JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

CHARACTERIZATION OF MECHANICAL AND WEAR PROPERTIES OF HYBRID COMPOSITES Al7075/B_4C/Gr BY STIR CASTING PROCESS

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Abstract: Aim of this project work is to synthesize Al7075/B_4C/Gr composite material using the Stir Casting process and to test the Mechanical properties by ASTM E8M-15a, ASTM D695, IS 1500-2010, ASTM G99 and SEM and EDAX images are used for morphological characterization. In last 10 years many researchers have investigated Aluminium Matrix composite with SiC, Grey cast iron, TiB, Al2O3, ceramic, copper, TiC, Mg etc.…, still many works are ongoing with varying % of reinforcement to attain the increasing demand for Automobile and marine applications. Despite B_4C having lower density, good wettability, significant thermal stability, and outstanding chemical inertness very few works are there using B_4C as a reinforcement agent. In the present study an effort has been made to synthesize B_4C and Gr reinforced Al7075 hybrid composite using stir casting method by varying weight percentage (0%, 1.5%, 3% and 4.5%) of B_4C and keeping the (1%) of Gr constant. Results from Tensile, compression, BHN shows there is increase in Brinell Hardness Number, Compression strength and Ultimate tensile strength of the composite respectively with varying percentage of Boron carbide and from wear test results it is observed that resistance to wear increases as the percentage of reinforcement increases gradually.
***Index Terms* – Al7075, B_4C, Gr, SEM, EDAX and ASTM**

I. INTRODUCTION

Aluminium have been using widely in manufacture industries because of its mechanical properties such as an excellence corrosion resistant, good thermal and electrical conductivity, and light weighted [1]. Also Aluminium has its limitations like softness and ductility, hence Aluminium needs to be combined with other materials to fulfil the higher demand of toughness, wear resistance and high strength for further application like on automotive and marine industry. For instance, need of a lightweight and material with high strength for the brake pads in automotive industry can be fulfilled by using a lightweight metal reinforced with high strength ceramic instead of conventional CI that is more expensive and heavy. Reinforcement was added in order to improve hardness, tensile, and yield while maintaining its ductility and light weight. Micron sized B_4C were chosen as the reinforcement due to its high stiffness modulus, high temperature resistance and high strength. With adding B_4C as reinforcement, graphite is needed to strengthen the interface between the reinforce and matrix.

1.1 Aluminium Metal Matrix Composite (AMMC):

Aluminium Matrix Composites owing to its excellent wear, higher strength to weight ratio, improved stiffness, corrosion resistance and lower density with limited thermal expansion coefficient, the exploitation of MMCs has been primarily used in marine and automotive applications. Among the various materials and alloys, Aluminium and Aluminium based alloys have been primarily used as a matrix material for synthesizing of MMCs particularly for functional and structural applications.

This is since these Aluminium based alloys possess exceptional mechanical properties and lower density in comparison with other materials. Nevertheless, the major drawback of these materials is it attributes low strength, low melting point, and inadequate wear behavior. To overcome such limitations inclusion of reinforcement in the Aluminium matrix makes the material high modulus and high strength.

The importance of Aluminium matrix composites (AMCs) reinforced with ceramic particles in modern engineering applications lies in the combined and distinctive characteristics that differentiated them from the rest of the engineering materials, such as environment resistance and adequate mechanical, light weight and physical properties. Number of different methods are used for manufacturing of MMC's, they can be classified into following main groups:

- Liquid state processes, such as melt stirring, casting and in-situ and infiltration.
- Solid state processes, such as diffusion bonding, powder metallurgy and physical vapor deposition (PVD).

Melt stirring method has a good potential in all-purpose applications as it's a low cost MMCs production method. Stir casting technique is a liquid state approach of composite substances fabrication, wherein a dispersed phase (short fibers and ceramic particles) is mixed with a molten metal through mechanical stirring. The liquid composite material is then cast by way of traditional casting methods and might also be processed with the aid of traditional Metallic forming technologies.

In preparing MMCs by stir casting process, following are the factors requires considerable attention in order to obtain homogeneous distribution of the reinforcement material.

- To obtain sufficient wettability between the two main substances.
- To reduce porosity in the casted Metal Matrix Composite.

II. PROBLEM DEFINITION

Review of literature [1-17] suggest Aluminium as a potential material for greater mechanical properties and stir casting process as one of the better processing method. In spite of that, there are very few researchers have used B_4C as a reinforcement even it has better strength, good wettability, and chemical inertness. Research carried out so far reveals right choice of suitable reinforcement can result in improved mechanical properties. Hence, the aim of the project was to fabricate AL7075/B_4C/Gr composite and test mechanical and wear properties of the composites.

III. OJECTIVES

- To manufacture hybrid composite material using Stir casting process for Aluminium 7075 metal matrix with Boron carbide (B_4C) and Graphite (Gr) particles as reinforcement.
- To prepare specimens for Tensile, Compression, BHN and Wear test as per ASTM E8M-15a, ASTM D695, IS 1500-2010 and ASTM G99 standards.
- To conduct test on computer interfaced UTM (Universal Testing Machine) to obtain yield and ultimate tensile strength, compression and hardness using BHN.
- To study microstructure of composite by SEM and EDAX.
- To conduct wear test for different composition and parameters using pin on disc.

IV. MATERIALS

4.1Al7075:

In the present study, aluminium alloy of Al7075 has been used as matrix for synthesizing aluminium hybrid composites using stir casting method. This material has been selected as matrix material due to its sufficient strength, high strength to weight ratio, low cost, low density, and excellent quality materials which are commonly selected by researcher for automobile and marine applications. Table 4.1 shows the chemical composition of Al7075.

Al	Ti	Cu	Si	Mg	Zn	Fe	Mn	Cr	Others
89.79	0.06	1.35	0.4	2.21	5.67	0.3	0.08	0.08	0.06

Table 3.1 Al7075 Chemical composition

4.2 BORON CARBIDE:

It is well known that increase in percentage of reinforcement decreases the density of composites. This can be achieved only when reinforcement particles have lower density. Considering this the commercially available reinforcement of B4C possesses the density of nearly 2.52 g/cm³ and The Melting Point of boron carbide is 2445 °C, which comparatively lower than Al7075 aluminum alloys (2.810 g/cm3) and other ceramic reinforcements such as SiC, TiC, ZrSiO4 and Al_2O_3. It is also proved that usage of B_4C as reinforcement exhibits significant thermal stability, good wettability, and chemical inertness. Considering the above advantages B_4C is used as primary reinforcement in this study.

