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Effect of III-Pass on Microstructure, Micro Hardness and Static Immersion Corrosion Resistance of AA6061-T6/SiC$_p$ Surface Composite Fabricated by Friction Stir Processing

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Abstract - In this current investigation, SiC particles 20μm in average size were incorporated into the commercially AA6061-T6 to prepare surface composite by using Friction stir processing (FSP). The morphology of the reinforcement inside the Al matrix has been evaluated from scanning electron microscope (SEM) and the corrosion characteristics of the resulted composite were evaluated using static immersion corrosion (SIC) behavior in 3.5% NaCl aqueous solution at various regimes. From the results, it observed that the SiC particles were distributed uniformly inside the stir zone (SZ) in both first and third-pass of FSP. The micro hardness of stir zone with SiC particles of I-pass was higher compared to III-pass and as-received Al alloy. In static immersion corrosion test the FSP AA6061-T6/SiC$_p$ exhibited significantly greater corrosion resistance in I-pass than compared to the III-pass and as-received Al alloy.

Key words - *Friction stir processing, AA6061-T6, Micro hardness, Static immersion corrosion.*

I. INTRODUCTION

Friction stir welding (FSW) technique was first invented by The Welding Institute (TWI) [1], widely used in welding of aluminum, magnesium and copper alloys. This technique not only being limited to welding, friction stir processing (FSP) has found various applications: grain refinement of wrought and casting parts[2,3], super plasticity improvement [4], formation of intermetallics [5] and composite fabrication [6]. FSP offers a low energy consumption route to introduce reinforcing phases into the metal matrix and to form bulk composites. Grain refinement is also enhanced by dynamic recrystallization and grain boundary pinning during FSP [7]. In recent years, most of the researches were carried out on surface composite fabrication with FSP. Mishra et al. [8] fabricated 5083Al based SiCp reinforced surface and some of the other studies were also done on fabrication of Mg and Al based nanocomposite by deep groove processing and grain size in the range of 100 nm to 4μm has been obtained [9, ,10]. The reinforcement particles (SiC, Al_2O_3 or their mixture) were distributed almost homogenously over the nugget zone by FSP without any defects except small some voids forming around the Al_2O_3 particles. The particulate hybrid composites containing 80% SiC + 20% Al_2O_3 exhibited superior wear resistance was reported by Essam R.I. et al [11]. Initial coarse microstructure of the cast NAB (NiAl bronze alloy) was transformed to a fine structure and defect free and FSPed NAB static immersion corrosion resistance was increased compared with the cast counterpart [12].

Metal-matrix composites (MMCs) represent a new class of structural materials as conventional metals and alloys approach their developmental limits. 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) ideal for many potential automotive and aerospace applications [15]. Further, the addition of ceramic reinforcement (SiC) raised performance limits of the Aluminum alloy 6061[16]. For example, discontinuously reinforced aluminum composites (DRA) are especially advantageous for electronic packages and thermal-management applications because of their combination of high thermal conductivity and low density. The SiC$_p$/Al MMCs have been also used in drive shafts, brake rotors and brake drums in automobile applications [17]. For long-term use of aluminum alloys based MMCs components in service, effective corrosion protection must be considered. Aluminum is a very reactive metal, but forms a protective oxide film when exposed to air. This film provides protection from general corrosion in neutral solutions. Aluminum is susceptible to localized corrosion, such as pitting and crevice corrosion, in solutions containing aggressive anions, such as chlorides. To protect aluminum and its alloys, a number of different protection methods are used. In contrast to aluminum alloys protection methods, relatively little are known about the corrosion protection of aluminum alloys based MMCs and the effectiveness of standard corrosion protection methods [18]. One of the main advantages in the use MMC is the influence of reinforcement on the corrosion rate is particularly important in aluminum alloy based composites, where a protective oxide film imparts corrosion resistance. The addition of reinforcing phase could lead discontinuities in the film, thereby increasing the number of sites for corrosion can be initiated and making the composites more susceptible for corrosion [19].

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 [13, 14]. Considering these problems, friction stir processing seems to be a good technique for successful preparation of SMMCs. In the present work, an attempt has been made to study the effect of III-pass on microstructure, micro-hardness behavior and SIC resistance of AA6061-T6/SiC_p surface composite fabricated by FSP technique.

