

# Corrosion Behaviour of Powder Metallurgy Processed Aluminium Self Lubricating Hybrid Metal Matrix Composites with B<sub>4</sub>C and Gr Additions

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**Abstract:** In this experimental study, self-lubricating hybrid metal matrix composite materials were fabricated with Aluminium (Al2024) used as matrix, Boron carbide (B<sub>4</sub>C) and graphite (Gr) were used as the reinforcements, various weight based composites like Al-B<sub>4</sub>C-Gr (93%-3%-4%, 90%-6%-4%, 87%-9%-4%, 84%-12%-4%), Al-Gr (96%-4%) and Al-B<sub>4</sub>C (97%-3%, 94%-6%, 91%-9% and 88%-12%) were fabricated by using powder metallurgy technique. RESTECH100 ball milling machine was used to mill the required weight composition of powders then they were consolidation under UTM to get green pellets and were sintered at an elevated temperature in a muffle furnace which was filled with argon gas to achieve the required composites. The density and corrosive behaviour of these composite materials were investigated. The results revealed that B<sub>4</sub>C reinforced hybrid composites exhibited less corrosion resistant over B<sub>4</sub>C reinforced composite and the base Aluminium alloy. It was also found that with an increase in the B<sub>4</sub>C content, there is an increase in corrosion rate and there is a decrease in density.

**Keywords:** Hybrid composite, Self lubricating, Powder metallurgy, Sintering; consolidation, Green pellets, Ball Milling, Corrosion.

## I. INTRODUCTION

The use and application of various composites are the key alternating materials for the existing materials. Among these composites, aluminium metal matrix is the best substitution due to their own advantages. The density of the aluminium composites is always less as compared to the most of the materials and these materials can be used in aircraft, automotive, construction, packing, electronics and military industries. Aluminium metal matrix composites (AMMCS) with different ceramic particle reinforcement are developed to suit the varying needs in aerospace and automotive application. Most of the existing materials used in aerospace and automobile industries can be replaced by these AMMCS due to its

good strength and sometimes less denser than the parent material. These materials are the encouraging materials to give better properties with low density and also cheaper than the other materials like Mg and Ti [6]. In place of steel and cast iron components, there is potential to use Aluminium composites. Al2024 was selected here on the basis of usage of material in aerospace and automobile applications which will lead to high strength to weight ratio and also having good mechanical properties. The reinforcing materials which can be used in the form of particles and whiskers [4] in aluminium matrix to give good properties are Alumina (Al<sub>2</sub>O<sub>3</sub>), Titanium carbide (TiC), Boron carbide (B<sub>4</sub>C) and Graphite (Gr). Due to robust nature and having high hardness value B<sub>4</sub>C was selected as one of the best reinforcing material among all these materials. The Graphite was used as another best reinforcing material, which is a less dense material and can be used as solid lubricant. To reduce the wear in between sliding elements, solid lubricant (graphite) was selected as another reinforcing material. In this context, components with excellent mechanical and fatigue properties, low density, corrosion resistance, high thermal and electrical conductivity and excellent machinability can be produced by Powder Metallurgy (P/M) technique. The net or near net-shaped parts, can be produced by P/M technique, this technique eliminates the operational and capital cost associated with complex machining operations. The hardness of the composite will increase with the increase of B<sub>4</sub>C and then it is very difficult to machine, to overcome this effect, small amount of Gr can be used for the fabrication of composites.

Linlin Zhang et.al [1] Al B<sub>4</sub>C composites prepared by powder metallurgy route, the corrosion behaviour of prepared composites in H<sub>3</sub>BO<sub>3</sub> solution could be significantly improved by the Shot Peening process and the corrosion rate decreased by 72.2% compared with the result obtained from the as-received specimen. Sunil Ratna Kumar K et.al fabricated and tested Al-B<sub>4</sub>C-Gr Hybrid composites

and revealed that the hardness gets increased with the increase in reinforcement. A. Fattah-alhosseinia et.al [3] studied that the corrosion behavior of Al/B<sub>4</sub>C/SiC hybrid composites which was fabricated by accumulative roll bonding (ARB) process and incorporated two different compositions of reinforcement particles were tested in 3.5 wt.% NaCl solution. Moreover, the results of EIS tests revealed that employing the ARB process has led to a higher polarization resistance of the produced hybrid composites as well as ARBed matrix alone. T. S. Senthilkumar et.al,[4] fabricated Al-SiC-Boron glass powder composites by modified stir cast route with different weight percentage of reinforcements and from the obtained results, Corrosion resistance was improved with increase in Boron glass powder concentration and SiC concentration. Yu-mei han et.all [5] the Al-B<sub>4</sub>C composites were fabricated by an ingot metallurgy route, the obtained composites are less corrosion resistant than the base Al alloy and that the corrosion resistance of the composites decreases when increasing the B<sub>4</sub>C particle volume fraction. Al-B<sub>4</sub>C composites are susceptible to pitting corrosion in the NaCl solution. Ravindranath V M et all[6], achieved uniform distribution of the reinforcement in the composite by the liquid stir casting technique. The corrosion media used is of 3.5wt% NaCl of 0.6M solution prepared by the standard procedure. The results of the samples show that the corrosion of the base alloy is least. The corrosion resistance of the B<sub>4</sub>C composite is higher due to the presence of carbide particles. The hybrid composite of B<sub>4</sub>C and Gr is least corrosive resistant among the three; the reason for this is due to presence of graphite content increases corrosion rate and decreases corrosion resistance of hybrid composites. C. Muthazhagan et.all [7] fabricated Al-B<sub>4</sub>C-Gr Hybrid metal matrix composites were successfully by using stir casting method and the obtained results shows that, the corrosion rate of the composite is increased with increasing of boron carbide and graphite particles in Aluminium matrix. H.M. Zakaria et.all[8] fabricated Al-SiC composites and investigated that the samples at room temperature exhibited better corrosion resistance than the pure Al matrix in 3.5 wt.% NaCl aqueous solution. Increasing the volume fraction of the SiC particulates increased the corrosion resistance of the Al/SiC composites. Moreover, reducing the SiC particles size enhanced significantly the corrosion resistance of the SiC composites. Fabrication of various composites and mechanical, corrosive behaviour of various composites were carried out by various research scholars[9-40]. Avinash Ben et al. [19] were explained about the better wear properties of aluminium based composites. E.D. Francis et al. [18] were explained about the flexural strength of Mg alloy with nanosized Al<sub>2</sub>O<sub>3</sub> Particles.

