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Optimization of Tribological Properties of Al6061, Boron And Graphite Mmcs Using Taguchi Method

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Abstract
Tribological properties of any substance give an overview of the life of the substance with respect to its application. Here an attempt is made to investigate the effect of parameters of wear test equipment considering the material type on the wear rate of different composition of hybrid MMC considered. Al6061 is considered as the base matrix and Boron 2wt% and Graphite 2wt% are considered as the reinforcement to develop the hybrid MMC with the traditional technique of stir casting. As the work deals with optimization process the design of experiments is done through Taguchi technique considering L27 orthogonal array with the varying parameters (input) as material (combination of Al-B, Al-Gr and Al-B-Gr), load and speed, to analyze the effects on wear rate as the response. A wear test was performed using pin-on disk apparatus at room temperature for constant load of 20N, 30N, 40N at a fixed sliding speed of 400,600,800 RPM and wear rate increased as the weight percentage of reinforcement increased. Scanning electron microscope (SEM) studies were carried out to evaluate the worn out surface. The major contribution along with the ranks of the parameters was found out using the Analysis of Variance, from which it is clear that, Boron is the significant factor that affects the hardness and wear loss of hybrid composites followed by Graphite. Confirmatory test was performed for the optimized parameters and the results were within the acceptable range when compared with the experimental results.

Keywords: *Hybrid Composite, Stir Casting, Wear Rate, Taguchi Techniques*

I. Introduction

Metal–matrix composites are materials in which tailored properties are achieved by systematic combinations of various constituents [1]. Aluminum is the most popular matrix for the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Aluminum matrix composites (AMCs) have been widely studied since the 1920s and are now used in sporting goods, electronic packaging, armours and automotive industries. They offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix.

The term “composite” broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix), and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of the boundaries (interfaces) between different constituents. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composites [2].

There is a considerable demand for lightweight, high specific strength and environmentally friendly materials in domestic, automotive and aerospace industries. From the beginning of space era, both metal matrix and hybrid composites with their unique properties such as specific stiffness, light weight and thermal expansion have been developed for the applications of aerospace and automobile industries. From the last two decades, metals are replaced by composite materials because of their improved and specific properties, since they are light weight and are structurally rigid. Their high performance leads to the adoption even in the engine and turbine applications. The demand is increasing for the advanced aluminium metal matrix composites because, as compared to other metals aluminium is abundantly available and cost of production is lesser and simple as compared to other composite materials.

II. Material and Experimentation

Alloy 6061 is one of the most widely used alloys in the 6000 series. This standard structural alloy is one of the most versatile of the heat-treatable alloys and is popular for medium to high strength requirements having good toughness characteristics. Al-6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to seawater. This alloy also offers good finishing characteristics and responds well to anodizing; however, where cosmetic appearance is critical, consider the use of alloy 6061 is considered.

The most common anodizing methods include clear, clear and color dye, and hardcoat. Alloy 6061 is easily welded and joined by various commercial methods.

A typical chemical composition of Al 6061 is presented in Table 1. Its superior corrosion resistance makes it a suitable candidate material for marine structural applications. The demand for lighter weight, cost effective and high performance materials for use in a spectrum of structural and non-structural applications has resulted in the need for fabrication of metal matrix composites (MMCs) of various types. In recent years, the aluminium alloy based MMCs have offered designers many added benefits particularly suited for applications requiring good strength at high temperatures, due to good structural rigidity, dimensional stability, light weight and low thermal expansion. The major advantages of Aluminium Matrix composites (AMCs) include greater strength, improved stiffness, reduced density, improved high temperature properties, controlled thermal expansion coefficient, thermal / heat management, enhanced and tailored electrical performance, improved abrasion and wear resistance and improved damping capabilities.

The chemical composition of the Al-6061 after the above treatments is given in Table 1.

Table1: Chemical composition of Al 6061

Elements	Cr	Cu	Mg	Zn	Fe	Mn	Si	Ti	Al
Actual value %	0.35	0.40	1.20	0.25	0.70	0.15	0.80	0.15	95.85

Figure 1: Al-6061,Graphite and Boron

Reinforcement Material

Reinforcement is commonly a high strength material, which is reinforced into the matrix that carries the load acting on it. The materials that are used as reinforcements may have much more strength, resist chemical corrosion, resist or conduct electricity, stiffness etc. The primary function of reinforcements is to take up the loads. The reinforcements used in this project work are graphite and boron.

Graphite is mainly used as reinforcement with aluminium matrix in order to improve its strength and stiffness. The particles of graphite can easily combine with aluminium matrix and it gives an identical property throughout the composite material.

In making Al-6061, Boron and Graphite metal matrix compositeses,Al-6061 is used as base alloy as it is very light weight. Graphite is used to avoid wear in the components and boron is added to give good hardness to the material. All these metals together contribute to the improved properties of the composite.

Preparation of composites

Al-6061 is taken as ingots and kept in the graphite crucible and once the matrix metal is melted and reaches liquid state, the particles of reinforcements are added and stirred at a constant speed to obtain uniform distribution of matrix material. The fabricated composite from the stir casting process is having considerably improved properties as compared to the other methods of manufacturing the metal matrix composites. The Microstructural images of aluminium metal matrix composites have clearly indicated fewer amounts of defects and identical distribution of the particulate reinforcements. Mechanical properties of the Aluminium Metal Matrix Composites (AMMCs) are investigated using Vickers Hardness Test Rig for hardness (VHTR), Pin on Disc Machine(PDM) for tribological behavior.

