2. ENGINEERING REQUIREMENTS

As in the above classification of joining methods, it is convenient to discuss the engineering requirements for the joining and assembly of components under the same three headings: mechanical, chemical and physical.

2.1 MECHANICAL REQUIREMENTS

Mechanical requirements include the strength, toughness and stiffness of the joint, and in bulk materials these are usually specified in terms of the mechanical properties: the uniaxial yield strength, the mode 1 fracture toughness and the elastic moduli (tensile modulus, shear modulus and Poisson's ratio). However, any joint in an assembled engineering system is a region of heterogeneity over which the material properties generally change dramatically, and sometimes discontinuously. It follows that the properties of the assembly cannot be described in terms of any simple average of the bulk properties of the constituent materials. That is, the bulk material parameters assume both homogeneity and continuity, which are absent at the join, and hence they lose much of their engineering significance in the assembly.

For tests on samples taken from an assembled system to be relevant in evaluating engineering design, or even for the control of quality, careful attention must be paid to the testing of the assembled module. For example, the fracture strength of a welded joint will depend on the weld geometry (the design of the joint) and the welding cycle, as well as on the composition of the filler metal, the dimensions of the test sample and the details of the fracture test procedure. The elastic compliance of an assembly and the load required to cause failure may be determined unambiguously, but it is much more difficult to specify an allowed design stress for an assembled system. If potential failure modes include high temperature creep, stress-corrosion or mechanical fatigue, then complete quality assurance can only be achieved through full-scale testing of the assembled system, although scaled-down test modules are also used.

2.2 CHEMICAL REQUIREMENTS

Chemical requirements for engineering systems include the effects of chemical attack by the environment, and degradation associated with irradiation. Ultra-violet radiation is a common cause of embrittlement and cracking in commercial plastics. High energy neutrons give rise to displacement damage in nuclear reactor pressure-vessel steels which raises their yield stress and reduces ductility, making the steel notch-sensitive, and hence susceptible to brittle fracture. Common forms of corrosion and oxidation are exacerbated by the chemical heterogeneities associated with the joining process, as well as by the effects of joint geometry on oxygen access to the corrosion site. Variations of chemical potential across the joint provide the driving force for corrosion. Thus, an insufficiently stabilized stainless steel may be susceptible to preferential corrosion at the heat-affected zone, in the vicinity of a weld line, a form of corrosion termed “weld deca”.

Riveted steel plates are frequently subject to crevice corrosion associated with the accumulation of H^+ ions in a reentrant crevice at the joint. The local decrease in pH (acidic conditions) is due to reduced access of oxygen in the crevice. This region then becomes anodic with respect to the rest of the surface, and at a sufficiently low pH ferrous ions are formed by direct dissolution of the metal, leading to intense, localized pitting corrosion. In this example, a local difference in chemical potential is generated by the difference in oxygen activity between the region of the crevice and the free surface of the assembled component. This difference in chemical activity in the solution provides the driving force for localized corrosion at the joint.

2.3 PHYSICAL REQUIREMENTS

The physical requirements for a joint may be limited to the need to seal an enclosure from the surroundings, and thus prevent access or egress of gas or liquid. The physical requirements may include adequate thermal or electrical conductivity (or insulation), or control over the optical properties (reflection, transmission or absorption of electromagnetic radiation). It is important to define the engineering requirements, quantitatively as far as possible, but it may not be easy to isolate these requirements. For example, the loss of a plasticizer from a thermoplastic component by evaporation (a physical process) may lead to embrittlement of the component during welding of the plastic, so that the component no longer fulfils the mechanical requirements.

2.4 JOINING DISSIMILAR MATERIALS

It is important to distinguish between joints made between similar materials (whether be metals, ceramics, composites or plastics) and joints which involve interfaces between dissimilar materials (steel bonded to copper, metal bonded to rubber or ceramic, or a metallic contact to a semiconductor). In the case of dissimilar (unlike) materials, the engineering compatibility of the two components must be considered. Mismatch of the elastic modulus is a common form of mechanical incompatibility which leads to stress concentrations and stress discontinuities at the d interface between the two materials. An example is illustrated in Fig. 2.1, in which a normal load is transferred across the interface between two materials with different elastic moduli.

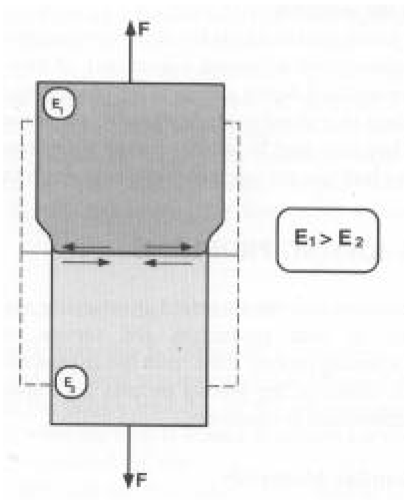

Fig. 2.1

Mismatch in the elastic constants of bonded components results in elastic constraint witch generates shear stresses parallel to the interface under normal loading conditions.

The stiffer (higher modulus) component restricts the lateral contraction of the more compliant (lower modulus) component, generating shear stresses at the interface which may lead to debonding. Thermal expansion mismatch represents a lack of physical compatibility and is a common problem in metal/ceramic joints. Thermal expansion mismatch leads to the development of thermal stresses which tend to be localized at the joint and reduce its load-carrying capacity, ultimately leading to failure of the component. Poor chemical compatibility is commonly associated with undesirable chemical reactions in the neighbourhood of the joint. These reactions may occur between the components, for example the formation of brittle, intermetallic compounds during the joining process, or they may involve a reaction with the environment, as in the formation of an electrochemical corrosion couple due to a change in the electrochemical potential across the joint interface.

2.5 DEFECTS AND TOLERANCES

In addition to the problems of materials compatibility, associated with the joining o unlike materials, joints may be subject to a variety of problems related to either the joining process or the joint structure. We have mentioned chemical effects leading to microstructural changes, such as the precipitation of new phases during brazing or welding. Many metastable microstructures will be modified in the course of the joining process, with resultant modification of the properties. The mechanical strength of the joint usually differs from that of the parent components, as does the joint's resistance to enviromnental attack. Most joining processes give rise to residual stresses in the assembled components, which may either improve or degrade the performance of the assembly.

All processes for joining and assembly should meet recognized standards for both the dimensional requirements (the permitted tolerances), as well as for any deleterious processing defects introduced during joining. Such processing defects may be regions of incomplete bonding in a glued joint; or porosity, inclusions or microcracks in a welded structure. They may lead to failure to meet a performance requirement, for example an excessive leak rate at a given over-pressure on an engine gasket.