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# Impact of boron carbide and graphite dual particulates addition on wear behavior of A356 alloy metal matrix composites

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**Abstract**

The current work gives the detailed microstructural analysis and wear behaviour of aluminium alloy A356 based metal matrix composite. Here, boron carbide ($B_4C$) and graphite (Gr) particulates were used as reinforcing phase to develop A356/ 4 wt% $B_4C$, A356/ 4 wt% Gr composites along with A356/ 4 wt% Gr/ 12 wt% $B_4C$ hybrid composites. The composites were developed by conventional stir casting method to improve the wear properties. The developed composites were subjected to scanning electron microscope (SEM) for microstructural analysis and then to DUCOM made wear test assembly to know the dry sliding wear behaviour. The wear tests were conducted for different loading conditions of 1, 2 and 3 kg for a sliding distance of 4000 m over the speed of 100, 200 and 300 rpm, respectively. The result show decreased wear upon addition of reinforcing particulates and SEM results of developed composites revealed utmost distribution of particulates. Wear morphology of worn surfaces were also carried out using SEM.

## 1. Introduction

Composite materials can be classified in to several types, but the present work concentrates on metal matrix composites because of its tremendous advantage over other types of composites. Metal matrix composite comprises of metal as its base alloy usually known a matrix phase which is major part of a composite. There are several types of metal matrix phases like aluminium, copper, magnesium, titanium etc., upon which intensive research work is being carried out. Aluminium alloys are widely being used both in wrought and as cast form because of its properties like corrosion resistant, light weight along with ease of handling, cost factors and wide range of applications [1-3]. Several types of dispersoids of different size and shapes are available in the form of particulates, whiskers and fibers [4]. Particulates are generally used in metal matrix because it renders isotropic properties upon application of load. There are several ceramic materials being used as reinforcements like silicon carbide, titanium carbide, aluminium oxide etc. [4,5]. In present work hard ceramic particles like boron carbide and graphite are selected as reinforcing material to develop hybrid composite materials. Boron carbide is known for its extreme hardness with less density (2.52 $g\cdot cm^{-3}$) and good chemical resistance, graphite on other hand has high melting point and soft in nature due to which it is used as dry lubricant [6]. Graphite too has low density of around 2.2 $g\cdot cm^{-3}$ [7]. There are various types of fabricating composites both in liquid state and solid state. The low cost and ease of fabricating method, liquid casting technique was chosen for processing hybrid material. Further, the processed materials were machined as per their respective ASTM standards and subjected to testing to evaluate their characteristics. Liquid metallurgy route helps in fabricating complex shaped products in high volume very easily there by resulting in to a cost effective metal matrix composite [8].

Harichandran *et al.* [9] used pure aluminum as metal matrix reinforced with boron carbide both in micron and nano size. $B_4C$ particulates were used in 2, 4, 6 and 8 wt% size and studied for their mechanical and tribological properties. The $B_4C$ particulates reinforced in 70 µm size showed improved strength and wear resistance when compared to aluminium matrix. The highest strength and wear resistance was observed in Al-8 wt% $B_4C$ composites compared to lesser reinforced $B_4C$ particulates and aluminium.

Mazahery *et al.* [10] has developed composite of $B_4C$ reinforced A356 aluminium alloy, the variation of reinforcement varies 0 wt% to 12.5 wt% in steps of 2.5 and the composite samples were developed using 1, 22 and 50 µm particle sizes. Wear test was conducted for all the samples, the maximum wear loss was observed in samples containing 1 µm particulates. The highest wear resistance was observed in samples consisting of 50 µm particle size. Further, among 50 µm particle size samples more wear resistance was observed in composite comprising 12.5 wt% $B_4C$ reinforcement.

Baradeswawan *et al.* [11] developed a composite using aluminium alloy 7075 as base matrix and graphite as reinforcing material by stir casting technique. Graphite was added from 5 to 20 wt% in the steps of 5, upon which tribological and mechanical tests were conducted. The results show maximum dry sliding wear resistance at minimum coefficient of friction at 5 wt% of graphite.

