Mechanical and Wear Behavior of Al-6061 Aluminum Alloy Composites Subjected to B_4C Particulates Produced using Stir Casting

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Abstract— **The improvement in the mechanical properties of composites is always an essential requirement for technological development. In this work, aluminum matrix composites fabricated using stir casting technique with addition of B_4C as reinforcement (6% by weight basis) was employed for the production of castings. Chills extract heat and promote directional solidification. Here chills with different thermal conductivity were used i.e. made of copper, cast iron and mild steel. In the current work an attempt is made to study the mechanical and wear behavior of Al6061 alloy reinforced with B_4C particulates. The effect of addition of B_4C with different chill materials on mechanical properties such as microstructure, micro hardness, tensile strength and wear properties (under dry sliding condition) was assessed from base alloy and alloy with B_4C addition. The result of the above investigation has been compared with base alloy and thorough analysis has been made. The results of the investigation are useful to the foundry men, automobile sector and aerospace industries to select this material as the candidate material for the specific application.**

Keywords—Aluminium alloy; B_4C particulates; stir casting;Chills

I. INTRODUCTION

Metal–matrix composites (MMCs) are most promising materials in achieving enhanced mechanical properties such as: hardness, Young's modulus, yield strength and ultimate tensile strength due to the presence of micro-sized reinforcement particles into the matrix and Aluminum-matrix composites (AMCs) reinforced with discontinuous reinforcements are finding increased use in automotive, military, aerospace and electricity industries because of their improved physical and mechanical properties. Among Al-alloys, 6061Al-alloy is widely used in engineering applications such as transport and construction sectors where superior mechanical properties like tensile strength, hardness etc., are essentially required [1]. As compared to different types of aluminium alloys, Al6061 containing Aluminium-Magnesium-Silicon alloy shows better resistance to wear, higher thermal conductivity, specific strength and lower thermal coefficient of expansion. Of late, it is one of the most commonly used reinforcement to advance the properties of composites. The presence of SiC in the metallic Al matrix recuperates overall strength along with corrosion and wear properties. The third hardest reinforcement material B_4C as compared to cubic boron nitride and diamond is one of the alternative reinforcements for SiC reinforced composites, where higher stiffness and wear resistance are the two major requirements for different applications in aerospace and automobile industries. This is primarily owing to the lower density, higher chemical inertness temperature stability of B_4C reinforcements. Liquid state processing such as stir casting process the shows better matrix-particle bonding due to the formation of vortex during stirring action of particles into the melts. The factors that determine properties of composites are microstructure, homogeneity of reinforcements and isotropy of the system are strongly influence properties of the matrix and the reinforcement [2]. It is well known that Al alloy-based composites freeze over a wide temperature range and are difficult to feed into a mould cavity during solidification. The dispersed porosity caused by the pasty type of solidification of long-freezing-range alloy castings can be effectively reduced by the use of chills. Chills extract heat from the melt more rapidly and promote directional solidification. Therefore, they are widely used by foundry men in the production of quality castings [3]. The effect of reinforcement type on the tensile properties of the Al- B_4C and Al-SiC composites and observed that the strength of Al-B_4C composite is greater than that of the Al-SiC composites [4,6].

The aim of present study is to synthesize 6061Al-B_4C particulate MMC by stir casting method using chills. In order to improve wettability and distribution of reinforcing particles a three stage mixing of the reinforcing particles is being adopted.

TABLE 1: CHEMICAL COMPOSITION OF AL-6061 ALLOY

ELEMENTS	%By Wt
Al	REMAINING
Cu	0.16
Mg	0.83
Si	0.52
Fe	0.26
Mn	0.03
Zn	0.01
Ti	0.10
Cr	0.15

TABLE 2: TYPICAL PROPERTIES OF BORON CARBIDE

	Value
Density (g.cm^{-3})	2.52
Melting Point (°C)	2445
Hardness (Knoop 100 g) (kg.mm^{-2})	2900 - 3580
Fracture Toughness (MPa.m$^{-½}$)	2.9 - 3.7
Young's Modulus (GPa)	450 – 470

Electrical Conductivity (at 25 °C) (S)	140
Thermal Conductivity (at 25 °C) (W/m.K)	30 - 42
Thermal Expansion Co-eff. x10^{-6} (°C)	5
Thermal neutron capture cross section (barn)	600

EXPERIMENTAL PROCEDURE

In the present study the matrix material used is Al6061 alloy. The B_4C particles with size of 105 microns with 6wt% are used as reinforcing material in the preparation of composites. Stir casting method has been used for the preparation of composites. Calculated amount of charge was placed in the graphite crucible and superheated to a temperature of 800°C in an electrical resistance furnace. A three stage mixing combined with preheating of the reinforcing particles is followed. To remove the observe gases from the particle surface the B4C particulates were preheated to a temperature of 200°C in an oven and introduced into the vortex of the molten alloy after effective degassing using solid hexachloroethane. The incorporation of B_4C particles in the matrix alloy was achieved in steps of three with intermediate mechanical stirring. Then, this molten metal was poured into the dried moulds with chills located in appropriate position. Specimen for structure examination, tensile studies and wear studies were machined from the base alloy and the alloy treated with reinforcement additions made using different chills.

