Solid-state welding

15.1 Introduction:

In solid-state welding no liquid or molten phase is present in the joint. The principle of solid-state welding is demonstrated best with the following example: If two clean surfaces are brought into close contact with each other under sufficient pressure, they form bonds and produce a joint.
To form a strong bond, it is essential that the interface be free of oxide films, residues, metalworking fluids, other contaminants, and even adsorbed layers of gas. Solid-state bonding involves one or more of the following phenomena:

- Diffusion: The transfer of atoms across an interface; thus, applying external heat improves the strength of the bond between the two surfaces being joined, as occurs in diffusion bonding. Heat may be generated internally by friction (as utilized in friction welding), through electrical-resistance heating (as in resistance-welding processes, such as spot welding), and externally by induction heating (as in butt-welding tubes).

- Pressure: The higher the pressure, the stronger is the interface (as in roll bonding and explosion welding), where plastic deformation also occurs. Pressure and resistance heating may be combined, as in flash welding, stud welding, and resistance projection welding.

- Relative interfacial movements: When movements of the contacting surfaces (faying surfaces) occur (as in ultrasonic welding), even very small amplitudes will disturb the mating surfaces, break up any oxide films, and generate new, clean surfaces-thus improving the strength of the bond.

15.2 Forge Welding

Forge welding is of historic significance in the development of manufacturing technology. The process dates from about 1000 BCE, when blacksmiths of the ancient world learned to join two pieces of metal **. Forge welding is a welding process in which the components to be joined are heated to hot working temperatures and then forged together by hammer or other means.** Considerable skill was required by the craftsmen who practiced it in order to achieve a good weld by present-day standards. The process may be of historic interest; however, it is of minor commercial importance today except for its variants that are discussed below.
Forge welding requires the application of pressure by means of either a hammer (hammer welding), rolls (roll welding), or dies (die welding). Joint configurations differ depending on whether the joints are to be produced

manually or using automatic equipment. Typical joint designs used in manual forge welding operations are shown in Fig. 1. The joint surfaces in Fig. 1 are slightly rounded or crowned to ensure that the centerline region of the components joined will be welded first to force any contaminants (for example, slag, dirt, or oxide) present on the surfaces out of the joint. Typical joint configurations used for automatic forge welding operations are shown in Fig. 2.

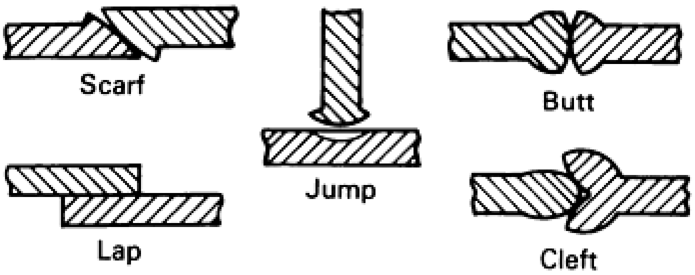

Figure (1) TYPICAL JOINT CONFIGURATIONS USED FOR MANUAL FORGE WELDING APPLICATIONS

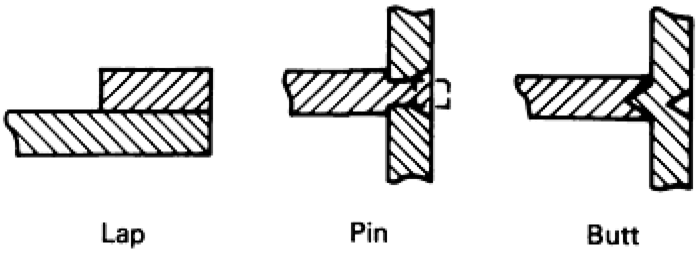

Figure (2) RECOMMENDED JOINT CONFIGURATIONS USED IN AUTOMATIC FORGE WELDING APPLICATIONS

Hydraulic presses are typically employed to apply pressure. Presses are often highly automated, featuring microprocessor control of pressure and temperature cycles.

The normal welding sequence is to:

(1) Apply sufficient pressure to firmly seat the faying surfaces against one another,
(2) Heat the joint to welding temperature.
(3) Rapidly apply additional pressure to upset the weld zone.

Forge welding is most commonly applied to carbon and low-alloy steels, with typical welding temperatures of about 1125 °C (2060 °F). Low-carbon steels can be used in the as-welded condition, but medium-carbon steels and low-alloy steels normally are given full heat treatments following welding Applications of this process include welding rods, bars, tubes, rails, aircraft landing gear, chains, and cans.

