50% level, and having recorded the strain, remove the load smoothly until the 10% level is achieved, thus completing one cycle.

Re-apply and remove the load for a further two cycles.

If the individual strains are not within a range of ±10% of their mean value at the upper loading stress (in N/mm^2), re-centre the specimen and repeat the test. If it is not possible to reduce the differences to within this range, do not proceed with the test.

E.5 Calculation

Determine the secant modulus for each of the three cycles, with the load increasing.

The value to be quoted for a particular grout is the mean of the three tests, with no test result being below the minimum value.

NOTE See ISRM Rock Characterization, Testing and Monitoring [4].

Annex F (normative) Determination of the expansion of grout

F.1 Principle

The expansion of grout is determined by measuring the percentage change in the length of a bar of set grout after a period of 14 days.

NOTE The test is generally in accordance with that specified in ASTM C490.

F.2 Apparatus

F.2.1 *Length comparator*, capable of accommodating the size specimen given in **F.2.3**, and incorporating:

a) a dial micrometer or other measuring device graduated to read in 0.001 mm or 0.002 mm units, accurate to within 0.002 mm in any 0.20 mm range, and within 0.004 mm in any 0.2 mm range, and of sufficient range (at least 8.0 mm) to allow for small variations in the actual length of the specimens;

b) plane, polished and heat-treated terminals fitted with collars held in place with set screws and extending (1.5 ±0.1) mm beyond the plane face of each terminal and having an inside diameter 0.5 mm greater than the average diameter of the gauge studs that fit into the collars;

c) a reference bar of steel alloy having an overall length of (300 ±1.5) mm and a coefficient of thermal expansion not greater than 2×10^{-6} K^{-1}, each end of which is machined to the same shape as the contact end of a gauge stud and heat-treated, hardened and polished;

d) a means for checking the measuring device against a reference bar at regular intervals.

F.2.2 *Grout mixer*, conforming to BS EN 196-1:2005, **4.4**.

F.2.3 *Moulds,* as shown in Figure F.1, having either one or two compartments giving specimens 25 mm × 25 mm × 285 mm and a gauge length of 250 mm.

F.2.4 *Sufficient grout* for filling of grout sample moulds.

F.2.5 *Water for mixing*.

F.3 Procedure

F.3.1 Preparation of test specimens

Mix the grout (**F.2.4**) in accordance with the manufacturer's instructions, using the grout mixer (**F.2.2**), with water (**F.2.5**) at a temperature of (20 ±1) °C.

Prepare two test specimens from the same batch of material. Leave the test specimens to cure at a temperature of (20 ±1) °C for a period not exceeding 24 h, at a humidity of not less than 75%.

F.3.2 Test method

Perform tests at a laboratory temperature of (20 ±5) °C.

Remove the test specimens from the moulds (**F.2.3**) as soon as is practicable.

Prior to measuring the initial length of the test specimens, read and record the comparator indication of the length of the reference bar [**F.2.1**c)].

Read and record the initial length of each of the test specimens.

Allow the test specimens to cure under water at a temperature of (20 ±1) °C for a period of 14 days from the time of preparation.

After the curing period, repeat the procedure of reading and recording the comparator indication of both the reference bar and the final length of each of the test specimens.

F.4 Results

The percentage change in length at 14 days (l) is given by:

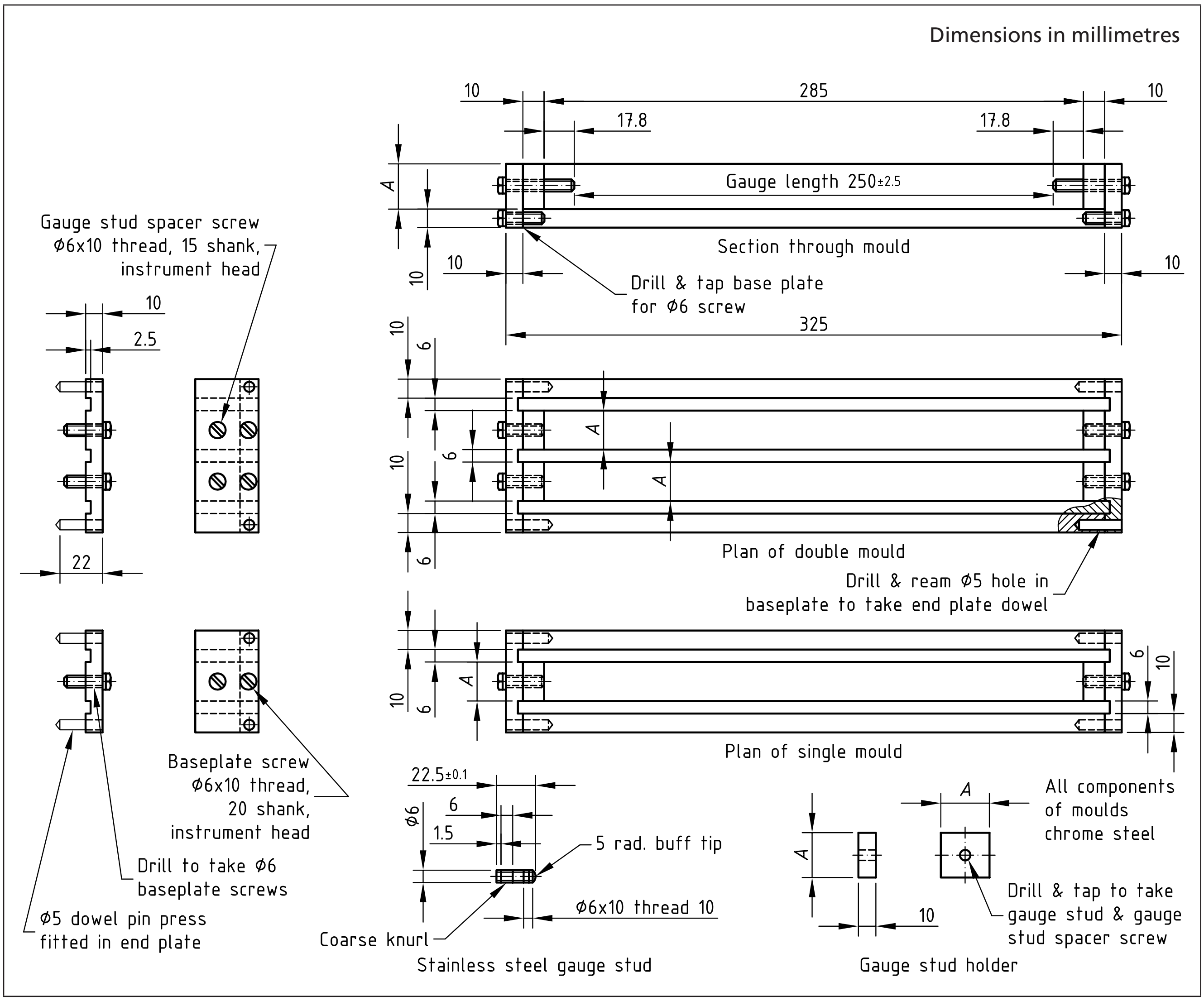
$$(l_2 - l_1)/G \times 100$$

where:

- l_1 is the initial comparator reading of the specimen minus the comparator reading of the reference bar at the same time, in mm;
- l_2 is the comparator reading of the specimen after 14 days, minus the comparator reading of the reference bar at the same time, in mm;
- G is the nominal gauge length, 250 mm.

