Effect of friction stir processing on microstructure and microhardness of the 6061 aluminum alloy reinforced with SiC_p

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Abstract

The performance of this study shows that SiC_p of particle size 1µm was dispersed into the surface layer of 6061 aluminum alloy sheet by friction stir processing (FSP) technique. The process parameters are rotational speed, traverse speed and axial force and all these parameters kept constant at 1750 rpm, 50 mm/min and 4 kN, respectively. All the specimens were subjected to different numbers of FSP (1 to 3 passes). The effect of FSP passes on the surface metal matrix composites was investigated. The microstructure across the stir zone (SZ) was evaluated by using an optical microscope, and the results showed a banded structure from the particle-rich and particle-free regions of the SiC_p. Significant variation in microhardness value of the surface metal matrix composites was observed due to the variation of FSP passes. Higher microhardness value was exhibited when the surface composites were fabricated after 3-pass FSP.

Keywords: friction stir processing; particle reinforcements; composite materials

تأثير عملة الرج بالاحتكاك على التركب الحبيبي والصلادة لسبيكة الالمنيوم 6061 بعد تسليحها بمادة السليكون كاربيد

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الخلاصة:

في هذه الدراسة تم نشر مادة السليكون كاربيد (SiCp) وبحجم 1 مايكروميتر مع سطح مادة سبيكة الالمنيوم 6061 بتقنية رج الاحتكاك (FSP). المتغيرات الثابتة التي تم اعتمادها في البحث هي السرعة الدورانية (1750 rpm) والسرعة الخطية 50mm/min والقوة العمودية المسلطة للماكنة (4kN) على التوالي. جميع العينات عرضت للخلط لمرات مختلفة (1 الى 3) مرة. تم فحص منطقة (SZ) بأستخدام المجهر الضوئي واظهرت النتائج اختلاف في نسبة خلط المادة (SiCp) من حيث كثافتها في منطقة الخلط. وقد تم ملاحظة اختلاف قيم الصلادة بسبب اختلاف عدد مرات الخلط. أعلى قيم الصلادة تم ملاحظتها عندما كانت عدد مرات الخلط (3).

الكلمات المفتاحية: عملية الرج بالاحتكاك, التسليح بالجسيمات, المواد المركبة

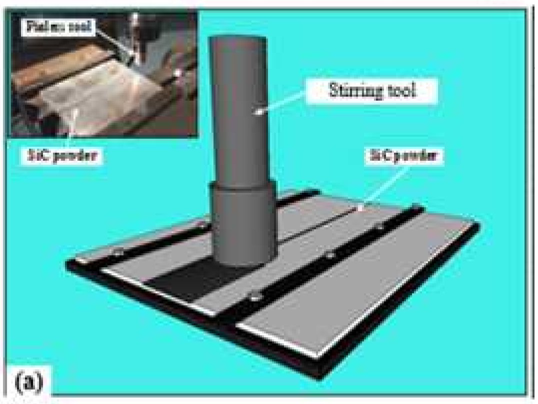
1. Introduction

A technique of FSP has been developed [1]. FSP is one of the main part that deals with solid state intense plastic deformation processes to modify the grain structure of the surface [2]. This method is to produce surface metal matrix composites and to improve the mechanical properties of the surface metal [3]. FSP has improved the wear resistance [4], microstructure and grain enhancement [5]. This process involves an inconsumable rotating tool which includes a pin and a shoulder [6]. The rotating tool introduces into the surface of sheet and stirs the material around the pin tool in terms of frictional heating. This heat is created through the severe plastic deformation which is assigned to the stirring material in the region of the pin tool [7]. The input parameters of FSP are the geometry of tool [8], traverse and rotating speed [9], spindle tilt angle and depth [7] which have important influences on the mechanical properties and microstructure of the products. The FSP was successfully implemented in fabricating the most of aluminum, which is used in the process with different reinforcements. The applied reinforcements were hard carbide particles such as TiC, SiC and Al_2O_3 [10-12].

