"Open Air" Welding of Commercially Pure Titanium

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This paper, presented at the institute's National Seminar 1979 held in Bangalore in February 1979, was adjudged the winner of the ADVANI-OERLIKON WELDING RESEARCH AWARD for the year 1979.

Abstract

Titanium can be welded by TIG welding, MIG welding, EB welding and in chambers in which the atmosphere can be controlled. Of these methods, MIG welding poses certain problems such as spatter and porosity. EB welding and controlled atmosphere chamber welding impose limitations on the size of the jobs that can be welded. A more flexible, but difficult method of welding compared to other methods of welding is the TIG welding in open air. This paper describes the open air welding of titanium as developed by BHPV and the various precautions that should be taken to get welded joints of adequate ductility.

Introduction

Aircraft and missiles flying at supersonic and hypersonic speeds are subjected to extremely high temperatures. Under such heavy thermal loading, conventional materials such as aluminium fail to operate satisfactorily because the operating temperatures are very near their softening or melting points. While steels can operate satisfactorily at these high temperatures, the higher specific weight of steel limits the use of steel in aircraft and missiles. Titanium is one metal which weighs 45% less than steel but can operate satisfactorily at temperatures upto 420°C without any significant reduction in its mechanical properties. Hence this light weight coupled with adequate mechanical properties at high temperatures, has led to the extensive use of titanium in aircraft and missiles.

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Metallurgy of Titanium

Commercially pure titanium, a non-heat treatable alloy, is a light weight metal having good mechanical properties.

Titanium has a close packed hexagonal structure called alpha, which transforms to a body centred cubic structure, called beta, at about 885°C. Addition of alloying elements stabilises the presence of one of the structures. Aluminium stabilises the alpha structure by raising the temperature of transformation from alpha to beta phase i.e., the beta transus. Chromium, molybdenum, vanadium, manganese and iron lower the beta transus making the beta phase more stable at lower temperatures. Tin is considered to be neutral.

The strength of commercially pure titanium can be varied by varying the interstitial elements such as oxygen. As oxygen content increases, the strength increases with a corresponding reduction in ductility. Thus ASTM B 265 grade 1 material contains 0.18% (max.) oxygen and grade 4 contains 0.4% (max.) oxygen with all other elements such as carbon and iron being the same. The corresponding tensile strengths are 24.5 kg/mm^2 and 56 kg/mm^2 (min.) Elongation drops from 24% min. to 15% min. or 2" gauge length respectively.

Welding of Commercially Pure Titanium

Welding of commercially pure titanium calls for a careful selection of base metal, filler wires, shielding practice and a number of precautions to be taken. These are described below.

Base Material

Base material used was commercially pure titanium 3 mm thk. corresponding to ASTM B 265 Gr. 2. The chemical composition of the base plate and mechanical properties are given in Table 1. The material was received in the annealed and pickled condition.

Filler Wire

The filler wire used was ER Ti-1 of 1.6 mm dia. supplied in coils from which long lengths were cut as desired.

Gas Used

Commercially pure argon was used as the shielding gas. However, several cylinders were tested for their purity by welding small lengths of titanium and selecting only those cylinders which gave least contamination of the weld.

Joint Preparation

Required sizes of test coupons were sheared from a large plate and the edges were milled. Grinding was not allowed as grinding grits are likely to contaminate the edges. Attention was paid to obtain a smooth and uniform finish on the edges. The edge preparation is shown in Fig. 1.

Degreasing and Pickling

The machined edges were degreased in acetone and pickled in a solution of 40% HNO_3 and 2 to 4% HF [1,2]. Pickling was carried out for 10 to 15 mins. Afterwards they were rinsed in cold running water and dried.

