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Evaluation of interfacial bonding in dissimilar materials of YSZ–alumina composites to 6061 aluminium alloy using friction welding

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ABSTRACT

The interfacial microstructures characteristics of alumina ceramic body reinforced with yttria stabilized zirconia (YSZ) was evaluated after friction welding to 6061 aluminum alloy using optical and electron microscopy. Alumina rods containing 25 and 50 wt% yttria stabilized zirconia were fabricated by slip casting in plaster of Paris (POP) molds and subsequently sintered at 1600 °C. On the other hand, aluminum rods were machine down to the required dimension using a lathe machine. The diameter of the ceramic and the metal rods was 16 mm. Rotational speeds for the friction welding were varied between 900 and 1800 rpm. The friction pressure was maintained at 7 MPa for a friction time of 30 s. Optical and scanning electron microscopy was used to analyze the microstructure of the resultant joints, particularly at the interface. The joints were also examined with EDX line (energy dispersive X-ray) in order to determine the phases formed during the welding. The mechanical properties of the friction welded YSZ–Al_2O_3 composite to 6061 alloy were determined with a four-point bend test and Vickers microhardness. The experimental results showed the degree of deformation varied significantly for the 6061 Al alloy than the ceramic composite part. The mechanical strength of friction-welded ceramic composite/6061 Al alloy components were obviously affected by joining rotational speed selected which decreases in strength with increasing rotational speed.

1. Introduction

Friction welding is a solid-state welding technology. It makes use of frictional heat generated at the rubbing surfaces of the two materials hence, raising the temperature at the interface high enough to cause the two surfaces to be forged together under high pressure [1]. Heat is generated by the conversion of mechanical energy into thermal energy at the interfaces of the components during rotation under pressure without requiring any energy from the environment. When two different materials are joined, the degree of success, depends on the properties of the interface created in the joint and the thermal expansion coefficient mismatch between the joined materials resulting in large residual stresses generation during cooling from the joining temperature [1].

Friction welding method has extensively been used in manufacturing of aerospace and automobile applications because of the advantages such as high material savings, low production times and minimal heat affected zone (HAZ) width.

This solid-state joining process can also be used to join dissimilar materials such as ceramics or composites to metals [2]. The process also has been used to build some wear prone industrial knives, valves, pump components, as well as plastic extrusion machines using wear resistant alloys. Ceramic surfacing of metallic materials leads to high hardness and results in insulating surfaces suitable for use in high temperature corrosive atmospheres. Ceramic composites have also been welded to high strength aluminum alloys for transportation industry applications including airframe structure, front disc brake rotors, turbo charger impellers, missile bodies and aircraft wing skins.

Different studies on the interface microstructure of the friction welding have been carried out by various researchers. Avinash et al. [3] investigated the feasibility of producing similar metal joints of titanium alloy by rotary friction welding method by using three different rotational speeds. They observed that in all the three cases of rotational speeds, the weld joints were continuous and the HAZ was very thin. However, there was a distinction between the microstructures developed near the interface in the two joints. Özdemir et al. [4] also studied the effect of rotational speed on the interface properties of friction welded steels of different types. They observed that the width of the full plastic deformed zone (FPDZ) had an important effect on the strength of friction-welded samples and that the strength increased with an increase in the

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Table 1
Chemical composition of the 6061 aluminum alloy (wt%) by XRF technique.

Al	Si	Mg	Fe	Cu	Cr	Mn	Ti	Zn	Ni	Ga	Bal
96.0	2.1	0.95	0.33	0.17	0.066	0.04	0.022	0.014	0.014	0.013	<0.01

Table 2
Chemical composition of the alumina (wt%) by XRF technique.

Al_2O_3	SiO_2	Na_2O	CaO	Fe_2O_3	NiO	CuO	ZnO	Ga_2O_3
99.4	0.33	0.11	0.024	0.081	0.014	0.001	0.001	0.001

rotational speed. Lin et al. [5] studied the effect of joint design and volume fraction on friction welding properties of aluminum/silicon carbide composites. They found that the HAZ consisted of three zones, i.e. fully plasticized region, partially deformed region and the undeformed region. In our previous work, we studied the interface of ceramic/metal alloy by friction welded components to understand the quality of bonding between two dissimilar materials [6]. The experimental results showed that the effect of rotation speed and the degree of deformation appeared to be high for the 6061 Aluminum alloy than the alumina part. It was discovered that the weld interface formed included three different regions: unaffected zone, deformed zone, transformed and recrystallized fully deformed zone. When the rotational speed increased, the thickness of FPDZ at the interface increased as a result of more mass discarded from the welding interface.