The present work is focused on preparation of a metal matrix composite comprising an alloy Al-6061 which is the matrix material of the composite, with a particulate mixture of boron and graphite serving as the reinforcements. The above combination of matrix and reinforcement materials are selected for the present work as this combination facilitates in developing a low density, high strength and structurally rigid MMC. In particular the significance of inclusion of boron in particulate form is its lightness than the aluminium. Further the addition of boron with graphite served as a solid lubricant since it is a soft, slippery and grayish-black substance. Because of the crystal loose interlamellar coupling, graphite has good lubricating properties and increases the strength and stability of the MMC.

Al-6061 is used as base matrix and boron and graphite as reinforcement materials for development of MMCs. For different compositions of Al- 6061, boron and graphite particulates were made according to their weight ratio by stir casting technique.

Specimen Preparation

The dimensions of the specimen prepared are as per ASTM standards**.** Microstructure of a material was observed using microscopy techniques. The Microstructural features vary immensely when observed at different length scales. So, it is important to consider length scale of observations during describing the microstructure of a material. The specimens that are used for microstructure test were used for the determination of density after the completion of microstructure test. The specimens that are used for the microstructure and density tests were used for the Vickers Hardness test after the completion of the microstructure test and density test. The wear test specimens were prepared by turning process in a conventional lathe according to ASTM G99 standards.The above experimentation procedure was repeated for different weight fractions of Al-6061 Boron and Graphite metal matrix compositeses.

III. Results and Discussions

Microstructural Analysis of the Composite

The study of microstructure helps in analyzing the distribution of distinct particles in the Al-6061 metal matrix phase. The microstructure was observed using optical microscope. For each composition, three samples at different places of the cast specimen were taken and subjected to microstructural analysis and the observations made were recorded.

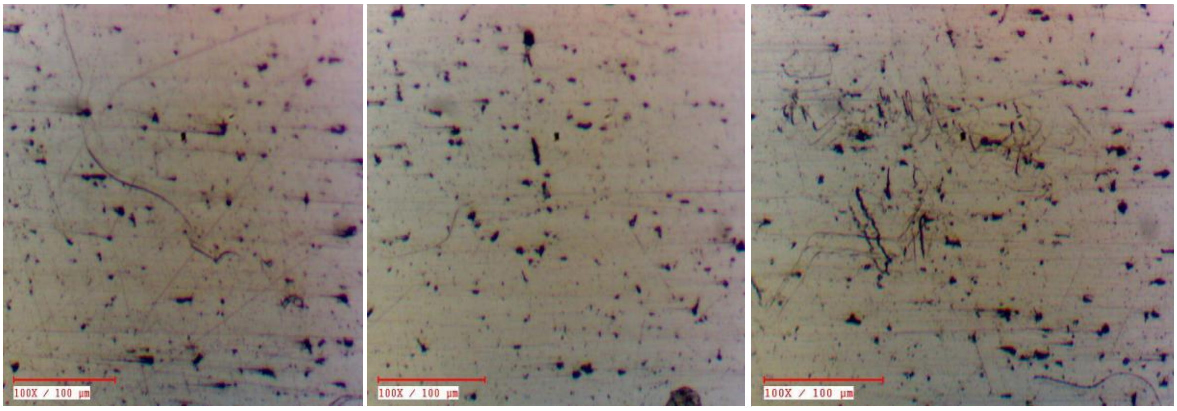

Fig. 5.1: Microstructure observation of Al-6061 at three different locations

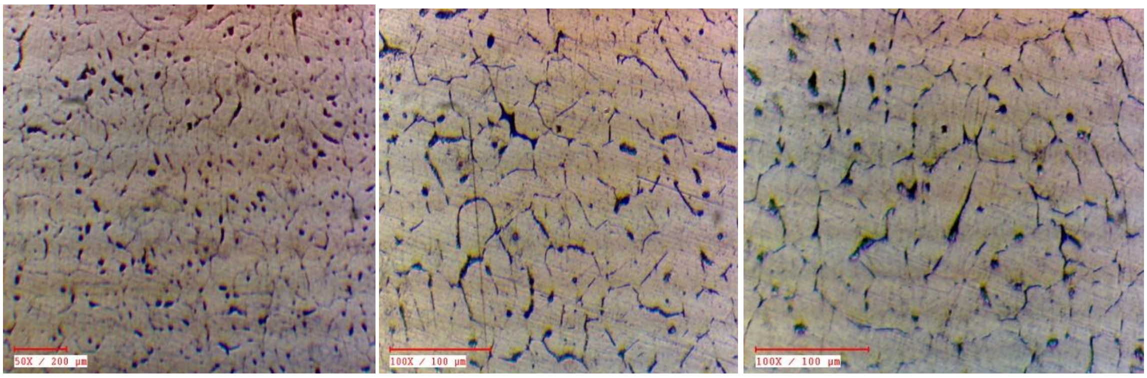

Fig.5.2: Microstructure observation of Al-6061-2%Graphite at three different locations.

