4. TEST METHODS

Joints are generally designed to support a load, and must be tested to evaluate their load-supporting capabilities. However, it is also important to evaluate, not the joint, but rather a specific joining capability. Hence, many tests are made in order to evaluate the competence of the welder rather than the weld, while many adhesive joints are prepared to test the properties of the adhesives rather than the join (especially their shelf life or environmental sensitivity). The following section looks at some of the common methods of evaluating the mechanical performance of a joint.

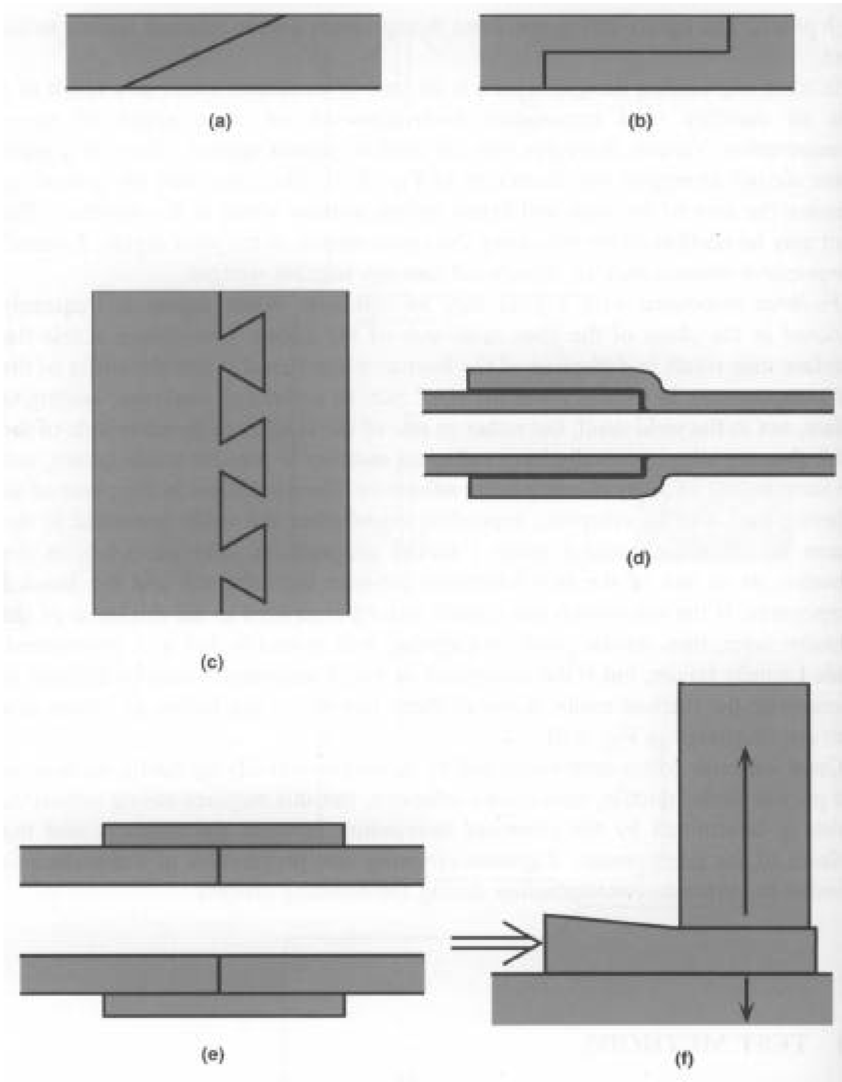

Fig. 4.1

Some failure modes at a joint.

a) brittle failure in the elastically stiffer component parallel to the join.

b) ductile failure (decohesion) within the bonded region.

c) loss of adhesion at the interface between an adhesive and one component.

d) ductilefailure of the adhesive bond at one interface.

