Surface Composite Fabrication of Aluminium Alloy Using Friction Stir Processing

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ABSTRACT:

Friction stir processing (FSP), which is a solid-state micro-structural modification technique using friction heat and stirring action, has recently attracted attention for making aluminium alloys with an excellent specific strength, and its studies have been actively performed. This process is the outgrowth of the basic principle of friction stir welding (FSW), and the mechanical properties of the Friction Stir Processed material are improved due to the grain refinement of the micro-structural modification. Friction stir processing (FSP) is best suited for preparation of surface composites and surface modification. In this project, aluminium alloy base surface composites were fabricated with Titanium Boride micro powder on an aluminium alloy plate using FSP under different process parameters. The mechanical properties like tensile strength, hardness and microstructures have been evaluated and the results are compared. From this investigation it is found that mechanical properties are improved with higher speeds and lower feeds.

Keywords: Friction stir processing, Aluminium alloys, Composites, Properties

1. INTRODUCTION

Friction stir welding and its variation of FSP, is a solid-state joining and surface modification technique were invented at The Welding Institute of UK in 1991. Application of FSW showed great promise in joining many ferrous and non-ferrous alloys that were joined by using conventional welding techniques with great difficulty. The convenience of the FSW as a joining technique has been demonstrated in a number of studies. Recently a new processing technique Friction stir processing (FSP) was developed by Mishra et al for micro-structural modification and fabrication of metal matrix composites are based on the principles of FSW.

In this case, a rotating tool with pin and shoulder was inserted into a single piece of material, for localized micro structural modification. The FSP caused intense plastic deformation, material mixing,

and thermal exposure, resulting in significant micro structural refinement, densification, and homogeneity of processed zone. This technique has been successfully applied in the production of fine grained structure and surface composite.

The schematic of FSP is shown in Figure1. To process a sheet by friction stir, a specially designed cylindrical tool is used which while rotating is plunged into the selected area. The tool has a small diameter pin with a concentric larger diameter shoulder. When the tool is plunged into the sheet, the rotating pin contacts the surface and friction between the sheet surface and the shoulder rapidly heats and softens a small column of metal, enabling the transverse movement of the tool through the material. During FSP, the area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the

entire selected area is processed to a desired (fine) grain size.

Fig. 1

Friction stir processing (FSP) is a recent technology for surface modification and developing surface composites and this friction stir processing can be done to aluminium alloys. Aluminium and its alloys mostly used in automobiles and aerospace industries because of its low density and high strength to weight ratio. The addition of reinforcements (Tib) raised performance limits of the aluminium alloys and matrix makes brittle. R.S.Mishra et al, demonstrated that the FSP is a versatile technique with a comprehensive function for the fabrication, processing and synthesis of materials.

In this work, aluminium alloy base surface hybrid composites were fabricated with Titanium-boride micro powder on an aluminium plate using FSP with higher speeds and lower feeds. The mechanical properties like tensile strength, hardness and microstructures have been evaluated and the results are compared.

2. EXPERIMENTATION

The base material employed in this study is a 100*80*6mm aluminium alloy plate was utilized for making the surface composites with Tib micro powder. The chemical composition of the base material is given in Table1. Tib2 particles with various ratios were used as reinforcements. The reinforcement particles have the similar average particle size of 1 μ m.

Table 1

Si	Cu	Mg	Fe	Zn
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0.682	0.215	0.748	0.462	0.146
Cr	Ti	Ga	Al	
0.015	0.017	0.009	97.3	

A square groove was made with dimensions of 1 mm width and 5 mm depth tangent to the pin in the advancing side, which is 1 mm far away from the centre line of the tool rotation on the Aluminium plate. The schematic of aluminium alloy plate for FSP is shown in Fig. 2.

Fig. 2

High speed steel tool (HSS) having square pin profile with shoulder diameter of 18 mm, pin diameter of 4 mm and 4 mm height was used.