4.3 Graphite:

Graphite possesses several unique properties that make it highly valuable for various applications. Addition of graphite to various materials has shown to improve their properties in several ways. Graphite is a two-dimensional carbon allotrope with exceptional electrical, mechanical, and thermal properties. Some of its notable properties include Strength, Chemical Stability, Flexibility and conductivity with addition of 1% of Graphite above mentioned properties can be improved.

V. EXPERIEMENTAL SETUP

5.1 Stir Casting Process

Al7075 rods of 1/2inch thickness and 7-inch length were procured from the supplier. It was cut to 2-inch length and required number of pieces. Mold box is made by the MS and CI and Furnace heating coil having capacity of 10HP.

- Very first set the furnace temperature is 0^o C to 750^o C Temperature.
- Clean the crucible thoroughly.
- Coat the Stirrer and crucible by Graphite powder.
- Reinforcement prior to the addition to the molten metal was separately pre heated to 450^0 C to remove volatile substances from the material.

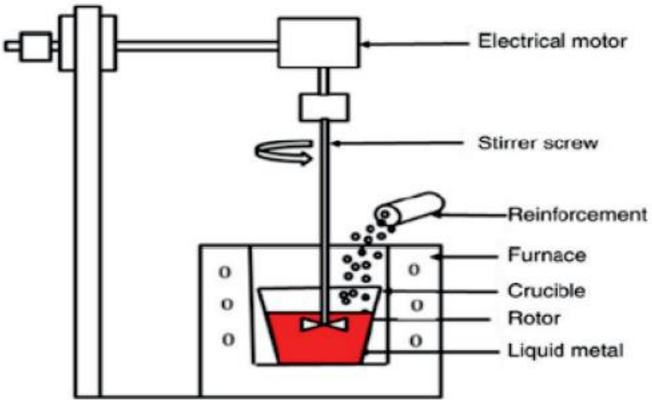


Fig.5.1 Stir casting process

Four compositions of the composite were prepared by varying the weight percentage of the reinforcement i.e., 0%, 1.5%, 3%, 4.5% of B_4C and keeping the Gr 1%. Al7075 pieces were placed in the crucible and melted at 750^0 C in a furnace with duration of 10 minutes. Stirring of the molten metal was carried using a mechanical stirrer placed on top of the Induction furnace. Required amount of reinforcement was added to the melt through a funnel placed in position. Vortex was created by rotating the stirrer at 500rpm, two step stirring was carried out to overcome heat loss and drop in furnace temperature. After complete melting Hexachloroethane was added as a degasification agent and Alkaline powder or Scum powder was added to remove the slag. Figure 5.1 Shows the stir casting process.

Table 5.1 specifies various parameters and wt.% of reinforcements used in the research.

Samples	Speed in rpm	Temperature in ^OC	Time in minutes	Al7075 in Kg	B_4C in gram	Gr in gram
1	500	750	10	1.5	0	15
2	500	750	10	1.6	24	16
3	500	750	10	1.7	51	17
4	500	750	10	1.8	81	18

Table 5.1 Wt.% of composites

5.2 Molding and Casting:

Permanent mold cavities for cylindrical and flat billets are cleaned using a wire brush and are coated with graphite powder along with water emulsion. Assembled molds were preheated to a temperature of 450^0 C for an hour in a separate furnace. After the completion of stirring the molten metal with reinforcements was poured to a pre heated permanent mold and allowed to solidify at room temperature.

After pouring the molten metal into the mold box casting is allowed to solidify, finally casted product is removed from mold and cleaned thoroughly.

5.3 Machining:

After Molding and casting, casted composites are cleaned thoroughly and machined to the required size and shape by Lathe machine to make composite ready for testing.

5.4 Testing:
5.4.1 Brinell Hardnesstest:
Test Method: IS 1500-2010
Ball Diameter: 5mm
Load: 250Kg

In this test method, a predetermined force (F) is applied to a tungsten carbide ball of fixed diameter (D) i.e., 5mm and held for a predetermined time, and then removed. The spherical indenter creates an impression on the test piece. Procedure is repeated for 3 experiments and then averaged to get the indentation diameter (d). Using this indentation size (d) Brinell Hardness Number (BHN) is calculated using the Brinell hardness test equation 5.1.
Fig. 5.2 Shows the dimensions of specimen for BHN test in mm.

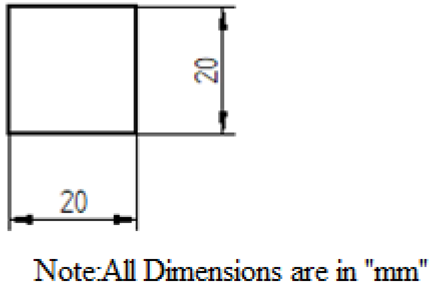


Fig. 5.2 Specimen dimensions for BHN test

BHN Formula:

$$BHN=\frac{2P}{\pi D(D-\sqrt{D^2-d^2})} \quad \text{.....(5.1)}$$

Where,

- BHN-Brinell Hardness Number
- P=Applied load in Kgf
- D=Diameter of Indenter in mm
- d=Diameter of indentation in mm

5.4.2. Compression Test:

Test Method: ASTM D695

Area: 113.11mm2

Compression Load: 52KN, 58.89KN,73.61KN and 78.23KN

It is one of the fundamental type of mechanical testing. compression tests used to determine a materials behavior under applied crushing loads on UTM and compressive strength of the material is determined.

Fig. 5.3 shows the dimensions of compression test specimen in mm.