Calculate the percentage change in length for each specimen to the nearest 0.05% and record the average of the two specimens to the nearest 0.01%.

Figure F.1 **Details of moulds**



Annex G (normative) Determination of uniaxial compressive strength (UCS) of resin grout

G.1 Principle

The UCS of resin grout is determined by subjecting test pieces of a defined geometry to a compressive force until failure occurs. The maximum compressive force is then used to calculate the compressive strength.

G.2 Apparatus

G.2.1 *Test machine*, calibrated to BS EN ISO 7500-1:2004, Class 1, with a capacity and capability to apply load at a rate required by **G.3.2.4**.

G.2.2 *Spacing blocks conforming to BS 6319-2*, if necessary, between the test specimen and platen.

G.2.3 *Moulds conforming to BS 6319-1*, to produce prism samples in accordance with **G.3.1**.

G.3 Procedure

G.3.1 Preparation of test specimens

Prepare eight test specimens from the same batch of resin, each measuring 12.5 mm × 12.5 mm × 25 mm (**G.2.3**).

Condition, proportion and mix the materials and condition and fill the moulds (**G.2.3**) in accordance with BS 6319-1, but at a laboratory temperature of 20^{+1}_{-5} °C.

G.3.2 Method

G.3.2.1 Carry out each test at a laboratory temperature of (20 ±1) °C, 24 h to 26 h after preparation of the test specimens.

G.3.2.2 Measure the width and thickness of each specimen at its centre to the nearest 0.1 mm and calculate the cross-sectional area.

G.3.2.3 Wipe clean the bearing surfaces of the testing machine (**G.2.1**) and any auxiliary platens. Remove any loose grit or other materials from surfaces of the test specimens that are to be in contact with the compression platens. Carefully place each test specimen on the lower platen and centre it in such a manner that the load is applied axially, i.e. parallel to the long axis of the test specimen.

G.3.2.4 Apply load (**G.2.1**) without shock to five of the eight specimens at a rate of 1 mm/min and record the maximum load.

G.3.2.5 If, after testing, a specimen is found to be incompletely mixed (i.e. not homogenous) or to contain voids of sufficient size to affect its strength, exclude this specimen from the results, test one of the spare specimens, and include the results of the test on the spare specimen.

G.4 Results

Calculate the UCS of each cube to the nearest 0.1 MPa as follows:

UCS = Maximum force/Original cross-section area (mm^2).

Discard the highest and lowest load values recorded during testing and use the mean of the remaining three test specimens to calculate the UCS.

Annex H (normative) Determination of elastic modulus of resin

H.1 Principle

A prism of 4:1 aspect ratio is subjected to a controlled axial compressive load, and the compressive stress is related to the longitudinal strain induced by that stress.

H.2 Apparatus

H.2.1 *Test machine*, calibrated to BS EN ISO 7500-1:2004, Class 1, with a capacity and capability to apply load at a rate required by **H.3.2.5**.

H.2.2 *Spacing blocks conforming to BS 6319-2*, if necessary, between the prism and the platen.

H.2.3 *Moulds conforming to BS 6319-1*, of a size to produce rectangular prisms in accordance with **H.3.1**.

H.2.4 *Two strain measuring devices*, either of the direct or indirect type, each:

- providing a minimum gauge length of 20 mm, a maximum sensitivity of 5 units of microstrain, and a continuous indication of change in gauge length;
- calibrated such as to ensure that the error does not exceed 2% of the actual strain;
- preferably incorporating a means of directly recording and plotting the load deformation curves with defined scales.

NOTE Examples of such devices are electrical resistance strain gauges, linear variable differential transformers (LVDTs), dial micrometers and optical devices.

H.2.5 *Sufficient resin* for filling of sample moulds.

H.3 Procedure

H.3.1 Preparation of test specimens

Prepare eight test specimens from the same batch of resin (**H.2.5**), each measuring 12.5 mm × 12.5 mm × 25 mm.

Condition, proportion and mix the materials, and condition and fill the moulds (**H.2.3**) in accordance with BS 6319-1, but at a laboratory temperature of 20^{+1}_{-5} °C.

H.3.2 Method

H.3.2.1 Carry out each test at a laboratory temperature of (20 ±1) °C, 24 h to 26 h after preparation of the test specimens.

H.3.2.2 Measure the width and thickness of each specimen at its centre to the nearest 0.1 mm and calculate the cross-sectional area.

H.3.2.3 For direct measurement, fit the strain measuring devices (**H.2.4**) to opposite cast sides of the test specimen at least 15 mm from the specimen ends, their gauge lengths being centrally disposed over the axis of the specimen.

For indirect measurement, locate the strain measuring devices between the machine platens, ensuring that they are positioned equidistant from the specimen and diagonally opposite each other as shown in Figure H.1

H.3.2.4 Wipe clean the bearing surfaces of the testing machine (**H.2.1**) and the auxiliary platens. Remove any loose grit or other materials from the surfaces of the specimen that are to be in contact with the compression platens. Carefully place the test specimen on the lower machine platen and centre it in such a manner that the load is applied axially, i.e. parallel to the long axis of the test specimen.

Apply load to 5 of the 8 specimens.

H.3.2.5 Without interrupting the loading cycles, apply the load (**H.2.1**) smoothly at a rate of (0.75 ±0.25) (N/mm^2)/s to a load of 7.5 kN, recording the strain at 2.5 kN and 7.5 kN. Smoothly remove the load at the same constant rate to a load of 2.5 kN.

Re-apply and remove the load for a further two cycles, ensuring that each specimen and platen are well seated and that the strain gauges are indicating consistently. Record the strain for each cycle whilst the load is increasing.

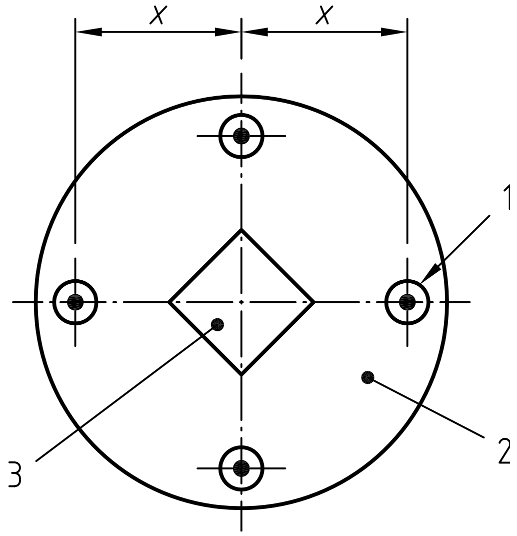
H.3.2.6 If, after testing, a specimen is found to be incompletely mixed (i.e. not homogenous) or to contain voids of sufficient size to affect its strength, exclude this specimen from the results, test one of the spare specimens, and include the results of test on the spare specimen.

H.4 Results

The elastic modulus is the mean of the three-secant moduli measured between the two levels of the applied load.

Discard the highest and lowest strain values recorded during testing and use the mean from the remaining three test specimens to calculate the elastic modulus.

Figure H.1 **Location of measuring devices for indirect strain measurement**



Key

1 LVDT

2 Machine platen

3 Test specimen

Annex I (normative) Determination of creep of resin

I.1 Principle

Test pieces of a defined geometry are subjected to a defined compressive force, and deformation is recorded against time.

I.2 Apparatus

I.2.1 *Test machine*, calibrated to BS EN ISO 7500-1, Class 1:2004, and of sufficient capacity and capability to apply load at a rate required by **I.3.2.5**.

