EFFECT OF SIC AND TiB₂ PARTICLES ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF COPPER SURFACE COMPOSITES FABRICATED BY FRICTION STIR PROCESSING

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Abstract

Pure copper is reinforced with 20µm ceramic particles like SiCp and TiB₂ using FSP to fabricate surface composites at constant rotational speed of 1120 revolutions per minutes and speed of the weld at 40mm/min. Cylindrical taper threaded profile pin made of high carbon high chromium was used to prepare the copper surface composites. Experiments were conducted on a vertical milling machine to prepare Surface composites by varying volume percentage of reinforcements (vol.%2, vol.%4, vol.%6). six combinations of surface composites Cu/2vol.%SiC, Cu/4vol.%SiC, Cu/6vol.%SiC; Cu/2vol.%TiB₂, Cu/4vol.%TiB₂ and Cu/6vol.%TiB₂ were fabricated. The processed composites were examined by using and optical microscope to reveal the microstructure. At 4 vol. % sic particles and 4vol.% of TiB₂ particles the microstructure reveals fine grains (equiaxed) at the processed region as compared with 2&6 vol.% of reinforcements. Mechanical tests were conducted to determine ultimate tensile strength, yield strength. Hardness survey was made on the processed sample and base metal. From the results, it is found that at 4 vol. % of SiC and 4 vol.% of TiB₂ superior properties were obtained as that of vol.% 2 and vol.% 6 of reinforcements. This is attributed to the fine grains formed in the copper surface composites. Cu surface composite reinforced with 6 vol. % of TiB₂ resulted in higher hardness. As the vol. % of SiC and TiB₂ increased the resistance to wear is also increased.

Keywords: Volume percentage (vol.%); SiCp (Silicon Carbide particles); TiB₂p (Titanium diboride particles); Cu/SiC (Copper surface composite).
I. Introduction

Copper metal is a highly efficient material that is widely used in many areas for its high formability, favorable combinations of strength, ductility, excellent resistance to corrosion, thermal, and electrical conductivity, but low hardness, low wear resistance due to this its application limited to a great extent. In various engineering fields, properties of the surface decide the components of life. [II]. Fabrication of surface composites is a combination of two or more materials that give in better-required properties than parent metal individual properties. [I]. Copper-based surface composites with reinforced particles such as SiC, B4C, Al2O3, TiC, and TiB, etc. Exhibit better properties then parent metal. By using FSP, surface composites are fabricated at ease without any difficulties and also with enhanced properties. Its principle of working is same as that of FSW. [VIII, IV, IV] Barmouz et al. [VI] SiC particles are of greater technological importance due to their reinforcement applications for metal matrix composites. Sathishkumar et al. [V] applied FSP to fabricate Cu/B4C surface composites which results in the fine mixing of B4C particles in the matrix. Asadi, et al [VIII] used in his investigation instead of the conventional groove technique he has studied the hole technique to reinforcement ceramic particles like SiC and TiB2 with copper matrix and found that the agglomerations were reduced and enhanced the tensile properties. The study on the influence of SiC and TiB2 reinforced particulates on matrix is not reported so far. This work is aim to fabricate copper based surface composite by SiC and TiB2 reinforcement via single-pass FSP and also to study the effect of SiC and TiB2 particulates on microstructure and mechanical properties of the processed Cu/SiC and Cu/TiB2 composites.

II. Experimental Procedure

A pure copper plate which is 200mm long and 120mm wide and 4 mm thick was used to prepare surface composite with 20µm reinforcements of SiC and TiB2 particles. The weight percentage of element in the base metal copper is shown in Table1 and the base metal mechanical properties shown in Table 2. A vertical milling machine was used to fabricate the surface composites using a tapper cylindrical pin with threads made of high carbon high chromium (HCHCr) tool steel with given dimensions as shown in Figure1. A number of blind holes were made on the copper plate as shown in Figure1 using a pin less tool completely replace up to holes while processing. The powders SiC &TiB2 are packed in the holes to avoid fly-off. The vol.% of reinforcements is calculated as volume of drilled holes to the volume of the stir zone. Based on the calculations the 2mm diameter and 3mm depth holes were made on the base plate to accommodate the reinforcement of SiC and TiB2 for vol.% 2,4 &6. The process parameters used are 40mm/min speed of the weld, 10kN and 2° tool tilt angle. The tapered cylindrical tool pin with threads is moved along the base plate and stirs the particulates in the blind holes in fabricates the composites.
Table 1: Chemical composition of copper plate (Wt. %)

| Element | Zn  | C   | Co  | Fe  | Al  | Ni  | Cu   |
|---------|-----|-----|-----|-----|-----|-----|------|
| Amount (Wt. %) | 0.03 | 0.02 | 0.003 | 0.0027 | 0.002 | 0.001 | Balance |

