End SEM/5th SEM

Different types of welding

1. Solid state welding

By definition, melting and solidification do not occur during solid-state welding. These processes depend on the formation of metallic bonds at the atomistic level to produce a joint. There are a number of nonfusion welding processes. They are normally distinguished by the way heat and deformation are generated at the interface. These processes include frictional heating by translation of the pieces relative to each other (friction welding) or by a third member (friction stir welding (FSW)), high-velocity collision (explosion welding), or simple heating to accelerate interdiffusion (diffusion welding).

In all cases, a combination of heat and deformation is required to produce a sound weld. As a result, a HAZ will also exist in a solid-state weld, the properties of which may be significantly different from the base metal. In general, two distinct regions can be identified: the *heat and deformation zone* and the ***T-HAZ***. In general, solid-state welding processes do not result in melting at the interface.

Within the heat and deformation zone, significant forging action may occur that promotes continuous (dynamic) recrystallization resulting in extremely fine grain size. Often, the strength of this region exceeds that of the T-HAZ and the base metal.

A few examples of microstructure evolution during solid-state welding are included in the following sections.

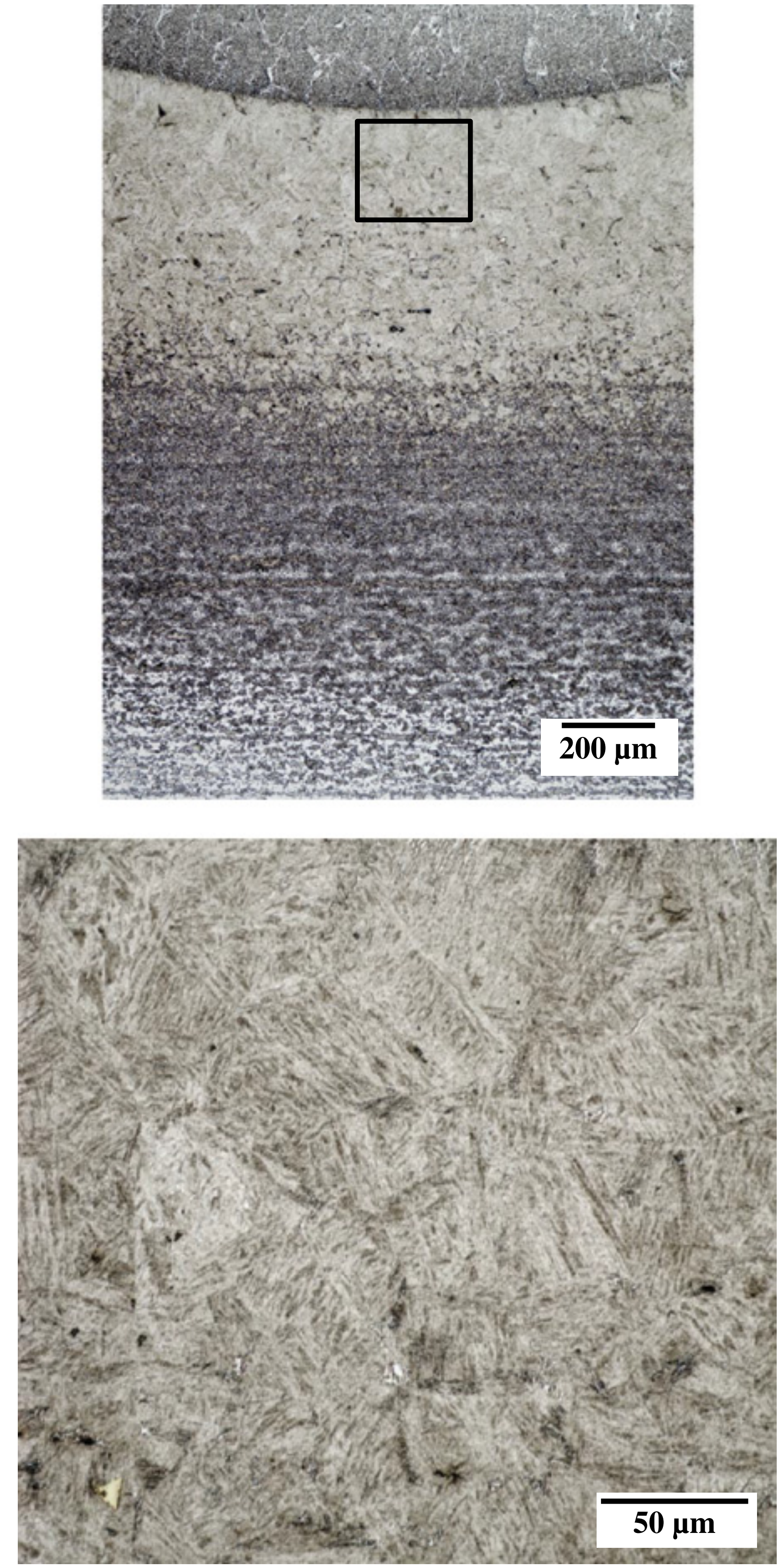

FIGURE 2.58 HAZ of a carbon steel in as-welded condition.

