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Test Methods for Assessing Durability Performance of Adhesive Joints

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ABSTRACT

This report presents three test methods that can be used to assess durability of adhesive joints under combined cyclic or static loading and hostile environments. Two of these methods: (i) thick adherend shear test (TAST) loaded in compression; and (ii) tapered strap joint can be used to characterise the shear behaviour of adhesive materials. These methods complement existing techniques by providing alternative solutions to the measurement of shear properties. The compression TAST specimen is a much smaller specimen than the standard geometry and is suitable for measuring the shear properties of bonded panels with a total thickness of 5 to 6 mm. The smaller specimen offers the potential for rapid environmental conditioning. The tapered strap joint is compatible for use with standard type extensometers. Thus, it is useful for measuring changes in stiffness for cyclic fatigue tests and for monitoring creep strain.

The third method, the skin-doubler test, in contrast is more representative of real-life structures (e.g. T-joint flange). The large bond length associated with the technique enables maximum load transfer from the skin to the doubler. The procedure allows the determination of shear stress/strain distributions along the bond length and can also be used to measure the ply drop strength for co-bonded and co-cured composites. Symmetric and non-symmetric specimen configurations are covered in the procedure. The technique can be used under combined hostile environments and cyclic loading conditions.

The draft procedures presented in this report are working documents written in the International Standards format.

The report was prepared as part of the research undertaken at NPL for the Department of Trade and Industry funded project on “Performance of Adhesive Joints - Combined Loading and Hostile Environments”.

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Approved on behalf of Managing Director, NPL, by Dr C Lea,
Head of Centre for Materials Measurement and Technology.

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INTRODUCTION

This report presents three test methods that can be used to assess durability of adhesive joints under combined cyclic or static loading and hostile environments. Two of these methods: (i) thick adherend shear test (TAST) loaded in compression; and (ii) tapered strap joint can be used to characterise the shear behaviour of adhesive materials. These methods complement existing techniques by providing alternative solutions to the measurement of shear properties. The compression TAST specimen is a much smaller specimen than the standard geometry (see NPL Report CMMT(A) 81 and ISO 11003-2) and is suitable for measuring the shear properties of bonded panels with a total thickness of 5 to 6 mm. The smaller specimen offers the potential for rapid environmental conditioning. The tapered strap joint is compatible for use with standard type extensometers. Thus, it is useful for measuring changes in stiffness for cyclic fatigue tests and for monitoring creep strain.

The overlap length of lap shear specimens is too short to ensure maximum shear transfer in the adhesive, thus the strength results from this geometry can be misleading. The “apparent” shear strength obtained will be dependent on adherend thickness and material, and failure will be invariably result from peel stresses rather than shear. The skin doubler geometry in contrast is more representative of real-life structures. The large bond length associated with the technique enables maximum load transfer from the skin to the doubler. The procedure allows the determination of shear stress/strain distributions along the bond length and can also be used to measure the ply drop strength for co-bonded and co-cured composites. Symmetric and non-symmetric specimen configurations are covered in the procedure. The technique can be used under combined hostile environments and cyclic loading conditions.

The draft procedures presented in this report are working documents written in the International Standards format.

The research discussed in this report forms part of the DTI funded project on “Performance of Adhesive Joints - Combined Cyclic Loading and Hostile Environments”, which aims to develop and validate test methods and environmental conditioning procedures that can be used to measure parameters required for long-term performance predictions. This project is one of three technical projects forming the programme on “Performance of Adhesive Joints - A Programme in Support of Test Methods”.

ACKNOWLEDGEMENTS

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Method 1

Thick Adherend Shear Test - Compressive Loading

1. SCOPE

1.1 This draft specifies a test method for determining the shear behaviour of an adhesive in a single lap joint bonded assembly when subjected to a compressive force.

Note 1 The method described in this draft was based on the International Standards specification ISO 11003-2 "Thick adherend shear test method" , but modified for determining shear properties under compressive loading.

1.2 The test is performed on specimens consisting of thick, rigid adherends, with a short length overlap, in order to obtain the most uniform distribution of shear stresses possible and to minimise other stresses which initiate failure.

1.3 This test method may be used to determine:

- the shear stress vs shear strain curve to failure of the adhesive;
- the shear modulus of the adhesive;
- other shear properties that can be derived from the stress/strain curve such as secant shear modulus and maximum shear stress; and
- the effect of temperature, environment, testing speed, etc on these shear properties.

1.4 This method is applicable to metallic materials and fibre-reinforced plastic composites in flat sheet form in thicknesses ranging from 2.5 to 10 mm thick.

1.5 This method is performed using specimens which may be moulded to the chosen dimensions, machined from flat areas of product or machined from semi-finished products such as mouldings, laminates and extruded or cast sheet.

1.6 The method specifies preferred dimensions for the specimen. Tests which are carried out on specimens or other dimensions, or on specimens which are prepared under different conditions may produce results which are not comparable. Other factors, such as the speed of testing, the support fixture used and the condition of the specimens can influence the result. Consequently when comparative data are required, these factors must be carefully controlled and recorded.

Note 2 This test geometry is unsuitable for testing continuous aligned fibre-reinforced plastic composites with fibres aligned perpendicular to the applied load.

Note 3 The shear strength results obtained from specimens that fail outside the critical bond area are considered unsatisfactory and should be rejected.

Note 4 This test method is unsuitable for cyclic loading conditions.

2. NORMATIVE REFERENCES

The following standards contain provisions which through reference in this text, constitute provisions of this draft. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this draft are encouraged to use the most recent editions of the standards listed below. Members of the IEC and ISO maintain registers of currently valid International Standards.

ISO 291:1977, *Plastic - Standard atmospheres for conditioning and testing*.

ISO 293:1988, *Plastics - Compression moulding test specimens of thermoplastic materials.*

ISO 294:1983, *Plastics - Injection moulding test specimens of thermosetting materials.*

ISO 295:1288, ISO 293: 1988, *Plastics - Compression moulding test specimens of thermosetting materials. Part 1: general Principles.*

ISO 468:1982, *Surface Roughness - Parameters, their values and general rules for specifying requirements.*

ISO 683-11:1987, *Heat treatable steels, alloy steels and free-cutting steels - Part 11: wrought case-hardening steels.*

ISO 1052:1982, *Steels for general engineering purposes.*

ISO 1268: 1974, *Plastics - Preparation of glass fibre reinforced, resin bonded, low-pressure laminated plates or panels for test purposes (under revision).*

ISO 2602:1980, *Statistical interpretation of test results - Estimation of the mean - Confidence interval.*

ISO / DIS 2818:1991, *Plastics - Preparation of test specimens by machining*.

ISO 4588:1989, *Adhesives - Preparation of metal surfaces for adhesive bonding*.

ISO 4995:1991, *Hot-rolled steel sheet of structural quality*.

ISO 5893: 1985, *Rubber and plastics test equipment - Tensile, flexural and compression types (constant rate of traverse) - Description.*

ISO 9353:1991, *Glass-reinforced plastics - Preparation of plates with unidirectional reinforcements by bag moulding*.

ISO 10365:1992, *Adhesives - Designation of main failure patterns*.

ISO 11003-2:1997 (revision), *Adhesives - Determination of shear behaviour of Structural bonds. The thick adherend shear test method*.

BS EN ISO 14126:1195, *Fibre reinforced composites - Determination of compression properties in the in-plane direction.*

3. PRINCIPLE

An adhesively bonded test specimen (see Figure 1) is subjected to a compressive force so that the adhesive is stressed in shear. The specimen is end-loaded in a supporting jig (see Figure 2). Failure of the specimen occurs in shear between two centrally located parallel grooves with a depth equal to half the specimen thickness and spaced equidistant from the specimen mid-length on opposing faces.

The relative displacement of the adherends is measured using a purpose-built transducer located in the central region of the specimen or by non-contact strain measurement techniques (i.e. video extensometry and electronic speckle pattern interferometry (ESPI)). Force and displacement are measured from the start of application of the load until fracture of the specimen. The shear stresses and strains are then calculated from bond dimensions.

4. APPARATUS

4.1 Test Machine

4.1.1 General

The test machine shall comply with ISO 5893 as appropriate to the requirements given in 4.1.2 and 4.1.3.

Note 5 Tensile test machine must be capable of producing fracture in the specimen at a tensile force between 10% and 80% of the full scale range, of the force transducer.

4.1.2 Speed of Testing

The test speed shall be kept constant.

4.1.3 Load indicator

The error for the load shall not exceed ± **1%** of full scale (see ISO 5893) at a shear strain of 0.01%.

4.1.4 Extensometer for measuring shear displacement

This device shall measure the shear displacement between two points of known separation on each adherend in the central region of the bond (see Figure 3). The points of contact with the adherends shall be within a distance of 2 mm of the bonded faces. The device shall be capable of measuring the shear displacement to an accuracy of 1 μm (see Notes 6 to 8).

Note 6 In order to achieve high accuracy in displacement measurements, it is necessary to minimise any rotation of contact extensometers about an axis normal to the specimen face on which the extensometer contacts. This has been achieved in the extensometer design shown in Figure 3 (ISO 11003-2) by the double pin contact on one of the adherends.

Note 7 The use of two contact extensometers on opposing faces of the specimen is recommended to minimise, by averaging the extensometer readings, any contribution to measurements from out-of-plane deformation of the specimen or uneven loading at the end of the specimen. The use of two extensometers will also serve to indicate any malfunctioning of one of the extensometers as revealed by significantly different readings from the two devices.

Note 8 Non-contact techniques can be used to measure shear deformation or shear strain directly.

4.1.5 **Micrometer or equivalent**, reading to less than or equal to 0.001 mm, for measuring the adherend thickness **h** and width **b** of the specimen.

The micrometer shall use faces appropriate to the surface being measured (i.e. flat faces for flat polished surfaces).

4.1.6 **Travelling microscope**, or equivalent, reading to less than or equal to 0.001 mm, for measuring the depth of, distance between, the notches and thickness of the adhesive bond.

4.1.7 **Loading fixtures**, a supporting jig, shown schematically in Figure 2. Load is applied direct to the end of the specimen. Figure 4 shows supporting jig with specimen.

4.1.8 **Torque wrench**, a suitable torque wrench for tightening the nuts of the supporting jig to the torque prescribed in 9.5.

5. TEST SPECIMENS

5.1 Specimen dimensions and configurations

Specimens shall be prepared either by bonding metal plates or strips together to produce the configuration shown in Figure 1a or by bonding adherends that have been machined to the shape shown in Figure 1b (see Note 9). The dimensions are the same, within variations in the bond thickness, for both preparation methods.

Note 9 The adherends shown in Figure 1a have a lower bending stiffness than the continuous geometry in Figure 1b. Consequently, the peel stresses at the ends of the adhesive in the specimen in Figure 1a will be higher than those in the specimen in Figure 1b. Since failure is generally initiated by these peel stresses, the specimen design shown in Figure 1a will probably fail at a lower stress and strain than the design shown in Figure 1b.