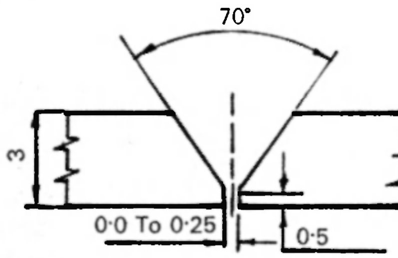

FIG. 1 TYPICAL JOINT PREPARATION FOR WELDING TITANIUM

Joint fit up

Poor fit up results in porosity. Hence adequate precautions should be taken to remove all burrs. If the plates are sheared, it is necessary to ensure that the edges are smooth and not rugged. In case the edges are rugged, these rugged edges should be trimmed by draw filing. Grinding other than surface grinding is not satisfactory because deep scratches and grooves might be left in the face of the edges. Milling is the best procedure to prepare the edges followed by removal of the final 0.05 to 0.08 mm by belt sanders.

Inert Gas Shielding

Titanium has great affinity for oxygen, nitrogen and hydrogen. These gases are highly soluble in molten titanium and relatively small amounts of these gases will reduce the ductility and toughness. Hydrogen in titanium is suspected to cause porosity in addition to increasing the brittleness. Since titanium continues to absorb oxygen and nitrogen down to temperatures around 600°C, it is essential that any shielding practice followed should not only protect the molten weld metal but also adjacent areas heated above 600°C. This does not pose any difficulty when titanium is being welded in closed chambers or in vacuum. But titanium welding in open air poses a challenging task.

Hence to prevent the contamination of weld bead as well as adjacent areas heated to a high temperature, secondary shielding is employed. Secondary shields provide inert atmosphere protection to the solidified and cooling weld bead. They shield the hot weld bead along a seam which is no longer protected by the gas flow from a moving torch. In some cases, the secondary shield is dispensed with and a stationary side shield, in effect, two stationary trailing shields set on their sides, with their diffusers pointing towards each other is employed.

Fig. 2 shows a typical side shield tried out at BHPV Ltd. The design of side shield is quite complicated as it was found that unless diffusers containing micropores were used, shielding would be erratic. Various configurations of the side shield were tried and was later abandoned since shielding of long seam lengths reliably could not be achieved by this technique.

Trailing Shield

Another technique of providing secondary shield-

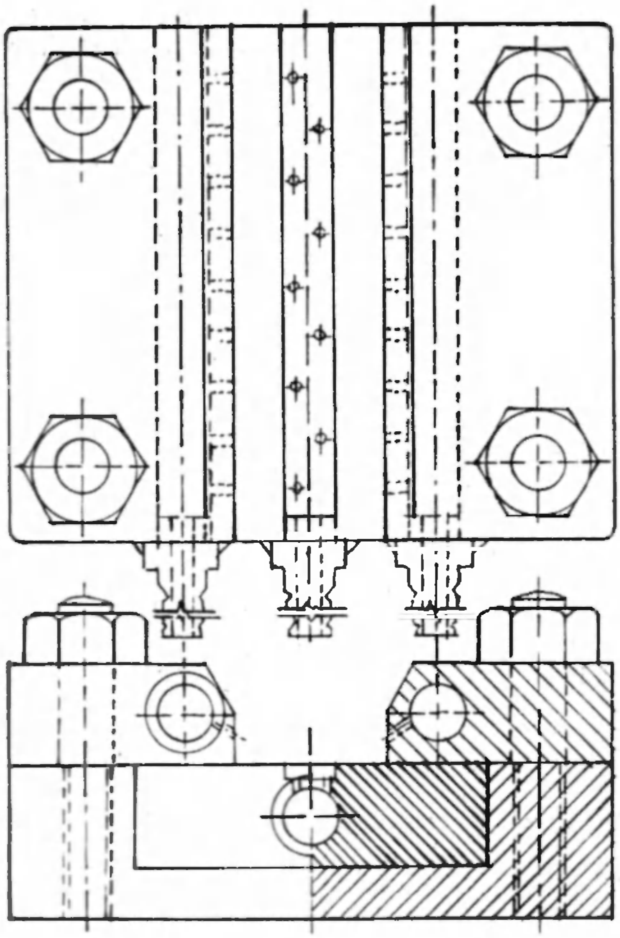

FIG. 2 TYPICAL SIDE SHIELD FOR WELDING TITANIUM

ing is by attaching a trailing shield immediately behind the torch which moves along with the torch. The design of trailing shield is dependent upon the contour of the job to be welded as well as the welding parameters. Hence trailing shields must be tailored to suit welding requirements.

