World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:1, No:11, 2007

Microstructure and Mechanical Behaviuor of Rotary Friction Welded Titanium Alloys

M. Avinash, G. V. K. Chaitanya, Dhananjay Kumar Giri, Sarala Upadhya, and B. K. Muralidhara

***Abstract*—**Ti-6Al-4V alloy has demonstrated a high strength to weight ratio as well as good properties at high temperature. The successful application of the alloy in some important areas depends on suitable joining techniques. Friction welding has many advantageous features to be chosen for joining Titanium alloys. The present work investigates the feasibility of producing similar metal joints of this Titanium alloy by rotary friction welding method. The joints are produced at three different speeds and the performances of the welded joints are evaluated by conducting microstructure studies, Vickers Hardness and tensile tests at the joints. It is found that the weld joints produced are sound and the ductile fractures in the tensile weld specimens occur at locations away from the welded joints. It is also found that a rotational speed of 1500 RPM can produce a very good weld, with other parameters kept constant.

***Keywords*—**Rotary friction weld, rotational speed, Ti-6Al-4V, weld structures.

I. Introduction

FRICTION welding method has been used extensively in the manufacturing methods because of the advantages such as high material saving, low production time and strong welded joints produced. There are many different methods of friction welding processes; some important methods have Rotational, Linear, Angular or Orbital types of relative movement between the joining parts.

In rotary friction welding process, the work pieces are brought together under load, one part being revolved against the other so that frictional heat is developed at the inner face. When the joint area is sufficiently plastic as a result of the increase in temperature the rotation is halted and the end force is increased to forge and consolidate the joint. The ideal weld is one, in which there is a complete continuity between the parts joined and every part of the joint is indistinguishable from the metal in which the joint is made [1]. It was the aim of the present studies to examine whether such good welds can be produced using rotary friction welding methods for Ti-6Al-4V alloy.

Friction time, friction pressure, upset time, upset pressure and rotational speed are the most important parameters in this process of joining. The quality and the strength of the welds depend on the correct choice of these parameters.

In friction rotary welding method, one of the components is rotated at constant speed, while the other is pushed toward the rotated part by sliding action under predetermined friction pressure. The friction pressure is applied for a certain length of time. Then the drive is released and the rotary component is quickly stopped while the axial pressure is being increased to a higher predetermined upset pressure, for a predetermined time. The parts burn off to a few mm after the joint is made. A simple set up of a rotary friction welding machine are shown in Fig. 1.

Manuscript received October 9, 2001. Authors are with the Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore 560 001, India (corresponding author to provide phone: 91-080-22961871; e-mail:sarala.upadhya@gmail.com)

Friction welding has been successfully carried out by many workers earlier for producing both similar and dissimilar metal joints [3] - [9].

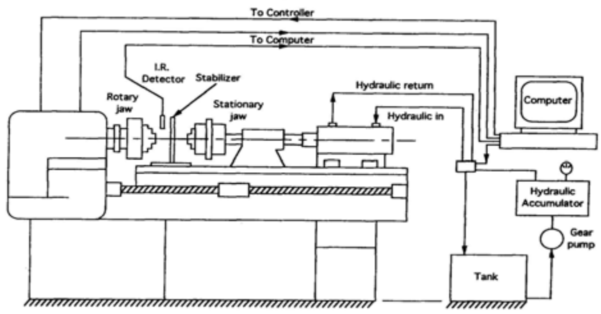

Fig. 1 A set up of a Friction welding machine

II. Experimental Details

The material used in the present investigations was the workhorse aerospace Titanium alloy: Ti 6Al 4V with the chemical composition of the base metal as shown in Table 1.Tests were conducted on weld joints, which were produced by rotary friction welding process using 10mm diameter rods of the Titanium alloy. In the present work, rotational speeds of 1000rpm, 1500rpm and 2000rpm were used to produce the weld joints. The other parameters of the process are: soft force: 0.1 ton; upset force: 0.3 tons; friction force: 0.15 tons, upset time: 2 seconds and burn off: 4mm. These are kept constant.

TABLE I
Chemical Composition of Titanium Alloy Used

Element	Percent
Al	6.00
V	3.92
O	0.2 max
Fe	0.25 max
Ti	rem

The welded specimens were sectioned at the weld-joint to study the microstructure. They were mounted suitably for this purpose. Vickers Hardness test were conducted across the interface. Tensile tests were conducted on the whole welded specimens, with the welded joints at the center of the specimens, on a 50 KN Instron Servo Hydraulic Machine (Model 8032), at a displacement rate of 0.5 mm/minute. The tests followed the ASTM Standards.

