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An Experimental Study on Wear Strength of Aluminium 7075 Reinforced with Magnesium and Boron Carbide

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Abstract: ***Over the past decade, the demand for lightweight materials with exceptional energy properties and high strength-to-weight ratios has significantly driven advancements in the automotive and aerospace industries, favoring the development and utilization of aluminium alloy-based composites. In this study, Aluminium 7075 (Al 7075) is reinforced with 2% by weight of magnesium and varying proportions of boron carbide particles. The composite is fabricated using the stir casting method. Aluminium 7075 serves as the base material, with a constant magnesium content and boron carbide particles added at variable ratios of 0%, 0.5%, 1%, 1.5%, and 2%. To ensure a uniform distribution of reinforcement particles, the mixed material is cast into cylindrical shapes using a metal mold. The resulting samples are machined to evaluate their pin-to-disk wear behavior under dry sliding conditions. A ground EN-32 disc with a surface roughness of 0.394 µm and a hardness of 62 HRC serves as the rotating counterpart, while the composite sample (pin) remains fixed. Testing parameters include a fixed sliding distance of 2000 meters, a velocity of 2.5 m/s, and a normal load of 20 N. The microstructure and mechanical properties of the composite specimens are examined to assess tensile strength, hardness, and wear performance in accordance with ASTM standards. Scanning Electron Microscopy (SEM) is employed to analyze particle distribution and surface characteristics.***

Keywords: Metal matrix composite, Aluminium 7075, Magnesium, Boron Carbide, Stir casting

1. Introduction

Materials which have been using from the last few decades, have such a large influence on our lives that mankind itself of ancient times, has been named after materials predominantly used in that age. Over the years, discoveries and inventions of scores of materials with ever evolving properties have resulted in the modern-day materials like alloys, composite materials, plastics and ceramics. Particularly, the scale and numeral of applications of composite materials has developed gradually, penetrating and successful fresh markets tirelessly.

Composite materials are the combination of two or more different materials to synthesize a new material with better performance. Aluminium is a noble material known for its suitability in the applications where high strength and low weight is significant. But its low wear characteristic restricts it in the application where a function of material wear is noticed. In this context, reinforcement of boron carbide and magnesium with suitable percentage is an added advantage to use the composite where low weight and high wear strength is required.

Experimentation:

1. Selection of Matrix Alloy

In this study, 99% pure Al 7075 and 99% pure industrial magnesium were used as the matrix for the synthesis of particle-reinforced metal matrix compound. The boron carbide particles act as a reinforcing agent to keep these particles in the melt. The chemical properties of Aluminium 7075 are mentioned in table 1.

Table 1: Chemical composition of the Aluminium 7075 (Al 7075) and Magnesium

Chemical properties of Aluminum 7075	
Fe	0.27
Mn	0.03
Cu	0.28
Zn	0.06
Si	0.52
Mg	1.03
Al	Bal.

2. Selection of Reinforcement

In this investigation, boron carbide (B_4C) with a purity of 99% is used for the reinforcement and the properties are shown in Table 2.

Table 2: Properties of Boron carbide (B_4C)

Sl. No	Properties	Values
1	Density	2.52 g.cm-3
2	Melting point	2445 °C
3	Hardness	2900-3580 kg. mm-2
4	Fracture toughness	2.9 – 3.7 MPa m-1/2
5	Young's modulus	450 – 470 GPa
6	Electrical conductivity	140s at 25 °C
7	Thermal conductivity	30 – 42 W/m. k at 25 °C
8	Thermal expansion	5°C
9	Thermal neutron captures cross section (barn)	600