Different types of welding

2. Friction stir welding

Friction stir welding (FSW) is a novel solid-state process that was introduced in the early 1990s and is shown schematically in Figure 2.59. Bonding relies on the frictional heat of a tool rotating between the two pieces to be welded. The friction heats the material to a temperature where it flows easily and the abutting pieces are joined by this metallic stirring action. No melting takes place, and a high integrity, solid-state joint is formed.

Three distinct regions can be identified in a friction stir weld. The ***stir zone*** is sometimes referred to as the weld "nugget" and represents the region that consumes the original joint. Metal is heated under the shoulder of the tool and is moved around the tool from front to back by the rotation of the tool. The end of the tool, called the pin (or probe), will sometimes have features machined into it that facilitate material flow in the stir zone.

The ***thermomechanically affected zone (TMAZ)*** represents the region surrounding the stir zone where some metal flow occurs. Minor recrystallization is often observed in this region. In some materials (steels, Ti alloys), it may be difficult to distinguish a TMAZ.

The ***HAZ*** of a FSW is analogous to that in a fusion weld—only the heat source is different. The HAZ of FSWs often exhibits the same metallurgical reactions as fusion

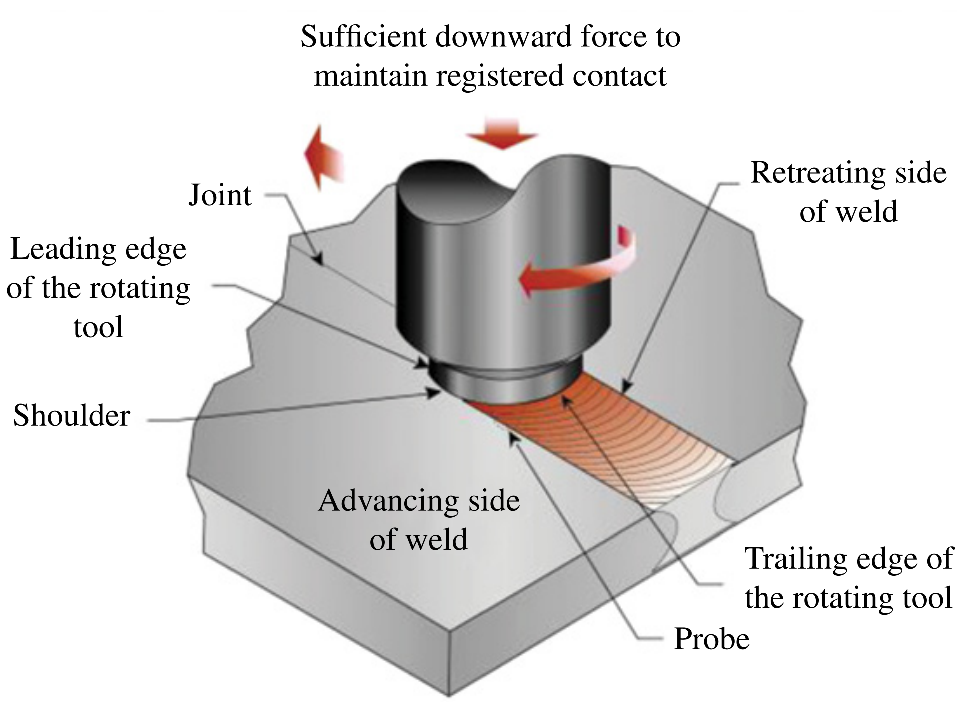

FIGURE 2.59 Schematic illustration of friction stir welding.

