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FRICTION WELDING OF FLY ASH REINFORCED AA6061 (P/M) COMPOSITE AND WROUGHT ALLOY

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ABSTRACT

The aim of this study is to investigate the feasibility of joining fly ash reinforced AA6061 (P/M) composite to the AA6061 wrought alloy by rotational friction welding. The AA6061 composites, reinforced with 2, 4, 6, 8 and 10 wt% fly ash particles, were produced by powder metallurgy and hot extrusion techniques. The integrity of the joints has been investigated by optical microscopy, while the mechanical properties assessment was obtained by micro hardness. The results indicated that the P/M composite could be joined to AA6061 wrought alloy by friction welding. However, it was pointed out that the quality of the joint was affected negatively with the increase in weight percentage of the fly ash particles in the P/M composite.

Key words: Composite Materials, Powder Metallurgy, Friction Welding

1. Introduction

Particulate reinforced metal matrix composites remain interesting field of materials, such as high specific modulus, high specific strength, low density and easy fabrication. Therefore, these materials are used not only in the field where the working costs are mainly influenced by weight, such as aerospace and aircraft, but also in other industrial fields, like the automotive industry. Along with a great deal of research about the fabricating processes and properties estimation for this kind of materials continuing, the further investigation on practical applications of secondary processing technologies (such as machining, joining, plastic forging, joining and so forth) is also becoming considerably important and urgent[1,2]. With regard to the joining of discontinuously reinforced aluminum alloy matrix composites, it is generally referred to the metallurgical joining processes.

Extensive efforts have been devoted to investigate the appropriate processes to join the similar or dissimilar composites. There are still many problems on the joining of discontinuously reinforced aluminum matrix composite materials by the generally used fusion welding processes, such as: (1) in the melting state, the liquid welding pool of composite had a great viscosity with poor flowability, therefore it is difficult for composite itself to mix with the filler materials. Consequently, the formation of weld and the quality of welded joint are not satisfactory. (2) When the molten welding pool was cooled down, the reinforcement phases were rejected by the solidification front, and the normal solidification processes of the welding pool had been broken down, and this would lead to micro segregation or inhomogeneous distribution of the reinforcement phases. Finally, there would be many defects in the weld [3]. Until now, however, it can be said that joining of metal matrix composites is an area still full of open questions. There are still many fundamental research works that should be done to investigate the joining performance of this kind of composite materials in detail [4,5].

Friction welding finds widespread industrial use as a mass-production process for the joining of materials. In the welding process, the joining surface of the samples is heated to the desired temperature through frictional heat and then a forging pressure is introduced to weld the parts. Friction welding can be used to join metals of widely differing thermal and mechanical properties. Often, combinations that can be friction welded cannot be joined by other welding techniques because of the formation of brittle phases, which make the joint poor in mechanical properties. The sub-melting temperatures and short weld times of friction welding allow many combinations of work metals to be joined [6,7]. Thus, friction welding technology appears to be the most promising for joining of discontinuously reinforced aluminum alloy matrix composites.

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Undoubtedly the metal matrix composites reinforced with ceramic particles are having more strength to weight ratio and wear resistance compared to monolithic alloys. To get still weight reduction in automobile assemblies, especially for break rotor systems, use of composite and wrought joints would certainly be a beneficial.

As mentioned above, friction welding might be successfully applied in case of a metal matrix composite (MMC) containing short fibers or ceramic particles as the strengthening phase. Several variants of technique have been used to join these materials, such as both inertia and continuous. In the present work, a preliminary research has been carried out to investigate the joining performance of fly ash particulate reinforced aluminum alloy matrix powder metallurgy (P/M) composites to wrought alloy by friction welding.