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From literature work it was observed that both hard particles $B_4C$ and soft natured Graphite individually improve the wear resistance of composites. In the present work we use Graphite and $B_4C$ in A356 alloy to find out its individual and combined effect of wear loss in composites. Further, reinforcement has particle size of average 80-90 µm

## 2. Experimental

### 2.1 Selection of material

As cast A356 alloy becomes popular choice as metal matrix because of its properties like excellent castability and machinability. Aluminium alloy A356 also imparts good resistance to corrosion which has better weldability characteristics [12]. Since A356 alloy has good castability it becomes automatic choice for developing complex shapes where excellent mechanical properties, pressure tightness and light weight are required.

**Table 1.** Chemical composition of AA2124 Alloy.

| Elements | Si | Cu | Mg | Mn | Fe | Zn | Ni | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| Weight (%) | 7.20 | 0.02 | 0.29 | 0.01 | 0.18 | 0.01 | 0.02 | 0.11 | Bal |

Reinforcing materials are usually added in matrix alloys to strengthen the final product. Several types of reinforcing particulates with various sizes like silicon carbide, aluminium oxide, titanium carbide, boron carbide etc., have already been used in developing composition materials so far [13]. Here, in the present work Boron Carbide ($B_4C$) and Graphite (Gr) have been used as reinforcing agent in A356 alloy. Boron carbide being one of the hardest materials known is used in particulate form with its average size 80-90 µm. The intention of using graphite within the composite is to act like a solid lubricant when subjected to wear.

### 2.2 Preparation of material

Though there are several approaches to create composites, a standard stir casting method was chosen to produce A356/$B_4C$/Gr hybrid composite because of low cost and simple processing method. Four different set of castings were achieved starting with as cast A356 alloy, A356-4 wt% Gr, A356-4 wt% $B_4C$ composites and A356-4 wt% Gr, -12 wt% $B_4C$ hybrid composite. Initially, calculated amount of A356 aluminium alloy was heated at 750°C in the furnace and the preheated reinforcements were added to the molten metal with continuous process of stirring. The addition of reinforcement was carried out in two stages to avoid agglomeration of particulates. Once the molten metal with reinforcement is intermixed by stirring, the stirrer and the furnace is turned off and the crucible containing molten composite is poured in pre heated dies. The melt is allowed to solidify within the moulds to get the composite. Further, these composites were machined as per ASTM standards and subjected to various studies.

### 2.3 Testing of material

SEM is used to check the distribution of $B_4C$ and Gr particulates within the composites. Here the small piece of material was cut from the developed composite which was further grinded, polished and etched with Keller's reagent so that the microstructural analysis of composite becomes easy [14]. Now the prepared specimen was subjected to SEM to check the particle distribution within the various developed specimen.

Under pre-defined conditions the amount of removal of material is known by conducting standard wear tests. Rotating wear testing machine also known as pin on disk machine (Model TR-20LE, Ducom) is used to carry out test as per ASTM G99 method [15]. The loads of 1, 2 and 3 kg were applied over the pin to know the respective wear. By varying load, disk speed at several sliding distances the wear test were conducted. The worn out surface of pin were further subjected to SEM to study the worn surface morphology.

**Figure 1.** Stir casting setup.

**Figure 2.** Al alloy composites in cast iron die.

## 3. Results and discussion

The microstructural studies are essential in determining the grain size, grain shape and distribution of reinforcing particulates within the base metal matrix, which have substantial effect on tribological properties [16]. The SEM results show almost uniform distribution of particulates within the developed composites. Figure 3(a) representing as cast A356 alloy without any reinforcement. Figure 3(b-d) reveal there is fair distribution of $B_4C$ and Graphite particulates within the matrix. The above SEM micrographs also reveal less porosity.

$B_4C$ particles are having sharp edges, as these are very hard particles. Both the $B_4C$ and graphite particulates are distributed uniformly throughout the matrix.