The selected ratios of reinforcement mixture i.e. Tib₂ particle mixture is packed in the groove. The groove opening was initially closed by means of the tool which has shoulder without pin to avoid the escapement of reinforcement particles from groove while processing. The experiments were carried out on a vertical milling machine (Make HMT 7.35 kw, 10 hp, 3000 rpm), shown in figure3, as per the following speeds and feeds shown in Table 2.

Table 2

Exp No	Rotational speed (RPM)	Feed (mm/min)	Load(N)
1	600	20	5
2	600	30	6
3	600	40	7
4	800	20	6
5	800	30	7
6	800	40	5
7	1200	20	7
8	1200	30	5
9	1200	40	6

Fig. 3

After FSP, the specimens were cut from the stir zone using wire-cut EDM then micro structural observations were carried out at the cross section of nugget zone (NZ), shoulder, HAZ and TMAZ of surface hybrid composites normal to the FSP direction by optical microscope (OM). The specimens were mechanically polished and etched with Keller's reagent (2 ml HF, 3 ml HCL, 20 ml HNO₃ and 175 ml H₂O).

The Scanning Electron Microscope (SEM) was also utilized for measuring the reinforcement particles size of surface hybrid composites. Micro hardness tests were carried out at the cross section of NZ of surface hybrid composites normal to the FSP direction. Samples were tested with a load of 10g and duration of 15 s using a Vickers digital micro hardness tester.

The tensile specimens were taken from the surface hybrid composites normal to the FSP direction to the required dimensions. The schematic sketch of tensile specimen is shown in Fig.4. The tensile test is carried out on a computer controlled universal testing machine (make: Associated Scientific Engg.

Works, New, Max 5 Ton) at a cross head speed of 0.5 mm/min.

Fig. 4

3. RESULTS AND DISCUSSIONS

The surface hybrid composites were successfully fabricated via FSP as shown in Fig. 5. There were no imperfections such as cracks, voids on the surface. It also revealed that the top surface appears to be smooth and fine quality with almost no depressions. The cross sectional micrograph of the aluminium surface hybrid composite is shown in Fig.6. It revealed clearly different regions on the surface hybrid composite after FSP.

Fig.5 Macrograph of FSP zone of surface hybrid composite

Fig.6 Cross-sectional Micrograph of surface hybrid composite

3.1 Microstructure Evaluation

The reinforcement particles were observed to be dispersed uniformly within the NZ due to the existence of dynamic stirring of the rotating tool during the FSP. And also received optical micrographs of surface hybrid composites and shows the structure at high tensile strength occurs at 800 rpm are shown in Fig.7. Figure 8 shows the SEM structures of various points in NZ of surface hybrid composite. It is seen that the scratches are

less in composite compared with base metal

because of the presence of Tib2 in the composite.

Fig. 7 - Optical Microstructures of the surface hybrid composite with Titanium boride powder:

(a) Base metal

(b) Tib at 800 rpm as-received aluminium alloy

Fig. 8 – SEM Micrographs of the surface hybrid composites with Tib2 powder:

(a) Base metal

(b) Tib at 800 rpm as-received aluminium alloy

3.2 Micro hardness survey

The micro hardness of composites was measured and presented in Fig.9. As compared with the average hardness of about HV 106 of matrix material, the hardness value of surface hybrid composite were increased due to the presence of Tib2 reinforcement particles. In the current investigation, the Al-Tib2 composite showed higher hardness value due to the presence of soft Tib2 micro powder. The higher hardness of the surface hybrid composite is mainly due to reinforcement particles. And also observed that, as the rotational speed increases, the micro-hardness decreases. This is due to the high heat generation that causes matrix softening which decreases the micro hardness. This softening of the NZ resulted in coarsening and dissolution of strengthening precipitates in the aluminium matrix which occurs especially in heat treatable aluminium alloys. The optimum micro hardness value was obtained at the rotational speed of 800 rpm. This was due to fact

that at 800 rpm the tool shoulder supplied enough heat input and shear force to make the reinforcement particles more easily wrapped by the softening metal and rotated with FSP tool which results in well separation and distribution in the nugget zone.