I.2.2 *Spacing blocks conforming to BS 6319-2*, if necessary, between the prism and the platen.

I.2.3 *Moulds*, conforming to BS 6319-1, of a size to produce rectangular prisms in accordance with **I.3.1**.

I.2.4 *Two strain measuring devices*, either of the direct or indirect type, each:

- providing a minimum gauge length of 20 mm and a maximum sensitivity of 5 units of microstrain and a continuous indication of change in gauge length;
- calibrated such as to ensure that the error does not exceed 2% of the actual strain;
- preferably incorporating a means of directly recording and plotting the load deformation curves with defined scales.

NOTE Examples of such devices are electrical resistance strain gauges, linear variable differential transformers (LVDTs), dial micrometers and optical devices.

I.2.5 *Sufficient resin* for filling of sample moulds.

I.3 Procedure

I.3.1 Preparation of test specimens

Prepare eight specimens from the same batch of resin (**I.2.5**), each measuring 12.5 mm × 12.5 mm × 50 mm.

Condition, proportion and mix the materials and condition and fill the moulds (**I.2.3**) in accordance with BS 6319-1, but at a laboratory temperature of 20^{+1}_{-5} °C.

I.3.2 Method

I.3.2.1 Carry out each test at a laboratory temperature of (20 ±1) °C, 24 h to 26 h after preparation of the test specimens.

I.3.2.2 Measure the width and thickness of each specimen at its centre to the nearest 0.1 mm and calculate the cross-sectional area.

I.3.2.3 For direct measurement, fit the strain measuring devices (**I.2.4**) to opposite cast sides of each test specimen at least 15 mm from the specimen ends, their gauge lengths being centrally disposed over the axis of the specimen.

For indirect measurement, locate the strain measuring devices between the machine platens, ensuring that they are positioned equidistant from the specimen and diagonally opposite each other as shown in Figure H.1.

I.3.2.4 Wipe clean the bearing surfaces of the testing machine (**I.2.1**) and any auxiliary platens. Remove any loose grit or other materials from surfaces of the test specimen that are to be in contact with the compression platens. Carefully place the test specimen on the lower platen and centre it in such a manner that the load is applied axially, i.e. parallel to the long axis of the test specimen.

Apply load to 5 of the 8 specimens.

I.3.2.5 Apply the load smoothly (**I.2.1**) at a rate of (0.75 ±0.25) (N/mm^2)/s to a load of 5 kN and maintain this load for a duration of 15 min. Record the strain between 0.5 min and 15 min.

I.3.2.6 If, after testing, a specimen is found to be incompletely mixed (i.e. not homogenous) or to contain voids of sufficient size to affect its strength, exclude this specimen from the results, test one of the spare specimens, and include the results of test on the spare specimen.

I.4 Results

The resistance to creep for each sample is the recorded strain between 0.5 min and 15 min expressed as a percentage.

Discard the highest and lowest strain values recorded during testing and use the mean value from the remaining three test specimens to calculate the resistance to creep.

Annex J (normative) Determination of bond strength and system stiffness of a resin anchored system

J.1 Principle

The bond strength and system stiffness are determined from a laboratory short encapsulation pull test in which a flexible reinforcement tendon sample installed in a confined rock core using resin grout is pull-tested under controlled conditions. Bond performance is assessed in terms of the bond displacement measured against the applied load.

J.2 Apparatus

J.2.1 *Installation apparatus*, comprising:

a) a machine tool lathe, such as that shown in Figure J.1, with a sufficient bed length to allow drilling operations to be carried out in a single pass, and capable of a traverse of 450 mm or more, a rotation speed of 440 r.p.m., and a minimum torque of 200 N·m;

NOTE An automated feed rate of 1.25 mm/rev is desirable, but not essential.

b) a hydraulic biaxial cell, a water feed system and drill assembly as shown in Figure J.2, with a nominal internal diameter of at least 145 mm and a minimum confining membrane length of 500 mm capable of applying a confining pressure of at least 10 MPa.

J.2.2 *Pull test equipment*, as shown in Figure J.3, suitably calibrated and comprising a hydraulic hollow ram jack, a pressure bearing plate or stressing stool, hydraulic hose, pressure gauge and/or load cell and hydraulic pump fitted with a non-return valve;

or

Tensile testing machine, as shown in Figure J.4, calibrated to BS EN ISO 7500-1:2004, Class 1, and capable of applying a load at least equivalent to 90% of the yield strength of the flexible reinforcement tendon under test.

J.2.3 *Autographical recording facility*, or other means of producing a load/extension graph, as shown in Figure J.3, either a linear variable differential transformer (LVDT) or dial indicator to record tendon-end displacement, and an in-line pressure gauge, preferably with an electronic sensor and/or suitable capacity load cell.

J.2.4 *Water feed*, allowing flushing water to be delivered effectively through a rotating drill rod, fixed in the chuck of the lathe, to the tip of the drill bit during drilling operations.

J.2.5 *Drill rod,* which is in good condition, clear of debris and has full flushing functionality.

J.2.6 *Sharp, undamaged drill bit,* of a type and dimension specified by the tendon supplier.

NOTE Most underground installations exhibit rifling of the hole wall, and this should be duplicated in the laboratory test through selection of drilling equipment (bit and rod) and positioning of the drill rod. It has been found that the length of drill rod between drill bit and chuck affects the quality of rifling. Optimum drill rod length may be determined through drilling trials prior to the test. Lack of rifling will almost certainly cause bond failure at the rock/resin interface at a relatively modest bond strength.

J.2.7 *Flexible reinforcement tendon*, which is clean and free from contaminants, and of sufficient length to allow assembly of the pull testing equipment (see Figure J.3) after tendon installation or for installation in a tensile testing machine (see Figure J.4).

J.2.8 *Rock test specimens,* consisting of sandstone rock cores:

a) with an external diameter suitable for installation in the biaxial cell used, and of sufficient length to extend approximately 10 mm beyond the membrane at both ends of the cell;

b) which, when tested in accordance with **J.3** using the standard consumables and criteria in Table J.1, provide test results which lie within the performance envelope shown in Figure J.5, with bond failure occurring at the rock/resin interface;

c) with cores comprising poorly cemented, medium grained, homogeneous sandstone with rounded, well-sorted grains, which, when tested according to ISRM Suggested Methods [5], have a UCS of between 21 MPa and 31 MPa and an elastic modulus of between 7 GPa and 10 GPa.

NOTE An example of a suitable rock is "Hollington Stone", extracted from Hollington Quarry in Staffordshire.

J.2.9 *Sufficient resin* for full encapsulation of the tendon.

J.2.10 *Calibrated borehole micrometer*.

Table J.1 **Standard consumables and criteria for rock core performance testing**

Hole diameter	(28.5 ±0.5) mm
Bond length	160 mm
Confining pressure (biaxial cell)	10 MPa
Drill rod type	19 mm AF, hollow, hexagonal
Bar type	M24 High tensile continuously threaded steel bar, grade 10.9 steel (typical yield strength 312 kN, UTS 346 kN)
Grout type	Resin grout conforming to Clause **7**.

J.3 Procedure

J.3.1 Rock core preparation

Discard core specimens with major irregularities, bedding or discontinuities. Remove any minor irregularities or depressions in the outer surface of the rock core or fill these with a suitable self-hardening filler compound to avoid localized deformation of the cell membrane under pressure.

