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SPECIMENS AND TEST METHODS FOR CARBON FIBRE REINFORCED PLASTICS

Recommendations by Government Laboratories

by

J. B. Sturgeon

MINISTRY OF AVIATION SUPPLY
FARNBOROUGH HANTS

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SUMMARY

This Report gives recommendations, which have been agreed by a number of government laboratories, on methods for determining short-term mechanical properties of unidirectional carbon fibre reinforced plastics.

Further copies of this Report may be obtained from TRC Branch, Ministry of Aviation Supply, Block A, Station Square House, St. Mary Cray, Orpington, Kent.

Departmental Reference: Mat 126

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CONTENTS

ILLUSTRATIONS

1 INTRODUCTION

The determination of the mechanical properties of carbon fibre reinforced plastics materials (CFRP) is one of the first objectives in its development for structural use. Unfortunately, at present, there are no standard methods of test applicable to this class of material. The result has been that laboratories and organizations involved in development work have developed test methods and specimens of their own and this has led to difficulty in comparing results from different sources.

Some standardization is desirable. As a first step the Ministry of Aviation Supply Carbon Fibre Working Party, under the Chairmanship of D Mat Av, has asked the various government laboratories, working in this field, to pool their information and prepare an agreed set of recommendations for test methods and specimens, as far as the present state of the art allows. It is intended that this should then be discussed progressively with other interested bodies so that generally accepted standards will eventually emerge. As a result of meetings held by the relevant government laboratories (listed in Appendix A) agreement has been reached on a number of recommendations and these are reported here.

It was found necessary to limit the scope of the exercise in a number of ways. In the first place attention has been limited to unidirectional material as little work has so far been done on the testing of CFRP in which the fibres run in more than one direction. Secondly, insufficient work has been done for recommendations to be made concerning long-term properties such as fatigue and creep; for this reason only short-term mechanical properties were considered at this stage. Even within these limitations it was clear that some properties had been investigated more thoroughly than others, consequently the recommendations are presented in two parts: the first part refers to properties where sufficient work had been done for a reasonably definite test method to be recommended; the second, and more speculative part, refers to properties where the work has not yet reached this stage, but where the specimens were deemed sufficiently meaningful to be worth reporting.

No attempt has been made at this stage to produce a detailed testing manual. For this reason recommendations on tolerances and precise testing procedure are not, in general, included.

This Report supersedes all previous documents on standardization of test methods and specimens for unidirectional CFRP issued by government laboratories

(mainly by RAE) and will be updated from time to time. Comment and contributions from any source will be welcome.

2 GENERAL CONSIDERATIONS

2.1 The recommendations are limited at this stage to the following properties of unidirectional CFRP and related measurements:

(a) tensile modulus, ultimate tensile strength and Poisson's ratio when the composite is loaded in the direction of the fibres (subsequently referred to as longitudinal properties).

(b) Compressive modulus, ultimate compressive strength and Poisson's ratio when the composite is loaded in the direction of the fibres.

(c) Flexural modulus and ultimate flexural strength when the composite is loaded in 3-point bending with the fibres running in the span-wise direction.

(d) Tensile modulus, ultimate tensile strength and Poisson's ratio when the composite is loaded in a direction normal to the fibres (subsequently referred to as transverse properties).

(e) Compressive modulus, ultimate compressive strength and Poisson's ratio when the composite is loaded in a direction normal to the fibres.

(f) Shear modulus and ultimate shear strength in a plane parallel to the fibres (subsequently referred to as interlaminar shear modulus and strength).

(g) Strength under impact normal to the fibre direction.

(h) Proportion of fibre, resin and voids in the composite by volume.

(i) Fibre density.

2.2 For each test specimen dimensions given in SI units are recommended. In some cases, however, similar specimens in Imperial units have been in existence for some time. These are reported where appropriate but it should be noted that the sizes of the specimens are not identical to the corresponding SI specimens. Comparisons between results from SI specimens and similar Imperial specimens should be made with caution.

It is recommended that in every case the specimen be produced to the nominal dimensions given on the sketches.

2.3 Measurements of properties of unidirectional CFRP will frequently be made on material which has been laminated from thin pre-impregnated sheets. For this reason the aim has been to design specimens which can be cut, as far as possible, from one board of constant thickness. The thickness chosen is 2 mm (0.1 in).

PART I FIRM PROPOSALS

3 INTERLAMINAR SHEAR STRENGTH

3.1 Design considerations

This test is designed to measure the ultimate composite strength when subjected to a shear stress in a plane parallel to the fibre direction. This property can be affected both by the properties of the matrix and, more usually, by the fibre-matrix bond. It is therefore particularly suitable for examining the nature of this bond and assessing the matrix performance in composite form.

Numerous methods for measuring this property have been used and compared[1]. The recommended method consists of applying 3-point loading to a specimen whose dimensions are chosen so that shear failure occurs before flexural failure. Specimen and roller dimensions are given in Fig.1.

3.2 Test conditions

The rollers should be accurately parallel to each other, the centre roller centred between the outer two and the fibre direction normal to the roller axes. Load should be applied at a rate which produces failure in 15 to 45 seconds.

3.3 Method of calculation

The following equation should be used to obtain the interlaminar shear strength τ_{12}.

$$\tau_{12} = \frac{3P}{4db}$$

where P is applied load,
d is depth of specimen
and b is width of specimen.

3.4 Limitations

Although it is probably less susceptible to stress concentration effects than most other methods, the value obtained from this type of test does depend on the span to depth ratio, and partly for this reason the method is not recommended for acquiring design data. The recommended span to depth ratio of 5:1 should ensure shear failures in most combinations of carbon fibre and resin,

but there will be cases, where the ratio of flexural to shear strength is particularly low, when flexural failure will occur first and where only a minimum value of interlaminar shear strength can consequently be quoted[2]. In such cases shear failures can be precipitated by progressively reducing the span to depth ratio to 3:1 at constant span. This method is not generally recommended as results cannot then be compared with those obtained from the standard specimen and are liable to errors arising from transverse compressive failure under the rollers.

Kedward[3] and Sattar and Kellog[4] have shown that specimen width can become significant when fibres of widely differing Young's modulus are compared. Such comparisons should therefore be made with caution.

4 FLEXURAL STRENGTH

4.1 Design considerations

This test is designed to measure the composite bending strength under 3-point loading. The property is of little use in design calculations but is a useful guide to the direct strength properties of a material, provided it is associated with the mode of failure.

It has been found experimentally that the flexural strength and mode of failure (i.e. tensile, compressive, shear or a combination of these) depend on the test span: depth ratio and the geometry of the loading anvils[5]. A span to depth ratio of 40:1 has been chosen to ensure true flexural failure and to minimise the effects of shear stresses and transverse crushing by the loading anvils.

The recommended specimen and test arrangement is shown in Fig.2.

4.2 Test conditions

The rollers should be accurately parallel to each other, the middle roller accurately centred between the outer two with the specimen fibre direction normal to the roller axes. The outer rollers should be held at constant span during the test and the load applied at a constant rate which produces failure in 30 to 180 seconds.

4.3 Method of calculation

The following equation should be used to obtain the ultimate flexural strength, σ_{1F}.

$$\sigma_{1F} = \frac{3PL}{2bd^2}$$

where P is applied load,
L is test span,
b is specimen width
and d is specimen depth.

The mode of failure should be stated.

4.4 Limitations

Although this test is quick and easy to perform, the mode of failure is often difficult to determine. Also, the equation used to obtain the flexural strength, based on simple bending theory, makes use of a number of assumptions not realised in practice. In particular, the degree of influence of shear and transverse stresses will depend on the matrix properties and the fibre volume fraction. Moreover the neutral axis will not lie on the central plane of the specimen if the longitudinal tensile and compressive moduli are different. If a comparison between dissimilar materials is to be made, these limitations must be taken fully into account.