15.3 Cold Welding (also known as cold pressure welding)

Cold welding (CW) is a solid-state welding process accomplished by applying high pressure between clean contacting surfaces at room temperature. The faying surfaces must be exceptionally clean for CW to work, and cleaning is usually done by degreasing and wire brushing immediately before joining. Also, at least one of the metals to be welded, and preferably both, must be very ductile and free of work hardening. Metal such as soft aluminum and copper can be readily cold welded. The applied compression forces in the process result in cold working of the metal parts, reducing thickness by as much as 50%; but they also cause localized plastic deformation at the contacting surfaces, resulting in coalescence. For small parts, the forces may be applied by simple hand-operated tools. For heavier work, powered presses are required to exert the necessary force. No heat is applied from external sources in CW, but the deformation process raises the temperature of the work somewhat. Applications of CW include making electrical connections.

15.4 Friction Welding

Friction welding is a widely used commercial process, amenable to automated production methods. The process was developed in the (former) Soviet Union and introduced into the United States around 1960. Friction welding (FRW) is a solid state welding process in which coalescence is achieved by frictional heat combined with pressure. The friction is induced by mechanical rubbing between the two surfaces, usually by rotation of one part relative to the other, to raise the temperature at the joint interface to the hot working range for the metals involved. Then the parts are driven toward each other with sufficient force to form a metallurgical bond. The sequence is portrayed in Figure 3 for welding two cylindrical parts, the typical application. The axial compression force upsets the parts, and a flash is produced by the material displaced. Any surface films that may have been on the contacting surfaces are expunged during the process. The flash must be subsequently trimmed (e.g., by turning) to provide a smooth surface in the weld region. When properly carried out, no melting occurs at the faying surfaces. No filler metal, flux, or shielding gases are normally used.

Nearly all FRW operations use rotation to develop the frictional heat for welding. There are two principal drive systems, distinguishing two types of FRW: (1) **continuous drive friction welding**, and (2) **inertia friction welding**. <u>*In continuous-drive friction welding, one part is driven at a constant rotational speed and forced into contact with the stationary part at a certain force level so that friction heat is generated at the interface.*</u>

When the proper hot working temperature has been reached, braking is applied to stop the rotation abruptly, and simultaneously the pieces are forced together at forging pressures. <u>*In inertia friction welding, the rotating part is connected to a flywheel, which is brought up to a predetermined speed. Then*</u>

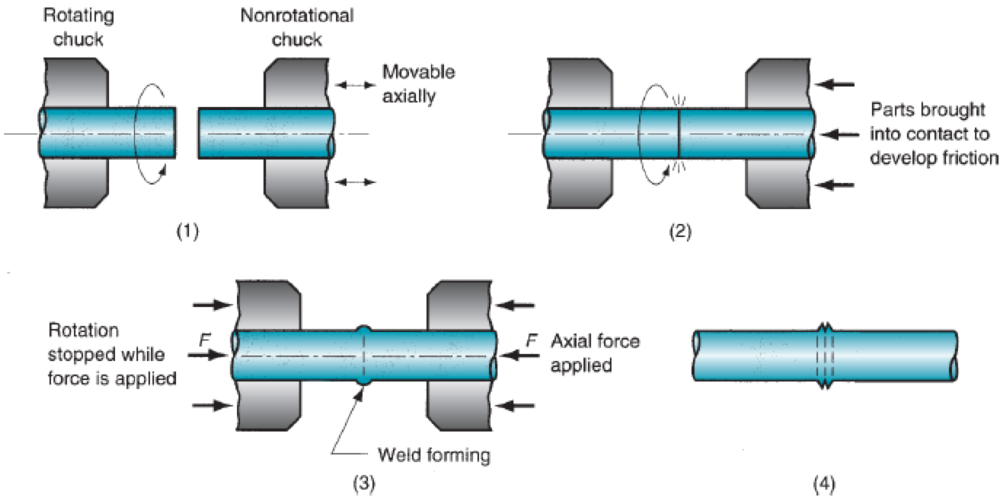

Figure (3) Friction welding (FRW): (1) rotating part, no contact; (2) parts brought into contact to generate friction heat; (3) rotation stopped and axial pressure applied; and (4) weld created.

<u>The flywheel is disengaged from the drive motor, and the parts are forced together.</u> The kinetic energy stored in the flywheel is dissipated in the form of friction heat to cause coalescence at the abutting surfaces. The total cycle for these operations is about 20 seconds.

Machines used for friction welding have the appearance of an engine lathe. They require a powered spindle to turn one part at high speed, and a means of applying an axial force between the rotating part and the nonrotating part. With its short cycle times, **the process lends itself to mass production**. It is applied in the welding of various shafts and tubular parts in industries such as automotive, aircraft, farm equipment, petroleum, and natural gas. **The process yields a narrow heat-affected zone and can be used to join dissimilar metals.** However, at least one of the parts must be rotational; flash must usually be removed, and upsetting reduces the part lengths (which must be taken into consideration in product design).

The conventional friction welding operations discussed above utilize a rotary motion to develop the required friction between faying surfaces. A more recent version of the process is linear friction welding, in which a linear reciprocating motion is used to generate friction heat between the parts. This eliminates the requirement for at least one of the parts to be rotational (e.g., cylindrical, tubular).