Comparison studies on mechanical and wear behavior of Stir Cast Al-SiC-B_4C metal matrix composites

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Comparison studies on mechanical and wear behavior of Stir Cast Al-SiC-B_4C metal matrix composites

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Abstract. This paper studies the surface tribology and mechanical properties of AA6061 graded aluminum alloy matrix composite, reinforcing Silicon Carbide and Boron Carbide. In this work, the AA6061 graded aluminum alloy is reinforced with 3%, 6%, 9% (By weight) of B_4C with constant 5% (By weight) of SiC under stir casting and producing three test samples A, B and, C respectively. The Samples were subjected to wear test, tensile test, impact test, and hardness test calculating wear loss, wear rate, coefficient of friction, ultimate tensile strength, impact strength, and brinell hardness. From analyzing the results from the test conducted, it is inferred that maintaining the optimum B_4C composition between 3% and 6% in Al-SiC produces better mechanical properties and wear resistance.

1. Introduction

As our world is running on the platforms which require high-performance material, Metal matrix composites are being developed to meet the requirement by showing enhanced mechanical and wear properties. Reinforcements make the material much stiffer in comparison with unreinforced material while retaining hardness and tensile strength even at elevated temperatures [1].

Aluminum alloys find their high-end applications because of their availability, low cost, better strength, durability, low density. Metal matrix composites are motivated due to their superior mechanical properties [2]. Hybrid composites are better substitutes for Al alloy resulting in increased hardness and wear resistance [3]. Metal matrix composites are usually manufactured using stir casting and it is considered to be the successful method. They are manufactured by varying the stirrer speed, stirring time, melting temperature and it is noticed that at high stirring time and stirrer speed, hardness, and microstructures are greatly influenced. Mechanical properties like tensile strength and hardness are affected by particle size and weight % of reinforcements [4-6]. Reinforcements improve wear resistance of the composites but no significant change is noticed with more than 20% addition. Wear resistance primarily depends on sliding speed [7]. The adhesion wear of different materials varies proportional to sliding speed, time and different load [8].

Increasing SiC in aluminum increases hardness but not as much as B4C. But increasing B4C content reduces toughness. So by having optimum SiC content and increasing B4C content can yield better toughness and hardness. So by keeping SiC at the constant composition of 5%[9,10] and varying B4C in Al-SiC enhances the mechanical and wear property of Al-SiC. And found that it was a less studied area [11].

2. Materials and methods

The samples are prepared by reinforcing 5% (by weight) SiC and 3%, 6%, 9% (by weight) B_4C into the AA6061 producing three samples A, B & C respectively under stir casting. In this process, the matrix metal AA6061 Aluminum alloy is initially superheated above the melting temperature and gradually reduced below liquidus to keep the melt in a slurry state. Now preheated reinforcements B_4C of 3%, 6%, 9% (by weight) with SiC of 5% (by weight) are introduced into the melt to get better wettability and maintain the melt temperature[12] and mixed using graphite stirrer (shown in table 1). The composite slurry temperature is raised fully to liquid state and stirring was continued to about 5 minutes at a speed of about 1994.916 mm/s (750 RPM) [5]. The reinforcements are uniformly distributed throughout the matrix which we can see from figure 5. Then the melt is superheated to a minimum temperature of 1000^{o}C and poured into the cast iron mold for preparing test samples. Coil type heating element is used to perform the experiment. The castings ejected from the mold are cut and the surfaces of the samples are polished to the desired testing. Then the samples are introduced to the mechanical test and wear test.

Table 1. Test sample composition.

Tests samples	SiC	B_4C	Al alloy
A	5%	3%	92%
B	5%	6%	91%
C	5%	9%	86%

Experimental work on wear rate, tensile test, impact test, and hardness test are conducted. The wear rate test is conducted using Pin-on-Disc apparatus(specification shown in table 2). The test is conducted according to ASTM G99 standard[13]. The pin and disc surfaces are cleaned with acetone. The wear test is conducted with 10N, 20N, 30N load. The test is conducted in the disc diameter of 60mm, speed of 628.32 mm/s (200 RPM), a sliding distance of 1000m and a sliding velocity of 1.047 m/s for 15mins. The wear loss is measured using the electronic microbalance. The microstructures before and after wear are carried out using an optical microscope with a high-resolution digital camera. (shown in figure 4 and figure 5)

Table 2. Pin-on-Disc technical specifications.