FSP was successfully applied to homogenize the TiC particles circulation in aluminum alloy surface based in situ composites, Bauri et al. [10]. A single pass FSP might rupture the particles from grain boundaries. Two passes of FSP are extremely enhanced TiC particles distribution and refined grain structure. As a result of above, the FSP has two advantages of the hardness and the strength which are enhanced after FSP. FSP was employed to produce bulk dispersal SiC_p reinforced aluminum metal matrix composite by Wang et al. [13]. The results of those researchers show that the bonding between SiC_p particles and base metal surface is extremely perfect. Also, they concluded that the microhardness of metal matrix composites may achieve to the amounts of 10% higher than the base metal. Izadi and Gerlich [11] continued Limetal.'s work [14] by production of CNT/aluminum composites throughout multi pass FSP. They distributed high volume of fraction (450%) of CNT during three passes of processing. The results exhibited that FSP could implant nanotubes in the lamellae regions of the aluminum alloy SZ. They established the increasing of the tool shoulder penetration depth and the rotational speed could develop the circulation of nanotubes in the aluminum alloy matrix. Aluminum-10% Al_2O_3 surface nano-composite formed on a 2024 aluminum by Zahmatkesh et al. [15]. The powder was spread on the aluminum surface (2024 sheet) by atmospheric plasma and then subjected to FSP. A homogeneous circulation of nano particles was accomplished after FSP and the wear rate of the surface nano-composite was reduced. As a role of thump, the grain structure might have refined during FSP [16]. Studies of SiC with Al_2O_3 reinforcement into the surface of pure aluminum were carried out by Miranda et al. [17]. The study showed that the packing of reinforcements in square shaped groove could increase the composite layer thickness.

In the current study, aluminum matrix reinforced with 30 vol. % of SiC_p was fabricated through FSP technique to enhance the microhardness properties. The new product of reinforcement with aluminum matrix has a homogenous distribution of reinforcement. These result are consistent with other studies [13, 18].

2. Materials and Experimental Procedures



treated and quenched to 65HRC. For the FSP technique, a tool with a shoulder diameter of 15 mm and a straight cylindrical pin with a

Table 1 Chemical compositions of the base metal (6061 aluminum alloy)

Element	Al	Si	Fe	Mg	Cu	Mn
wt.%	97.57	0.525	0.339	1.062	0.120	0.080

Table 2 Chemical compositions of the medium carbon steel tool

Element	C	Mn	P	Fe
wt.%	0.44	0.79	0.012	Balance

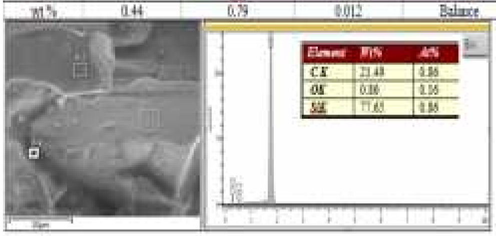


Fig.1: FESEM micrograph and EDX results of the SiCp particles

Moreover, the workpiece was set using a backing plate and rigidly clamped as shown the schematic diagram in Fig. 2(a). The longitudinal slots with 1mm width and 3mm depth were packed with the required volume fraction of SiC_p powder along the aluminum sheet. To avoid scatter of SiC_p powder through FSP technique, a tool shoulder without pin (Fig. 2(b)) was used to press the powder into the slot as much as possible before applying the FSP technique.

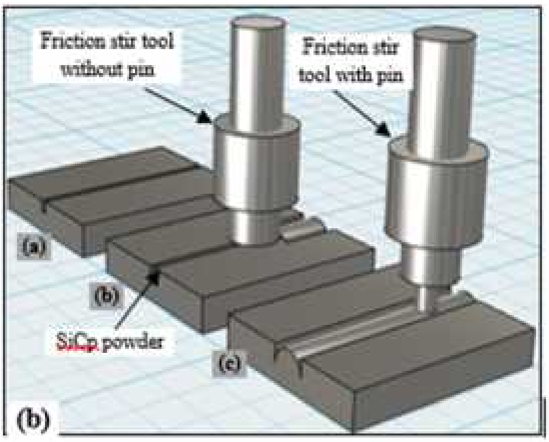


Fig. 2: (a) FSP fixture and (b) reinforced with 30 vol. % SiC_p powder.