5 FLEXURAL MODULUS

5.1 Design considerations

This test is designed to measure the resistance of a composite to flexure under 3-point loading, the load being applied perpendicularly to the fibre direction. This loading mode imposes shear deflection on the specimen in addition to the deflection due to bending. However, from strain energy considerations[6] it is estimated that at a span to depth ratio of 100:1 the shear deflection is reduced to around 1 to 2 per cent of the deflection due to bending. This large span to depth ratio is therefore chosen in order that the shear deflection may be disregarded.

The recommended specimen is shown in Fig.3.

5.2 Test conditions

The test conditions are as in section 4.2. The deflection under the central roller should be measured by a means independent of the machine cross-head movement.

5.3 Calculation

The following equation should be used to obtain the flexural modulus E_{1F}:

$$E_{1F} = \frac{ML^3}{4bd^3}$$

where L is the test span,
d is the specimen depth,
b is the specimen breadth
and M is the ratio of the applied load to the deflection produced.

5.4 Limitations

This test as outlined above may only be used for quality control of similar resin-fibre systems. With some resin systems creep will be observed at high loads; in general the maximum load should be about one fifth the failing load. The simple formula given above assumes the tensile and compressive moduli to be equal; if this is not the case there will be an error in the result.

Some resin-fibre systems may suffer quite large indentations by the bottom rollers which may contribute a significant error to the determined modulus value[7]. If comparisons between different fibre-resin systems are required this indentation error must be eliminated.

6 TENSILE MODULUS, STRENGTH AND POISSON'S RATIO IN THE LONGITUDINAL DIRECTION

6.1 Design considerations

The specimen is intended for use up to failure and to give tensile strength, modulus and Poisson's ratio simultaneously. For CFRP composites the ratio of longitudinal tensile strength to interlaminar shear strength is high so that load transfer into the specimen is difficult. Consequently the specimen is made long enough to allow shear loads to be diffused into the gauge length and is waisted to limit failure to a predetermined area away from stress concentrations caused by end effects[8]. For ultimate tensile strength only, a simple waisted specimen may be used, but for modulus determinations a 10 mm parallel waist is ground in the centre. Soft aluminium alloy end plates are glued to the specimen to allow easy gripping and to spread the load over the required area. (See Appendix C.)

The specimen is shown in Fig.4.

If the Imperial specimen is used for Poisson's ratio determinations it must be widened to ½ inch, all other dimensions remain unchanged.

6.2 Test conditions

Loading is performed by wedge grips which should be adjusted to produce, as nearly as possible, a simple tensile load in the gauge length. Failure should occur within 30 to 90 seconds of commencement of the test. For a modulus determination a larger time to failure may be necessary but the time taken should be quoted. Strain gauges are recommended for strain measurements, see Appendix B. For low strain modulus determinations any specimen of uniform cross-section subjected to simple tension will suffice.

Any failures outside the waisted area should be disregarded. If such failure becomes a regular occurrence faulty laminate preparation, off-axis loading, or badly bonded end-plates should be suspected.

6.3 Calculation

The longitudinal tensile strength σ_{1T} is given by:-

$$\sigma_{1T} = \frac{P}{bd}$$

where P is applied load,

b is breadth at the waisted region

and d is depth at the waisted region.

6.4 Limitations

This specimen has proved successful for all fibre-resin combinations investigated to date.

7 IMPACT STRENGTH

7.1 Design considerations

No single test has yet been devised which gives all the desirable information about the behaviour of CFRP under impact loading. However it was agreed that the Izod test gives useful information and is sufficiently widely used to justify standardizing.

The ASTM standard 20 ft lbf machine with an anvil velocity of 11 ft/sec has been found satisfactory for most types of CFRP when used with the specimen shown in Fig.5, and is recommended.

7.2 Test conditions

The specimen is installed vertically in the test machine, exactly one half of the specimen being below the top of the horizontal face of the vice (see British Standard BS 2782). For notched specimens the relevant notch is made in the presented face.

7.3 Calculations

The impact strength is calculated as follows:-

$$\text{Impact strength} = \frac{\text{energy absorbed}}{\text{specimen cross-sectional area}} .$$

7.4 Limitations

The specimen should cause a loss of anvil energy within the range 2 to 18 ft lbf. If the energy absorption is larger than 18 ft lbf the presented face width may be reduced by a factor of 2. Further reduction in the face width causes width effects to become significant. The specimen depth must not be reduced.

8 FIBRE, RESIN AND COMPOSITE DENSITY

8.1 Fibre density

8.1.1 Test conditions

The recommended method is a density bottle technique using bromobenzene[9], although some use has been made of white spirit and also water[10]. Care must be taken to ensure that the fibres are wetted out and that a constant temperature is maintained throughout the test.

8.1.2 Calculation

The fibre density ρ_f is given by the following equation:-

$$\rho_f = \frac{D\rho_w}{(D + C - E)} \frac{(C - A)}{(B - A)}$$

where A is the weight of the density bottle in air
B is the weight of the density bottle filled with water
C is the weight of the density bottle filled with bromobenzene
D is the weight of carbon fibre
E is the weight of density bottle + carbon fibre and bromobenzene
and ρ_w is the density of water.

8.1.3 Limitations

There are no limitations on the type of fibre which may be used in this determination.

8.2 Resin density

8.2.1 Test conditions

On grounds of simplicity an Archimedian or density bottle method is recommended using water as the liquid medium. Care must be taken to ensure no air bubbles adhere to the surface of the specimen in the water. The resin sample must also have experienced the same manufacturing and curing cycle as the composite matrix with which it will be compared.

8.2.2 Calculation

For the Archimedian method the resin density ρ_R is given by:-

$$\rho_R = \frac{A\rho_w}{A - B}$$

where ρ_w is the density of water at the test temperature
A is the weight of resin in air
and B is the weight of resin in water.

For the density bottle method the resin density ρ_R is given by:

$$\rho_R = \frac{X\rho_w}{X + Y - Z}$$

where ρ_w is the density of water at the test temperature
X is the weight of resin
Y is the weight of the density bottle full of water
Z is the weight of the density bottle plus the resin and water.

8.2.3 Limitations

There are no limitations on this method.

8.3 Composite density

8.3.1 Test conditions

The Archimedian method of section 8.2 or a density column method are both recommended. For the latter zinc chloride solutions with densities of 1.4 and 1.7 are used with an addition of 5% by volume of concentrated sulphuric

acid. Ref.10 gives details of the apparatus and setting up, Appendix D gives a list of suppliers. By interpolating from marker buoys of known density the composite density is obtained.

8.3.2 Neither method has any limitations but the density column has a finite useful life.

9 DETERMINATION OF COMPOSITE FIBRE CONTENT BY VOLUME AND VOID CONTENT

9.1 Design considerations

The composite fibre content by volume cannot be calculated from figures for composite and fibre weight and fibre and resin density only, as this assumes that the composite void content is zero. If the composite density also is known, the expressions given in section 9.3 then allow fibre content by volume and void content to be determined uniquely. Methods for measuring fibre, resin and composite density are given in section 8: of the methods which have been used to determine fibre content by weight[11,12,13,14,15], the wet digestion using concentrated sulphuric acid and 50% hydrogen peroxide solution is recommended and is outlined in section 9.2.

