Project PAJ2
Dynamic Performance of Adhesively Bonded Joints

Report No. 3 – August 1997

Proposed Draft for the Revision of ISO 11003-2

Adhesives - Determination of Shear Behaviour of Structural Bonds

Part 2: Thick-adherend tensile-test method

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CMMT(A)81
August 1997

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Part 2: Thick-adherend shear test method

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SUMMARY

The thick-adherend shear test was evaluated and used to characterise the shear behaviour of a range of adhesive materials as part of Project 1 of the first DTI funded adhesives programme. The title of the project was Determination of Basic Mechanical Properties of Adhesives for Design. As a result of this work, it was realised that there was scope for making some improvements to the ISO standard for this test method. This draft shows the proposed changes in bold italic text.

It has been prepared to support a New Work Item Proposal in ISO TC61 for a revision of the existing standard. The author would be pleased to receive comments on this draft which can then be discussed in committee, and implemented, if appropriate, in developments of the draft which will lead to a new ISO standard.

ISSN 1361-4061

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1 SCOPE

This part of ISO 11003 specifies a test method for determining the shear behaviour of an adhesive in a single lap joint bonded assembly when subjected to a tensile force.

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

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

2 NORMATIVE REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 11003. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 11003 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

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

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

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

3 PRINCIPLE

An adhesively bonded test specimen **(*see figure 1*)** is subjected to a tensile force so that the adhesive is stressed in shear.

The relative displacement of the ***adherends is measured using a purpose-built transducer located in the central region of the specimen. 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 **Tensile testing machine,** ***capable*** of producing fracture in the specimen at a tensile force between 10% and 80% of the full scale range, ***of the force transducer***.

4.2 **Device for *introducing a force into* the specimen,** so that ***negligible*** torque develops when force is applied to the specimen. For this purpose, ***the simple universal joint design shown in figure 2 is satisfactory***.

4.3 ***Force transducer capable of measuring the force in the specimen with an accuracy of 1% of the force at a shear strain of 0.01.***

4.4 ***An extensometer for measuring shear displacement.***

This device shall measure the shear displacement between 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 mm (see notes 1 and 2).

Note 1. In order to achieve high accuracy in displacement measurements, it is necessary to minimise any rotation of the extensometer about an axis normal to the specimen face on which the extensometer contacts. This has been achieved in the design shown in figure 3 by the double pin contact on one of the adherends.

Note 2. The use of two extensometers on opposing faces of the specimen is recommended to minimise, by averaging the extensometer readings, any contribution to measurements from a bending moment applied to 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.

4.5 ***Data logging equipment***, to continuously record the relative displacement of the ***adherends and the applied load***, from the start of application of the load until the specimen breaks.

4.6 ***Micrometer having an accuracy of better than 0.002 mm to measure the dimensions of the adherends.***

4.7 **Optical microscope** ***having an accuracy of better than 0.002 mm***, to measure the thickness of the ***adhesive bond when the specimen configuration shown in figure 1a is used.***

5 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. The dimensions of the specimen are given in figure 1 and are the same, within variations in the bond thickness, for both preparation methods (see note 3).

Note 3. The adherends shown in figure 1a have a lower bending stiffness than the continuous geometry shown 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 is likely to fail earlier (at lower stress and strain) than the design shown in figure 1b.

5.2 Adherends

For the purpose of the measurement of the properties of the adhesive, steel adherends are recommended because of their high modulus (see note 4).

Note 4 A suitable steel is XC18 or E24 grade 1 or 2.

Machine ***the*** 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 adherends

Specimens with bonded adherends have the configuration shown in figure 1a and may be prepared as panels, pre-cut panels or as separate specimens from machined bars.

6.1.1 Panels

The panels from which the specimens are cut shall consist of two sheets with dimensions in accordance with figure ***4***, bonded together on one side in accordance with the adhesive manufacturer's instructions.

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.

Cut the bonded panels into specimens using a suitable tool such as a band saw. Then subject the specimens to the required machining. Perform the last pass on the edge of the specimen parallel to the longitudinal direction of the specimen so as to avoid any metal burrs along the bonded joint.

Drill holes at the ends of the specimen for pins for holding the specimen to the tensile testing machine.

Delineate the overlap zone by milling two grooves as shown in figure 5.

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

6.1.2 Pre-cut panels

Proceed as in ***6.1.1***, using two pre-cut sheets so as to obtain a panel in accordance with figure ***6***.