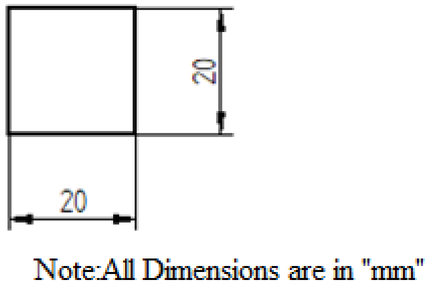


Fig.5.3 Dimensions of compression test specimen

Procedure:

- Step1: specimen preparation-material to be tested should be cleaned thoroughly to eliminate defects and flaws
- Step2: test Setup-Specimen is placed between grips and securely tightened
- Step3: Set the Testing Parameters-Desired parameters i.e., test speed, load limit etc. are setup.
- Step4: Starting and monitoring the test-Once parameters are set, actuator starts applying force onto the specimen and load cell measures the force being applied as illustrated in Fig.4.12.
- Step5: Analysis of Results-Final step is to analyze to find out the compressive strength of the specimen using equation 5.2.

Compressive strength of specimen can be calculated by:

- $F = \frac{P}{A}$ .....(5.2)

$$\text{Compressive strength (MPa)} = \frac{Maximum\ Load\ in\ N}{\text{cross sectional area of material in } mm^2}$$

5.4.3 Tensile Test:

Test Method: ASTM E8M-15a

Ultimate Tensile Load: 14.42KN, 17.08KN, 17.48KN, 19.74KN

Tensile test on UTM is recognized as one of the most commonly using method to analyze the mechanical characteristics of material. Tensile test is the process of applying the load and determining how the specimen reaction to forces being applied in tension.

Fig. 5.4 shows the dimensions of Tensile test specimen in mm.

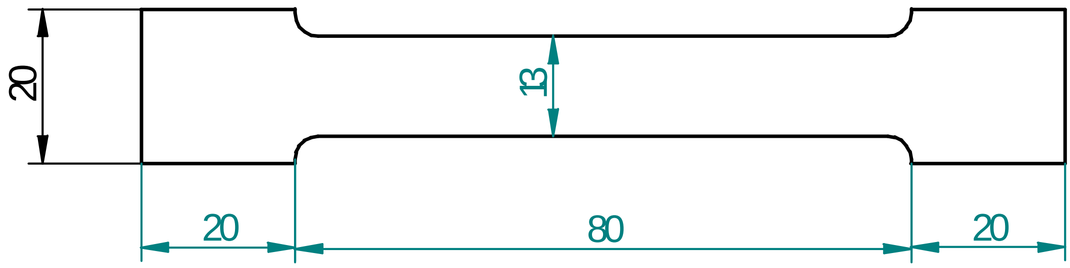


Fig.5.4 Dimensions of Tensile test specimen in "mm"

Procedure:

- Step1: Specimen preparation-material to be tested should be cleaned thoroughly to eliminate defects and flaws
- Step2: Test Setup-Specimen is placed between grips and securely tightened
- Step3: Set the Testing Parameters-Desired parameters i.e., test speed, load limit etc. are setup
- Step4: Starting and monitoring the test-Once parameters are set, actuator starts applying the force to firmly fixed specimen and load cell measures the force being applied.
- Step5: Analysis of Results-Final step is to analyze to determine the Ultimate Tensile strength of the specimen using equation 5.3.

Compressive strength of specimen can be calculated by:

$$\sigma = \frac{P}{A} \quad \text{………………………………………………………………………………(5.3)}$$

$$\text{Tensile strength (MPa)} = \frac{\mathit{Maximum\ Load\ in\ N}}{\text{cross sectional area of material in } mm^2}$$

5.4.4 Wear Test

Pin-on-disk apparatus is used for determining the coefficient of friction of material during sliding. This method includes a pin with a tip which is positioned perpendicular to the flat circular disk and a rigidly held ball used as the pin specimen.
Parameters-Load, sliding speed, distance, temperature and atmosphere
Fig. 5.5 shows the dimensions for wear test specimen in mm.

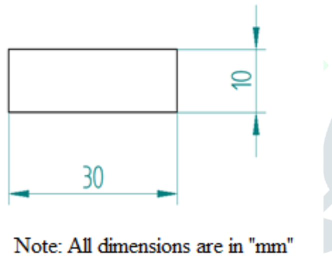


Fig. 5.5 Dimensions for wear test specimen

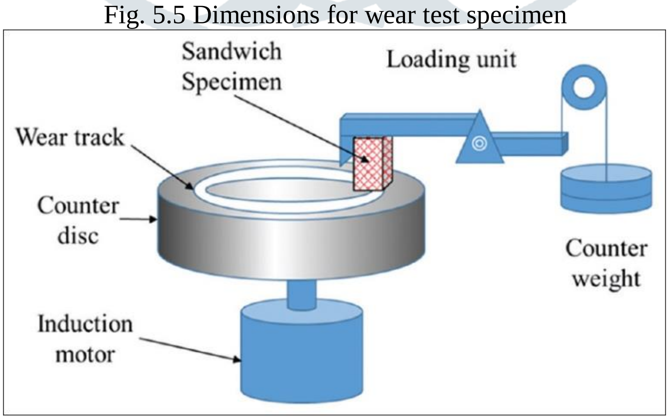


Fig.5.6 Pin-On-Disk apparatus

Procedure:

- The pin specimen is pressed against the disk at a load by means of attached weights, hydraulic or pneumatic. As illustrated in Fig.5.6.
- Results are reported as volume loss in mm^3 and by measuring the appropriated linear dimensions of the specimen before and after the test amount of wear can be obtained/determined.
- Usually results are obtained by conducting wear test for selected value of speed, load and distance.
- Volumetric loss can be calculated by formula 5.4.

$$\mathit{Volumetric\ Loss} = \frac{\text{Mass Loss}}{\text{Density}} \text{ X } 1000 \text{ mm}^3 \quad \text{……………………………………………………………(5.4)}$$

VI. RESULTS AND DISCUSSION

6.1 Brinell Hardness Test:

Table 6.1 shows the results of BHN Test on different specimen samples namely specimen without adding the B_4C, specimen sample with addition of 1.5%, 3% and 4.5% of B_4C at pouring temperature of 750DegC. The result of Hardness testing shows that the inclusion of B_4C to Aluminium Matric Composite shown an improvement in the value of matrix hardness. Specimen samples without B_4C addition have the lowest level of hardness compared to samples with B_4C. From results, specimen with 4.5% of B_4C has hardness of 110 and this is more than samples with 1.5% and 3% of B_4C having 89 and 93 BHN respectively. As indicated in Fig. 6.1.