4.1 TEST CONFIGURATION

A uniaxial load can be applied by a standard testing machine to create tensile, compressive or shear stresses (Fig. 4.2). Combined modes of testing are also common, for example in a three- or four-point bend test, in which the stresses vary with position in the sample (Fig. 4.3). The applied load may also be varied during the test, as in a mechanical fatigue test, or held constant at elevated temperatures while the displacement is monitored, as in a creep test. If the specimen is loaded to a given strain and the load is then monitored as a function of time at this strain, then the process of load relaxation can be followed. Tests performed in a controlled environment are used to investigate susceptibility to failure by stress corrosion (crack propagation at constant stress in a chemically-active environment), corrosion fatigue (environmentally exacerbated failure by mechanical fatigue) or radiation damage (degradation of the mechanical properties associated with irradiation in a nuclear reactor or some other radiation source).

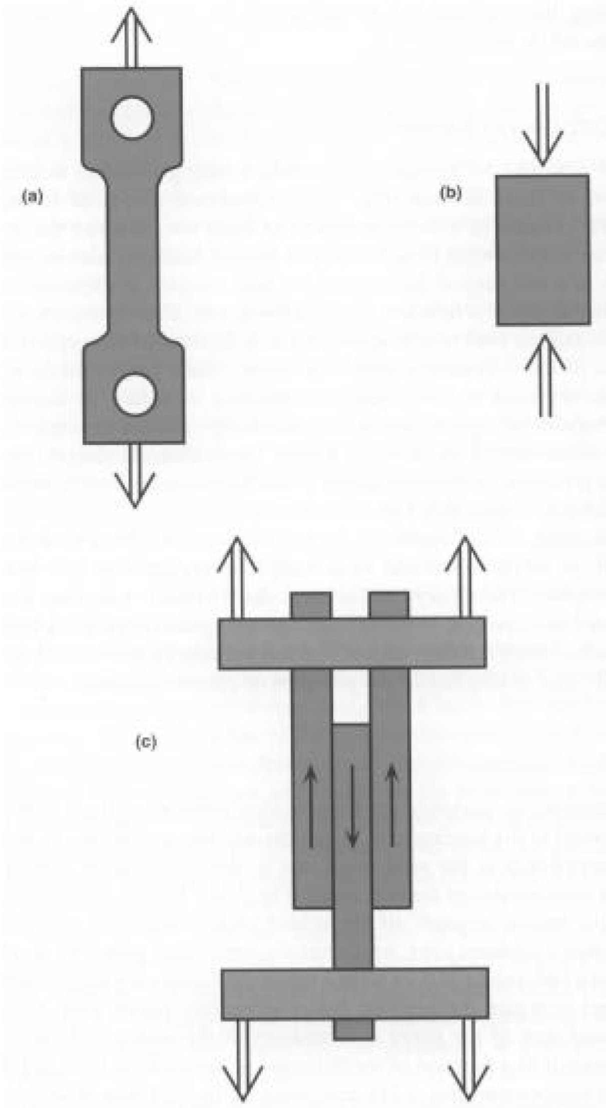

Fig. 4.2
A uniaxial loading machine can be used to test in.
a) tension. b) compression. c) shear.

Impact loading of the specimen is the characteristic feature of the standard Charpy test, in which a notched bend sample is impacted at low velocity by a swinging hammer. The Charpy and other, related impact tests were developed to evaluate notch sensitivity to brittle failure. The energy absorbed in a Charpy test has no design value (since it clearly depends on test geometry), but it is a clear indication of a possible loss of ductility in the presence of plastic constraint.