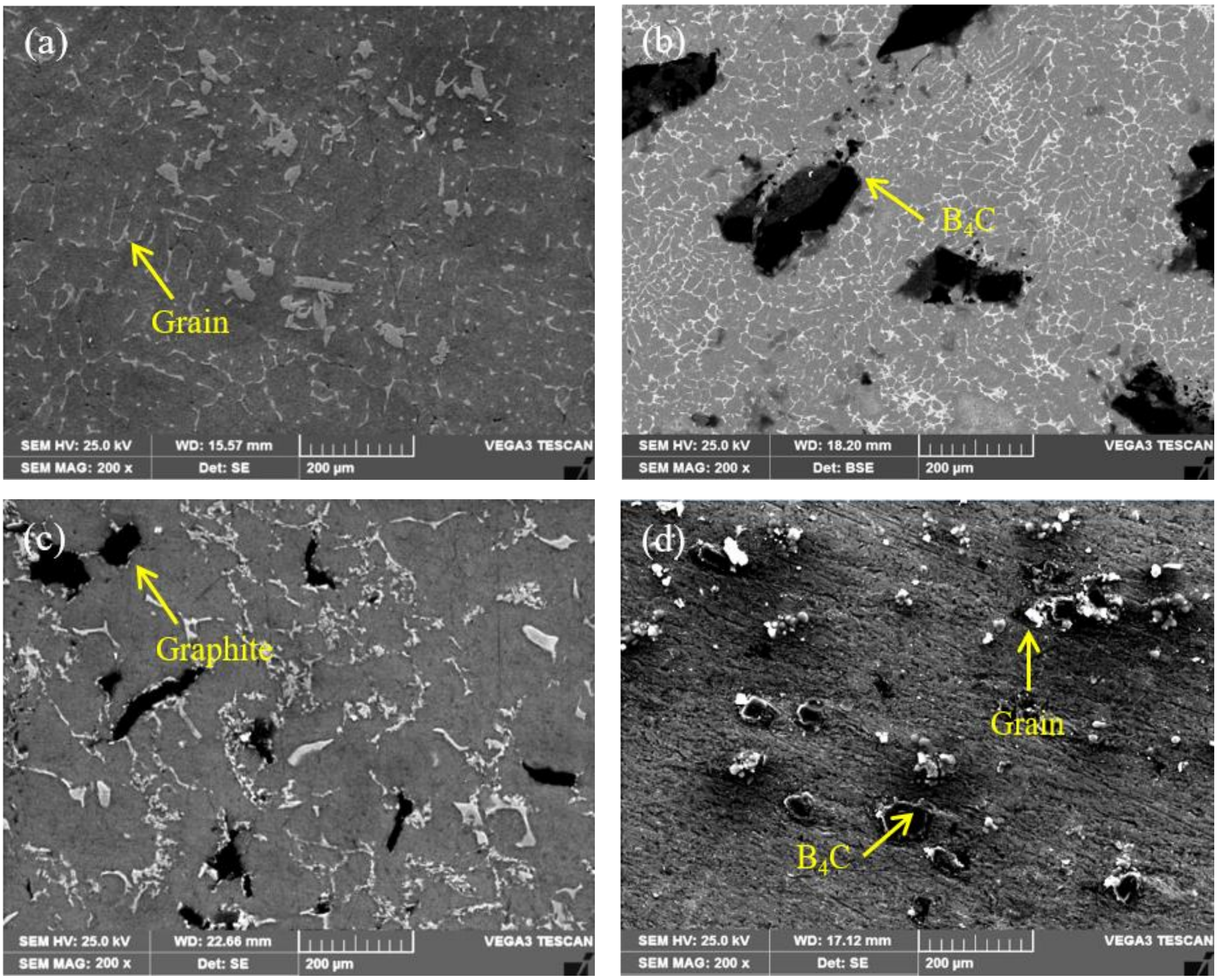


**Figure 3.** Scanning electron micrographs of (a) as cast A356 alloy, (b) A356-4 wt% $B_4C$, (c) A356-4 wt% Gr and (d) A356-4 wt% Gr +12 wt% $B_4C$.