Normal load range	Up to 200N
Frictional Force	200N (max)
Wear track radius	50-145mm
Wear disc diameter	Diameter-100mm & thickness-6-8mm
Pin diameter	4-8 mm diameter in steps of 2mm
Wear	0-2000 micron

The tensile strength is calculated using Universal Testing Machine. The test is conducted according to ASTM E8 standard. Each sample is first machined from the specimen according to the dimension required by the ASTM-D638[14]. The machined sample is then subjected to the tensile test. Strain measurement is measured with the extensometer and Poisson’s ratio is measured using strain gauges. The Charpy Impact test method is used to determine the impact energy, where a notched specimen fixed in an anvil is struck by a pendulum load. The specimen is 55mm long and 10mm in width. The notch depth is 2mm with a tip radius of 0.25 mm. And Hardness of the composite are determined from the Brinell hardness test defined in ASTM E10 [15].

3. Results and discussions

3.1. Wear analysis

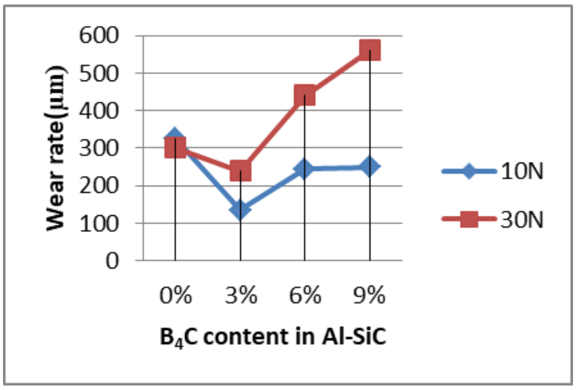

Figure 1. Wear rate plot.

From figure 1 we can see that the wear rate increases with the addition of B_4C. The wear rate reduction is appreciable between 0% and 3% composition for both the loads. With the increase in the composition of B_4C, the wear rate also increases. The reduction in wear with the inclusion of SiC and B_4C is attributed due to dispersion hardening of reinforcements which hinders the plane to slip and thus reducing wear. But with an increase in the composition of reinforcements, embrittlement of materials begin to happen due to chemical reaction between matrix and reinforcement and hence wear rate increases for 6% and 9% composition. But this implies that there is a range for reinforcement composition under which it shows better wear resistance. And we see that for 10N load with an increase in the composition of B_4C, the wear rate has no appreciable effect. This is because, with the increase in composition, the interfacial bonding increases which increase hardness and thus wear rate change is less

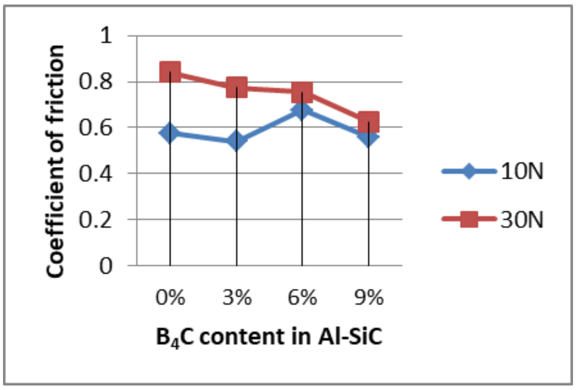

Figure 2. Coefficient of friction.

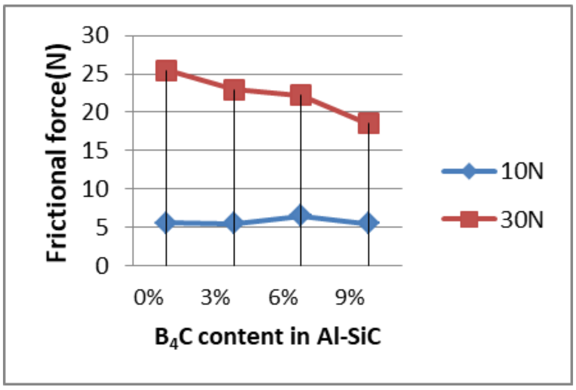

Figure 3. Frictional force.

From figure 2, we can see that the coefficient of friction increases for 10N load when composition increased from 3% to 6% and decreases with further increase in composition to 9%. But for 30N load, the coefficient of friction decreases with composition.