### 1. Corrosion

The mechanical properties of the components influenced by various surroundings like

sea water, water, atmosphere, various solutions, organic environments etc. Corrosion is a slow, progressive or rapid deterioration of a metal's properties such as its appearance, its surface aspect, or its mechanical properties. The corrosion is due to the formation of oxides of the various metals in the specimen.

#### 1.1. Types of corrosion

Various types of corrosion which occur on the aluminium and its allots are such as uniform corrosion, pitting corrosion, stress corrosion, etc are more or less visible to the naked eye. The rate of corrosion is depending upon number of factors that are intrinsic to the metal. There is no form of corrosion that is *specific to aluminium and its alloys*

#### 1.2. Uniform Corrosion

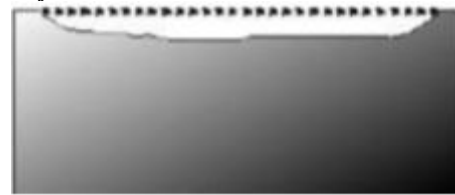


Figure.1 Uniform corrosion

This type of corrosion forms pits of very small diameter, in the order of a micrometre, this will results uniform and continuous decrease in thickness over the entire surface area of the metal. This type of corrosion is observed in aluminium, especially in highly acidic or alkaline media, in which the solubility of the natural oxide film is high. The dissolution rate of the film is greater than its rate of formation. However, the ratio of both rates can change over time. The rate of uniform corrosion can be easily determined by measuring the mass loss, or the quantity of released hydrogen.

#### 1.3. Pitting Corrosion



Figure.2. Pitting Corrosion

This localised form of corrosion is characterised by the formation of irregularly shaped cavities on the surface of the metal. The size and shape depend on several parameters related to the metal, the medium and service conditions. Aluminium is prone to pitting corrosion in media with a pH close to neutral, which basically covers all natural environments such as surface water, seawater, and moist air. Pitting is more difficult to detect and considered to be more dangerous. The failure of entire component is due to the formation of small, narrow pit on the surface as shown in figure2. When the metal is put into permanent or intermittent contact with aqueous media like water, seawater, rain water, and humidity then Pitting corrosion occurs.

#### 1.4. Galvanic Corrosion

Galvanic Corrosion follows the Principle of a galvanic cell. When two dissimilar metals are in direct contact in a conducting liquid then one among them may corrode. This is called galvanic corrosion. Whenever these metals are separated in the same medium then the kind and intensity of corrosion is different. Unlike other types of structural corrosion, galvanic corrosion does not depend on the metal's texture, temper. Galvanic corrosion may occur with any metal, as soon as two are in contact in a conductive liquid. It works like a battery

**1.5. Stress Corrosion**

It is due to the combined action of a mechanical stress (bending, tension) and a corrosive environment. The residual stresses in the specimen are due to Cold deformation and forming, welding, heat treatment, machining and grinding. The magnitude and importance of such stresses is often underestimated. The residual stresses set up as a result of welding operations tend to approach the yield strength. The residual cracks leads to fine cracks in the material.

**II. EXPERIMENTAL PROCEDURE**

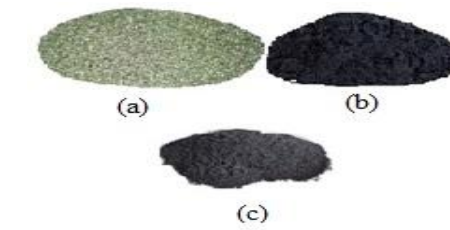
**II.1. Selection of materials**

Al 2024 plate was received from Perfect Metal Works, Bangalore, India then filing and sieving operations were carried out on the plate to get required aluminium particles of an average size 60µm. This Aluminium powder was used as the matrix for the fabrication of aluminium hybrid composites. Table 1 shows the composition of various elements present in Al2024. The reinforcing elements B<sub>4</sub>C with an average size of 50µm/graphite with an average size of 45 µm were supplied by Sigma Aldrich, India. The details of the reinforcement were shown in Table 2.

**Table 1: Elemental composition of Al 2024**

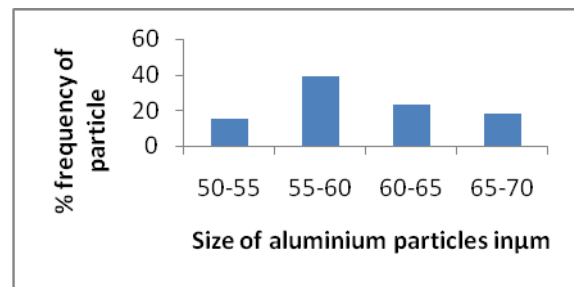
Component	% of Weight
Aluminium	90.7-94.7
Copper	3.8-4.9
Chromium	Max 0.1
Ferrous	Max 0.5
Magnesium	1.2-1.8
Manganese	0.3-0.9
Silicon	Max 0.5
Titanium	Max 0.15
Zinc	Max 0.25
Other total	Max 0.3

**Table 2: Details of Reinforcement**

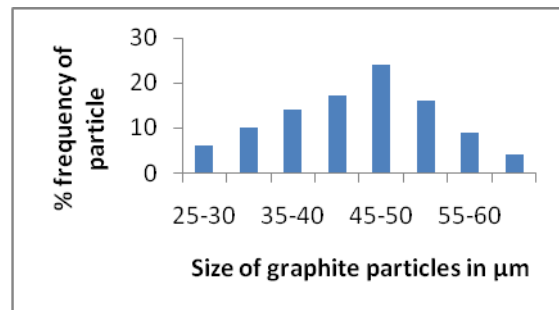


**Figure 3: Powders before composition (a) Aluminium powder (b) Gr powder (c) B<sub>4</sub>C Powder**

The size distribution of the Al 2024 and Gr particles was measured using particle size analyzer. The results were shown in Figure 4 and Figure 5. The Figure 3 shows images of all the powers for the fabrication of the composites.