Most important dimensions of the trailing shield are length of the trailing shield and its width. To decide upon these dimensions, the following technique was adopted.

(a) determine welding parameters which give full penetration at slow to moderate welding speeds by experiments.

(b) use these parameters to calculate the temperature profiles in titanium plate during welding, assuming the heat source to be linear using equations of Rykalin[3].

(c) find out time required for the temperature to drop to a safe level below which contamination from outside atmosphere will not occur.

(d) multiply this time by welding speed to arrive at the distance by which the torch would have moved during this time.

(e) the distance so determined gives length of the trailing shield.

(f) to find out the width of the trailing shield, find out the maximum diameter of the circle which reaches a predetermined temperature during welding with parameters used as in (a) above[4].

(g) this diameter gives width of the trailing shield.

It should be noted here that the dimensions so determined are only first approximations which may require modification during actual welding. Further, the trailing shield design is closely linked with welding parameters. So, if drastically different parameters which give relatively slow cooling rates are used, this trailing shield may be ineffective.

Backing Bar

The backing bar is used to provide shielding of the underside of the weld. The design of the backing bar is also critical, since, gas flowing through large holes with sufficient velocity, creates turbulence leading to pin-point defects. These pin-points appear to be mirror images of holes in the backing bar. However, these defects can be avoided by distributing holes more uniformly and by increasing the number of holes and by using minimum gas flow that gives just sufficient shielding.

Welding Current

Titanium is welded by DCSP TIG welding. To control penetration, the first pass was made with a pulsed current. Filler metal was added in the first pass. The second pass was made without pulsation but at a lower current.

Precautions to be taken

Before welding was commenced, the pickled plates and welding jig were degreased with acetone. The filler wire was also pickled, rinsed in water and degreased with acetone. Care was taken to avoid touching with bare hands, the bevels and points up to a distance of about 25 mm from the bevels. The filler wire was always held at one end during degreasing using surgical cotton dipped in acetone. Unneccessary handling was avoided. Water cooled copper jig used for welding was also degreased just before welding, using acetone.

Welding Technique

The test coupons were held in the jig mentioned above. After tightening the jig, joint area was again wiped with acetone to remove finger prints. The gas flow rate for back purge, torch nozzle and trailing shield was adjusted and welding started. The welder was instructed not to take out the filler rod from the argon shield and not to stop welding in the middle. If by any chance the filler rod was removed from argon shield, it was discarded and another rod which was degreased earlier was used to complete the weld. At the end of welding, the power supply to the torch was cut off but the shielding gas flows were maintained till the weld seam and adjacent areas cooled sufficiently below which contamination may not occur. After the root pass was completed, the test coupon was allowed to come to room temperature. The weld as well as the adjacent areas of the weld were wire brushed using a stainless steel wire brush. The wire brushed portions were again cleaned with acetone, to remove slight oxidized layer dislocated by wire brushing and also to clean the joint. The filler pass was completed taking the usual precautions.

Test Results

Extreme precautions were taken during the preparation of specimens. After machining, all specimens were degreased and pickled to remove any hard layer that might have developed either during welding or during machining.

Table 2 shows typical results of mechanical tests.

Conclusions

(1) Titanium can be welded in 'open air' using carefully selected welding procedures and precautions.

(2) Side shields become ineffective where long lengths are to be welded.

(3) Trailing shields are found to be quite effective.

(4) Trailing shields can be designed if the temperature distribution during welding can be predicted.

(5) Careful cleaning and shielding practice followed, has resulted in titanium joints of acceptable mechanical properties.

Table—1

Chemical Composition and Mechanical Properties of Titanium Plate

Fe —0.015%
O_2 —0.15%
H_2 —60 ppm

Balance Titanium+Carbon	
Ultimate tensile strength	—452 N/mm^2
Yield strength	—353 N/mm^2
Elongation	—29% on 2"
Bend test	—105° on 5T

Table—2

Mechanical Properties of Welded Titanium Plates

UTS	45.36 kg/mm^2	
	46.10 kg/mm^2	Broke in fusion zone

Bend Test D=8t, 180°

Face bends 1 No. satisfactory
Root bend 1 No. satisfactory

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