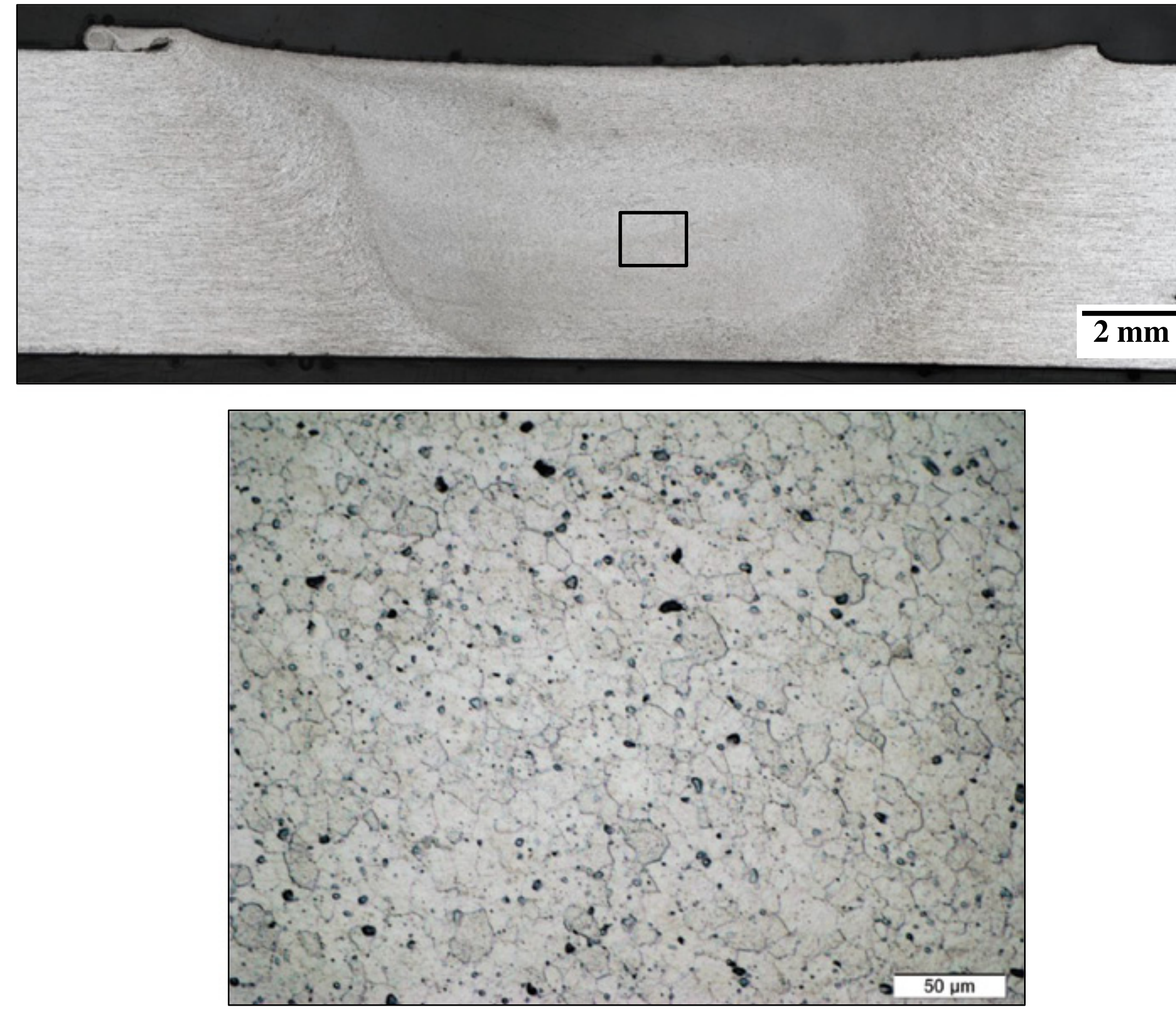

FIGURE 2.61 FSW of aluminum Alloy 6061 (Courtesy of Peter Ditzel).

alpha grain structure develops with an average grain size on the order of 1 µm. This represents a 500× grain refinement relative to the original base metal.