The specimens shall be straight sided and of rectangular cross-section with the following dimensions.

Overall length, L_T (mm)	**Adherend Thickness, h (mm)**	**Width, b (mm)**
80 ± 1	2.5-10 ± 0.1	10 ± 0.3

The minimum thickness of bonded regions of adherends manufactured from steel sections or materials stiffer than steel should be 2.5 mm. For materials with stiffness less than steel, the following relationship can be used to determine the required adherend thickness $\mathbf{h_A}$.

$$h_A = \frac{E_S h_S}{E_A}$$

where $\mathbf{E_S}$ is the tensile modulus of steel, $\mathbf{E_A}$ is the tensile modulus of the adherend and $\mathbf{h_S}$ is the minimum recommended thickness of the steel adherend (i.e. 2.5 mm).

5.2 Adherends

5.2.1 For the purpose of the measurement of the adhesive properties, steel adherends are recommended because of the materials high stiffness.

Note 10 A suitable steel is XC18 or E24 grade 1 or 2.

5.2.2 Machine steel panels or bars to be used for the adherends in accordance with ISO 683-11, ISO 1052 and ISO 4995 and with dimensions given in Figure 1a or 1b depending on which specimen configuration is chosen.

5.3 Preparation of surfaces before bonding

The surfaces to be bonded shall be prepared in accordance with ISO 4588, unless otherwise specified.

6. SPECIMEN PREPARATION

6.1 Specimens with bonded metal adherends

Specimens with bonded adherends have the configuration shown in Figure 1a and may prepared as panels, pre-cut panels or as separate specimens from machined bars. Preparation of specimens from panels and pre-cut panels is almost identical (see ISO 11003:2).

6.1.1 Panels

6.1.1.1 The panels from which the specimens are to be cut shall consist of two sheets with dimensions in accordance with Figure 4 and bonded together in accordance with the adhesive manufacturer's instructions.

6.1.1.2 In order to define the thickness of the adhesive, shims or spacers (metal foil) or calibrated metal wires shall be incorporated outside the overlap zone.

6.1.1.3 Cut the bonded panels into specimens using a suitable tool such as a band saw. Then machine the specimen to the dimensions. Ensure there is no burrs or other forms of machine damage along the bonded joint.

6.1.1.4 Two parallel grooves, one in each face of the specimen and 6.5 ± 0.1 mm apart, shall be machined across the entire width of the specimen and spaced equidistant from the specimen mid-length. The incision shall penetrate to the inner surface of the underlying substrate and no further. The grooves shall be 1.5 ± 0.1 mm wide and parallel to within 0.1 mm

6.1.1.5 When the specimens are machined, care shall be taken to ensure that the assembly is not heated above 50 °C. No liquid shall be used for cooling.

6.1.2 Individual metal specimens

6.1.2.1 Bond two bars of dimensions 80 mm x 10 mm x 2.5 mm (or greater) in accordance with the adhesive manufacturer's instructions. Ensure that the sides of the adherends are parallel to the nearest 0.1 mm.

6.1.2.2 Proceed as in 6.1.1, using the two bars so as to obtain a specimen in accordance with Figure 1a.

6.1.3 Specimens with pre-shaped metal adherends

6.1.3.1 The adherends for this specimen type shall be machined with the dimensions given in Figure 1b prior to bonding. The adherends shall be bonded whilst held securely in a frame that ensures accurate alignment of the adherends.

6.1.3.2 In order to promote a bond of well-defined shape and length, strips of steel or PTFE of thickness 1.5 mm shall be inserted in the gaps between the adherends after the application of the adhesive and prior to curing. The strips shall be removed after the adhesive is cured. Steel strips should be coated with a release agent.

6.2 Specimens with bonded fibre-reinforced plastic composite adherends

Specimens fabricated with fibre-reinforced plastic composites can have either configuration shown in Figure 1 and may prepared as panels, pre-cut panels or as separate specimens from machined bars, or as pre-shaped sections. Preparation of specimens from composite materials is essentially the same as in Section 6.1 with differences only being in the machining requirements for the different classes of material.

6.2.1 Moulding or extrusion compounds

Specimens shall be prepared in accordance with the relevant material specification. When none exists, or unless otherwise specified, specimens shall be either compression or injection moulded from the material in accordance with ISO 293, ISO 294, ISO 295 or ISO 2557-2, as appropriate.

6.2.2 Panels

Specimens shall be machined from plates in accordance with ISO 2818.

6.2.3 Long-fibre reinforced plastic materials

Specimens machined from a panel shall be prepared in accordance with ISO 1268 or other specified or agreed-upon-preparation procedure. Some guidance on machining plastics is given in ISO 2818.

6.3 Parallelism

Machine the loading ends of each specimen to be parallel to one another and perpendicular to the longitudinal axis of the specimen. The allowed deviation in the parallelism of the supporting areas is 0.1% of the overall specimen length $\mathbf{L_T}$. The tolerance on the parallelism along the specimen length shall be a maximum of 1% of the initial length. For dully aligned fibre-reinforced composites, the test specimen shall be taken with its axis within 0.5° of the mean fibre axis.

6.4 Checking

The specimens shall be free of twist and shall have mutually perpendicular pairs of parallel surfaces. The surfaces and edges shall be free from burrs, scratches, pits, sink marks and flashes. The specimens shall be checked for conformity with these requirements by visual observation against straight-edges, squares and flat plates, and by measuring with a micrometer. Specimen showing measurable or observable departure from one or more requirements shall be rejected or machined to proper size and shape before testing.

7. NUMBER OF SPECIMENS

7.1 At least five specimens, giving valid failures, shall be tested. The number of measurements may be more than five if greater precision of the mean value is required.

It is possible to evaluate this by means of the confidence interval (95% confidence interval, see ISO 2602).

7.2 The results of the specimens that do not fail along the plane between notches in accordance with 9.10 shall be discarded and new specimens tested in their place.

8. CONDITIONING

The test specimens shall be conditioned as specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, (e.g. for testing at elevated or low temperatures).

9. PROCEDURE

9.1 Conduct the test in an atmosphere, which is specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, (e.g. for testing at elevated or low temperatures).

9.2 Measure the length of the overlap **l** and the width **b** of each test specimen to the nearest 0.1 mm. Discard any specimen(s) with either a overlap length or a width exceeding the tolerance of ± 2% of the mean value and replace the specimen with another one, sampled by chance. Average the mean overlap length and width for the set of specimens.

9.3 Measure the thickness of the adhesive layer in the overlap region at both ends and on each side of the specimen to with an accuracy of 0.01 mm. Use the average value of the four measurements. If the difference between the end values is greater than 20% of the average value, eliminate the specimen. The bond thickness (i.e. adhesive thickness) for specimens with pre-shaped adherends (Figure 1b) may be obtained from measurements carried out on the shaped ends prior to bonding and from the thickness of the bonded specimen in the overlap region.

Note 11 Report if specimens are used that cannot meet the thickness tolerance.

9.4 Measure the depth of both grooves for each test specimen to the nearest 0.01 mm. Discard any specimen(s) with a notch depth exceeding the tolerance given in 6.1.1.4.

9.5 Mount the specimen in the supporting fixture to be used (see Figure 2). Tighten the nuts of the jig with the torque wrench of 4.1.8 to a torque of 0.1 Newton metre (Nm). Place the assembly between the loading platens of the test machine.

9.6 Strain measurements can be carried out by placing an extensometer on one or both sides of the specimen (Figure 3).

9.7 Load the specimen in compression in a universal tensile / compression testing machine at a constant displacement rate. For purposes of comparing the shear properties of different materials, a displacement rate (or cross-head speed) of 1 mm / min ± 0.2 mm / min is recommended.

9.8 Record the load and displacement of the specimen continuously, using, if practicable, an automatic recording system that yields a complete load / displacement curve to failure for this operation. Record the test temperature and relative humidity.

9.9 Determine the shear properties from the load / displacement data.

9.10 Check that the test was valid. The test is only valid if failure occurs along the plane between the grooves. Strength results of tests where failure occurs within the adherend are not valid.

10. EXPRESSION OF RESULTS

10.1 Calculation of the shear stress τ in the adhesive

The shear stress, expressed in pascals (Pa), in the adhesive can be calculated using the equation:

$$\tau = \frac{F}{bL}$$

where:

F = applied load, in Newtons
b = width of the specimen, in metres
L = bond or overlap length, in metres

10.2 Calculation of the shear strain g in the adhesive

The shear strain in the adhesive is:

$$\gamma = \frac{d_S}{t}$$

where:

d_S = shear displacement of the adhesive (see Figure 5)
t = bond thickness, in metres (see Figure 5)

The shear displacement of the adhesive **d_S** is less than the measured displacement **d** because of the contribution to **d** from the deformation of the adherends (see Figure 5). Assuming a uniform shear stress acts in the region of the adherend that is spanned by the extensometer then the shear displacement **d_S** can be approximated by the following equation:

$$d_S = d - \frac{\tau(t_A - t)}{G_A}$$

where:

d = measured displacement, in metres
t = shear stress corresponding to the measured displacement, in metres
t_A = pin separation of the extensometer (see Figure 5), in metres
G_A = shear modulus of the adherend, in pascals

Note 12 This simple correction gives a more accurate value for **d_S** than is obtained from measurements on a dummy specimen that has the same geometry as the bonded specimen, but is machined from a single piece of adherend material. The shear distribution in this dummy specimen is highly uniform and for a particular applied load, the stress in the central region will be lower than that obtained in a bonded specimen under the same load.

10.3 Presentation of the stress/strain curve

A plot of the shear stress against shear strain illustrates the mechanical behaviour of the adhesive under constant deformation rate and can be used for the acquisition of certain data needed for design (see Note 13).

Note 13 After the initial linear response of the adhesive, its stiffness decreases progressively with increasing strain. As the stiffness decreases, a greater proportion of the total displacement applied by the test machine is developed across the adhesive. Thus, in a test carried out at a constant displacement rate, the strain rate in the adhesive is not constant, but increases until the maximum stress is reached.

10.4 Calculation of the shear modulus G of the adhesive

The shear modulus is equal to the gradient of the linear, low-strain region of a plot of shear stress against shear strain (see Notes 14 and 15).

Note 14 The stress vs strain plot is unlikely to pass through the origin due to the difficulties of measuring small strains, thus manipulation of the raw data may be required. Where such manipulation has been correctly undertaken, the shear modulus **G** may be obtained using the following relationship:

$$G = \frac{\tau}{\gamma}$$

where shear stress t and shear strain g in the adhesive (along the centre line of the specimen) correspond to a point on the linear region of the curve.