Two holes shall be provided in each sheet so that the two sheets can be superposed correctly using an assembly with two centring lugs.

Cut panels and machine specimens as explained in 6.1.1.

6.1.3 Individual specimens

Bond two bars of dimensions 110 mm x 25 mm x 6 mm in accordance with the adhesive manufacturer's instructions. ***Ensure that the sides of the adherends are parallel to the nearest 0,1 mm.***

Define the thickness of the adhesive joint as indicated in 6.1.1.

Machine specimens to the required size.

Drill holes for applying the load.

Make two grooves by milling to delineate the overlap.

Take the same precautions as in 6.1.1.

6.2 Specimens with pre-shaped adherends

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.

In order to produce 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. They shall be removed after the adhesive has cured. If steel strips are used they shall be coated with a release agent.

7 NUMBER OF SPECIMENS

At least three specimens shall be tested for a given adhesive.

8 PROCEDURE

The temperature of the test shall be one of the standard temperatures specified in ISO 291.

Measure the length of the overlap l and the width of the specimens b to the nearest 0,1 mm.

Measure the thickness of the adhesive joint in the overlap zone at both ends and on each side of the specimen 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. ***Where specimens having pre-shaped adherends (figure 1b) are used, the bond thickness may be obtained from measurements, prior to bonding, of the thickness of the shaped ends of the adherends and of the thickness of the bonded specimen in the overlap region.***

Place an extensometer on ***one or both*** sides of the specimen (see figure 3).

Test the specimen in a tensile testing machine at a constant machine speed. ***For purposes of comparison, of results on different materials, a speed*** of 0,5 mm / min ***is recommended***.

Record the force ***on, and the displacement of, the specimen as it is loaded*** to fracture. ***Record the temperature also.***

9 EXPRESSION OF RESULTS

9.1 Symbols

b ***width of the specimen, in metres (see figure 1)***

l ***bond length, in metres (see figure 1)***

t ***bond thickness, in metres (see figure 7)***

t_a ***pin separation of the extensometer, in metres (see figure 7)***

d ***measured displacement, in metres (see figure 7)***

d_s ***shear displacement of the adhesive, in metres (see figure 7)***

F ***force on the specimen, in Newtons***

t ***average shear stress on the adhesive, in pascals***

g ***shear strain in the adhesive along the centre line of the specimen***

G ***shear modulus of the adhesive, in pascals***

G_a ***shear modulus of the adherend, in pascals***

9.2 Calculation of the average shear stress t in the adhesive

At any applied force F on the specimen, the average shear stress in the adhesive is

$$t = \frac{F}{lb}$$

9.3 Calculation of the shear strain g in the adhesive

The shear strain in the adhesive is

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

The shear displacement of the adhesive d_S is less than the measured displacement d because of some contribution to d from the deformation of the adherends (see figure 7). d_S can be calculated to a good approximation by assuming a uniform shear stress τ acts in the region of the adherend that is spanned by the extensometer.

The following equation then enables d_S to be calculated.

$$d_s = d - \frac{t\left(t_a - t\right)}{G_a}$$

where τ is the shear stress corresponding to the measured displacement (see note 5).

Note 5. 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 the adherend material. The shear stress distribution in this dummy specimen is highly non-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.

9.4 Presentation of the stress/strain curve

A plot of the shear stress against the 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 6).

Note 6. 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 constant speed, the strain rate in the adhesive is not constant but increases until the stress maximum is reached.

9.5 Calculation of the shear modulus 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 7 and 8).

Note 7. Because of the difficulties in the measurement of small strains in the specimen, a stress vs strain plot is unlikely to pass through the origin without some manipulation of the raw data. Where such manipulation has been correctly undertaken, the shear modulus may be obtained using

$$G = \frac{t}{g}$$

where τ and γ correspond to a point on the linear region of the curve.

Note 8. When the adhesive is being tested under conditions where it is significantly viscoelastic (eg at temperatures approaching its glass-to-rubber transition temperature), there is no region of the stress/strain curve that is linear, even at low strains where behaviour is linear viscoelastic. Furthermore, under these conditions, stress/strain behaviour is highly dependent upon 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.

10 PRECISION

The precision of this test method is not known because interlaboratory data are not available. When interlaboratory data are obtained, a precision statement will be added at the time of revision.