It is also possible to FSW/P steels using appropriate high-temperature tool materials, including tungsten-based tools and polycrystalline cubic boron nitride (PCBN). FSW/P of steels is conducted at temperatures in the range from 1000 to 1200°C where the material is austenitic (fcc). The extreme grain refinement that is achieved in the stir zone of other materials is usually not achieved in steels because of the austenite grain growth that occurs during cooling from the processing temperature. An example of the microstructure associated with a friction stir weld in an HSLA steel (HSLA-65) is shown in Figure 2.63. Note that distinct regions are developed surrounding the stir zone with a HAZ similar to that formed in a fusion weld. In this steel, the stir zone microstructure exhibits a relatively coarse prior austenite grain size and a bainitic microstructure that forms during cooling.

Different types of welding

3. Diffusion welding

Diffusion welding is accomplished by heating two components to elevated temperature while in intimate contact. This process requires long times at elevated temperature and is usually conducted in vacuum or protective atmosphere to prevent oxidation at the interface. Pressure is generally applied that is of sufficient magnitude to promote some local deformation at the interface.

Although the interfaces in intimate contact must be macroscopically flat, at the microscopic level, they exhibit surface roughness in the form of "asperities" that limit complete interfacial contact, as shown in Figure 2.64. These asperities undergo high local stress when the two surfaces are subjected to a moderate load. This is because the small area of contact distributed over the asperity peaks must support the entire applied load (F), where stress is determined by the applied force divided by the area of contact.

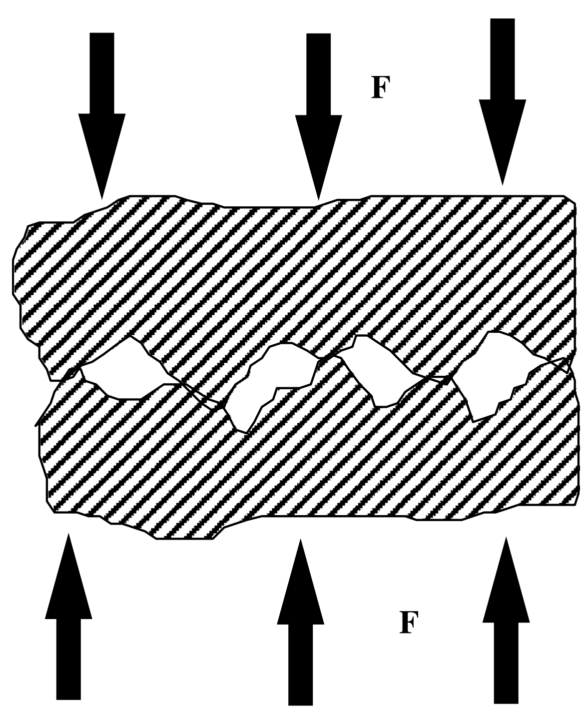

FIGURE 2.64 Microscopic features of a diffusion weld interface prior to bonding.

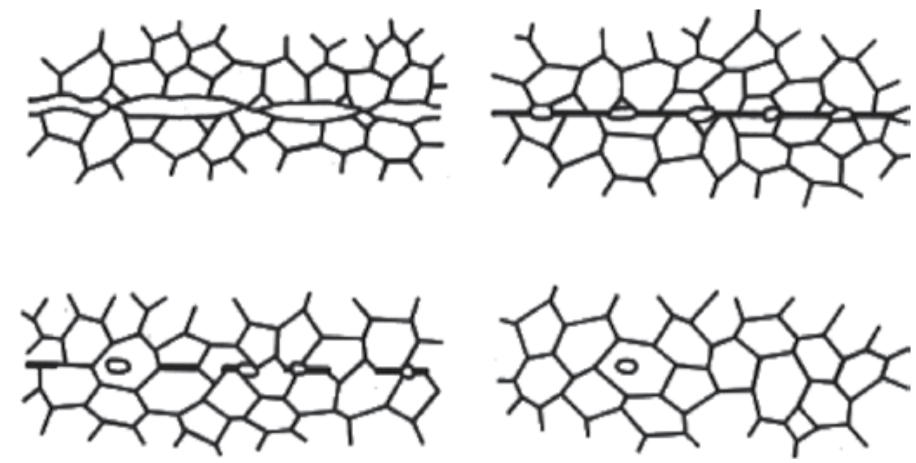

FIGURE 2.65 Principles of diffusion welding.

As a result of this high stress, the asperities sustain elastic and (at higher load levels) plastic deformation. Elastic deformation is temporary by nature and is removed when the load is removed, forcing the surfaces apart. Plastic deformation is permanent. Once the material is plastically deformed, it cannot revert to its original shape.

