A Microstructure Study on the Al_2O_3-Al and Al-Steel Interfaces for Ceramic-Metal Joints via Friction Welding

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ABSTRACT

The joining of ceramic-metal could be done through a few techniques: brazing, diffusion bonding, friction welding etc. However, the mechanism of ceramic-metal joining was still not properly understood. In this study, alumina rod was bonded to mild steel rod via friction welding technique by using Al 1100 sheet as interlayer. The diameter of the rods was 10 mm. Friction pressure of 20 MPa and forging pressure of 40 MPa were used. Rotational speeds were maintained at 900 rpm and friction times of 2 to 20 seconds were applied. The joining strength was determined through four point bending test. The maximum bending strength, 240 MPa was obtained at the friction times of 20 seconds. Under optical microscope and SEM observation, the deformation of the aluminum interface was clearly obtained. Mechanical interlocking and close contact between the alumina-aluminum and aluminum-mild steel were observed at magnifications of 3000X. The strength of alumina-steel bonding is much dependent on the wettability of the alumina surface by the molten aluminum and the existing of mechanical interlocking between interlayer and sample materials.

Keywords

ceramic-metal joining, friction welding, four point bending test, optical microscope and SEM observation, alumina-aluminum and aluminum-steel interfaces

INTRODUCTION

Metal/ceramic joints become more and more important in modern technology, because they combine the properties of metals like ductility and high electrical and thermal conductivity and the properties of ceramics [1]. The excellent elevated temperature strength and resistance to corrosion make ceramic materials highly attractive for use in electronic, aerospace, nuclear and automotive industries [2]. Instead of the single piece ceramic component, joining of such materials is often preferred.

Microstructural development at ceramic-metal interfaces plays a critical role in all of these processes. The phenomenon of ceramic-metal interface formation is not simple and requires an understanding of the thermodynamics, kinetics, and mechanical properties of all of the phases that are present (including the interfaces between phases, which also have unique properties and, thus, act as independent constituents) [3].

METHODS AND MATERIALS

The steel samples were machined to produce the rods of 10 mm in diameter while the Al_2O_3 rods were prepared through slip casting with 10 mm in diameter and sintered at 1600°C for 4 hours. Aluminum sheet with thickness of 1.0 mm was used. The surfaces to be connected of steel and alumina were ground to a smooth surface and sharp edges around it were trimmed. The steel and alumina samples were then put into ultrasound bath of acetone solution to remove dirt, grease etc. The small pieces of aluminum sheet were folded to steel rod as an interlayer. The joints were prepared on a direct drive friction welding machine modified from an existing lathe (model: APA TUM-35). Friction pressure of 20 MPa was applied and forging pressure was maintained at 30 MPa, rotational speeds of 900 rpm was used, while friction and forging times were varied from 2 s to 20 s were used.

Bending test of the successful friction joint was measured through four point bending test by using Instron model 8501. The fractured samples were sectioned along the longitudinal length and ground to a smooth finish with 240 grit, 600 grit, 1200 grit, 2000 grit SiC paper and 0.05 μm alumina suspensions in succession. Samples were observed under the optical microscope (model Olympus BX-51M) and a Zeiss Supra 35VP SEM (Scanning Electron Microscope) to evaluate the shape of the interface and the extent of bonding.

RESULTS AND DISCUSSIONS

Figure 1 shows the correlation between interlayer thickness (after joining process) and bending strength at different friction time. The bending strength was increased with the increase in friction time. The highest bending strength was observed at the friction time of 20 s with 240 MPa. Meanwhile, the interlayer thickness after joint was obtained decreased with the increase in friction time. This result indicates that the joint strength was dependence to the interlayer thickness. Since the shorter duration of friction times, the heat generated not enough to deform the interlayer and then it's become thicker. Incomplete wettability process also occurred due to lower friction times. The results were inversely obtained for the longer duration of friction times.