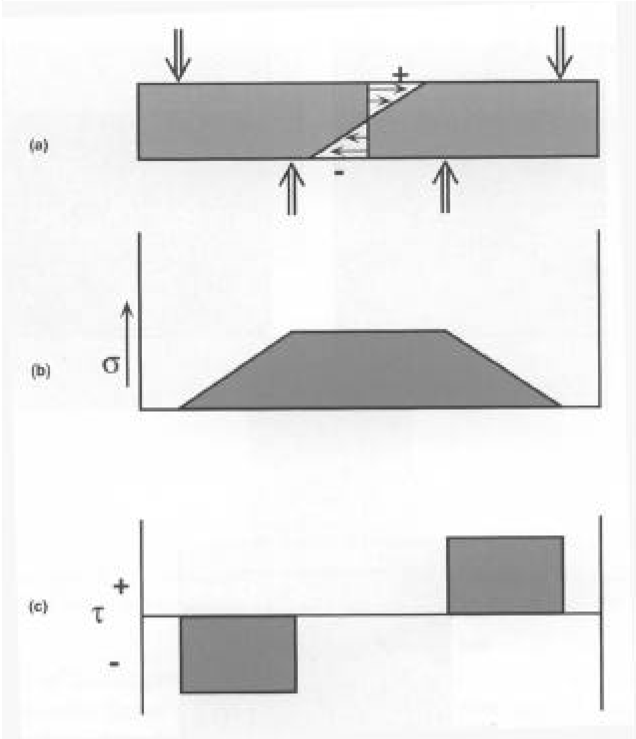

Fig. 4.3
A four-point bend test generates a controlled stress pattern.
a) In the central region the stress parallel to the specimen axis is a maximum at the surface and varies linearly through the thickness from tensile to compressive, passing through a neutral axis at the midline.
b) The axial stress at the surface is constant in the central region but falls linearly between the top and bottom loading points.
c) A constant shear stress is generated in the through-thickness direction between the top and bottom loading points, but the shear stress is zero elsewhere.

4.2 WELD TESTING

Tensile specimens are normally cut from welded metal alloy sheet with the line of the weld normal to the loading axis. A satisfactory test will be one in which tensile failure occurs neither in the weld metal, nor in the heat-affected zone (HAZ), but rather in the cross section of the bulk metal (Fig. 4.4). In such a case it is commonly stated that the tensile 'strength' of the welded joint exceeds that of the bulk metal. However, when a soldered joint, which has the same basic geometry as a weld, fails in the region of the solder, it does so in a region of maximum plastic constraint, and it is incorrect to regard the nominal failure stress (the failure load divided by the cross sectional area of the joint) as a measure of the strength of the solder. The measured strength is a function of the thickness of the soldered joint and the surface finish of the components (Fig. 4.5), increasing as the thickness of solder decreases, with the surface roughness limiting the minimum thickness of solder.

The thermal history of a welded joint has a large influence on its ductility. An effective quality control test is used to check for loss of ductility. The welded joint is bent about an axis parallel to the weld line in a mandrel of standard radius. If a U-bend can be produced without any sign of visible cracking in either the weld bead or the HAZ, then the weld is deemed satisfactory (Fig. 4.6).

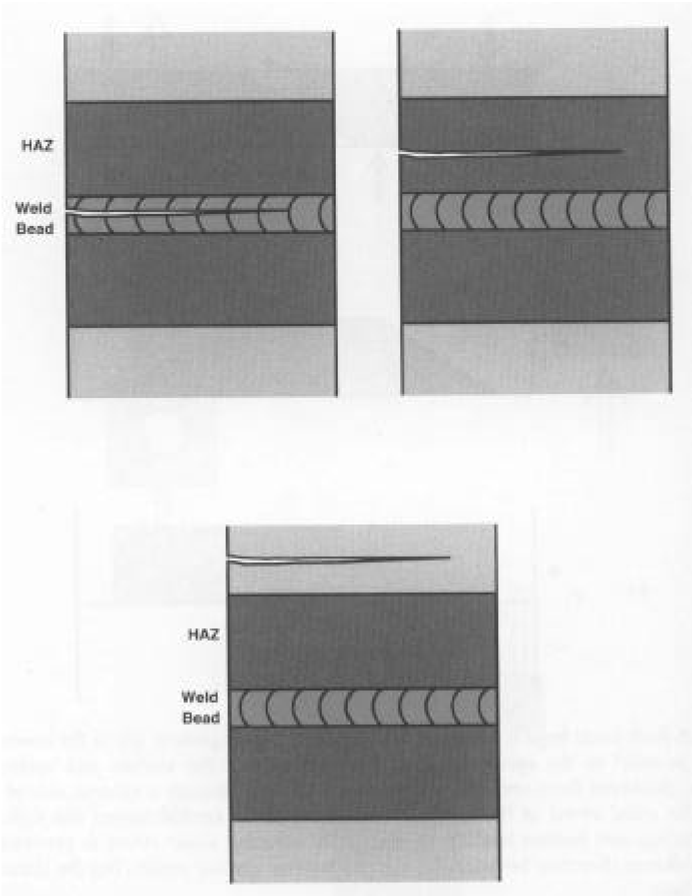

Fig. 4.4
A tensile weld specimen may fail within the weld bead, in the heat-affected zone (HAZ) or in the bulk metal.