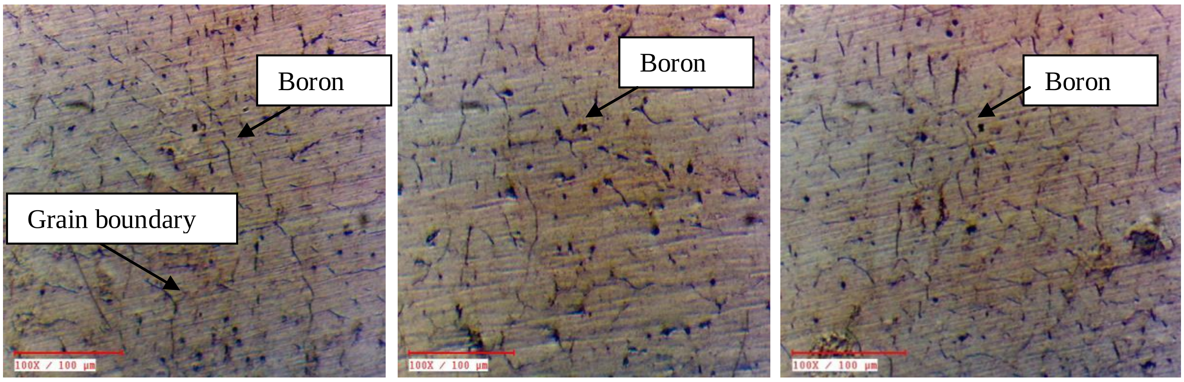

Fig. 5.3: Microstructure observation of Al-6061-2%Boron at three different locations

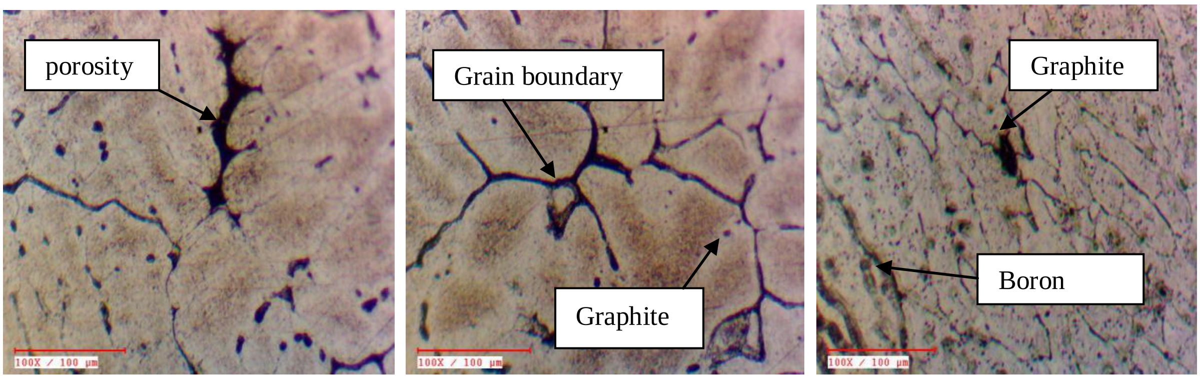

Fig. 5.4: Microstructure observation of Al-6061-2%Graphite and 2%Boron at three different locations.

The data presented in Figs 5.1, 5.2, 5.3 and 5.4 reveals the microphotographs of Al-6061, Al-6061 with 2% Graphite, Al-6061 with 2% Boron and Al-6061 with 2% Graphite and 2% Boron particulates respectively. From figures it is clear that, the homogenous distribution and excellent binding of reinforcing particulates in both the composites 2% Graphite and 2% Boron are fairly uniform. The size of the Graphite and Boron particles appears to be uniform throughout the aluminium matrix. Metallographic examination reveals that the presence of reinforcement particles was observed on the matrix phase as dark spots. Number of dark spots area increased in the matrix phases as the addition of 2 wt. % Graphite and 2%wt. of Boron particles dispersed in matrix.

5.2 Scanning Electron Microscopy (SEM)

The etched specimen was subjected to SEM. The scanning electron microscope produces images of the sample by scanning with an intensive beam of electrons. The electrons interact with the atoms of the sample and produce several signals that can be identified containing the information about the sample to be examined.