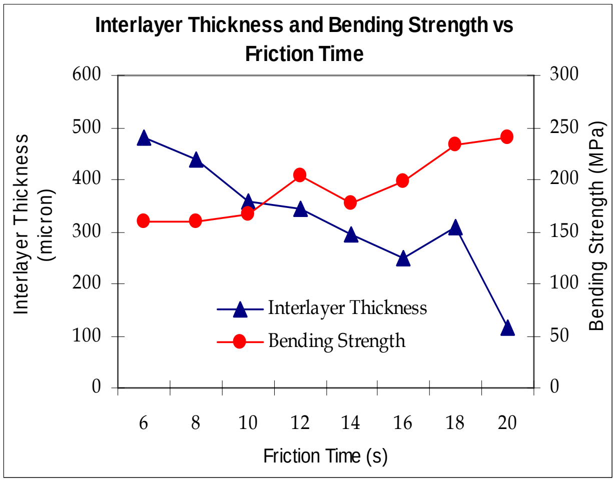
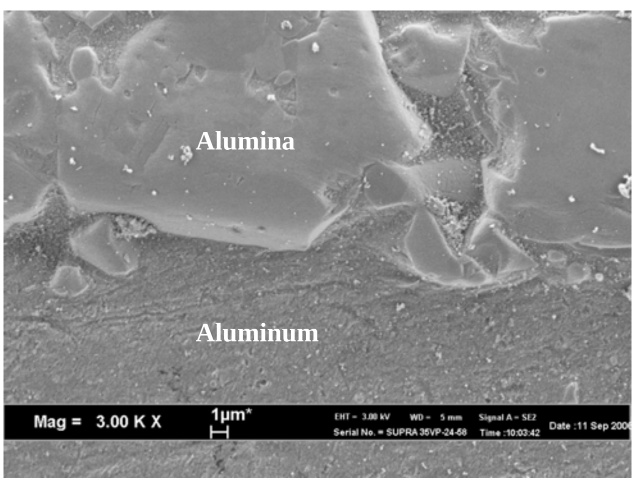


Figure 1: Correlation between interlayer thickness and bending strength at different friction time.

The SEM evaluation revealed some significant facts as shown in Fig. 2. All the micrographs show mechanical interlocking at the interfaces of the joining. It may be due to breaking of oxide layer was occurred. Finally, there are two interfaces were obtained for each friction welded alumina to mild steel with intermediate layer; alumina-aluminum and aluminum-mild steel.



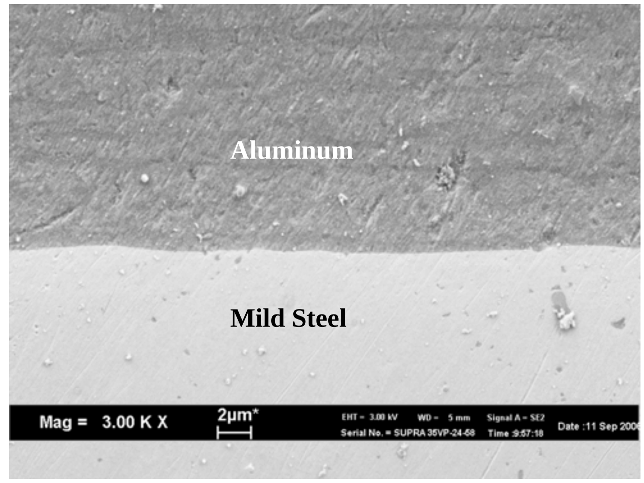


Figure 2: Mechanical interlocking between steel-aluminum and alumina-aluminum.

CONCLUSION

In this work it has been demonstrated that successful joint of alumina-steel was achieved through the introduction of aluminum sheet as interlayer. The highest bending strength of 240 MPa was obtained with the interlayer thickness of about 117 µm. It is believed that the joint strength depends on the aluminum interlayer thickness and the mechanical interlocking at the interface of both sides joining; mild steel-aluminum interfaces and aluminum-alumina interfaces.

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