Note 15 When the adhesive is being tested under conditions where it is significantly viscoelastic (e.g. at temperature approaching the glass-transition temperature), there is no region of the stress/strain curve that is linear, even at low strains where behaviour is linear viscoeleastic. Furthermore, under these conditions, stress/strain behaviour is highly dependent upon the strain rate and temperature. The derivation of a modulus from a test under constant strain rate is then not appropriate, and dynamic mechanical or stress relaxation tests should be carried out to characterise linear viscoelastic behaviour.

Note 16 Annex A provides details of an extensometer for measuring strain of the bonded joint of the specimen.

11. PRECISION

The precision of this method is not known because interlaboratory data are not available. When inter-laboratory data are obtained, a precision statement will be added in the next revision.

12. TEST REPORT

The test report shall include the following information:

a) reference to this draft and ISO 11003;

b) all information necessary for full identification of the adhesive (classification, type, supplier, commercial reference, batch number, date of manufacture, proportions of the mixture for two-component adhesives);

c) all information necessary for full identification of the adherends tested, including type, source, method of manufacturing, manufacturer's code number, form and previous history, where these are known;

d) detailed information on any surface preparation used;

e) curing conditions for the adhesive;

f) test temperature;

g) information on the conditioning of the specimens;

h) dimensions of the specimens (length of overlap **l** and width of the specimen **b**);

i) thickness of the adhesive layer and details on the method used to control bondline thickness;

j) number of specimens used;

k) speed of testing;

l) type and accuracy of the test machine used (see ISO 5893);

m) description and accuracy of the instrument used for measuring strain;

n) the individual property measurements of the adhesive determined in clause 9;

o) designation of the fracture pattern of the specimen in accordance with ISO10365;

p) standard deviations and the 95% confidence intervals of the mean values, if required.

ANNEX A

(Informative)

The extensometer consists of a rigid frame and an internal part which can move parallel to the frame by means of spring blades. The coil of a movement sensor (inductive sensor type LVDT) is fixed on the external moving part, while a solenoid plunger is fixed on the rigid frame.

Three measuring points of a transducer are fixed on one side of this extensometer, one on the frame and the other two on the internal moving part.

While the specimen is being stressed, the two halves of the specimen move away from each other. The relative movement of these two parts of the specimen is detected by the points, which makes the solenoid plunger move in the electrical coil of the sensor.

The sensor is connected to an amplifier whose output signal is proportional to the relative movement between the measuring points. The sensor display can be calibrated to read directly in millimetres.

Two extensometers of this type are fixed to the specimen by means of a special mount (one on each side of the specimen).

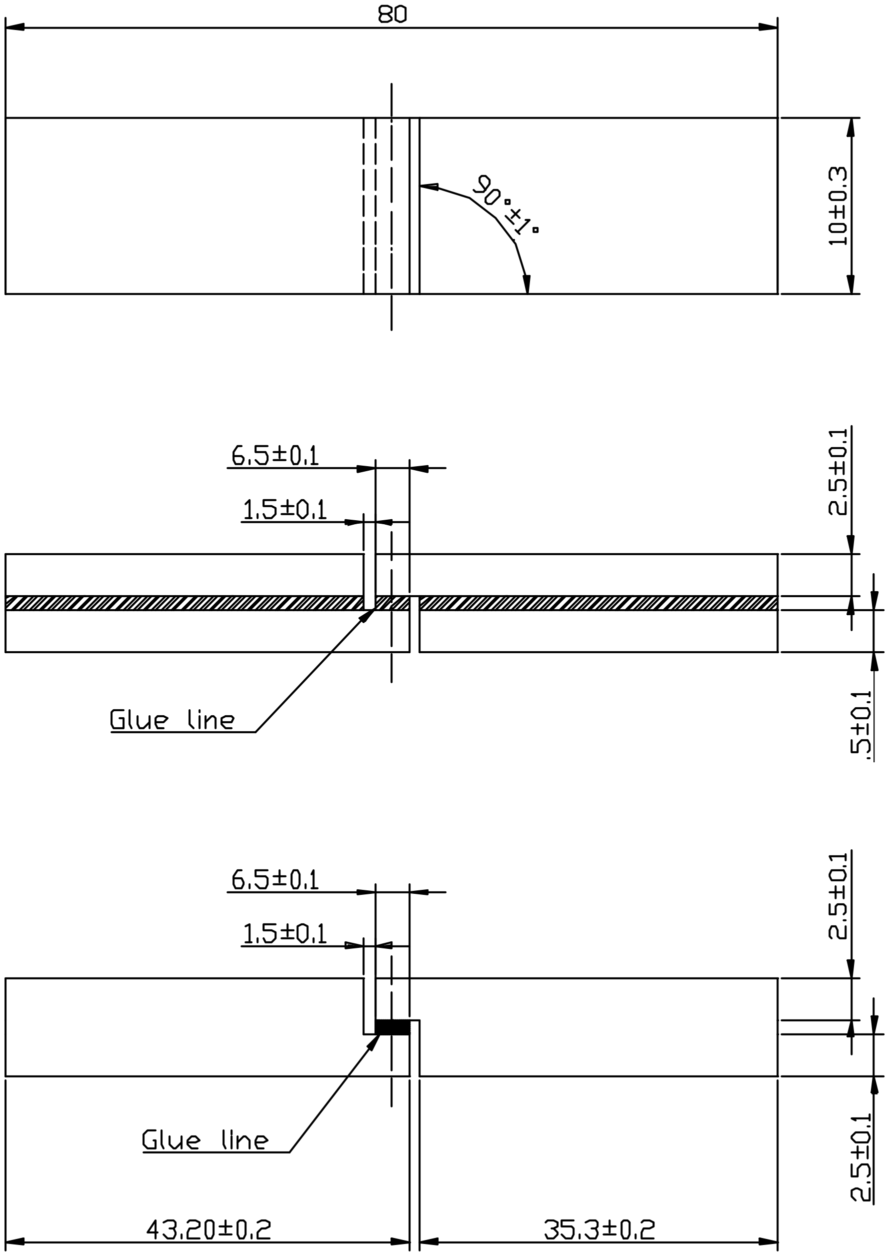
A calibration assembly with a precision micrometer screw makes it possible to calibrate the extensometer before the test.

Using these extensometers, displacements of 1 mm can be measured with an accuracy of 1 μm in a temperature range of -100 °C to +200 °C depending on the sensors used.

Non-contact strain measurement techniques (i.e. video extensometry and electronic speckle pattern interferometry (ESPI)) can also be used.

(a)

(b)



dimensions in millimetres

Figure 1 Specimen dimensions and configurations for the test specimen.
Bonded adherends - 1(a); pre-shaped adherends - 1(b).

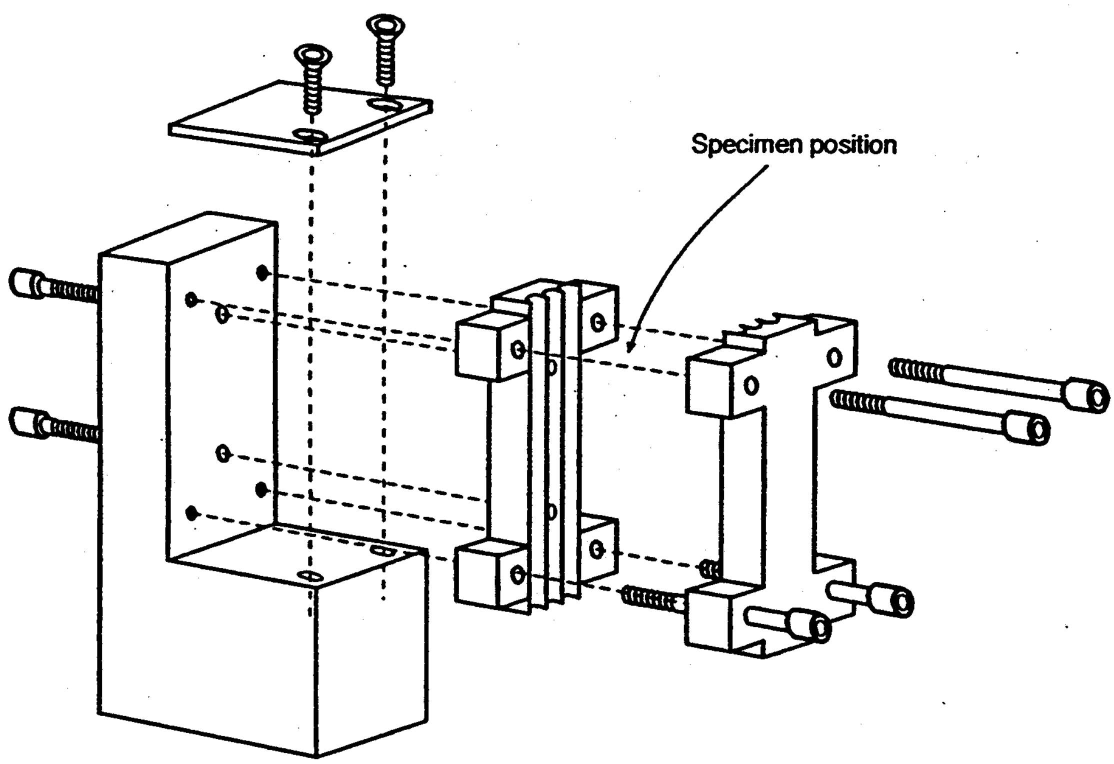


Figure 2 Schematic of supporting fixture.

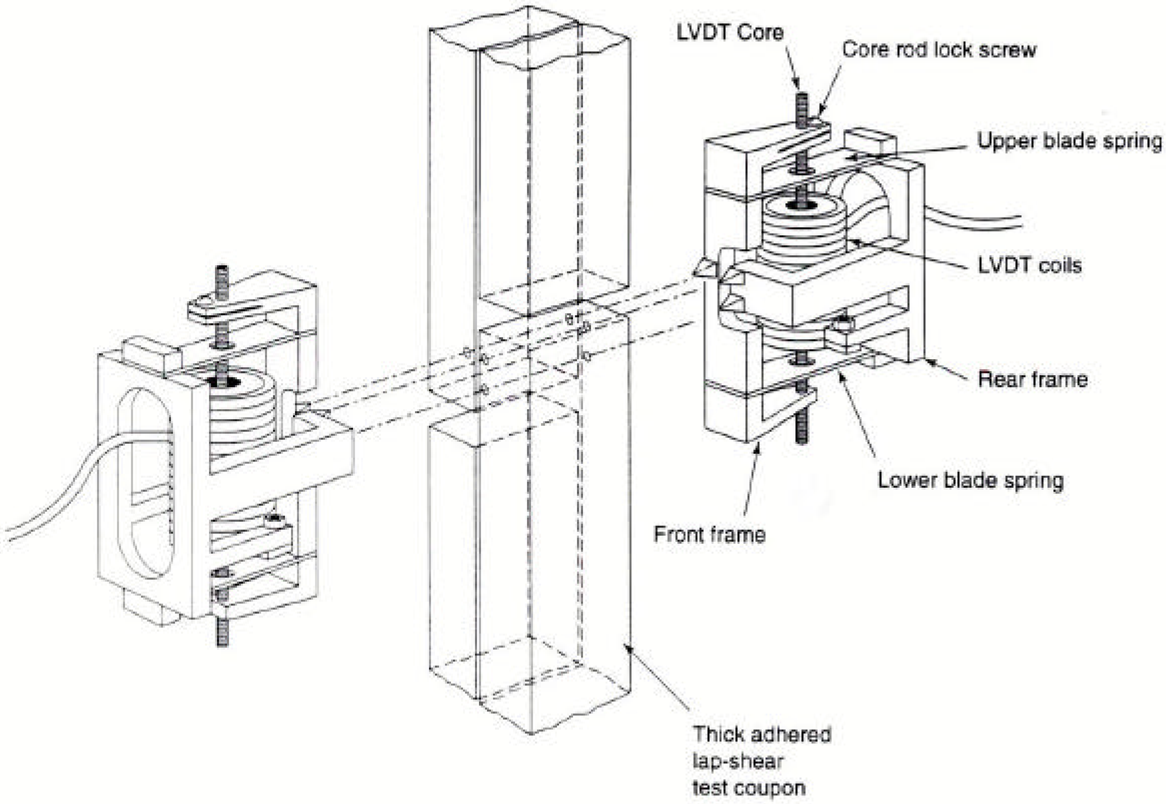


Figure 3 Diagram of extensometers and test specimen.

