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Effect of post-process artificial aging treatment on tensile properties of SiC particle reinforced AA6061-T6 surface metal matrix composite fabricated via Friction stir process

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Abstract. This paper reports on studies of the influence of post-process artificial aging (PPAA) treatment on tensile properties of SiC particles reinforced AA6061-T6 surface metal matrix composite via Friction stir process (FSP). In FSPed composite the SiC particles were uniformly distributed in stir zone without any defect and exhibited higher micro hardness than as-received Al alloy. FSPed composite was exhibited lower tensile properties compared to as-received Al and after the application of post-process artificial aging treatment the tensile properties were increased around 50% than the untreated material at 170^{o}C for soaking period of 16hr.

Keywords: Friction stir processing, Surface metal matrix composite, Tensile properties, Post-process artificial aging

1 Introduction

Metal-matrix composites (MMCs) are represent a new class of structural materials as conventional metals and alloys approach their developmental limits and with proper processing, the reinforcement of a metal matrix with various particulate reinforcements can yield MMC with significantly improved properties (e.g. lower density, higher specific modulus and higher specific yield strength)[1]. High strength to weight ratio, high thermal conductivity, and corrosion resistance has made Aluminum alloys very popular structural material [2-6]. The addition of ceramic reinforcements (SiC & Al_2O_3) raised performance limits of the Aluminum alloys especially in wear resistance and hardness; it has been used in automotive and aerospace industries [7-9].

Friction stir processing is a recent technology for surface modification and developing surface and bulk reinforcement MMCs and it is an adaptation of friction stir welding and based on the concept of friction stirring. The stirring action and frictional heat generated by the FSP tool can be used to distribute ceramic particles as reinforcement on the surface of light metals like aluminum, copper and magnesium alloys. Wei Wang et al [12] attempted FSP to produce bulk SiC particles reinforced 5A06Al metal matrix composite and concluded that SiC particles were uniformly distributed in stir zone, obtained excellent bond with base metal and also the FSPed composite exhibited higher micro hardness compared to untreated material. Essam R.I. et al [13] applied FSP to prepare hybrid composites by varying the volume percentage of reinforcements (A 1050-H24/SiC, Al_2O_3). It was observed that the reinforcements were distributed almost homogenously over the nugget zone without any defects except small some voids forming around the Al_2O_3 particles. Hybrid composite (having 20% Al_2O_3 + 80% SiC) was exhibited high hardness and superior wear resistance. Mohesn Barmouz studied that Cu/SiC metal matrix composite was produced via FSP and shown that MMC layer produced by FSP had lower strength and elongation than pure copper while a remarkable elongation for FSPed specimen without SiC particles [14]. Jun Qu et al. [15] have prepared aluminum 6061 sub micro size ceramic particles (SiC&Al_2O_3) surface composite via FSP to improve surface hardness and wear resistance without sacrificing the ductility and found that the FSP-formed composite surface exhibited substantial friction and wear reduction by 40% and 90% respectively, when rubbed against a bearing steel and also post-FSP heat treatment afforded further enhancement of wear resistance.
K.Elangovan et al [16] reported that the post-weld heat treatments (Solution treaded, Solution treaded and Aged and artificially aged) were introduced among these artificially aged treatment was found to enhance the tensile properties of the Friction stir welded AA6061 aluminum alloy joints.

It is commonly known that the preparation of surface metal matrix composites (SMMCs) by conventional fusion techniques such as thermal spraying and laser beam lead to deteriorate the properties. In this case SiC may react with the molten aluminum to form brittle Al_4C_3, no refinement of grain size and reinforcement and also bonding problem between SiC and Al alloy [17, 18]. Considering these problems, friction stir processing seems to be a good technique for successful preparation of SMMCs. In the present work, an attempt was made to enhance tensile properties by applying post-process artificial aging (PPAA) treatment of SiC particles (20µm in average size) reinforced AA6061-T6 Friction stir processed (FSPed) surface metal matrix composite.

2 Experimental procedure:

Commercial SiC particles (average size: 20µm) and AA6061-T6 rolled plate (thickness: 4mm) were used to fabricate composite by FSP and the chemical composition of AA6061-T6 shown in Table 1. The SEM image of as-received SiC_p was shown Fig.7.