Figure 1 shows the prepared green sand mould to produce composites.

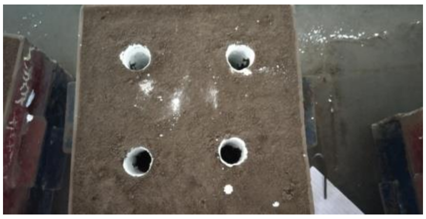


Figure 1: Green sand Mould

Microstructural studies were conducted using optical microscopy (Nikon Microscope LV150 with Clemex Image Analyser confirming to ASTM E3-11 specification) with specimen dimension of 20mm diameter and 10 mm height as shown in figure 2.

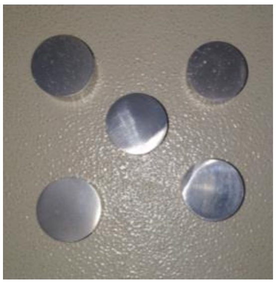


Figure 2: Specimens for Microstructure examination

To investigate the mechanical behavior of the composites the hardness and tensile tests were carried out using Brinell hardness tester and bench type tensometer and the specimens were as shown in figure 3 & 4.

In hardness studies, 5 mm diameter ball indenter, 100 kg load was applied for 30 seconds duration and the average indentation was measured (travelling microscope). The above procedure was followed to assess the hardness of the base alloy and the alloy reinforced with B_4C additions made using different chill materials. Specimen conforming to ASTM E8 standard has been used for the assessment of UTS properties. Dimension of the specimen: 20mm diameter and 10mm height.

Figure3: Brinell hardness specimen

Machined Specimen conforming to ASTM E8 standard has been used for the assessment of UTS properties.

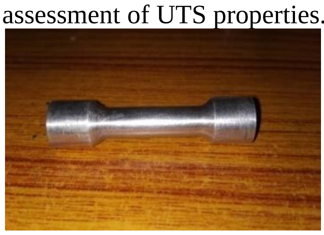


Figure 4: Bench type tensometer specimen

Specimen conforming to ASTM G99-05 standard has been used for the assessment of wear properties and dry sliding conditions. Fig 5 and 6 shows the standard wear specimen and pin on disc machine used to assess the sliding wear of the specimen. The parameters considered during test were track radius: 50mm, time: 5minutes constant, load applied: 1kg 2kg and 3kg and speed: 600rpm.

Figure 5: pin on disc machine

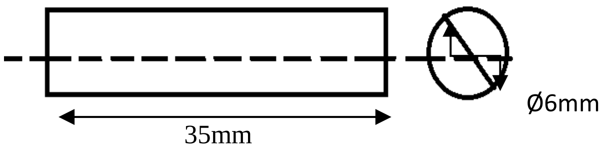


Figure 6: standard pin on disc specimen.

- Length : 35mm
- Diameter : 6mm

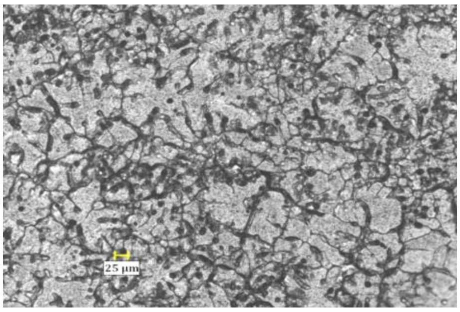
RESULTS AND DISCUSSION

A. Microstructure Examination

Microstructure examination was carried out using using Nikon Microscope LV150 with Clemex Image analyzer. Following figures 7, 8, 9 and 10 show the details of the optical micrographs of base alloy and alloy with B_4C additions made using three different chill materials. It can be observed that the reinforcement addition namely B_4C particles are uniformly dispersed in matrix material.

