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A Novel Technique for Development of Aluminum Alloy Matrix/TiB_2/Al_2O_3 Hybrid Surface Nanocomposite by Friction Stir Processing

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Abstract

Compared with non-reinforced aluminum, the aluminum matrix composites reinforced by ceramic phase presents high elastic modulus, high wear resistance, high specific strength, better corrosion resistance at high temperatures and fracture behaviors, which make them as reliable material for aerospace and automotive application. However, their low ductility and softness, which are inherent properties of non-formable reinforcing materials, have limited their applications. Typically, the Material life cycles depend highly on the surface behaviors. Therefore, an optimal situation is to improve the surface layer through reinforcing them by ceramic powders; while the bulk material retains the original compositions with a ductile behavior. In this research work, friction stir processing (FSP) was used to fabricate Aluminum Alloy Matrix/TiB_2/Al_2O_3 hybrid nanocomposites for surface applications. Particles morphology and microstructure characterization was studied by SEM and TEM. Mechanical properties such as tensile test and hardness measurements were carried on surface hybrid nanocomposite and base metal. Micro hardness testing was carried by the use of Vickers hardness measurement method. The improved distributions of nanoparticles were obtained after each FSP pass and progress in mechanical properties was observed.

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Keywords: Aluminum alloy; hybrid surface nanocomposite; friction stir processing.

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1. Introduction

In many industrial applications, the surface of base metal needs to have proper mechanical properties like improved strength and better hardness and wear resistance. Surface metal matrix composites (SMMCs) exhibit a unified combination of high tribological properties of the surface and high toughness of the interior bulk metal when compared with both metal matrix composites and monolithic materials. Friction stir processing (FSP) has been successfully evolved as an alternative effective solid state processing technique based on the principle of friction stir welding (FSW), technique for fabricating surface metal matrix composites, Mishra et al. (2003), Wang and Liu (2004), Soleymani et al. (2012). In FSP, the heat generating between the tool and work piece, can be changing the properties of a metal through intense, localized plastic deformation.

Hybrid composites are a class of material system with two or more discrete particulate reinforcement. The properties of hybrid composites such as low thermal expansion, wear resistance, high mechanical properties and so on, are more excellent than those of the single reinforcement, Zhang (2007), Fei and Wang (2004). Aluminium-matrix composites have emerged as an important class of engineered materials because of their good attributes, such as high specific stiffness and strength and increased wear resistance over unreinforced alloys. As reinforcement, TiB_2 is incorporated in several ceramic microstructures to improve mechanical properties, Gotman et al. (1998), Vallauri et al. (2008). The addition of TiB_2 to an Al_2O_3 matrix considerably increases hardness, strength, fracture toughness, and electrical conductivity, Davies and Ogwu (1995) Therefore; TiB_2–Al_2O_3 composite is useful for a variety of applications like cutting tools, wear-resistant substrates and lightweight armor, Mishra et al. (2006), Keller and Zhou. (2003). In this research work, Friction stir processing (FSP) was used to fabricate Aluminium Alloy Matrix/TiB_2/Al_2O_3 hybrid nanocomposites for surface applications. The stirring action and frictional heat generated by the FSP tool can be used to distribute hybrid ceramic particles as reinforcement on the surface of aluminium base alloy.

Nomenclature

SMMCs	Surface metal matrix composites
FSP	Friction stir processing
FSW	Frictions stir welding

2. Experimental Procedure

2.1. Materials

A rectangular 8026 Aluminium alloy plate of 5 mm thickness with chemical composition of Fe-1.24wt%, Si-0.6wt%, Mn—0.448wt%, Mg-0.356wt%, were used as the base metal. Mixtures of TiB_2 ceramic powders with an average particle size of 5µm and Al_2O_3 powder with an average particle size of 70 nm were used as the reinforcement particles. Fig. 1 shows Microscopic images of the reinforcement particles of TiB_2 and Al_2O_3. For homogeneous distribution of TiB_2 and Al_2O_3 powders, mechanical mixing process was used.

2.2. Friction stir processing

The main tool used in the FSP includes a pin and a shoulder. Diameter and length of the pin both equal to 5mm and diameter of the tool shoulder is 18mm. A threatened pin with a pitch size of 0.5mm was prepared. Fig. 2 shows the tools used in the FSP. The material of tool was selected as H13 tool steel with a hardness of 20 R_C. In order to increase the wear resistance of the tool during the FSP, the hardness of the tool was increased to 52 R_C by using flame hardening. For creating a composite layer on parts, in the first stage, a groove with a depth of 4.2mm and a width of 1.2mm was created on the aluminium part. Then, for composite manufacturing process, the reinforcement powder was poured into the groove in the second stage, FSP tool without-pin is attached to the milling machine and it was moved with linear progression speed of 50mm/min perpendicular to the surface of the groove at the rotation speed of 1000 rpm in order to encapsulate the reinforcement particles. The groove was encapsulated in order to prevent from running away of reinforcement particles from the track and production of sound composite materials.

