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# Friction welding of TiAl and AISI4140

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The promising properties of the intermetallic TiAl alloys as low density, excellent high temperature strength retention, high specific stiffness, excellent creep and oxidation/corrosion resistance and thermal expansion comparable to currently used alloy make them candidates for replacing heavier Ni-based superalloys and Ti-alloys in future jet engines.

The ability to join TiAl itself and to other materials opens up the possibility to produce more complex parts as dual properties components. Conventional fusion welding process such as gas tungsten arc (GTA), laser, electron bean (EB) welding and brazing are possible to use when joining TiAl. However, the low ductility of the material in combination with high residual stresses makes fusion welding complicated. Solid state bonding such as friction welding and diffusion bonding avoids many of these problems and are attractive for relatively brittle intermetallic materials like TiAl [1–6].

Although TiAl and steel has been successfully joined by diffusion bonding and brazing [2, 3, 6], these welding methods need vacuum equipment, shield gas, filler wire. Friction welding, which has represented the specific joint characteristic when joining dissimilar material, has many process advantages [7]. This paper aims to demonstrate the feasibility of friction welding of TiAl alloy to AISI 4140 steel and the focus is placed on the interfacial microstructure and mechanical properties of joints.

The materials used in the present work were investment cast TiAl alloy (Ti-47at%Al) and commercial available AISI 4140, which were machined to a rod shape 20 mm in diameter and 120 mm in length and 24 mm in diameter and 120 mm in length, respectively. The friction welding parameters are rotating speed $N$, friction time $t_1$, upset time $t_2$, friction pressure $P_1$ and upset pressure $P_2$ when welding with brake type machine. In this present work, $t_2$ and $N$ were fixed at 5 s, 2000 rev/min, respectively. The $t_1$ was varied from 30 to 50 s and the $P_2$ was changed from 300 to 460 MPa. The resultant welds were sliced using an electron discharge machine were ground with SiC paper, and finally micro polished using 0.05 $\mu$m $Al_2O_3$ powder. The microstructures of friction welded interfaces were observed by OM (optical microscope), and SEM (scanning electron microscope) Elements and phases near the weld zone were analyzed using EDS (energy dispersive spectrometer). Tensile testing was performed at room temperature using an Instron type testing machine with

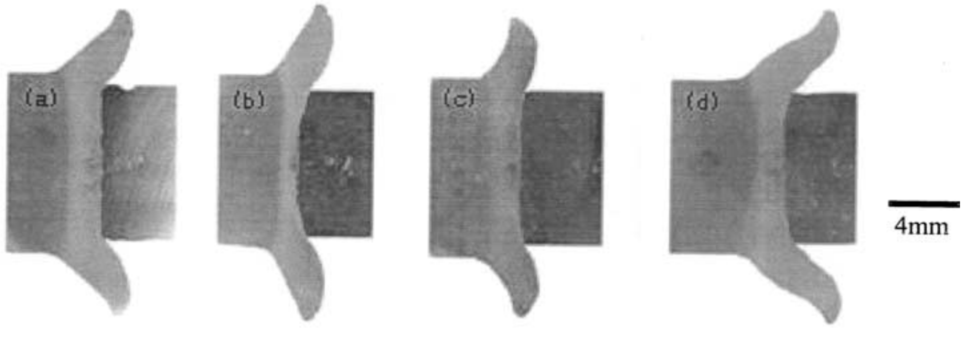

*Figure 1* Macro-images of friction welded TiAl/AISI 4140 with various welding conditions: (a) $P_1 = 130$ MPa, $P_2 = 360$ MPa, $t_1 = 50$ s, (b) $P_1 = 130$, $P_2 = 460$, $t_1 = 50$ s, (c) $P_1 = 170$, $P_2 = 360$, $t_1 = 30$ s, and (d) $P_1 = 170$, $P_2 = 360$, $t_1 = 50$ s.

