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Analysis of Microstructure, Hardness and Wear of Al-SiC-TiB_2 Hybrid Metal Matrix Composite

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Abstract

Good mechanical and thermal properties of hybrid metal matrix composites make them more demanding in various fields such as automotive, aerospace and structural applications.In this paper an effort has been made to fabricate a hybrid metal matrix composite, silicon carbide and titanium diboride reinforced in Al 6061 matrix using stir casting method. Microstructure and mechanical properties such as micro hardness and wear are studied for various compositions of reinforcements, 10% SiC and 2.5%, 5% and 10% TiB_2. The results indicate that the hardness value increases with the addition of the SiC and TiB_2 reinforcements to matrix Al6061, while the wear resistance increases up to certain amount and reduces drastically when crossed the transition load.

Keywords: Al 6061, Hybrid Metal Matrix composite, Hardness SiC, Stir Casting, TiB_2, °Wear Resistance.

1. Introduction

Since aluminium has lesser density than steel, good corrosion resistance, good mechanical and recycling properties, aluminium and its alloys have been widely used in various sectors such as automotive and aerospace. Aluminium metal matrix composites reinforced with ceramic particles are gaining wide popularity as high performance material because of their improved strength, high elastic modulus and increased wear resistance, their ability to exhibit superior strength-to-weight and strength- to-cost ratio over conventional base alloy[1,2]. Al alloy based metal matrix composites are presently used in several applications such as pistons, pushrods, cylinder liners and brake discs.

The manufacturing techniques of the aluminium metal matrix composites are classified into three types namely

1. Liquid state methods,
2. Semisolid methods and
3. Powder metallurgy methods[3]

In liquid state methods, the ceramic particulates are incorporated into a molten metallic matrix and casting of the resulting MMC is done. Stir Casting is a liquid state method of composite materials fabrication, in which a ceramic particle is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods[4]. Aluminium 6061 is a metal alloy with low density and high thermal conductivity, but it has poor wear resistance. To overcome this drawback, Al alloy is reinforced ceramic materials so that its hardness, young's modulus and abrasion wear resistances are increased[5]. Ceramic materials generally used to reinforce Al alloys are SiC, TiC, TiB_2, ZrB_2, AlN, Si_3N_4, Al_2O_3 and SiO_2.Among these reinforcing ceramic particles, titanium diboride (TiB_2) which exhibits high Young's modulus (345-409 GPa), low density (4.5 g/cm^3), superior Vickers hardness (3400 HV), high melting point (3225C° ± 20), superior wear resistance and good thermal stability, and Silicon Carbide (SiC) which exhibits high elastic modulus (410 GPa), low

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density (3.2 g/cm^3) and high Vickers hardness (2600 HV) are very attractive[6,7].

Ramesh et al.[8] investigated the mechanical properties of Al 6061-TiB_2 in-situ composites fabricated by liquid metallurgy route using Al 6061 as the matrix material and Al-10% Ti and Al-3% B as reinforcements. The developed in-situ composites exhibited considerable improvement in the mechanical properties as compared to the base metal.

Jayashree et al.[9] reported that mechanical properties of aluminium metal matrix are improved by adding reinforcement of SiC. Devi et al.[10] studied micro structural behaviour of Aluminium with SiC (grit size 60) by varying mass fractions of 5%, 10%, 15%, and 20%. They observed that there is a uniform distribution of silicon carbide in aluminium metal matrix. Suresh et al.[11] prepared Al6061 reinforced with TiB_2 particles by stir casting method. Experiments were conducted by varying weight fraction of TiB_2 (0%, 4%, 8% and 12%), while keeping all other parameters constant. This study revealed that the addition of TiB_2 improves the wear resistance of aluminium composites. The results showed that increase in the mechanical properties, such as wear resistance and hardness were caused by the percentage of TiB_2 present in the samples. Prashant et al.[12] investigated the effect of SiC reinforcement particles. The hardness of metal matrix composite increases with increase in reinforcement content and the wear rate of the Al6061-SiC composite decreased with increasing SiC content. The review of literature shows that currently there is a lot of interest in fabricating hybrid MMC. Reinforcement of SiC and TiB_2 with aluminium matrix forms a hybrid metal matrix composite. The addition of TiB_2 to metal matrix composites has been observed to exponentially enhance stiffness, hardness and wear resistance[13]. In this study, reinforcement of SiC and TiB_2 for various compositions with aluminium matrix is carried out. The microstructures of composites were investigated by optical microscope and the mechanical properties like hardness and wear resistance were analyzed.