With copper chills

100X



500X

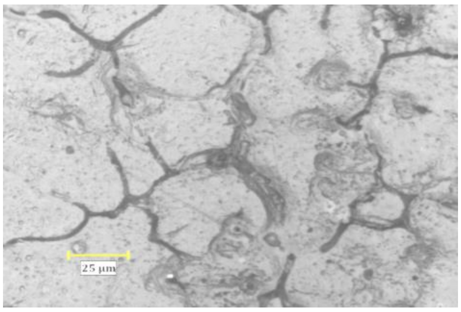
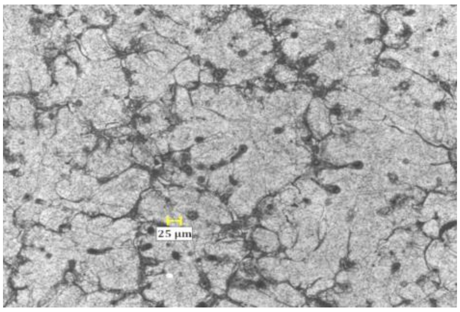


Figure 7: the microstructure of casting made by using copper chill

Figure 7 shows the details of microstructure of castings reinforced with boron carbide using copper as chill material. Homogenous dispersion of the boron carbide is observed in the above microstructure. Fine grain structure is also observed.

With Mild steel chills

a) 100X



b) 500X

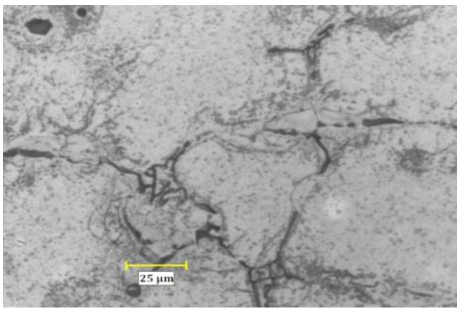
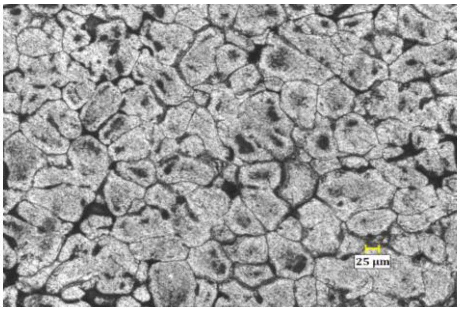


Figure 8: the microstructure of casting made by using Mild Steel chill

Figure 8 shows the details of microstructure of castings reinforced with boron carbide using mild steel as the chill material. Here also Homogenous dispersion of the boron carbide is observed in the microstructure. Coarse grain structure is seen. The reason might be moderate heat extraction of the chill material used (mild steel).

With Cast Iron chills

a) 100X



b) 500X

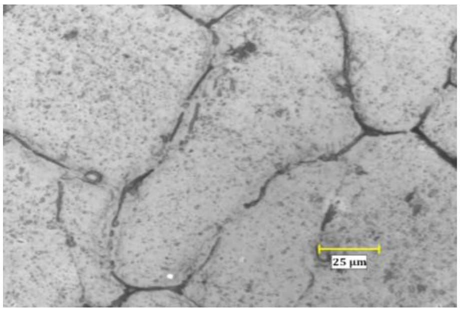
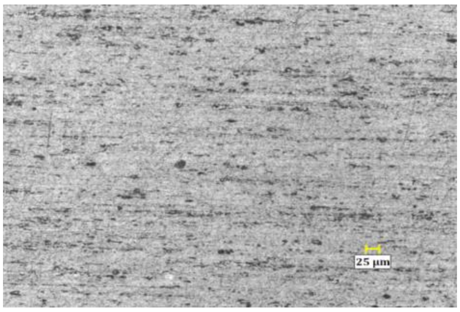


Figure 9: the microstructure of casting made by using Cast Iron Chill

The details of microstructure of castings reinforced with boron carbide using cast iron as the chill material is shown in figure 9. Homogenous dispersion of the boron carbide is observed in the above microstructure. Coarse grain structure is seen in the above case. Moderate heat extraction with respect to chill material used (cast iron) may be the reason for coarsening of the structure.

Base Alloy

a) 100X



b) 500X

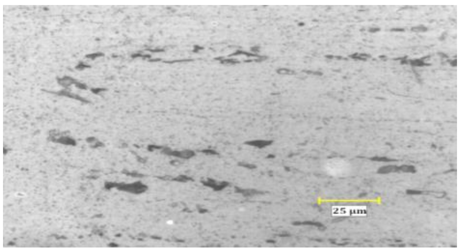


Figure 10: the microstructure of base alloy
Figure shows the details of the microstructure of the base alloy.

