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Effect of tool plunge depth on reinforcement particles distribution in surface composite fabrication via friction stir processing

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ABSTRACT

Aluminium matrix surface composites are gaining alluring role especially in aerospace, defence, and marine industries. Friction stir processing (FSP) is a promising novel solid state technique for surface composites fabrication. In this study, AA6061/SiC surface composites were fabricated and the effect of tool plunge depth on pattern of reinforcement particles dispersion in metal matrix was investigated. Six varying tool plunge depths were chosen at constant levels of shoulder diameter and tool tilt angle to observe the exclusive effect of plunge variation. Process parameters chosen for the experimentation are speed of rotation, travel speed and tool tilt angle which were taken as 1400 rpm, 40 mm/min, and 2.5°respectively. Macro and the microstructural study were performed using stereo zoom and optical microscope respectively. Results reflected that lower plunge depth levels lead to insufficient heat generation and cavity formation towards the stir zone center. On the other hand, higher levels of plunge depth result in ejection of reinforcement particles and even sticking of material to tool shoulder. Thus, an optimal plunge depth is needed in developing defect free surface composites.

1. Introduction

It is common knowledge that aluminium alloys are materials of choice for various structural applications in aerospace, defence, automobile, and marine industries owing to their lower weight density, higher strength to weight ratio and higher corrosion resistance [1]. However, stiffness and strength of some of these alloys is not adequate for some structural purposes thereby necessitating requirement of suitable reinforcement. Aluminium metal matrix composites (AMMCs) exhibit improved metallurgical, mechanical, and tribological characteristics [1–3]. Metal matrix composites (MMCs) can be synthesized using various techniques like laser technique [4], electron beam irradiation [5], plasma spraying [6], casting [7], mechanical alloying [8], etc. Most of these techniques are based on the principle of liquid phase processing which leads to formation of intermetallic reactions and undesirable phases between base metal (BM) and reinforcement [9,10]. In view of the these shortcomings, employment of a process for composite fabrication which can be conducted below melting points of the matrix material can go a long way to improve and consequently optimize the MMCs design and fabrication issue. Friction stir processing (FSP) offers an excellent choice for development of surface composites (SCs) of metal alloys [11].

FSP is a newly developed solid state processing technique which is a variant of friction stir welding (FSW) process initiated at The Welding Institute (TWI) in 1991 [12]. In its simple operation, a non-consumable rotating tool with an exclusively designed pin and shoulder plummets into a BM plate and is made to traverse in predefined direction to cover up the desired realm. Softening and plasticization of BM occurs owing to frictional heat generation between rotating tool and the workpiece [10,13]. As the tool traverses, the material is forged beneath the shoulder resulting in the processed region. The work on composite fabrication using FSP, was started with the maiden work done by Mishra et al. [11]. In this work, composites with Al 5083 alloy as BM and SiC as reinforcement were fabricated. A maximum microhardness of 173 Hv was achieved using 27 vol % of SiC particles which is almost double of the microhardness of BM (85 Hv). Numerous research studies on composite fabrication are reported since the initial work by Mishra et al. and a number of research projects are still in progress. Initially, FSP was used to modify aluminium alloys but with the passage of time FSP has gained a shining role in developing composites of

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other alloys like magnesium [14], copper [15], titanium [16] and even steel [17].

The addition of hard phase reinforcement particles make MMCs brittle [18]. In many engineering applications, the service life of materials mainly depends on the surface properties of materials. Therefore, SCs are mostly prepared by combining a ductile metallic matrix with hard ceramic reinforcement up to a desired depth. The soundness of SCs apart from other aspects mainly depends on optimal selection of process parameters. Several authors [19–22] investigated the effect of various process parameters in developing SCs. Dolatkhah et al. [19] evaluated the effects of rotational and travel speeds, FSP pass count and size of reinforcement particles in fabrication of Al 5052/SiC composites. They reported that speed of rotation and FSP pass counts have major effect on uniform dispersion of reinforcement particles. Similarly, Zohoor et al. [21] investigated the effects of speed of rotation, FSP pass count and size of reinforcement particles in the fabrication of AA5083/Cu composites. They reported that best powder dispersion was achieved with four FSP pass count. Devaraju et al. [20] reported that speed of rotation and type of reinforcement particles have a strong impact on wear, microhardness and tensile strength of fabricated AA 6061/SiC + Al_2O_3 hybrid SCs. Reddy et al. [23] investigated the effect of reinforcement particles (B_4C and SiC) on the wear and mechanical properties of fabricated SCs.

