Chapter 12

Joining and Fastening Processes

Questions

12.1 Explain the reasons that so many different welding processes have been developed.

A wide variety of welding processes have been developed for several reasons. There are many types of metals and alloys with a wide range of mechanical, physical, and metallurgical properties and characteristics. Also, there are numerous applications involving a wide variety of component shapes and thicknesses. For example, small or thin parts that cannot be arc welded can be resistance welded, and for aerospace applications, where strength-to-weight ratio is a major consideration, laser-beam welding and diffusion bonding are attractive processes. Furthermore, the workpiece may not be suitable for in-plant welding, and the welding process may have to be brought to the site, such as pipelines and large structures. (See also Section 12.1.)

12.2 List the advantages and disadvantages of mechanical fastening as compared with adhesive bonding.

By the student. Advantages of mechanical fastening over adhesive bonding:

(a) disassembly is easier (bolted connections);
(b) stronger in tension;
(c) preloading is possible; and
(d) no need for large areas of contact.

Limitations:

(a) often costlier;
(b) requires assembly;
(c) weaker in shear; and
(d) more likely to loosen (bolted connections).

12.3 What are the similarities and differences between consumable and nonconsumable electrodes? – Broad question with broad range of answers

By the student. Review Sections 12.3 and 12.4. Comment, for example, on factors such as the role of the electrodes, the circuitry involved, the electrode materials, and the manner in which they are used.

12.4 What determines whether a certain welding process can be used for workpieces in horizontal, vertical, or upside-down positions, or for all types of positions? Explain, giving appropriate examples.

By the student. Note, for example, that some welding operations (see Table 12.2 on p. 734) cannot take place under any conditions except horizontal, such as submerged arc welding, where a granular flux must be placed on the workpiece. If a process requires a shielding gas, it can be used in vertical or upside-down positions. Oxyacetylene welding would be difficult upside-down because the flux may drip away from the surface instead of penetrating the joint.

12.5 Comment on your observations regarding Fig. 12.5.

By the student. The students are encouraged to develop their answers considering the significance of the layered weld beads and the quality of their interfaces. For example, there may be concerns regarding the weld strength since the interfaces between adjacent beads may have some slag or surface contaminants that have not been removed. The heat-affected zone and fatigue implications of such welds are also a significant concern.

12.6 Discuss the need for and role of fixtures in holding workpieces in the welding operations described in this chapter.

By the student. The reasons for using fixtures are basically to assure proper alignment of the components to be joined, reduce warpage, and help develop good joint strength. The fixtures can also be a part of the electrical circuit in arc welding, where a high clamping force reduces the contact resistance. See also Section 14.11.1.

12.7 Describe the factors that influence the size of the two weld beads in Fig. 12.13.

The reason why electron-beam weld beads are narrower than those obtained by arc welding is that the energy source in the former is much more intense, confined, and controllable, allowing the heating and the weld bead to be more localized. Other factors that influence the size of the weld bead are workpiece thickness, material properties, such as melting point and thermal conductivity. See also pp. 749-751.

12.8 Why is the quality of welds produced by submerged arc welding very good?

Submerged arc welding (see Fig. 12.6) has very good quality because oxygen in the atmosphere cannot penetrate the weld zone where the shielding flux protects the weld metal. Also, there are no sparks, spatter, or fumes as in shielded metal arc and some other welding process.

12.9 Explain the factors involved in electrode selection in arc welding processes.

By the student. Refer to Section 12.3.8. Electrode selection is guided by many factors, including the process used and the metals to be welded.

12.10 Explain why the electroslag welding process is suitable for thick plates and heavy structural sections.

Electroslag welding (see Fig. 12.8) can be performed with large plates because the temperatures attainable through electric arcs are very high. A continuous and stable arc can be achieved and held long enough to melt thick plates.

12.11 What are the similarities and differences between consumable and nonconsumable electrode arc welding processes?

By the student. Similarities: both require an electric power source, arcing for heating, and an electrically-conductive workpiece. Differences: the electrode is the source of the weld metal in consumable-arc welding, whereas a weld metal must be provided in nonconsumable-arc welding processes.

12.12 In Table 12.2, there is a column on the distortion of welded components, ranging from lowest to highest. Explain why the degree of distortion varies among different welding processes.