Figure 4 Support fixture with specimen.

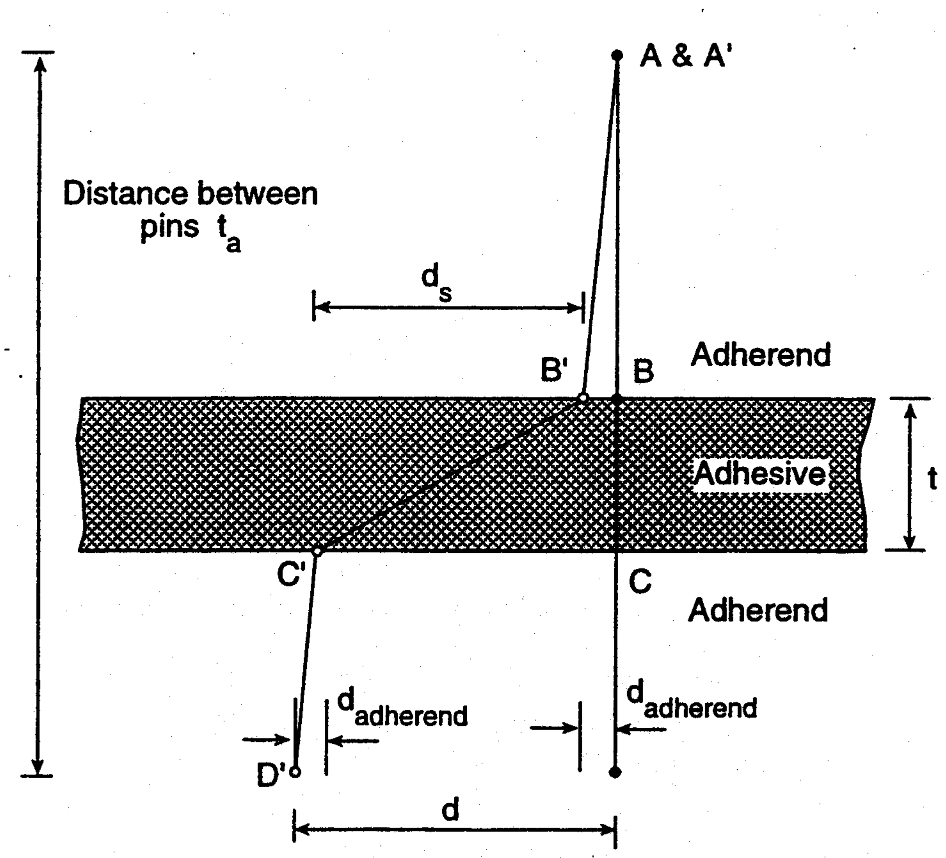


Figure 5 Deformation measured by the extensometer. The section line ABCD deforms to the points A'B'C'D' on application of a force.

Method 2

Tapered Strap Joint

1. SCOPE

1.1 This draft specifies a test method for determining the tensile shear behaviour of adhesive joints using a tapered strap joint. This method can be used for comparing adhesives under static and cyclic fatigue conditions.

Note 1 The method described in this draft was developed for use with standard extensometry (i.e two arm instruments commonly used for measuring elastic properties for bulk adhesive tests).; as an alternative to thick adherend test and associated strain measurement technique.(see ISO 11003-2).

1.2 The test is performed on specimens consisting of two thick, rigid adherends, with two short length straps bridging the two inner adherends. The straps have taperd ends in order to obtain the most uniform distribution of shear stresses possible and to minimise other stresses which initiate failure. The inner adherends are separated by a thin strip of PTFE to create a double overlap area.

1.3 This test method may be used to determine:

- the shear stress vs shear strain curve to failure of the adhesive;
- the shear modulus of the adhesive;
- other shear properties that can be derived from the stress/strain curve such as secant shear modulus and maximum shear stress; and
- the effect of temperature, cyclic and static fatigue, environment, testing speed, etc on these shear properties.

1.4 This method is applicable to metallic materials and fibre-reinforced plastic composites.

1.5 This method is performed using specimens which may be moulded to the chosen dimensions, machined from flat areas of product or machined from semi-finished products such as mouldings, laminates and extruded or cast sheet.

1.6 The method specifies preferred dimensions for the specimen. Tests which are carried out on specimens or other dimensions, or on specimens which are prepared under different conditions may produce results which are not comparable. Other factors, such as the speed of testing, the support fixture used and the condition of the specimens can influence the result. Consequently when comparative data are required, these factors must be carefully controlled and recorded.

Note 2 This test geometry is unsuitable for testing continuous aligned fibre-reinforced plastic composites with fibres aligned perpendicular to the applied load.

Note 3 The strength results obtained from specimens that fail in the adherend or outside the critical bond area are considered unsatisfactory and should be rejected.

2. NORMATIVE REFERENCES

The following standards contain provisions which through reference in this text, constitute provisions of this draft. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this draft are encouraged to use the most recent editions of the standards listed below. Members of the IEC and ISO maintain registers of currently valid International Standards.

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ISO 295:1288, ISO 293: 1988, *Plastics - Compression moulding test specimens of thermosetting materials. Part 1: general Principles.*

ISO 468:1982, *Surface Roughness - Parameters, their values and general rules for specifying requirements.*

ISO 683-11:1987, *Heat treatable steels, alloy steels and free-cutting steels - Part 11: wrought case-hardening steels.*

ISO 1052:1982, *Steels for general engineering purposes.*

ISO 1268: 1974, *Plastics - Preparation of glass fibre reinforced, resin bonded, low-pressure laminated plates or panels for test purposes (under revision).*

ISO 2602:1980, *Statistical interpretation of test results - Estimation of the mean - Confidence interval.*

ISO / DIS 2818:1991, *Plastics - Preparation of test specimens by machining*.

ISO 4587:1979, Adhesives - *Determination of tensile lap-shear strength of high strength adhesive bonds.*

ISO 4588:1989, *Adhesives - Preparation of metal surfaces for adhesive bonding*.

ISO 4995:1991, *Hot-rolled steel sheet of structural quality*.

ISO 5893: 1985, *Rubber and plastics test equipment - Tensile, flexural and compression types (constant rate of traverse) - Description.*

ISO 9353:1991, *Glass-reinforced plastics - Preparation of plates with unidirectional reinforcements by bag moulding*.

EN ISO 9664:1996, *Adhesives - Test methods for fatigue properties of structural adhesives in tensile shear*.

ISO 10365:1992, *Adhesives - Designation of main failure patterns*.

ISO 11003-2:1997 (revision), *Adhesives - Determination of Shear behaviour of Structural Bonds. The thick adherend shear test method*.

3. PRINCIPLE

This method consists of tensile loading a butt joint with tapered overlaps bridging the inner adherends (see Figure 1). The inner adherends are separated by a thin PTFE spacer to create a double overlap area. Load is applied until the joint breaks or until the maximum load is reached. The symmetry of the test geometry makes this technique more suitable for testing than the conventional double lap joint.

The relative displacement of the adherends is measured using either clip gauges or standard extensometers, a purpose-built transducer located in the central region of the specimen or by non-contact strain (i.e. video extensometry and electronic speckle pattern interferometry (ESPI)). The specimen contains parallel grooves located on either side of the central butt joint (see Figure 2) to allow for the use of a clip gauge or a two-arm extensometer. A central gap between the inner adherends, although not recommended, can be produced to allow the insertion of non-standard contact extensometers. The shear stresses and strains are then calculated from bond dimensions.

4. APPARATUS

4.1 Test Machine

4.1.1 General

The test machine shall comply with ISO 5893 as appropriate to the requirements given in 4.1.2 and 4.1.3.

Note 4 Tensile test machine must be capable of producing fracture in the specimen at a tensile force between 10% and 80% of the full scale range, of the force transducer.

4.1.2 Speed of Testing

The test speed shall be kept constant.

4.1.3 Load indicator

The error for the load shall not exceed ± **1%** of full scale (see ISO 5893) at a shear strain of 0.01%.

4.1.4 Extensometer for measuring shear displacement

This device shall measure the shear displacement between two points of known separation symmetrically located either side of the central butt joint on the inner adherends in the central region of the bond (see Figure 2). The points of contact with the adherends shall be within the overlap length l of the joint. The device shall be capable of measuring the shear displacement to an accuracy of 1 μm (see Notes 5 to 7).

Note 5 In order to achieve high accuracy in displacement measurements, it is necessary to minimise any rotation of contact extensometers about an axis normal to the specimen face on which the extensometer contacts.

Note 6 The use of two contact extensometers on opposing faces of the specimen is recommended to minimise, by averaging the extensometer readings, any contribution to measurements from out-of-plane deformation of the specimen or uneven loading at the end of the specimen. The use of two extensometers will also serve to indicate any malfunctioning of one of the extensometers as revealed by significantly different readings from the two devices.

Note 7 Non-contact techniques can be used to measure shear deformation, although there is a limit on the accuracy of measurements as these devices tend to be single-sided.

4.1.5 Micrometer or equivalent, reading to less than or equal to 0.001 mm, for measuring the thickness of the inner adherends and the bridging straps and width of the specimen.

The micrometer shall use faces appropriate to the surface being measured (i.e. flat faces for flat polished surfaces).

4.1.6 Travelling microscope, or equivalent, reading to less than or equal to 0.001 mm, for measuring the overlap length and thickness of the adhesive bond.

5. TEST SPECIMENS

5.1 Specimen dimensions and configurations

Specimens shall be prepared by bonding metal or composite sections together to produce the configuration shown in Figure 1. The specimens shall be straight sided and of rectangular cross-section with the following dimensions. The basic dimensions are shown below.