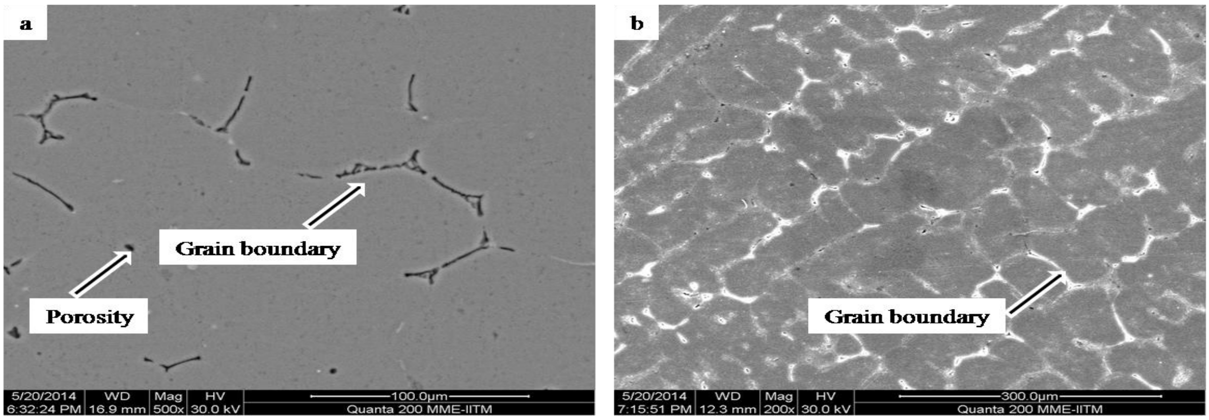

Fig.5. 5: SEM micrographs of Al-6061 Composition

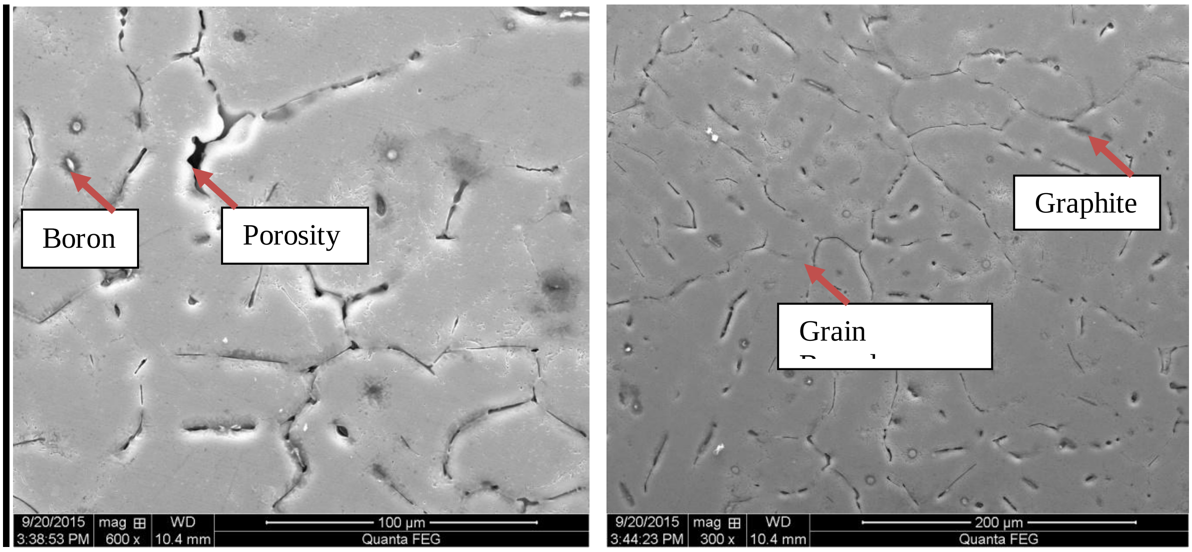

Fig. 5.6: SEM micrographs of MMC’s Composition Al-6061-2%Graphite

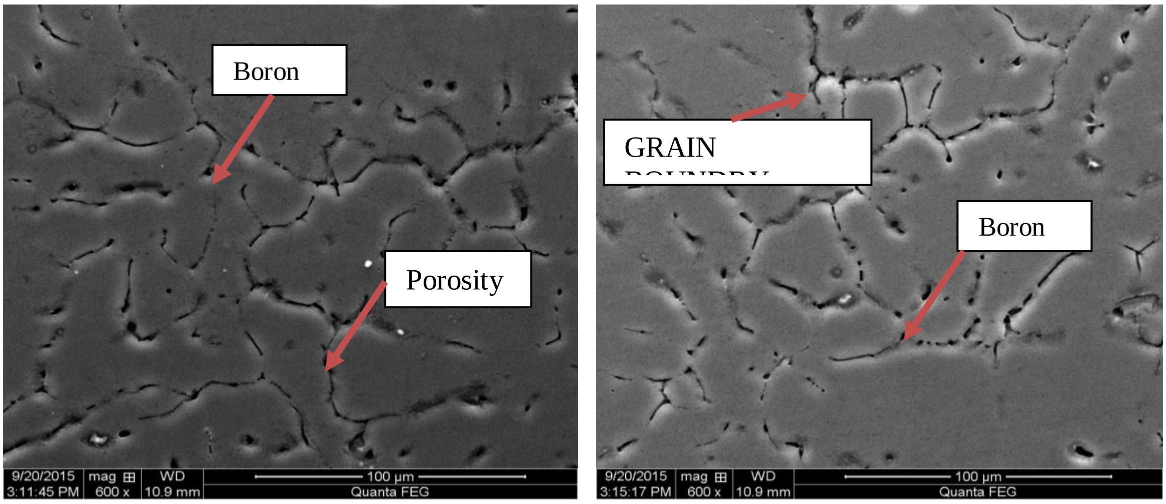

Fig. 5.7: SEM micrographs of MMC’s Composition Al-6061-2%Boron

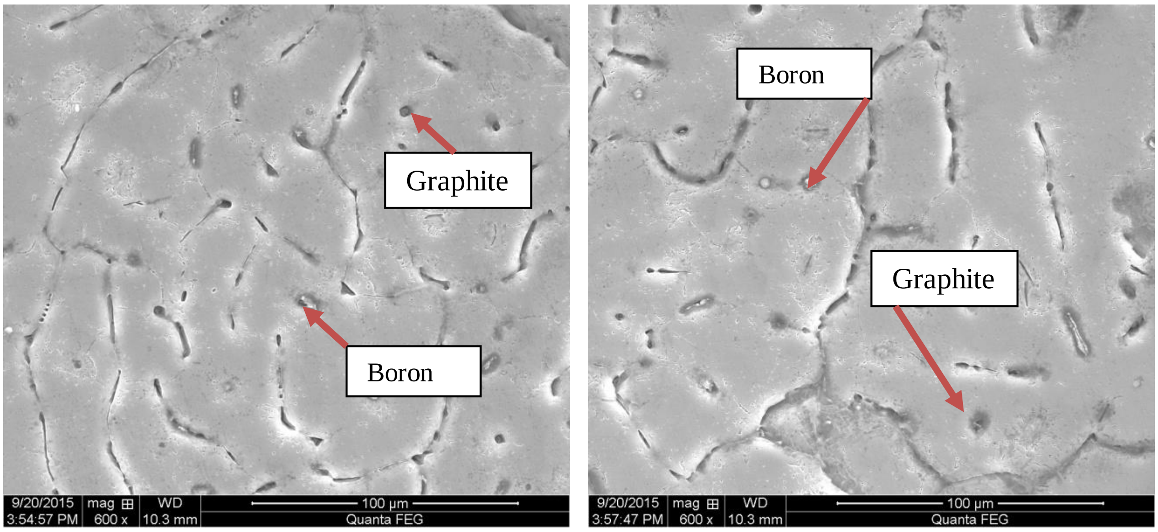

Fig. 5.8: SEM micrographs of MMC’s Composition Al-6061-2%Boron and 2%Graphite

The microstructures of stir cast Al-6061, Graphite, Boron particulate composites specimen were studied by SEM (Figs 5.5 to 5.8). The SEM micrographs in Figs 5.6 and 5.7 clearly indicate that the Graphite and Boron are distributed evenly in Al-6061 matrix. The particles are tightly packed with a homogeneous spatial distribution in each composite. Particulates are seen in between the matrix in small sizes with grain boundaries and we can observe that the addition of reinforcements differ in structure increasing the porosity and mechanical defects and they are relatively large and oval grains. Fig 5.8 shows microstructure composite with the combination of 2% wt. of Graphite, 2% wt. Boron particulates. The Graphite, Boron particulates are observed to be in irregular shape. The observation made in the study is on far with the experimental data conducted.

5.3 Density Test

Density is the physical property that reflects the characteristics of the composites. In a composite, the proportion of the matrix and the reinforcement has been expressed either as the weight fraction (wt), which is relevant to fabrication, or the volume fraction, which is commonly used in property calculations. Results of the density test conducted by water displacement method for the different compositions of the composites and the base metal are tabulated and presented in Table.5.1. The unreinforced and reinforced Al alloy density is calculated theoretically by rule of mixture concept.

1. Composition A = Al-6061
2. Composition B = Al-6061-2% Graphite
3. Composition C = Al-6061-2% Boron