III. Results and Discussions

A. Microstructures

The microstructures of the welded joints, taken at 200X, are shown in Fig. 2 to 4 at the three rotational speeds of the process. It is generally observed in all the three cases of rotational speeds that the weld joints are continuous and the Heat Affected Zone (HAZ) is very thin. But there is a distinction between the micro structures developed near the interface in the two parts joined.

In the joint produced at 1000 RPM, a more refined grain structure seen on the right part than on the left part. The HAZ itself is almost non-existent as shown in Fig. 2. It is also found that there is a distinct deformed zone on either side of the weld interface. This is the Transition Zone (TZ).The effect of rotation of the specimen before welding can be seen in this zone, as the grains are pulled in the direction of rotation, being subjected to torque at high temperature. The degree of deformation appears to be very high. But there is good blending of the deformed zone into the parent metal.

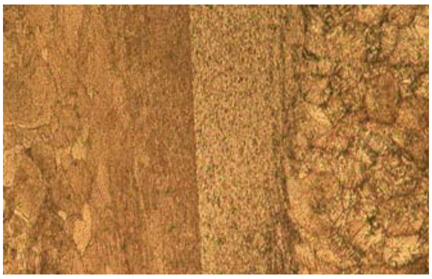

Fig. 2 Interface of specimen welded at 1000 RPM

In the welded structure produced at 1500 RPM, the grains have grown to be larger and there is a marked distinction between the structures of the two pieces welded as shown in Fig. 3. Shearing of the grains in rotation is observed in this case also. However the joint appears to be continuous in the microstructure.

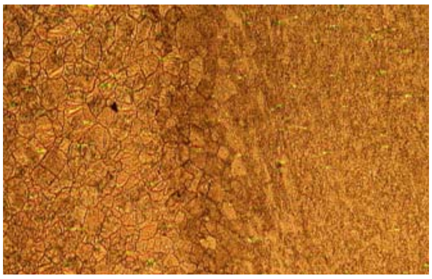

Fig. 3 Interface of specimen welded at 1500 RPM

In the welded structure taken at 2000 RPM the same effect is seen, with uniform grains formed very close to the interface. As seen at lower magnification, the effect of rotational movement of one piece against the other at the welded joint is not shown distinctly (Fig. 4).

Fig. 4 Interface of specimen welded at 2000RPM

In the TZ of the weld, between the welded interface and the parent metal, very large grains are formed. This shows the effect of dynamic recrystallization. There is a hint of the typical 'basket weave structure' of Ti-6Al-4V formed, as shown Figs. 5, 6 and 7.

Fig. 5 TZ in the specimen welded at 1500 RPM

Fig. 6 TZ in the specimen welded at 2000RPM

Fig. 7 TZ in the specimen welded at 2000 RPM (a second location)

B. Vickers Hardness Tests

The Hardness profiles given in Figs. 8, 9 and 10 show the variations of VHN with the location from the weld interface for the three rotational speeds. It is interesting to note that in the case of specimens obtained at 1000RPM and 1500 RPM rotational speeds, the peak Hardness occurs at the center or very close to the center. In the case of the specimen obtained at 2000 RPM rotational speed, the hardness variation is negligible across the section.

At lower rotational speeds there is a marked welded interface structure and TZ. There is also a region of very fine grains in TZ, in the case of 1000 RPM specimen. This is reflected in the drop in the VHN value.

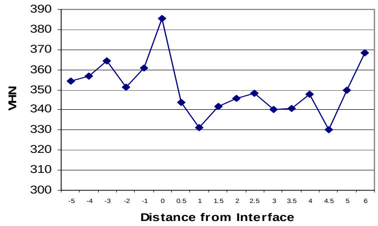

Fig. 8 VHN vs. Location for 1000 RPM Specimen

In the case of specimen welded at 1500 RPM, the variation in VHN value on the right side is negligible up to about 3.5 mm. On the left side there are large variations in the VHN values. This is in conformity with the microstructure changes in the specimen.