9.2 Test conditions

A piece of composite is accurately weighed and placed in a double-necked, pear shaped 100 ml flask containing 20 ml of concentrated sulphuric acid. A 25 ml dropping funnel and an air inlet are attached to one neck and a water pump, with a non-return trap, is attached to the second. (This outlet attachment should slope downwards to prevent cool condensed liquid falling back into the flask.) 20 ml of 50 per cent hydrogen peroxide solution is poured into the funnel and the flask gently heated until the acid fumes. The heat is then turned off and hydrogen peroxide added to the acid at the rate of one drop every two seconds, increasing to one drop every second after five minutes. When all the hydrogen peroxide has been added the apparatus is allowed to cool so that it can be handled. (If all the resin has not been digested, further heating and addition of hydrogen peroxide may be necessary.) The contents of the flask are poured into a beaker containing 200 ml of distilled water, no fibres should remain in the flask. The contents of the beaker are transferred to a weighed 20 ml sintered glass filter (Gallenkamp CW 520, porosity Grade 1, 200-250 μm) which is attached to a filtration flask and filter pump. The contents of the filter are washed with successive quantities of distilled water until wide range indicator paper (pH paper) shows the washing liquid to be neutral. The

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8.2.2 Calculation

For the Archimedian method the resin density ρ_R is given by:-

$$\rho_R = \frac{A\rho_w}{A - B}$$

where ρ_w is the density of water at the test temperature
A is the weight of resin in air
and B is the weight of resin in water.

For the density bottle method the resin density ρ_R is given by:

$$\rho_R = \frac{X\rho_w}{X + Y - Z}$$

where ρ_w is the density of water at the test temperature
X is the weight of resin
Y is the weight of the density bottle full of water
Z is the weight of the density bottle plus the resin and water.

8.2.3 Limitations

There are no limitations on this method.

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filter and contents are dried at a temperature between 120°C and 160°C for at least 2 hours, care being taken not to lose any fibre. The filter and contents are allowed to stand, under the same laboratory conditions in which the empty filter was weighed, until constant weight is achieved. The fibre weight is determined from the difference between the weights of the filter with and without the fibre.

NOTE Hydrogen peroxide can be dangerous and should be handled with care.

9.3 Method of calculation

The fibre, resin and void contents by volume are calculated using the expressions:-

$$\text{Fibre content by volume,} \quad v_f = \frac{W_f}{W_c}\frac{\rho_c}{\rho_f} \quad .$$

$$\text{Resin content by volume,} \quad v_r = \frac{(W_c - W_f)\rho_c}{W_c \rho_r} \quad .$$

$$\text{Void content by volume,} \quad v_v = 1 - (v_f + v_r)$$

where W_c is weight of composite,

W_f is weight of fibre in composite of weight W_c,

ρ_c is density of composite (see section 8.3),

ρ_f is density of fibre, as determined in accordance with section 8.1,

ρ_r is density of resin, (see section 8.2).

9.4 Limitations

No common resin system has been tried which failed to be digested given a suitably high temperature and long enough digestion time[15].

PART II TENTATIVE PROPOSALS

COMPRESSIVE STRENGTH, MODULUS AND POISSON'S RATIO IN THE LONGITUDINAL DIRECTION

).1 Design considerations

This test is designed to yield the ultimate strength, modulus and ɔisson's ratio when compressive loading is applied along the fibre axis. A est specimen is required which will not fail at the ends when under load[16]. or this reason solid aluminium alloy end-pieces are used. The specimen and nd-pieces are shown in Fig.6. The central slot and one face (face A) are achined parallel, face B is machined perpendicular to face A. Only a simple lat bed is then required to produce a finished specimen which will be fully ıligned between the test machine platens. The CFRP specimen is coated with ıdhesive within the end blocks to hold it in place under test and to reduce ɜtress concentrating effects. This adhesive layer should not be thicker than).04 mm on either side of the specimen. This reduces the tendency to buckle in the end pieces. If necessary shims must be added to maintain the adhesive layer thinner than 0.04 mm. By adding shims to the same side of the slot in both end pieces the specimen alignment is preserved.

10.2 Test conditions

The specimen is tested between parallel platens at a rate which causes failure within 30 to 90 seconds. To reduce the tendency for premature failure the specimen with only a simple waisting is used for a strength test. When modulus and Poisson's ratio are to be determined a 10 mm parallel waisted section must be added to the gauge length, to give a total of 30 mm between the end pieces, and bonded strain gauges used. (See Appendix B.)

10.3 Calculation

The compressive strength σ_{1C} is given by:-

$$\sigma_{1C} = \frac{P}{bd}$$

where P is the load applied to cause failure,
b is the specimen width
and d is the specimen depth.

10.4 Limitations

When gauge lengths longer than 20 mm are employed buckling of the specimen may occur; type 2 treated fibre composite is particularly susceptible. It is, therefore, unlikely that modulus to failure can be obtained for every specimen. For this reason caution must be exercised in interpreting results.

11 TENSILE STRENGTH, MODULUS AND POISSON'S RATIO IN THE TRANSVERSE DIRECTION

11.1 Design considerations

This test gives the tensile strength, modulus and Poisson's ratio of CFRP when the applied loading is normal to the fibre direction. In general a CFRP composite is weak in this mode of loading and care must be taken to avoid bending. To this end long flexible aluminium end butt plates are bonded to the specimen, the load being transferred to the specimen by aluminium alloy butt straps. Waisting is performed to ensure failure away from the end plates. The specimen is shown in Fig.7.

11.2 Test conditions

The specimen is tested in a machine with wedge grips. Care must be taken to ensure that the specimen is aligned to give a true transverse loading. Failure should occur within 10 to 45 seconds of commencement of the test.

To obtain the modulus and Poisson's ratio strain gauges (see Appendix B) are bonded to a central 10 mm parallel waisted section. This has not been indicated in Fig.7.

11.3 Calculation

The transverse tensile strength σ_{2T} is given by

$$\sigma_{2T} = \frac{P}{bd}$$

where P is the load applied at failure,

b is the specimen width in the waisted region

and d is the specimen depth in the waisted region.

11.4 Limitations

There are no limitations on the use of this specimen. However if failure occurs outside the central waisted region the result should be disregarded and recorded as a faulty specimen.

12 COMPRESSIVE STRENGTH IN THE TRANSVERSE DIRECTION

12.1 Design considerations

This test is intended to give the compressive strength of CFRP when a load is applied perpendicular to the fibre direction. The composite is relatively weak in this loading condition and consequently good alignment with no bending of the specimen is required. For this reason solid aluminium alloy end blocks, described in section 10, are used. The specimen is waisted to cause failure away from the end blocks. The dimensions are given in Fig.8.

12.2 Test conditions

The end blocks are attached with adhesive (see section 10) and the specimen is tested in compression between parallel test machine platens at a speed which causes failure within 10 to 45 seconds of commencement of the test.

12.3 Calculation

The transverse compressive strength σ_{2C} is given by:-

$$\sigma_{2C} = \frac{P}{bd}$$

where P is the load applied at failure,
b is the specimen width in the waisted region
and d is the specimen depth in the waisted region.

12.4 Limitations

Only strength tests can be performed with this waisted specimen. If a modulus determination is required a low strain value can be obtained on an unwaisted specimen.

13 INTERLAMINAR SHEAR MODULUS

13.1 Design considerations

At present there is no simple test which may be employed to provide the required data, but a tube loaded in torsion appears to offer the best prospect.

Any design of specimen should ensure that the gauge length has a stress field free from end effects and that the ratio of specimen wall thickness to overall diameter is small to reduce stress variation through the wall thickness.

A less satisfactory alternative is a solid rod containing axially aligned fibres. It suffers from having a more non-uniform stress distribution than a tube but will yield the modulus at low strains.

It is perhaps worth noting that both rods and tubes can be used to estimate shear strength as well as modulus.