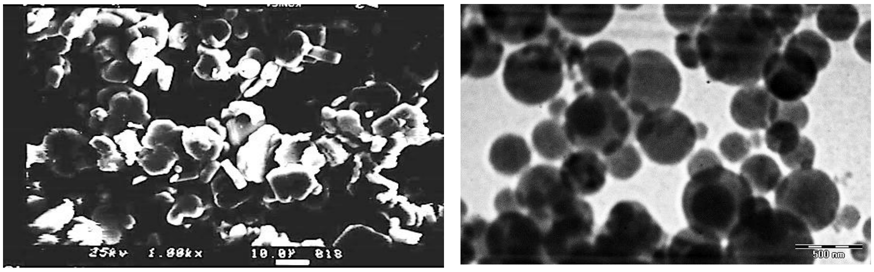

Fig. 1. Morphology of: (a) SEM image of microsized TiB_2; (b) TEM image of nanosized Al_2O_3.

In the third stage, after the closure of the groove surface, for producing surface composite, the main tool was placed into milling machines, and then the tool with a certain rotational speed at tilt angle of 3 degrees was drilled into the part. After proper engagement of the part with tool pin and shoulder, at certain linear moving speed, rotating tool proceeded in forward and backward manner to produce final surface composite. Micro hardness testing was carried on the base metal and surface composites by the use of Vickers hardness tester with a load value of 200 g and duration of 15 seconds. The microstructure of the specimens was examined by the use of scanning electron microscopy (SEM). Tensile test was carried on surface composites and base metal. All tests were conducted under a constant strain rate of 5×10^{-4} mm/s and at the ambient temperature. Information about produced composite layers and process parameters in this research are presented in table 1.

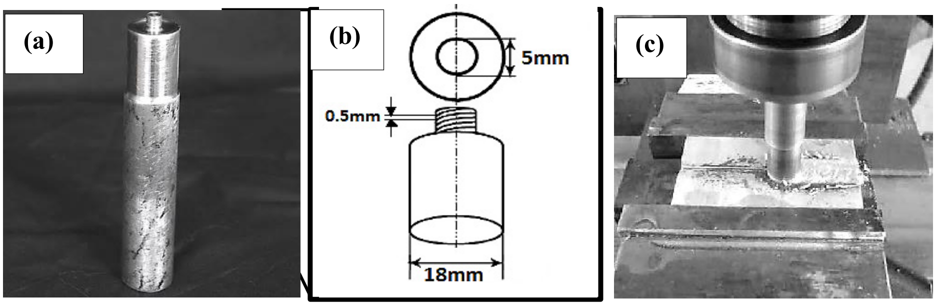

Fig. 2. (a) picture of the FSP tool; (b) Dimensions; (c) FSP applied on the aluminium surface.

Table 1. FSP parameters for various tests.

Specimen (FSP)	rotation speed (rpm)	linear progression speed (mm/min)	number of passes
Q1	800	80	2
Q2	1600	80	2
Q3	800	40	2
Q4	1600	40	2
Q5	800	40	4
Q6	1600	40	4

3. Results and Discussion

3.1. Microstructure

Figure 3 shows SEM images of the microstructure of surface composite materials produced by hybrid reinforcement particles. According to the images, it seems that Al_2O_3 and TiB_2 particles were distributed uniformly in the aluminium matrix. Also, in higher magnification images, good bond in aluminium particles are observed which in turn is an important and determining factor for increasing the strength of the interface between aluminium matrix and reinforcement particles. Aluminium matrix could undergo recrystallization due to the high input heat caused by friction between the pin and the shoulder of the tool with the part during FSP and could also cause grain refinement. Grain refinement of aluminium matrix can have a considerable impact on determining mechanical properties of composite materials. The influence of the manufacturing parameters including the number of passes, the tool rotational speed and linear progression speed in FSP is one of the important factors in determining the quality of the connection, reinforcement particles distribution and also the modification of the microstructure in the alloy matrix. According to the images in fig. 3, it seems that by increasing the number of passes and the rotation speed of the tool and also decreasing the progression speed of the tool, reinforcement particles were distributed better in the Aluminium matrix which could be due to an increase in the rheology of plastic materials in stir zone.