J.3.2 Installing rock core in biaxial cell

Locate the rock core (**J.2.8**) inside the biaxial cell [**J.2.1**b)], ensuring the cell membrane has full circumferential and axial contact with the rock core. Apply a confining pressure of 10 MPa to the rock core using the biaxial cell, and maintain this throughout testing. Securely mount the biaxial cell on the lathe [**J.2.1**a)] stock such that the axis of the rock core is in alignment with the axis of the lathe chuck and the end, with not more than 10 mm of rock core protruding from the biaxial cell and facing the lathe chuck.

J.3.3 Drilling

Mark the drill rod (**J.2.5**) 450 mm from the bit end. Mount the drill rod in the lathe chuck such that it is concentric, not more than the required length of drill rod extends beyond the face of the chuck, and the water feed is attached.

Advance the lathe saddle until the face of the rock core is close to the drill bit. Operate the lathe at the correct rotational speed (approximately 440 r.p.m.), apply flushing water (**J.2.4**), then manually advance the lathe saddle to initiate drilling. Once the drill bit has begun to penetrate the rock core, ensure that rock penetration continues at the appropriate rate (approximately 1.25 mm/rev).

When the rock core has been drilled to the correct depth (450 mm), withdraw the stock slowly, maintaining lathe rotation and flushing water pressure. Ensure the hole is free of debris and is 450 mm long.

J.3.4 Tendon installation and pull testing

J.3.4.1 General

The procedure for installation of the flexible tendon (**J.2.7**) and testing of the assembly depends on whether pull test equipment or a testing machine (**J.2.2**) is used.

J.3.4.2 Installation of the flexible tendon

Measure and record the internal diameter of the drilled hole using a calibrated borehole micrometer (**J.2.10**), recording the diameter for at least six positions evenly distributed along the length of the borehole. From these readings determine the average borehole diameter.

Cut the end of the tendon to be inserted into the rock core normal to the axis of the tendon.

J.3.4.3 Using pull test equipment

Remove the confined rock core from the lathe [**J.2.1**a)] and place it upright on the laboratory floor. Mix sufficient resin (**J.2.9**) for full encapsulation of the tendon, according to the manufacturer's instructions and ensuring the catalyst is fully dispersed, and pour into the borehole. Push the tendon to be tested into the borehole by hand, ensuring as far as possible that the tendon is central and fully to the back of the hole. Leave the assembly for at least 1 h and pull test within 2 h of mixing.

Assemble the pull test equipment on the installed tendon and core, as shown in Figure J.3.

Operate the hydraulic pump (**J.2.2**) at a slow and smooth rate (approximately 1 kN/s), applying increasing pressure to the hydraulic ram. Record the tendon-end displacement at regular load intervals. Cease pumping either when the tendon end displacement exceeds 10 mm in total, or at 90% of the load at which the yield strength of the tendon would be reached.

After pull testing, relieve the pressure from the pull test ram before relieving the pressure from the biaxial cell to prevent tensile failure of the rock core.

J.3.4.4 Using a tensile testing machine

Depending on the space available in the testing machine (**J.2.2**), it might be necessary to install the tendon when the core assembly has been located in the machine. An example arrangement is given in Figure J.4. Mix sufficient resin for full encapsulation of the tendon (**J.2.9**), according to the manufacturer's instructions and ensuring the catalyst is fully dispersed, and pour into the borehole. Mark the tendon 450 mm from the end and then lower the tendon through the platens and into the hole. Install to the bottom of the hole, rotating the tendon to promote effective distribution of resin. With the tendon fully installed as indicated by the mark, wipe away excess resin from the surface of the core and allow to cure in accordance with **J.3.4.3**.

Fit a displacement transducer or instrument to the free section of tendon between the platens, and adjust to record displacement of the tendon. Leave assembly for at least 1 h and pull test within 2 h. Operate the testing machine to provide a steady loading rate of not more than 1 kN/s and note or auto-record load and displacement. Cease pumping either when displacement exceeds 10 mm in total, or at 90% of the load at which the yield strength of the tendon would be reached.

Following the test, it might be necessary to cut the sample between the platens in order to remove the test equipment from the machine.

Maintain the pressure in the biaxial cell until after removal from the tensile testing machine to prevent tensile failure of the rock core.

J.3.5 Core examination

After testing, withdraw the rock core from the biaxial cell and split the core in the axial plane in order to inspect the quality of installation and mode of bond failure. Examine both the resin/tendon and the resin/rock interfaces and note the location of any shear failure.

J.4 Number of tests

Carry out five pull tests for each target hole diameter.

J.5 Results

Prepare a graph of applied load against bond displacement for each test, where:

> Bond displacement (mm) = Measured displacement – Extension in tendon free length (see Equation J.1).

Determine:

a) bond strength, which is the load at which the slope of the load/displacement characteristic falls below 20 kN/mm; take the mean of the best three results of five tests for each target hole diameter;

b) system stiffness, which is the slope of the load/displacement characteristic in the specified load range; take the mean of the best three results of five tests for each target hole diameter.

$$\text{Extension in tendon free length} = \frac{F \times L}{E^S \times Pi \times D^2 / 4} \quad (J.1)$$

where:

F is the applied force (N);

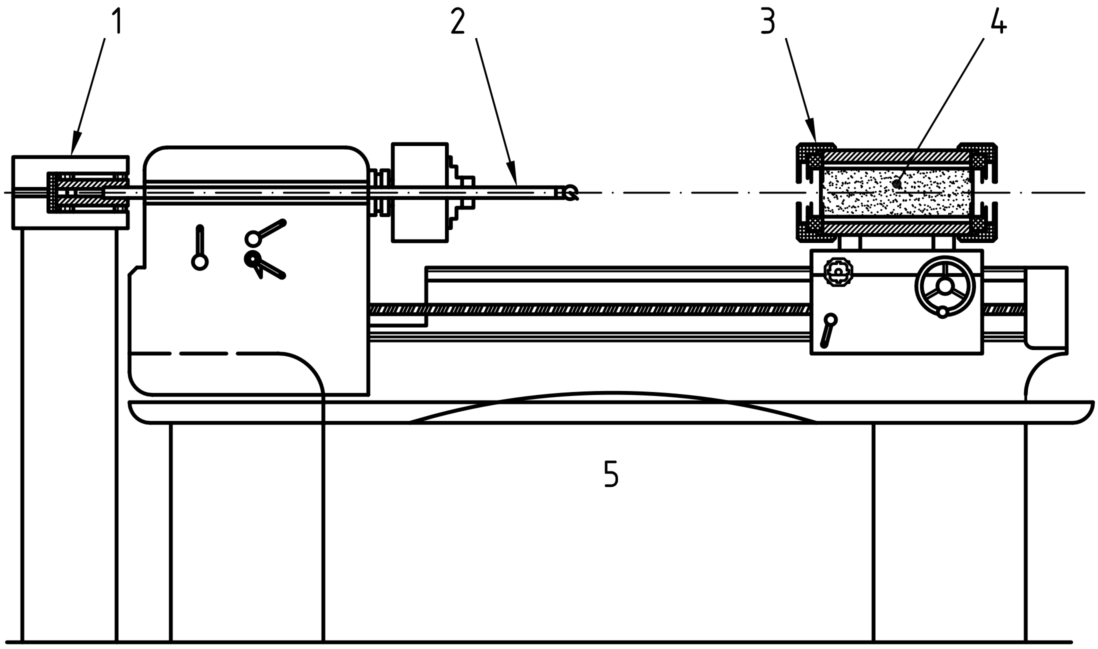
L is the tendon free length (mm);

E^S is the elastic modulus of the tendon material (MPa);

D is the nominal tendon diameter (mm).