Al7075+0%B_4C+1%Gr: **Test Method: IS 1500-2010**

Ball diameter: 5mm

Load 250 Kg

Sample	% of B_4C	Result-1	Result-2	Result-3	Average
01	0	77.3	78.6	78.1	78.0
02	1.5	89.8	90.1	89.2	89.7
03	3	94.0	93.0	93.0	93.0
04	4.5	109.1	110.0	109.0	110.0

Table.6.1 BHN Test Results

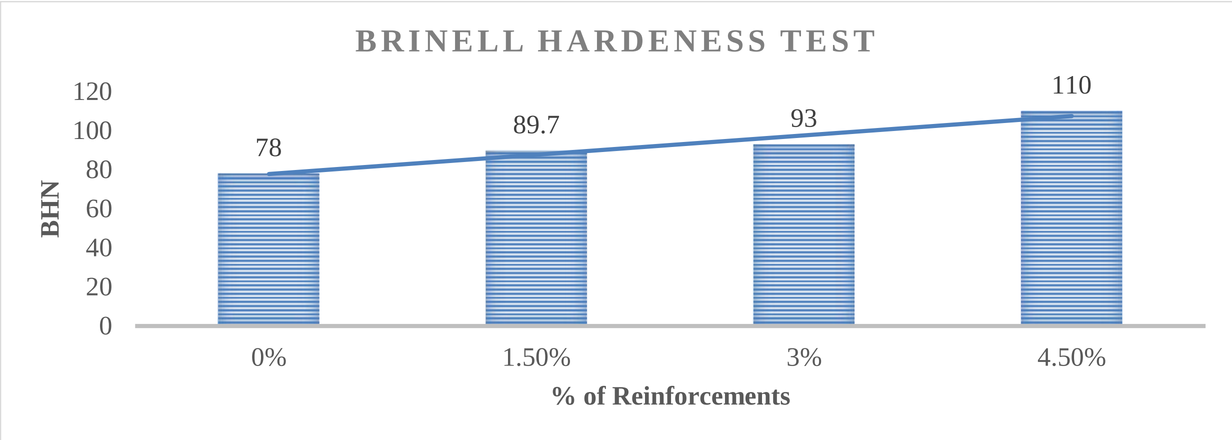


Fig.6.1 BHN Test results

Research conducted by [8] and [9] also showed that the composite material hardness would increase with addition of B_4C and/or Gr. Data from the obtained results of BHN test confirms the findings reported by [9], in which the mechanical characteristics of cast depend on the volume fraction along with distribution of reinforcements and their properties.

6.2 Compression Test:

As per ASTM D695 standard composite specimens for various percentage of reinforcement i.e., 0%, 1.5%, 3% and 4.5% of B_4C by weight have been conducted a compression test with computer interface to determine the mechanical properties of specimen and obtained compressive strength in MPa are presented in Table 6.2.

Test Method: ASTM D695

% Of Reinforcement	Compression Strength in MPa
0%	460.24
1.50%	520.67
3%	651.32
4.50%	691.65

Table. 6.2 Compression test results

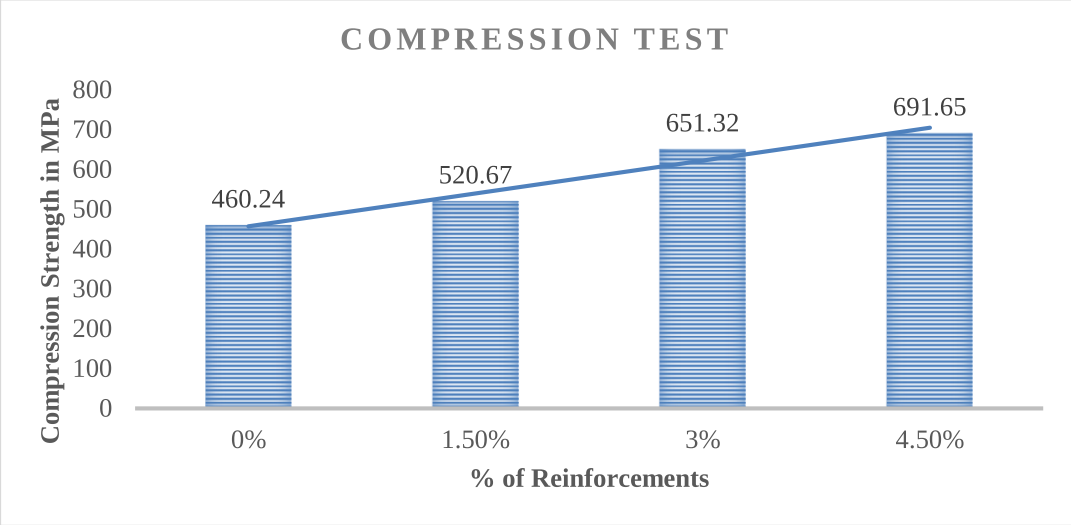


Fig.6.2 Compression test result

Figure 6.2 shows the various % of reinforcements i.e., B_4C across compressive strength in MPa. From the obtained results it is clear that with increase in percentage of B_4C compressive strength increases drastically.

6.3 Tensile Test:

As per ASTM E8M-15a standard composite specimens for various reinforcements such as 0, 1.5, 3 and 4.5% by weight have been conducted a tensile test with computer interface to determine the mechanical propeties and stress-strain results of obtained yield stress and UTS (Ultimate Tensile Strength) are listed in Table 6.3.

Test Method: ASTM E8M-15a

% Of Reinforcements	UTS in MPa
0%	219.45
1.50%	258.79
3%	278.7
4.50%	301.25

Table.6.3 Tensile Test results

Table 6.3 shows that with the raise in percentage % of reinforcement i.e., rate of B_4C in composite Ultimate tensile strength enhances gradually, by above table with no addition of B_4C UTS recorded is 219.45MPa and with 4.5% of B_4C UTS increases to 301.25MPa this increases the overall strength of the final composite and make it suitable for applications.