11 TEST REPORT

The test report shall contain the following items:

a) reference to this part of ISO 11003;

b) all the 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) identification of the adherends ***and method of manufacture*** used for the test;

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) speed of the test (speed of machine travel);

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

j) thickness of the adhesive;

k) number of specimens tests;

l) type of test machine used;

m) description of the instrument used for measuring strain;

n) designation of the fracture pattern of the specimen in accordance with ISO 10365;

o) properties of the adhesive determined in clause 9.

Annex A
(informative)

Extensometer for measuring strain of the bonded joint in the specimen

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 internal 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 rigid 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 extensometers before the test.

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

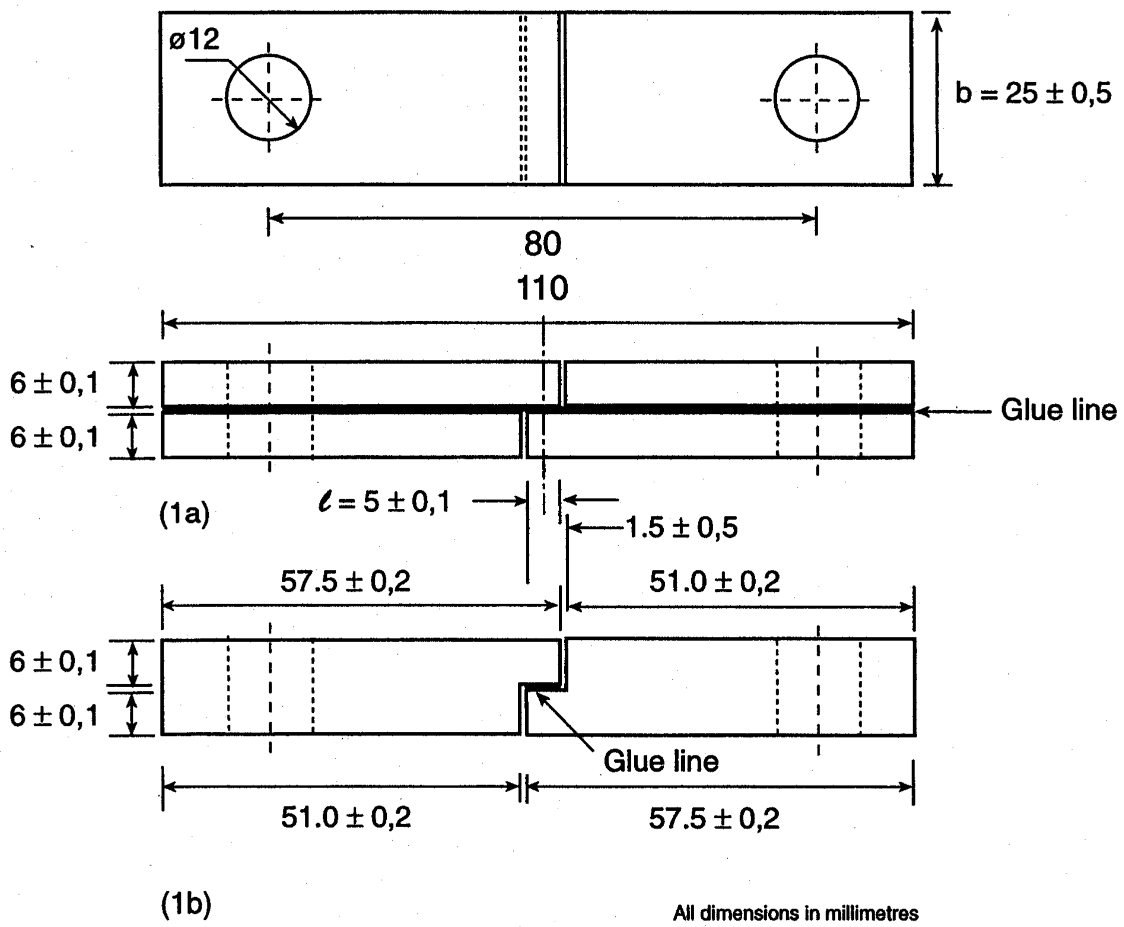

Figure 1. Specimen dimensions and configurations for the test specimen. Bonded adherends - (1a): pre-shaped adherends - (1b)