**Figure 4: Particle size distribution of as-received Aluminium particle.**



**Figure 5: Particle size distribution of as-received graphite powder**

Reinforcement	Average Size	Density(g/cm <sup>3</sup> )
B <sub>4</sub> C	50 µm	2.52
Gr	45 µm	2.09-2.33

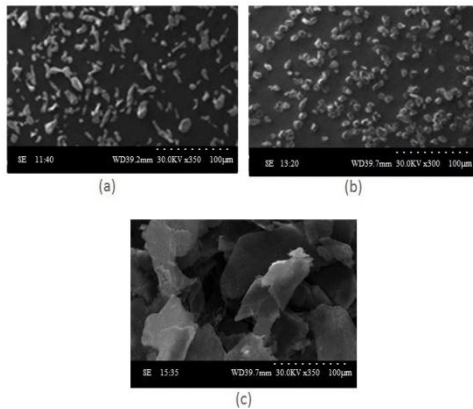


Figure 6: SEM micrographs of as-received: (a) Aluminium powders, (b) B<sub>4</sub>C particles, (c) Gr particles.

## II.2. Blending of Powder

The final results of the mechanical alloying will be influenced by the Ball milling Parameters like milling time, milling speed, milling environment and were chosen from the literature. The mechanical milling and alloying was carried out by a Retsch100 Ball Mill, Germany make as shown in Figure 7. High energy ball milling experiment was conducted on Al<sub>2</sub>O<sub>3</sub>, B<sub>4</sub>C and Graphite. A set of operation parameters must be chosen in order to obtain the optimum values. Proper ball diameter was chosen to mix the powder and analyses the optimal performance. The numbers of balls were selected to obtain ball to powder weight ratio (BPR). The ball to powder ratio of 10:1 was performed with planetary by using tungsten carbide balls for the dispersion of the matrix and the reinforcements. The best route was obtained with 24 balls with diameter of 10 mm. To randomize the motion, no combinations of small and large balls were used. To achieve uniform dispersion among Al<sub>2</sub>O<sub>3</sub>, B<sub>4</sub>C and Gr particles, the proposed milling time was selected as 6 hours at a selected speed of 400 rpm in an interval of 10 minutes per hour. Toluene was used as process control agent to maintain milling environment inside the chamber to control cold weld of the particles and avoid oxidization. In wet milling best medium must be chosen in order to avoid agglomeration. The volatile matter present in the homogeneous mixture (Figure 8) obtained from planetary ball mill was evaporated by keeping in air for about 24 hours. Different blends with various compositions like Al-B<sub>4</sub>C-Gr(93%-3%-4%, 90%-6%-4%, 87%-9%-4%, 84% 12%-4%), Al-Gr(96%-4%) and Al-B<sub>4</sub>C(97%-3%, 94% 6%, 91%-9% and 88%-12%) were blended in ball milling machine.



Figure 7: Ball mill machine used to mix powders



Figure 8: Mixed Al 2024 & B<sub>4</sub>C and Graphite powders

## II.3. Preparation of Pellets

Five Pellets for each composition were obtained for different analysis as shown in Figure 9. The compaction of the blended and mixed powders by using cold compaction technique was performed on the hydraulic press (UTM). To get the required pellets, die-punch (male and female parts) made up of hardened steel was used. The various pellets of 12mm diameter and approximately 15mm height were obtained after the compaction. To obtain green compacts, constant amount of mixture was consolidated under uniaxial press at a pressure of 400 Mpa at room temperature. The well-mixed powders of a particular sample were first put in the die. The die was filled with approximately same quantity of powder for every pellet to be made. The lubrication between the die walls and the powder was obtained by using Silicon spray. It was sprayed into the die before the powder was put in the dye so as to provide proper lubrication. Then the punch was placed over the powder in the dye (filled up to the brim). Before each run, die wall lubrication was performed manually using silicon spray. The pressure was applied for about 1 minute and was released then the pellets were ejected out from die after the compaction. The dimensions length of the various pellets was measured using a Vernier Calliper. Three different readings were taken for each pellet at various sites of the pellet and then an average of these was taken as the length of a particular pellet.



Figure 9: pellets obtained after compaction

## II.4. Sintering

The grain growth, grain bonding and larger contact area among the particle boundaries of the pellets was obtained by sintering process. An electric muffle furnace at a closely regulated temperature of 630°C with an increase in temperature 1°C per second for about 120 min in an Argon atmosphere as suggested by Yamagushi[21]. After the sintering process, the samples were allowed to cool in the furnace itself to room temperature. Finally, in order to reach to the proper shape and size, all the compacts were trimmed to an exact size with a diameter of 12



mm and a height of 15 mm. The equipment for sintering was shown in Figure 10 and the pellets inside the furnace were shown in Figure 11. The samples were taken out from furnace after the sintering process is over. The obtained Hybrid composite samples Al-B<sub>4</sub>C-Gr(93%-3%-4%,90%-6%-4%,87%-9%-4%,84%12%-4% ) are represented as C1, C2, C3, C4.



Figure 10: Equipment used for Sintering



Figure 11: pellets placed inside muffle furnace

### III. Results and discussions

#### III.1 Morphology of aluminium, graphite and Boron carbide powder

The size distribution of the B<sub>4</sub>C and Gr particles was shown in Figure 4 and Figure 5. The size distribution of the Al 2024 and Gr particles was measured using particle size analyzer.