Table 2: Mechanical properties of base material

| Material     | Ultimate Tensile Strength (MPa) | Yield Strength (MPa) | Percentage of Elongation (MPa) | Impact Strength (J) | Micro Hardness (HV) |
|--------------|---------------------------------|----------------------|-------------------------------|---------------------|---------------------|
| Pure Copper  | 260                             | 231                  | 31                            | 18                  | 110                 |

Fig.1: Schematic diagram of FSP tool and representation of design of blind holes on Cu plate.

The microstructure of specimens was obtained from the stir zone of fabricated surface composites these are polished for observing the microstructure. Optical microscope was used to study the microstructure changes in the nugget zone. Vickers's digital hardness tester was used to carry out the microhardness test with a 15g load for 15s duration at the Stir zone of surface composites.

The tensile specimens were cut from surface composites the using a EDM by following the standard procedure mentioned by ASTM E8. Computer-controlled universal testing machine was used to conduct the tensile test.

To find out the impact toughness value, samples were cut the transverse direction to the tool direction. The impact test was conducted using a charpy v- notch impact test. Figure 2 shows the sketches of tensile and impact specimens. The SEM was used to analyze tensile and impact specimens fractured surfaces for fractographical studies.
**Fig. 2:** Schematic sketches of tensile and impact specimen.

**Wear Test**

A pin-on-disc meter is used to conduct the wear test. Weight lost method is used to find the rate of wear of the processed specimen. The experiment is conducted at a load of 40N; speed of the disc is at 650 rpm under dry sliding conditions. Using this test the loss of mass, frictional force and coefficient of friction were found. Figure 3 shows the diagram of pin-on-disc tribometer. Standard specimens with 10mm diameter 4mm thickness for wear test were prepared through wire-cut EDM.

**Fig. 3:** Schematic diagram of Pin-on-Disc Geometry

**III. Results and Discussion**

**Microstructure**

Surface morphology of Cu/SiC & Cu/TiB₂ surface composites are shown in Figure 4. The optical micrographs of the defect-free FSPed specimens produced by single-pass FSP were shown in Figure 5. It is observed that at Cu/4vol%SiC and Cu/4vol%TiB₂ surface composites the reinforced particles are dispersed uniformly in the processed zone due to the severe dynamic recrystallization and fairly homogeneous distribution of reinforced particles. The microstructures reveal fine grains and no cluster particles are seen. Figure 5 shows the micrographs of the processed samples.

**Fig. 4:** Surface morphology of copper surface composites.
(a) Cu/2% SiC (b) Cu/4% SiC (c) Cu/6% SiC (d) Cu/2% TiB$_2$ (e) Cu/4% TiB$_2$ (f) Cu/6% TiB$_2$

**Fig. 5:** Microstructures of processed samples.

(a) Cu/2% SiC   (b) Cu/4% SiC (c) Cu/6% SiC (d) Cu/2% TiB$_2$ (e) Cu/4% TiB$_2$ (f) Cu/6% TiB$_2$

**Microhardness**

![Microhardness graph]

**Fig. 6:** Microhardness survey of Cu/SiC & Cu/TiB$_2$ surface composite

The Vicker's digital hardness tester was used to measure the microhardness of specimens. Microhardness survey of copper surface composites and base metal was shown in Figure 6. The pure copper shows an average hardness of 110HV. It was found that the microhardness of a surface composite made by Cu/6% SiC, Cu/6% TiB$_2$ was higher than that of the parent metal and other conditions of surface composites. The refinement of grains in the surface composites fabricated by FSP is due to the presence of the SiC and TiB$_2$ particles which restricted grain growth.

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during the processing. In all the processed composites, the increase in hardness in the Stir zone region of surface composites is due to the hard phase dispersion of SiC and TiB$_2$ particles.

**Mechanical Properties**

The mechanical properties are presented in Table 3. The higher tensile properties were observed at Cu/4%SiC and Cu/4%TiB$_2$ surface composites; this may be due to a homogeneous mixture of SiC and TiB$_2$ particles in a copper matrix and also the refinement of grains in the fabricated composites as that of other conditions.