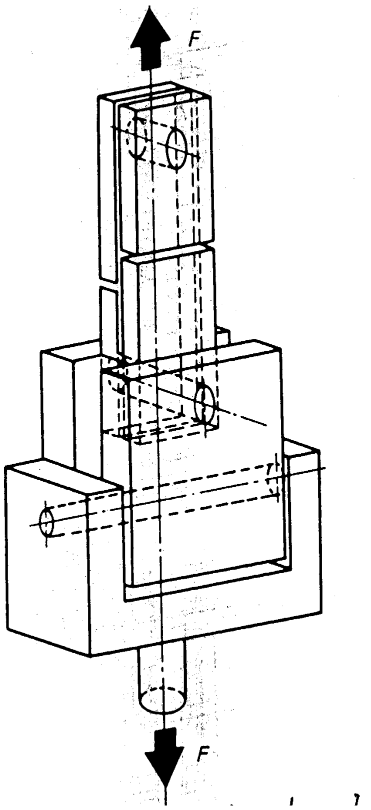

Figure 2 – Device for loading the specimen in a tensile testing machine

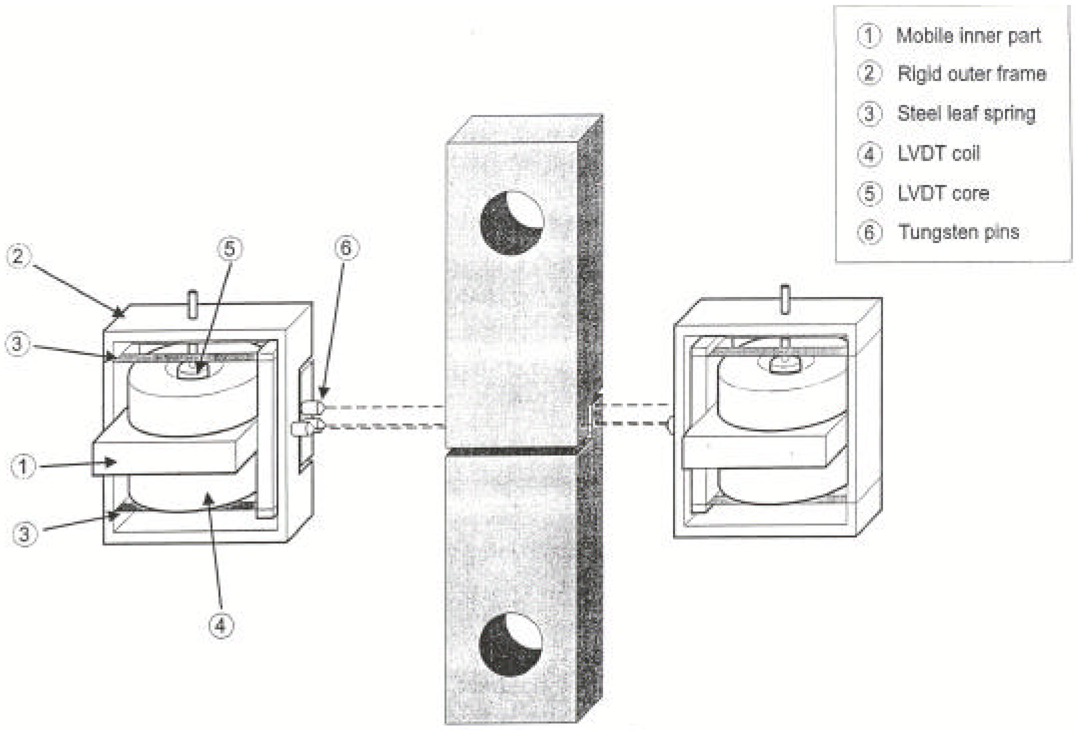

Figure 3 – Diagram of extensometers

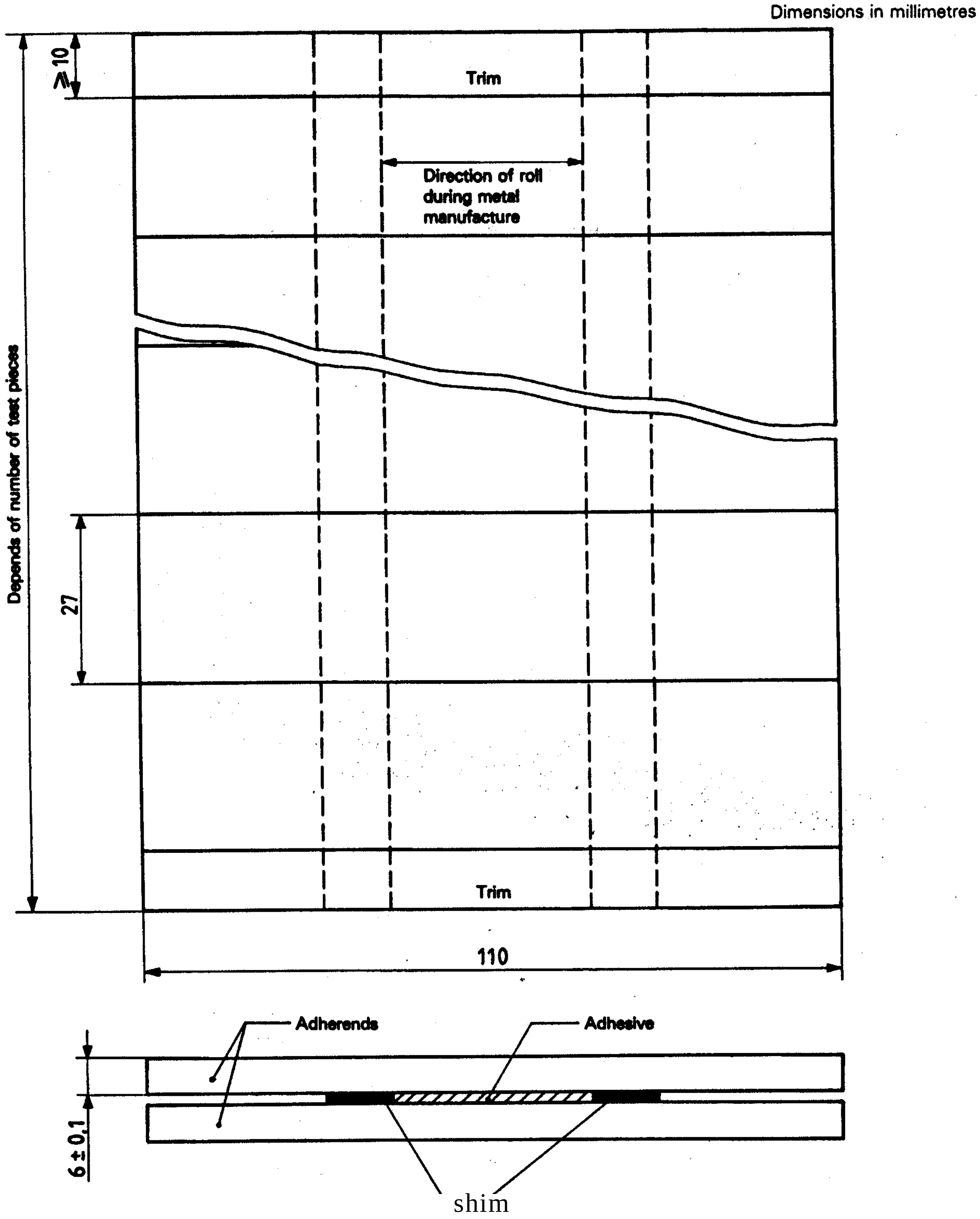

Figure 4 – Test Panel for