PART III

14 PRESENTATION OF RESULTS

The following information should be given when presenting test results.

(a) Value of composite property determined.

(b) Fibre type and properties.

(c) Resin type and curing agents.

(d) Pressing schedule, cure cycle and any environmental ageing.

(e) Fibre and void volume content of the specimen.

As this Report is not a testing manual no exact guide is given to the number of test specimens which may be necessary to produce meaningful results for a given laminate. At the present time, each individual result should be quoted in addition to any averaging which may be performed. A value of fibre and void content should accompany each specimen tested.

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Appendix A

COLLABORATING LABORATORIES

Laboratories represented at the agreement of the test specimens outlined in this Report were:-

Admiralty Materials Laboratory,
Holton Heath,
Poole,
Dorset BH16 6JU

Atomic Energy Research Establishment,
Harwell,
Didcot,
Berks.

Explosives Research and Development Establishment,
Powdermill Lane,
Waltham Abbey,
Essex.

Military Vehicles and Engineering Establishment,
Barrack Road,
Christchurch,
Hants.

National Physical Laboratory,
Teddington,
Middlesex.

Royal Aircraft Establishment,
Farnborough,
Hants.

Appendix B

STRAIN GAUGES

The Micro Measurements gauge type EA-06-125BT-120 (option L) has been found satisfactory for use with CFRP (see Appendix D).

The manufacturer's instructions on gauge preparation and recommended adhesives should be followed. Any instructions which are relevant to glass fibre reinforced plastics, or any other plastic, should also be followed. In all cases it is advisable to remove the surface gloss from a CFRP composite by light abrasion before bonding on the gauge. This abrasion should be continued until a continuous water film can be formed on the surface. An excess of organic degreasing agents should not be used.

A low gauge voltage, not greater than 6 volts, is recommended to reduce any effects caused by the thermal expansion characteristics of CFRP.

For Poisson's ratio determinations the EA type gauge can be stuck transversely on the specimens.

It is perhaps worthy of note that with CFRP strain gauges are used rather than conventional extensometers as the latter have sharp knife edges which act as stress raisers. They disturb the uniform stress field in the gauge length, which has been obtained by careful design, and can also cause premature failure due to surface damage of the CFRP.

Appendix C

ADHESIVE BONDING

C.1 Adhesives

To minimize thermal stresses all aluminium end plates are bonded with cold setting epoxy adhesives. The following two have been found adequate:-

(a) 3 M's company EC2216 two-part adhesive.

(b) Ciba BSL 403 two-part adhesive.

The makers instructions should be followed.

C.2 CFRP preparation

Light abrasion of the composite surface is recommended with silicon carbide paper no coarser than 280 grade, followed by a light degreasing with dichloro-ethane or trichloro-ethane and an acetone rinse. No loose particles of composite should remain on the surface. Alternatively abrasion may be carried out in soapy water until a continuous water film is obtained. All trace of soap must be removed by light abrasion in clear water and careful washing.

C.3 Preparation of aluminium

The aluminium alloy end plates should be abraded and degreased in dichloro-ethane or trichloro-ethane and washed in acetone. They should then be etched in a chromic acid bath. After 30 minutes in the etch they are washed thoroughly in water and finally in distilled water. They are then dried in air at 50^{o}C.

The chromic acid solution is prepared in the following proportions:-

chromium trioxide (red)	10 grams
sulphuric acid (conc)	36 ml
distilled water	160 ml.

NB add the acid to the water not the other way round.

Appendix D

ADDRESSES OF SUPPLIERS

(a) Density column equipment

Davenport (London) Ltd.,
Welwyn Garden City,
Herts.

Techne Ltd.,
Duxford,
Cambridge.

(b) Strain gauges

Welwyn Electric Ltd.,
70 High Street,
Teddington,
Middlesex.

(c) Adhesives

Minnesota Mining and Manufacturing Company Ltd.,
3M House,
Wigmore St.,
PO Box 1ET,
London W1.

Ciba (ARL) Ltd.,
Duxford,
Cambridge.

Appendix E

SYMBOLS

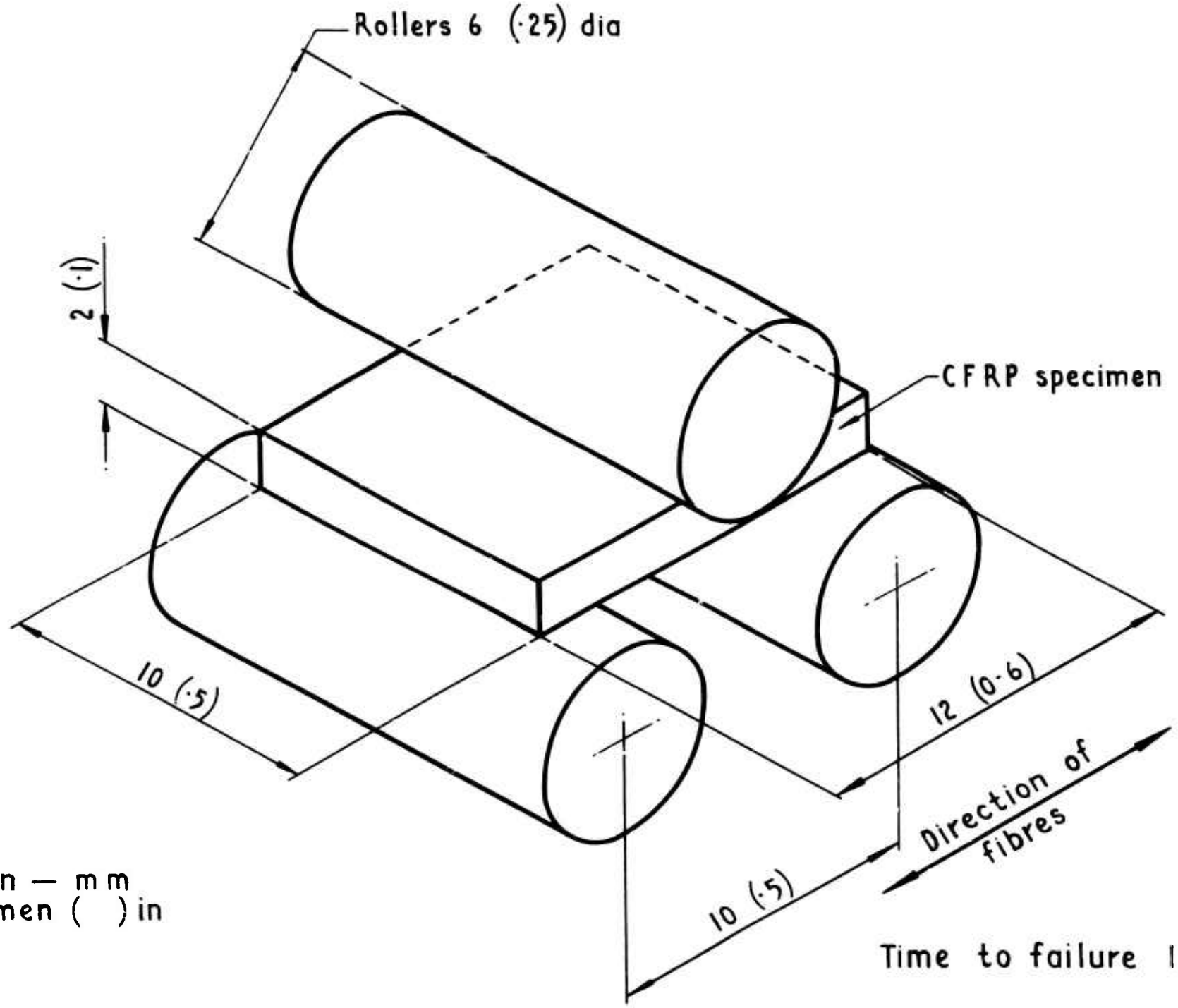
The following property symbols are recommended for use with composite materials. Where possible, reference is made to the appropriate specimen which may be used to determine the property.