3. Fabrication Procedure:

Aluminium is used as a matrix materials and magnesium as a reinforcement with constant quantity of 2 Wt.% in all casting along with boron carbide with varying weight fraction of as cast of (0%), 0.5%, 1%, 1.5% and 2 Wt.% of Aluminium. For the fabrication of specimen stir casting method is employed. The electric furnace is preheated to 300°C for oxidation and evaporate the impurity. The raw material of Aluminium alloy is heated to a temperature of 650°C to convert it into molten metal state. The magnesium in chip form of 2 wt. % in each casting and boron carbide in power form with its grain size of approximately 10µm is used as the reinforcing materials. Magnesium chips and boron carbide powder were added in uniform manner as in percentage weight ratio and stir in electrical stirrer in clockwise, anticlockwise and radial direction for a period of 8 minutes to conform the uniform mixture and then poured to mould to get the required shape of specimens. Then the specimen is machined to get cylindrical pin of dia.10 mm and length30 mm.

4. Heat treatment:

The heat treatment process was selected as a sideline. Heat treatment is a type of industrial, thermal, and metallurgical process used to change the physical and sometimes chemical properties of materials. Heat treatment is also used in manufacturing of materials such as glass, ferrous and nonferrous. Annealing, surface hardening, precipitation hardening, tempering, carburizing, normalizing and quenching include heat treatment processes.

The challenge is to select a heat treatment cycle that can provide the most suitable characteristics. The heat treatment of metal matrix composites (MMC) has another aspect, because the particles introduced into the matrix will change the surface characteristics of the alloy and increase the surface energy.

Heat treatment of the composite specimen is done in three stages.

1) Dissolution: Heat the sample to a temperature of 530°C for 3 hours until the dissolved elements of the alloy are completely dissolved in the Al solid solution.
2) Annealing: The solution-treated sample is quickly cooled in water to prevent material deformation. The sample is superheated to 170°C for 2 hours each before precipitation of dissolved elements.

5. Material Characterization:

Composed materials are subjected for their characterization. Scanning electron microscopy (SEM) is used for testing and the images are depicted in Figure 1(a to e) and the EDAX in Figure 2;

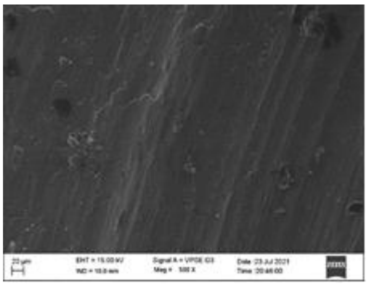
Sem And Edax Results

Al 7075 is used as the base material and 2% by weight of magnesium to improve the wettability of the compound. B_4C is added as a reinforcing material in various amounts of 0.5, 1.0, 1.5, and 2.0% by weight.

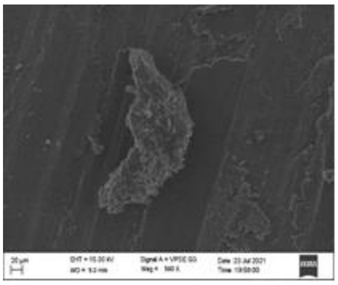
The distribution of particles in the matrix composition was observed by SEM and the results were shown together with EDAX analysis. Scanning electron microscope (SEM) a focused electron beam which generates an image over the surface. The electronic beam which is related with beam for producing alternative signal used to gather information on topography and composition of materials surface. Figures shows the distribution of Al7075 with magnesium and boron carbide.

SEM Results

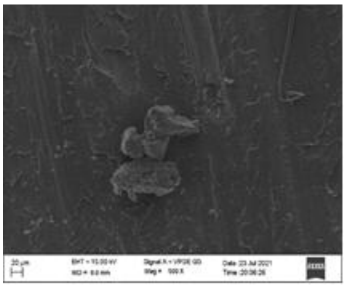
A scanning electron microscope (SEM) scans an electron beam focused on the surface to create an image. The electrons in the electron beam interact with the sample and generate various signals, which can be used to obtain information about the topography and properties of the surface. Figure 1,2 shows a micrograph of the composite material obtained with a scanning electron microscope. The figure shows the distribution of Al 7075 and boron carbide.