#### III.2 X-ray diffraction analysis

For the fabricated composites, X-ray diffraction(XRD) results were shown in Figure 12. The presence of Aluminium was represented by the largest peaks, the reinforcements B<sub>4</sub>C and Gr(Carbon) were represented by minor peaks. The intensity of B<sub>4</sub>C peaks will increase, with increase in B<sub>4</sub>C content. From XRD, the various elements(Al2024, B<sub>4</sub>C and Gr) of the hybrid composite were clearly indicated. These XRD results were taken from Central Electrochemical Research Institute, Karaikudi, Tamil Nadu, India, using HITACHI SU-6600

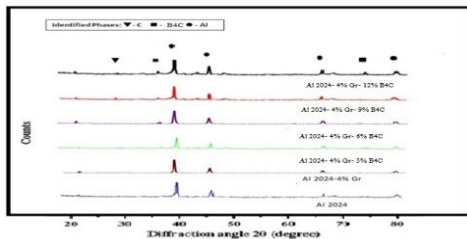


Figure 12: XRD results of various compositions

#### III.3 Micro structural analysis

For Microstructure examinations, Scanning electron microscopy(SEM) was used. Aluminium, boron carbide and graphite were detected in the analysis. It is not possible to use EDS spot analysis on a single particle to measure the average size of the particles with less than 60 μm, therefore mapping scanning was employed. Due to the limitations of e-beam in SEM. From micrographs, the grain structures and reinforced particle size, shape and their distribution were observed. The important use of optical microscope in microstructure examination was the analysis of reinforced particles in aluminium matrix. Standard hand polishing using 240, 600, 800 and 1000-grit silicon carbide papers for Metallographic specimens of sintered performs. The specimens were then finish-polished using 1 μm diamond paste suspended in distilled water to obtain mirror-like surface finish. To expose the micro structural features, the polished specimens were etched with Keller etching solution. The etch-polish-etch procedures were used to attain good microstructure. These graphite and B<sub>4</sub>C particles are uniformly distributed throughout the Al 2024 matrix phase. The absence of cracks can also be observed from the micrographs. Figure 13 shows the distribution of the elements aluminium (Al), Boron carbide (B<sub>4</sub>C), graphite (Gr) respectively.

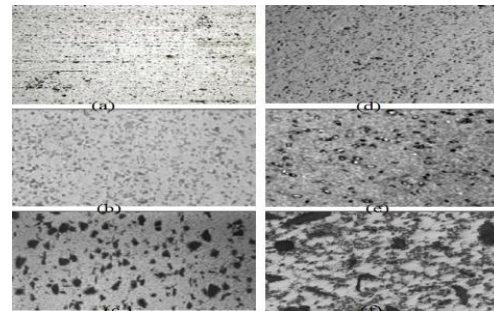
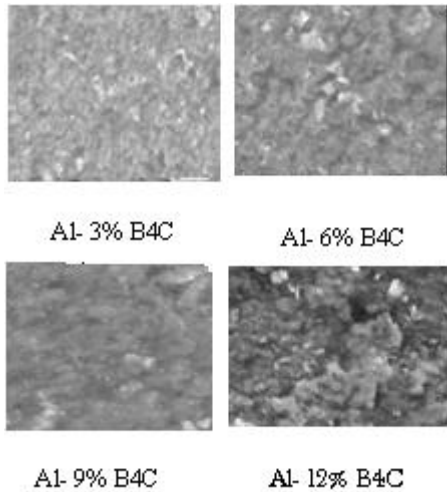


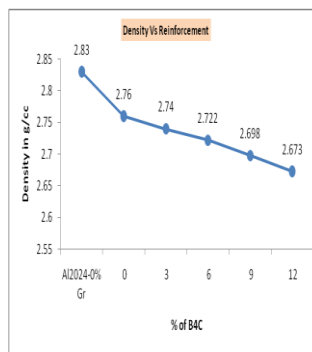
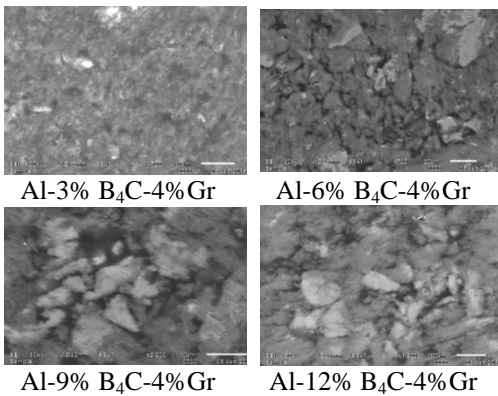
Figure 13: Optical micrographs of the produced composites. (a) Al 2024 (b) Al-Gr 4%, (c) Al-Gr 4%-B<sub>4</sub>C 3%, (d) Al- Gr 4%-B<sub>4</sub>C 6%, (e) Al-Gr 4%-B<sub>4</sub>C 9%,(f) Al-Gr 4%-B<sub>4</sub>C 12%.



Al 2024/ 4 wt% of Gr/ 3 wt% of B <sub>4</sub> C hybrid composite	2.740
Al 2024/ 4 wt% of Gr/ 6 wt% of B <sub>4</sub> C hybrid composite	2.722
Al 2024/ 4 wt% of Gr/ 9 wt% of B <sub>4</sub> C hybrid composite	2.698
Al 2024/ 4 wt% of Gr/ 12 wt% of B <sub>4</sub> C hybrid composite	2.673

Figure 14: variation of density with increase in the reinforcement

III.5 Corrosion Resistance Test



III.4 Density measurement

Archimedes’s principle with a high precision digital electronic weighing balance with an accuracy of 0.0001 g was used to determine the density of the composite specimens. Table 3 shows the experimental values of density for the fabricated hybrid composites. Figure 14 shows the variation of density of the hybrid composites with variation of B<sub>4</sub>C content. It was observed that there is a decrease in density with the increase of B<sub>4</sub>C reinforcement. There is a sudden decrease in the density due to less denser property of the graphite as compared with the other two materials Whenever only 4% of graphite was added to the aluminium, after which the density gradually decreased with the increase in B<sub>4</sub>C, due to the decrease in volume of the aluminium which is having high density and this volume was occupied by the less denser reinforcement of B<sub>4</sub>C. This can be attributed to the addition of lower density reinforcements which are B<sub>4</sub>C and Gr.

