Titanium and Titanium Alloys - Welding and Brazing

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Topics Covered

Background

Titanium is not a difficult material to weld but strict precautions must be taken to guard against contamination at the high temperatures these processes entail. This applies not only to the atmospheric gases (oxygen, nitrogen and water vapour) but also to any dirt or other surface layer on the metal. Fusion welding techniques must be aimed, therefore, at the exclusion of atmospheric contamination by welding in argon, helium or vacuum, following careful cleaning and edge preparation of the areas to be joined. All heated surfaces, both front and back, must be equally protected.

Joining Different Grades of Titanium and Joining Titanium to other Metals

Titanium can be joined by fusion, resistance, flash-butt, explosion, and friction welding. Plasma, TIG, MIG and electron beam are all suitable for the material, but techniques such as oxyacetylene, carbon arc and atomic hydrogen cause contamination of the titanium and must not be used.

Welds between some of the different grades of titanium are possible, autogenous welds having properties that are the average of those of the two parent materials. The filler wire which is selected if two commercially pure grades are welded together depends on the properties that are required from the weld, either strength or ductility. Generally, fusion welds between titanium and other metals are not possible because of the formation of brittle intermetallic compounds. However, other techniques are available if a joint has to be made between titanium and a non-compatible material. These include mechanical fasteners, adhesive bonding, explosion welding or frictional welding.

The method which is most commonly used for the fabrication of titanium equipment for the process industries is that of tungsten inert gas (TIG) welding although plasma is growing in importance, particularly where thick plate is to be welded and where automatic techniques are applicable. In the aerospace industry the welding of the more complex alloy grades is normally by the use of electron beam.

Tungsten Inert Gas Welding (TIG)

Sources of Contamination

In TIG welding as with other fusion processes, cleanliness is vital, both with respect to the metal adjacent to where the weld is to be made and also to the welding shop. Any thick oxide layer must be removed from the titanium surface by grit blasting and/or pickling. In addition, materials to be welded, filler wire, welding equipment and clamps must all be absolutely dry, since small amounts of moisture can result in severe contamination.

Argon Supply

To prevent any contact being made between atmospheric oxygen and the hot metal, argon must be supplied at the correct rate to all titanium parts that are heated above about 400°C. A grooved copper backing bar fed with argon is effective in shielding the underbead against contamination. Argon flow rates to both top and bottom surfaces of welds should be sufficient to exclude air but not so great as to induce turbulent flow.

Welding Current

The welding current used for any particular piece of fabrication should be determined by pre-weld tests, the aim being to obtain uniform but not excessive penetration at a reasonable speed.

Visual Inspection

Visual inspection of a titanium weld gives a good indication of its integrity. Lack of fusion defects, undercutting, poor weld profiles, etc. can be easily seen as with other metals. However, with titanium there is an advantage that the colour of the weld bead may give a good indication of the extent of contamination by atmospheric gases. Any discoloration indicates that some reaction with oxygen has occurred either during the actual welding operation or in subsequent cooling down of the metal. The aim should always be to produce a bright silver weld.

Radiography

Standard radiography can be used to detect lack of root or sidewall fusion defects, tungsten inclusions or porosity. Other NDT methods of weld inspection that can be used include ultrasonic, dye penetrant, fluorescent crack detection and acoustic emission.

Electron Beam Welding

Electron beam welding results in very little contamination because it is carried out in a vacuum chamber. It can, moreover, provide a very narrow weld bead and heat affected zone, However, control of edge cleanliness is necessary to avoid porosity problems and good edge preparation is also important because of the narrow beam that is used.

Plasma Welding

Limitations on welding thick titanium plate by the TIG technique can be overcome to some extent by the use of keyhole plasma welding. Here again, the combination of the low density and high surface tension of titanium make it an ideal material with no tendency for the molten pool to fall through. Fabrication of large diameter titanium pipe is now commonly carried out by a combination of plasma welding with a TIG capping run to provide a good weld bead shape.

Resistance Welding

Resistance welding entails a shorter operating cycle than fusion welding. Surface preparation and cleanliness are just as important as for other welding techniques, but the weld cycle is usually so short that inert gas shielding is not necessary. Flash butt welding is suitable for larger sections such as the joining of rolled or extruded bars to make rings or pipework flanges. The forging operation during the final upset will usually expel most of the molten metal and give a good grain structure; because of the somewhat longer welding cycle, however, inert gas protection is desirable for the larger sections. Pressure or friction welding is suitable for the welding of bar or tubular stock. The low thermal conductivity of titanium helps to localise the heat; a joint deformation of 30% or more will usually give a good joint even at pressures as low as 70 to 100 MPa. Radial frictional welding is now being developed for the joining of lengths of titanium pipe. Here, a wedge shaped ring of titanium is spun against the ends of two long lengths of pipe, the pipe remaining stationary.

Weldability

Weldability is dependent upon the particular grade or alloy of titanium that is to be joined. Generally, all of the commercially pure grades can be welded, although care must be taken with the highest oxygen containing material. Other alpha or near alpha alloys are also fully weldable, components in the near alpha creep resistant alloys being widely used in the aerospace industries. However, for the alpha-beta alloys the properties of the weld zone can differ markedly from those of the parent metal. For example, Ti-6%Al-4%V (ASTM Grade 5) has weld zone hardness and strength not very different from the parent metal but ductility and bend performance are inferior. For maximum toughness and ductility in Grade 5 joints produced by TIG welding it is preferable to use either commercially pure or Ti-3%Al-2.5%V (ASTM Grade 9) filler wire. However, provided that some loss in ductility can be tolerated, it is still possible to use Grade 5 filler and a number of critical components have been produced in this way recently. The higher strength alpha-beta alloys are not normally considered to be weldable but work carried out in the aircraft industry within the past few years has shown that even these materials can be fusion welded under certain circumstances.

Brazing

Brazing operations are limited by the chemical and metallurgical properties of titanium since filler materials tend to alloy with and attack the base metal forming brittle intermetallic compounds. Alloys of aluminium or silver have been used on occasions but the technique is not widespread with titanium. For torch brazing, it is essential to use a reactive flux containing, for example, a barium chloride-sodium chloride-lithium fluoride-zinc chloride mixture. Furnace brazing in either an inert gas or in vacuum can produce better joints by operating at higher temperature for longer periods and using a thin film of copper or cupro-nickel which melts and diffuses into the titanium to give a relatively ductile and strong titanium rich joint. With induction brazing, on the other hand, time at high temperature can be kept very short, resulting in less contamination, less alloying and, consequently, improved ductility.

Source: Materials Information Service – The Selection and Use of Titanium, A design Guide

For more information on this source please visit The Institute of Materials, Minerals and Mining.