2. Materials and Methods

The composites used in the experiments were produced by powder metallurgy (P/M) followed by hot extrusion [8]. AA6061 matrix alloy, blended with elemental powders, was shear mixed in a jar at 400 rpm for 1 hr. The chemical composition of the matrix material listed in Table 1 and its micrograph is shown in Fig 1a. This matrix alloy powder was then added with particulate fly ash (average size 10μm) in the weight fractions of 2,4,6,8 and 10% separately to obtain five composites. The fly ash was collected from National Thermal Power plant, Visakhapatnam, Andhra Pradesh, India whose chemical composition is given in Table 2 and its micrograph is shown in Fig 1b.

Table 1: Chemical composition of AA6061 matrix alloy

Element	Mg	Si	Cu	Sn	Al
Amount (wt.%)	1.0	0.6	0.25	0.1	Bal

Table 2: Composition of fly ash, wt.%

SiO_2	Al_2O_3	MgO	Fe_2O_3	TiO_2	LOI
56.40	30.40	2.01	8.44	2.75	1.8

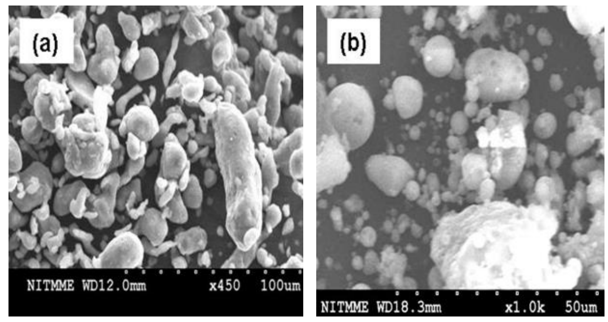


Fig 1. SEM pictrues of a) AA6061 matrix alloy powder b) Fly ash particles

Particle size was estimated by using computerized particle laser analyzer. The composite mixtures were then cold compacted in a tool steel die under a pressure of 345 MPa and sintered at 620°C in N_2 atmosphere for 4 hrs (optimized conditions). Finally, they were extruded at 500ºC with an extrusion ratio of 4:1 so that the final size of the extrusion was 16 mm in diameter. Wrought AA6061 rods with T6 condition and with a density of 2.7 g/cm³ were acquired. The chemical composition of wrought alloy is given in Table 3. The extruded P/M composite samples and wrought alloy samples were machined and faced using lathe to suit the friction welding requirements. The dimensions of the machined parts were 70 mm length and 15mm diameter each.

Table 3: Chemical composition of Wrought AA6061 alloy

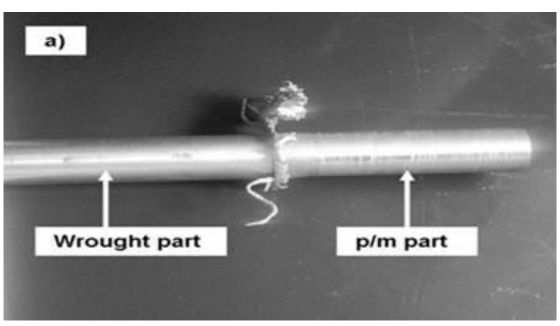
Element	Mg	Si	Cu	Cr	Fe	Mn	Al
Amount (wt. %)	0.97	0.65	0.22	0.2	0.7	0.1	Bal

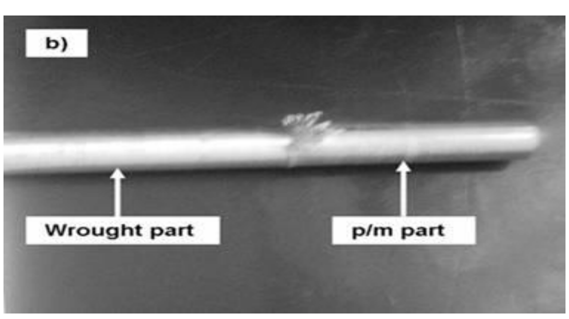
The compositions of P/M composite samples are given in table 4. These composites were friction-welded to wrought alloy samples in a direct drive friction welding machine under the conditions of rotation speed = 1500 rpm, friction pressure = 30 MPa, forging pressure = 60 MPa, forging time = 3s and burn off length was 3 mm. The photographs of the joints are shown in Fig 2. The welded samples were cut exactly at the center longitudinally.