Two necessary conditions must be met before a satisfactory diffusion weld can be made: (i) mechanical intimacy of the faying surfaces and (ii) disruption and dispersion of surface contaminants (oxides). This is illustrated in Figure 2.65. Stage 1 involves deformation of asperities. This deformation may be temperature and time dependent, similar to creep. Stage 2 includes boundary migration, recrystallization, and pore size reduction. Stage 3 involves bulk diffusion phenomena including oxide and contaminant dissolution and further pore size reduction.

If the diffusion weld is properly made, there may be no distinguishing features at the bond line. In some cases, there may be oxides present that indicate the location of the original bond interface. In situations where dissimilar metals are diffusion welded, there will be a composition gradient present (interdiffusion zone). Depending on the material system, this may lead to the formation of intermetallic compounds. In some cases, interlayer materials may be introduced that prevent interdiffusion and suppress intermetallic formation.

Different types of welding

4. Explosion welding

Explosion welding is a form of impact (or collision) welding that can be used to join metallurgically incompatible materials and/or to apply cladding to the surface of a material. The explosion weld forms almost instantaneously, thereby suppressing most metallurgical reactions, such as the formation of embrittling intermetallic phases. A schematic showing the typical setup for explosion welding is shown in Figure 2.66.

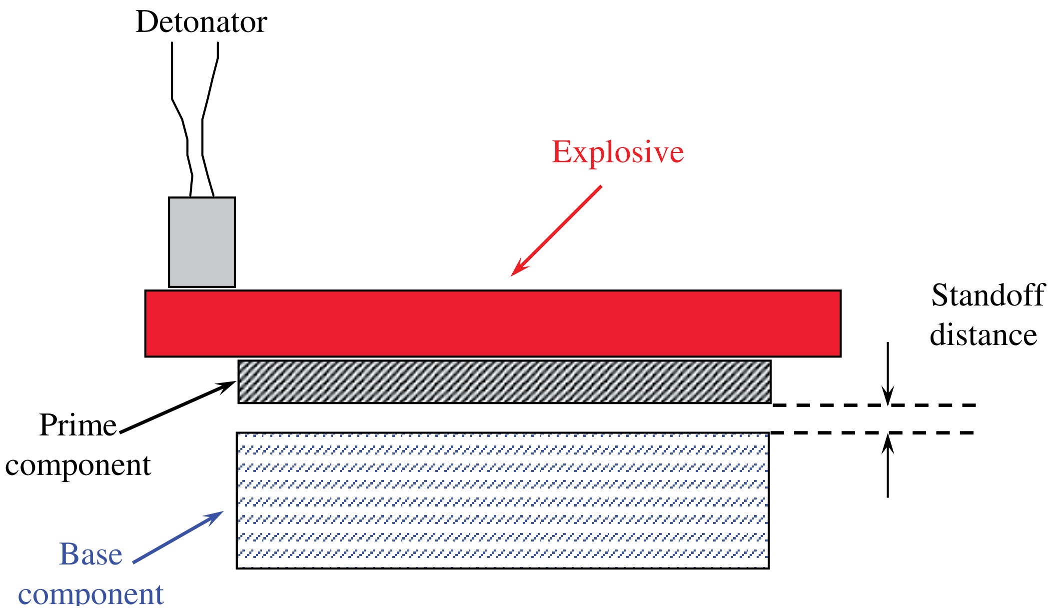

FIGURE 2.66 Explosion welding setup.