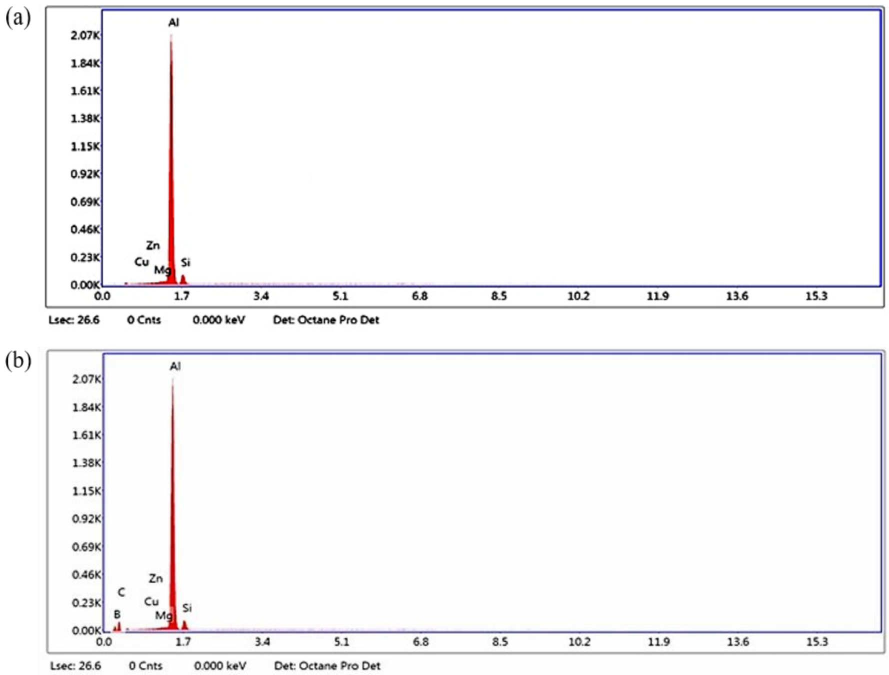


**Figure 4.** Energy Dispersive Spectrography of (a) A356 and (b) A356- 4 wt% Gr -12 wt% $B_4C$.

Figure 4(a) represents the EDS analysis of A356 alloy in which presence of aluminium phase can be seen as maximum peak with other chemicals as small peaks. Figure 4(b) presents the EDS analysis of A356-4 wt% Gr-12 wt% $B_4C$ hybrid composites in the spectrum above which prove the presence of boron (B), carbide (C) and graphite in the form of carbon (C) within the aluminium alloy A356.

Wear test is conducted on the fabricated as cast A356 aluminium alloy, A356 -4 wt% Gr, A356 -4 wt% $B_4C$ composites and A356/Gr/$B_4C$ hybrid composites. The test specimens are machined according to the ASTM G99 standard for wear test.

The load is one of the significant parameters which plays important role in wear loss. Lot of work carried out on the influence of normal load in wear experiments to understand the wear rate of aluminium alloys. Further, to study the effect of load on wear, graphs have been plotted for wear loss in terms of microns against different loads of 1, 2 and 3 kg at constant distance of 4000 meters and sliding speed of 300 rpm as shown in the Figure 4.

Figure 5 is indicating the effect of applied normal load on the wear behavior of A356 alloy, A356 alloy-4 wt% of $B_4C$, A356 alloy-4 wt% of graphite and A356 alloy-4 wt% of graphite and 12 wt% of $B_4C$ hybrid composites. From Figure 4, it is observed that as load increases from 1 kg to 3 kg, there is increase in wear for all the composites and base A356 alloy. At maximum load of 3 kg the temperature of sliding face increases and reaches the critical value. Therefore, as the load increases on the pin there is also increase in the wear loss of the matrix A356 alloy, A356 alloy-4 wt% of $B_4C$, A356 alloy-4 wt% of graphite and A356 alloy-4 wt% of graphite and 12 wt% of $B_4C$ hybrid composites. The wear loss of as cast A356 alloy is highest in all the loading conditions and is represented in the Figure 5. It is seen that the wear loss of the composites decreases with addition of $B_4C$ and graphite in the A356 alloy. The increase in wear resistance of the A356 alloy with $B_4C$ and graphite reinforced composites may be due to the high hardness of $B_4C$ and self-lubrication property of graphite particulates which acts as the barrier for the wear loss. It can also be seen that with increase in addition of hard $B_4C$ particles the wear resistance also increases; in present research work increase in wt% of $B_4C$ as 12 wt% along with 4 wt% of graphite particles also resulted in the increase in wear resistance.