Overlap length, L (mm	Thickness (mm)		Width, b (mm)
	Inner Adherend, t_I	Outer Adherend, t_O	
25-50 ± 0.3	5-10 ± 0.1	2.5-5 ± 0.1	25 ± 0.3

The overlap length **L** should be at least 5 times the thickness of the inner adherend $\mathbf{t_i}$ with the length of each inner adherend being 110 + **L**. Taper angle q shall have a value of 30°.

Note 8 It is undesirable to exceed the yield point of the adherend in tension, hence the overlap length **L** should be sufficient to ensure adhesive failure occurs before the adherend yields. The maximum permissible length, which is a function of thickness and stiffness of the adherend, can be determined from the following equation:

$$L \geq \frac{\sigma_Y t_I}{1.5\tau}$$

where:

s_Y = yield stress of the adherend, in pascals
t = average shear strength of the adhesive, in pascals
t_I = inner adherend thickness, in metres

Note 9 From a design perspective, a taper angle of q **= tan^{-1}**(0.1) or a slope of 1 in 10 will minimise peel stresses at the ends of the overlap.

The minimum thickness of inner adherends and straps manufactured from steel sections or materials stiffer than steel should be 5 mm and 2.5 mm, respectively. For materials with stiffness less than steel, the following relationship can be used to determine the required adherend thickness $\mathbf{t_A}$.

$$t_A = \frac{E_S t_S}{E_A}$$

where $\mathbf{E_S}$ is the tensile modulus of steel, $\mathbf{E_A}$ is the tensile modulus of the adherend and $\mathbf{t_S}$ is the minimum recommended thickness of the steel adherend.

5.2 Adherends

5.2.1 For the purpose of the measurement of the adhesive properties, steel adherends are recommended because of the materials high stiffness.

Note 10 A suitable steel is XC18 or E24 grade 1 or 2.

Note 11 Unprotected mild steels are not particularly durable for environmental tests.

5.2.2 Machine steel bars to be used for the adherends in accordance with ISO 683-11, ISO 1052 and ISO 4995 and with dimensions given in Figure 1a or 1b depending on which specimen configuration is chosen.

5.3 Preparation of surfaces before bonding

The surfaces to be bonded shall be prepared in accordance with ISO 4588, unless otherwise specified.

6. SPECIMEN PREPARATION

6.1 Individual specimens with metal adherends

6.1.1 Specimens shall conform to the form and dimensions shown in Figure 1.

6.1.2 The adherends shall be bonded whilst held securely in a frame that ensures accurate alignment of the adherends. All parts of the joint should be first assembled and then co-bonded. A two-stage bonding process is not recommended.

6.1.3 Machine the two inner bars to dimensions of 100 mm x 25 mm x 10 mm (or greater). The inner adherends shall be of equal thickness and separated by a 2 mm gap filled with a suitable strip of PTFE to prevent a tapered joint in the overlapping area. PTFE spacer shall be inserted in the gaps between the adherends after the application of the adhesive and prior to curing. The strips shall be removed after the adhesive is cured.

6.1.4 The outer adherends (or straps) shall conform to the dimensions shown in Figure 1. The straps shall be 5 mm thick (or greater) with a 30° external taper.

I

6.1.5 Place the two outer adherends across the top and bottom of the joint ensuring that the centre of the overlaps coincides with the specimen mid-length.

6.1.6 Ensure that the sides of the adherends are parallel to the nearest 0.1 mm.

6.1.7 The adherends shall be bonded together in accordance with the adhesive manufacturer's instructions.

6.1.8 It is recommended that the notches for locating the extensometers be machined into the inner adherends prior to bonding.

6.2 Specimens machined from bonded metal plates

6.2.1 The bonded panels from which the specimens are to be cut shall conform to the dimensions, with the exception of width, to the dimensions in Figure 1.

6.2.2 Cut the bonded panels into specimens using a suitable tool such as a band saw. Then machine the specimen to the dimensions. Ensure there is no burrs or other forms of machine damage along the bonded joint.

6.2.3 When the specimens are machined, care shall be taken to ensure that the assembly is not heated above 50 °C. No liquid shall be used for cooling.

6.3 Specimens with bonded fibre-reinforced plastic composite adherends

Specimens fabricated with fibre-reinforced plastic composites are essentially identical to those used for metal adherends in Section 6.1 with differences only being in the machining requirements for the different classes of material.

6.3.1 Moulding or extrusion compounds

Specimens shall be prepared in accordance with the relevant material specification. When none exists, or unless otherwise specified, specimens shall be either compression or injection moulded from the material in accordance with ISO 293, ISO 294, ISO 295 or ISO 2557-2, as appropriate.

6.3.2 Panels

Adherend sections shall be machined from plates in accordance with ISO 2818. The tapers should be ground to avoid damage to the composite material.

6.3.3 Long-fibre reinforced plastic materials

Specimens machined from a panel shall be prepared in accordance with ISO 1268 or other specified or agreed-upon-preparation procedure. Some guidance on machining plastics is given in ISO 2818.

6.4 Parallelism

Machine the loading ends of each specimen to be parallel to one another and perpendicular to the longitudinal axis of the specimen. The allowed deviation in the parallelism of the supporting areas is 0.1% of the overall specimen length **L**. The tolerance on the parallelism along the specimen length shall be a maximum of 1% of the initial length. For dully aligned fibre-reinforced composites, the test specimen shall be taken with its axis within 0.5° of the mean fibre axis.

6.5 Checking

The specimens shall be free of twist and shall have mutually perpendicular pairs of parallel surface. The surface and edges shall be free from burrs, scratches, pits, sink marks and flashes. The specimens shall be checked for conformity with these requirements by visual observation against straight-edges, squares and flat plates, and by measuring with a micrometer. Specimen showing measurable or observable departure from one or more requirements shall be rejected or machined to proper size and shape before testing.

7. NUMBER OF SPECIMENS

7.1 At least five specimens, giving valid failures, shall be tested. The number of measurements may be more than five if greater precision of the mean value is required.

It is possible to evaluate this by means of the confidence interval (95% confidence interval, see ISO 2602).

7.2 The results of the specimens that do not fail in shear mode in the overlap area in accordance with 9.8 shall be discarded and new specimens tested in their place.

8. CONDITIONING

The test specimens shall be conditioned as specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, (e.g. for testing at elevated or low temperatures).

9. PROCEDURE

9.1 Conduct the test in an atmosphere, which is specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, (e.g. for testing at elevated or low temperatures).

9.2 Measure the length of the overlap **L** and the width **b** of each test specimen to the nearest 0.1 mm. Discard any specimen(s) with either a overlap length or a width exceeding the tolerance of ± 2% of the mean value and replace the specimen with another one, sampled by chance. Average the mean overlap length and width for the set of specimens.

9.3 Measure the thickness of the adhesive layer in the overlap region at both ends and on each side of the specimen to with an accuracy of 0.01 mm. Use the average value of the four measurements. If the difference between the end values is greater than 20% of the average value, eliminate the specimen.

Note 12 Report if specimens are used that cannot meet the thickness tolerance.

9.4 Strain measurements can be carried out by placing an extensometer on one or both sides of the specimen

9.5 Load the specimen in tension in a tensile testing machine at a constant displacement rate. For purposes of comparing the shear properties of different materials, a displacement rate (or cross-head speed) of 1 mm / min ± 0.2 mm / min is recommended.

9.6 Record the load and displacement of the specimen continuously, using, if practicable, an automatic recording system that yields a complete load / displacement curve to failure for this operation. Record the test temperature and relative humidity.

9.7 Determine the shear properties from the load / displacement data.

9.8 Check that the test was valid. The test is only valid if failure occurs in the bonded region between inner and outer adherends. Strength results of tests where failure occurs within the adherend are not valid.

10. EXPRESSION OF RESULTS

10.1 Calculation of the shear stress t in the adhesive

The shear stress, expressed in pascals (Pa), in the adhesive can be calculated using the equation:

$$\tau = \frac{F}{2bL}$$

where:

F = applied load, in Newtons
b = width of the specimen, in metres
L = bond or overlap length, in metres

10.2 Calculation of the shear strain g in the adhesive

Shear deformation (i.e. gap displacement between the inner adherends D**)** is measured using two extensometers located on either side of the specimen. The shear deformation measurements obtained from the two extensometers are averaged to minimise any misalignment effects.

Note 13 The use of two extensometers will also serve to indicate any malfunctioning of one of the extensometers as revealed by significantly different readings from the two devices.

The shear strain in the adhesive g can be calculated using the following equation:

$$\gamma_A = \frac{\delta}{2t_A}$$

where:

d = relative displacement (in the adhesive), in metres
$\mathbf{t_A}$ = thickness of the adhesive, in metres

The value of d is related to the gap displacement D (or pin separation of the extensometer), in metres, and peak strain in the outer substrate (i.e. strap) $\mathbf{e_R}$ by the following relationship:

$$\delta = \Delta - he_R$$

where **h** = initial gap length, in metres.

Peak strain $\mathbf{e_R}$ is given by:

$$e_R = \frac{F}{2bE_R t_R}$$

where:

b = specimen width, in metres
F = applied load, in Newtons
$\mathbf{E_R}$ = Young's modulus of the straps, in pascals
$\mathbf{t_R}$ = thickness of the straps, in metres

10.3 Presentation of the stress/strain curve

A plot of the shear stress against shear strain illustrates the mechanical behaviour of the adhesive under constant deformation rate and can be used for the acquisition of certain data needed for design (see Note 14).

Note 14 After the initial linear response of the adhesive, its stiffness decreases progressively with increasing strain. As the stiffness decreases, a greater proportion of the total displacement applied by the test machine is developed across the adhesive. Thus, in a test carried out at a constant displacement rate, the strain rate in the adhesive is not constant, but increases until the maximum stress is reached.

10.4 Calculation of the shear modulus G of the adhesive

The shear modulus is equal to the gradient of the linear, low-strain region of a plot of shear stress against shear strain (see Notes 15 and 16).

Note 15 The stress vs strain plot is unlikely to pass through the origin due to the difficulties of measuring small strains, thus manipulation of the raw data may be required. Where such manipulation has been correctly undertaken, the shear modulus **G** may be obtained using the following relationship:

$$G = \frac{\tau}{\gamma}$$

where shear stress t and shear strain g in the adhesive (along the centre line of the specimen) correspond to a point on the linear region of the curve.

Note 16 When the adhesive is being tested under conditions where it is significantly viscoelastic (e.g. at temperature approaching the glass-transition temperature), there is no region of the stress/strain curve that is linear, even at low strains where behaviour is linear viscoeleastic. Furthermore, under these conditions, stress/strain behaviour is highly dependent upon the strain rate and temperature. The derivation of a modulus from a test under constant strain rate is then not appropriate, and dynamic mechanical or stress relaxation tests should be carried out to characterise linear viscoelastic behaviour.