B. Hardness test

Figure 11 shows the histogram drawn for the hardness values of base alloy and alloy made by using three different chill materials. It can be observed from figure that the base alloy exhibits least BHN value compared to other conditions. Alloy reinforced with B_4C addition exhibit higher BHN value compared to base alloy, indicating that B_4C has an effect in BHN. Maximum value of BHN is observed for specimen made by using Copper chill material. This might be attributed to higher heat extraction (thermal conductivity) compared to the other two chill materials studied.

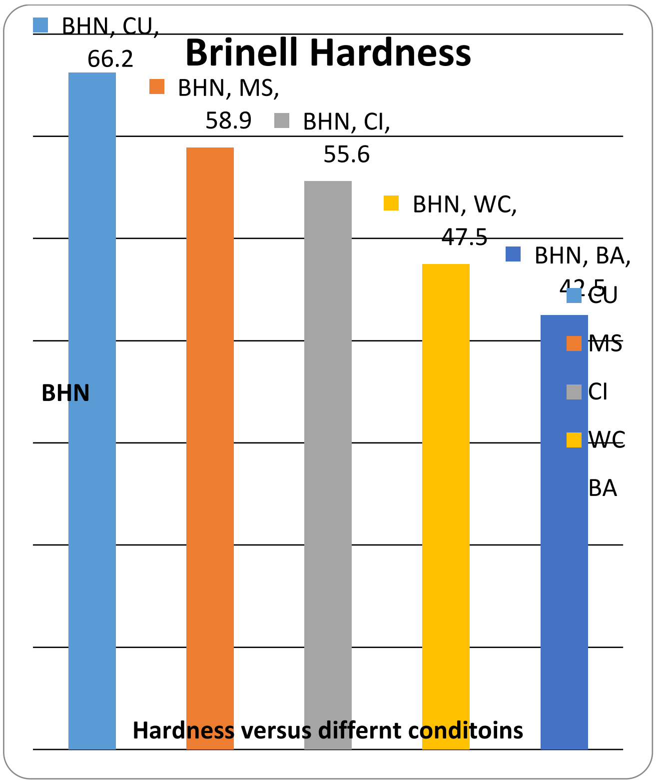


Figure 11: Hardness versus different conditions

C. Tensile test

Figure 12 shows the histogram drawn for the UTS values of base alloy and alloy made by using three different chill materials. It can be observed from figure that the base alloy exhibits least UTS value compared to other conditions. Alloy reinforced with B_4C addition exhibit higher UTS value compared to base alloy, indicating that B_4C has an increasing value in UTS. Maximum value of UTS is observed for specimen made by using Copper chill material. This might be attributed to higher heat extraction (thermal conductivity) compared to the other two chill materials studied.

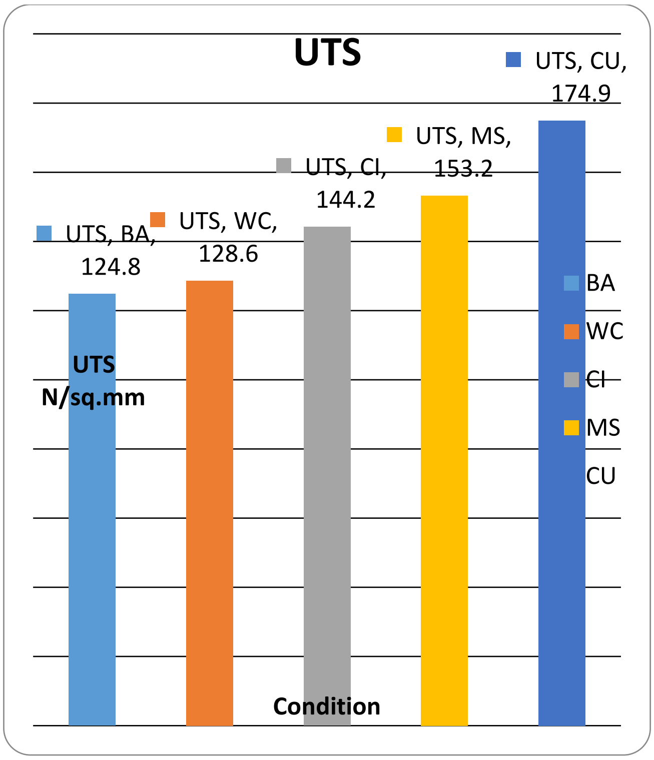


Figure 12: Histogram-UTS Values-Different conditions.

D. Wear Testing (Dry sliding conditions)

Following Figures show the line graph and histogram drawn for the weight loss of base alloy and specimen made by using three different chill materials. It can be observed from figure that the base alloy exhibits higher wear value compared to other conditions. Alloy reinforced with B_4C addition exhibit lower wear value compared to base alloy. Specimen made using Copper chill exhibit lower wear compared to the ones made by using other two different chill materials. Similar trend in wear values is observed for other conditions.