FSP technique was implemented on a KAMA vertical milling machine (X6325; 3 Hp; TRPER R8; 30 kN).The technique was applied by setting the milling machine spindle to a prearranged speed (1750 rpm and 50 mm/min) in a counter clockwise direction, which was normal to the rolling direction. The multi pass FSP (1-3 pass) was carried out to formulate the slots with the SiC_p powder and the axial force was rest from a maximum value of 4 kN. The specimens for metallographic assessment were cut to the necessary sizes from the SZ. Afterward, the specimens were ground with 180 to 1200 grit silicon carbide papers. Final polishing was executed using a diamond paste of particle size of 0.5μm. A solution of Keller's reagent (3ml of hydrochloric acid, 5ml of nitric acid, 2ml of hydrofluoric acid and 190 ml of distilled water) was prepared to detect the microstructures according to the American Standard Testing of Materials (ASTM: E407-07: ETD 2013). The microstructures of the specimens were noticed using an optical microscope (Olympus BX41RF).

For the microhardness measurements, at least 21 Vickers type indentations were outright on traverse section of samples, using a load of 9.8 N (1 kg) and a dwell time of 15 sec by a Future-Tech (FV-700e) microhardness tester (Future-Tech Corp., Japan). The microhardness was more closely measured, with measurements being taken every 1 to 1.5 mm. The method of the microhardness test was repeated until at least five impressions were made at widely spaced locations along the FSP line.

3. Results and Discussion

3.1 Microstructural investigation

An optical microscope for the SZ of each specimen was observed in a bright field (Fig. 3) to illustrates the distribution of the reinforcing SiC_p particles in the aluminum matrix. It is evident that the reinforcements have been distributed properly and more uniform in the SZ of 3-pass specimen. In the multi pass FSP, the tool could supply further shear force to make the powder flow and disperse in the SZ [6]. In Fig. 3, the microstructure shows that the reinforcement powder are clustered and distributed heterogeneously in the matrix as a result of production processes. The inhomogeneous distributions of reinforcement powder in the microstructure of aluminum base metal can affect the isotropy of mechanical properties. It is accepted that the stirring action during FSP causes a break up of clustered reinforcement and homogenous distribution in the SZ due to the mixing of material and severe plastic deformation [19, 20].

The alternating layer of SiC_p particles was found in rich region (Fig. 3(b,c) and free region (Fig. 3(a)). In addition, the number of FSP passes can change the distribution and volume of SiC_p particles in the SZ [21]. In conclusion, the material flow behaviour, recrystallisation and heat input (i.e. number of passes) are main factors for uniform particle distribution effect. Hence the quality of SZ can be improved if the temperature of the SZ can be carefully controlled [22].

Fig. 3: Distribution of SiC_p particles in the SZ of aluminum matrix after FSP, (a) 1-pass, (b) 2-pass, and (c) 3-pass.

Transverse microhardness through the cross section of a SZ can give an indication about the change of various phases and reinforcement distribution in FSP [23, 24]. Two different profiles of microhardness curves have been observed in the cross section of aluminum matrix composite. Firstly, it is well accepted that the highest microhardness value occurs in the centre of the SZ followed by a gradual decrease across the transverse section until reaching the microhardness value of the base metal as shown in Fig. 4. This is attributed to more grain refinement in the SZ due to the presence and pinning effect of SiC_p particles due to FSP action [25]. Fig. 4 also illustrated that the 3-pass specimen gives higher results of microhardness due to more uniform distribution of finer reinforcement particles in the SZ. These conclusions agreed with the Hall–Petch equation (inversely proportional relation between microhardness and grain size) and the Orowan microhardness mechanism can be improved if finer particles distribute homogenously [26]. Furthermore, it may be concluded from Fig. 4 that lower heat input (1-pass sample) leads to the formation of coarse grains because of incomplete distribution of SiC_p particles, and thus a reduction of the SZ microhardness.