From figure 3 we can see that frictional force for 10N load increases for composition 3% to 6% and decreases by 9% composition. And for 30N load the frictional force decreases with composition This is because the coefficient of friction varies in the same way.

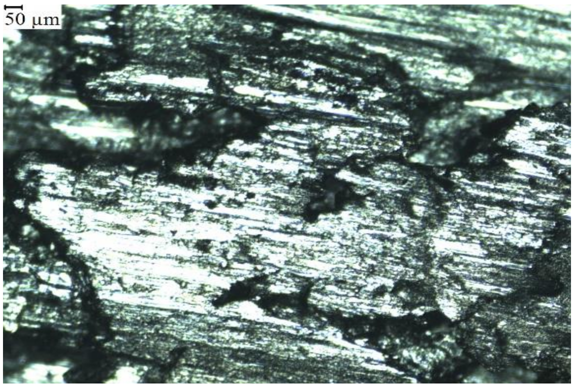

Figure 4. Sample C before wear test.

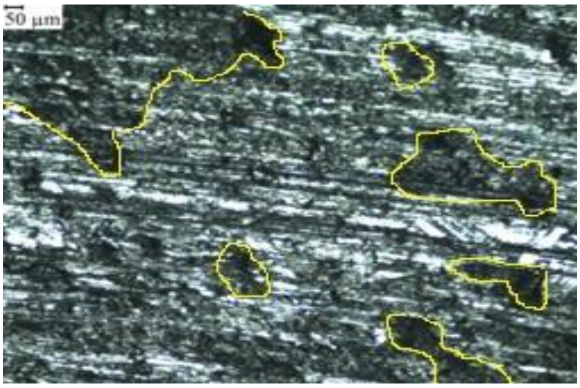

Figure 5. Sample C after the wear test.

From figure 4, we can see that the surface is not even and rough. The white part is the matrix(Aluminum) and black spots are the reinforcements(SiC and B4C). In figure 5 we can see that the uneven surface got fractured and became smoother. The spot outlined with the yellow line is the fractured region which occurs due to embrittlement of B4C and thus removing the matrix with it because of strong interfacial bonding with reinforcements. And we can also see the uniform distribution of reinforcements in the matrix in figure 5.

3.2. Mechanical test

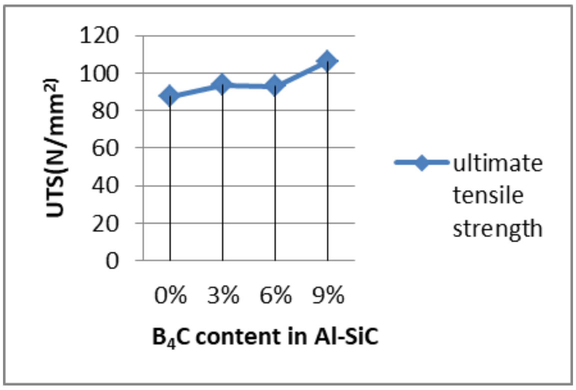

Figure 6. Ultimate tensile strength.

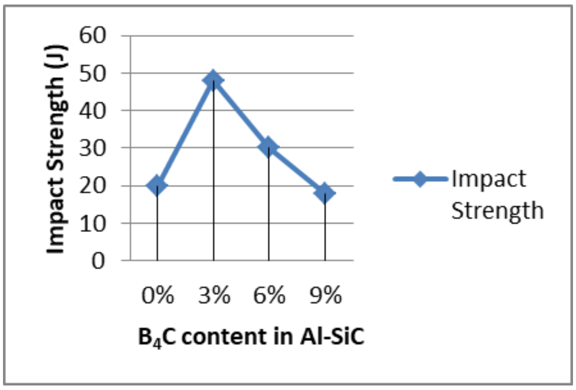

Figure 7. Impact strength plot.

From figure 6, we can see that with the inclusion of reinforcements, tensile strength increases and is maximum for 9% B_4C composition and is almost the same for 3% and 6% composition. This increase is because, with the application of load, the dislocation of lattice occurs. With the inclusion of reinforcements, these dislocations are hindered due to dispersion hardening and resulting in increased strength.

From figure 7, we can see that the Impact strength of composite decreases with an increase in B4C. With the addition of B4C, the brittleness of material increases and hence the material will fracture without plastically deforming resulting in low toughness.