Property		Symbol
Longitudinal tensile strength	(Fig.4)	σ_{1T}
Longitudinal modulus	(Fig.4)	E_{1T}
Poisson's ratio (a longitudinal extension causing a transverse contraction under longitudinal tensile loading)	(Fig.4)	ν_{12T}
Longitudinal compressive strength	(Fig.6)	σ_{1C}
Longitudinal compressive modulus	(Fig.6)	E_{1C}
Poisson's ratio (a longitudinal contraction causing a transverse extension under longitudinal compressive loading)	(Fig.6)	ν_{12C}
Transverse tensile strength	(Fig.7)	σ_{2T}
Transverse tensile modulus	(Fig.7)	E_{2T}
Poisson's ratio (a transverse extension causing a longitudinal contraction under transverse tensile loading)	(Fig.7)	ν_{21T}
Transverse compressive strength	(Fig.8)	σ_{2C}
Transverse compressive modulus		E_{2C}
Poisson's ratio (a transverse contraction causing a longitudinal extension under transverse compressive loading)		ν_{21C}
Flexural strength (measured with the fibres running spanwise)	(Fig.2)	σ_{1F}
Flexural modulus (measured with the fibres running spanwise)	(Fig.3)	E_{1F}
Interlaminar shear strength	(Fig.1)	τ_{12}
Interlaminar shear modulus		G_{12}

The fibre axes 1, 2 are defined in Fig.9.

REFERENCES

No.	Author(s)	Title, etc.
1	D.F. Adams R.L. Thomas	12 National SAMPE Symposium Section AC-5
2	N.J. Wadsworth J. Hutchings	RAE Technical Memorandum Mat 14 (1967)
3	K.T. Kedward	Lecture at NPL 15 July 1970 IPPS Conference "The Testing of Fibrous Composites"
4	S.A. Sattar D.H. Kellog	ASTM STP 460 (1969)
5	H. Wells W.J. Colclough P.R. Goggin	AERE Report R6149 (1969)
6	S. Timoshenko	Strength of materials. J. Wiley (1955)
7	T.A. Collings R.G. Finbow	RAE Technical Report 70006 (1970)
8	P.D. Ewins	Unpublished RAE Report. Lecture at NPL 15 July 1970 IPPS Conference "The Testing of Fibrous Composites"
9	Marie E. Hussey	Internal RAE report. Structures Test Note 1742 (1969)
10		Grafil test methods. Courtaulds Ltd., (1970)
11	W.H. Haynes T.C. Tolbert	Journal of composite materials, October 1969
12	R.J. Kuhbander	AFML Technical Report 67-243
13	B.M. Parker	RAE Technical Memorandum Mat 88 (1970)
14	R. Childs	RAE Technical Memorandum Structures 783 (1970)
15	Barbara Crossland T.F.R.W. Fennell	RAE Technical Memorandum Mat 105 (1971)
16	P.D. Ewins	RAE Technical Report 70007 (1970)



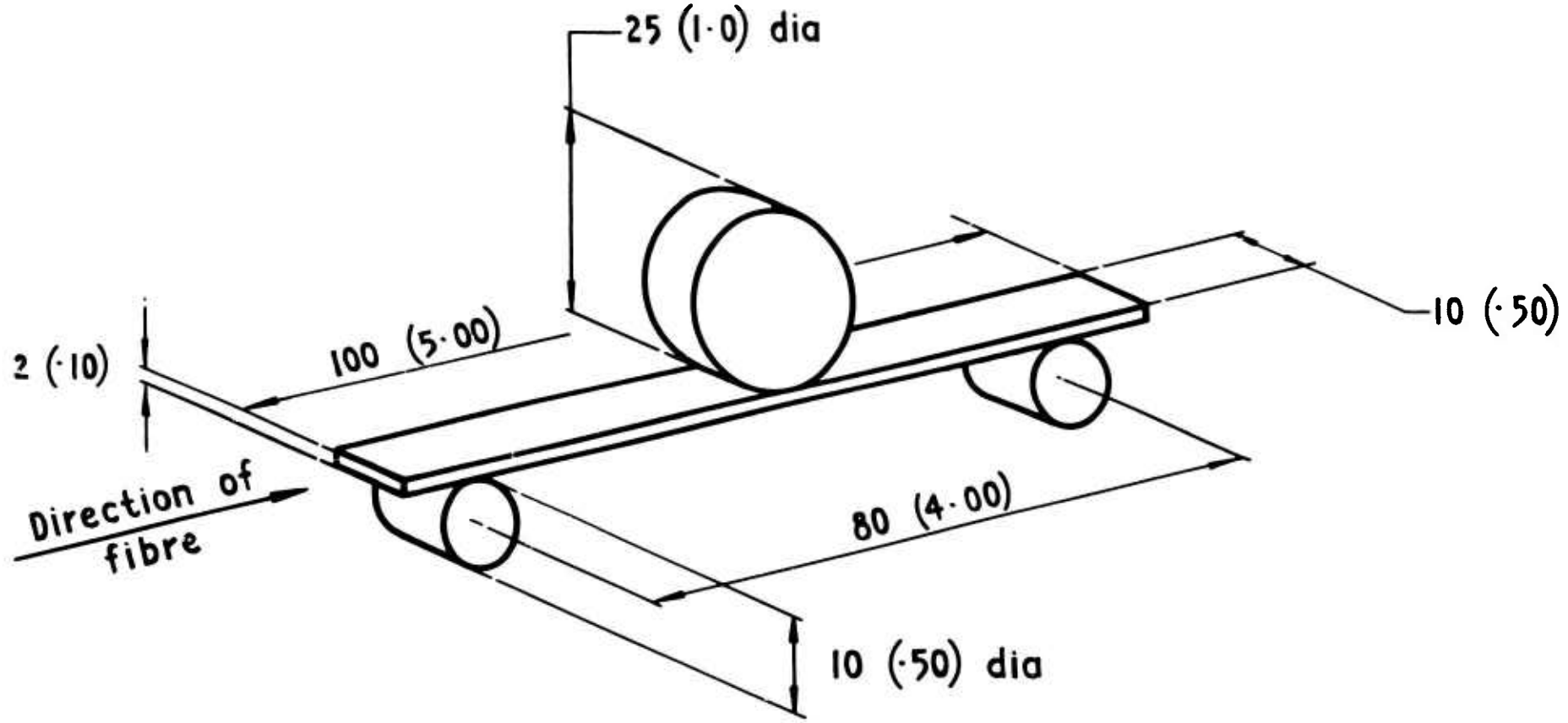
Dimensions
Metric specimen — mm
Imperial specimen ( ) in