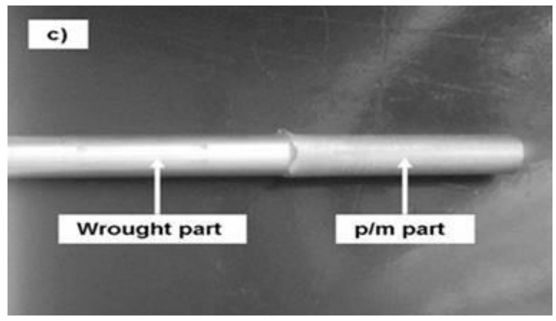
Table 4: The compositions of P/M composite samples

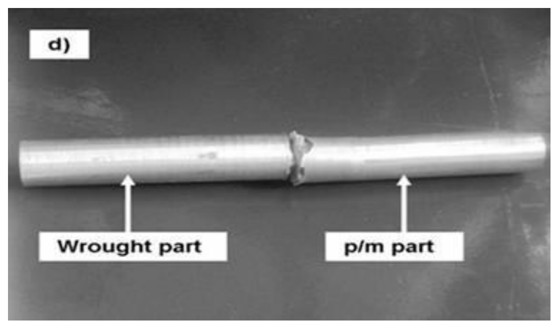
Composite Name	Composition
C1	AA6061-2 wt% fly ash
C2	AA6061-4 wt% fly ash
C3	AA6061-6 wt% fly ash
C4	AA6061-8 wt% fly ash
C5	AA6061-10 wt% fly ash

After cold mounting the specimens were polished for metallurgical studies according to ASTM standards. The microstructure of the weld interface was observed through Image Analyzer. The micro hardness of the welded samples was found out using Vickers hardness tester. Loads of 100g and 200g were used for reproducibility of the values. Indentations were made across the weld interface and also along the periphery of each sample. The integrity of the joints was examined by optical microscopy for the structural changes. Micro hardness profiles were measured across the welded joints both at the periphery and at axial region.









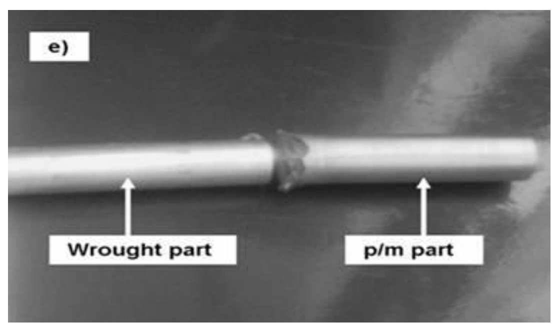


Fig 2. Photographs of joined couples of Wrought AA6061 and a) C1 b) C2 c) C3 d) C4 e) C5

3. Results and Discussions

3.1 Weldability

The composites, whose compositions listed in the Table 4, were joined to wrought alloy by rotational friction welding. Photographs of all the joints are shown in Fig 2. A typical friction welding process chart for the joint (wrought alloy and C1) is shown in Fig 3. The respective chart produced by the machine shows the variation of pressure, torque and deformation of the materials (burn-off) as the process proceeds. It can be observed from the Fig 3 that typically two peaks are seen for torque. The first shoot up of torque occurs due to resistance offered by the solid material.