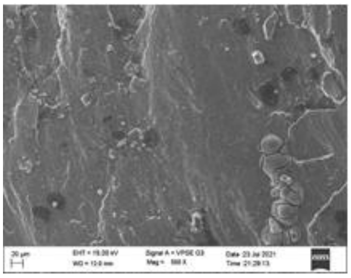
(a). Al 7075-Mg-0%B_4C



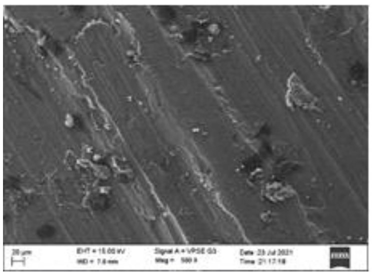
(b). Al 7075-Mg-0.5% B_4C



(c). Al 7075-Mg-1% B_4C

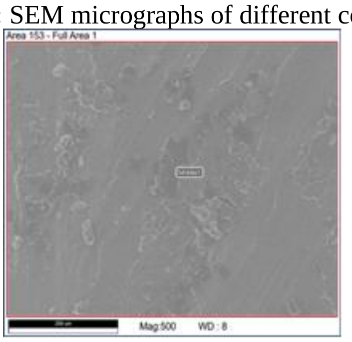


(d). Al 7075-Mg-1.5% B_4C



(e). Al 7075-Mg-2% B_4C

Figure 1: SEM micrographs of different composite



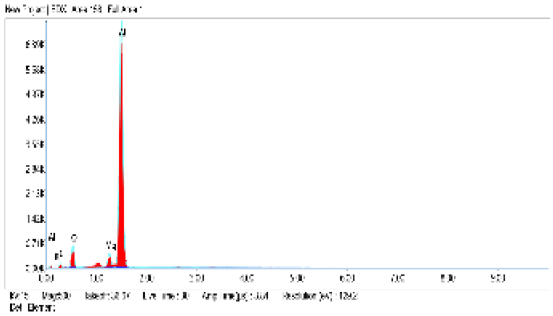


Figure 2: EDAX of composite Al7075-Mg-B_4C

Testing:

Experiments are conducted to measure the tensile strength, hardness and wear strength of the material. ASTM E-8 are referred for the preparation of components and followed for test procedure.

Tensile properties

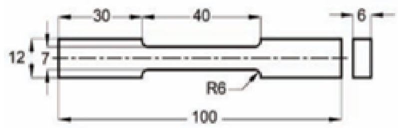


Figure 3: Schematic representation of tensile specimen ASTM E-8 standard

All composite materials are tested on a universal testing machine at a speed of 1mm/min under uniaxial loading. The average value of these tensile strength, yield strength and elongation are given in the tensile strength value of the material.

Hardness of Composite

The measurement oh Brinell hardness for composites formation of Al-2Wt.%Mg-B4C with hardened steel round ball indenter with 5 mm diameter of 250kg load applied to the specimen for 30 seconds, and with the help of tool manufacturer microscope, the indentation diameter was measured. For through indentation, the hardness was calculated using average of three diameter calculated perpendicular to each other. Three indentation were made at different location on each specimen for hardness measurements then the average of these values was recorded as the hardness of specimens.

Wear test

Aluminium is reinforced with different weight percent of boron carbide and a constant 2 weight percent of magnesium. A constant load of 20 N is applied as normal load. The experiment is conducted and the wight loss of the material when it slides on the disc is noted.

$$BHN = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

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2. Results and Discussions

Tensile strength:

The yield strength, ultimate tensile strength, and elongation of the casting and heat treatment composition are measured. The untreated and heat-treated compositions are compared and listed in the table below. These results indicate that the yield strength and tensile strength of the untreated and heat-treated compositions increase as the weight percentage B4C increases by 2% by weight. B4C has the highest yield strength and tensile strength, and 0wt% elongation is the highest.