Time to failure 15 – 45 sec

Fig.1 Interlaminar shear specimen

Fig1

Dimensions
Metric specimen mm
Imperial specimen ( )in



Time to failure 30 to 180 sec

Fig.2 Flexural strength specimen

Dimensions
Metric specimen mm
Imperial specimen ( ) in

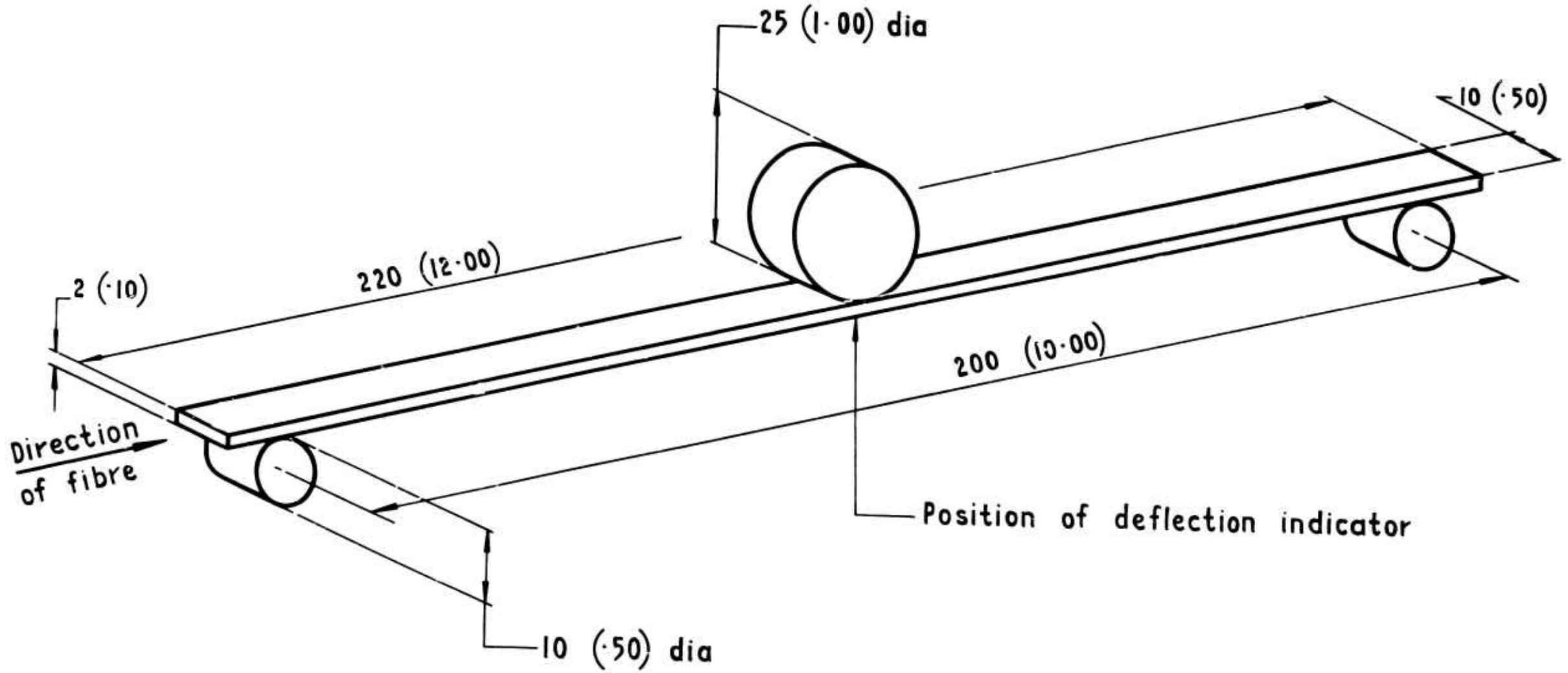
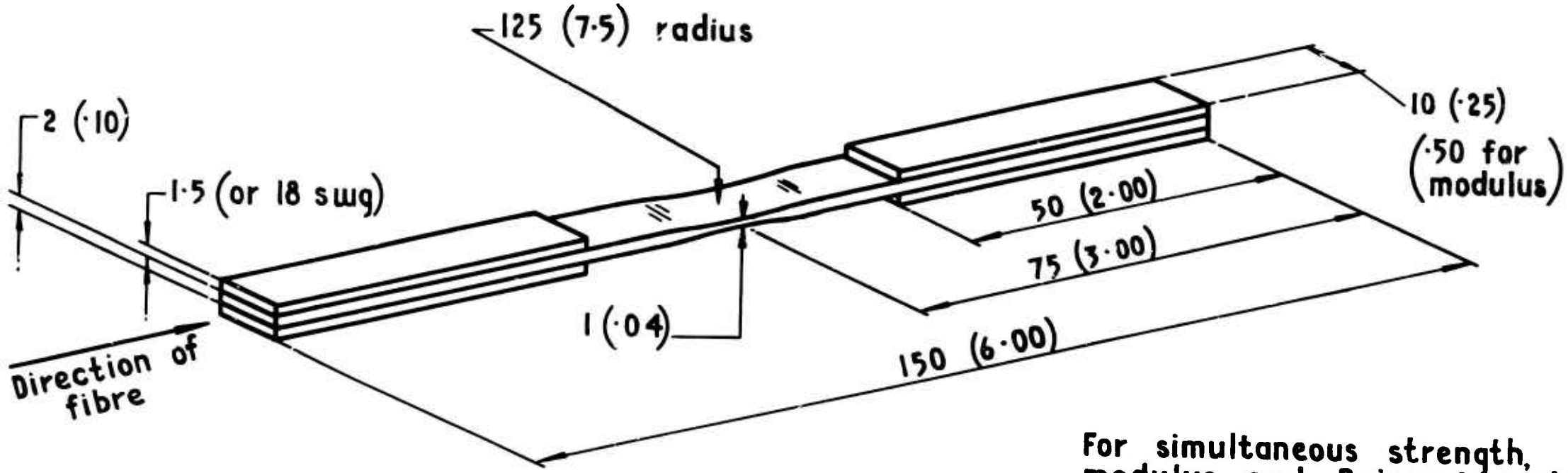


Fig.3 Flexural modulus specimen

Fig.3

Dimensions
Metric specimen mm
Imperial specimen ( )in

Time to failure 30 - 90 sec



For simultaneous strength, modulus and Poisson's ratio determination a 10 mm parallel waist must be ground in the centre

