Hybrid composites of Al5083- graphene - fly ash by friction stir processing: machining studies

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Abstract. Hybrid composites are the modern engineered materials which exhibit presence of two or more than two reinforcements in a matrix. In the current work, Al5083 - Graphene and fly ash were dispersed in Al5083 alloy to develop hybrid composites by friction stir processing (FSP). Microstructural studies revealed band structures in the stir zone. Increased hardness was measured for the composites due to the grain refinement resulted from FSP and also due to the presence of reinforcements (Graphene and fly ash). The variations within the measured hardness values were observed as higher for the composites due to the variations in the concentration of the Graphene and fly ash in the stir zone. Lower cutting forces were recorded for the composites during drilling experiments conducted on the base materials and the composites. Here, the role of graphene as solid lubricant can be noticed as an important factor. The overall results demonstrate that Al5083-Graphene-fly ash hybrid composites can be successfully developed by FSP which exhibit better mechanical properties and machining behaviour.

Keywords: Machining, composites, FSP, hardness, drilling

1. Introduction

Friction stir processing (FSP) is a solid state processing route can be used to develop composites without melting the materials [1]. Recently, surface metal matrix composites (MMCs) are becoming a promising choice for various engineering applications where material properties are altered at the surface itself without altering the core [2]. Composite materials exhibit better properties compared with their constituting phases. Several properties such as mechanical, wear and corrosion resistance, machining behaviour are influenced by the type of dispersing phase, size, shape and fraction of the dispersing reinforcement [3]. Hybrid composites contain more than one dispersing phase and they exhibit excellent properties. Each of the reinforcements serves a special purpose in the hybrid composites and the combined effect of these reinforcements promotes performance of the composite particularly when subjected to extreme environment conditions during the application.
It was reported in the literature that Al7075 alloy with B4C and MoS2 reinforcements added by friction stir processing (FSP) has demonstrated improved mechanical properties and wear properties. Particularly, addition of MoS2 reduced the coefficient of friction due to the lubrication effect attained in the hybrid composite [4]. Zayed et al. [5] also produced hybrid composites of Al5083 by dispersing SiC and Al2O3 reinforcements. Higher hardness (up to 30%) was observed for the hybrid composite and also higher wear resistance was noticed with the composite that contains 50% SiC and 50% Al2O3. Heiderpour et al. [6] also developed surface composites by dispersing Al2O3-TiO2 into Al5083 matrix by FSP. Better mechanical properties were measured for the hybrid composite due to the dispersed phases. Additionally, coefficient of friction was measured as decreased and wear resistance was observed increased for the hybrid composite. Machining operations are important group of manufacturing processes which must be required to develop structures in various applications. Machining of composites is difficult due to the presence of combined phases compared with single phase materials. The machining characteristics of composite material depend on the type of reinforcement and the amount of dispersing phase. Due to the addition of graphene into Al5083 alloy, lower cutting forces were recorded for the composite which was claimed to the solid lubricant effect imparted into the composite by adding graphene [7].

Al5083 aluminum alloy that contains magnesium as the main constituting alloying element is widely used in marine applications compared with its relatively better corrosion resistance among all other aluminium alloy [8]. On the other side, Graphene; an isotope of carbon that has reported with high potential as advanced material with excellent properties. [9]. Fly ash is a waste product results from the coal burning in the thermal power plant which contains SiO2 and Fe2O3 phases. In the current research work, hybrid composites made of Al5083 – graphene – fly ash were prepared by FSP route. The effect of reinforcements on microhardness and machining behaviour of the composite were investigated.

2. Materials and methods

Al5083 aluminium alloy sheets (Venku metals, Hyderabad, India) of 100 X 100 X 5 mm size were used as base material. Graphene powder was procured from Nano Wings, Khammam, India. Fly ash was obtained from Dr. Narla Tataro Thermal Power Station, Vijayawada, India. Equal amount of graphene and fly ash by wt.% was mixed and used as reinforcement to develop Al5083 based composite by FSP. The workpieces were placed on the worktable of a universal milling machine (Fig 1(a)). The workpieces were machined with a groove of 1 mm (width) and 2 mm (depth) and the groove was filled with the reinforcement mixture. Initially, the groove was subjected to surfacing by using an FSP tool that has no pin to avoid the escape of the reinforcement. The detailed procedure has been explained in our earlier work [7]. The surface treated workpieces were then subjected to FSP at 1400 rpm tool rotational speed with a tool travel speed of 25 mm/min. In the present study, the spindle of the milling machine does not have the vertical axis tilting facility and hence, the tool tilt angle was assumed to be 0 degrees. FSP process was carried to develop the surface MMCs. Fig 1 (b) shows the photograph of composite preparation by FSP.