Table 3: Density of Various Composites

Composition (Wt %)	Density(g/cm <sup>3</sup> )
Al 2024	2.830
Al 2024/ 4 wt% of Gr composite	2.760

The samples obtained after sintering process were machined on the lathe machine to get the final samples of 15mm length with 10 mm diameter. Al-B4C-Gr hybrid and Al-B4C test samples were used along with base alloy Al2024 for the corrosion test. All the samples were polished with different grit emery papers to get uniform smoothness. The samples are thoroughly degreased using mild soap and washed with distilled water are kept in the muffle furnace which are dried at 100 °C for 1 hr. The dried samples were placed in Standard corrosive media solution of 1 litre capacity have been prepared with concentration of water to HCL ratio of 19:1. The equally distribution of concentrated solution of 200ml were poured in five beakers which of 500 ml capacity. All the samples were initially weighed individually and placed in category wise for simplicity. Care has been taken to keep at least 1 inch difference for each sample. Samples were taken out at an interval of 2 hours and thoroughly washed with distilled water. Dried samples

were dipped in alcohol and weight loss is measured after drying.



Figure.15 Corrosive test apparatus

III.6. Observations

Table 10.2: Observations made for Al-B<sub>4</sub>C composites:

Time in hours	MATERIAL WEIGHT LOST IN GRAMS			
	3% B <sub>4</sub> C	6% B <sub>4</sub> C	9% B <sub>4</sub> C	12% B <sub>4</sub> C
2	0.01	0.03	0.04	0.06
4	0.03	0.05	0.08	0.09
6	0.05	0.07	0.10	0.13
8	0.06	0.08	0.13	0.17
10	0.08	0.10	0.16	0.21

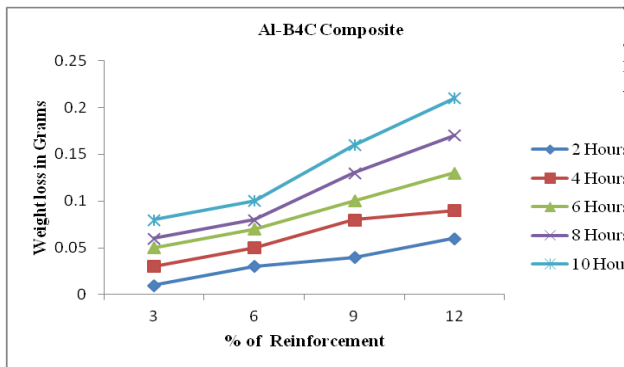


Figure.16. Corrosion test graph for Al-B<sub>4</sub>C composite

From the above graph, the weight loss of the various composites were increased with the increase in the % of composition, this is due to the presence of B<sub>4</sub>C particles in Al2024 alloy. The increase in B<sub>4</sub>C content and there is a significant increase in weight loss. This is due to the formation of aluminium borides at the interface of Al-B<sub>4</sub>C particles. In the case of composites introduction of considerable amounts of alloy additions and reinforcing elements to the matrix releases inter-metallic phases in the structure, which lead to the formation of galvanic couples favourable to corrosion.

Observations made for Al-B<sub>4</sub>C-Gr hybrid composite:

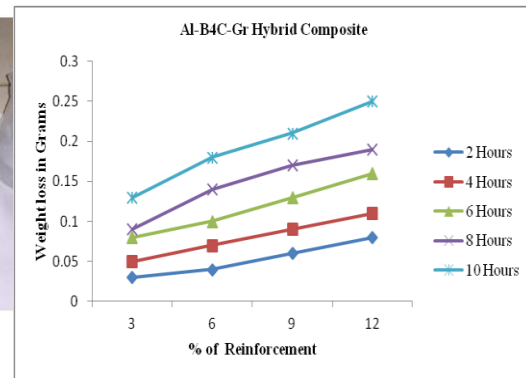


Figure.17 Corrosion test graph for Al-B<sub>4</sub>C-Gr Hybrid composite

From the above graph, the weight loss of the various composites were increased further with the increase in the % of B<sub>4</sub>C and fixed amount of Gr in aluminium alloy Al2024. The increase of corrosion is due to the addition of graphite leads to Aluminium carbides at the interface of Al-Gr particles and Aluminium Borides at the interference of Al-B<sub>4</sub>C particles. The high corrosion is due to higher amount of intermetallic present in the matrix. The corrosion rate increased with increase in B<sub>4</sub>C and fixed amount of Gr due to irregular corrosion which is a localized attack along the grain boundaries or an adjacent to the grain boundaries. The corrosion penetration along the interfaces caused interfacial de-bonds which will lead to rupture or degrade of the interface.