NOTE If a tensile testing machine is used, it might be necessary to determine the combined stiffness of the strand and that through displacement inherent in the lower platen box. This can be done by tensile testing a length of strand with a lower end termination replacing the bonded section and biaxial cell.

Figure J.1 **Machine tool lathe**



Key

1 Water feed unit

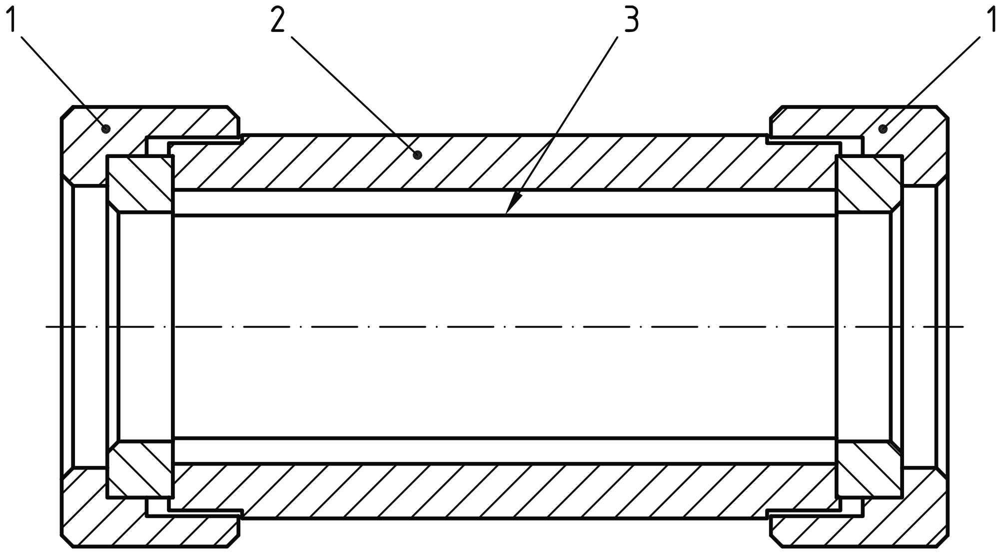
2 Drill rod and bit assembly

3 Biaxial cell mounted on lathe stock

4 Rock core

5 Machine tool lathe

Figure J.2 **Hydraulic biaxial pressure cell**



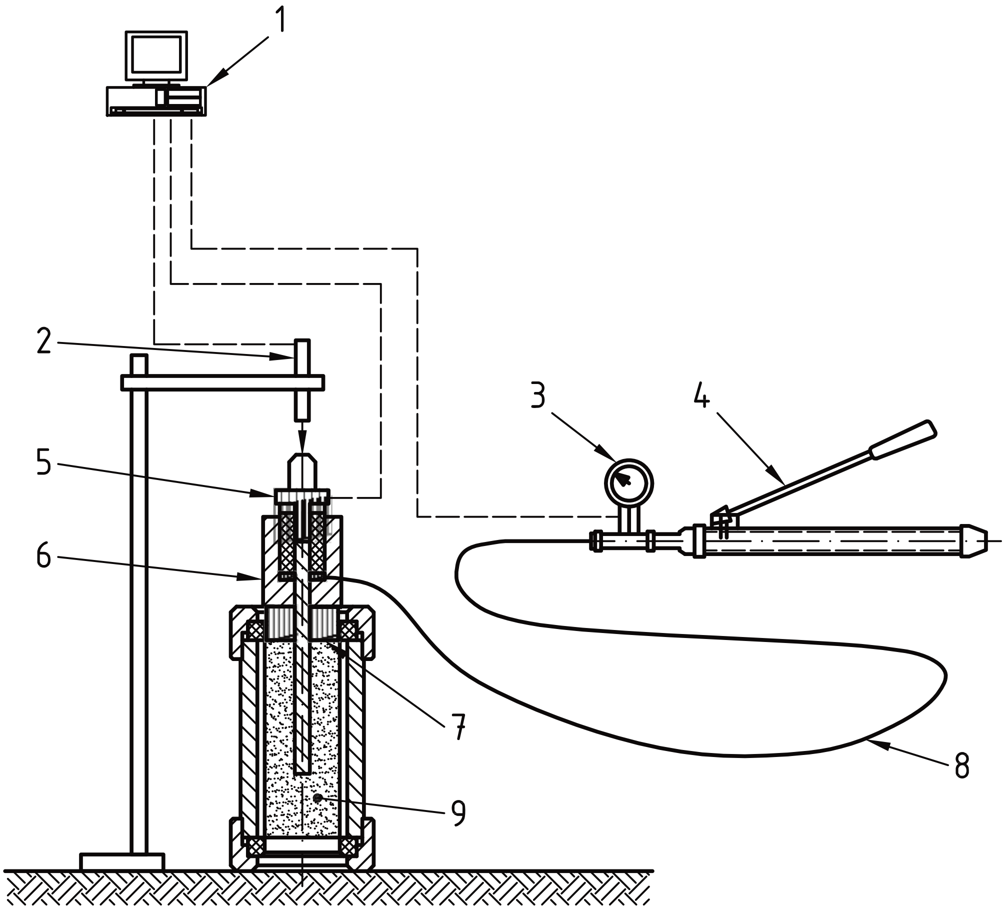
Key

1 End cap

2 Cell body

3 Cell membrane

Figure J.3 **Pull testing equipment**



Key

1 Data connection system

2 LVDT/Dial indicator

3 Pressure gauge transducer

4 Hydraulic pump

5 Load cell

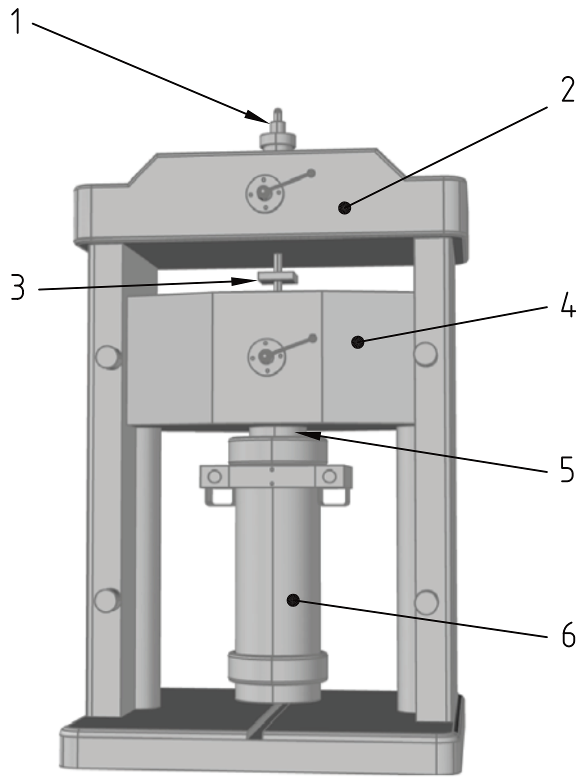
6 Hydraulic ram

7 Bearing plate

8 Hose

9 Rock core housed in biaxial cell

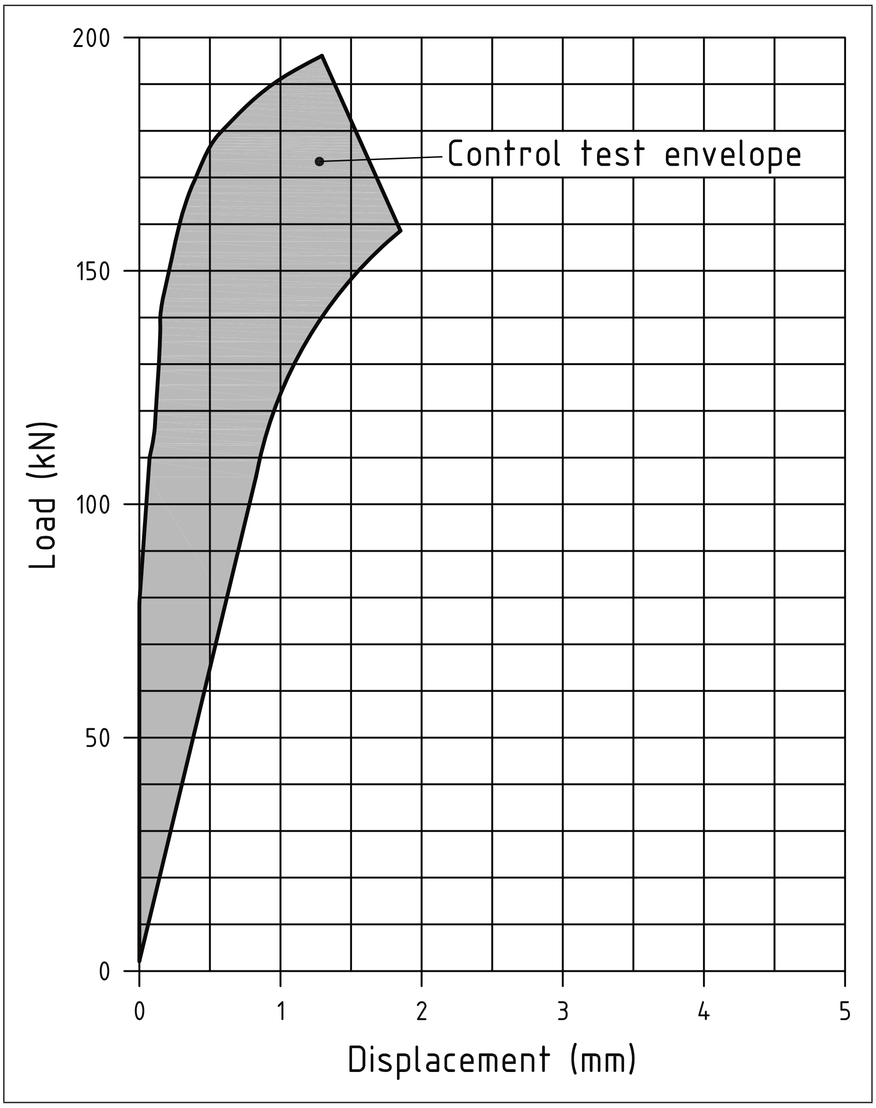
Figure J.4 **Tensile testing machine**



Key

1 Tendon end fitting and bearing plate
2 Upper M/C platen
3 LVDT attached to tendon
4 Lower M/C platen
5 Bearing plate
6 Biaxial cell with test sample installed

Figure J.5 **Rock core type test: Performance control envelope**



Annex K (normative) Determination of bond strength and system stiffness of a cementitious grout anchored system

K.1 Principle

The bond performance of a flexible reinforcement tendon and an associated cementitious grout is determined from a laboratory short encapsulation pull test. A tendon sample installed in a confined rock core using cementitious grout is pull tested under controlled conditions. Bond performance is assessed in terms of load and slope values obtained from the load/bond displacement characteristic.

K.2 Apparatus

K.2.1 *Installation apparatus*, comprising:

a) a machine tool lathe, such as that shown in Figure J.1, with a sufficient bed length to allow the drilling operations to be carried out in a single pass, and capable of a traverse of at least 320 mm (with biaxial cell mounted), a rotational speed of 440 r.p.m., and a minimum torque of 200 N·m;

NOTE An automated feed rate of 1.25 mm/rev is also desirable, but not essential.

b) a hydraulic biaxial cell, a water feed system and drill assembly as shown in Figure J.2, with a nominal internal diameter of at least 145 mm and a minimum confining membrane length of 500 mm, and capable of applying a confining pressure of at least 10 MPa.

K.2.2 *Pull test equipment*, suitably calibrated and comprising a hydraulic hollow ram, a pressure bearing plate or stressing stool, hydraulic hose, pressure gauge and/or load cell, and hydraulic pump fitted with a non-return valve, as shown in Figure J.3.

NOTE The centre hole of the hollow ram should be sufficiently large to allow assembly onto a steel embedment tube. Experience shows that a 95 tonne capacity ram is required to provide a sufficiently large centre hole.