Although it is suggested that multiple tool pin passes may be useful to further improve the uniform dispersion of nanotubes in the composites, fracture of carbon nanotubes could be more serious. Nevertheless, carbon nanotube reinforced composites showed the significant strengthening effect, as evidenced by the drastic increase in the microhardness in the friction stir processing zone. Besides, it can be seen from same figure, the microhardness distributions along the SZ are declined. This occurrence arises from the mode of distribution of the powder reinforcement [27].

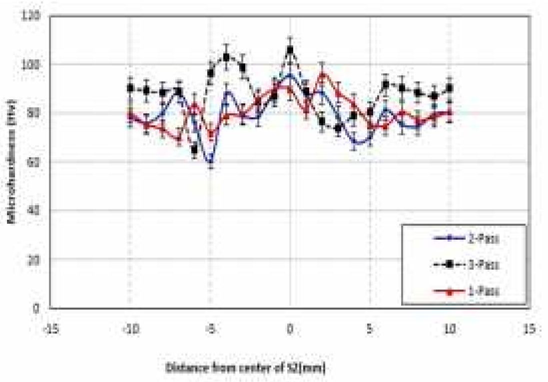


Fig. 4: Microhardness behavior of specimens at the SZ of different passes.

4. Conclusion

1. The reinforcement particles of SiC_p were distributed uniformly in the SZ with devoid of imperfections.
2. The material flow behaviour, recrystallisation and heat input are main factors for uniform particle distribution effect. Hence the quality of SZ can be improved if the temperature of the SZ can be carefully controlled
3. The microhardness values of aluminum matrix composites of 3-pass sample were increased as compared with the average microhardness of other samples and the base metal due to the presence of hard reinforcement particles and uniform distribution of SiC_p particles.

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References

[1] Zhang Z, Yang X, Zhang J, Zhou G, Xu X, Zou B. Effect of welding parameters on microstructure and mechanical properties of friction stir spot welded 5052 aluminum alloy. Materials & Design. 2011;32:4461-70.
[2] Yadav D, Bauri R. Effect of friction stir processing on microstructure and mechanical properties of aluminium. Materials Science and Engineering: A. 2012;539:85-92.
[3] Sun K, Shi Q, Sun Y, Chen G. Microstructure and mechanical property of nano-SiCp reinforced high strength Mg bulk composites produced by friction stir processing. Materials Science and Engineering: A. 2012;547:32-7.
[4] Aldajah S, Ajayi O, Fenske G, David S. Effect of friction stir processing on the tribological performance of high carbon steel. Wear. 2009;267:350-5.
[5] Azizieh M, Kokabi A, Abachi P. Effect of rotational speed and probe profile on microstructure and hardness of AZ31/Al 2 O 3 nanocomposites fabricated by friction stir processing. Materials & Design. 2011;32:2034-41.
[6] Arab SM, Karimi S, Jahromi SAJ, Javadpour S, Zebarjad SM. Fabrication of novel fiber reinforced aluminum composites by friction stir processing. Materials Science and Engineering: A. 2015;632:50-7.
[7] Mishra RS, Ma Z. Friction stir welding and processing. Materials Science and Engineering: R: Reports. 2005;50:1-78.
[8] Bahrami M, Givi MKB, Dehghani K, Parvin N. On the role of pin geometry in microstructure and mechanical properties of AA7075/SiC nano-composite fabricated by friction stir welding technique. Materials & Design. 2014;53:519-27.
[9] Bilgin MB, Meran C. The effect of tool rotational and traverse speed on friction stir weldability of AISI 430 ferritic stainless steels. Materials & Design. 2012;33:376-83.