4. Composition D = Al-6061-2% Graphite,-2% Boron

Table: 5.1 Density of different compositions of composites

Composition	Mass of sample in air (grams)	Mass of sample in water (grams)	Density for each trial (grams/cc)	Density (grams/cc)
Composition A	6.290	3.580	2.710	**2.70±0.05**
	6.171	3.470	2.701	
	6.256	3.556	2.700	
Composition B	6.314	3.964	2.686	**2.69±0.05**
	5.839	3.676	2.699	
	6.278	3.950	2.696	
Composition C	6.881	4.327	2.694	**2.696±0.05**
	6.102	3.836	2.691	
	6.106	3.835	2.688	
Composition D	6.238	3.901	2.669	**2.679±0.05**
	6.321	3.967	2.685	
	6.314	3.962	2.684	

The data presented in Table 5.1 indicates that the density of base metal (Al-6061) is very near to its theoretical value (2.7 g/cc). The density of Al-6061 with 2% Graphite, 2% Boron and combination of Al6061 with 2% Graphite and 2% Boron are nearer to that of theoretical values (2.7 g/cc) with slightly variation of 0.01g/cc. The probable reason for variation of density of composites as compared to the base metal is attributable to heterogeneous dispersion of particles in the composites.

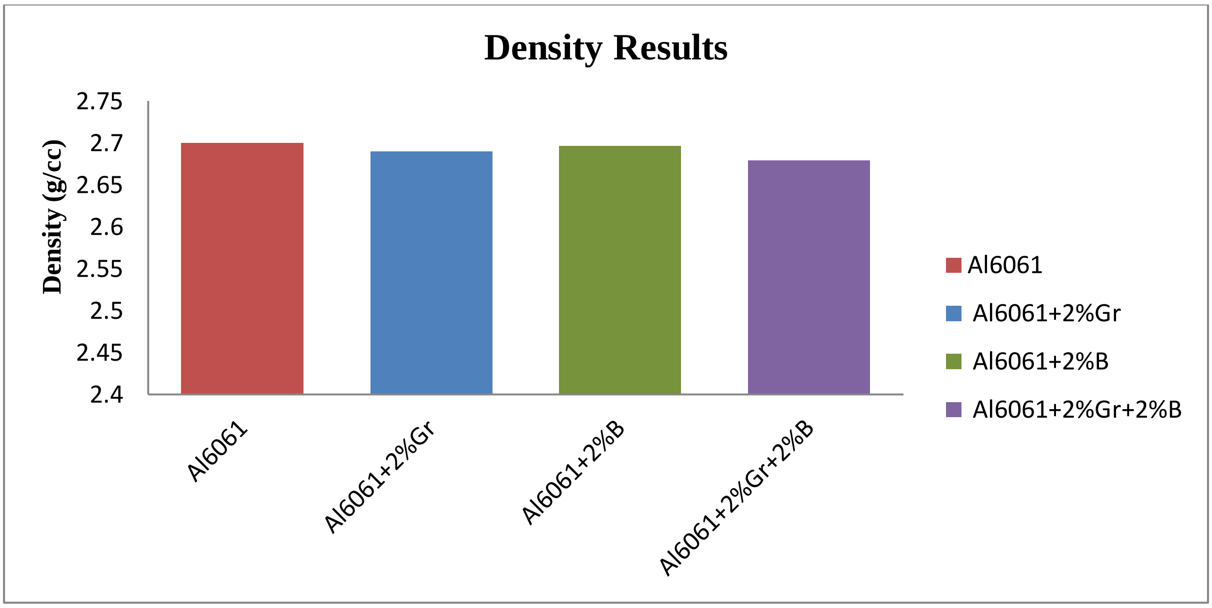

Fig. 5.9: Graph of Density v/s % weight of different material compositions

5.4 Micro Vickers Hardness Test

The specimens prepared as per ASTM standards were subjected to Micro Vickers Hardness test, and the results obtained are tabulated and presented in Table 5.2.The data presented in Table 5.2 and illustrated in Fig 5.10 clearly indicates that there is a variation of density. The hardness of Al-6061 with 2%wt. Graphite is 13% higher than the base metal (Al-6061).similarly the hardness of Al-6061 with 2% wt. Graphite and 2%wt. Boron composite is 4.4% higher than that of base metal (Al-6061). The probable reason for increasing the hardness by adding Graphite and Boron as reinforcement materials may be due to arresting the motion of dislocation of the matrix lattice. Another interesting property of particulates is its renders its property of hardness to the soft matrix.