Majority of published research mainly focuses on the evaluation of effects of process parameters, namely tool rotation speed, travel speed, FSP pass count and tool dimensions on the surface and mechanical properties of fabricated SCs. Also, reinforcement particle type and its size remains center of research focus. Literature also report that the SCs imperfections can be reduced by accurate prediction of these process parameters. In addition to these process parameters, correct decision on suitable tool plunge depth (TPD) is also essential to achieve defect free and uniformly distributed SCs. Interestingly, TPD is not changed in-situ after the process has started and investigations on effect of TPD over distribution of reinforcement particles in SCs fabrication are very few. Present work investigates the effect of varying TPD on SCs fabrication by keeping all other parameters constant at optimized level. Six levels of TPD from 0.10 mm to 0.35 mm in steps of 0.05 mm were used to investigate and determine the role of plunge depth on material flow, uniformity of powder dispersion and tendency of defect formation. Additionally, proper care has also been taken to minimize the adverse effects originating from factors like machine vibrations, non-uniformity of BM and backing plate thickness which is normally not paid enough attention.

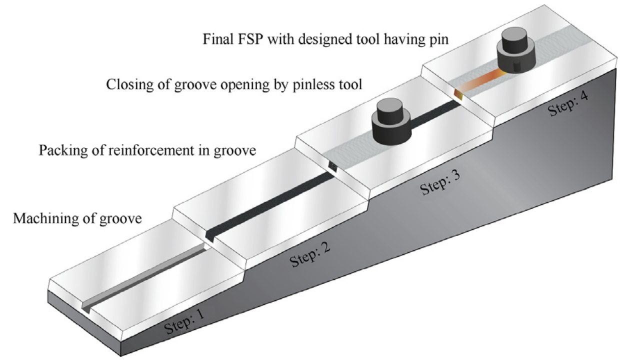
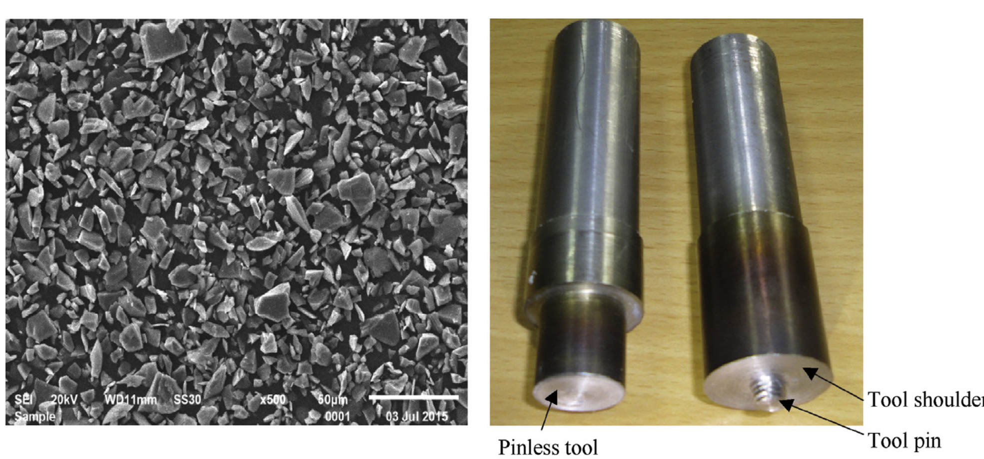


Fig. 2. Steps in SCs fabrication using groove technique.

2. Materials and methods

In this study, AA 6061-T6 alloy sheet of 5 mm thickness was used as base material. AA 6061-T6 is commonly used in aerospace, defence and marine sectors due to its light weight, good strength to weight ratio and good corrosion resistance [24,25]. The composition (weight %) of BM is 0.85% Mg, 0.68% Si, 0.22% Cu, 0.07% Zn, 0.05% Ti, 0.032% Mn, 0.06% Cr and remaining aluminium. FSP samples of size 60 mm wide and 200 mm long were machined from the sheet. SiC powder having average particle size of ~10 μm was used as reinforcement (SEM image is shown in Fig. 1(a). Six such FSP samples were prepared by cleaning them with acetone and machining square grooves of 2 mm width and 2 mm depth along the length. Subsequently, SiC powder was filled and compressed in the groove and upper surface (open) of the groove was closed by means of a tool (15 mm shoulder diameter, see Fig. 1(b) without a pin in order to prevent the sputtering of powder during FSP. Finally, FSP was performed on a retrofitted vertical milling machine as shown in Fig. 3 using a tool with a threaded cylindrical pin. The tools utilized for FSP were made of H-13 tool steel (see Fig. 1(b)). Steps involved in SCs formation using groove technique are schematically illustrated in Fig. 2. The values of process parameters such as speed of rotation, traverse speed and tilt angle of tool (see Table 1) were chosen by trial experiments performed on AA6061



(a) SEM image of SiC powder (b) Tools used during FSP

Fig. 1. Showing images of SiC powder and tools used; (a) SEM image of SiC powder; (b) Tools used during FSP.