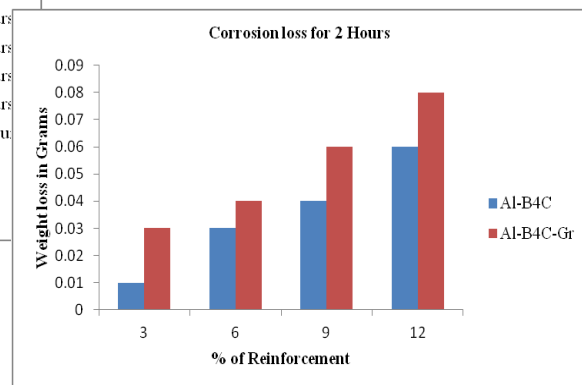


Figure.18 comparison between Al-B<sub>4</sub>C & Al-B<sub>4</sub>C-Gr Hybrid composite at 2 Hours

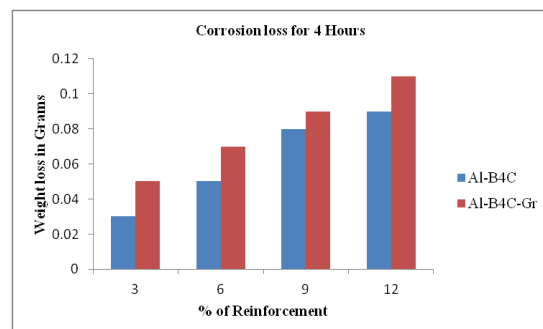


Figure.19 comparison between Al-B<sub>4</sub>C & Al-B<sub>4</sub>C-Gr Hybrid composite at 4 Hours

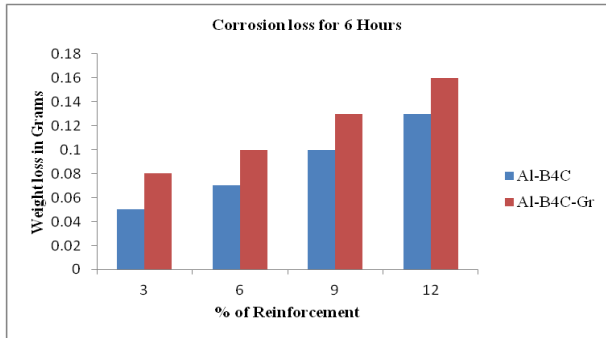


Figure.20 comparison between Al-B<sub>4</sub>C & Al-B<sub>4</sub>C-Gr Hybrid composite at 6 Hours

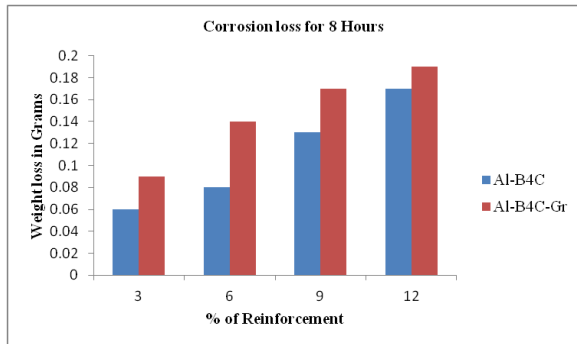


Figure.21 comparison between Al-B<sub>4</sub>C & Al-B<sub>4</sub>C-Gr Hybrid composite at 8 Hours

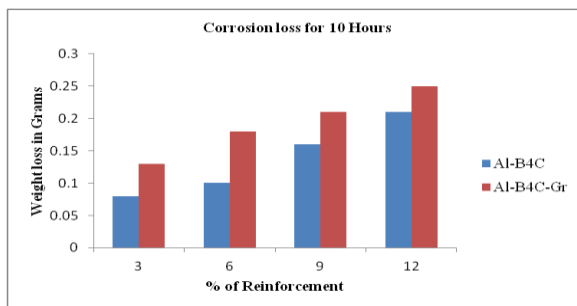


Figure.22 comparison between Al-B<sub>4</sub>C & Al-B<sub>4</sub>C-Gr Hybrid composite at 10 Hours

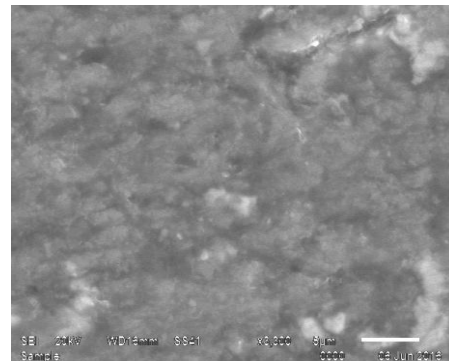
From the above figures (18-22), it has been observed that for all the specimens, the corrosion (weight loss) was increased for Hybrid composites (Al-B<sub>4</sub>C-Gr) as compared with the Composites without graphite (Al-B<sub>4</sub>C). Due to the soft nature of graphite.

Conclusion:

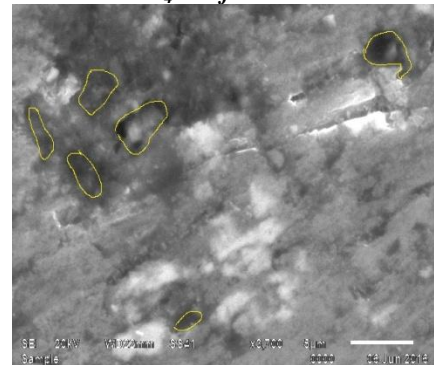
Al-B<sub>4</sub>C-Gr Hybrid and Al-B<sub>4</sub>C Metal-metal composites were successfully produced through powder metallurgy technique. The uniform

distribution of the reinforcements in the Aluminium matrix was confirmed by the optical microscope images (Figure 13). The graphite addition results more corrosion due to its soft nature and also low hardness. The increase in B<sub>4</sub>C will enhance the corrosion rate. In Al-B<sub>4</sub>C-Gr hybrid composites, the corrosion is more than the Al-B<sub>4</sub>C composite due to presence of Graphite. Therefore the corrosion is less for the base metal as compared to the composites.