II. 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.4.

TABLE I : TYPICAL CHEMICAL COMPOSITION OF ALUMINUM ALLOY 6061-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

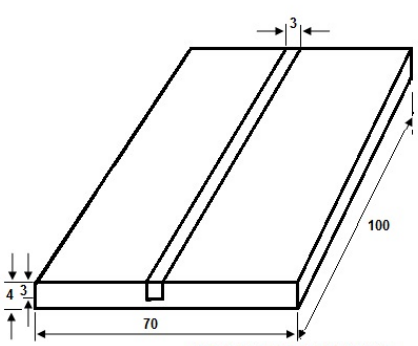

Fig. 1: Schematic diagram of Al alloy plate

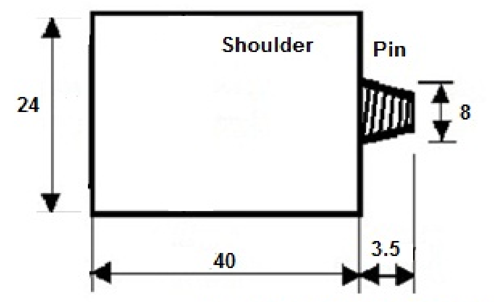

Fig. 2 : Schematic diagram of FSP Tool

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 centre line before processing. The FSP tool was made of H13 tool steel and had a cylindrical shape shoulder (⌀24mm) with a screwed taper pin profile (⌀8 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 selected. The tool was tilted an angle of 2.5^0 and constant vertical load is about 5KN is applied.

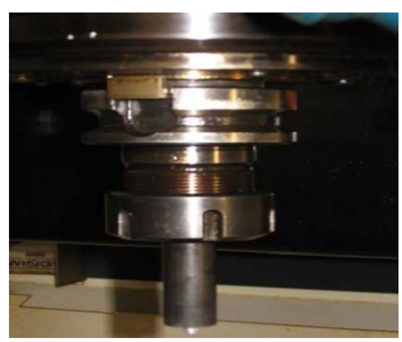

Fig. 3: VMM Tool Arbor

Third pass was applied to improve the homogeneity of the reinforcement particles distribution and in this the tool was travelled along the same line as the first pass after completion of second pass which is opposite to the first pass direction. The process is carried out on a vertical milling machine (VMM) (Make HMT FM-2, 10hp, 3000rpm) and the tool arbor was shown in Fig.3.

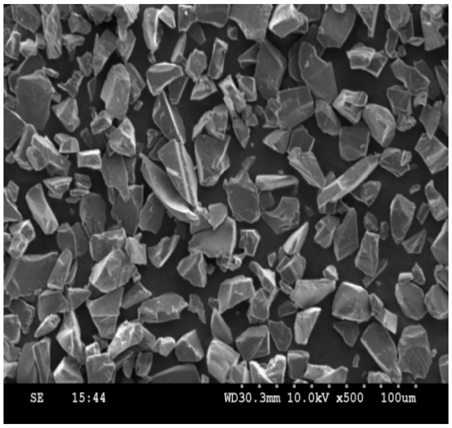

Fig. 4 : SEM of as-received SiC particles

The first and third passes macrostructures were shown in Fig. 5 & 6. 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 15sec.

In SIC test, samples were machined from the stir zone with a dimension of 10mm x10mm x 3.5mm and were ground with 1000 SiC abrasive paper to provide a uniform surface finish. Prior to test, the samples were degreased in acetone and blow dried and weighed carefully. Samples were immersed into a glass beaker containing of 500ml of a 3.5wt% NaCl solution at room temperature. The solution was prepared from distilled water and reagents grade chemicals. The corroded samples were taken out after 48, 96, 192 and 384hrs respectively. The corroded samples were flushed with water and immersed in the solution of 500ml HCl (density, 1.19) + 1000ml of H_2O for 2 min to clean off the corrosion products, then completely rinsed out using a toothbrush and flushed with water and immersed in ethanol and blow-dried, and finally weighed. The gravimetric measurements were made by using a weighing balance. The weight loss for each condition was obtained by averaging two results. For the purpose comparison, the base material samples with the same size were tested under the same conditions.