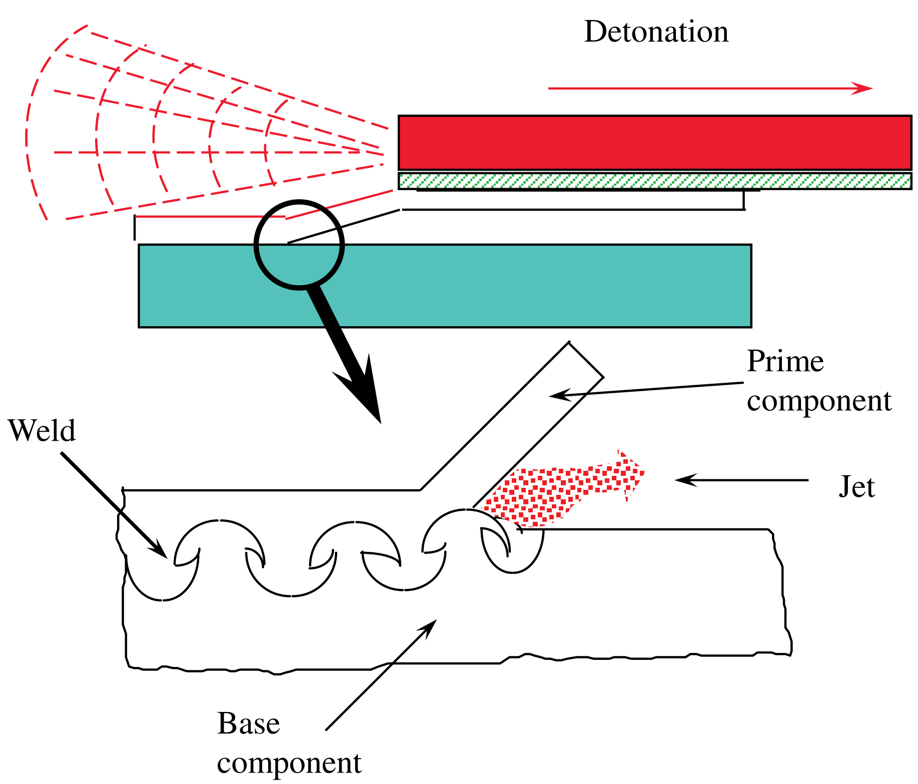

FIGURE 2.67 Characteristics of an explosion weld.

The collision between the components generates kinetic energy that produces local melting, vaporization, and possibly plasma formation. Most of the liquid and vapor is expelled from the joint by a strong jet action at the interaction point. This "jetting" action removes oxides and other contaminants from the surface and produces metallurgically clean interfaces that are easily bonded. The resulting weld interface often has a wavy appearance, as illustrated in Figure 2.67. In general, the bond line of an explosion weld can be revealed using metallographic techniques. Some welds will exhibit the classic wavy appearance, but this is not always the case. Occasionally, local melting can be observed, usually at the tip of the wave. The HAZ of explosion welds is extremely narrow and often undetectable.