making specimen assemblies

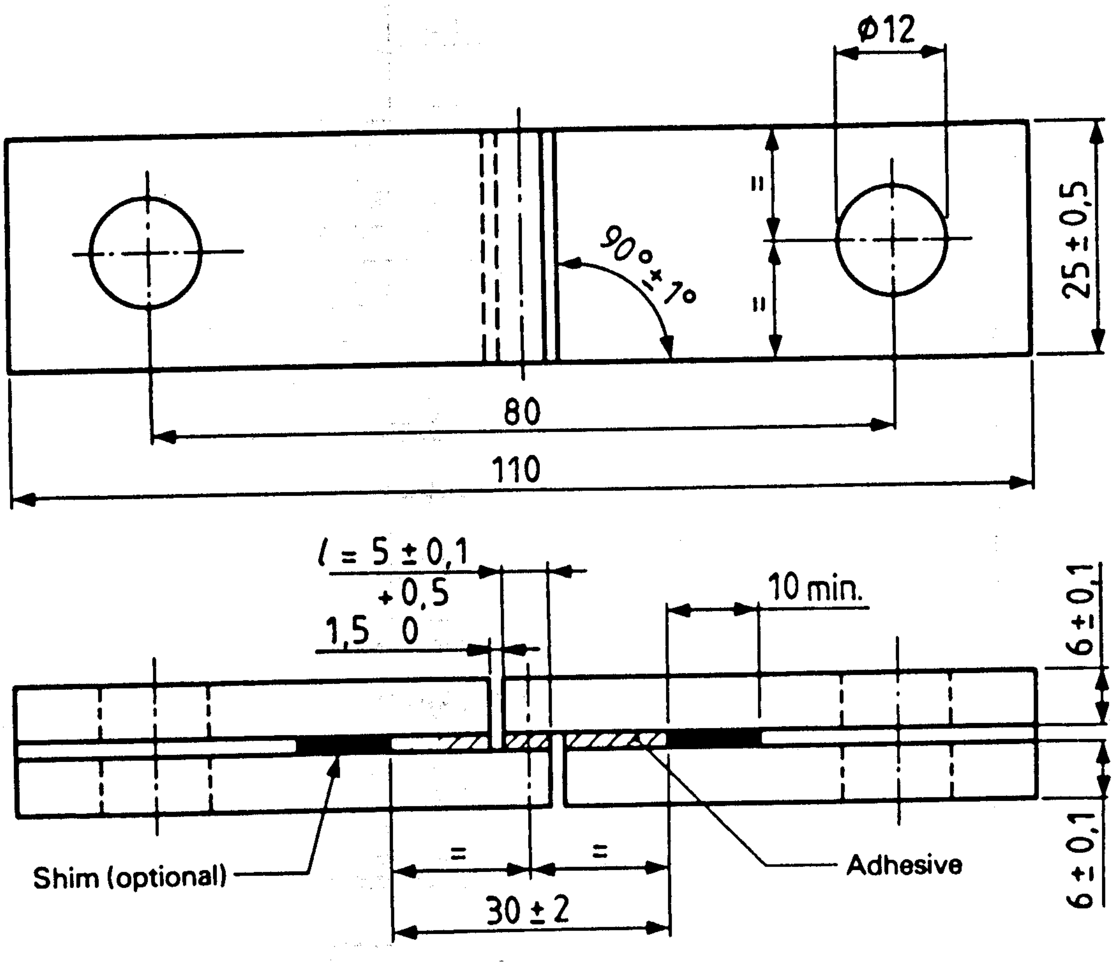

Figure 5 – Specimen with bonded adherends (all dimensions in mm)