Fig. 5 : Macrostructure of first pass

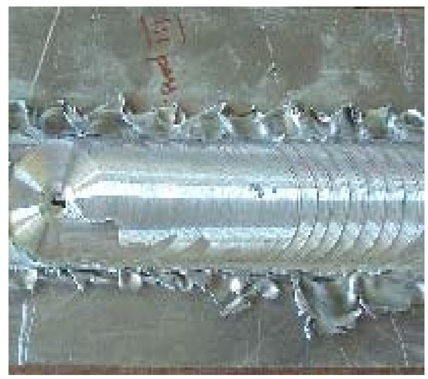

Fig. 6 : Macrostructure of third pass

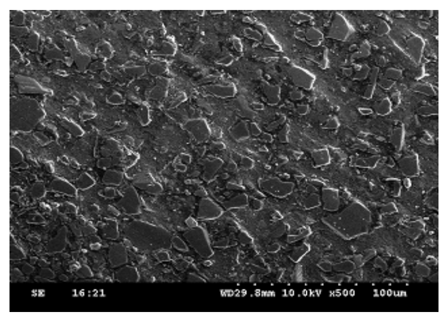

Fig. 7 : SEM of first pass

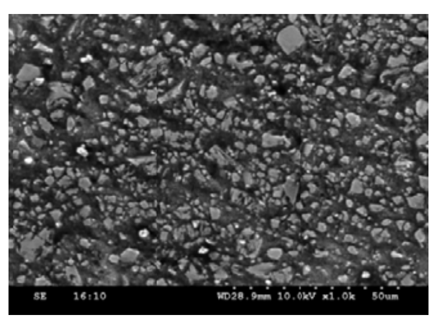

Fig. 8 : SEM of third pass

III. RESULTS AND DISCUSSIONS

I) Microstructure:

Microstructure of the AA6061-T6/SiC_p FSPed composite nugget cross- section zone was observed by SEM. The SEM microstructures of first and third passé are shown in Fig.7&8 respectively. It is observed that after the first and third pass of FSP the SiC particles were uniformly distributed in the stir zone without any defect than. This was due to the stirring action generated in each pass by the rotated tool. There is no reaction between SiC_p and the base metal because of solid-state process. FSP is a solid-state processing, and peak temperature during process was below the melting point of base metal [11]. In third pass the reinforced particles were easily wrapped by softening the metal and rotated with the FSP tool rather than the first pass.

II) Microhardness:

Microhardness behaviour 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 microhardness of the first pass of FSPed composite in 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. Where as in third pass of FSPed composite, the microhardness was lower compared to first pass and as-received Al alloy this is due to the material become more softening and annealing effect of heat input during the process. The FSP with the SiC particles is considered to make fine grains more effectively due to the enhancement of the induced strain and the pinning effect the SiC particles [6].

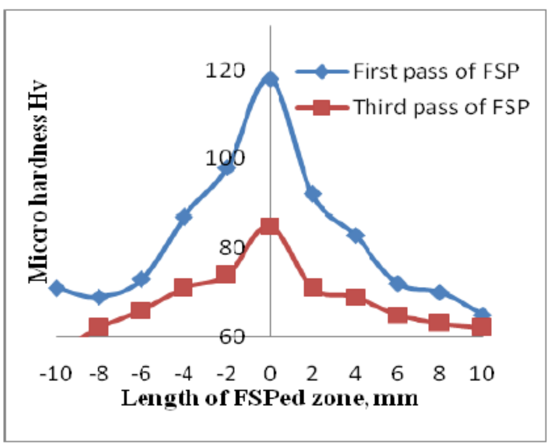

Fig.9 Micro hardness behavior

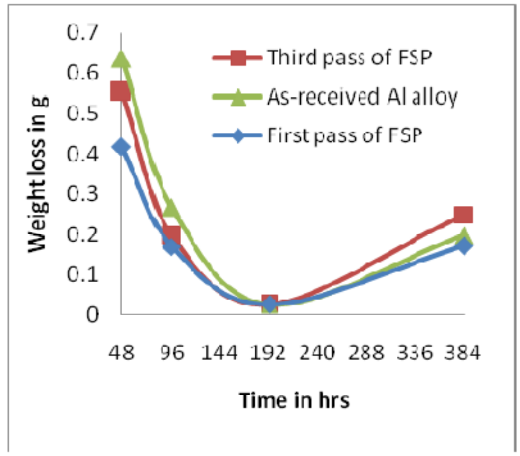

Fig. 10 Weight loss of FSPed composite

iii) Static Immersion Corrosion resistance:

The weight loss rates of first pass, third pass of FSPed composite and as-received Al alloy were shown in Fig10. It seen that the base metal exhibited apparently higher weight loss than the first pass, third pass of FSPed composite during the test and the weight loss rates of all the samples decreasing with increasing time. In third pass weight loss is higher than first pass due to the material become softened by applying third pass. The weight loss rates can be divided into two stages: higher rate before 192hr and lower rate after which tended to be steady. Increase in the corrosion resistance of composite material (FSPed) compared base metal due to the formation of a film of a hydrated Al oxide/hydroxide, and this layer is formed by hydrolysis to produce an Al hydroxide layer adjacent to the metal and these layers acted as a barrier and hampered the ionic transport across the corrosion product. Corrosion behavior of Aluminum alloy 6061/SiC_p MMC has well documented previously. The decreased in corrosion resistance of Al/SiC particulate to crevices forming at the interfaces [24].