2. Methodology

Stir casting method is used for the manufacturing of metal matrix composites. This method helps to get uniform distribution of reinforcement in the matrix material by creating the vortex condition in molten metal. Al6061 is selected as a matrix material because of its properties such as high strength to mass ratio, moderate strength and low density. Silicon carbide and titanium diboride are used as reinforcement materials. SiC is a ceramic material with a very high hardness while TiB_2 is used because of the very high wear resistance and thermal stability. The mean grit sizes for SiC and TiB_2 are 30 and 12 microns respectively. Preheated reinforcement particle SiC and TiB_2 is added to the molten form of Al6061 and stirred with the stirrer at the speed of 450 rpm for duration of 15-20 mins and cast. Samples are prepared for the microstructure, micro hardness and wear test.

3. Experimental Details

3.1 Microstructure

Samples are prepared for microstructure study by using standard metallographic procedure. Samples are grinded on belt grinder followed by polishing on emery paper. Further polishing using alumina powder is done for mirror finish. Keller's reagent is applied to the samples and observed under optical microscope.

3.2 Hardness

Micro hardness of the metal matrix composites is taken for the specimens with various reinforcement proportions of 10% SiC and 2.5%, 5% Tib_2 particles in Al6061.Test is conducted on Vicker's Micro hardness tester (Matsuzawa MMT-X) with 200 gram force for duration of 10 s using a diamond indenter.

3.3 Wear Test

Wear resistance of the Al-SiC-TiB_2 composites is studied. The reciprocating type pin on plate wear concept is used for wear testing. In this study, pin is made up of mild steel with the dimensions of 8 mm diameter and 25 mm length and specimen sample is of 30×30×10 mm of metal matrix composite. Reciprocating type pin on plate wear test is carried out with the stroke of reciprocating steel pin as 17 mm and is held against the fixed specimen plate. The sliding distance is 1.2 km with sliding velocity of 0.33 m/s. Readings are taken at 50 N and 70 N load for each proportion for one hour. Analysis of wear Vs time and coefficient of friction Vs time is carried out for each specimen.

4. Results and Discussion

4.1 Microstructure

The Microstructures of samples are shown in Figures 1-3. Figure 1 shows microstructure of 10% SiC reinforcement sample. SiC is present in inter dendritic structure and is uniformly distributed in the aluminium matrix. Figure 2 shows microstructure of 10% SiC and 2.5% TiB_2 reinforcement sample. TiB_2 is present in hexagonal crystal form. These crystals are surrounded by inter dendritic structure of SiC uniformly distributed in the Al matrix. Figure 3 shows microstructure of 10% SiC and 5% TiB_2reinforcement sample. Hexagonal crystal of TiB_2 are surrounded by inter dendritic structure of SiC uniformly distributed in Al matrix.

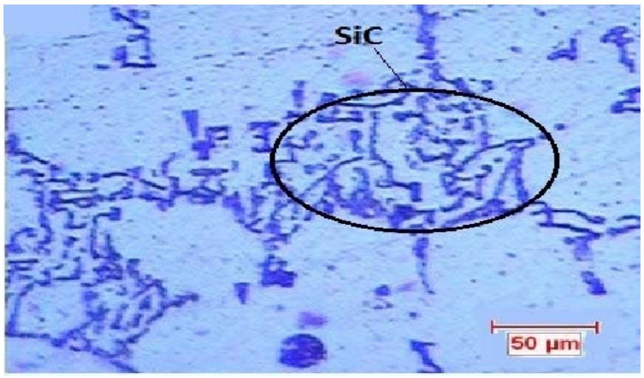

Figure 1. 10% SiC reinforcement.

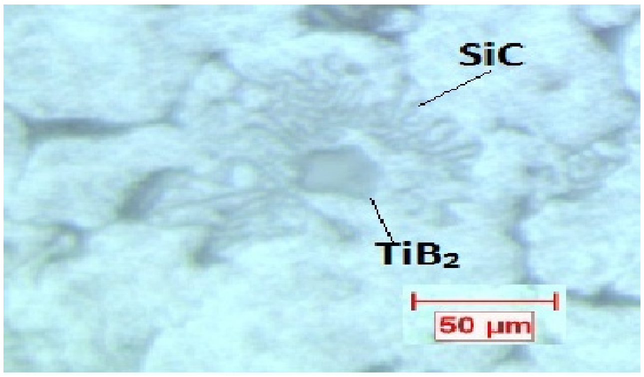

Figure 2. 10% SiC and 2.5% TiB_2 reinforcement.