By the student. Refer to Table 12.2 on p. 734. The distortion of parts is mainly due to thermal warping because of temperature gradients developed within the component. Note that the lowest distortions are in electron beam and laser beam processes, where the heat is highly concentrated in narrow regions and with deeper penetration. This is unlike most other processes where the weld zones are large and distortion can be extensive.

12.13 Explain why the grains in Fig. 12.16 grow in the particular directions shown.

The grains grow in the directions shown in Fig. 12.16 because of the same reasons grains grow away from the wall in casting process solidification, described in Section 5.2. Heat flux is in the opposite direction as grain growth, meaning a temperature gradient exists in that direction, so only grains oriented in the direction perpendicular from the solid-metal substrate will grow.

12.14 Prepare a table listing the processes described in this chapter and providing, for each process, The basic steps in soldering the connections on such a board are as follows:

(a) Apply solder paste to one side.

(b) Place the surface-mount packages onto the board; also, insert in-line packages through the primary side of the board.

(c) Reflow the solder (see bottom of p. 777).

(d) Apply adhesive to the secondary side of the board.

(e) Attach the surface mount devices on the secondary side, using the adhesive.

(f) Cure the adhesive.

(g) Perform a wave-soldering operation (p. 778) on the secondary side to produce electrical attachment of the surface mounts and the in-line circuits to the board.

12.22 Discuss the factors that influence the strength of (a) a diffusion bonded component and (b) a cold welded component.

Diffusion bonded strength (Section 12.12) is influenced by temperature (the higher the temperature, the more the diffusion), pressure, time, and the materials being joined. The cleanliness of the surfaces is also important to make sure no lubricants, oxides, or other contaminants interfere with the diffusion process. For this reason, these joints are commonly prepared by solvent cleaning and/or pickling to remove oxides. Cold welded components (Section 12.7) involve similar considerations except that temperature is not a relevant parameter.

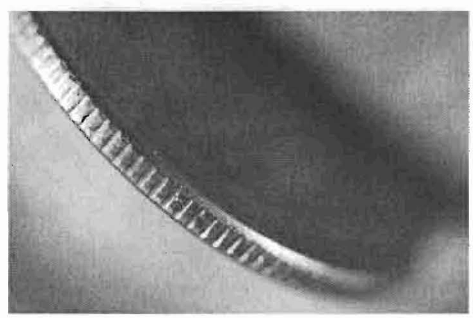
12.23 Describe the difficulties you might encounter in applying explosion welding in a factory environment.

By the student. Explosives are very dangerous; after all, they are generally used for destructive purposes. There are safety concerns such as hearing loss, damage resulting from explosions, and fires. The administrative burden is high because there are many federal, state, and municipal regulations regarding the handling and use of explosives and the registration involved in using explosives.

12.24 Inspect the edges of a U.S. quarter, and comment on your observations. Is the cross-section, i.e., the thickness of individual layers, symmetrical? Explain.

By the student. This is an interesting assignment to demonstrate the significance of cold welding. The side view of a U.S. quarter is shown below. The center of the coin is a copper alloy and the outer layers are a nickel-based alloy. (Note that pennies and nickels are typically made of one material.) The following observations may be made about the coins:

- The core is used to obtain the proper weight and feel, as well as sound.
- The strength of roll-bonded joints is very high, as confirmed by the fact that one never encounters coins that have peeled apart (although during their development such separation did occur).
- The outer layers, which are made of the more expensive alloy, are thin for cost reduction.
- The thicknesses of the two outer layers is not the same. This is due to the smearing action that occurs around the periphery during blanking of the coins, as can be recalled from Section 7.3.



12.25 What advantages do resistance welding processes have over others described in this chapter?

By the student. Recall that resistance welding is a cleaner process for which electrodes, flux, or shielding environment are not needed; the metals to be welded provide all of these inherently. The process is easily automated and production rate is high.

equipment and appliances found in homes, offices, and factories will give ample opportunity for students to respond comprehensively to this question.

12.33 Could the projection welded parts shown in Fig. 12.36 be made by any of the processes described in other parts of this text? Explain.

By the student. The projection-welded parts shown could possibly be made through resistance spot welding (although it would require several strokes) and resistance projection welding. Various other processes may be able to produce the parts shown, but the joint strength developed or the economics of the processes may not be as favorable. The shape can also be achieved through arc or gas welding processes (followed by finishing such as grinding, if necessary), as well as brazing or soldering (see Section 12.13). With a modified interface, mechanical fastening and adhesive bonding also could be suitable processes.

