Influence of nano fly ash on wear behavior of friction stir weld joints of Al6063/nano fly ash composites

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Abstract. The manufacturing industries attracted aluminium metal matrix composites (AMCs) to utilize in the modern spectrum of applications. Inexpensive particulate reinforced composites are exhibiting superior qualities at reduced costs. Fly ash is an industrial waste that can be adopted as reinforcement, particularly for aluminium matrix materials. Friction stir welding (FSW) is best suitable to weld aluminum-based materials. In this work, the Al6063/nano fly ash composites with 0, 1, 2, and 3% wt. of nano fly ash were fabricated through ultrasonic-assisted stir casting. Consequently, FSW joints were obtained for the fabricated composites by considering rotational tool speed and transverse tool speed as welding parameters. Wear analysis carried on weld beads of composites through the pin on disc equipment. The nano fly ash addition in the composites results in increased wear resistance in the FSW joints. Higher wear resistance was achieved with increased reinforcement inclusion. Increased tool feed rate also enhances the wear resistance of FSW joints. It can be concluded that the nano fly ash particles are the most influential in improving the mechanical properties of the AMC weld beads, and FSW is the better option to weld aluminum composites.

Keywords: Fly ash, Composites, Friction Stir Welding, Wear

1. Introduction

Manufacturing ease of particulate composites enhanced the demand for lightweight low-density aluminium metal matrix composites (AMCs). Various sectors like aerospace, automotive, transportation and sports goods, etc. utilize inexpensive material reinforced AMCs for its counterparts due to enhanced isotropic properties at low-cost with production ease. Boron carbide reinforcement particles improved the properties of aluminum-based composites through the stir casting route. Different weight percentages of particles were reinforced into the melt, and higher properties were achieved with increased reinforcement material [1, 2]. Nano-sized reinforcements provide better properties to the aluminium based composites due to their increased surface area [3]. The fly ash is viable reinforcement material to produce AMCs through stir casting technique, and improved properties can be achieved [4, 5, 6]. Expensive reinforcements are beneficially replaced by inexpensive fly ash to produce AMCs of aluminium 6063 alloy as matrix material [7]. FSW is a
relatively new joining method that provides better welding joints faster and a potential candidate to join AMCs without any defects associated with traditional fusion welding processes [8].

The FSW parameters like rotational tool speed and tool transverse speed have significant effect on the weld bead characteristics of the aluminium matrix-based composites [9]. The FSW joints’ mechanical properties are improved by the proper selection of FSW parameters [10, 11]. The grain refinement of the weld bead during the FSW process leads to enhanced properties of the weld joints [12]. The clusters of fly ash particles were collapsed due to tool rotation, and uniform distribution of reinforcement achieved [13]. The FSW tool probe profile is another important parameter that influences the weld quality of the FSW joint [14]. Dissimilar materials can be welded with relative ease with selecting proper materials on advancing and retrieval sides [15].

In the present work, it was proposed to fabricate Al6063/nano fly ash composites through stir casting and to weld the fabricated composites by FSW. The investigation carried to establish the influence of reinforcement material on wear behaviour of the FSW joints of Al6063/nano fly ash composites. The wear loss at different weight percentages of nano fly ash and FSW parameters was studied.

2. Methodology

The FSW machine used in the experimentation was shown in figure 1. The nano fly ash with 0, 1, 2, 3% weight was used as reinforcement material to produce Al6063/nano fly ash composites through stir casting [2]. The stirring speed of 250 rpm was considered to reinforce pre-heated nano fly ash into the Al6063 alloy melt at 670°C. Argon gas shielding was provided during the casting process, and an ultrasonic probe with 20 kHz frequency was immersed in the melt to disperse the fly ash particles in the primary aluminium [4]. The molten mix was poured into a pre-heated mould to cast Al6063/nano fly ash composite plates. Hence the fabricated composite plates were welded using an FSW machine by considering 800, 1000, 1200, 1400 rpm tool rotational speeds and 50, 60, 70, 80 mm/min tool feed rates as FSW parameters [8]. The center of the weld beads was considered for wear analysis of the FSW joints. Pin on disc apparatus was used to test the wear resistance of the FSW joints.

3. Results and Discussion

The FSW joints of Al6063/nano fly ash composites were tested in a pin-on-disc wear testing machine for wear loss. The constant sliding speed of the disc 200 rpm & wear load 20N were considered for all weld beads of Al6063/nano fly ash composites specimens. Wear rate was obtained for weld beads of
Al6063/nano fly ash composites containing 0, 1, 2, and 3%wt. of nano fly ash. The wear resistance on FSW joints of Al6063/nano fly ash composites was shown in figures 2 to 5. It was observed that the wear resistance against the frictional force on the FSW joints of Al6063/nano fly ash composite samples was decreased with the increased %wt. of nano fly ash reinforcement. The amount of nano fly ash inclusion, tool rotational & traverse speeds influence the wear resistance of FSW joints.