4.2 Hardness

Table 1 shows the micro hardness reading for composite samples with different reinforcement percentage. It is seen that, with addition of the reinforcement, hardness of the composite increases when compared to Al 6061. Silicon carbide particle have very high hardness and when it is reinforced in the matrix material, it helps to improve the hardness properties of composite by considerable amount. Hardness of the composite depends on various factors like porosity, non-uniform distribution, and presence of cluster formation. Hardness increases by 38% in the case of Al/10 SiCp while in the case of Al/10SiCp/5TiB_2 it is 35.7%

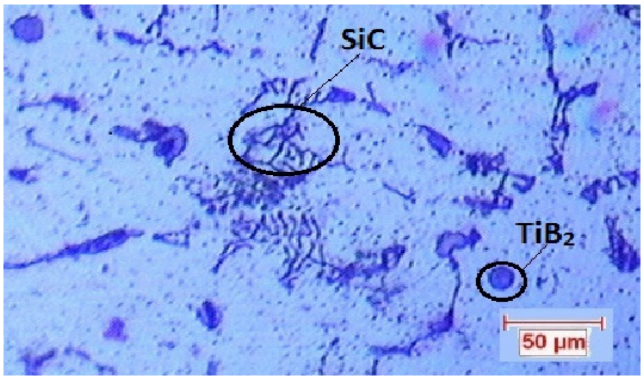

Figure 3. 10% SiC and 5% TiB_2 reinforcement

Table 1. Micro hardness reading

Specimens	Hardness
Aluminium 6061	45 HV
Al with 10% SiC reinforcement	72.28 HV
Al with 10% SiC and 2.5% TiB_2 °reinforcement	71.46 HV
Al with 10% SiC and 5% TiB_2 °reinforcement	70.03 HV

4.3 Wear Test

The Figures 4-7 show the reading of wear test taken for various samples of the composites. Figure 4 and 5 shows the graph of wear vs time for load of 50 N and 70 N respectively while Figure 6 and 7 shows the graph of coefficient of friction vs time graph for 50 N and 70 N respectively. The blue, red and green colors represent 10% SiC, 10% SiC with 2.5% TiB_2 and 10% TiB_2 reinforcement samples respectively. Samples are cleaned with acetone before and after the tests.

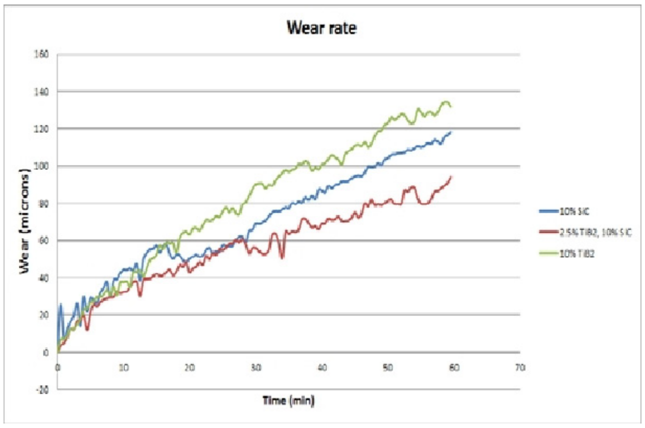

Figure 4. Graph of Wear vs. Time (50 N).

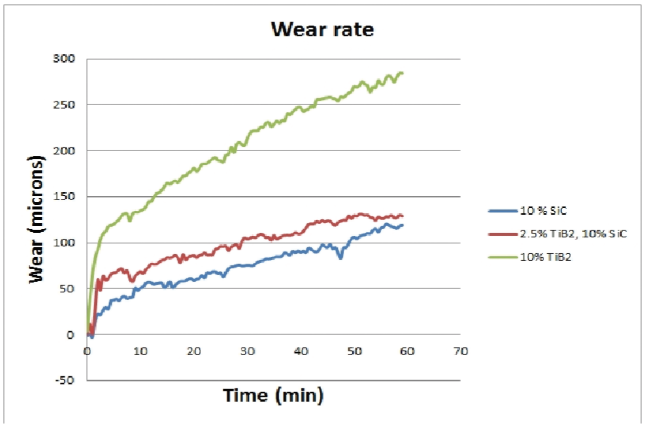

Figure 5. Graph of Wear vs. Time (70 N).