In the present work, a ceramic composite of YSZ–Al_2O_3 and 6061 Al alloy were joined by the friction welding. The joining of alumina rods containing 25 and 50 wt% of yttria-stabilized zirconia to the aluminum alloy was carried out by direct drive friction welding machine with constant friction time and friction pressure. However, the effect of different rotational speeds was investigated in detail. The influence of increasing the rotational speed on the interface and welding quality of the joints were also evaluated by four point bending test and Vickers microhardness.

2. Experimental

2.1. Materials and specimen preparation

The test materials used in the present investigations were commercial 6061 Al alloy rods used for aerospace applications and alumina rods containing 25 and 50 wt% yttria stabilized zirconia prepared through slip casting technique. The chemical composition of these materials as determined by X-ray fluorescence (XRF) technique are shown in Tables 1–3. Tests were performed on the weld joints produced by the friction welding of 16 mm diameter rods of the ceramic composite and aluminum alloy. The rotational friction-welding machine was modified from an existing lathe machine. The dimensions of the specimens used for the friction welding are shown in Fig. 1.

The starting raw materials were commercial alumina powder supplied by Maju Santifik Sdn Bhd (high purity, with average particle size 1.04 μm, specific area 8.65 m^2/g) and 5.2-mol% yttria stabilized zirconia powder (average particle size 1.77 μm) from STREM Chemicals, USA. Appropriate predetermined amount of alumina and zirconia powders were mixed in distilled water for ∼24 h

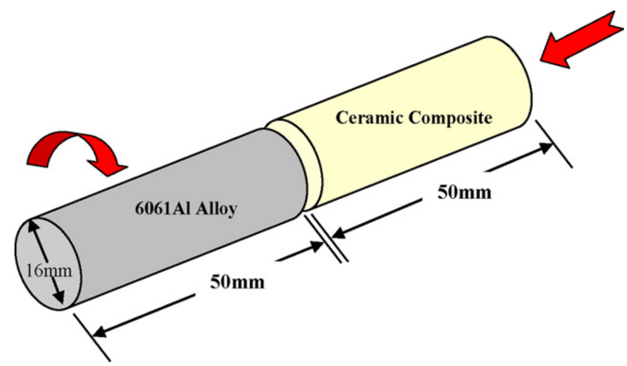

Fig. 1. The dimensions of specimens used for friction welding.

using a ball mill with zirconia ball as mixing media. The ceramic composite rods were prepared by slip casting in plaster of Paris (POP) molds. Subsequently, the cast alumina/YSZ–zirconia rods were sintered at 1600 °C with a heating rate of 5 °C per min and soaking time of 5 h. The aluminum alloy rods were supplied by a local supplier (Heap Sing Huat Metal and Machinery Sdn Bhd). The aluminum rods were cut and machine down using a lathe machine to the diameter of 16 mm.

2.2. Friction welding operation

The friction welding was carried out using a modified existing lathe machine model: APA TUM-35. The connecting surface of the

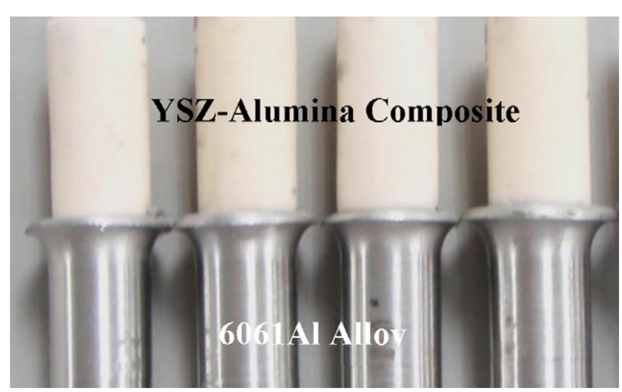

Fig. 2. Overview of friction welded YSZ–alumina composite with 6061 Al alloy joints.

Table 3
Chemical composition of the yttria stabilized zirconia (wt%) by XRF technique.

ZrO_2	Y_2O_3	HfO_2	MnO	Fe_2O_3	SiO_2	TiO_2	CaO	MgO
91.14	6.3	2.3	0.15	0.092	0.083	0.03	0.004	0.001