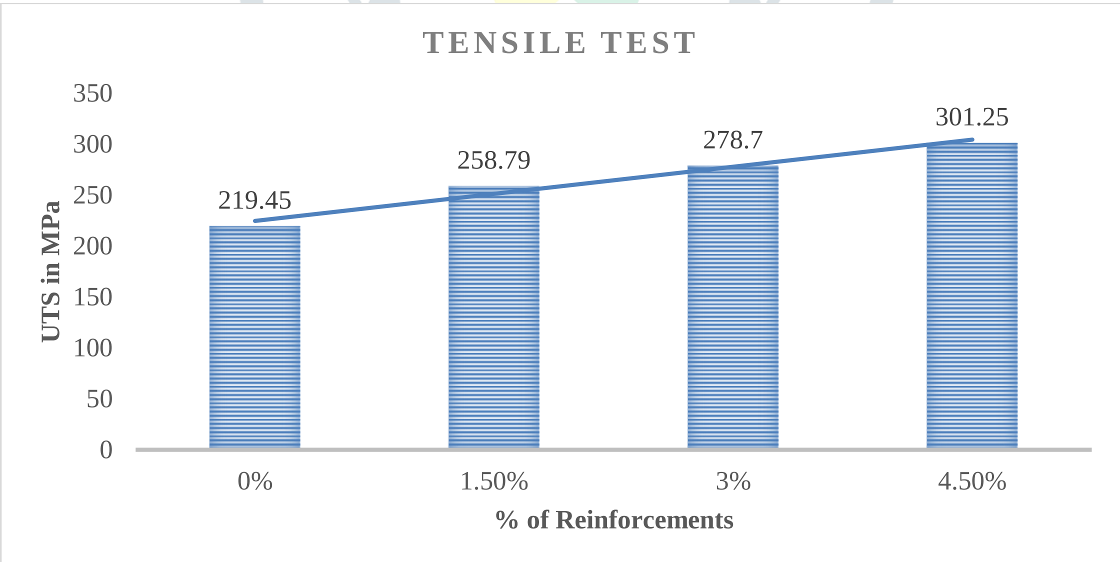
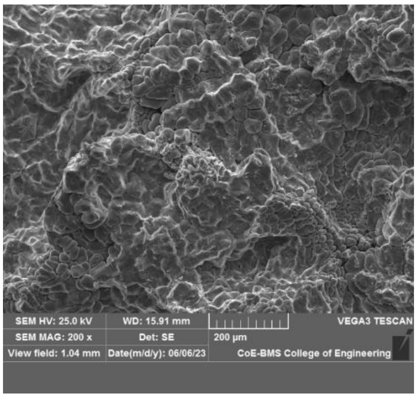


Fig.6.3 Tensile test results

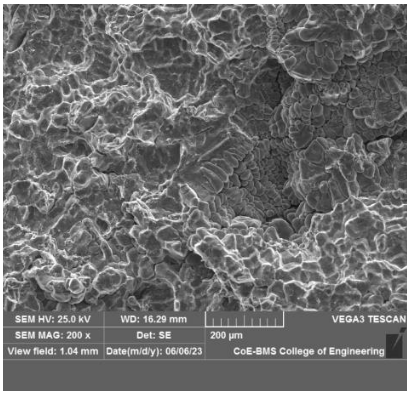
From the obtained results indicated in Fig 6.3 it is clear that with raise in percentage of B_4C yield strength and ultimate tensile strength improves drastically.

6.4 Scanning Electron Microscope:

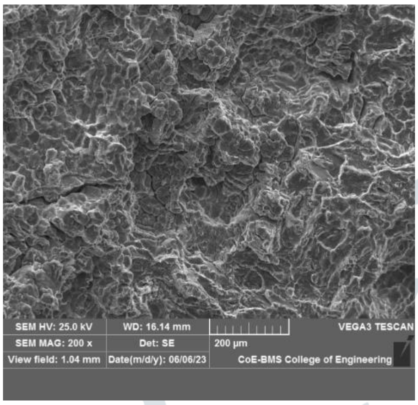
Figure 6.4 (a), (b), (c) and (d) shows the typical microstructure of fractured surface of tensile test samples at 200X magnification. The general arrangements of Al7075/B4C/Gr are faintly visible in the images.



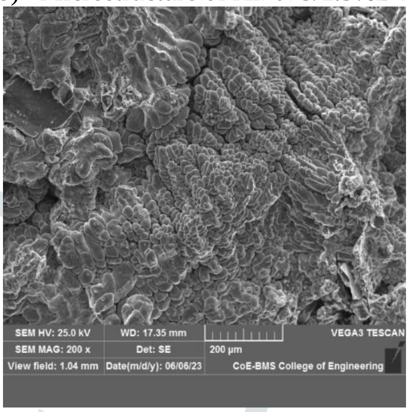
(a) Microstructure of Al7075/0%B4C/Gr



(b) Microstructure of Al7075/1.5%B4C/Gr



(c) Microstructure of Al7075/3%B4C/Gr



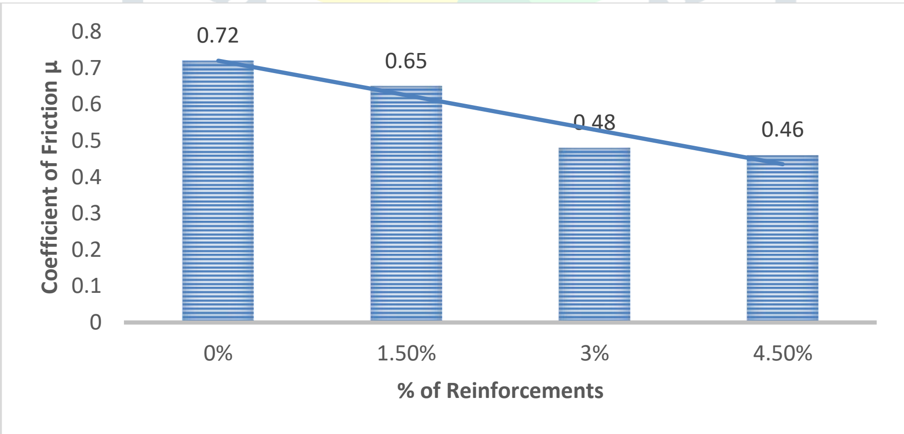
(d) Microstructure of Al7075/4.5%B4C/Gr

Fig.6.4 Microstructure of Al7075/B_4C/Gr

From Fig.6.4 (a), (b), (c) and (d) one can see optimal measures can obviously improve the microstructure of the composite with the stir casting process. Here lighter particles are aluminium and the darker ones are Boron carbide also it is detected that reinforcements are dispersed unevenly and some micro cracks and porous sites are there.