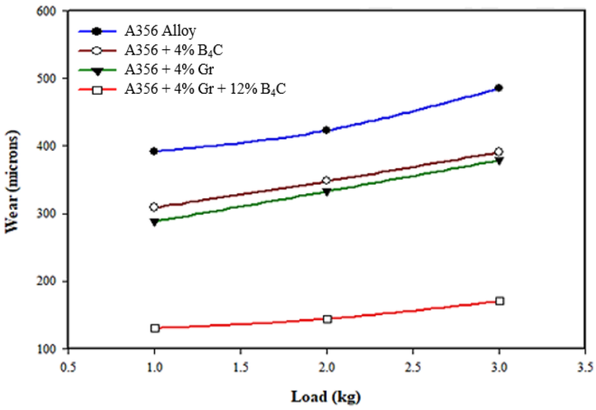


**Figure 5.** Wear loss of A356 and its composites at varying loads.

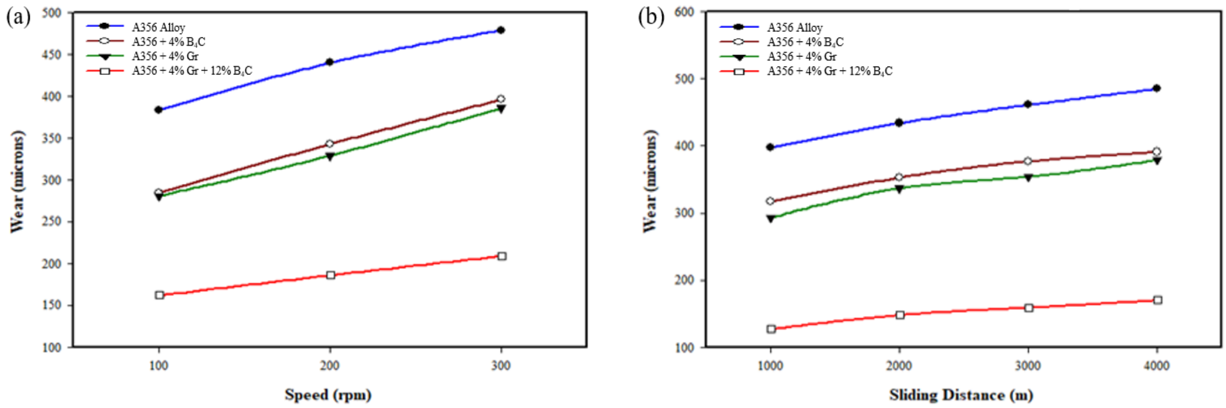


**Figure 6.** (a) Wear loss of A356 alloy and its composites at varying speeds and (b) wear loss of A356 alloy and its composites at varying sliding distances.

Figure 6(a-b) shows the wear loss of different compositions of composites for varying speed and varying distance. It is observed that with increase in speed and sliding distance wear also increases with respect to any combination of composite taken viz., A356 alloy, A356-4 wt% $B_4C$, A356-4 wt% Gr, A356-4 wt% Gr-12 wt% $B_4C$. The maximum wear resistance is shown by hybrid composite with the combination of A356-4 wt% Gr-12 wt% $B_4C$.

Figure 6(a) shows the wear loss with the variation of speed for several test samples with varying compositions. The test is conducted with varying disc speed of 100, 200 and 300 rpm by retaining load of 3 kg. From the Figure 6(a), it is concluded that wear loss increases with the increasing sliding speed. For base A356 alloy the effect of sliding speed is more when compared to $B_4C$ and graphite reinforced hybrid composites. Although at all the sliding speeds, the wear loss of the composites is much lower, when compared with the A356 alloy matrix and is much lesser in the case of A356 alloy-4 wt% graphite-12 wt% of $B_4C$ particles reinforced hybrid composites. Basically, with the addition of graphite and $B_4C$ particulates the wear loss of the composites decreases as compared to the base A356 alloy. The decrease in wear loss is mainly due to the presence of hard ceramic boron carbide and high wear resistant graphite particle. These particles acts as wear resistant asperities during the dry sliding wear process. Similar results were obtained by Lashgari *et al.* [17] developed and conducted wear tests on A356/10 wt% $B_4C$ composites. The addition of $B_4C$ particle in A356 alloy shows decrease in wear when compared with base A356 alloy.

In all the three varying parameters A356-4 wt% Gr. Composite has better wear resistance when compared to as cast A356 alloy and A356-4 wt% $B_4C$, this is because of soft nature of Graphite which decreases wear [18]. Also wear resistance of A356-4 wt% $B_4C$ composite is better compared to A356 base alloy because of hard nature of reinforcing $B_4C$ particulate [19]. Combined effect of 12 wt% $B_4C$ and 4 wt% Gr. Within A356 alloy show improved wear resistance than other combinations. Nagaral *et al.* [12] have developed graphite based AMC, it is concluded that graphite in A6061 has improved wear resistance particularly at 6 wt% of Gr and it is also concluded that increase in sliding speed also increases the wear loss. Hence the results obtained in present work are similar and are in line with the previous research work carried out.