Table 3: Tensile properties of the compositions

Compositions	Yield strength (MPa)		Tensile strength (MPa)		Elongation %	
	Untreated	Heat treated	Untreated	Heat treated	Untreated	Heat treated
Al-Mg	120.81	189.61	145.64	229.36	12.06	13.57
Al-Mg-0.5%B4C	149.31	203.4	173.62	246.31	10.68	11.48
Al-Mg-1%B4C	165.87	236.3	186.31	279.33	9.48	10.82
Al-Mg-1.5%B4C	192.14	262.3	223.41	309.47	8.46	9.33
Al-Mg-2%B4C	208.72	296.34	241.31	343.65	8.04	9.04

The variations in the mechanical strengths are shown in Figure 4 to fig6.

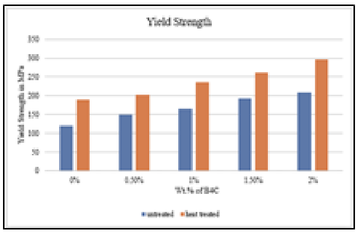

Figure 4: Yield stress with increasing addition of Boron carbide

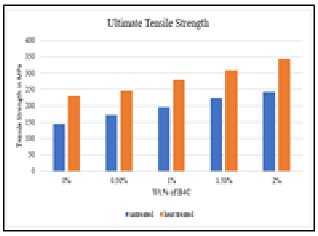

Figure 5: Tensile strength with increasing addition of Boron carbide

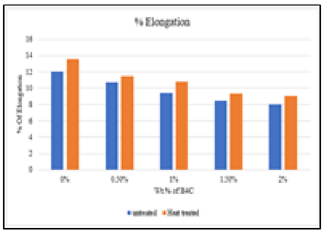

Figure 6: Percentage of elongation with increasing addition of Boron carbide

Table 3, Shows the yield strength and tensile strength of cast composites increase with the increase in addition of boron carbide, the composite with 2 wt.% of B_4C exhibiting highest yield strength and ultimate tensile strength. and 0wt.% has highest percentage of elongation in both untreated and heat treated.

Hardness:

The hardness is calculated using average of three diameter calculated perpendicular to each other. Three indentations were made at different location on each specimen for hardness measurements then the average of these values was recorded as the hardness of specimens.

Table 4: Brinell hardness test result

Samples	Compositions	BHN (untreated)	BHN (Heat treated)
1	Al-Mg	66.76	76.33
2	Al-Mg-0.5%B4C	78.4	91.36
3	Al-Mg-1%B4C	87.0	103.23
4	Al-Mg-1.5%B4C	99.2	114.2

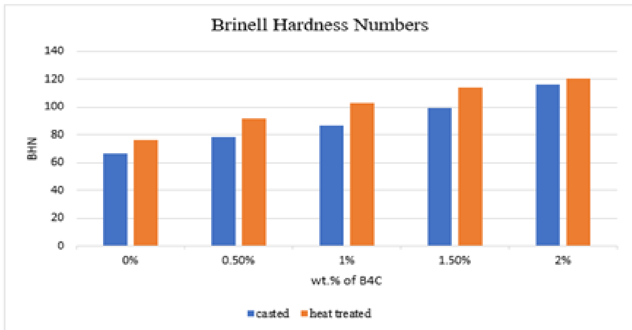

Figure 7: Hardness value of Al 7075-Mg-B4Ccomposites

Brinell hardness test concluded the macro hardness results of both untreated and heat treated of specimens shows that Al 7075 and Mg shows lowest hardness when compared to other reinforcement with 2 wt.% of B4C composition leads to the higher hardness compare to other specimen.

WEAR Results

Aluminium is reinforced with different weight percent of boron carbide and a constant2 weight percent of magnesium. A constant load of 20 N is applied as dead load. The experiment is conducted and the wight loss of the material when it slides on the disc is noted and tabulated as in table.