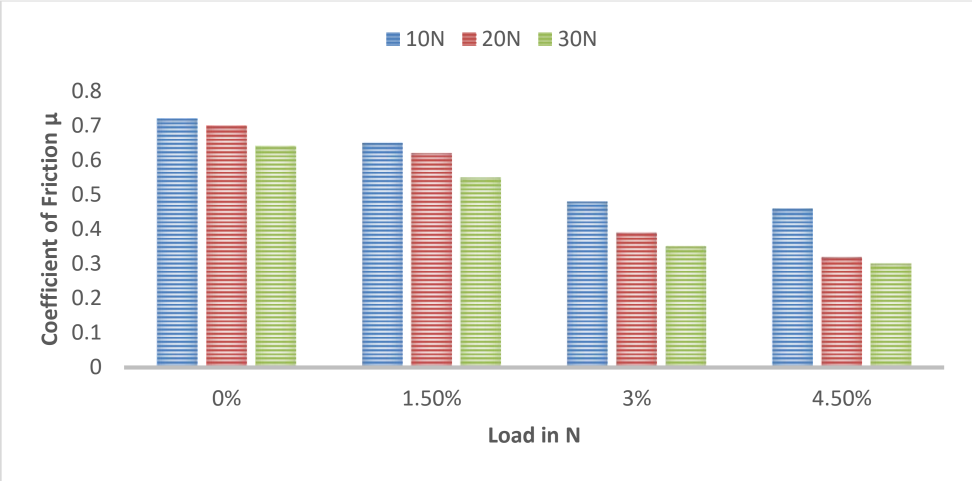
6.4 Wear Test:
Test Method: ASTM G99

Wear test is conducted by pin on disk method to analyze the effect of parameters, sliding speed as well as load against co-efficient of friction.



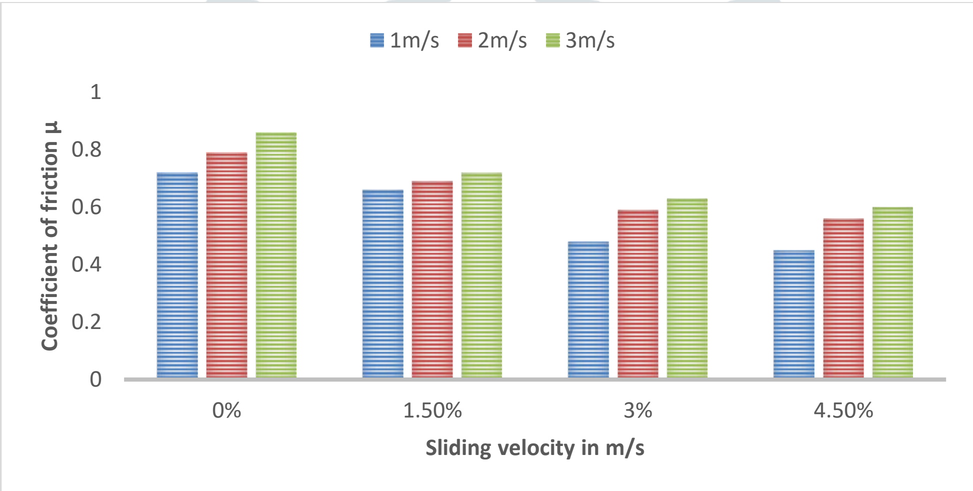
(a) % of reinforcement vs co-efficient of friction

Fig. 6.5 (a) describes the effect of wt. % of reinforcements on coefficient of friction and from the figure it can also be seen that with 0% of B_4C coefficient of friction is 0.72 and by adding B_4C coefficient of friction reduces gradually and with 4.5% of Boron Carbide 0.46 coefficient of friction can be achieved.



(b) Load vs co-efficient of friction

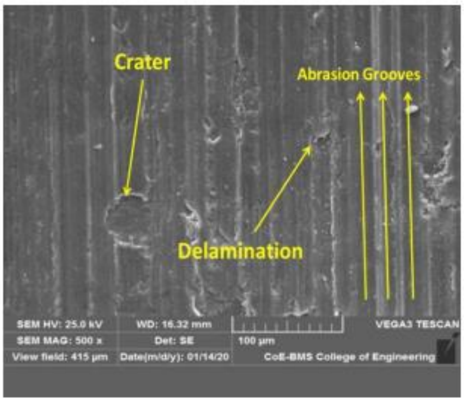
Fig. 6.5 (b) indicates the effect of load on coefficient of friction. Load i.e., 10N, 20N and 30N are applied on corresponding specimen to determine the value of coefficient of friction with varying load and results are plotted. It is noticed that with gradual increase in load coefficient of friction decreases.