[10] Bauri R, Yadav D, Suhas G. Effect of friction stir processing (FSP) on microstructure and properties of Al–TiC in situ composite. Materials Science and Engineering: A. 2011;528:4732-9.
[11] Izadi H, Gerlich AP. Distribution and stability of carbon nanotubes during multi-pass friction stir processing of carbon nanotube/aluminum composites. Carbon. 2012;50:4744-9.
[12] Mazaheri Y, Karimzadeh F, Enayati M. A novel technique for development of A356/Al 2 O 3 surface nanocomposite by friction stir processing. Journal of Materials Processing Technology. 2011;211:1614-9.
[13] Wang W, Shi Q-y, Liu P, Li H-k, Li T. A novel way to produce bulk SiCp reinforced aluminum metal matrix composites by friction stir processing. Journal of materials processing technology. 2009;209:2099-103.
[14] Lim D, Shibayanagi T, Gerlich A. Synthesis of multi-walled CNT reinforced aluminium alloy composite via friction stir processing. Materials Science and Engineering: A. 2009;507:194-9.
[15] Zahmatkesh B, Enayati M. A novel approach for development of surface nanocomposite by friction stir processing. Materials Science and Engineering: A. 2010;527:6734-40.
[16] Zahmatkesh B, Enayati M, Karimzadeh F. Tribological and microstructural evaluation of friction stir processed Al2024 alloy. Materials & Design. 2010;31:4891-6.
[17] Miranda R, Santos TG, Gandra J, Lopes N, Silva R. Reinforcement strategies for producing functionally graded materials by friction stir processing in aluminium alloys. Journal of Materials Processing Technology. 2013;213:1609-15.
[18] Deepandurai K, Parameshwaran R. Multi Response Optimization of FSW Parameters for Cast AA7075/SicP Composite. Materials and Manufacturing Processes. 2015.
[19] Ni D, Chen D, Wang D, Xiao B, Ma Z. Influence of microstructural evolution on tensile properties of friction stir welded joint of rolled SiCp/AA2009-T351 sheet. Materials & Design. 2013;51:199-205.
[20] Kalaiselvan K, Dinaharan I, Murugan N. Characterization of friction stir welded boron carbide particulate reinforced AA6061 aluminum alloy stir cast composite. Materials & Design. 2014;55:176-82.
[21] Nami H, Adgi H, Sharifitabar M, Shamabadi H. Microstructure and mechanical properties of friction stir welded Al/Mg 2 Si metal matrix cast composite. Materials & Design. 2011;32:976-83.
[22] Salih OS, Ou H, Sun W, McCartney D. A review of friction stir welding of aluminium matrix composites. Materials & Design. 2015;86:61-71.
[23] Kumar A, Mahapatra M, Jha P, Mandal N, Devuri V. Influence of tool geometries and process variables on friction stir butt welding of Al–4.5% Cu/TiC in situ metal matrix composites. Materials & Design. 2014;59:406-14.
[24] Minak G, Ceschini L, Boromei I, Ponte M. Fatigue properties of friction stir welded particulate reinforced aluminium matrix composites. International Journal of Fatigue. 2010;32:218-26.
[25] Devaraju A, Kumar A. Dry sliding wear and static immersion corrosion resistance of aluminum alloy 6061-T6/SiCp metal matrix composite prepared via friction stir processing. Int J Adv Res Mech Eng. 2011;1:62-8.
[26] Periyasamy P, Mohan B, Balasubramanian V, Rajakumar S, Venugopal S. Multi-objective optimization of friction stir welding parameters using desirability approach to join Al/SiC p metal matrix composites. Transactions of Nonferrous Metals Society of China. 2013;23:942-55.
[27] Sun Y, Fujii H. The effect of SiC particles on the microstructure and mechanical properties of friction stir welded pure copper joints. Materials Science and Engineering: A. 2011;528:5470-5.