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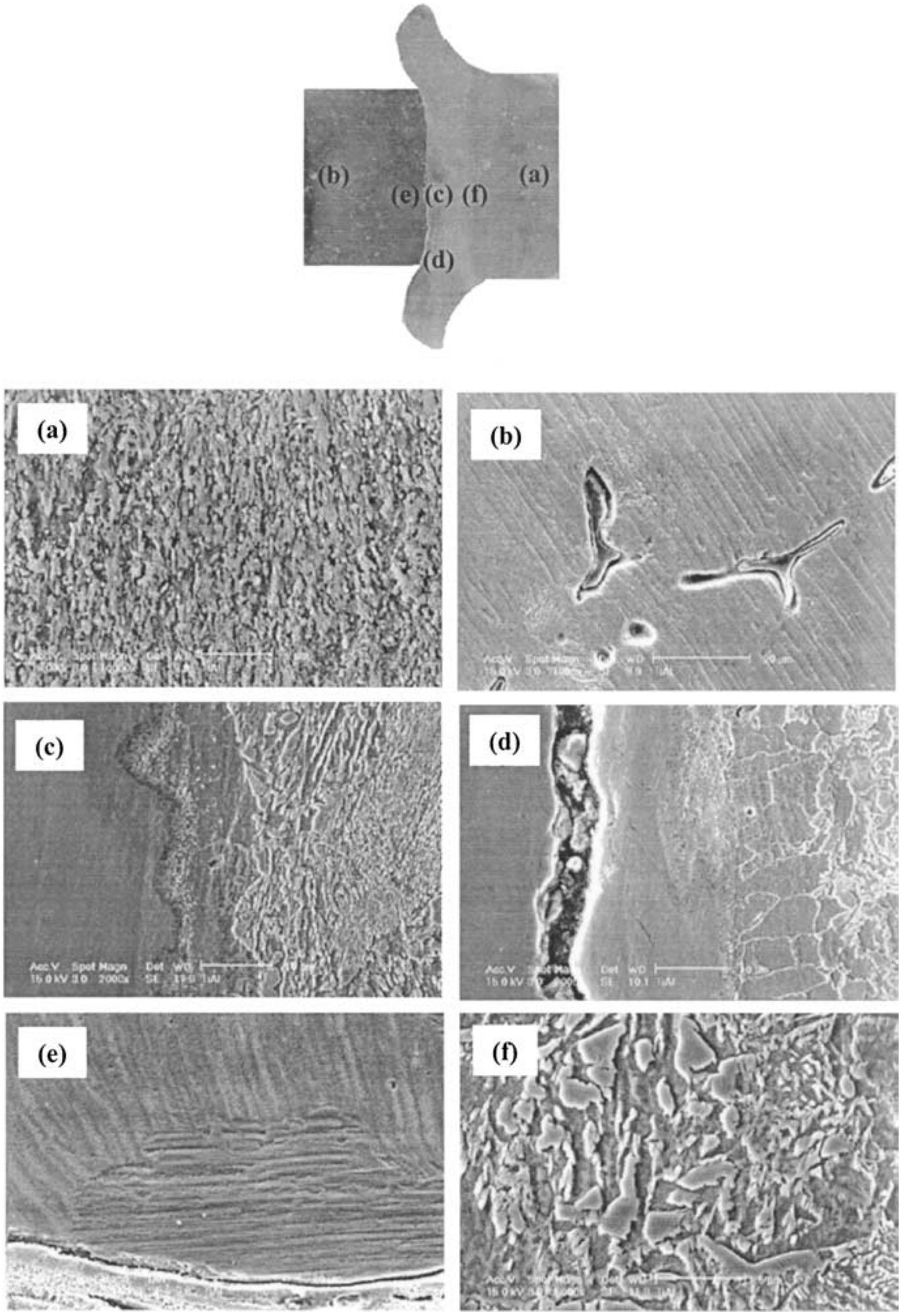


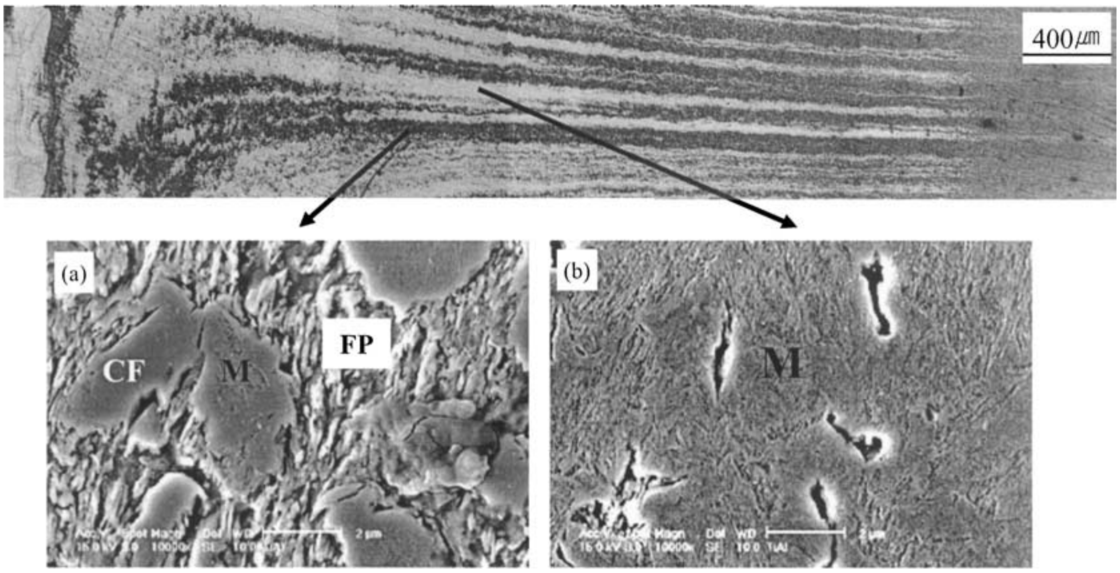
*Figure 2* Macroimage of weld and SEM microstructures of each region: (a) AISI 4140, (b) TiAl, (c) central interface, (d) peripheral interface, (e) Ti side of interface, and (f) AISI 4140 side of interface.