Table 4: based on percentage of reinforcement of B_4C and 2Wt.%Mg

(Al7075+2Wt.%Mg)

LOAD	W1	W2	W1-W2	WEAR IN Gms	
				IN Gms	PRECENTAGE
20N	6.546	6.535	0.011	0.011	0.168
20N(HT)	6.899	6.875	0.024	0.024	0.347

(Al7075+2Wt.%Mg+0.5%B_4C)

LOAD	W1	W2	W1-W2	WEAR IN Gms	
				IN Gms	PRECENTAGE
20N	6.473	6.459	0.014	0.014	0.216
20N(HT)	6.486	6.462	0.024	0.024	0.370

(Al7075+2Wt.%Mg+1%B_4C)

LOAD	W1	W2	W1-W2	WEAR IN Gms	
				IN Gms	PRECENTAGE
20N	6.613	6.585	0.028	0.028	0.423
20N(HT)	6.395	6.235	0.16	0.16	2.501

(Al7075+2Wt.%Mg+1.5%B_4C)

LOAD	W1	W2	W1-W2	WEAR IN Gms	
				IN Gms	PRECENTAGE
20N	6.624	6.610	0.014	0.014	0.211
20N(HT)	6.237	5.994	0.243	0.243	3.896

(Al7075+2Wt.%Mg+2%B_4C)

LOAD	W1	W2	W1-W2	WEAR IN Gms	
				IN Gms	PRECENTAGE
20N	6.330	6.320	0.010	0.010	0.157
20N(HT)	6.300	6.223	0.077	0.077	1.222

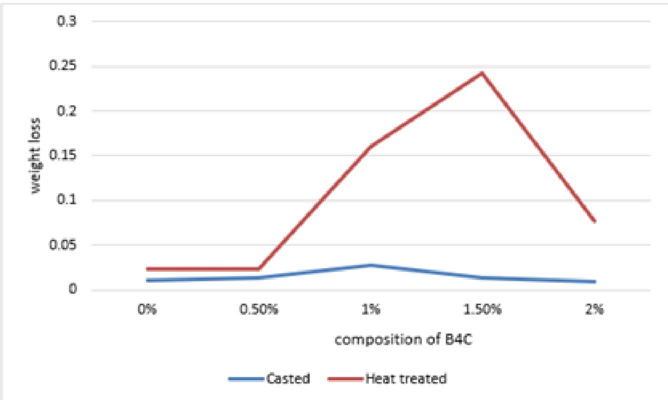

Figure 8: Weight loss comparison of untreated and heat treated at 20N.

It has been noticed that the decreasing of wear loss in untreated materials as the percentage of boron carbide increased from 0% to 2% for 20N load.

Also, for heat treated materials the wear loss is increased as the percentage of boron carbide increased from 0% to 2% with the application of 20N normal load.

3. Conclusions

Using aluminium 7075 as a matrix material, adding 2% by weight of magnesium and 0, 0.5, 1, 1.5, 2 wt.% of boron carbide (B4C), by employing stir casting and successfully developed aluminium metal matrix composites (AMMCs). With the addition of boron carbide, the improvement of the casting structure and the influence on the mechanical properties of the new mixture were studied. The conclusions are drawn as follows:

1. The hardness of the composite material increases with the addition of B_4C. The maximum hardness of the untreated sample found 116.13 BHN and improved to the heat-treated sample is 120.13 BHN at2 wt.% addition of B_4C. The composite with 2 wt.% of B_4C addition exhibit good yield strength of 208.72 MPa for untreated and 296.34 MPa for heat treated and tensile strength of 241.31 MPa for untreated and 343.65 MPa for heat treated specimen exhibited. The percentage of elongation is 8.04 % for untreated and 9.04 % for heat treated.
2. In the case of untreated specimens, wear loss reduced from 0.042 gms to 0.010 gms as the percentage of boron carbide increased from 0% to 2% for the normal load 20N kept constant throughout the experiment (9%).
3. Under the normal load of 20N when the boron carbide content increases from 0% to 2%, the wear amount of the heat-treated sample increases from 0.024g to 0.077g(68.0834%).

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