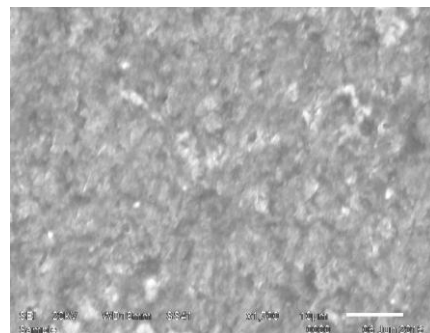
SEM images of corroded surfaces:



Al-3%B<sub>4</sub>C before corrosion

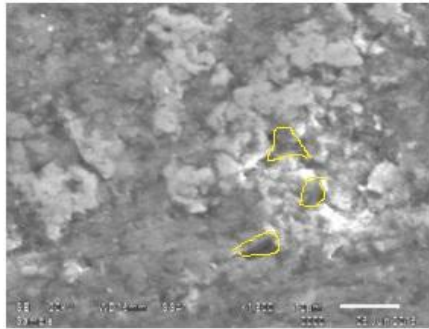


Al-3%B<sub>4</sub>C after corrosion

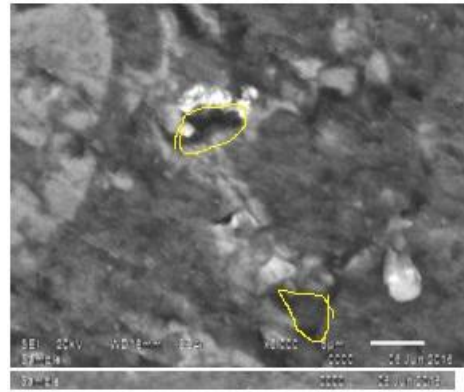


Al-6%B<sub>4</sub>C before corrosion



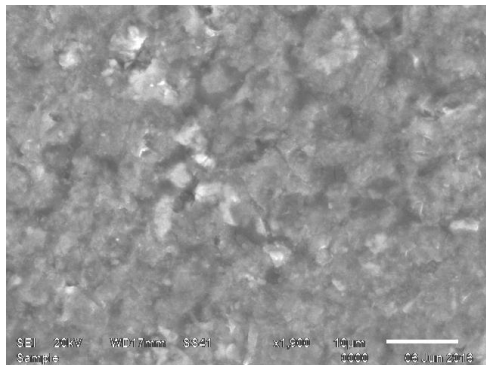


*Al-6%B<sub>4</sub>C after corrosion*

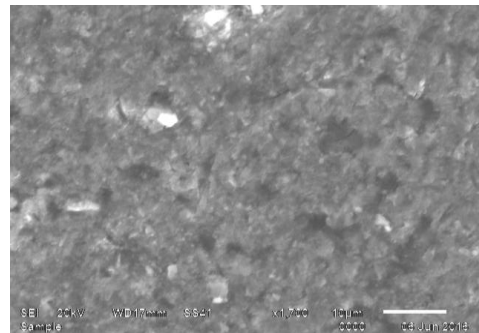


*Al-12%B<sub>4</sub>C after corrosion*

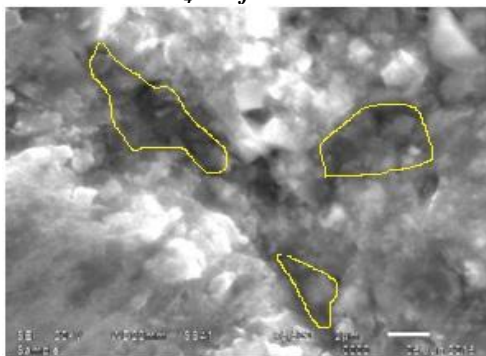
*Figure 23. SEM images before and after corrosion of Al-B<sub>4</sub>C composites*



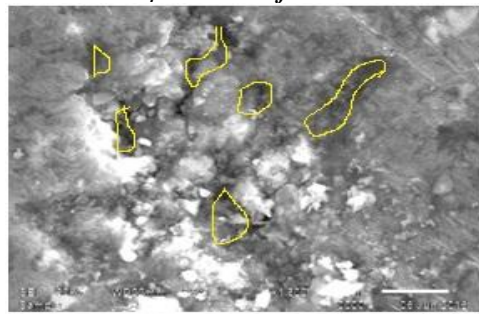
*Al-9%B<sub>4</sub>C before corrosion*



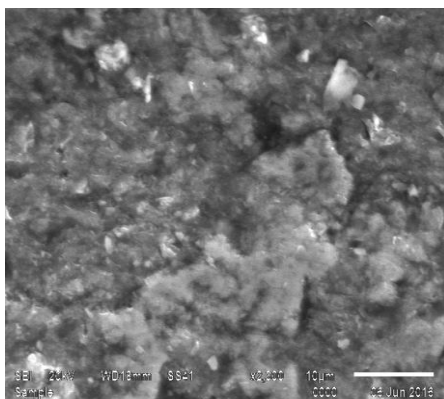
*Al-3%B<sub>4</sub>C-4%Gr before corrosion*



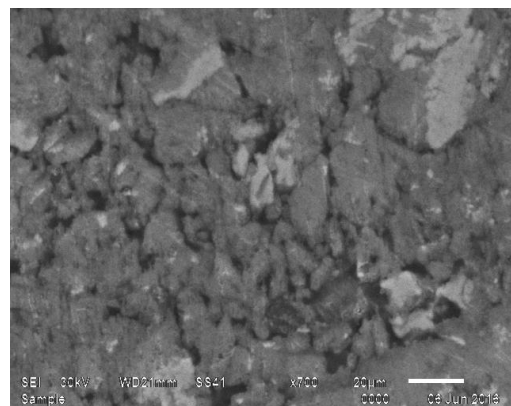
*Al-9%B<sub>4</sub>C after corrosion*



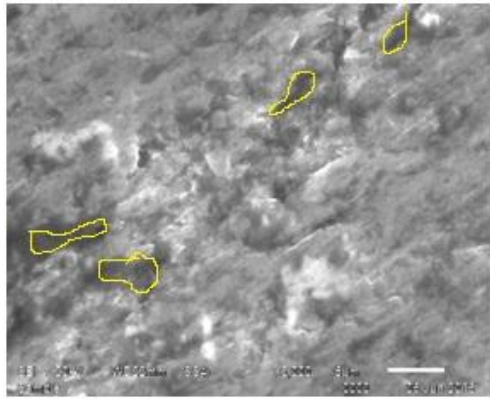
*Al-3%B<sub>4</sub>C-4%Gr after corrosion*