**Table 3: Mechanical properties of the Copper surface composites**

| S.No | Vol.% | Ceramic particles | Ultimate Tensile Strength (MPa) | Yield Strength (MPa) | Percentage of Elongation (MPa) | Impact strength (J) | Micro Hardness (HV) |
|------|-------|-------------------|-------------------------------|---------------------|-------------------------------|---------------------|---------------------|
| 1    | 2     | SiC               | 229                           | 151                 | 7.04                          | 12                  | 124                 |
| 2    | 4     | SiC               | 248                           | 163                 | 9.07                          | 14                  | 132                 |
| 3    | 6     | SiC               | 208                           | 138                 | 7.82                          | 08                  | 153                 |
| 4    | 2     | TiB$_2$           | 277                           | 175                 | 12.7                          | 22                  | 151                 |
| 5    | 4     | TiB$_2$           | 292                           | 208                 | 14.8                          | 18                  | 160                 |
| 6    | 6     | TiB$_2$           | 220                           | 191                 | 10.9                          | 14                  | 166                 |
| 7    |       | Base metal        | 260                           | 231                 | 31                            | 18                  | 110                 |

Yield strength is found to be low when compared to pure copper because of SiC and TiB$_2$ particles. As the volume percentage increases mechanical properties are deteriorated. This may be due to improper mixing of plasticized copper with SiC and TiB$_2$ particles, which aids the formation of agglomerations. The comparison of tensile properties of copper surface composites and base metal is shown in Figure 7.

Fig. 7: Comparison of tensile properties of copper surface composites and base metal.

The energy-dispersive X-ray (EDX) analysis results were shown in Figures 8 and 9. These show the presence of Si, C, Ti, B and Cu in surface composite layers.

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Fractography

The SEM was used to analyze the fracture surfaces of tensile and impact specimens of the processed samples. The results are presented in Figures 10 and 11 respectively. From the results, it is observed that the samples made at Cu/4%SiC, Cu/4%TiB₂ show ductile fracture as compared to other conditions. This is due to the presence of dimples and fine voids at fractured surfaces.

Fig. 8: SEM Micrograph (a) and EDX results (b) of Cu/4Vol.% SiC surface composite.

Fig. 9: SEM Micrograph (a) and EDX results (b) of Cu/4Vol.% TiB₂ surface composite.

Fig. 10: Tensile fracture features of copper surface composites.
Fig. 11: Impact fracture features of copper surface composites.

Wear Properties

Figure 12. shows the rate of wear versus volume percentage of SiC and TiB$_2$ reinforcements. It is observed that the wear rate is decreased when the volume percentage of both SiC and TiB2 particles is increased. This may be due to the enhanced hardness by the distribution of SiC and TiB2 particles. The wear rate is low at the condition of 6 vol. % of TiB2.

Fig. 12: Wear rate values for Cu/SiC and Cu/TiB$_2$ surface composites

V. Conclusion

The effect of vol.% of SiC and TiB$_2$ on mechanical properties and microstructure of Cu/SiC and Cu/TiB$_2$ surface composites were studied and the following conclusions were drawn.

- The highest hardness of 166 HV has been recorded in the stir zone of processed composites at Cu/6 vol.% SiCp/TiB$_2$ of the reinforcements. This may be due to the hard phase dispersion of SiCp/TiB$_2$ reinforced particles.
- The microstructure at the processed zone of Cu/SiC and Cu / TiB$_2$ surface composites with
4 vol % of SiC/TiB₂ particles exhibits fine grains and better tensile properties compared to the other conditions of surface composites.

- There is a marginal improvement in the UTS (248 MPa) of Cu/SiC and 292 MPa of Cu/TiB₂ surface composites at the conditions of 4Vol% SiC and 4Vol% TiB₂ reinforcements respectively. This may be due to the increase in recrystallization temperature and restricting the grain boundary sliding.
- The ductile fracture was found in both the tensile and impact fracture surfaces of FSPed samples made by 4Vol% SiC and 4Vol% TiB₂ reinforcement particles. This is due to the formation of dimples and fine voids at fractured surfaces.
- It is found that as the vol. % of both SiC and TiB₂ particles are increased then the wear rate is decreased, this may be due to increased hardness by the uniform distribution of SiC and TiB₂ particles respectively.

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