Table 1. Typical chemical composition of the alloy AA6061-T6

Element	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Others
Amount (Wt %)	Bal	0.8-1.2	0.4-0.8	Max. 0.7	0.15-0.40	Max. 0.25	Max. 0.15	Max. 0.15	0.04-0.35	0.05

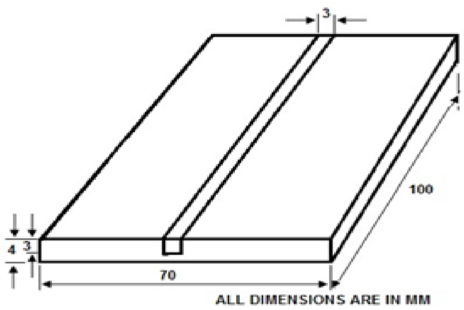

Fig. 1. Schematic diagram of Al alloy plate

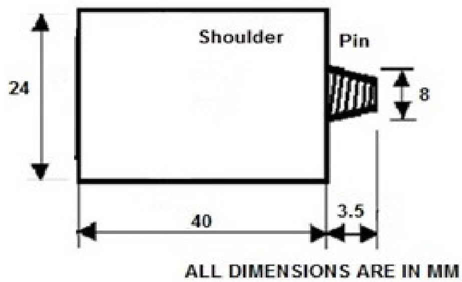

Fig. 2. Schematic diagram of FSP Tool

A groove was prepared with dimensions of 3mm width and 3mm depth on the Al alloy as shown in Fig1. The groove was placed at the edge of pin in the advancing side and 2mm far away from the center line before processing. The FSP tool was made of H13 tool steel and had a cylindrical shape shoulder (φ24mm) with a screwed taper pin profile (φ8 mm) as shown in Fig.2. In the beginning of the FSP, the groove was filled with SiC particles and covered with a modified FSP tool that only had a shoulder without pin to prevent the SiC particles from being displaced out of the groove. Then the tool penetrated into the plate until the shoulder's head face reached 0.25mm under upper surface for stirring the stir zone and producing composite. The FSP parameters such as tool rotational speed and travelling speed were 1400rpm, 40mm/min respectively. The tool was tilted an angle of 2.5^0 and constant vertical load is about 5KN is applied. The process is carried out on a vertical milling machine (VMM) (Make HMT FM-2, 10hp, 3000rpm) and tool arbor as shown in Fig.3 & 4 respectively. For various testing the required dimensions of the specimens were cut from the region under the tool shoulder (stir zone) by using wire EDM. The distribution of the dispersed SiC_p was observed by scanning electron microscopy (SEM) in the stir zone of FSPed composite. Micro hardness properties were measured on the cross section of the FSPed composite perpendicular to the processing direction by using Vickers hardness tester utilizing a 100g load for 15 s. Only tensile samples were subjected to PPAA treatment at 170^0C for with different soaking periods of 4, 8 and 16 hr [16]. Tensile testes of as-received Al alloy, the FSPed composite and PPAA FSPed composite were determined at ambient temperature and two tensile specimens were machined from each sample and the average was reported. Fig. 6 shows the schematic diagram of the tensile test specimens.

Fig. 3. Picture of Verticle Milling Machine

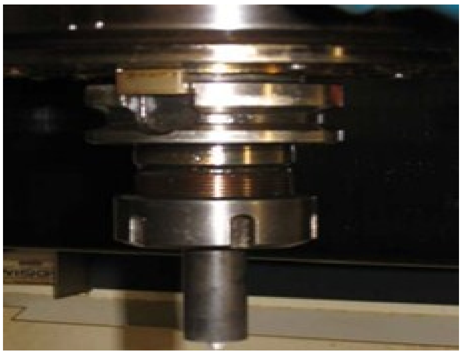

Fig. 4. Picture of VMM Tool Arbor

Fig. 5. Macrostructure of FSPed composite

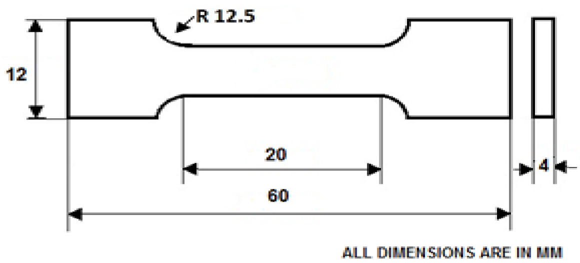

Fig. 6. Schematic diagram of tensile test specimen

3 Results and Discussions

3.1 Microstructure

After the AA 6061-T6/SiC_p was fabricated by FSP, microstructure at cross-section of stir zone was observed by SEM (the parameters are 1400rpm and 40mm/min) and microstructure was shown in Fig.8. In such higher rotational speed and lower travel speed enough heat input was produced and the tool also supplied shear force to make the SiCp flow and disperse in stir zone [12]. It is seen that the reinforcement particles distributed uniformly in the nugget zone without any defect. It observed that breaking and some refinement of SiC particles in stir zone. This was due to the stirring action generated in pass by the rotated tool. There is no reaction between SiC_p and the base metal was observed because of FSP is a solid-state process, and peak temperature during process was below the melting point of base materials.