11. PRECISION

The precision of this method is not known because interlaboratory data are not available. When inter-laboratory data are obtained, a precision statement will be added in the next revision.

12. TEST REPORT

The test report shall include the following information:

a) reference to this draft;

b) all information necessary for full identification of the adhesive (classification, type, supplier, commercial reference, batch number, date of manufacture, proportions of the mixture for two-component adhesives);

c) all information necessary for full identification of the adherends tested, including type, source, method of manufacturing, manufacturer’s code number, form and previous history, where these are known;

d) detailed information on any surface preparation used;

e) curing conditions for the adhesive;

f) test temperature;

g) information on the conditioning of the specimens;

h) dimensions of the specimens (length of overlap **l** and width of the specimen **b**);

i) thickness of the adhesive layer and details on the method used to control bondline thickness;

j) number of specimens used;

k) speed of testing;

l) type and accuracy of the test machine used (see ISO 5893);

m) description and accuracy of the instrument used for measuring strain;

n) the individual property measurements of the adhesive determined in clause 9;

o) designation of the fracture pattern of the specimen in accordance with ISO10365;

p) standard deviations and the 95% confidence intervals of the mean values, if required.

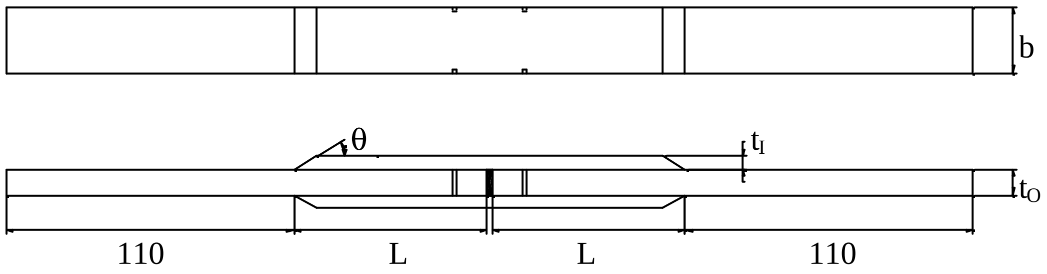


Figure 1 Specimen dimensions and configuration for the test specimen.

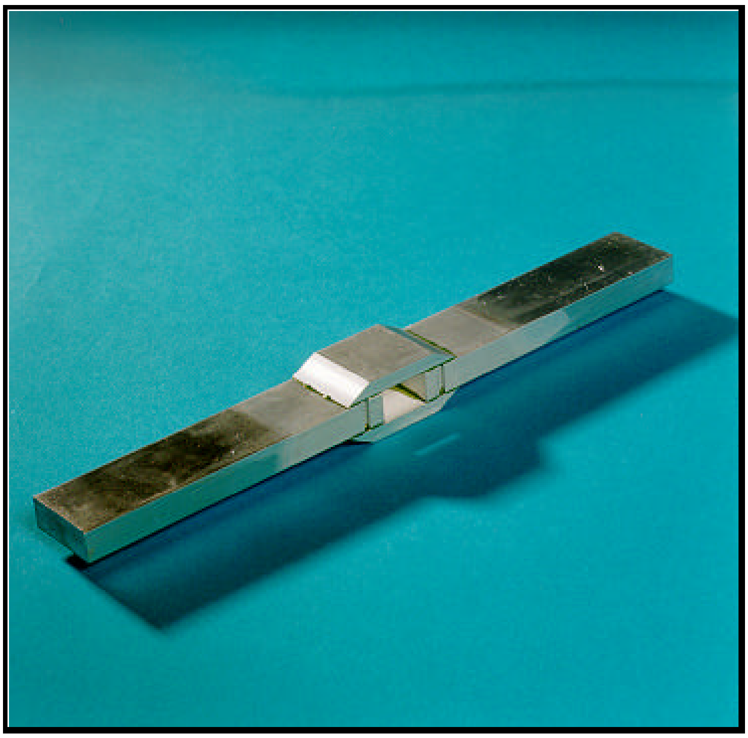


Figure 2 Photograph of specimen with notches for insertion of extensometer.

Method 3

Skin-Doubler Test

1. SCOPE

1.1 This draft specifies a procedure for determining the strength of adhesive joints using the skin-doubler test method.

Note 1 The overlap length of lap shear specimens is too short to ensure maximum shear transfer in the adhesive, thus the strength results from this geometry can be misleading. The "apparent" shear strength obtained will be dependent on adherend thickness and material, and failure will be invariably result from peel stresses rather than shear. The skin-doubler geometry in contrast is more representative of real-life structures. The large bond length associated with the technique enables maximum load transfer from the skin to the doubler.

1.2 The test is performed on specimens consisting of a infinitely long thin, rigid skin bonded to a infinitely long doubler, in order to develop a full, efficient shear stress distribution in the adhesive and to minimise peel stresses which initiate failure in joints with short overlap lengths.

1.3 This test method may be used to determine:

- static, fatigue and creep design allowables;
- peak shear stress
- shear stress vs shear strain curves to failure of the adhesive (along the bond length);
- the effect of temperature, environment, testing speed, etc on shear behaviour; and
- the ply drop strength in fibre-reinforced plastic composites.

1.4 This method is applicable to metallic materials and fibre-reinforced plastic composites in flat sheet form in thicknesses ranging from 2 to 10 mm thick.

1.5 This method is performed using specimens which may be moulded to the chosen dimensions, machined from flat areas of product or machined from semi-finished products such as mouldings, laminates and extruded or cast sheet.

1.6 The method specifies preferred dimensions for the specimen. Tests which are carried out on specimens or other dimensions, or on specimens which are prepared under different conditions may produce results which are not comparable. Other factors, such as the speed of testing, the support fixture used and the condition of the specimens can influence the result. Consequently when comparative data are required, these factors must be carefully controlled and recorded.

Note 2 This test geometry is unsuitable for testing continuous aligned fibre-reinforced plastic composites with fibres aligned perpendicular to the applied load.

Note 3 The shear strength results obtained from specimens that fail in the adherend or outside the critical bond area are considered unsatisfactory and should be rejected.

2. NORMATIVE REFERENCES

The following standards contain provisions which through reference in this text, constitute provisions of this draft. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this draft are encouraged to use the most recent editions of the standards listed below. Members of the IEC and ISO maintain registers of currently valid International Standards.

ISO 291:1977, *Plastic - Standard atmospheres for conditioning and testing*.

ISO 293:1988, *Plastics - Compression moulding test specimens of thermoplastic materials.*

ISO 294:1983, *Plastics - Injection moulding test specimens of thermosetting materials.*

ISO 295:1288, ISO 293: 1988, *Plastics - Compression moulding test specimens of thermosetting materials. Part 1: general Principles.*

ISO 468:1982, *Surface Roughness - Parameters, their values and general rules for specifying requirements.*

ISO 683-11:1987, *Heat treatable steels, alloy steels and free-cutting steels - Part 11: wrought case-hardening steels.*

ISO 1052:1982, *Steels for general engineering purposes.*

ISO 1268: 1974, *Plastics - Preparation of glass fibre reinforced, resin bonded, low-pressure laminated plates or panels for test purposes (under revision).*

ISO 2602:1980, *Statistical interpretation of test results - Estimation of the mean - Confidence interval.*

ISO / DIS 2818:1991, *Plastics - Preparation of test specimens by machining*.

ISO 4588:1989, *Adhesives - Preparation of metal surfaces for adhesive bonding*.

ISO 4995:1991, *Hot-rolled steel sheet of structural quality*.

ISO 5893: 1985, *Rubber and plastics test equipment - Tensile, flexural and compression types (constant rate of traverse) - Description.*

ISO 9353:1991, *Glass-reinforced plastics - Preparation of plates with unidirectional reinforcements by bag moulding*.

ISO 10365:1992, *Adhesives - Designation of main failure patterns*.

3. PRINCIPLE

The bonded joint is between an infinitely long thin rigid skin and a thin rigid doubler also of infinite length. The skin is loaded in tension, and the adhesive layer transfers the tension load into the doubler. The bond length is sufficiently long to ensure maximum load transfer between the skin and doubler. The maximum adhesive shear (at the doubler tip) decreases to zero at a some point along the joint length. At this point the tension stress, or strain, in the doubler equals that in the skin, no further load transfer is required. The distance required for the shear stress in the adhesive to decrease to zero is known as the ineffective length and is dependent upon the adhesive shear modulus and thickness, and on the stiffness and thickness of the doubler and skin. Beyond this limit, any increase in bond length is ineffective in reducing peak adhesive shear and peel stresses.
The shear strain at the doubler tip is measured using a purpose-built transducer located as shown in Figure 2. Non-contact strain measurement techniques (i.e. video extensometry and electronic speckle pattern interferometry (ESPI)) can also be used. Force and displacement are measured from the start of application of the load until fracture of the specimen. The shear stresses and strains are then calculated from bond dimensions.

4. APPARATUS

4.1 Test Machine

4.1.1 General

The test machine shall comply with ISO 5893 as appropriate to the requirements given in 4.1.2 and 4.1.3.

Note 5 Tensile test machine must be capable of producing fracture in the specimen at a tensile force between 10% and 80% of the full scale range, of the force transducer.

4.1.2 Speed of Testing

The test speed shall be kept constant.

4.1.4 Load indicator

The error for the load shall not exceed ±**1%** of full scale (see ISO 5893) at a shear strain of 0.01%.

4.1.4 Extensometer for measuring shear displacement

This device shall be able to measure the shear strain at the doubler tip and the shear strain distribution over the entire ineffective length (see Clause 3). Displacement between two points of known separation on the skin and doubler in the central region of the bond (see Figure 2) are measured. For maximum stress measurements, the points of contact with the adherends shall be within a distance of 2 mm of the overlap ends. The device shall be capable of measuring the shear displacement to an accuracy of 1 μm (see Notes 6 to 8).

Note 6 In order to achieve high accuracy in displacement measurements, it is necessary to minimise any rotation of contact extensometers about an axis normal to the specimen face on which the extensometer contacts. This has been achieved in the extensometer design shown in Figure 2 by the double pin contact on one of the adherends.

Note 7 The use of two contact extensometers on opposing faces of the specimen is recommended to minimise, by averaging the extensometer readings, any contribution to measurements from out-of-plane deformation of the specimen or uneven loading at the end of the specimen. The use of two extensometers will also serve to indicate any malfunctioning of one of the extensometers as revealed by significantly different readings from the two devices.

Note 8 Non-contact techniques can be used to measure shear deformation.

4.1.5 Micrometer or equivalent, reading to less than or equal to 0.001 mm, for measuring the skin and doubler thickness and width **b** of the specimen.

The micrometer shall use faces appropriate to the surface being measured (i.e. flat faces for flat polished surfaces).

4.1.6 Travelling microscope, or equivalent, reading to less than or equal to 0.001 mm, for measuring the thickness of the adhesive bond.