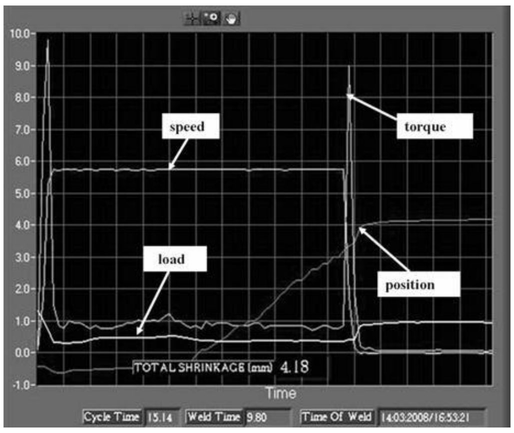


Fig 3. Friction welding parameter curves for C1 joint

As the material becomes plastic, the torque drops. Again at the end of the friction stage, when the spindle comes to rest, the material regains its solid properties. This will lead to the second peak in the torque curve. By comparing the charts of all welded samples, it has been observed that the total shrinkage was higher for C1 joint. This maybe explained due to the higher amount of flash released by the composite and more compaction occurring in the P/M part. More shrinkage could imply higher ductility in the material, thus resulting in more plastic deformation.

Generally in friction welding after the set burn-off length is achieved, the rotation of the spindle is stopped and the forge load is applied. Due to upsetting action of the forge load some more reduction in part's length occurs. Thus the final burn off length is calculated from process chart, shown in Fig 3, as the total shrinkage. The friction welding parameter curves given above indicated that the initial peak of the torque was similar for all burn off lengths but in forging stage, the end peak of the torque varied gradually with change in burn off length. The inferences made from the experiment are listed in Table 5.

Table 5: Experimental observations

Welded Samples	Observations
WA & C1	Satisfactory weld with maximum flash
WA & C2	Satisfactory weld with little flash
WA & C3	Satisfactory weld with less flash
WA & C4	Did not weld
WA & C5	Did not weld

WA =Wrought Alloy

3.2 Microstructure

The microstructure of the welded composite C1 with wrought alloy is shown in Fig 4. Microstructural evaluation of the friction welding joint revealed four distinct zones which were identified as base wrought alloy part, composite diffused region **A** on the wrought part side and plastically deformed region **B** on composite (p/m part) side and base p/m part. Another important feature concerning friction welding of composite materials was that the reinforcing particles close to bonding line change their size and distribution compared to the base material region [9]. This effect can be observed clearly from the micrographs. Also there is an effective diffusion of elements on either side of the joint so that no broad separation of composite and wrought structures has been found. North et al. [10] and North [11] justifies this phenomenon explaining that particle fracture occurs very early in the friction-joining operation and these particles are retained at the bond-line as a direct result of plasticized material flow. Particle fracture occurs as a direct result of severe plastic deformation at relatively low temperatures imposed in the very beginning of friction joining process [12].

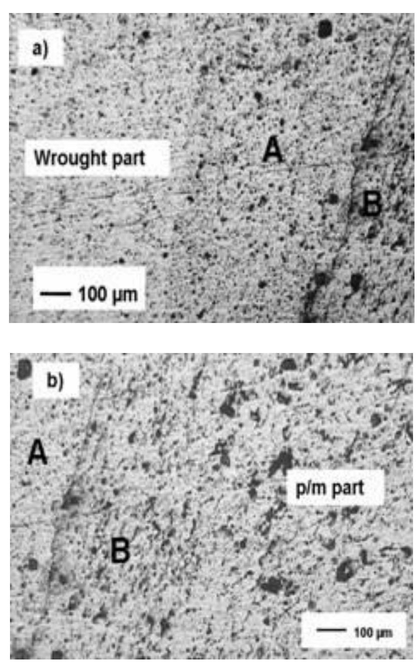


Fig 4. The optical micrographs of WA and C1 joint showing structural variation on a) wrought part side and b) p/m part side

3.3 Hardness

The hardness values obtained by conducting microhardness test across the weld interface both at central and along the periphery of the welded couples at two loads are given in tables 6 and 7.