$1.67 \times 10^{-2}$ mms$^{-1}$ cross head speed. The hardness distribution of each material in the vicinity of the weld interface was measured with a load of 1.96 N, for 10 s.

Photo macrographs of the cross sections with welding conditions are shown in Fig. 1. In the case of dissimilar materials joints by friction welding, the formation of the flash depends on two parent materials mechanical properties. The flashes were symmetrically formed around the weld interface on AISI 4140 side. The amount of flash increased with increasing $t_1$, $P_1$ and $P_2$, while TiAl side was not macroscopically deformed because TiAl has brittle nature and thus is more resistant to deformation.

Fig. 2 shows the macroimage of the weld and SEM microstructures of base metals and the weld zone. AISI 4140 (a) had a very fine pearlite structure. TiAl alloy (b) had a duplex microstructure (near lamellar) consisting of lamellar grains of alternating $\alpha_2$ ($Ti_3Al$) and $\gamma$ (TiAl) strip and some of globular gamma grains. Friction welded interface of central region (c) and peripheral region (d) showed the reaction layer of two materials and some of the deformed microstructure. There was no defect at central interface. On the other hand, a large crack was formed in TiAl side at the peripheral region. Since the relative region velocity varies initially from zero at central region to maximum of 3 m/s at the peripheral region of the joint, the peripheral side received a severe plastic deformation relative to the central region [8]. The crack might be formed due to the severe plastic deformation and also the brittle nature of TiAl alloy during the weld process.

The microstructures near the interface represented a slightly different feature compare to those of base metals. Though the duplex structure of TiAl alloy was



FP: Fine Pearlite, CF: Coarsened Ferrite and M: Martensite

*Figure 3* SEM microstructures of AISI 4140 side's HDAZ region: (a) black layer and (b) white layer.

still remaining, the globular $\gamma$ phase disappeared and may be dissolved in the matrix by the welding heat (e). Very fine pearlite of AISI 4140 was changed to coarsened structure (f).

Microstructural change near the interface was observed at the AISI 4140 side. Fig. 3 shows macroimages which give the evidence of the microstructural variation of AISI 4140 and SEM images of the two layer