5. TEST SPECIMENS

5.1 Specimen dimensions and configurations

Specimens shall be prepared by bonding metal or composite sections together to produce the configuration shown in Figure 1a (non-symmetric) or 1b (symmetric). The specimens shall be straight sided and of rectangular cross-section with the following dimensions. The basic dimensions are shown in the table below.

Thickness (mm)		Length (mm)	
Skin	**Doubler**	**Skin**	**Doubler**
2	2	300	200

The standard geometry shall have a skin and doubler of equal thickness. The width of the specimen is 25 ± 0.3 mm. It is recommended that the fillet of the adhesive has 30° taper. Materials of greater thickness than the standard geometry can be tested provided the thicknesses of the doubler and skin are equal and the skin length is equal to 50 + 75 times the skin thickness.

Note 9 A taper angle of q **=** $\tan^{-1}(0.1)$ or a slope of 1 in 10 on the doubler will minimise peel stresses at the ends of the overlap.

The minimum thickness of adherends manufactured from steel sections or materials stiffer than steel should be 2.0 mm. For materials with stiffness less than steel, the following relationship can be used to determine the required adherend thickness $\mathbf{h_A}$.

$$h_A = \frac{E_S h_S}{E_A}$$

where $\mathbf{E_S}$ is the tensile modulus of steel, $\mathbf{E_A}$ is the tensile modulus of the adherend and $\mathbf{h_S}$ is the minimum recommended thickness of the steel adherend (i.e. 2.0 mm).

5.2 Adherends

5.2.1 For the purpose of the measurement of the adhesive properties, steel adherends are recommended because of the materials high stiffness.

Note 10 A suitable steel is XC18 or E24 grade 1 or 2.

5.2.2 Machine steel panels or bars to be used for the adherends in accordance with ISO 683-11, ISO 1052 and ISO 4995 and with dimensions given in Figure 1a or 1b depending on which specimen configuration is chosen.

5.3 Preparation of surfaces before bonding

The surfaces to be bonded shall be prepared in accordance with ISO 4588, unless otherwise specified.

6. SPECIMEN PREPARATION

6.1 Individual specimens with metal adherends

6.1.1 Specimens shall conform to the form and dimensions shown in Figure 1a or 1b. Configuration Figure 1b is recommended for measuring the shear strain distribution along the bond length.

6.1.2 The adherends shall be bonded whilst held securely in a frame that ensures accurate alignment of the adherends. All parts of the joint should be first assembled and then co-bonded. A two-stage bonding process is not recommended.

6.1.3 Machine the skin to dimensions of 300 mm x 25 mm x 2 mm (or greater) and the doubler dimensions to 200 mm x 25 mm x 2 mm (or greater).

6.1.4 The skin and doubler shall conform to the dimensions shown in Figure 1a or 1b. The skin and doublers shall be 2 mm thick with a 30° external taper on the adhesive fillet.

6.1.5 Ensure that the sides of the adherends are parallel to the nearest 0.1 mm.

6.1.6 The adherends shall be and bonded together in accordance with the adhesive manufacturer's instructions.

6.2 Specimens machined from bonded metal plates

6.2.1 The bonded panels from which the specimens are to be cut shall conform to the dimensions, with the exception of width, to the dimensions in Figure 1.

6.2.2 Cut the bonded panels into specimens using a suitable tool such as a band saw. Then machine the specimen to the dimensions. Ensure there is no burrs or other forms of machine damage along the bonded joint.

6.2.3 When the specimens are machined, care shall be taken to ensure that the assembly is not heated above 50 °C. No liquid shall be used for cooling.

6.3 Specimens with bonded fibre-reinforced plastic composite adherends

Specimens fabricated with fibre-reinforced plastic composites is essentially identical to that used for metal adherends in Section 6.1 with differences only being in the machining requirements for the different classes of material.

6.3.1 Moulding or extrusion compounds

Specimens shall be prepared in accordance with the relevant material specification. When none exists, or unless otherwise specified, specimens shall be either compression or injection moulded from the material in accordance with ISO 293, ISO 294, ISO 295 or ISO 2557-2, as appropriate.

6.3.2 Panels

Specimens fabricated with fibre-reinforced plastic composites is essentially identical to that used for metal adherends in Section 6.1 with differences only being in the machining requirements for the different classes of material. Adherend sections shall be machined from plates in accordance with ISO 2818.

6.3.3 Long-fibre reinforced plastic materials

Specimens machined from a panel shall be prepared in accordance with ISO 1268 or other specified or agreed-upon-preparation procedure. Some guidance on machining plastics is given in ISO 2818.

6.4 Parallelism

Machine the loading ends of each specimen to be parallel to one another and perpendicular to the longitudinal axis of the specimen. The allowed deviation in the parallelism of the supporting areas is 0.1% of the overall specimen length. The tolerance on the parallelism along the specimen length shall be a maximum of 1% of the initial length. For dully aligned fibre-reinforced composites, the test specimen shall be taken with its axis within 0.5° of the mean fibre axis.

6.5 Checking

The specimens shall be free of twist and shall have mutually perpendicular pairs of parallel surface. The surface and edges shall be free from burrs, scratches, pits, sink marks and flashes. The specimens shall be checked for conformity with these requirements by visual observation against straight-edges, squares and flat plates, and by measuring with a micrometer. Specimen showing measurable or observable departure from one or more requirements shall be rejected or machined to proper size and shape before testing.

7. NUMBER OF SPECIMENS

7.1 At least five specimens, giving valid failures, shall be tested. The number of measurements may be more than five if greater precision of the mean value is required.

It is possible to evaluate this by means of the confidence interval (95% confidence interval, see ISO 2602).

7.2 The results of the specimens that do not fail along the plane between notches in accordance with 9.8 shall be discarded and new specimens tested in their place.

8. CONDITIONING

The test specimens shall be conditioned as specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, (e.g. for testing at elevated or low temperatures).

9. PROCEDURE

9.1 Conduct the test in an atmosphere, which is specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, (e.g. for testing at elevated or low temperatures).

9.2 Measure the length of the overlap **L** and the width **b** of each test specimen to the nearest 0.1 mm. Discard any specimen(s) with either a overlap length or a width exceeding the tolerance of ± 2% of the mean value and replace the specimen with another one, sampled by chance. Average the mean overlap length and width for the set of specimens.

9.3 Measure the thickness of the adhesive layer in the overlap region at both ends and on each side of the specimen to with an accuracy of 0.01 mm. Use the average value of the four measurements. If the difference between the end values is greater than 20% of the average value, eliminate the specimen. The bond thickness (i.e.

adhesive thickness) for specimens with pre-shaped adherends may be obtained from measurements carried out on the skin and doubler sections prior to bonding and from the thickness of the bonded specimen in the overlap region.

Note 11 Report if specimens are used that cannot meet the thickness tolerance.

9.4 Strain measurements can be carried out by placing an extensometer on one or both sides of the specimen (Figure 2).

9.5 Load the specimen in tension in a universal tensile/compression testing machine at a constant displacement rate. For purposes of comparing the shear properties of different materials, a displacement rate (or cross-head speed) of 1 mm/min ± 0.2 mm/min is recommended.

9.6 Record the load and displacement of the specimen continuously, using, if practicable, an automatic recording system that yields a complete load/displacement curve to failure for this operation. Record the test temperature and relative humidity.

9.7 Determine the shear properties from the load/displacement data.

9.8 Check that the test was valid. The failure location of each specimen (e.g. cohesive, interfacial, tensile, etc.) is to be identified by visual inspection, or by low power microscopy. The test is only valid if failure occurs within the bonded region. Strength results of tests where failure occurs within the adherend are not valid.

10. EXPRESSION OF RESULTS

10.1 Calculate the failure load **F** per unit width **b** (i.e. **F/b)**, expressed in Newtons/metres.

10.2 Calculate the shear stress $t_{\mathbf{MAX}}$**,** expressed in pascals (Pa), in the adhesive using the equation:

$$\tau_{MAX} = \frac{KF}{\sqrt{\frac{t t_s E_a}{G_a}}}$$

where:

F = applied load, in Newtons
t = bondline or adhesive layer thickness, in metres
$\mathbf{t_s}$ = adherend (i.e. skin and doubler) thickness, in metres
$\mathbf{E_a}$ = tensile modulus of the adherend, in pascals (Pa)
$\mathbf{G_a}$ = shear modulus of the adherend, in pascals (Pa)
K = 0.71 (only when skin and doubler have identical thickness and material properties)

10.3 Calculation of the shear strain g **in the adhesive**

The shear strain in the adhesive is:

$$\gamma = \frac{d_s}{t}$$

where:

$\mathbf{d_S}$ = shear displacement of the adhesive, in metres (see Figure 3)
t = bondline or adhesive layer thickness, in metres (see Figure 3)

The shear displacement of the adhesive $\mathbf{d_s}$ is less than the measured displacement **d** because of the contribution to **d** from the deformation of the adherends (see Figure 3). Assuming a uniform shear stress acts in the region of the adherend that is spanned by the extensometer then the shear displacement $\mathbf{d_S}$ can be approximated by the following equation:

$$d_S = d - \frac{\tau(t_a - t)}{G_a}$$

where:

d = measured displacement, in metres
t = shear stress corresponding to the measured displacement, in pascals
$\mathbf{t_a}$ = pin separation of the extensometer (see Figure 3), in metres
t = bondline or adhesive layer thickness, in metres
$\mathbf{G_a}$ = shear modulus of the adherend, in pascals

Note 12 This simple correction gives a more accurate value for $\mathbf{d_S}$ than is obtained from measurements on a dummy specimen that has the same geometry as the bonded specimen, but is machined from a single piece of adherend material. The shear distribution in this dummy specimen is highly uniform and for a particular applied load, the stress in the central region will be lower than that obtained in a bonded specimen under the same load.

10.4 Presentation of the stress/strain curve

A plot of the shear stress against shear strain illustrates the mechanical behaviour of the adhesive under constant deformation rate and can be used for the acquisition of certain data needed for design (see Note 13).

Note 13 After the initial linear response of the adhesive, its stiffness decreases progressively with increasing strain. As the stiffness decreases, a greater proportion of the total displacement applied by the test machine is developed across the adhesive. Thus, in a test carried out at a constant displacement rate, the strain rate in the adhesive is not constant, but increases until the maximum stress is reached.

10.5 Calculation of the shear modulus G of the adhesive

The shear modulus is equal to the gradient of the linear, low-strain region of a plot of shear stress against shear strain (see Notes 14 and 15).

Note 14 The stress vs strain plot is unlikely to pass through the origin due to the difficulties of measuring small strains, thus manipulation of the raw data may be required. Where such manipulation has been correctly undertaken, the shear modulus **G** may be obtained using the following relationship:

$$G = \frac{\tau}{\gamma}$$

where shear stress t and shear strain g in the adhesive (along the centre line of the specimen) correspond to a point on the linear region of the curve.