*Al-12%B<sub>4</sub>C before corrosion*

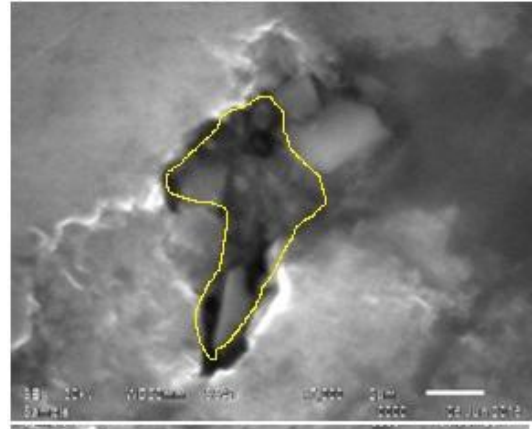


*Al-6%B<sub>4</sub>C-4%Gr before corrosion*

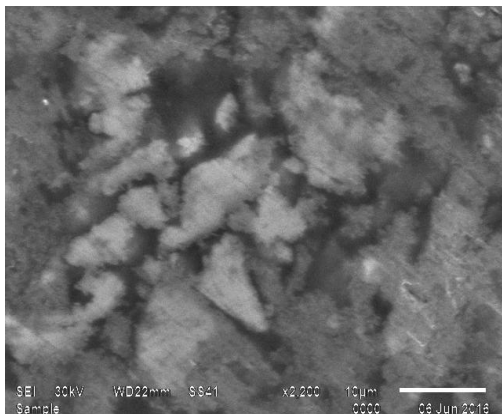


*Al-6%B<sub>4</sub>C-4%Gr after corrosion*

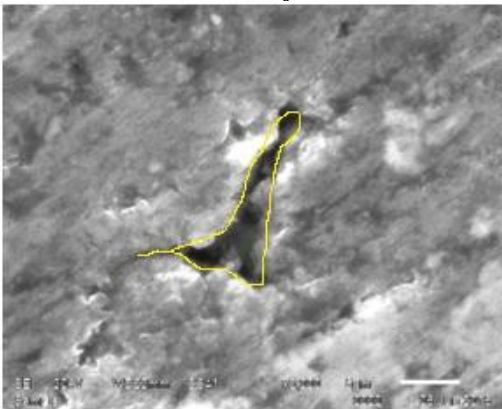
*Al-12%B<sub>4</sub>C-4%Gr before corrosion*



*Al-12%B<sub>4</sub>C-4%Gr after corrosion*



*Al-9%B<sub>4</sub>C-4%Gr before corrosion*



*Al-9%B<sub>4</sub>C-4%Gr after corrosion*

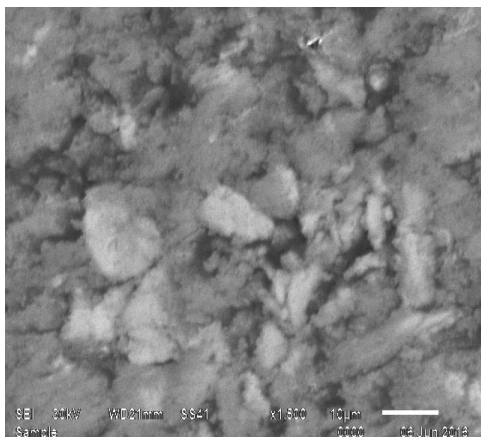


Figure 24. SEM images before and after corrosion of Al-B<sub>4</sub>C composites

In powder metallurgy components, the corrosion is due to the pit, Galvanic and residual stress. It is well known that a very thin oxide layer is quickly formed on a fresh aluminium surface after exposure to air. The formation of pits at the Al–B<sub>4</sub>C–Gr interfaces may occur due to the defects existing at the interface between aluminum and other reinforcing materials. Chlorine can easily penetrate and attack the Al matrix and leads to degrade the composite. The galvanic coupling effect between the Al matrix and the reinforcing (B<sub>4</sub>C,Gr) particles leads to galvanic corrosion. Consequently, the Al matrix at the interfaces dissolves, and pits form around B<sub>4</sub>C particles. Once a pit is formed, the local chemical environment is substantially more aggressive than the bulk solution, and therefore the matrix is more severely corroded. Additionally, with increased B<sub>4</sub>C particles in the composite, the cathodic and anodic area ratio (AC/AA) increases due to the cathodic character of the B<sub>4</sub>C particles. Figure 23 and 24 shows the surface appearance of Non hybrid and Hybrid composites. The rate of corrosion increased with the increase in B<sub>4</sub>C.

Uneven layers of corrosion formed on the outermost surface of the base alloy and composites. It is found that the thickness of the corroded layers increases linearly with the B<sub>4</sub>C content. Moreover, Figure 23 shows that only the composites suffer severe pitting, which confirms that the Al-B<sub>4</sub>C composite is more sensitive toward pitting than the base alloy in the HCl solution. In case of hybrid composites, due to the presence of Graphite, the corrosion rate further increases and leads to the increase in size of pits as shown in Figure 24 and leads more corrosion rate than the base and Al-B<sub>4</sub>C composites.

**Conclusions:**

Al-B<sub>4</sub>C and Al-B<sub>4</sub>C-Gr composites were fabricated successfully by powder metallurgy

technique. From SEM analysis, The reinforcing particles (B<sub>4</sub>C,Gr) were distributed uniformly throughout the Aluminium alloy. The density of the fabricated composites was decreased with the increase in the reinforcement. The fabricated composites were influenced by the corrosive media (HCL) and there is degradation on the composites. This degradation is due to the formation of oxides known as corrosion. This corrosion is due to pits formation at the interfaces of the particles, residual stresses during the compact of the specimens at the time of making pellets and galvanic corrosion in between the particles. Hence the corrosion is more in Hybrid composite compared with the nonhybrid and base aluminium alloy.

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