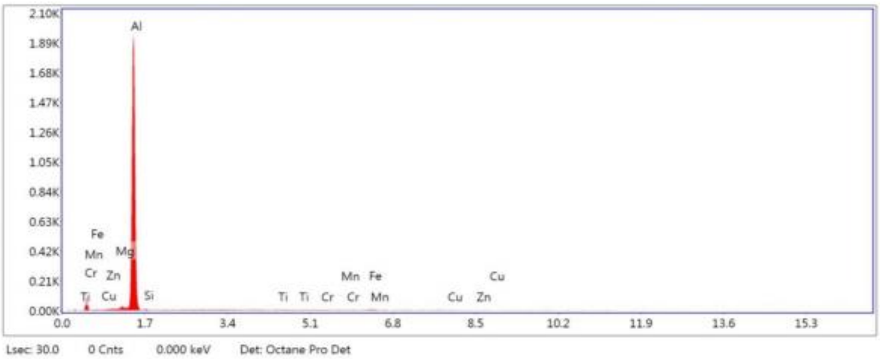
(c) Sliding velocity vs co-efficient of friction

Fig. 5.5 Wear Test results

Fig. 6.5 (c) indicates the outcome of sliding velocity i.e., 1m/s, 2m/s and 3m/s on specimen and corresponding results are plotted. For 0% of reinforcement test is conducted for different sliding velocity and it is revealed that with the gradual increase in sliding velocity coefficient of friction increases and test was repeated similarly for other specimens.



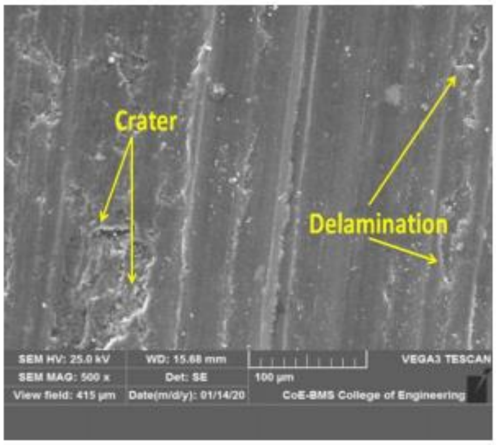
(a)



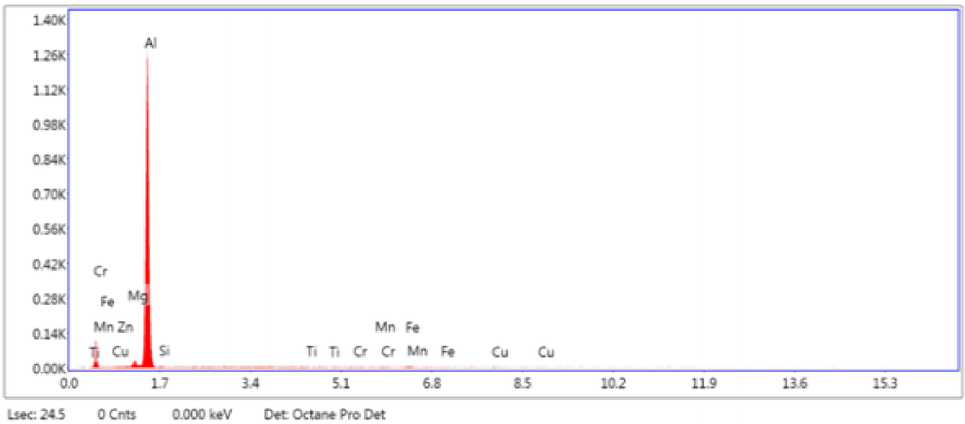
(b)

Fig.6.6 Al7075-10N-1 m/s with ratio 4:1

Fig 6.6 shows the EDAX and SEM images obtained for hot ejected Al7075 alloy with load of 10N, sliding velocity 1m/s for extrusion ration 4:1 with 1.86K intensity for the matrix at 1m/s.



(a)

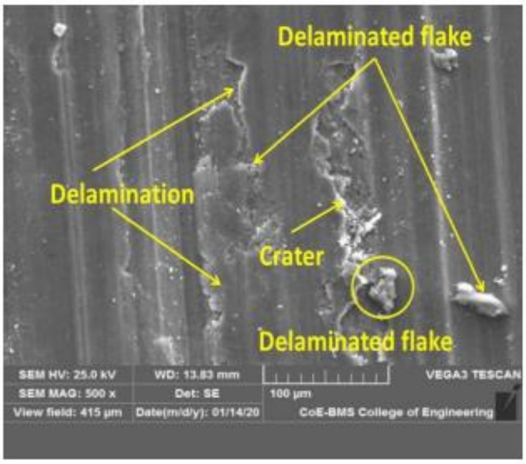


(b)

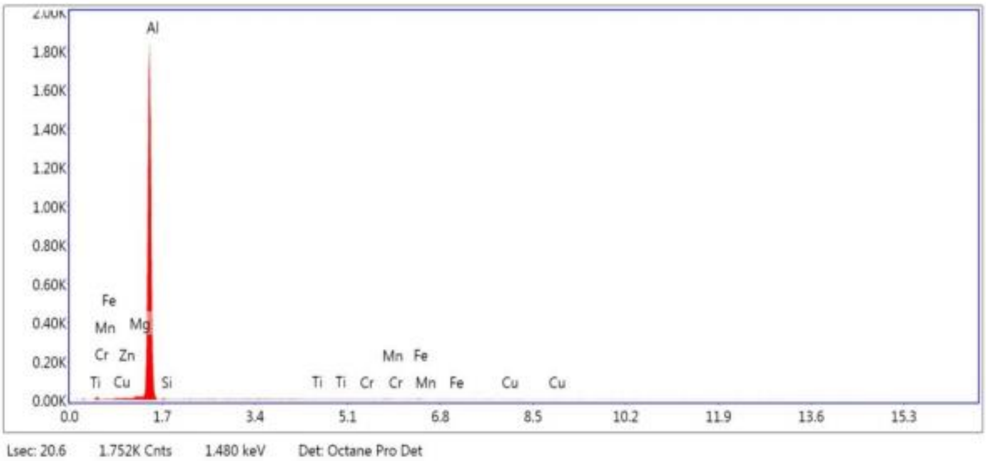
Fig. 6.7 Al7075-10N-3 m/s with ratio 4:1

Fig 6.7 shows the EDAX and SEM images obtained for the hot extruded Al7075 alloy with load 10N and sliding velocity of 3m/s for the extrusion ration 4:1 with 1.26K intensity for matrix at 3m/s.

From Fig 6.6 and Fig.6.7 it is revealed that friction increases as speed increases resulting in more amount of delamination occurred with sliding velocity 3m/s compared to 1m/s.