Table 6: Hardness values (VHN) at load = 100g and Indentation spacing ≈ 10µm

Sample	Wrought alloy		Interface		P/M part	
	Away from the weld	Near to the weld	Cen-tral	Peri-phery	Away from the weld	Near to the weld
WA&C1	62.0	68.6	64.3	73.8	75.5	66.3
WA&C2	86.9	70.7	58.4	67.9	59.5	52.3
WA&C3	103.0	95.5	73.1	97.0	74.1	76.3

Table 7: Hardness values (VHN) at load = 200g and Indentation spacing ≈ 100µm

Sample	Wrought alloy		Interface		P/M part	
	Away from the weld	Near to the weld	Cen-tral	Peri-phery	Away from the weld	Near to the weld
WA&C1	63.2	60.9	61.4	79.3	74.5	63.2
WA&C2	88.0	72.0	63.2	69.6	65.7	59.5
WA&C3	99.8	93.0	71.1	96.3	76.0	77.6

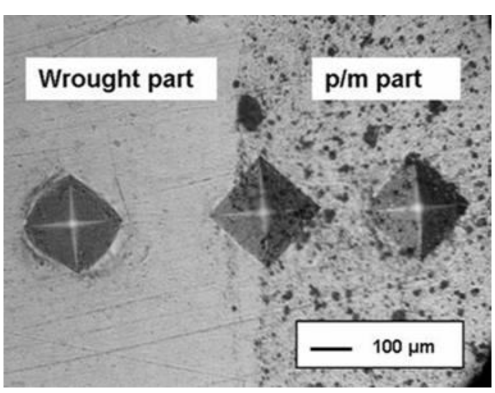


Fig 5. Vickers micro indentations across the weld interface.

Figure 5 shows the indentations made during hardness test of one of the samples across the weld interface. The hardness in the central region, exactly at the interface was lesser in magnitude (58-70 VHN) in comparison to that of the base materials. However, it was found to be higher at the periphery (70-99 VHN) which can be explained due to the higher magnitude of velocities experienced by the periphery regions of the rods than the central regions. The presence of voids at the interface of the joints due to insufficient welding might have reduced the hardness. This fact can be observed from the micrograph of the joint shown in Fig 6. In addition, it has been observed that the hardness lies in the same range at the interface in all the samples for both the loads.

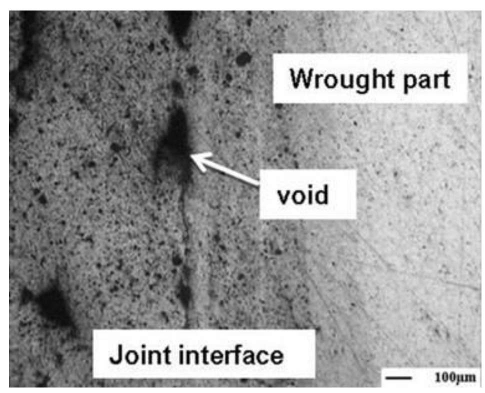


Fig 6. Optical micrograph showing voids in the weld interface.

4. Conclusions

In this work, the feasibility of joining of fly ash reinforced AA6061 composite with wrought AA6061 alloy by friction welding was investigated. The present study has demonstrated that fly ash composite could be joined to wrought alloy using friction welding technique.

The following conclusions can be presented:

- Fly ash may act as a lubricant and thereby reduces friction between the faying surfaces resulting in a poor weld. Thus the composites with 2%, 4% and 6 % fly ash content bonded properly and those with higher contents of 8% and 10% did not weld at all.

- The friction welding parameter curves illustrate that the total shrinkage is found to be higher for 2% fly ash composite in comparison to the others. This maybe explained due to the higher amount of flash released by the 2% composite. The amount of flash produced decreases as the fly ash content increases.

- The microstructural and hardness studies show that better bonding was achieved at the periphery compared to the axial region. This is attributed to the higher velocity which results in higher heat generation, aiding in better material mixing at the periphery of the welds.

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