K.2.3 *Autographical recording facility,* or other means of producing a load/extension graph, as shown in Figure J.3; either a linear variable differential transformer (LVDT) or dial indicator to record displacement and an in-line pressure gauge, preferably with an electronic sensor and/or suitable capacity load cell, to record the applied pressure and hence load.

K.2.4 *Water feed*, allowing flushing water to be delivered effectively through a rotating drill rod, fixed in the chuck of the lathe, to the tip of the drill bit during drilling operations.

K.2.5 *Drill rod,* which is in good condition, clear of debris and has full flushing functionality.

K.2.6 *Sharp, undamaged drill bit*, of a type and dimension specified by the tendon supplier.

NOTE Most underground installations exhibit rifling of the hole wall, and this should be duplicated in the laboratory test through selection of drilling equipment (bit and rod) and positioning of the drill rod. However, hole wall rifling is not as critical to bond performance as when testing resin bonded tendons, principally because the larger hole diameter used with cementitious grouted systems provides a high level of shear strength at the rock/grout interface (relative to that achieved with smaller diameter holes used for resin bonded systems) without relying on geometrical discontinuity.

K.2.7 *Flexible reinforcement tendon*:

a) which is clean and free from contaminants;

b) of sufficient length to allow installation into the borehole, and with an overall length of around 1 m;

c) with a “tail” section of straight strand(s) which will protrude beyond the embedment tube and is of sufficient length to allow fitting of spacer plates and barrel/wedge assemblies or other end termination;

d) the end of which to be inserted into the rock core has a fully developed profile and is cut normal to the axis of the tendon.

K.2.8 *Rock test specimens*, consisting of sandstone rock cores*:*

a) with an external diameter suitable for installation in the biaxial cell, and of sufficient length to extend approximately 10 mm beyond the membrane at both ends of the cell;

b) which, when tested in accordance with **K.3** using the standard consumables and criteria in Table K.1, provide test results which lie within the performance envelope shown in Figure J.5, with bond failure occurring at the rock/grout interface;

c) comprising poorly cemented, medium grained, homogeneous sandstone with rounded, well-sorted grains, which, when tested according to ISRM Suggested Methods [5], have uniaxial compressive strength of between 21 MPa and 31 MPa and an elastic modulus of between 7 GPa and 10 GPa.

NOTE An example of a suitable rock is "Hollington Stone", extracted from Hollington Quarry in Staffordshire.

Table K.1 **Standard consumables and criteria for rock core performance testing**

Hole diameter	(28.5 ±0.5) mm
Bond length	160 mm
Confining pressure (biaxial cell)	10 MPa
Drill rod type	19 mm AF, hollow, hexagonal
Bar type	M24 High tensile continuously threaded steel bar, grade 10.9 steel (yield strength 312 kN, UTS 346 kN)
Grout type	Cementitious grout conforming to Clause **6**.