IV. CONCLUSIONS

The SiC particles dispersed Aluminum alloy 6061-T6 was successfully fabricated by the FSP. The micro structure, micro hardness behavior and SIC resistance was evaluated. The obtained results can be summarized as follows:

- The SiC particles were distributed uniformly inside the stir zone (SZ) in both first and third-pass of FSP with defect free.

- The micro hardness of stir zone with SiC particles of I-pass was higher compared to III-pass and as-received Al alloy.
- In static immersion corrosion test the FSP AA6061-T6/SiC_p exhibited significantly greater corrosion resistance in I-pass than compared to the III-pass and as-received Al alloy.

REFERENCES

[1] Thomas WM, Nicholas ED, Needham JC, Church MG, Templesmith P, Dawes CJ. The Welding Institute, TWI, International Patent Application No. PCT/GB92/02203 and GB Patent Application No. 9125978.8 1991.

[2] Y.J. Kwon, N. Saito and I. Shigematsu, Friction stir process as a new manufacturing technique of ultrafine grained aluminum alloy, Mater Sci Let 21 (2002), pp. 1473–1476.

[3] Z.Y. Ma, S.R. Sharma and R.S. Mishra, Effect of friction stir processing on the microstructure of cast A356 aluminum, Mater Sci Eng A 433 (2006), pp. 269–278.

[4] Z.Y. Ma, R.S. Mishra and M.W. Mahoney, Superplastic deformation behavior of friction stir processed 7075Al alloy, Acta Mater 50 (2006), pp. 4419–4430.

[5] C.J. Hsu, P.W. Kao and N.J. Ho, Ultrafine-grained Al–Al_2Cu composite produced in situ by friction stir processing, Scripta Mater 53 (2005), pp. 341–345.

[6] W. Wang, Q.Y. Shi, P. Liu, H.K. Li and T. Li, A novel way to produce bulk SiCp reinforced aluminum metal matrix composites by friction stir processing, J Mater Proc Tech 209 (2009), pp. 2099–2103

[7] C.J. Lee, J.C. Huang and P.J. Hsieh, Mg based nano-composites fabricated by friction stir processing, Scripta Mater 54 (2006), pp. 1415–1420

[8] R.S. Mishra, Z.Y. Ma and I. Charit, Friction stir processing: a novel technique for fabrication of surface composite, Mater Sci Eng A 341 (2003), pp. 307–310.

[9] C.I. Chang, Y.N. Wang, H.R. Pei, C.J. Lee and J.C. Huang, On the hardening of friction stirprocessed Mg–AZ31 based composites with 5–20% nano-ZrO_2 and nano-SiO_2 particles, Mater Trans 47(2006), pp. 2942–2949.

[10] A. Shafiei-Zarghani, S.F. Kashani-Bozorg and A. Zarei-Hanzaki, Microstructures and mechanical properties of Al/Al_2O_3 surface nano-composite layer produced by friction stir processing, Mater Sci Eng A 500 (2009), pp. 84–91.

[11] Essam R.I , Wear characteristics of surface-hybrid-MMCs layer fabricated on aluminum plate by friction stir processing, Wear 268(2010) 1111 – 1121

[12] D.R. Ni, Corrosion properties of friction stir processed cast NiAl bronze, Corrosion science 52 (2010) 1610 - 1617

[13] R.S. Mishra, Z.Y. Ma, Mater. Sci. Eng. R 50 (2005) 1–78.

[14] M. Gui, S.B. Kang, Mater. Lett. 51 (2001) 396–401.

[15] S. Rawal, JOM, Vol. 53, No. 4, (2001), p. 14-17.

[16] D.M Aylor, Corrosion of Metal Matrix Composites, Metal Hand Book, Vol.13, Ninth Edition, ASM, 1987, pp. 859

[17] L.H. Hihara, "Corrosion of Metal-Matrix Composites" in ASM Handbook Vol. 13 B, Corrosion: Materials, S.D. Cramer and B.S Covino, Jr., Ed., ASM International, Materials Park, OH, 2005, p. 526-542

[18] H.J Greene and F. Mansfeld, Corrosion, Vol. 53, (1997), 920-927

[19] A.J. Trowsdate, B. Noble, S.J. Haris, I.S.R. Gibbins, G.E. Thomson, g.c. Wood, Corrosion Science 38 (1996) 177

[20] Mansfeld, F., Lin S., Kim, s., an d Shih H., 1990, Journal Electrochemical Society, 137 (1), pp.78-82

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