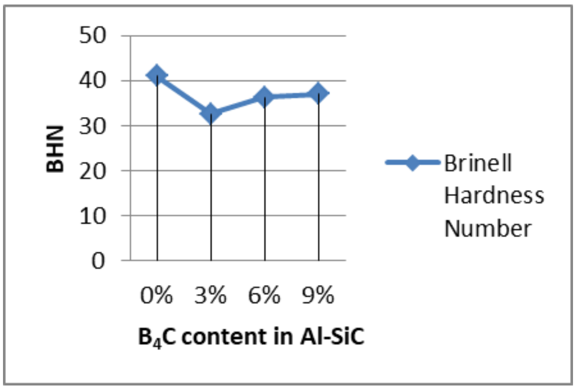

Figure 8. Brinell hardness plot.

From figure 8, we see that, increasing B4C content, increases the hardness of the composite. This is because, with the inclusion of hard particles, the hardness of the composite also increases. As B4C is the third hardest material known, the hardness of material increases with its composition

From figure 7 and figure 6, we see that composition A has maximum toughness and minimum tensile strength of the sample preparation. And from figure 8 it is implied that hardness of composition B and C are almost the same and the hardness increase between 3% and 6% is moderately less. From wear resistance results we conclude that having an optimum composition between 3% and 6% of B4C by weight shows increased wear resistance. So from the overall result, we conclude that preparing composite containing optimum B4C content in Al-SiC composite between 3% and 6% shows a better wear resistance and mechanical properties.

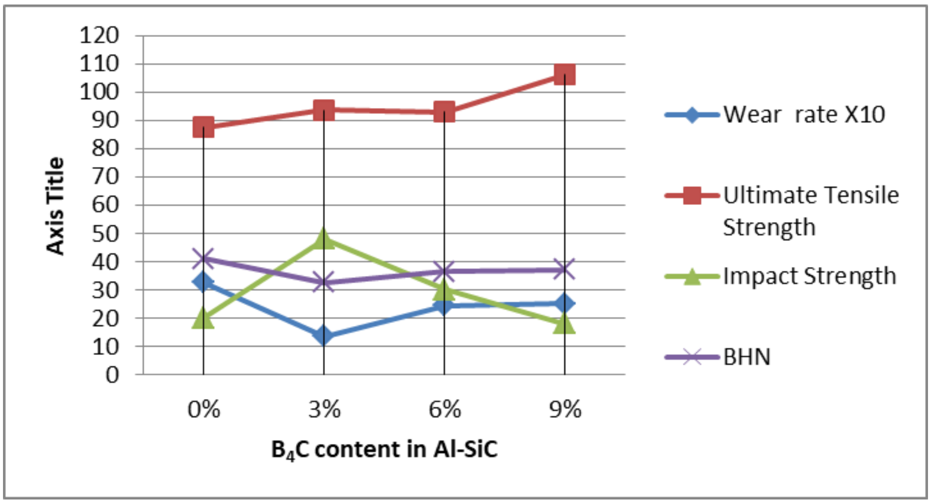

Figure 9. Comparison of Mechanical Properties and Wear.

Hardness and wear rate variation follows a similar trend while tensile strength and impact energy follow inverse variation trend. And from figure 9, we can see that hardness and wear rate increase with the composition of B4C while impact energy and tensile strength vary inversely with B4C content. (i.e. tensile strength increases and impact energy decreases). With increases in reinforcements, interfacial bonding of reinforcement with matrix increases, providing hindrance to lattice dislocation, resistance to abrasion and indentation for the load. Because of which tensile strength, wear rate and hardness increase. But with the increase in B4C content, brittleness of the material increases due to which impact energy decreases.

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4. Conclusion

The aluminum alloy matrix composites were prepared by reinforcing SiC and B_4C of various composition and subjected to wear test and various mechanical test. Following are the conclusions made from this work:

Wear resistance of material increases with the addition of B_4C in Al-SiC composite but decreases with an increase in its inclusion.

Tensile strength of material increases with an increase in B_4C content in Al-SiC

Toughness of material degrades with the addition of B_4C

Hardness increases with the inclusion of B_4C

From observing the curve trends obtained from the different plot, it is seen that composite having B_4C content between 3% and 6% by its weight shows better mechanical properties and wear resistance

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