K.2.9 *Embedment tube,* 450 mm long, with:

a) an internal diameter nominally the same as the diameter of the drill bit used to drill the core;

b) a groove 1 mm deep and 2 mm in pitch machined in its internal surface along its full length;

c) a thickness of at least 10 mm;

d) material of a minimum yield stress of 400 MPa;

e) one end threaded on the outer surface to accept a reaction plate.

K.2.10 *Sufficient grout* to fully encapsulate the tendon.

K.2.11 *Calibrated borehole micrometer*.

K.2.12 *Spacer plates and barrel/wedge assemblies or other termination*.

K.2.13 *100 mm cube mould*.

K.2.14 *Reaction plate.*

K.3 Procedure

K.3.1 Rock core preparation

Discard core specimens with major irregularities, bedding or discontinuities. Remove any minor irregularities or depressions in the outer surface of the rock core or fill these with a suitable self-hardening filler compound to avoid localized deformation of the cell membrane under pressure.

K.3.2 Installing rock core in biaxial cell

Locate the rock core inside the biaxial cell, ensuring that the cell membrane has full circumferential and axial contact with the rock core and that approximately 10 mm of rock core overlaps the membrane at both ends of the cell [**K.2.8**a)]. Apply a confining pressure of 10 MPa to the rock core. Securely mount the biaxial cell [**K.2.1**b)] on the lathe [**K.2.1**a)] saddle such that the axis of the rock core is in alignment with the axis of the lathe chuck.

K.3.3 Drilling

Mark the drill rod (**K.2.5**) 320 mm from the bit end. Mount the drill rod in the lathe chuck such that it is concentric, the required length of drill rod extends beyond the face of the chuck, and the water feed (**K.2.4**) is attached. Advance the lathe saddle until the face of the rock core is close to the drill bit (**K.2.6**). Operate the lathe at the correct rotational speed (approximately 440 r.p.m.), apply flushing water, and then manually advance the lathe stock to initiate drilling. Once the drill bit has begun to penetrate the rock core, ensure that rock penetration continues at the appropriate rate (approximately 1.25 mm/rev), preferably by engaging an auto-feed mechanism.

When the rock core has been drilled to a depth of 320 mm, disengage the feed mechanism and withdraw the stock slowly, maintaining lathe rotation and flushing water pressure. Ensure the hole is free of debris and has a depth of 320 mm.

K.3.4 Tendon installation and pull testing

Measure and record the internal diameter of the drilled hole, using a calibrated borehole micrometer (**K.2.11**), recording the diameter for at least six positions evenly distributed along the length of the borehole. From these readings determine the average borehole diameter.

If the tendon is bulbed, ensure that the test piece is prepared such that sufficient bulbs will be located within the rock core to reproduce its in situ behaviour. Do not locate bulbs such that they straddle the end of the borehole. Depending on the manufacturer's designed bulb spacing, typically at least two bulbs would be fully located within the borehole. For a twin strand bulbed tendon, the bulbs in the two strands shall be offset and bound together in the same way as intended to be used in the field. Typically, two bulbs from one strand and a single bulb from the other strand would be fully located within the borehole. Record bulb spacing and location within the borehole and steel embedment tube.

Complete the assembly of the test tendon (**K.2.7**) by securing a 320 mm length of breather or grouting tube, as specified by the tendon supplier, to the distal end. Seal any breather tube of less than 10 mm bore at both ends. Leave open a larger breather tube or grouting tube to admit grout.

Remove the biaxial cell, complete with confined rock core, from the lathe and place it upright on the laboratory floor. Place a sealing membrane around the periphery of the mating face of the steel tube and place the embedment tube (**K.2.9**) on top of the rock core, taking care to centralize the core and tube holes and ensuring that the tendon's "tail" section of straight ends protrudes beyond the embedment tube. Carefully insert the tendon into the assembly and locate to the back of the core hole. Fit spacer plates and barrel/wedge assemblies or other termination (**K.2.12**). Prepare a sufficient quantity of grout to fully encapsulate the tendon (**K.2.10**), taking care to adhere to manufacturers' requirements for water-to-solids ratio, mixing time, etc. Pump the grout slowly into the assembly until full. Top up as necessary as settling occurs.

Fill a 100 mm cube mould (**K.2.13**) from every mix prepared. Allow the grout to cure for 14 days before UCS testing the cube samples in accordance with Annex D and pull testing the tendon/rock/grout assembly as follows.

With the core installed in the biaxial cell and pressurized to 10 MPa, install the pull test equipment on the test assembly, as shown in Figure J.3. Install a reaction plate (**K.2.14**) onto the embedment tube, fit an end termination onto the tendon, and locate to bear on the reaction plate. Fit a dial indicator or LVDT (**K.2.3**) to the end fitting in order to record bond displacement.

Operate the hydraulic pump (**K.2.2**) at a slow and smooth rate (approximately 1 kN/s), applying increasing pressure to the hydraulic ram. Record load and bond displacement incrementally so that a minimum of twenty data points have been recorded when displacement exceeds 10 mm in total, or at 90% of the load at which the yield strength of the tendon would be reached. Cease pump operation at this point.

After pull testing, relieve the pressure from the pull test ram (**K.2.2**) and then relieve the pressure in the biaxial cell.

K.3.5 Core examination

After testing, withdraw the rock core from the biaxial cell and split the core in the axial plane in order to inspect the quality of installation and mode of bond failure. Examine the grout/tendon and the grout/rock interfaces and note the location of any shear failure.

K.3.6 Number of tests

Carry out five pull tests for each target hole diameter.

K.4 Results

Plot load to a base of measured displacement for each test. Determine:

a) bond strength, which is the load at which the slope of the load/displacement characteristic falls below 20 kN/mm; take the mean of the best three results of five tests;

b) system stiffness, which is the slope of the load/displacement characteristic in the range 150 kN to 300 kN; take the mean of the best three results of five tests.

Annex L (normative) Shear test on a tendon/grout system

L.1 Principle

The shear strength of a flexible reinforcement system is determined in the laboratory by testing a flexible reinforcement tendon/grout double embedment assembly in a single shear frame.

L.2 Apparatus

L.2.1 *Single (guillotine) shear frame*, suitable for the testing of a flexible reinforcement tendon/grout double embedment assembly, as shown in Figure L.1.

L.2.2 *Test machine*, calibrated to BS EN ISO 7500-1:2004, Class 1, having an autographic recording facility or other means of producing a force/displacement graph.

L.2.3 *Three test assemblies* (see Figure L.1), consisting of two thick-walled hollow steel tubes, each 450 mm long and with:

a) an internal diameter nominally the same as the diameter of the drilled hole recommended by the manufacturer for tendon installation;

b) a wall thickness of at least 10 mm; and

c) a 1.0 mm deep by 2.0 mm pitch thread machined onto their internal surface in order to provide a standard surface finish intended to inhibit failure between this surface and the grout.

L.2.4 *Displacement transducer*, to record the separation of the two tubes, for example, by measuring the relative displacement of the testing machine platens.

L.2.5 *Flexible reinforcement tendon*, 900 mm in length.

L.2.6 *Sufficient slow-set resin or grout*, mixed in accordance with the manufacturer's instructions, to fully encapsulate one tube/tendon assembly and tube.

L.2.7 *Strong adhesive tape*.

L.3 Procedure

L.3.1 Preparation of test assemblies: general

Prepare three test assemblies (**L.2.3**).