12.34 Describe the factors that influence flattening of the interface after resistance projection welding takes place.

Review Fig. 12.36 and note that:

(a) The projections provide localized areas of heating, so the material in the projection soften and undergo diffusion.

(b) The normal force between the parts flattens these softened projections by plastic deformation.

(c) Important factors are the nature of the mating surfaces, the materials involved, the shape of the projections, the temperatures developed, the magnitude of the normal force, and length of time.

12.35 What factors influence the shape of the upset joint in flash welding, as shown in Fig. 12.37b?

The important factors are the amount of heat generated (if too little heat, the material will not deform to the required extent), the nature of the contracting surfaces (oxide layers, contaminants, etc.), the force applied (the higher the force, the greater the upset volume), the exposed length between the pieces and the clamps (if too long, the part may buckle instead of being upset), thermal conductivity (the lower the conductivity, the smaller the upset length), and the rate at which the force is applied (the higher the rate, the greater the force required for upsetting, due to strain-rate sensitivity of the material at elevated temperatures).

12.36 Explain how you would fabricate the structures shown in Fig. 12.41b with methods other than diffusion bonding and superplastic forming.

By the student. These structures can be made through a combination of sheet-metal forming processes (Chapter 7) and resistance welding, brazing, mechanical joining, or adhesive bonding. Note, however, that such complex parts and interfaces may not allow easy implementation of these various operations without extensive tooling.

12.37 Make a survey of metal containers used for household products and foods and beverages. Identify those that have utilized any of the processes described in this chapter. Describe your observations.

By the student. This is an interesting project for students. It will be noted that some food and beverage containers are three-piece cans, with a welded seam along the length of the can; others may be soldered or seamed (see, for example, Fig. 12.53). These containers are typically used for shaving cream, laundry starch sprays, and various spray cans for paints and other products.

12.38 Which process uses a solder paste? What are the advantages to this process?

Solder paste is used in reflow soldering, described in Section 12.13.3, which is also used for soldering integrated circuits onto printed circuit boards (Section 13.13).

12.39 * Explain why some joints may have to be preheated prior to welding.

Some joints may have to be preheated prior to welding in order to:

(a) control and reduce the cooling rate, especially for metals with high thermal conductivity, such as aluminum and copper,

(b) control and reduce residual stresses developed in the joint, and

(c) for more effective wave soldering (p. 778).

12.40 What are the similarities and differences between casting of metals (Chapter 5) and fusion welding?

By the student. Casting and fusion welding processes are similar in that they both involve molten metals that are allowed to recrystallize, cool, and solidify. The mechanisms are similar in that solidification begins with the formation of columnar grains (Section 5,3). The cooled structure is essentially identical to a cast structure with coarse grains. However, the weld joint (Fig. 12.15) is different in that selection of fillers and heat treatment (after welding) influence the joint's properties.

12.41 Explain the role of the excessive restraint (stiffness) of various components to be welded on weld defects.

Refer to Section 12.6.1. The effect of stiffness on weld defects is primarily through the stresses developed during heating and cooling of the weld joint. Note, for example, that not allowing for contraction (such as due to a very stiff system) will cause cracks in the joint due to high thermal stresses (see Fig. 12.22).

12.42 Discuss the weldability of several metals, and explain why some metals are easier to weld than others.

By the student. This is a challenging assignment and will require considerable effort. Review Section 12.62 and note that, as expected, weldability depends on many factors. See also Table 3.8 and the Bibliography at the end of this chapter.

12.43 Must the filler metal be of the same composition as that of the base metal to be welded? Explain.

It is not necessary for the filler metal, rod, or wire to be the same as the base metal to be welded. Filler metals are generally chosen for the favorable alloying properties that they impart to the weld zone. The only function the filler metal must fulfill is to fill in the gaps in the joint. The filler metal is typically an alloy of the same metal, due to the fact that the workpiece and the filler should melt at reasonably close temperatures. To visualize why this is the case, consider a copper filler used with a material with a much higher melting temperature, such as steel. When the copper melts, the steel workpiece is still in a solid state, and the interface will be one of adhesion, with no significant diffusion between the copper and the steel. (See also bottom of p. 743 and p. 773.)

12.44 Describe the factors that contribute to the difference in properties across a welded joint.

By the student. An appropriate response will require the students to carefully review Section12.6.