Figure 6(b) shows the wear loss with the variation of sliding distance for several test samples with varying compositions. The test is conducted with varying sliding distances of 1000, 2000, 3000 and 4000 m at constant load of 3 kg and sliding speed of 300 rpm. From Figure 5(b), it is evident that as sliding distance increases from 1000 to 4000 m, there was increase in wear loss of as cast A356 alloy, A356 alloy-4 wt% of $B_4C$, A356 alloy-4 wt% of graphite and A356 alloy-4 wt% of graphite and 12 wt% of $B_4C$ hybrid composites. Further, graphite and $B_4C$ particulates reinforced hybrid composites exhibits superior wear resistance as compared base matrix and 4 wt% of $B_4C$ and 4 wt% of graphite reinforced single phase composites.

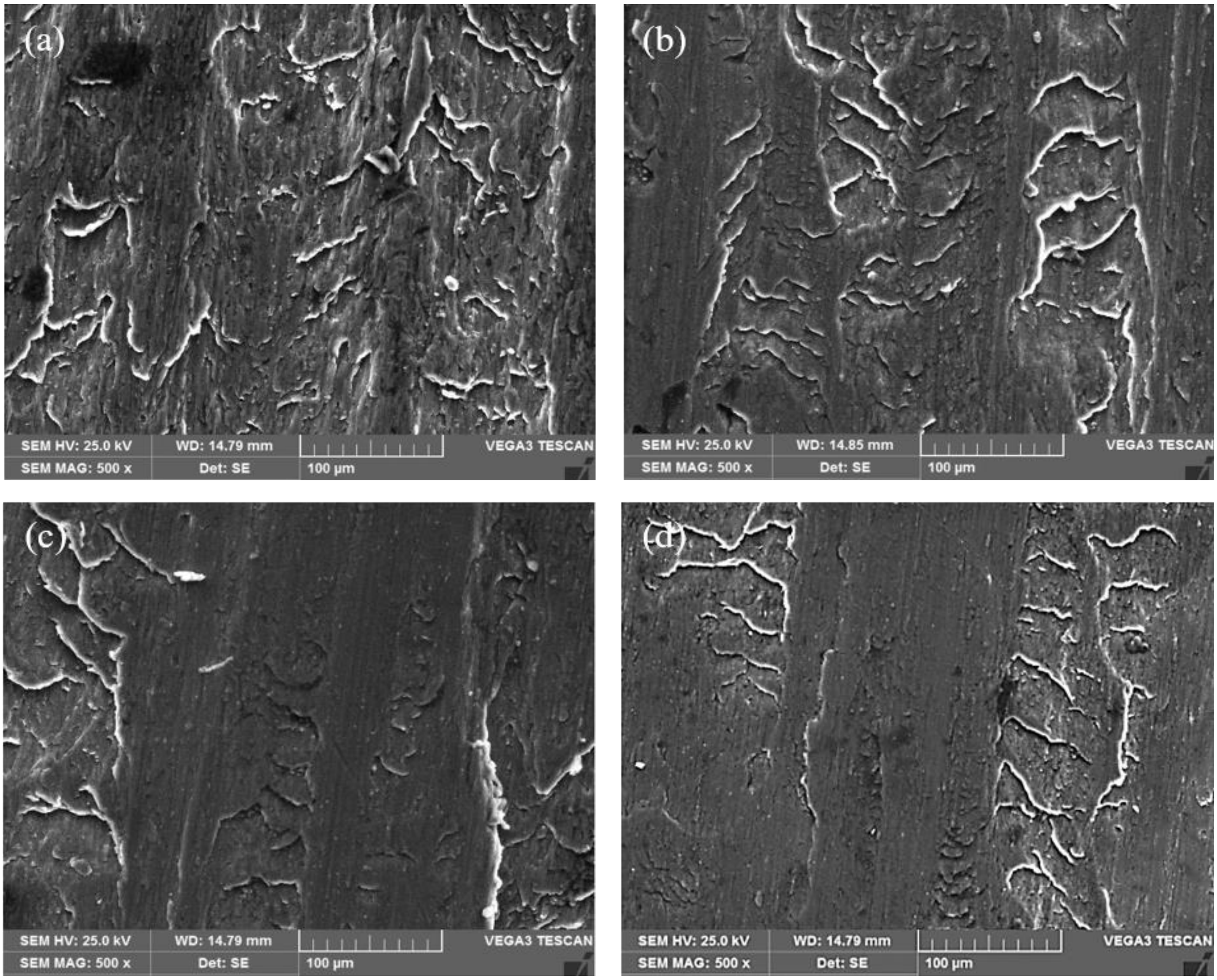


**Figure 7.** SEM results of worn surfaces of (a) A356, (b) A356-4 wt% $B_4C$, (c) A356-4 wt% Gr and (d) A356-12 wt% $B_4C$-4 wt% Gr.

It's significant to study the worn-out surface morphology of A356 alloy, A356 alloy-4 wt% of $B_4C$, A356 alloy-4 wt% of graphite and A356 alloy-4 wt% of graphite and 12 wt% of $B_4C$ hybrid composites as it shows the type of wear the materials with different composition have undergone. During sliding the A356 alloy matrix is softer than the rubbing disc material and hence shows viscous flow of A356 matrix, which is in the form of pin causing plastic deformation of the specimen surface, resulting in very high material loss. The worn surface of A356 alloy shows presence of grooves, micro-pits and fractured oxide layer as shown in Figure 7(a), which would have caused the increase of wear loss. Whereas $B_4C$ and graphite particles in A356 alloy-4 wt% of $B_4C$, A356 alloy-4 wt% of graphite and A356-4 wt% of graphite and 12 wt% of $B_4C$ composites restrict the viscous flow of the matrix as shown in Figure 7(b-d) it is observed that the grooves or erosion have reduced with addition of $B_4C$ and graphite particles means there is more and more resistance to wear loss. Meanwhile, the stress seems to be transferred on $B_4C$ and graphite particles and strain concentration occurs around these particles and worn surface area shows less and less cracks and grooves with the addition of $B_4C$ and graphite particles.