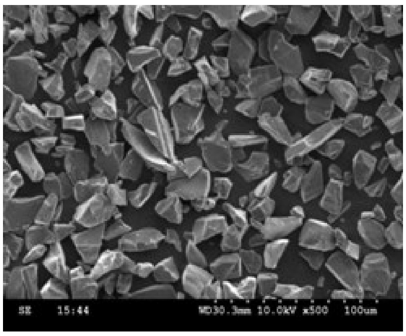

Fig. 7. SEM image of as-received SiC particles

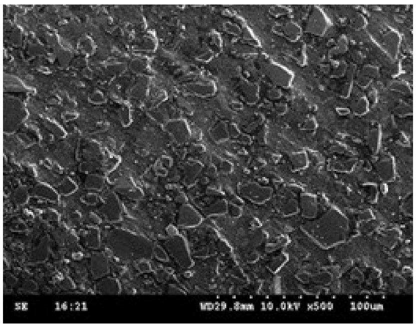

Fig. 8. SEM microstructure of FSPed composite

3.2 Micro hardness behavior

Micro hardness behavior was measured over the length of stir zone on the cross section of the FSPed composite perpendicular to the processing direction and graphically represented in Fig.9. It observed that micro hardness of the FSPed composite at nugget zone is higher than that of the as-received Al alloy which was measured to be 104Hv. It is considered that higher value was obtained due to the pinning effect and presence of hard SiC particles. At lower traverse speed SiC particles were well separated and consequently an intense pinning effect occurs in stir zone leading to a further enhancement of micro hardness values.

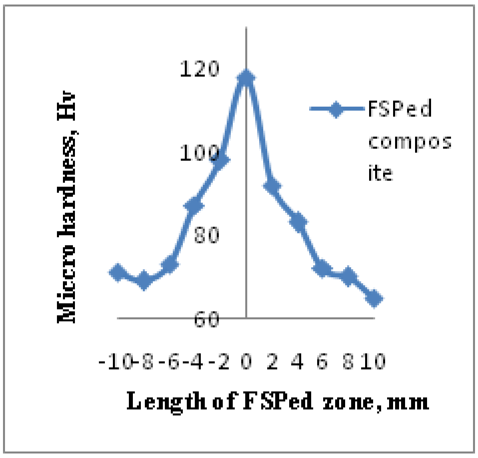

Fig. 9. Micro hardness values of the FSPed composite

3.3 Tensile test results

Table 2. Tensile properties of FSped composite

Tensile properties	AA6061-T6	FSPed composite	FSPed composite with Artificially aged (Hr)		
			4	8	16
UTS-MPa (Ultimate tensile strength)	293	104	86	56	158
YS-MPa (Yield strength)	271	98	65	38	142

Tensile properties are including yield strength (YS) and ultimate tensile strength (UTS) of the as-received Al alloy, FSPed composite (with also PPAA treatment) shown in Table 2. It can be seen that yield and ultimate strength of the specimen FSPed composite with SiC particles decreased in comparison with as-received Al alloy. According to the mentioned results in micro hardness behavior, this phenomenon could be because of remarkable annealing softening which occurred during FSP and which may be concluded as presence of hard SiC particles that enhances the hardness and consequently reduces the tensile properties. Moreover, the presence of SiC particles could restrict the grain boundary sliding. PPAA treatment was applied because the precipitates of the as-received Al alloy are completely dissolved in matrix during the FSP so there is no need to again solution treatment mentioned in literature [16]. The tensile properties of FSPed composite were increased with increasing aging/soaking period and found that 50% of tensile properties were increased at 170^{0}C with 16hr of soaking period this due to the considerable increase in the density of spherical and needle shaped Mg2Si precipitates and absence of precipitate free zone with a dislocation density [16].

4 Conclusions

The SiC particles were dispersed in AA6061-T6 successfully by the FSP technique. The micro structure, micro hardness and tensile properties (with PPAA) were evaluated. The SiC particles were distributed uniformly inside the nugget zone without any defect. Micro hardness of FSPed composite is higher than the as-received Al alloy. A simple artificial aging treatment was found to enhance the tensile properties of FSPed composite. Tensile properties of FSPed composite reduced than as-received Al alloy due to loss of precipitates and weak bonding of reinforcement to the matrix and increased 50% by applying the post-process artificial aging treatment at at 170^{o}C for soaking period of 16hr.

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