Fig.4 Longitudinal tensile specimen

Fig.4

Dimensions
Metric specimen mm
Imperial specimen ( ) in

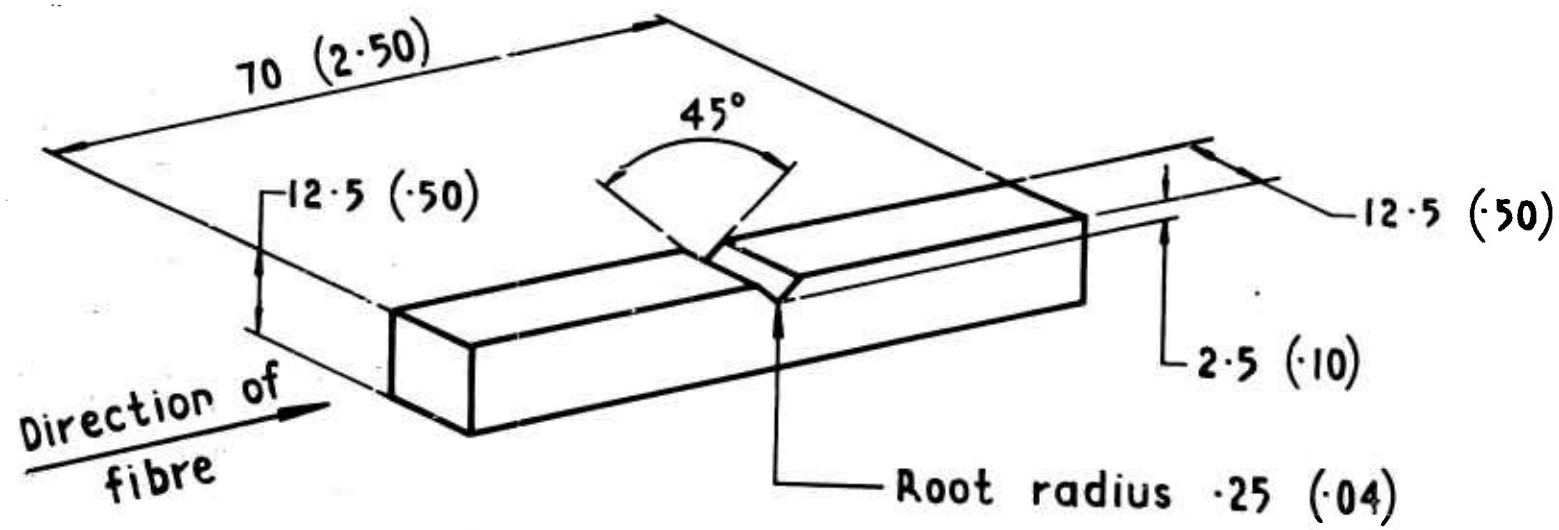
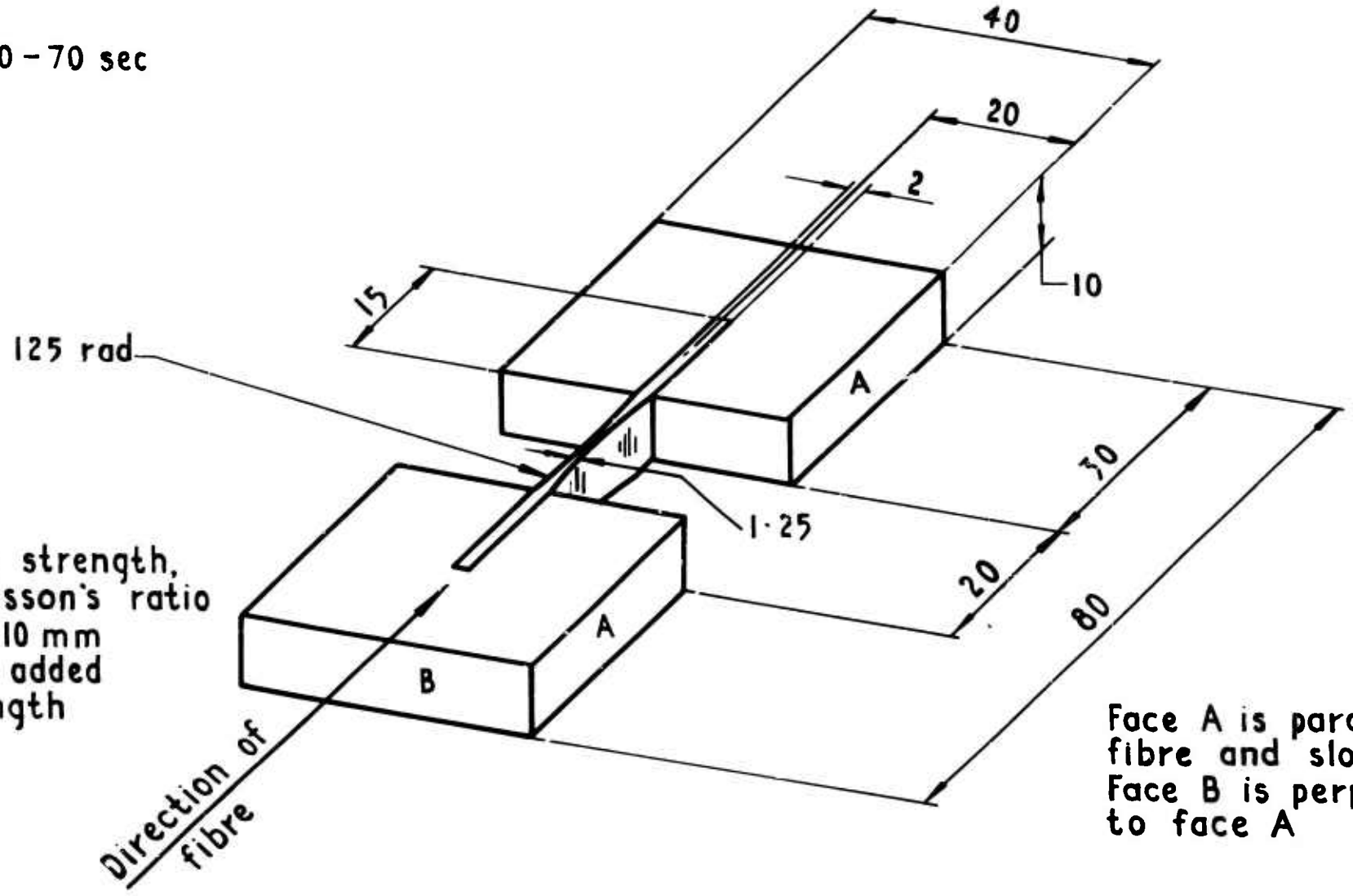


Fig.5 Impact specimen

Dimensions mm

Time to failure 30 – 70 sec



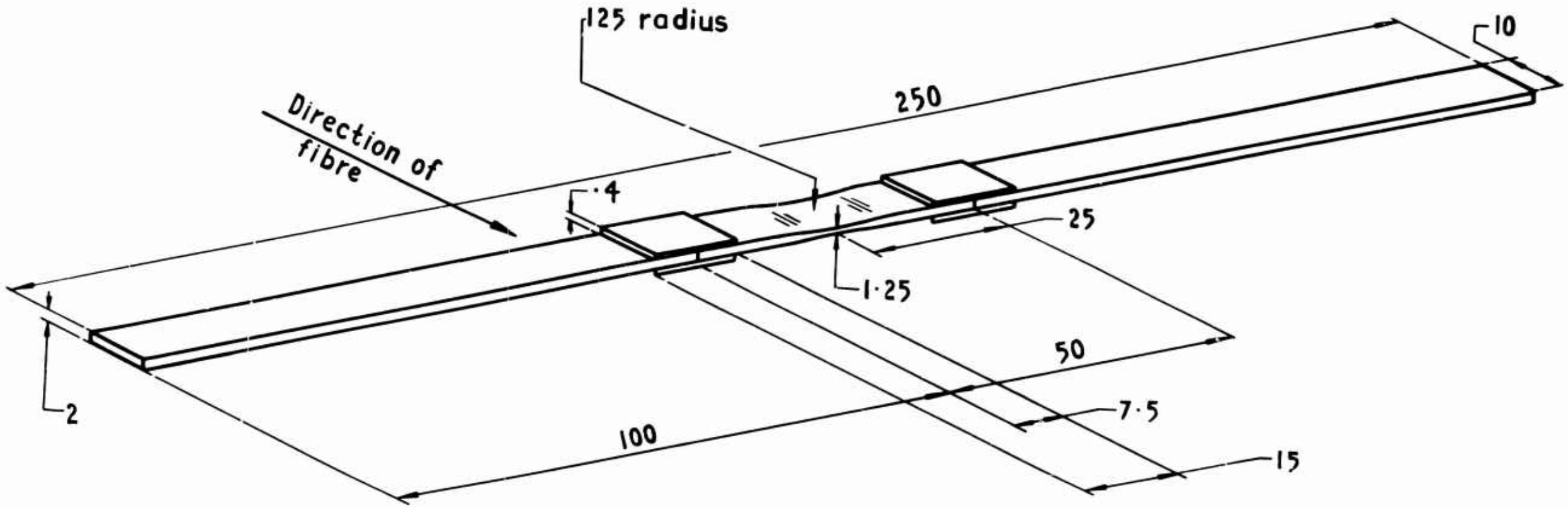
For simultaneous strength, modulus and Poisson's ratio determination a 10 mm parallel waist is added to the gauge length

Face A is parallel to the fibre and slot directions. Face B is perpendicular to face A