Table 5.2 Hardness Test Results

Variations of reinforcements (wt. %)	Load applied (grams)	Time (Sec)	HV	HV
Composition A	1000	10	68	68±0.5
			67	
			69	
Composition B	1000	10	76	77±0.5
			78	
			77	
Composition C	1000	10	68	68.0± 0.5
			67	
			69	
Composition D	1000	10	71.7	71.0± 0.5
			71.2	
			71.3	

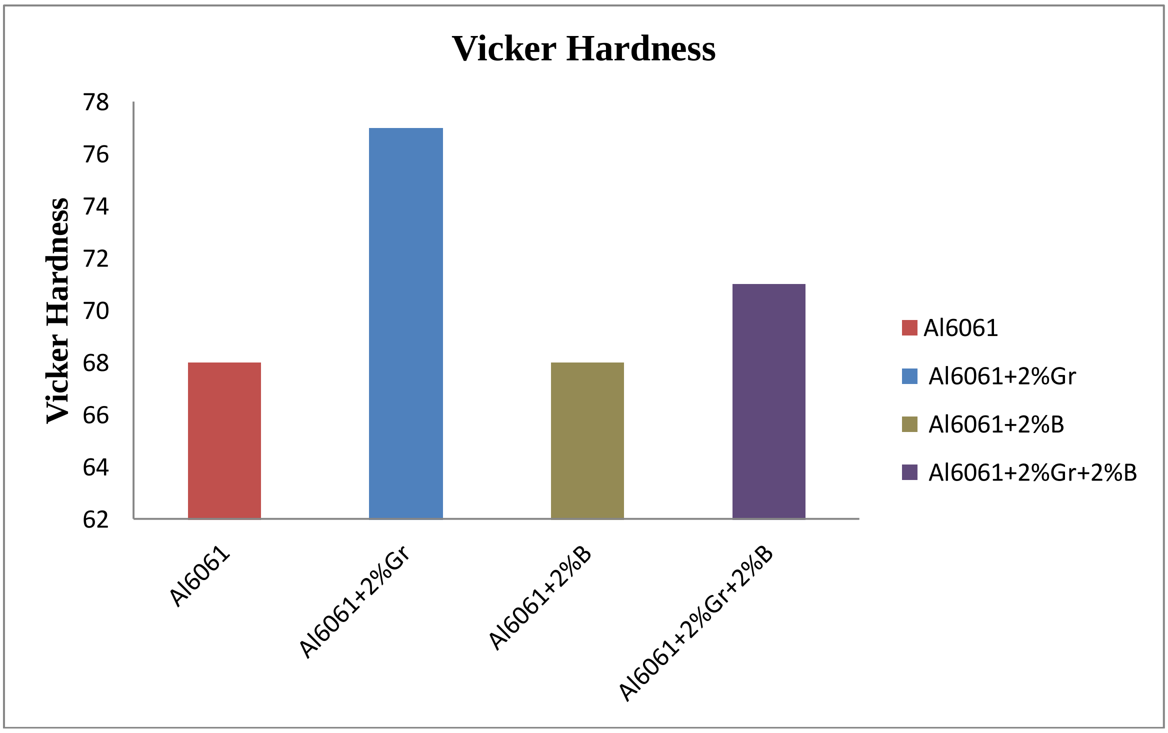

Fig. 5.10: Graph of vicker hardness v/s % weight of different material compositions

5.5 Tensile Test

The tensile tests were conducted using computerized UTM which has a capacity of 100 KN. KALPAK is the software used for data acquisition. For each composition three trials were conducted and the averages of those readings were taken as the final values. The ultimate tensile strength (UTS) of different compositions and base metal is tabulated and presented in Table 5.3

Table 5.3 UTS of various compositions of composite and base metal.

Wt % of reinforcement	**Sample number**	**Tensile strength (MPa)**	**UTS (MPa)**
Composition A	1	137.69	134.92
	2	129.65	
	3	137.42	
Composition B	1	142.62	140.24
	2	146.25	
	3	131.85	
Composition C	1	177.35	152.49
	2	156.34	
	3	123.79	
Composition D	1	163.27	160.43
	2	161.53	
	3	156.51	

The data presented in Tables 5.3 and 5.4 clearly indicates that composite material has higher tensile strength then the base metal Al-6061.The reinforced combination of 2% Boron and 2% Graphite with base metal yielded higher tensile strength 160.43 MPa closely followed by the 2% boron with base metal 152.49 MPa and 2% Graphite with base metal 140.24 MPa.

From the results it can be concluded that the composites developed higher tensile strength compared to the base metal (Al-6061). The tensile strength of base metal increased by adding 2% wt. of graphite and boron as reinforcement materials. This is because the reinforcements added take up the load and because of the soft nature of the graphite and boron the ductility increased and thereby needs more loads to break. The percentage elongation is increased by adding graphite content and because of the soft nature of the graphite the hardness of the composites decreased.