3.1. Effect of nano fly ash on wear resistance of FSW joints

Lower wear resistance was observed in weld bead of pure Al6063 alloy samples compared to weld beads of Al6063/nano fly ash composites with different %wt. of nano fly ash, as shown in figures 2 & 3. It was observed that the resistance offered against wear loads increased with an increase in the addition of nano fly ash. The amount of wear loss was decreased drastically with an increased %wt. of nano fly ash reinforcing particles in the Al6063 alloy. The nano fly ash particles reduce the grain size, which causes reduced dactility in the weld beads with increased brittleness. The weld beads of pure Al6063 alloy exhibit higher wear loss than weld beads of nano fly ash, reinforced composites [8].

Figure 2. Influence of nano fly ash on wear resistance of FSW joints of Al6063/nano fly ash composites at different FSW tool rotational speeds

Figure 3. Influence of nano fly ash on wear resistance of weld beads of Al6063/nano fly ash composites at different FSW tool feed rates

Figures 2 and 3 show the variation of wear loss on weld beads of Al6063/nano fly ash composites with an increase in %wt. of nano fly ash at constant wear load 20N and 200 rpm disc speed. The decrease in wear loss was observed with increased nano fly ash reinforcement and a comparative increase in wear loss found at higher wear loads.
3.2. Effect of tool rotational speed on wear resistance of FSW joints

An increase in wear loss was observed in the weld beads of Al6063/nano fly ash composites with an increase in tool rotational speed, as shown in figure 4. The FSW tool rotational speed was responsible for generating enough heat input to the weld zone of Al6063/nano fly ash composite, which leads to dynamic recrystallization of microstructure due to the stirring of material during FSW tool rotation. The fine microstructure achieved due to the FSW tool's rotation, which improves the wear resistance and comparatively mixed trend in wear resistance, was observed in the weld beads of Al6063/nano fly ash composites with an increase in tool rotational speed.

The continuous decrease in wear loss was observed with increased tool rotational speed at lower tool feed rates and increased wear loss obtained at higher feed rates. The material in the stir zone converted to soft material due to high temperatures developed by the rotating tool, and proper mixing of the material was carried through the rotating tool's stirring action. Homogeneity achieved in the stir zone of weld bead material through the rotating tool leads to the enhanced wear resistance of the FSW joint of Al6063/nano fly ash composites.

![Figure 4](image)

Figure 4. Influence of FSW tool rotational speed on wear resistance of weld beads of Al6063/nano fly ash composites at different %wt. of nano fly ash

3.3. Effect of tool feed rate on wear resistance of FSW joints

The FSW tool feed rate influences the wear resistance on weld beads of Al6063/nano fly ash composites, as shown in figure 5. The material transfer from the advancing side to the retrieving side was handled by tool movement along the weld line. Slow tool feed rate develops enhanced heat inputs in the stir zone, which leads to large TMAZ & coarse microstructure results in poor wear resistance.

![Figure 5](image)

Figure 5. Influence of FSW tool feed rate on wear loss of weld beads of Al6063/nano fly ash composites at different %wt. of nano fly ash
A relative decrease in wear resistance was observed in the weld beads of Al6063/nano fly ash composites with increased tool feed rates. The base material of Al6063/nano fly ash composites exhibit lower wear resistance than weld beads of Al6063/nano fly ash composites due to the composites' increased brittleness. The hard nano fly ash particle inclusion, reduces the wear loss on account of increased hardness & brittleness and increase in tool rotational & traverse speeds impart mixed effect on the wear loss of the weld beads of Al6063/nano fly ash composites.

4. Conclusions
The following conclusions were drawn from the investigations found in the wear analysis on FSW joints of Al6063/nano fly ash composites

1. The reinforcement nano fly ash highly influenced the wear resistance on the FSW joints in the Al6063/nano fly ash composites.
2. Wear loss was decreased in the FSW joints of Al6063/nano fly ash composites with an increased weight percentage of nano fly ash.
3. The wear loss on weld beads of Al6063/nano fly ash composites increased with an increase in rotational tool speed and tool feed rate.
4. The minimum wear loss on FSW joints of Al6063/nano fly ash composite specimens were 0.7845 mm³/kg obtained at tool feed speed 80 mm/min, rotational tool speed 800 rpm 3% wt. of nano fly ash.

Future Scope:
1. Weld bead properties of Al6063/nano composites could be compared with other welding techniques.
2. The Al6063/nano fly ash composites could be welded by considering other FSW process parameters.

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