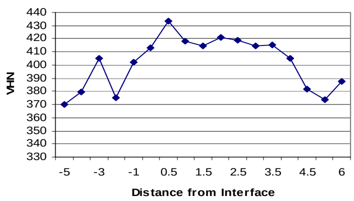

Fig. 9 VHN vs Location for 1500 RPM Specimen

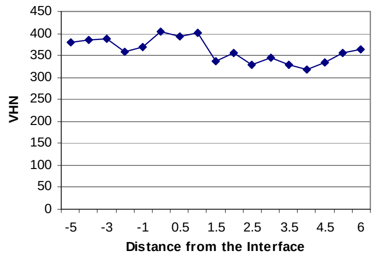

Fig. 10 VHN vs. Location for 2000RPM specimen

The grains in the specimen welded at 2000 RPM are nearly of the same size. Some recrystallization has taken place very close to the weldments in the TZ. The hardness value increases after this recrystallization zone as the work hardening caused by applied load of forging pressure. A little further away from this zone, the heat of friction and work hardening effects is low. Hence the hardness values are closer to that of the base metal. Similar behaviuor is reported in the literature also [10]

C. Tensile Tests

The results of the tensile tests are shown in Fig 11 for the three types of specimen prepared using friction welded joints obtained at the three rotational speeds mentioned above. The specimen obtained at 1500 RPM shows the highest strength.

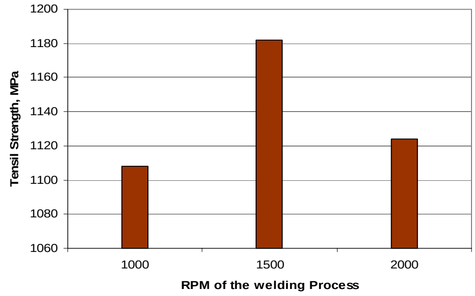

Fig. 11 The results of the tensile tests

The same specimen also shows very little variation in VHN value across the welded interface. It was noted that all the specimens displayed cup and cone fracture, with the final break occurring in the base metal. The welds remained intact during tension. There was uniform elongation in the location of the weld interface, as if it is an integrated continuous material.

IV. Conclusion

In this study, Ti-6Al-4V similar metal joints were welded successfully by Rotary friction welding process using three different rotational speeds. Some interesting developments of microstructure and properties have been found to occur in the weldments. The tensile strength is affected by the rotational speed. The HAZ is very narrow, if not non-existent in the case of 1500 and 2000 RPM specimens. The time taken to weld the specimens is a few seconds. But the performance of the welded specimens is good taking all factors into account.

References

[1] P T Houldcroft, "Welding Process technology", Cambridge University Press, Cambridge 1977,p1.
[2] "Exploiting Friction Welding in Production", Information Package Series, The Welding Institute, Cambridge, 1979.
[3] U. Kamachi Mudali, B.M. Ananda Rao, K. Shanmugam, R. NAtarajan, Baladev Raj "Corrosion and Microstructural Aspects of Dissimilar Metals Joints of Titanium and Type 304L Stainless steel" Journal of Nuclear Materials 321, pp. 40-48.
[4] N.Ozdemir, F.Sarsirlmaz, A.Hascalik "Effect of Rotational Speed on Interface Properties of frictional Welded AISI -304L to 4340 Steel" Materials & Design, Vol 28, Issue 1,2007, pp 301-307.
[5] S. FuKumoto, H. Tsubakino, K.Okita, M.Aritoshi "Friction Welding Process of 5052 Aluminum alloy to 304 Stainless steel" materials science & Technology, Vol 15, Number 9, Sept 1999, pp 1080-1806.
[6] T. Shinoda, K.Miyahara,M.Ogawa, S. Endo "Friction Welding of Aluminium And Plain Low Carbon Steel" Welding International (UK), Vol 15, No.6, 2001, pp435-445.
[7] A. Vairis, M.Frost "High Frequency Linear Friction Welding of a Titanium Alloy" Wear, Vol 217,1998, pp 117-131.
[8] C. Kwietniewski, J. F. dos Santo, A.A. M da Silva, L. Pereira, T. R. Strohaecker, A. Reguly " Effect of Plastic Deformation on the Toughness Behaviuor of Radial Friction Welds of Ti-6Al-4V-0.1Ru Titanium Alloy" Materials Science & engineering A ,Vol 417 , 2006, pp 49-55.
[9] P. D. Sketchley, P.L.Threadfill, I.G. Wright " Rotary Friction Welding of an Fe3Al based ODS Alloy" Materials Science & Engineering A, Vol 329-331, June 2002, pp756-782.
[10] Paul Danielson, R. Wilson,D Alman,"Microstructure of Titanium Welds', U S Department of Energy, Albany Research Center.