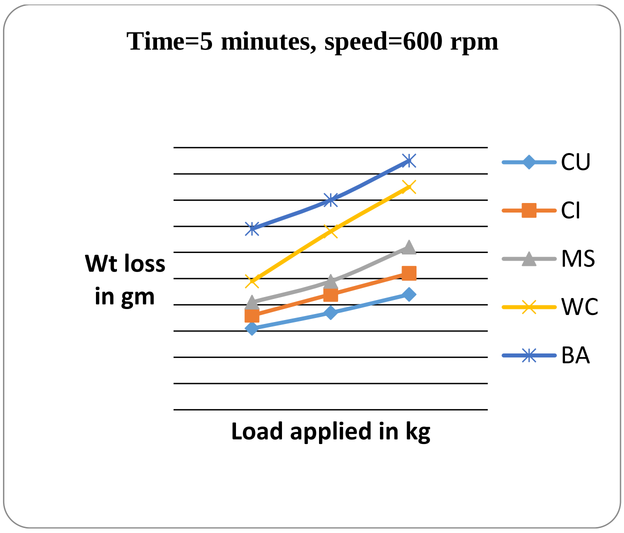


Fig 13: Variation of weight loss with load.

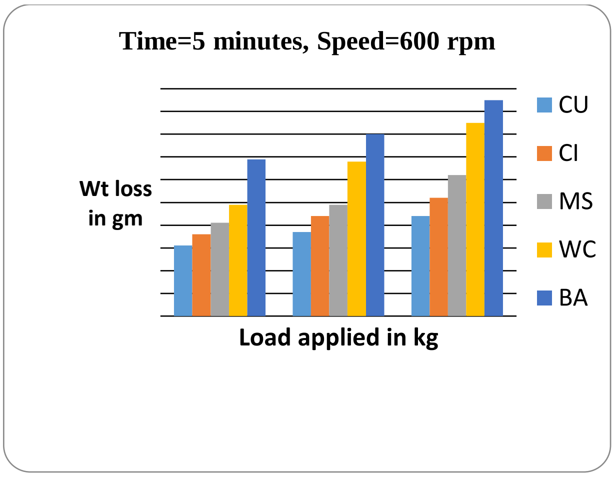


Fig 14: Histogram- Variation of weight loss with load.

CONCLUSION

The studies on mechanical properties and wear properties of Al-6061 alloy reinforced with B_4C addition produced using stir cast method with different chill materials indicate the following.

- Aluminum 6061 reinforced with B_4C composites was successfully produced using different chill materials.
- Microstructure examination reveals the presence of B_4C particles. Fine grain structure was observed in specimen made using copper as the chill material.
- Hardness value was found to be more for the specimen made using copper as chill material with B_4C addition.
- UTS value was found to be more for the specimen made using copper as chill material with B_4C addition.
- From the dry sliding wear studies it is clear that, the specimen reinforced with B_4C additions using copper chill material exhibits least wear compared with other chill materials.

REFERENCE

[1] Bharath V, , Madev Nagaral, , V Auradi ,and S. A. Kori "Preparation of 6061Al-Al2O3 MMC's by Stir Casting and evaluation of Mechanical and Wear Properties" Procedia Materials Science 6 (2014) 1658 – 1667 , 2211-8128 © 2014 Elsevier Ltd

[2] Gowrishankar M C, Pavan Hiremath, Manjunath Shettar, Sathyashankara Sharma, Satish Rao U "Experimental validity on the casting characteristics of stir cast aluminium composites" https://doi.org/10.1016/j.jmrt.2020.01.028 2238-7854/© 2020

[3] K.H.W. Seah , J. Hemanth , S.C. Sharma "Mechanical properties of aluminum quartz particulate composites cast using metallic and non-metallic chills" Materials and Design 24 (2003) 87–93,doi:10.1016/S0261-3069(02)00144-9

[4] S. Rama Rao, G. Padmanabhan "Fabrication and mechanical properties of aluminium-boron carbide composites" International Journal of Materials and Biomaterials Applications 2012; 2(3): 15-18, ISSN 2249–9679

[5] ASM handbook vol.2 properties and selection: Nonferrous Alloys and Special-Purpose Materials.

[6] K.C. Nagaraja, S. Rajanna, G.S. Prakash, P.G. Koppad, and M. Alipour, "Studying the effect of different carbon and glass fabric stacking sequence on mechanical properties of epoxy hybrid composite laminates," Composites Communications, pp. 100425, 2020.