삽입금속을 이용한 TiAl 합금과 AISI 4140 스틸의 마찰용접

Friction welding of TiAl alloy and AISI 4140 steel using insert layer

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1. Introduction

In various intermetallic compounds, TiAl has been focused on as the most practical lightweight heat-resistant material. With highly attractive properties of low density and high-temperature strength retention, TiAl alloys based on gamma TiAl have an excellent potential to become one of the most important high-temperature structural materials [1].

Recently, the properties of TiAl alloys has been remarkably improved through alloy design and microstructure control to meet requirements for some gas-turbine and automobile engine components that may be used up to 1033K [2]. However, appropriate joining techniques are indispensable for the full utilization of these materials. In the practical application of TiAl to the components, technology developments not only in the alloy design but also in processing, surface modification and joining techniques are necessary[3].

Reported joining techniques concerning similar TiAl are brazing or vacuum brazing, infrared welding, diffusion bonding, electron beam welding and friction welding[4]. However, the technique applied to the joining of dissimilar TiAl and steels are brazing, diffusion bonding and friction welding[3]. Although rather good joint properties can be obtained by brazing, the long process time and the high corresponding operation cost may render this joining method non-useful for practical application, especially for the joining large-sized workpieces. Moreover, the friction welding of TiAl and structural steel was not successful because of cracking at the brittle interfaceof the joint due to the internal stress induced by the martensite transformation of the structural steel on cooling after joining [5]. As similar as brazing technique, to prevent crack formation, the weld design is absolutely needed to acquire defect free weld zone when friction welding method was intended to join TiAl and Structural steel.

Because friction welding has many advantages, therefore, in this study, friction welding was applied to join the investment cast TiAl and commercial AISI 4140 steel using an OFC (Oxygen Free Copper) for buffer for the stress.

2. Experimental procedure

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 20mm in diameter and 120mm in length and 24mm in diameter and 120mm in length, respectively. The OFC (oxygen free copper) as buffer for stress was 22mm in diameter and 50mm in length.

The friction welding parameters are rotating speed N, friction time t1, upset time t2, friction pressure P1 and upset pressure P2when welding with brake type machine. In this present work, t2, P1 and N were fixed at 5sec, 100 MPa and 2000 rev/min, respectively. The t1 was varied from 30 to 50 s and the P2 was changed from 300MPa to 460MPa when friction welding was carried out without insert metal. In case OFC was used as buffer for stress, two trials of friction welding were carried out to complete the joints. Firstly, TiAl was bonded to OFC with condition of t1=0.5 and P2=300MPa. And then TiAl/OFC joint was secondly bonded with AISI 4140 with various P2 to control the layer thickness of insert metal.

The resultant welds sliced using an electron discharge machine were ground with SiC paper, and finally micro polished using 0.3m Al_2O_3powder. 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 1.6710^{-2}mm/s cross head speed.

3. Results

Fig.1 shows the macroimage of the weld and SEM microstructures of the weld zone welded without insert metal.

AISI 4140 had a very fine pearlite structure and TiAl alloy had a duplex microstructure (near lamellar) consisting of lamellar grains of alternating Ti_3Al and TiAl strip and some of globular gamma grains. Friction welded interface of central region (b) and peripheral region (c) showed the reaction layer of two materials and a 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.

Microstructural change near the interface was remarkably observed at the AISI 4140 side as shown in Fig. 1 (d). Deformed region reached about 2-4 mm from the interface depending on the welding conditions. Lath-like structures, which may be martensite structure, were transformed by the welding thermal cycle and rapid cooling rate after welding. During the friction welding process, the temperature near the interface would be reached between A3temperature 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.

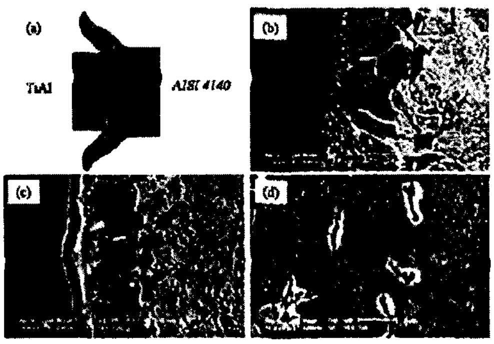

Fig. 1 Macrostructure of joints (a) and SEM microstructure of each region (b) central interface, (c) peripheral interface (d) AISI 4140 near interface.