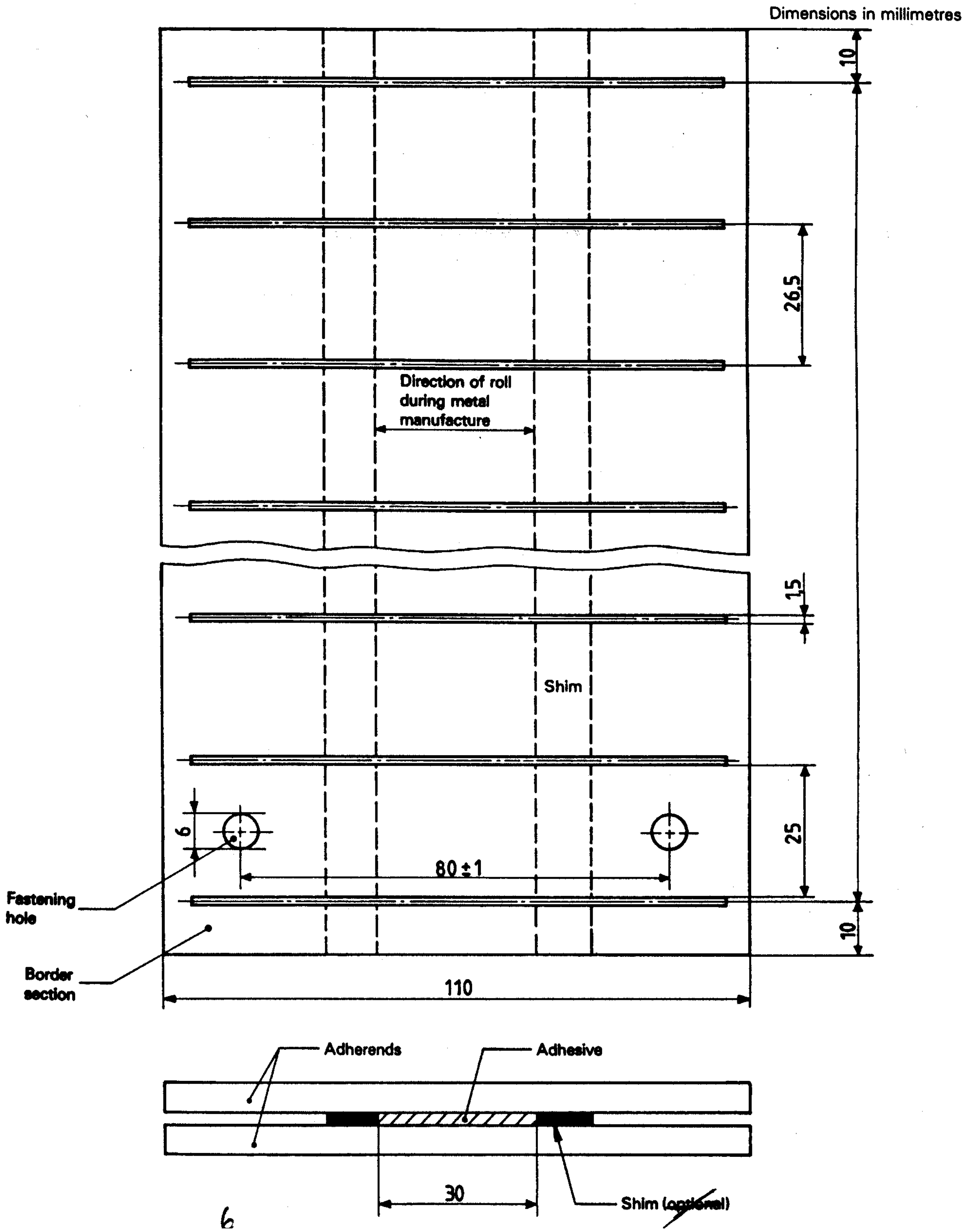

Figure 6 – Pre-cut panel for making specimen assemblies

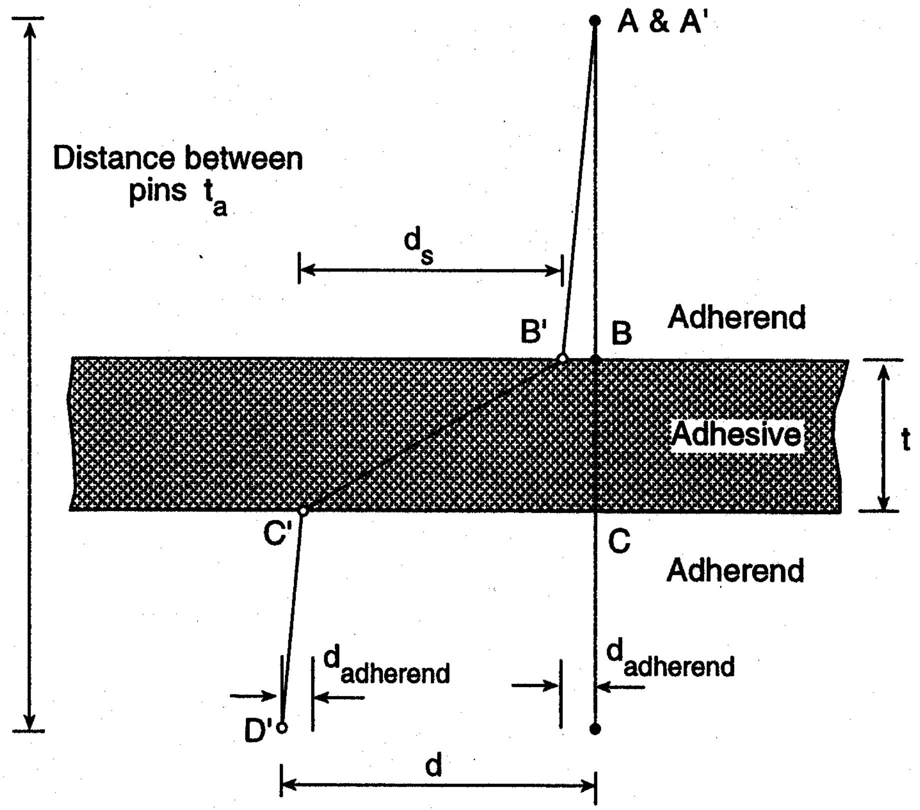

Figure 7 - Deformation measured by the extensometer. The section line ABCD deforms to the points A'B'C'D' on application of a force