Fig.6 Longitudinal compression specimen

Dimensions mm

Time to failure 10 - 45 sec

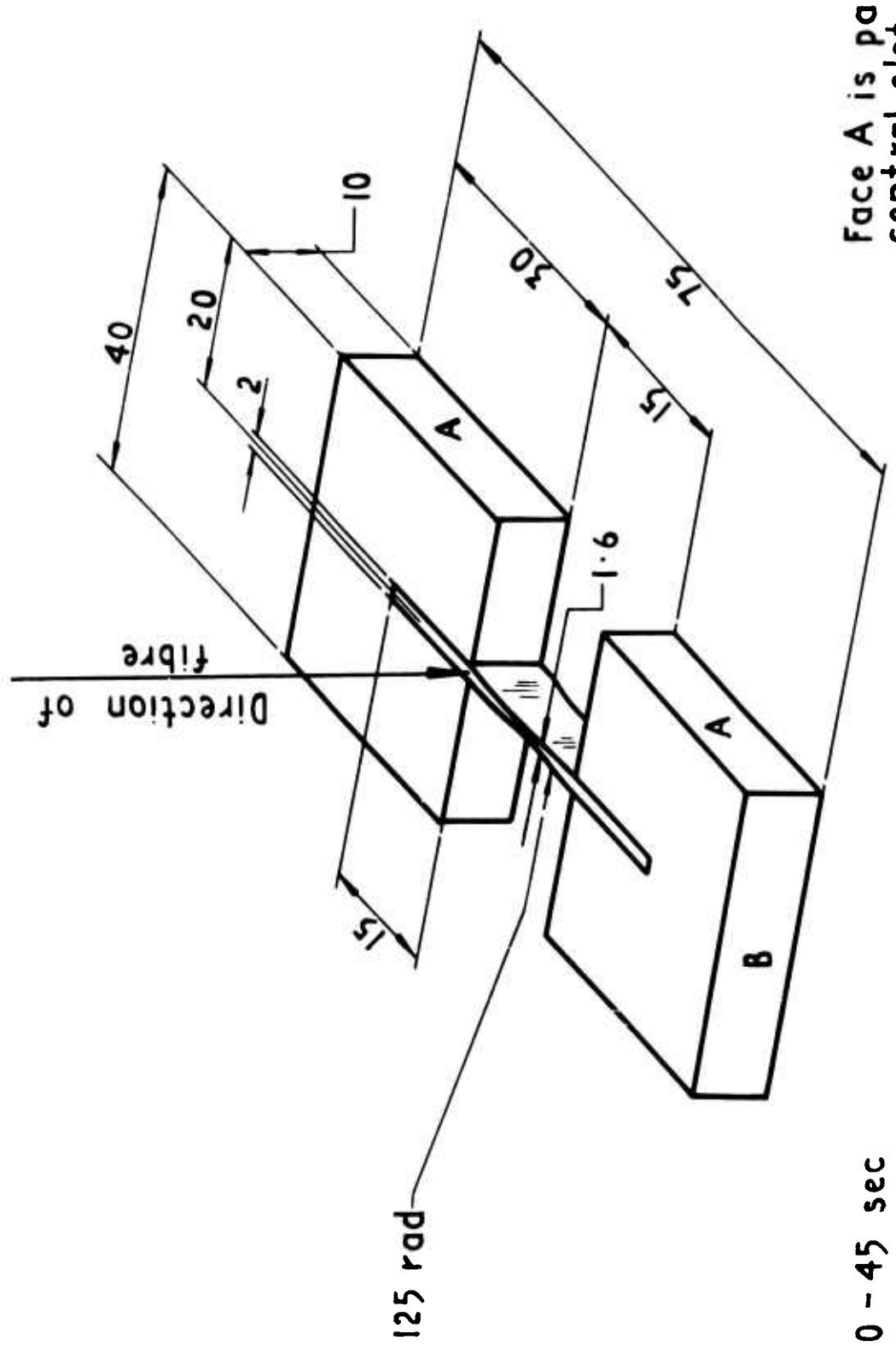


For simultaneous determination of strength, modulus and Poisson's ratio a 10 mm parallel waist is ground in the specimen centre

Fig.7 Transverse tensile specimen

Fig.7

Fig.8



Face A is parallel to the central slot. Face B is perpendicular to face A

Dimension mm

Time to failure 10 - 45 sec

Fig.8 Transverse compression specimen

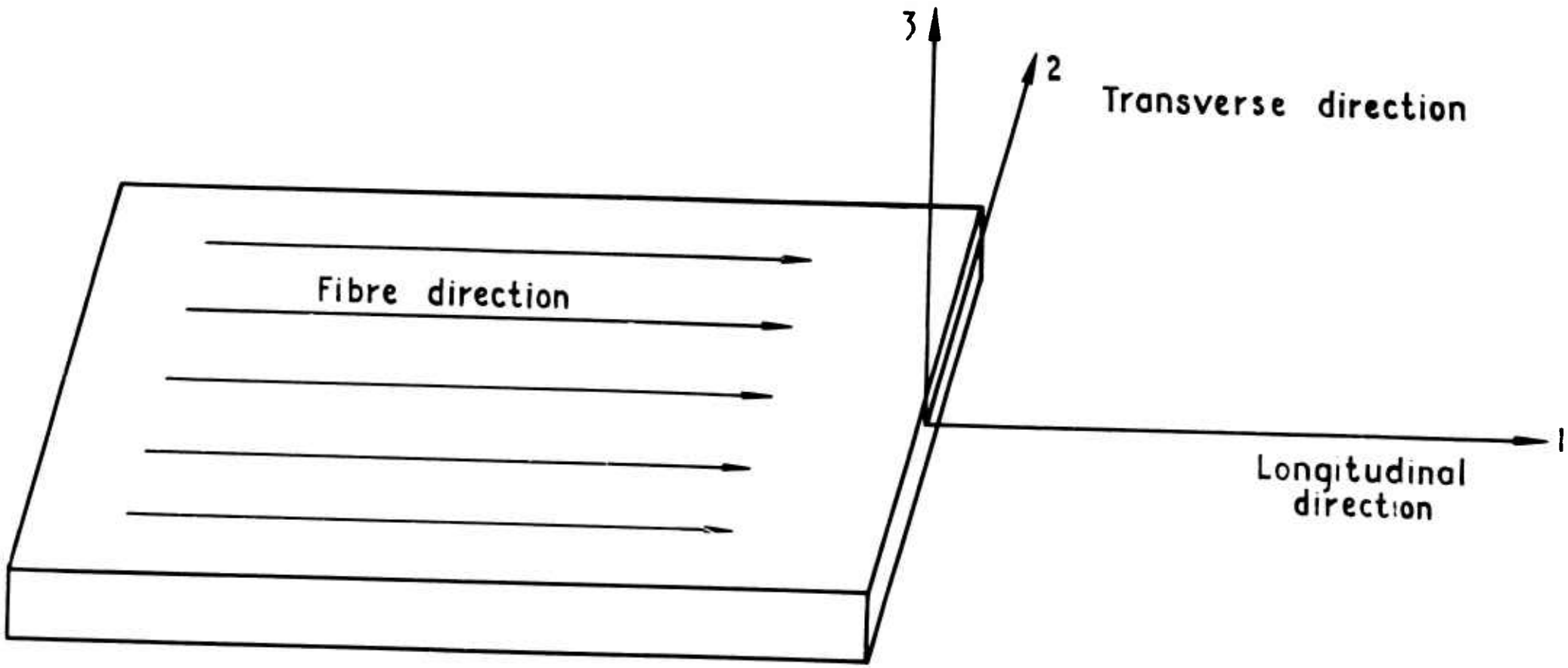


Fig.9 Material axes

Fig.9