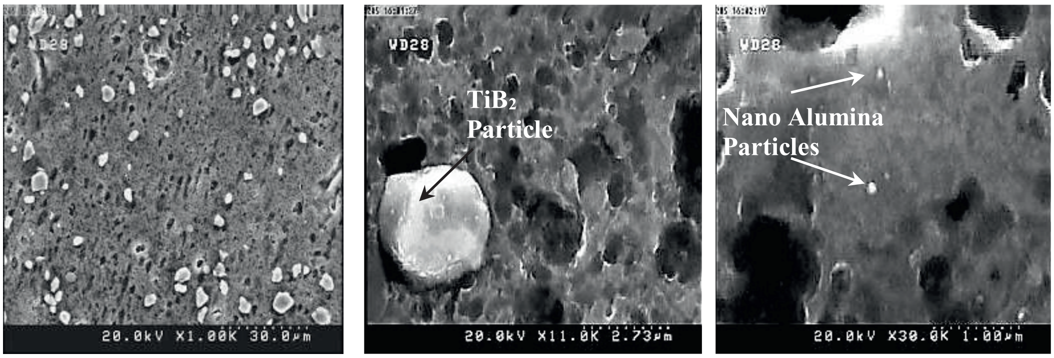

Fig. 3. SEM micrographs showing the hybrid particle dispersion.

3.2. Mechanical Properties

Table 2 shows the tensile properties and others mechanical properties of the surface aluminum matrix composites reinforced with hybrid particles. It was seen that Young's modulus (E), ultimate yield strength (UYS) and ultimate tensile strength (UTS) of the composites were more than that of base metal surface, while their elongation has decreased.

Table 2. Mechanical properties of specimens produced by FSP.

Specimen (FSP)	E (Gpa)	UYS (Mpa)	UTS (Mpa)	(%) Elongation
base metal	70	138	164	4.67
Q1	139	257	295	3.23
Q2	135	241	273	3.92
Q3	135	238	270	3.98
Q4	136	225	256	4.29
Q5	138	245	284	4.09
Q6	134	233	271	4.46

Figure 4 shows the hardness value in the surface of produced composites. As seen in Fig. 4, the base metal hardness was found to be about 85 Hv. The hardness of the points located on the stir zone increased in some areas and in some points it reached 175 Hv, which this value of hardness is about 105% more than the base metal. Possible strengthening mechanisms which might operate in particle-reinforced MMCs are Lloyd, (1994): (1) Orowan strengthening. (2) Grain and substructure strengthening. (3) Work hardening, due to the strain misfit between the elastic reinforcing particles and the plastic matrix. With increasing rotation speed from 800rpm to 1600rpm and decreasing linear progression speed of the tool from 80mm/min to 40mm/min, the hardness of the composites was reduced, which could be due to the smoother movement of dislocations caused in turn by the increase of the rheology of the plastic materials. By increasing the number of passes from 2 to 4, the hardness of the surface composites increased. The refinement of the microstructure of the base metal and the reduction of the grains size of the aluminium matrix caused by increasing the number of passes can be considered as the main reasons for the increase of the hardness of the surface composites.

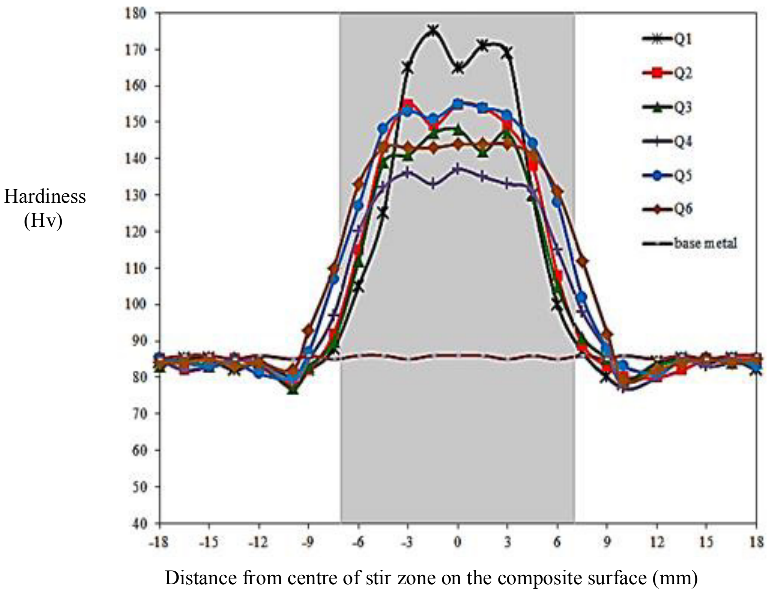

Fig. 4. Hardness variation for base metal and surface aluminium reinforced composites.

4. Conclusion

In the present investigation, the FSP technique has been successfully used for producing the Aluminum Alloy Matrix/TiB_2/Al_2O_3 hybrid surface nanocomposites layers. The microstructural study of surface composite layers fabricated by FSP indicated that hybrid ceramic particles were well distributed in the Al matrix, and good bonding with the Al matrix was generated. The FSP with TiB_2/Al_2O_3 particles obviously increased the microhardness of the substrates. At all feed rates employed in the present experiments, the best mechanical properties were obtained at a tool rotational speed of 800 rpm.

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