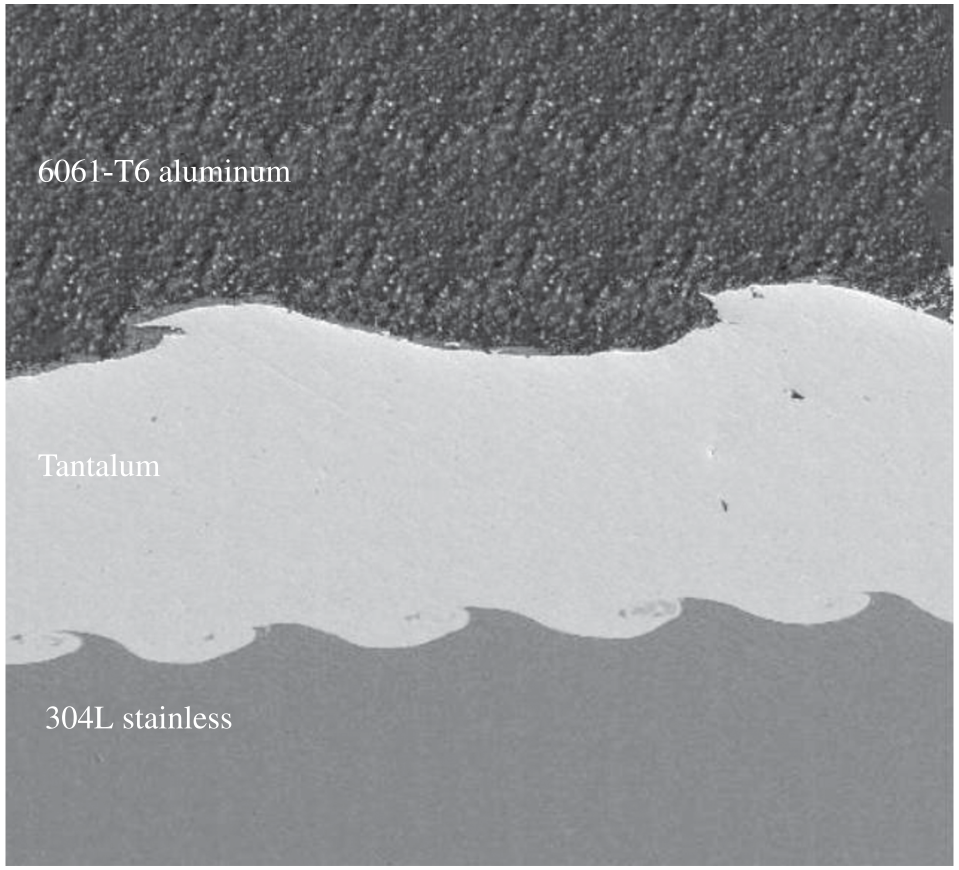

FIGURE 2.68 Explosion weld bond line microstructure between 304L stainless steel and 6061 aluminum using a tantalum interlayer (Courtesy of High Energy Metals, Inc.).

An example of an explosion weld interface is shown in Figure 2.68. In this case, aluminum Alloy 6061-T6 is bonded to Type 304L stainless steel. Because of the metallurgical incompatibility of aluminum and steel, a tantalum interlayer is used as a buffer. Note the wavy appearance of both bond lines, but with a different periodicity in the wave pattern.

Different types of welding

5. Ultrasonic welding

Ultrasonic welding can also be used to join difficult-to-weld materials and is widely used to join both metals and plastics. Ultrasonic waves are transmitted to the interface of the two materials. This results in local heating of the interface. Force is then applied to break down surface asperities and allow metallic bonding to occur. A schematic of the process is shown in Figure 2.69.

The bond line is usually detectable in ultrasonic welds using appropriate metallographic techniques. Because the heat input is very low, there is usually no apparent HAZ. Often, the bond line may contain oxides that are not removed prior to welding or not disrupted by the welding process.

An example of an ultrasonic weld in aluminum is shown in Figure 2.70. The ridges on the surface are the result of the grid pattern on the sonotrode tip and anvil, which are needed to engage the pieces to be welded. This process also develops a wave pattern at the interface that increases the bond area and improves bond strength. The darker etching features at the bond line are entrapped oxides. Note that there is no evidence of grain growth due to the localized heating at the interface.