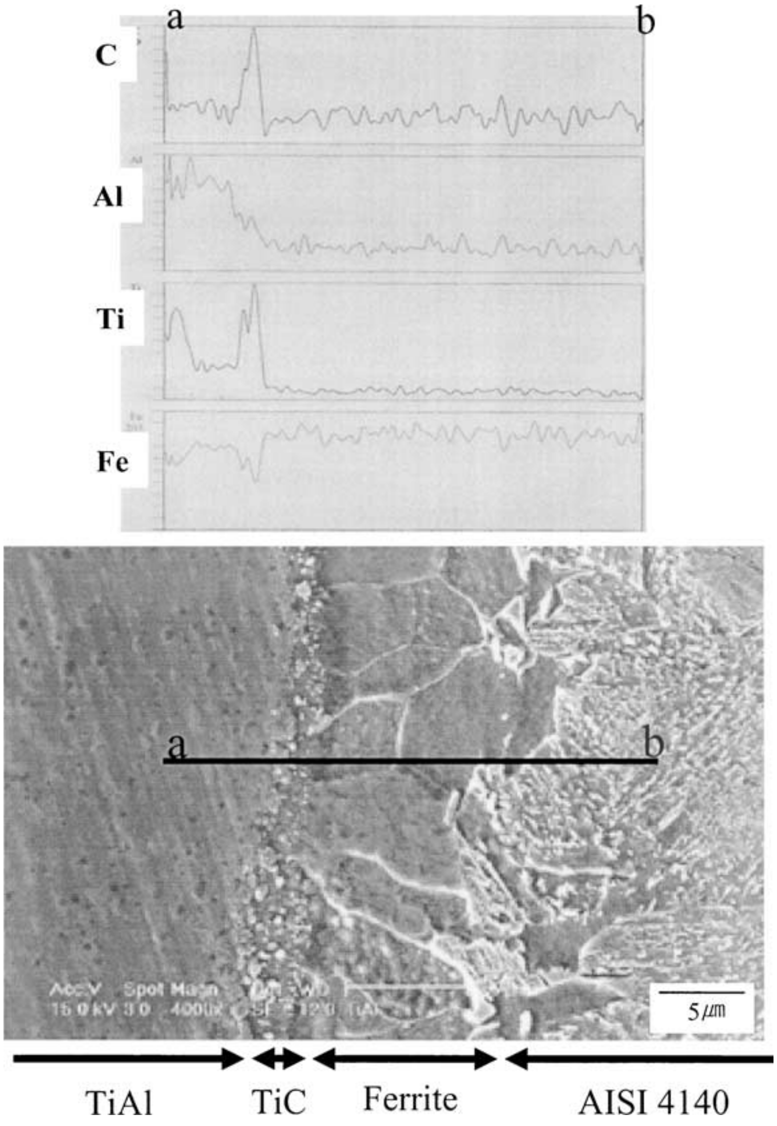


*Figure 4* SEM microstructure of central interface and EDS line scan result.

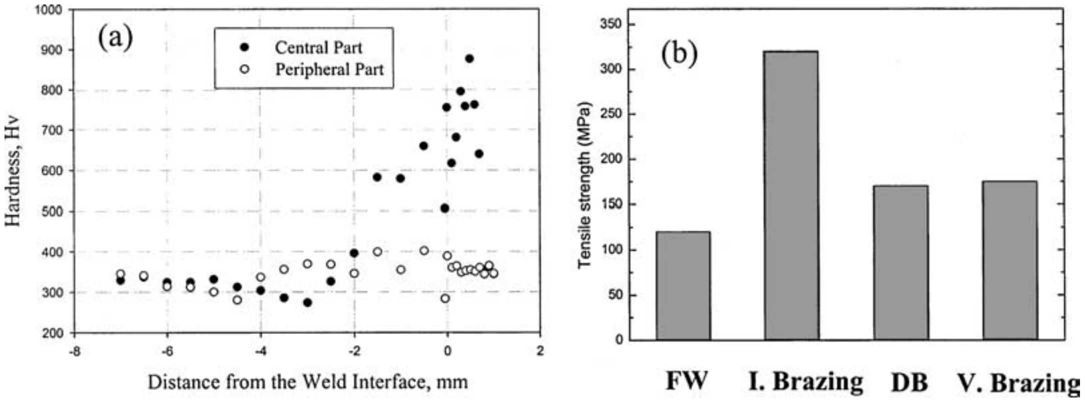


*Figure 5* Hardness distribution of the weld zone (a) and tensile strength (b) comparing other joining method.

structure. The black region (a) was composed of the coarsened ferrite, the lath-like martensite structure and fine pearlite. The white region (b) showed a lath-like structure, which may be martensite structure. The area of white region increased close to the interface. During the friction welding process, the temperature near the interface would be reached between $A_3$ temperature and the melting point of AISI 4140 steel. Therefore, the microstructure of AISI 4140 steel was transformed to the austenite. The austenite microstructure was changed to the other phases due to the diffusion of carbon to the grain boundary and rapid cooling rate. The fine pearlite structure of AISI 4140 may be transformed to the martensite because the friction welded TiAl/AISI 4140 joint experienced the rapid cooling after finishing the welding process. The results of microstructural variation on AISI 4140 steel were the same as that of M. Eroglu *et al.* [9].

Fig. 4 shows the microstructure of the joint and EDS line scan result. The weld zone was divided into the 4 region, TiAl lamellar structure, Ti carbide (TiC), recrystallized ferrite and fine pearlite, from the microstructure and EDS analysis. TiC layer was formed by chemical reaction between the diffused carbon from the steel and Ti. The layer thickness of TiC was approximately less 2 $\mu$m and very thin layer relative to that of the diffusion bonded interface [6]. Carbon decomposition region may be resulted in the formation of recrystallized and equiaxed ferrite region on the AISI 4140 side. Its grain size about 5 $\mu$m.

Fig. 5 shows the cross-sectional hardness profile (a) near friction welded joint and tensile strength (b) relative to those of the other bonding process [2, 3, 6]. Hardness of the reaction layer and AISI side near the interface remarkably increased and reached approximately 600–900 HV. This hardened region could be attributed to the brittle intermetallic layer and martensite structure. However, there was no hardness variation at TiAl side.

The tensile strength of friction welded joint shows 120 MPa which was lower value relative to that of the other bonding process due to a large cracking exited in peripheral interface. To apply the friction welding to join brittle TiAl alloy and AISI 4140, it is absolutely needed to prevent the formation of the crack at the peripheral region such as using a buffer layer for stress release.

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