12.45 How does the weldability of steel change as the steel's carbon content increases? Why?

By the student. Review Section 12.6.2. As the carbon content increases, weldability decreases because of martensite formation, which is hard and brittle (see p. 238).

12.46 Are there common factors among the weldability, solderability, castability, formability, and machinability of metals? Explain, with appropriate examples.

By the student. This is an interesting, but very challenging, assignment and appropriate for a student paper. As to be expected, the relationships are complex, as can also be seen by reviewing Table 3.8 on p. 117. Note that for some aluminum alloys, for example, machinability and weldability are opposite (i.e., D-C vs. A ratings). The students should analyze the contents of the following: Weldability - Section 12.6.2; solderability - p. 777; castability - Sections 5.4.2 and 5.6; formability - Sections 6.2.6 and 7.7; machinability - Section 8.5.

12.47 Assume that you are asked to inspect a weld for a critical application. Describe the procedure you would follow. If you find a flaw during your inspection, how would you go about determining whether or not this flaw is important for the particular application?

By the student. This is a challenging task, requiring a careful review of Section 12.6.1. Note, By the student. Mechanical joining methods, described in Section 12.15, date back to 3000-2000 B.C., as shown in Table 1.1 on p. 3. These methods have been developed mainly because they impart design flexibility to products, they greatly ease assembly (especially disassembly, thus simplifying repair and part replacement), and have economic advantages.

12.53 Explain why hole preparation may be important in mechanical joining.

By the student. See Section 12.15.1. Note, for example, that if a hole has large burrs (see Fig. 7.5) it can adversely affect joint quality, and also possibly causing crevice corrosion (p. 109). If the hole is significantly larger than the rivet, no compressive stress will be developed on its cylindrical surface when the rivet is upset.

12.54 What precautions should be taken in mechanical joining of dissimilar metals?

By the student. In joining dissimilar metals, one must be careful about their possible chemical interaction. Often, two dissimilar metals react in a cathodic process, causing galvanic corrosion and corrosive wear (see Section 3.9.7). This is especially a concern in marine applications, where sea salt can cause major degradation, as well as in chemical industries.

12.55 What difficulties are involved in joining plastics? What about in joining ceramics? Why?

By the student. See Section 12.16. Plastics can be difficult to join. The thermal conductivity is so low that, if melted, plastics will flow before they resolidify; thermosets will not melt, but will degrade as temperature is increased. Thermoplastics are generally soft and thus cannot be compressed very much in threaded connections, so the bonds with these processes will not be very strong. Thermoplastics are usually assembled with snap fasteners when strength is not a key concern, or with adhesives. Ceramics can be joined by adhesive bonding, and also by mechanical means in which the brittleness and notch sensitivity of these materials are important concerns.

12.56 Comment on your observations concerning the numerous joints shown in the figures in Section 12.17.

By the student. The students may respond to this question in different ways. For example, they can compare and contrast adhesive bonded joints with those of welded and mechanically assembled joints. Note also the projected area of the joints, the type of materials used, their geometric features, and the locations and directions of the forces applied.

12.57 How different is adhesive bonding from other joining methods? What limitations does it have?

By the student. Review Section 12.14. Adhesive bonding is significantly different from other joining methods in that the workpiece materials are of various types, there is no penetration of the workpiece surfaces, and bonding is done at room temperature. Its main limitations are the necessity for clean surfaces, tight clearances, and the longer times required.

12.58 Soldering is generally applied to thinner components. Why?

Solders have much lower strength than braze fillers or weld beads. Therefore, in joining members to be subjected to significant loads, which is typical of members with large thickness, one would normally consider brazing or welding, but not soldering. A benefit of soldering when joining thin components is that it takes place at much lower temperatures than brazing or welding, so that one does not have to be concerned about the workpiece melting due to localized heating, or significant warping in the joint area.

12.59 Explain why adhesively bonded joints tend to be weak in peeling.

Adhesives are weak in peeling because there is a concentrated, high tensile stress at the tip of the joint when being peeled (see Fig. 12.50); consequently, their low tensile strength reduces the peeling forces. (Recall that this situation is somewhat analogous to crack initiation and propagation in metals under tensile stresses; see Fig. 3.30.) Note, however, that tougher adhesives can require considerable force and energy to peel, as can be appreciated when trying to peel off some adhesive tapes.