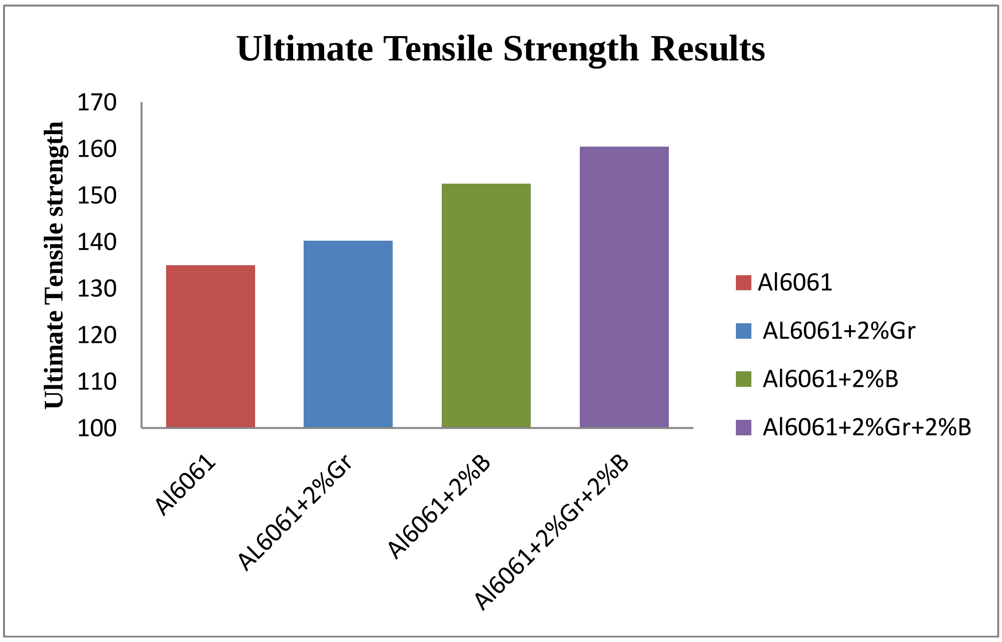

Fig 5.11: Graph of ultimate tensile strength v/s % weight of different material compositions

Table 5.4 Percentage of elongation of various compositions of composite and base metal

Wt % of reinforcements	**Sample number**	**Percentage of elongation (%)**	**Average percentage of elongation(%)**
Composition A	1	8.50	8.423
	2	8.41	
	3	8.36	
Composition B	1	10.06	9.55
	2	9.04	
	3	9.55	
Composition C	1	9.92	9.606
	2	9.55	
	3	9.35	

Composition D	1	10.37	10.55
	2	10.66	
	3	10.61	

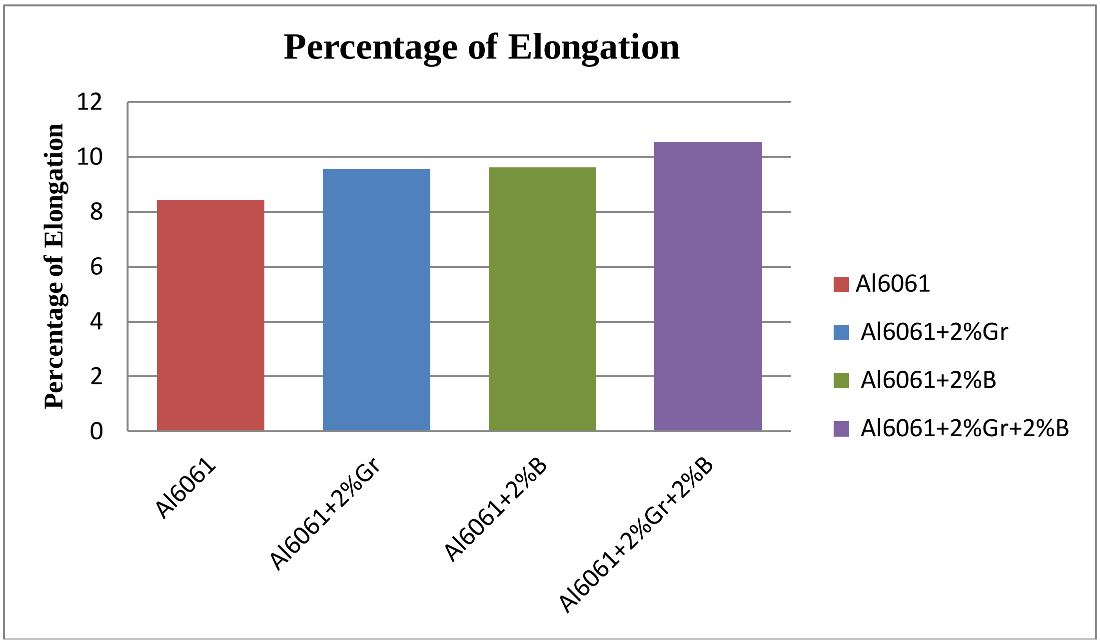

Fig. 5.12: Graph of percentage of elongation v/s % weight of different material compositions

Further the data in Table 5.4 and illustrated in Fig 5.12 indicates that the percent elongation of composite with combination of 2% Graphite and 2% Boron was found to be higher (10.55%), closely followed by the combination of base metal with 2% wt. of Boron and base metal with 2%wt. of Graphite than that of the elongation of base metal (8.423%). It is because the better bonding was observed at the interface between the hard particles present in a soft matrix. Difficulty in achieving the uniformity of the distribution of hard particles in the matrix metal pronounced more because of clusters formation of the particles and problems associated with porosity formation increased as the addition of particles increased. This may be attributed to refined grain structure, reduced porosity and voids, and formation of intermetallic bonding.