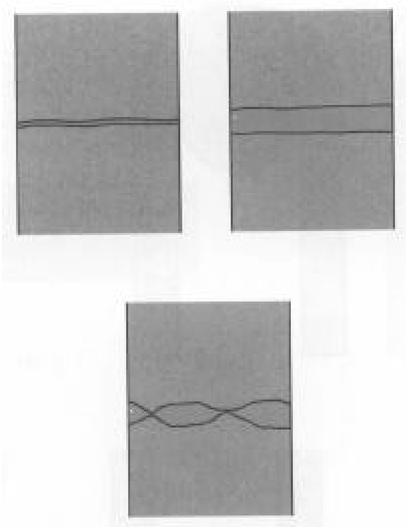

Fig. 4.5
The strength of a soldered joint depends on the thickness of the solder layer and the surface finish of the components, and not only on tensile strength of the solder.

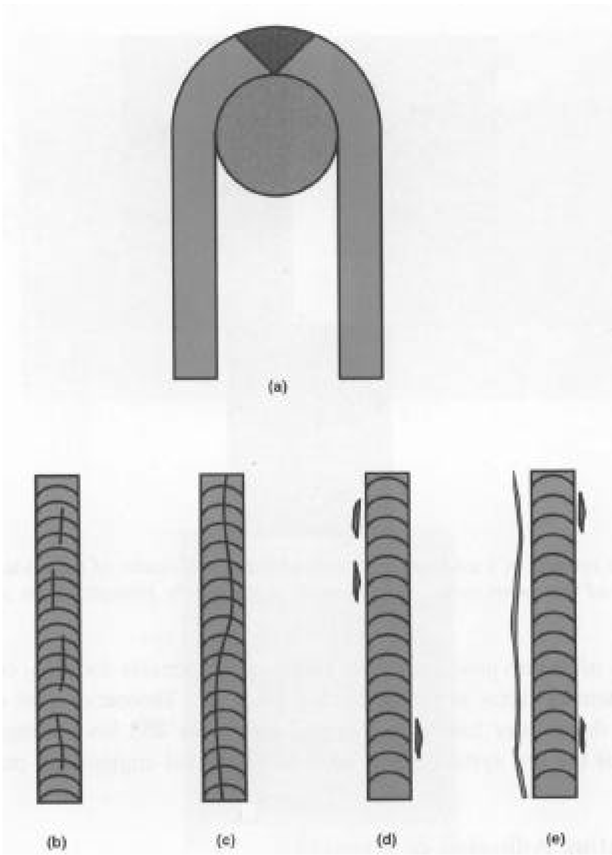

Fig. 4.6
a) A welded strip is bent about an anvil of standard radius. b) Incipient cracking in the weld bead.
c) Failure of the weld bead. d) Incipient cracking in the HAZ. e) Failure in the HAZ.

4.3 MIXED-MODE TESTING

Welded lap-joints are tested in shear, although offset of the tabs either side of the weld introduces a considerable component of normal stress. The test conditions must be standardized and the results have little design significance. Seam welds are a typical example of the lap-joint configuration, but spot-welds are also tested in this geometry. A satisfactory test result is one in which tearing of the welded sheet occurs outside the spot-weld zone, that is, holes are tom in the welded sheet.

Peel tests are not dissimilar in configuration and are used to estimate the adhesive strength of a glued joint. They are best supplemented by a double-lapped shear test (Fig. 4.2c) in which the applied stress approximates pure shear and the test configuration corresponds to a mode II fracture toughness test. There is a continuous spectrum of test configurations, running from tensile tests on a glued joint (analogous to a mode I fracture toughness test), to a peel test and a single-lapped shear test (both mixed-mode tests, but with different mode mixities), and finally o the double-lapped shear test. These options are illustrated in Fig. 4.7.

