Chapter 26

Dissimilar Metal Welding

–– *Shobhna Mishra, Dr. Surender Kumar Sharma*

Design of complex hybrid structures made up of dissimilar material combinations has increased the demand of dissimilar metal joining that meets the structural and functional requirements. Dissimilar metal welding refers to joining of two different metals/alloys and such joints are found to be productive in the automobile and aeronautical industries, developing next generation medical products, consumer devices, and also in the manufacturing and nuclear industry. Presently, automotive/aerospace industries are working towards design and development of light weight products having high strength to combat fuel economy, global warming and alike. This increases demand of dissimilar metal joining like the high strength to lightweight aluminium-steel based tube-to-tube or tube-to-bar dual metallic components. Tubular steel components which are difficult to join are used in plenty of structural and nuclear industries [1]. Lightweight aaluminum alloys are highly suitable for application in aerospace, shipbuilding, railway, appliances and automobile industries. Apart from these aluminium alloys are also preferred in nuclear industries that is in the research reactors due to its excellent nuclear properties. However, achieving a reliable dissimilar metal joint is challenging than joining similar material or alloys with minor differences in composition. Dissimilar metal joints can be classified broadly into two kinds i.e. joints between metals dissimilar in their major constituents and joints between metals dissimilar in their alloying elements.

26.1. Challenges of Dissimilar Metal Welding

Difference in melting point

Due to this when the metals are subjected to the heat source, one of the metals will be molten and overheated before the other. The molten metal penetrates into the grain boundaries of the overheated zone causing loss of the metal.

Difference in linear expansion co-efficient

Thermal contraction of the base metal and weld metal due to melting and solidification results in generation of residual stresses. The distribution and magnitude of these stresses are not alike across the weld joint. If the difference between these stresses is large, internal stresses get developed causing component failure during service.

Difference in thermal conductivity and specific heat capacity

This affects the crystallization of the weld metal and may result in coarsening of the grains.

Difference in electromagnetic properties

It affects the stability of the welding arc, ultimately worsening the weld.

Formation of inter-metallics at weld joints

The intermediate phase formed having composition in between two pure metals is called an intermetallic compound that formed due to incomplete solid solubility i.e when solute element exceeds the limit of solid solubility. They are generally hard, brittle and their presence at the weld joint increases the crack sensitivity, reduces ductility and increases corrosion susceptibility.

Formation of Heat Affected Zones (HAZ)

In fusion welds, there are four major zones formed i.e. the fusion zone, the partially melted zone, the unmelted HAZ and the unaffected base metal as shown in Figure 26.1. HAZ part of the base metal is subjected to heating (below the melting temperature of the metal) followed by cooling down to room temperature. There occurs no phase change in the HAZ however, due to the thermal cycle it's mechanical and metallurgical properties vary from that of the base metal and hence, becomes prone to failure due to weld defects. The extent of HAZ formation depends on the welding parameters and is found to be significant in fusion welding but negligible in solid state welding.

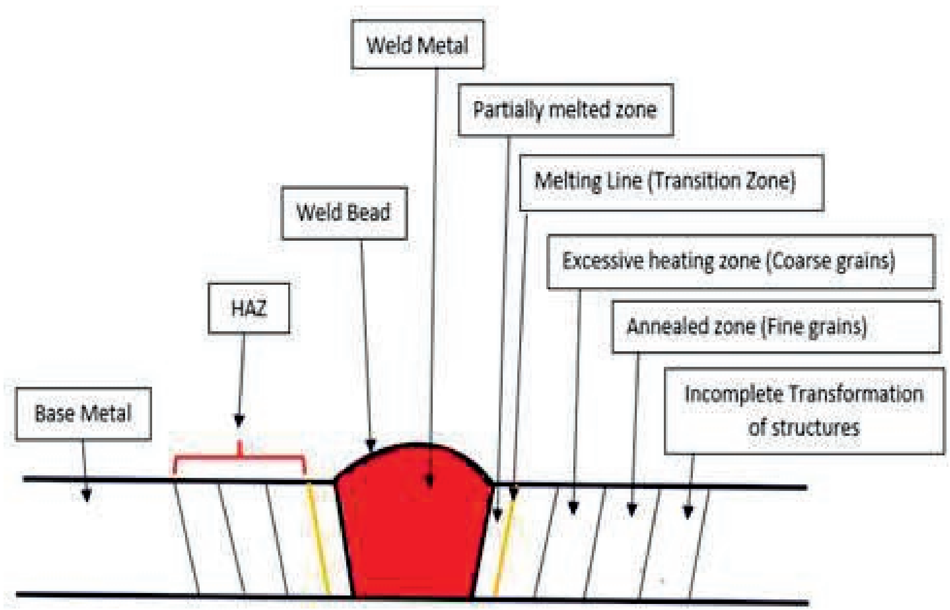

Figure 26.1. Fusion weld joint.