Specimens were cut from the FSPEd samples across the processed zone and also from the base materials for the microstructural studies and micorahrdness measurements. Initially, the samples were polished by using coarse graded polishing paper and then followed by fine graded polishing papers. Then fine graded alumina paste was used to complete the polishing process. The polished specimens were then cleaned and chemically etched by using Keller’s reagent. Microstructures were recorded by optical microscope (make: Leica, Germany) for both the samples. The hardness of the samples was assessed by Vickers indentation method (Omni Tech, India) by applying 100 g load. Drilling 6 mm holes was done for base alloy and the composite to study the machinability. A load cell (Kestler, Germany) was used to measured the cutting forces. Drilling experiments were done by using a 6 mm
dia drill bit at two different rotational speeds and two feed rates without any lubricant. While drilling the composites, holes were produced in the middle of the stir zone. Measurement of cutting forces was started when the tool tip touched the workpiece surface and continued for a few seconds.

![Photograph of vertical milling machine and developing surface composites by FSP.](image1)

3. Results and discussion

The FSPed regions in the composite were identified with defect free zone. The microstructures of the samples are shown in Fig 2. Al5083 alloy contains solid solution grains and intermetallic at the grain boundaries as shown in Fig 2 (a). Combination of black and white bands was observed in the composite. Due to the material flow and mixing within the stir zone of FSPed composite, the reinforcements are distributed in the nugget zone Fig 2 (b). This is similar to the earlier findings where bands of material flow can be seen [10]. In the present work, Graphene and fly ash reinforcement has been incorporated within the matrix and the combination of dark and bright regions were appeared in the stir zone. The distributed phases influence the bulk properties of the composite. FSP process also introduces grain refinement. The mechanism behind grain refinement has been explained elsewhere [1]. Due to the dynamic recrystallization during FSP, smaller grains are produced.

![Optical microscope images: a) Al5083 and b) composite](image2)
From the microhardness measurements, higher hardness values were observed for the composite. Fig 3 shows the average hardness values and the hardness distribution. From the hardness data, composite was found with higher hardness compared with the base alloy. Furthermore, the distribution of the hardness within the composite was also observed as higher within the composite. The presence of reinforcement and also due to the smaller grains, the hardness values were observed as higher in the composite. The increased hardness certainly influences the machining behaviour of the composite.

![Microhardness measurements](image)

**Fig 3** Microhardness measurements: a) average hardness values and b) hardness distribution of the samples.

![Cutting force profiles](image)

**Fig 4** Cutting force profiles of the composites obtained from the drilling experiments: a) 120 rpm with 42 mm/min feed, b) 120 rpm with 15 mm/min feed, c) 300 rpm with 42 mm/min feed and d) 300 rpm with 15 mm/min feed.

Fig 4 shows the cutting force profiles of the compotes at different combinations of machining parameters during the drilling operations. It can be seen that the increased rotational speeds has decreased the cutting forces. It is true that the heat generation is higher with the increased rpm. Increased heat within the machining zone reduces the cutting forces. The mean cutting forces observed
in the composite were observed as slightly higher compared with the base alloy [9]. The incorporated Graphene and fly ash combination increased the material resistance against the cutting edges of the drill bit. Presence of different phases within the composite influenced the cutting forces and hence, the variations within the cutting forces were also observed as higher in the composites. The results from the machining studies of the composites confirm the influential role of added reinforcements on improving the mechanical properties and further machinability.

4. Conclusions

In the current research work, Al5083-graphene-fly ash composites were produced by FSP. No defects were observed in the stir zone of FSPed composite. Increased hardness was noticed for the composite due to the grain refinement and reinforced graphene and fly ash. Drilling experiments demonstrated the important role of added reinforcement to increase the cutting forces in the composite compared with the base alloy. Higher variations in the cutting forces were also noticed in the composites which is due to the added graphene and fly ash. The results suggest that by incorporating graphene and fly ash into Al5083, structures with higher hardness and improved machinability can be produced.

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