Where tests are performed on joints between unlike materials, mixed-mode failure is to be expected at the joint, although the loading angle can be varied with respect to the direction of failure propagation, in order to compensate for a K_{II} component of the stress intensity factor at the advancing crack tip. Theoretical and experimental work along these lines has been reported by Evans and his colleagues, but the complexity of the test system is not justified in normal engineering practice.

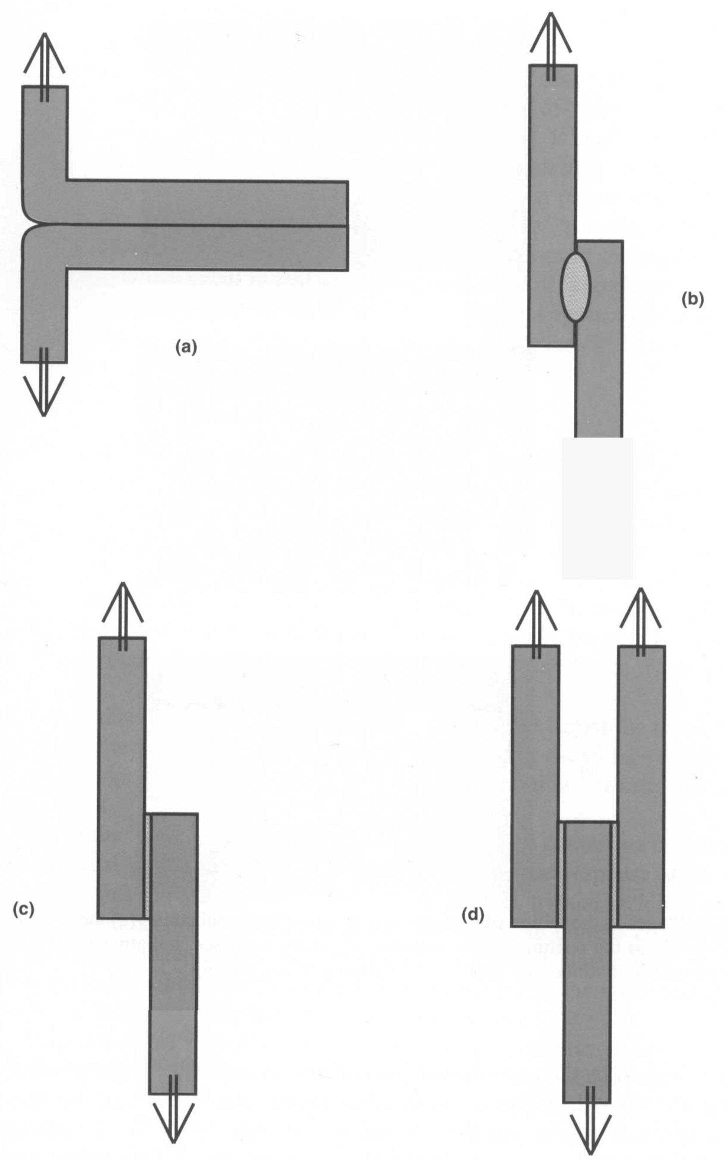

Fig. 4.7
More uniaxial testing geometries.
a) the peel test.
b) testing of a seam weld.
c) testing a glued, single lap-joint.
d) testing a double lap-joint.

4.4 COATING ADHESION & STRENGTH

The adhesive strength of *coatings* is a special area of interest. Several methods for evaluating the strength of the bond between a substrate and a coating have been reported. Among the more exotic, *piezoelectric excitation* has been used to generate compressive acoustic waves in the bulk sample, which are reflected from the coating interface as a tensile wave. At a sufficiently high input energy, the coating is *spalled* away from the surface. Of more practical importance are a number of *qualitative* tests, in which the substrate is bent about a mandrel and the critical surface tensile strain for the onset of cracking and flaking of the coating is determined. Such tests are sensitive to the position of the *neutral axis* of bending with respect to the coating interface, and in analysing test results it is usual to assume that the coating is *thin* with respect to the distance from the neutral axis and experiences a uniform tensile stress.