Fig. 9

Table 3 Hardness of specimens at centres

Exp no	Hardness value (HV)
Exp No-1	75
Exp No -2	78
Exp No -3	96
Exp No -4	79
Exp No -5	96
Exp No -6	106
Exp No -7	102
Exp No -8	99
Exp No -9	73

3.3 Tensile Report

In general, the Al surface composites are found to have higher elastic modulus, tensile and fatigue strength over monolithic alloys. In case of heat treatable Al-alloys and their composites, the yield strength of composites increase after heat treatment by reducing the cracking tendency and improving the precipitation hardening. The composites, before fabrication process, are heat treated to an under aged condition as the materials can be shaped more easily and after fabrication, these materials are heat treated to the peak aged condition so as to provide improved mechanical properties. Among many ceramic materials, like Al_2O_3 and TiB_2 are widely in use, due to their favourable combination of density, hardness and cost effectiveness. When these reinforcements are combined with Al alloy, the resulting material exhibits significant increase in its elastic modulus, hardness and wear resistance.

In this the specimens was loaded into a computerized universal testing machine that can apply a load to the specimen at a specific rate by turning a lever. For every 1mm deflection the load was determined and the readings were tabulated and continue until the specimen fails. As the specimen is axially loaded in tension at the point of specimen gets elongated and a neck is formed and then the failure occurs variation of ultimate yield strength and ultimate tensile strength of Aluminium alloy and Aluminium / TiB_2 composite is shown in Table 4.

Table 4

Exp. No.	Yield strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation
1	166.2	238.8	10.45%
2	174.6	243.4	10.17%
3	172.4	255.1	10.00%
4	164.7	258.7	9.50%
5	192.9	267.4	9.02%
6	223.6	285.3	8.24%
7	194.2	267.2	9.22%
8	161.5	259.3	9.30%
9	186.1	272	8.50%

It is observed that composite shows decrease in properties of ultimate tensile strength, yield strength and elongation when compared with unreinforced alloy. Basically tensile properties of composite material are a strong function of nature properties of reinforced particles and matrix alloy. The fine size and shape of the reinforcement also contributed to decrease in tensile strength and yield strength of composite due to incorporation of non deformable TiB_2 .

4. CONCLUSIONS

In the present study, AA 6061 aluminium alloy base surface hybrid composites with TiB_2 reinforcement particles were successfully fabricated by using FSP. The microstructure, micro hardness and tensile behaviour were evaluated observing the matrix grains and dispersion of the reinforcement particles. The Following results were obtained:

1. It has been demonstrated that FSP was an appropriate method to modify the microstructure and mechanical properties of 6061 Al-alloy.
2. In general, FSP decreased the grain size and increased the hardness of processed-material.
3. FSP treatments improve the formability of plain samples; hence they could be used for super plastic applications.
4. The micro hardness of the Tib2 added composites surface increases significantly with increasing rotation speed. The hardness value of Aluminium with Tib2 (about HV 100) surface hybrid composites were increased as compared with the average hardness of about HV 106 of the aluminium matrix due to the presence of hard reinforcement particles.
5. The high microhardness of Al/Tib2 composite can be attributed to the presence of reinforcement particles, which also improved the tensile strength.
6. With further research efforts and increased understanding, FSP could be conducted for mechanical behaviour of these composites, like fatigue and creep response and new tool design for uniform distribution of reinforcement particles into the matrix materials.
7. Increased rotation speed and low travelling speeds caused more heat input which affects the thickness of the surface layer, grain size and distribution of the precipitates and reinforcing particles.
8. Good dispersion of Tib2 can be obtained for the composite layer produced by $\omega = 800\text{rpm}$ and $v = 15\text{ mm/min}$.
9. Good interfacial conditions between particles and base metal can be formed during this solid-state process which avoids the chemical reactions on the interface.
10. Tensile properties are decreased as compared to the base material due to the presence of reinforcement particles which make the matrix brittle.

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