Wear morphology of worn out surfaces are shown below in Figure 7(a-d) as it is necessary to know the type of wear the material has undergone. The worn surface of A356 alloy shows presence of grooves, micro-pits and fractured oxide layer as shown in Figure 7(a) below, which would have caused the increase of wear loss. Figure 7(b-c) show less and smaller grooves when compared with Figure 7(a) which indicates reduced wear loss because of individual effect of hard $B_4C$ particles and soft natured Graphite. Further, in Figure 7(d) we can see very less groves when compared to Figure 7(a-c) which indicates least wear loss because of the combined effect of $B_4C$ and Gr reinforcing particles. $B_4C$ particles restrict the viscous flow of the matrix [20]. Meanwhile, the stress seems to be transferred on $B_4C$ particles and strain concentration occurs around these $B_4C$ particles. The graphite particles are soft in nature and hence act as solid lubricants reducing the wear loss [21].

## 4. Conclusions

The individual effect of graphite and boron carbide reinforced in A356 and the combined effect of reinforcements in A356 were characterized, developed by liquid metal stir casting. From the work carried out it can be concluded that,

1) The composite samples of A356/4 wt% Gr, A356/4 wt% $B_4C$ and A356/4 wt% Gr/12 wt% $B_4C$ were successfully developed by liquid stir cast technique.

2) The SEM images taken show almost uniform distribution of particulates within aluminium A356 alloy.

3) The EDS images taken prove the presence of different elements boron, graphite, carbon and aluminium in phases.

4) The wear test results show the increase in wear with increase in parameters like Sliding speed, Load and Sliding distance.

5) Aluminium alloy A356 has high wear loss when compared with A356/4wt% $B_4C$ composite. Because hard $B_4C$ ceramic particles give resistance to friction and hence reduction in wear loss.

6) Aluminium alloy A356 has high wear loss when compared with A356/4 wt% Gr composite. This is because of slushy nature of graphite which acts as solid lubricant.

7) Aluminium alloy A356/4 wt% Gr has slightly less wear loss when compared to A356/4 wt% $B_4C$.

8) There is highest resistance of wear in A356/4 wt% Gr/12 wt% $B_4C$ hybrid composite when compared to A356 alloy, A356/4 wt% Gr and A356/4 wt% $B_4C$ composites.

9) The SEM images of worn out test specimen surface were taken to understand the nature of wear.

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