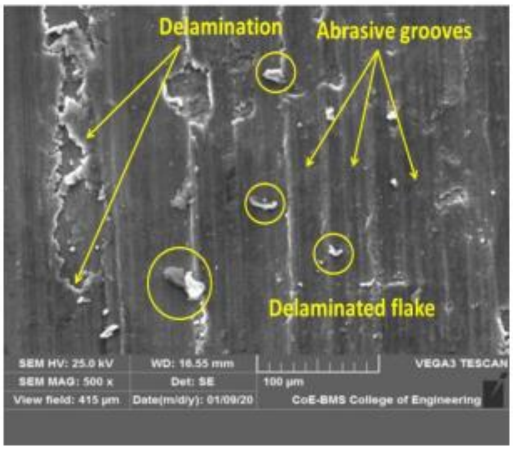
(a)



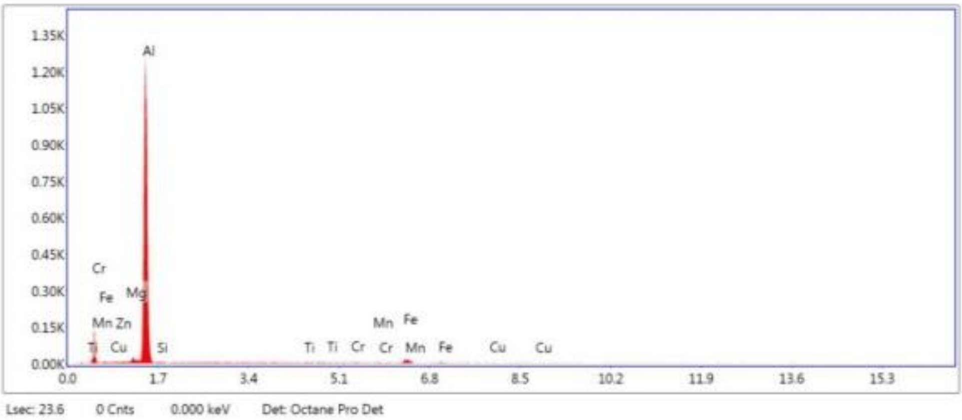
(b)

Fig. 6.8 Al7075-30N-1 m/s, ratio 4:1

Fig 6.8 shows the EDAX and SEM acquired for hot extruded Al7075 alloy for load 30N and sliding velocity 1m/s for extrusion ration 4:1 with an intensity 1.86K for matrix at 1m/s.



(a)



(b)

Fig. 6.9 Al7075-30N-3 m/s with ratio 4:1

Fig 6.9 shows the EDAX and SEM acquired for hot extruded Al7075 alloy for load 30N with sliding velocity 1m/s for extrusion ration 4:1 with a 1.26K intensity for matrix at 3m/s.

From Fig 6.8 and Fig. 6.9 at a sliding velocity of 1m/s and 3m/s and load of 30N for same extrusion ratio and alloy, it is observed that surface delamination is more with 30N load as ompared to 10N load and from flakes of th images it is observed that as load increases from 10N to 30N more surface area and large sized delaminated flakes was worn with energy of 1.2K and 1.8K and from EDAX it is evident that small amount of Fe from the disc can be observed.

VII. Summary of The Project

7.1 Conclusion

From the obtained results it is observed that usage of stir casting method for processing/fabricating hybrid composite of Al7075/B_4C/Gr with varying percentages of B_4C i.e., reinforcements, the wear and mechanical characteristics are enhanced very much as evident from the graph and SEM images, also wear properties with respect to parameters like load, speed and distance also coefficient of friction, resistance to wear increases as percentage of reinforcement increases. As observed from the graphs and EDAX images further addition of reinforcements may result in increasing the brittleness of the composite which may cause brittle fraction. So, the optimum combination of 4.5%B_4C and 1% of Gr resulted in improved properties of wear and mechanical properties as noticed from Fractography and SEM images of wear and mechanical specimens machined and tested to ASTM standards.

7.2 Scope for Future Work:

Further improvement of the results of Al7075/B_4C/Gr hybrid composite will be observed by various heat treatment processes and quenching it to air, any fluid like water/oil etc.., cooling it to sub-zero temperature and further heating it to T_6 heat treatment process.

7.3 Outcomes:

- Production of Al7075/B_4C/Gr hybrid composite using stir casting process.
- Mechanical characterization of Al7075/B_4C/Gr composite by Tensile, compression and BHN tests.
- Interpretation of SEM and EDAX images of stir casted composite.
- Wear characterization of Al7075/B_4C/Gr hybrid composite by Pin on Disk Apparatus.

VIII. Acknowledgment

I am deeply honored to extend my heartfelt appreciation to our esteemed Principal, **Dr. HANUMANTHA REDDY,** for their unyielding belief in fostering academic growth and innovation. Your visionary leadership has created an environment where students are encouraged to explore and excel. Your unwavering support has been pivotal in making this project a reality.

I would like to express my profound gratitude to the Head of the Department, **Dr. KORI NAGARAJ**, for their invaluable guidance and mentorship. Their expertise and dedication to academic excellence have not only shaped the trajectory of this project but have also influenced our broader understanding of the subject. Their ability to challenge us while providing unwavering support has been a driving force behind our progress.

A special acknowledgment goes to the PG Coordinator, **DR. C. THOTAPPA** for their proactive involvement and continuous support. Their keen insights and willingness to assist with various logistical aspects have significantly eased the journey of completing this project. Their commitment to facilitating a conducive learning environment is truly commendable.

I am immensely thankful to our project guide **Dr. M. BALAJI** whose contributions have been invaluable. Their unwavering commitment to our growth, insightful feedback, and patient mentorship have been a constant source of inspiration. Their ability to navigate complex concepts and present them in an understandable manner has enriched our understanding and approach.

I extend my heartfelt gratitude to each of these exceptional individuals. The culmination of this project would not have been possible without their collective efforts, guidance, and support. Their impact extends beyond the project itself, shaping us into more knowledgeable and confident individuals as we step into the next phase of our academic journey.

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