26.2. Methods to weld Dissimilar Metals

Despite the difficulties associated with dissimilar metal welding, it has been explored that a variety of dissimilar materials can still be successfully joined with selection of an appropriate joining process. Some of the widely employed dissimilar metals joining processes are [2]:

26.2.1. Fusion Welding

It is a joining process that establishes joints by heating the materials to the melting point and causing them to fuse together by solidification.

Shielded Metal Arc Welding (SMAW) is an arc welding technique wherein the electrode used to produce the electric arc is coated with flux. The flux coating decomposes due to arc heat and helps in arc stability and weld pool protection.

Gas Metal Arc Welding (GMAW) is an arc welding technique that produces welds with an electric arc between a metal electrode reel that is continuously fed and the metal job. This technique does not require the use of flux; however, a shielding gas is necessary to avoid weld pool contamination.

Submerged Arc Welding (SAW) is an arc welding technique wherein joining of two metals is established with electric arcs which along with the metal electrode tip and weld pool is submerged under a blanket of flux.

Flux Cored Arc Welding (FCAW) is an arc welding technique wherein the tubular electrode used for establishing the electrode arc has a central cored filled with flux.

Gas Tungsten Arc Welding (GTAW) is an arc welding technique that produces welds with an electric arc between the tungsten electrode and the metal job. This technique uses a shielding gas like Nitrogen, argon, helium and alike to avoid weld pool contamination.

26.2.2. Low Dilution Welding

This joining technique also falls under fusion welding category however it involves relatively less melting of base metals into the weld pool and no use of filler metals.

Electron Beam Welding is a joining technique that utilizes a beam of high velocity electrons i.e. the kinetic energy of the electrons gets converted to thermal energy as soon as they strike the metal surfaces to join them together.

Laser Beam Welding is a welding process that establishes joints with the help of heat produced from the application of a concentrated laser beam i.e. a coherent light over the metal surfaces meant to be joined.

26.2.3. Solid State Welding

In this joining technique there is no application of external heat source and no use of filler material and the coalescence of metals takes place at temperatures below their melting points.

Friction Welding is a joining process wherein metals are joined by the frictional heat produced due to rubbing of the metal surfaces under pressure.

Diffusion Bonding is established between two materials held against each other at an elevated temperature under pressure for a time interval due to atomic diffusion. The technique involves no melting or deformation of the joining surfaces.

Ultrasonic Welding is a joining technique that establishes joints with the application of high frequency vibratory energy on the materials held together under pressure. The joining surfaces are neither subjected to pressures nor large deformations.

High Velocity Impact Welding (HVIW) is a joining technique wherein welding is achieved in a few microseconds as the metal plates, initially stationed at an angle, collide with each other at high velocities. Due to this collision a metal jet is emitted that cleans the surfaces on each impacting plate resulting in a lap joint at the interface.

26.3. Case Studies

26.3.1. Dissimilar Joining of Aluminium (Al) to Stainless Steel (SS)

Welding of metals like magnesium, titanium, copper, zirconium and steel to aluminium is quite difficult because, when aluminium is melted by the heat, brittle intermetallic compounds start to form. These crystallized structures are hard, brittle and are prone to failure.

26.3.2. Dissimilar Joining of Titanium (Ti) to Stainless Steel (SS)

Formation of brittle inter-metallic is the main issue that acts as crack initiation sites and reduces the overall strength of the Ti-SS joint. Significant differences in the thermal expansion coefficient and thermal conductivity of titanium alloys and stainless steels leads to development of high tensile residual stresses in the weld joints. Titanium alloys are also chemically active and forms undesired oxides and nitrides in case joining method which involves heat for an extended period in non-inert atmospheres is employed [3].

26.3.3. Dissimilar Joining of Copper (Cu) to Aluminium (Al)

Copper and Aluminium have largely different melting temperatures. This means that if these two materials are to be joined using fusion processes, there is risk of overheating and weakening of aluminium side.

26.3.4. Dissimilar Joining of Zirconium (Zr) to Stainless Steel (SS)

The intermetallic and eutectic phases formed in the molten zone during fusion welding and solidification corrodes severely in a corrosive environment and affects the integrity of these joints [4].

26.4. Conclusion

Dissimilar joints prepared by solid-state joining processes, especially HVIW are considered as the best way forward. Dissimilar material joining by this technique is particularly considered for materials with extremely different physical and mechanical properties. Since this process does not involve heat, there occurs no melting at the interface, also formation of secondary precipitates is least by these processes, and hence the component does not fail by corrosion during service.

References

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Questionnaire

1. What is dissimilar metal welding?

2. What are the precautions that are to be considered while joining dissimilar metals?

3. State some of the widely used welding methods to join dissimilar metals.

4. What is Heat Affected Zone (HAZ) in a weld joint? Explain with diagram.