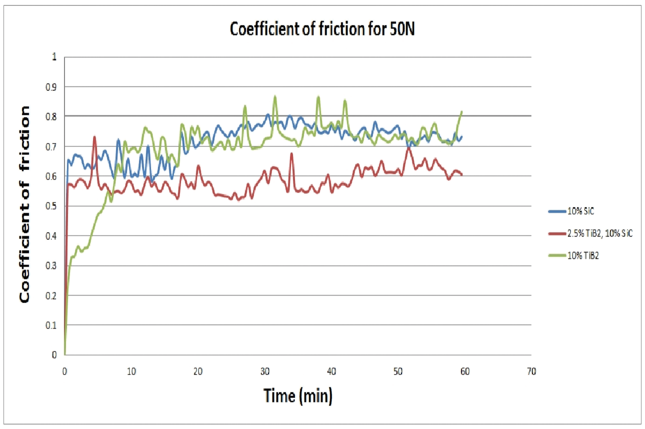

Figure 6. Graph of coefficient of friction vs. Time (50 N).

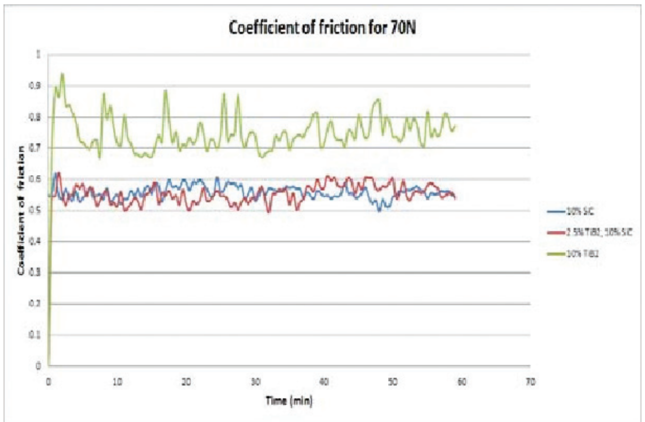

Figure 7. Graph of coefficient of friction vs. time (70 N)..

Major portion of applied load is carried by SiC. Major role of reinforcement is to carry the applied load, stresses and to avoid plastic deformation which leads to decrease in the wear rate. TiB_2 has very good wear resistance and as it uniformly distributed with the Al matrix, it helps to improve the wear resistance of the composites. Wettability is also one of the important factors in composites. Poor wettability can lead to weak interfaces between matrix and reinforcement. If bonding between matrix and reinforcement is good, then wear resistance increases considerably. But if bonding is not good enough, then wear resistance increases up to certain amount and then decreases. An increase in applied load increases the pressure on the pin resulting in an increase in the interfacial temperature, leading to the softening of the material and an increase in the plastic flow. When the loads are greater than transition load, severe wear occurs which leads to seizure of material. From the various literature survey carried out, it is found that the transition load for TiB_2 reinforced metal matrix composites is around 40 to 50 N. Beyond this load, severe wear occurs. This is very evident from the figures, wear rate increases considerably for load of 70 N. A higher degree of delamination was observed at lower applied loads, which reduces to minor delamination at higher applied loads. This may be due to greater compaction of subsurface leading to formation of dense laminated layers at higher applied loads. Similarly, results was reported by Dwivedi[14] in hypereutectic Al-Si alloy, the wear rate gradually increases with increasing applied load from 10 to 50 N. Wear rate decreased in the range of 19.46 % for an addition of TiB2p from 2.5 to 20% under tested conditions. This observed decrease may be attributed to the increase in hardness of TiB2p composites compared to the unreinforced alloy. Similar results have been during wear studies on AlSi17 alloy[15].

5. Conclusion

Al 6061 reinforced with SiC and TiB_2 hybrid composites are fabricated using stir casting method. The micro structure and mechanical properties such as micro hardness and wear of the Al-SiC-TiB_2 composites are studied. The main conclusions obtained from the present investigations are given below.

i. Dendritic structure of the SiC and hexagonal shaped crystal of the TiB2 are observed in the microstructure. Microstructure shows uniform distribution of the reinforcement with some amount of cluster formation.
ii. Hardness value increases on addition of SiC and TiB_2 to the Al6061matrix by considerable amount. Hardness increases by 38% in the case of Al/10 SiCp while in the case of Al/10SiCp/5TiB_2 it is 35.7%
iii. Wear rate and coefficient of friction decreases on addition of SiC and TiB_2 to the matrix material.
iv. The hardness and wear values decrease up to certain amount and then remain unaffected further because of dependence on various factors such as wettability and bonding between matrix and reinforcement. Excess formation of Al_3Ti flakes may decrease the wear resistance of the composite.

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7. References

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