Fig.2 shows the microstructure near weld zone inserted by OFC between TiAl and AISI 4140 steel with interlayer thickness. Layer thickness can be controlled by the adjusting friction welding parameters such as friction time and upset pressure. In this study, layer thickness of insert metal between TiAl and OFC/AISI 4140 joints was controlled below 1 mm with changing P2 ranged from 220 MPa to 250 MPa.

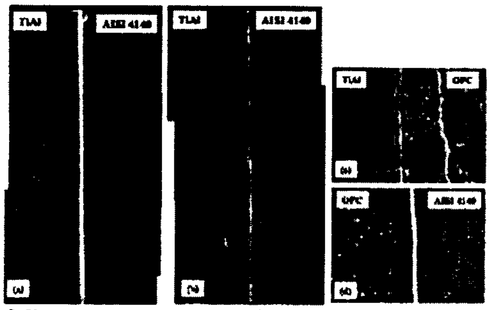

Fig.2 Microstructures near the weld zone inserted by OFC between TiAl and AISI 4140

Defects such as crack and cleavage were not observed at both interfaces of TiAl/OFC and OFC/AISI 4140 regardless of interlayer thickness and this result meant that joints between TiAl and AISI 4140 can be successfully achieved using insert metal. Any kinds of intermediate phase were not formed at the interface between OFC and AISI 4140. However, at the interface of TiAl and OFC, two kinds of intermediate phases (AlCuTi and TiCu), which was not yet been exactly analyzed, were formed. A wide range of phase transformed region observed at the AISI 4140 side remarkably decreased because of applying lower P2 and shorter t1. Deformed region decreased less than 0.5 mm from the weld interface.

Fig.3 shows the room temperature tensile strength variation and fractured specimen with various layer thicknesses of insert metal. The tensile strength increased as decreasing layer thickness and it meant a higher P2 positively affected on the joint property. At the 600 m of layer thickness, the tensile strength was about 250 MPa. The fracture mainly occurred at the interface of TiAl/OFC and was partially introduced at the central interface of OFC/AISI 4140. However, when the layer thicknesses were controlled at 200 or 300 m, the tensile strength showed 345 MPa or 375 MPa, respectively. Generally, in friction welding process, mechanical property increases as increasing P2 till it reached critical strength due to introducing a higher compressive force to the interface and the repulsion of the brittle intermediate phase outside the interface [7]. In spite fracture occurred at the TiAl base metal in case of 200 and 300 m, lower tensile strength of 200 m interlayer thickness than that of 300 m didn't resulted from lower joint strength, but from the microstructural irregularity in as casted TiAl base metal.

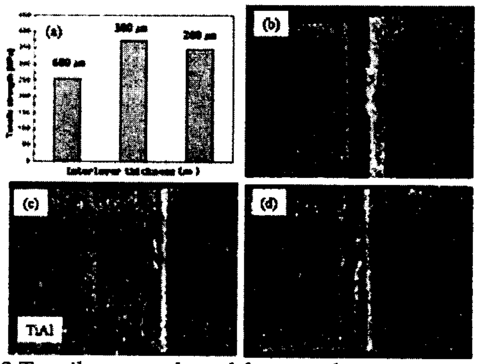

Fig.3 Tensile strength and fractured specimens with interlayer thickness

4. Conclusion

The joints between TiAl and AISI 4140 practically used a part of turbo charger was successfully achieved by the friction welding method using insert metal, which was well acted as buffer for stress. The formation of crack and a wide range of martensite transformation were prevented using insert metal. The highest tensile strength, 375MPa, at room temperature was acquired relative to those of other welding methods. Fracture occurred at the TiAl base metal.

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