Note 15 When the adhesive is being tested under conditions where it is significantly viscoelastic (e.g. at temperature approaching the glass-transition temperature), there is no region of the stress / strain curve that is linear, even at low strains where behaviour is linear viscoeleastic. Furthermore, under these conditions, stress / strain behaviour is highly dependent upon the strain rate and temperature. The derivation of a modulus from a test under constant strain rate is then not appropriate, and dynamic mechanical or stress relaxation tests should be carried out to characterise linear viscoelastic behaviour.

Note 16 Annex A provides details of an extensometer for measuring strain of the bonded joint of the specimen.

11. PRECISION

The precision of this method is not known because interlaboratory data are not available. When inter-laboratory data are obtained, a precision statement will be added in the next revision.

12. TEST REPORT

The test report shall include the following information:

a) reference to this draft;

b) all information necessary for full identification of the adhesive (classification, type, supplier, commercial reference, batch number, date of manufacture, proportions of the mixture for two-component adhesives);

c) all information necessary for full identification of the adherends tested, including type, source, method of manufacturing, manufacturer’s code number, form and previous history, where these are known;

d) detailed information on any surface preparation used;

e) curing conditions for the adhesive;

f) test temperature;

g) information on the conditioning of the specimens;

h) dimensions of the specimens (length of overlap **l** and width of the specimen **b**);

i) thickness of the adhesive layer and details on the method used to control bondline thickness;

j) number of specimens used;

k) speed of testing;

l) type and accuracy of the test machine used (see ISO 5893);

m) description and accuracy of the instrument used for measuring strain;

n) the individual property measurements of the adhesive determined in clause 9;

o) designation of the fracture pattern of the specimen in accordance with ISO10365;

p) standard deviations and the 95% confidence intervals of the mean values, if required.

ANNEX A

(Informative)

The extensometer consists of a rigid frame and an internal part which can move parallel to the frame by means of spring blades. The coil of a movement sensor (inductive sensor type LVDT) is fixed on the external moving part, while a solenoid plunger is fixed on the rigid frame.

Three measuring points of a transducer are fixed on one side of this extensometer, one on the frame and the other two on the internal moving part.

While the specimen is being stressed, the skin and doubler of the specimen move away from each other. The relative movement of these two parts of the specimen is detected by the points, which makes the solenoid plunger move in the electrical coil of the sensor.

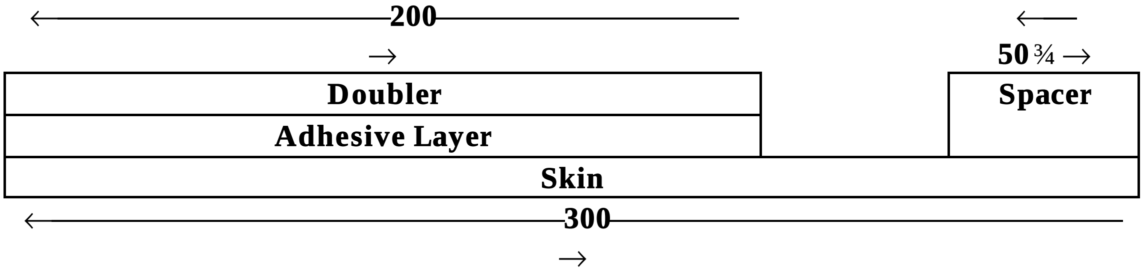
The sensor is connected to an amplifier whose output signal is proportional to the relative movement between the measuring points. The sensor display can be calibrated to read directly in millimetres.

For symmetric specimens (Figure 1(a)) two extensometers are fixed by means of a special mount (one on each side of the specimen). A single extensometer is mounted across the bond for non-symmetric specimens (Figure 1(b)).

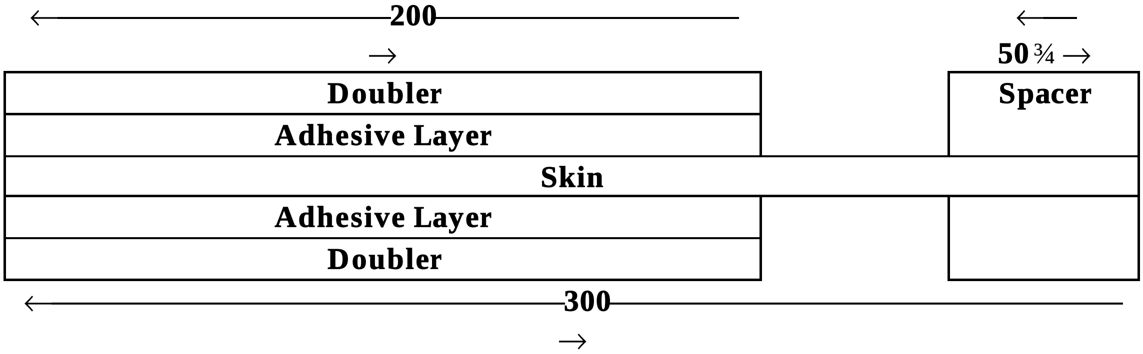
A calibration assembly with a precision micrometer screw makes it possible to calibrate the extensometer before the test.

Using these extensometers, displacements of 1 mm can be measured with an accuracy of 1 μm in a temperature range of -100 °C to +200 °C depending on the sensors used.

Non-contact strain measurement techniques (i.e. video extensometry and electronic speckle pattern interferometry (ESPI)) can also be used.



(a) Non-symmetric configuration.



(b) Symmetric configuration.

dimensions in millimetres

Figure 1 Specimen dimensions and configurations for the test specimen.

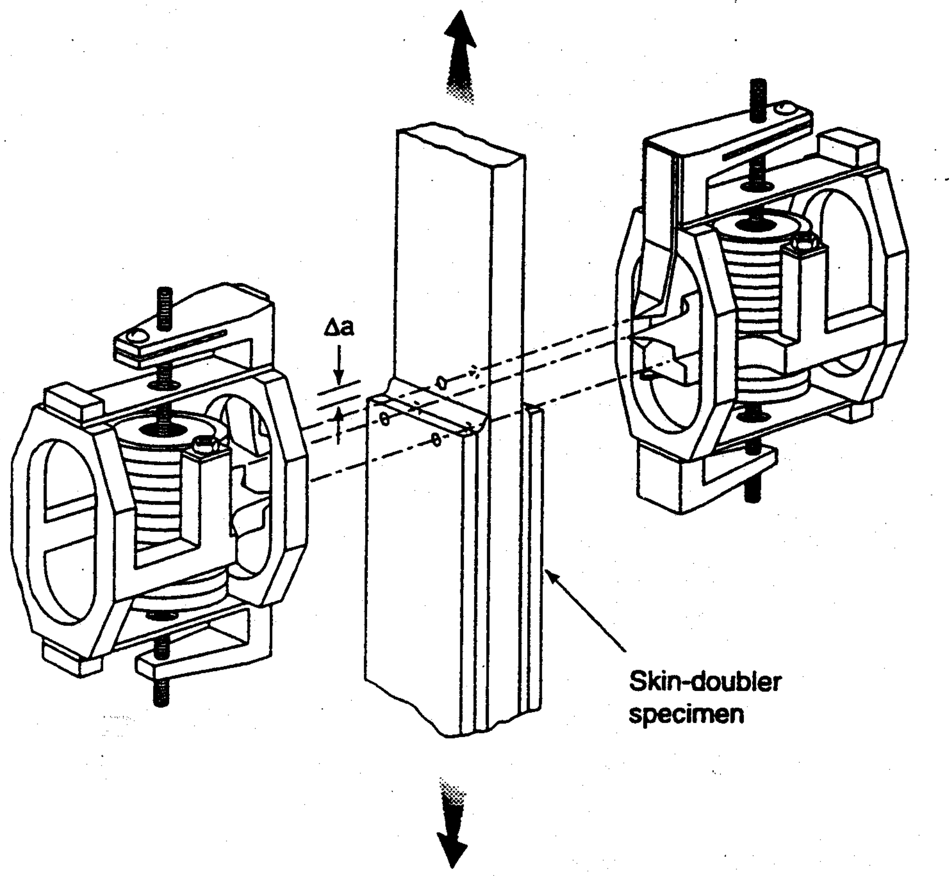


Figure 2 Schematic of symmetric specimen with extensometers.

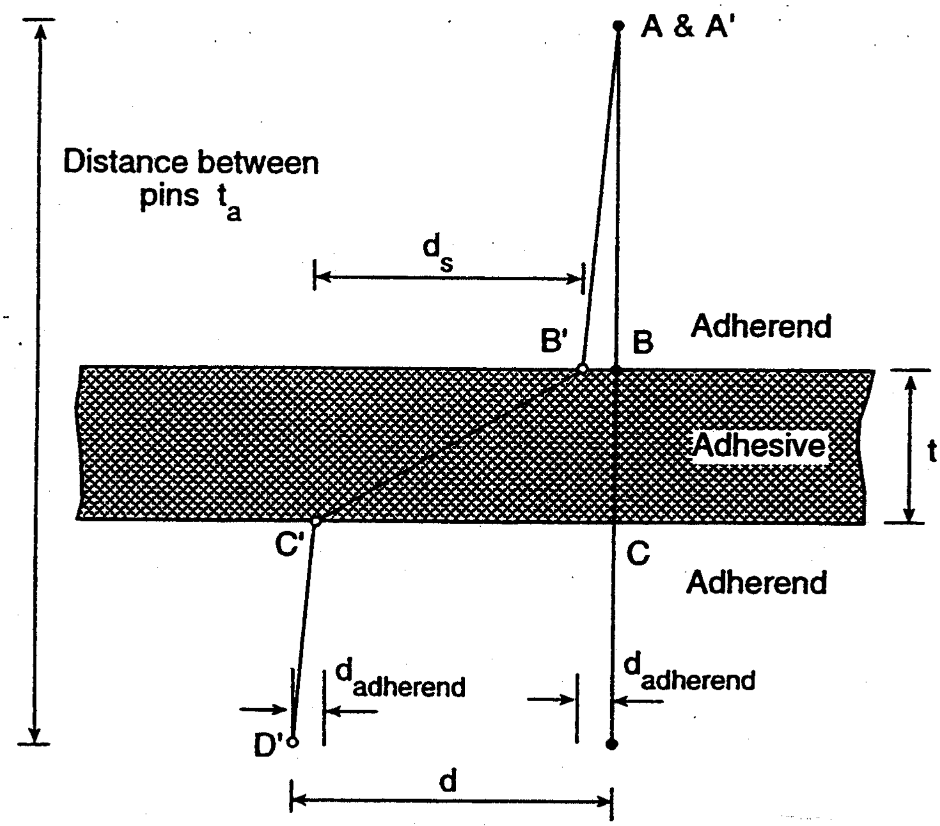


Figure 3 Deformation measured by the extensometer. The section line ABCD deforms to the points A'B'C'D' on application of a force.