By testing the substrate in *tension* and monitoring the separation of the cracks formed in the coating as a function of the tensile strain in the substrate, it is possible to obtain a more *quantitative* estimate of both the *tensile strength* of the coating and the *adhesive strength* at the interface. Failure occurs in two stages, the first being tensile failure of the coating. At this stage *tensile* cracks propagate through the coating thickness *normal* to the applied stress, with a crack-opening displacement which reflects the through-thickness elastic relaxation. *Shear* failure at the interface between the coating and the substrate then marks the onset of *adhesive* failure (Fig. 4.8). As the (predominantly mode II) shear failure propagates along the interface, the coating then peels and flakes off.

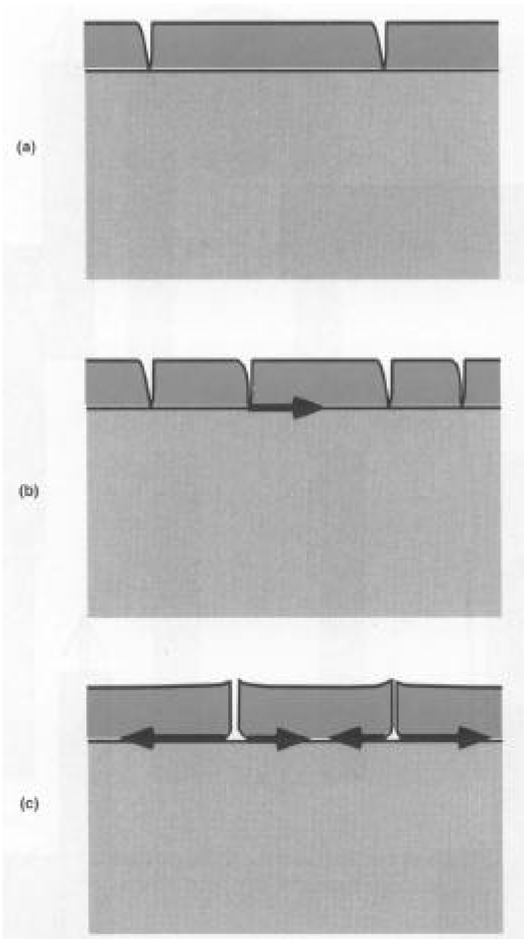

Fig. 4.8
Stages in the failure of a brittle coating on a ductile substrate:
a) through-thickness tensile cracks in the coating.
b) the number of cracks increases, initiating loss of adhesion and peeling.
c) continued peeling leads to flaking of the coating.

4.5 BOND STRENGTH COMPOSITE MATERIALS

Similar failure processes to those observed at joints are also found in *composite materials*. High strength reinforcing fibres deflect cracks in a brittle matrix, which are then *bridged* by the partially-debonded fibres, reducing the stress intensity factor at the crack tip and inhibiting catastrophic failure. The strength of the *interfacial bond* between the reinforcing fibre and the brittle matrix determines the effectiveness of the reinforcement. If the interface bond is too weak, then matrix cracking initiates at very low loads and only the fibres carry the load. If the interface bond is too strong, then the matrix crack generates sufficient stress concentration to fracture the fibres before debonding can occur, and the material fails by catastrophic brittle fracture. In the intermediate range the fibres *partially* debond and *bridge* the matrix cracks, increasing the effective toughness of the composite.

A major tool for evaluating the mechanical design of a joint is *finite element* analysis, in which the joint is modelled by a *mesh* of volume elements. Self-consistent stress analysis, using iterative computer codes, is used to derive the *stress distribution* in and around the joint. *Computer modelling* of an engineering component requires an accurate analysis of the operating parameters and boundary conditions for the system, as well as a knowledge of the appropriate material parameters. However, *no* model can take complete account of the detailed structure and processes which occur in real joints. Engineering skill, knowledge and intuition are the only reliable guides to the design, evaluation and application of mechanical tests needed to ensure the performance of a joint in service.