L.3.2 Preparation of test assemblies: resin grouted systems

Blank off one end of each tube (**L.2.3**) with strong adhesive tape (**L.2.7**). Push the tendon (**L.2.5**) into the resin by hand, whilst at the same time slowly rotating the tendon and ensuring as far as is possible that the tendon is centrally positioned within the tube assembly. Remove any excess resin (**L.2.6**) from the tube outer surface and face. Allow to cure for 1 h. Prepare another batch of resin, and fill the second tube. Encapsulate the remaining section of tendon in the second tube, taking care to centralize the tendon within the tube and ensure that the tube faces are fully butted together. Allow the assembly to cure for at least 24 h at a room temperature of (20 ±2) °C.

L.3.3 Preparation of test assemblies: cementitious grouted systems

Blank off the end of one of the tubes with strong adhesive tape, and butt together the open ends, securing the joint temporarily with strong adhesive tape. Pour grout (**L.2.6**) into the tubes. Push the tendon into the grout by hand, whilst at the same time slowly rotating the tendon, and ensuring, as far as is possible, that the tendon is centrally positioned within the tube assembly. Allow the assembly to cure at a room temperature of (20 ±2) °C for 14 days.

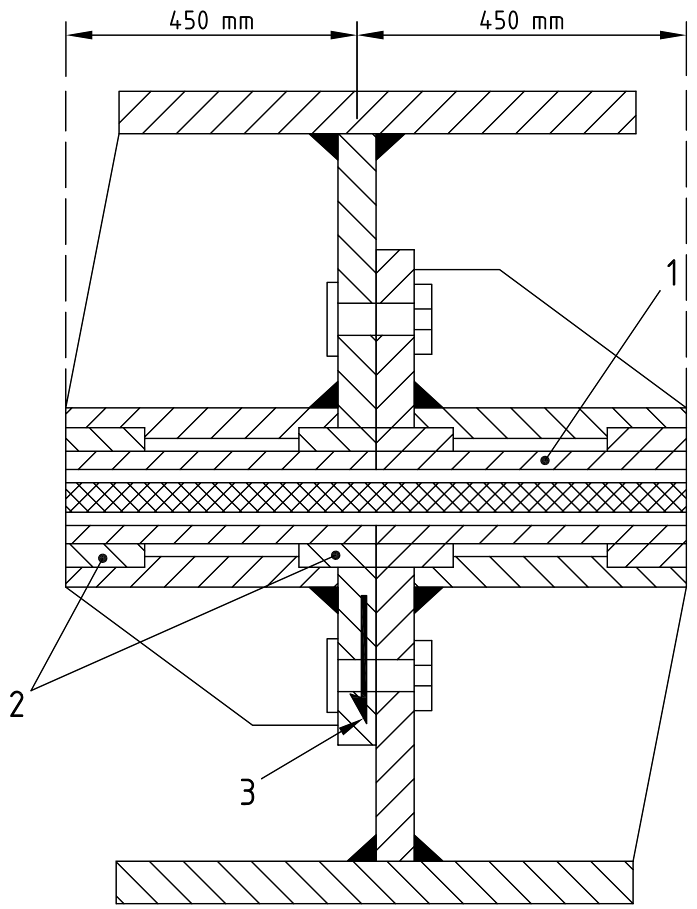
L.3.4 Method

Place a test assembly (**L.2.3**) in the test machine (**L.2.2**) and apply load at a rate not exceeding 2 kN/s until such time as the maximum force is achieved. Record load and displacement (platen displacement or piston stroke are sufficient) (**L.2.4**) at intervals of not greater than 2 s during the test.

L.4 Results

Plot a load vs displacement characteristic and note maximum load. Determine the shear strength of the grouted flexible reinforcement tendon from the mean of the three test results.

Figure L.1 **Sectional diagram of shear frame**



Key

1 Double embedment tube containing tendon encapsulated in grout

2 Hardened steel bushes interchangeable to accommodate different tube sizes

3 Load applied to upper section of shear frame only. Lower section remains static.

Annex M (informative) Notes on corrosion

The steel used for flexible strata reinforcement is susceptible to corrosion when in contact with mine strata water or humid air from the roadway. On installation, flexible reinforcement is protected against corrosion by the physical barrier that the grout forms and by the chemical effect of the alkalinity in fresh cementitious grout. However, the physical and chemical protection provided by the grout is likely to become less effective over time as strata movement leads to cracking of the grout, which allows access of water/humidity. Protection by cementitious grout should be regarded as short term and the possible effects of corrosion should be considered where flexible strata reinforcement is used to provide long-term support, i.e. over a period of more than two years.

Corrosion weakens reinforcement wires by pitting or generally reducing their thickness. A group of small diameter wires has a higher surface area than a solid rockbolt of equivalent cross-section. Consequently, corrosion can cause a more rapid loss of strata support from flexible reinforcement than with solid rockbolts. It is recommended, therefore, that where flexible strata reinforcement is intended to provide long-term support for mine workings, steel wire is coated with zinc as described in **5.1.4**.

It is reported from the deep mining industry outside the UK that corrosion inhibitors have been mixed with cementitious grout to protect flexible reinforcement from corrosion. Corrosion inhibiting grouts are also employed in the civil engineering industry for rockbolts and ground anchors. While the addition of corrosion inhibitors is outside the scope of this standard, their use might be beneficial for some mining situations. Before adding corrosion inhibitors, it is recommended that the performance tests in this standard are carried out to prove that the setting properties of the grout mixed with the inhibitor and the mechanical performance of the reinforcement system are not adversely affected.

The steel wire used in the strata reinforcement systems that are covered by this standard is also used in civil engineering, e.g. for bridge construction. There have been some reports of steel wire failures in bridges caused by stress corrosion cracking.

At the time of publication, there have been no reported failures of stranded reinforcement due to stress corrosion cracking. Where flexible reinforcement is intended to provide strata support for more than five years and the strata water contains more than 1 000 p.p.m. chloride ions and/or its pH is less than 5.5, there could be a risk of stress corrosion cracking. For reinforcement used in these conditions, it is recommended that samples of the wires are tested to demonstrate resistance to stress corrosion cracking. A suitable test is described in BS EN ISO 15630-3:2002, Clause **10**.

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 7861-1:2007, *Strata reinforcement support system components used in coal mines – Part 1: Specification for rockbolting*

BS EN 196-3:2005, *Methods of testing cement – Part 3: Determination of setting time and soundness*

BS EN ISO 9000, *Quality management systems – Fundamentals and vocabulary*

BS EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ASTM C490/ C490M - 08 *Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete*

Other publications

[1] UNITED KINGDOM. The Health and Safety at Work etc. Act 1974. London: The Stationery Office.

[2] UNITED KINGDOM. The Chemicals (Hazard Information and Packaging for Supply) Regulations (CHIP) 2009, SI 2009, No. 716. London: The Stationery Office.

[3] UNITED KINGDOM. The Control of Substances Hazardous to Health Regulations 2002, S.I. 2002, No. 2677. London: The Stationery Office.

[4] ULUSAY, R. AND J. A. HUDSON (eds): *The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974–2006*, Lisbon: ISRM.

[5] INTERNATIONAL SOCIETY FOR ROCK MECHANICS (ISRM) COMMISSION ON STANDARDIZTION OF LABORATORY AND FIELD TESTS. "Suggested Methods for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials", *Int. J. Rock Mechanics & Min. Sci. & Geomech*. Abs. Vol. 16. No. 2, pp 135–140 (1979).

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