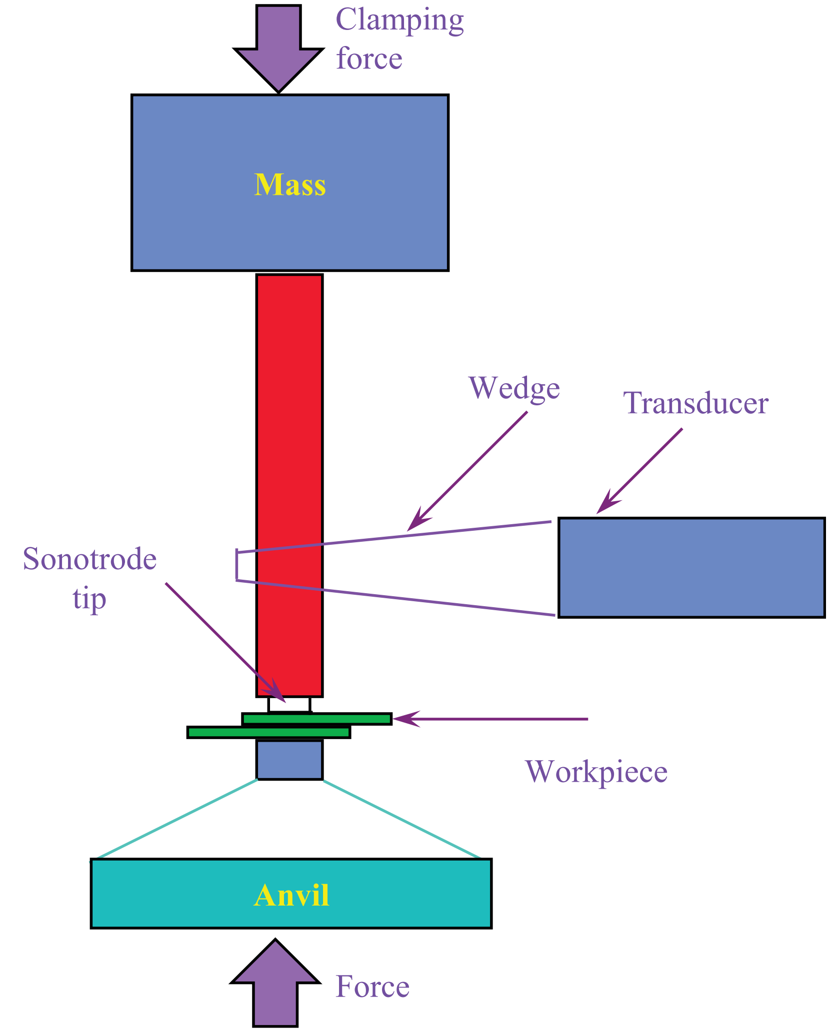

FIGURE 2.69 Schematic of ultrasonic welding.

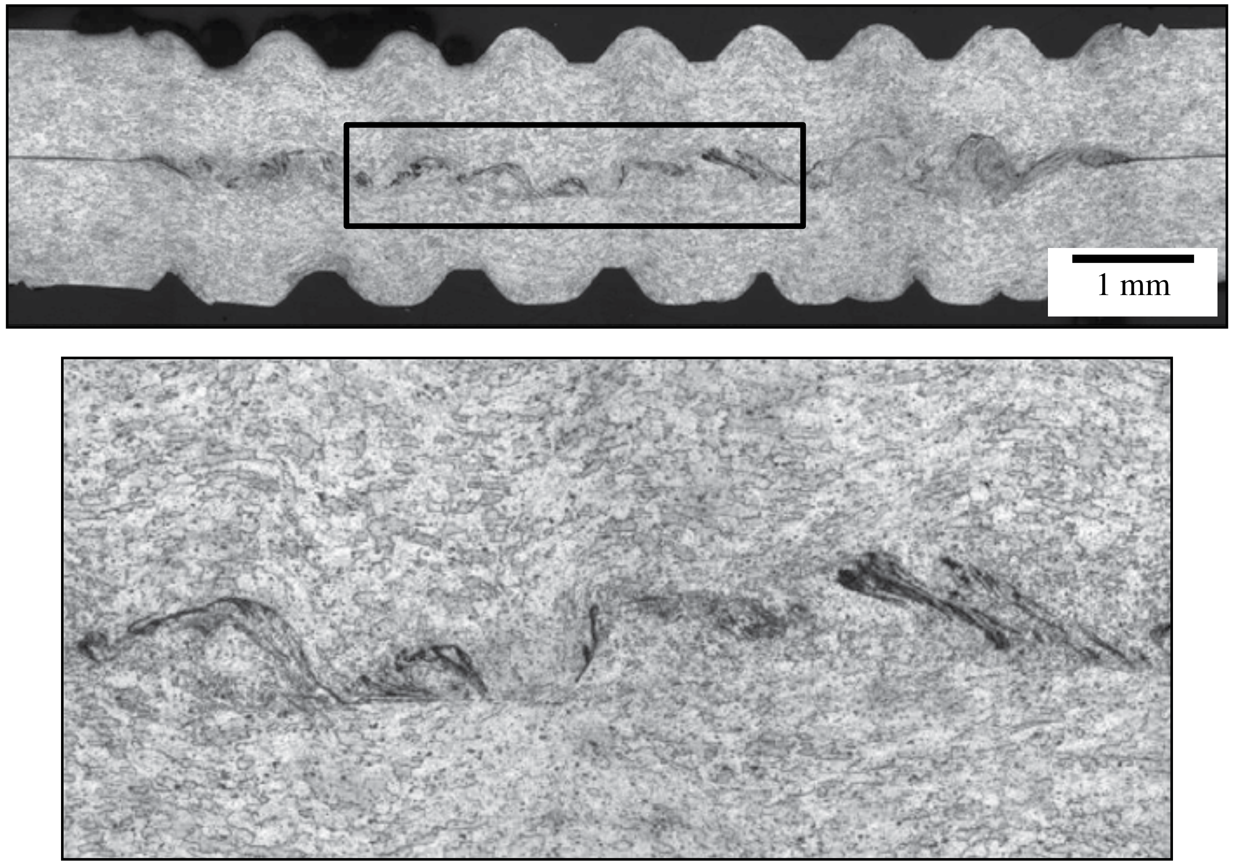

FIGURE 2.70 Ultrasonic weld bond line microstructure in aluminum (Courtesy of Sonobond Ultrasonics, Inc.).