5.6 Fracture Analysis

The fractography study of the tensile specimen conducted after tensile loading is exhibited in Fig.13 to Fig.16. The micrograph reveals the ductile failure as the dimples on the fractured surface are visible. In few locations it is observed as bond like feature revealing in the location. This type of feature is mainly due to insufficient flow of material during casting process. The influence of aluminium particles clustering, agglomeration and the interfacial reactions between matrix and graphite and boron particles of the composites were analyzed by examining SEM fracture surfaces of the tested specimens and illustrated in Fig.13 to 16. Two factors which control the ductility of the composites. They are distribution of boron particles and deformation behaviour of the metal matrix. The Al-6061 metal matrix contains the alloying elements, which were added to enhance the mechanical properties of the composites. These alloying elements would react with the metal matrix and the reinforcement particles to form various intermetallic phases in the composite. These intermetallic phases (which are brittle in nature) act as void nucleation sites during the plastic deformation of the composites by their rupture. Debond between the matrix and reinforcement also occurs during the plastic deformation of the composites.

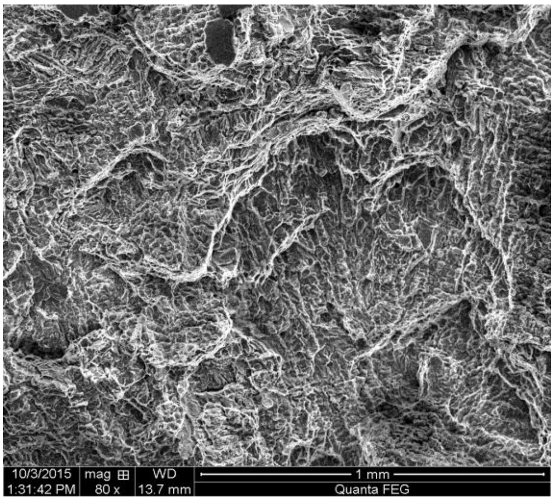

Fig. 5.13: SEM fracture surface of Al-6061

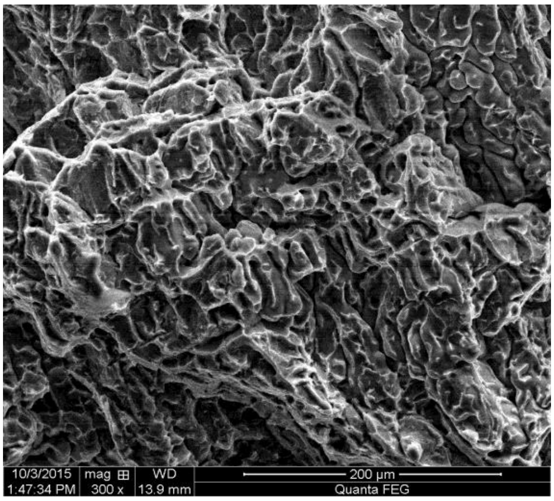

Fig.5.14: SEM fracture surface of Composition Al6061-2%Graphite

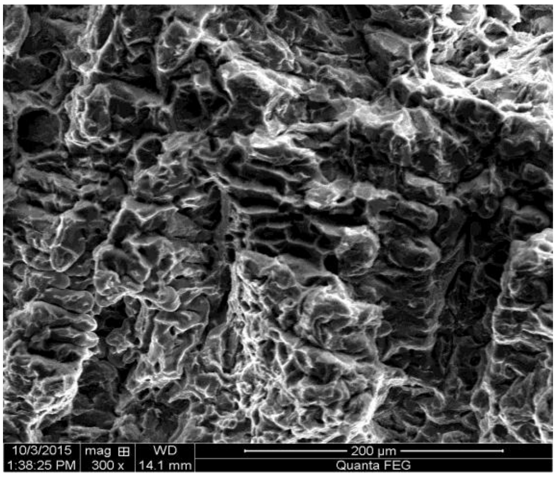

Fig. 5.15 S:EM fracture surface of Al6061- 2%Boron

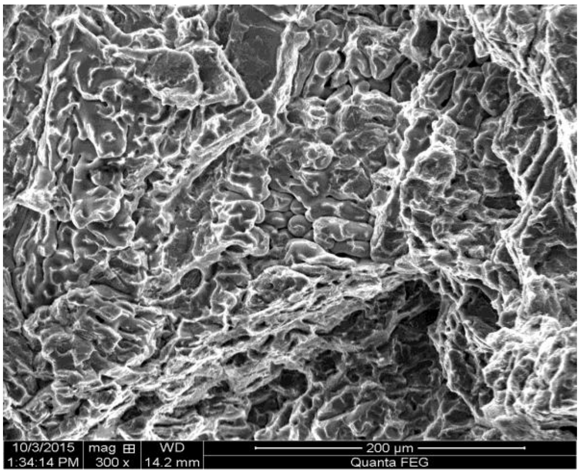

Fig. 5.16: SEM fracture surface of Composition Al6061-2%Boron and 2%Graphite

5.7 Wear Test

Wear rate is volume loss per unit distance and its unit is (mm^3/m). It is independent of load applied. Specific wear rate depends on applied load to cause wear. Its unit is (m^3/Nm).

Table: 5. 5 Constant speed 400rpm/Wear rate (mm^3/m)

Load (N)	Al-6061+2% Graphite	Al-6061+2% Boron	Al-6061+2% Graphite+2% Boron
20	6.63E-07	7.95455E-07	2.51E-06
30	6.82765E-06	8.22311E-06	9.69E-06
40	1.29583E-05	1.50474E-05	1.7964E-05

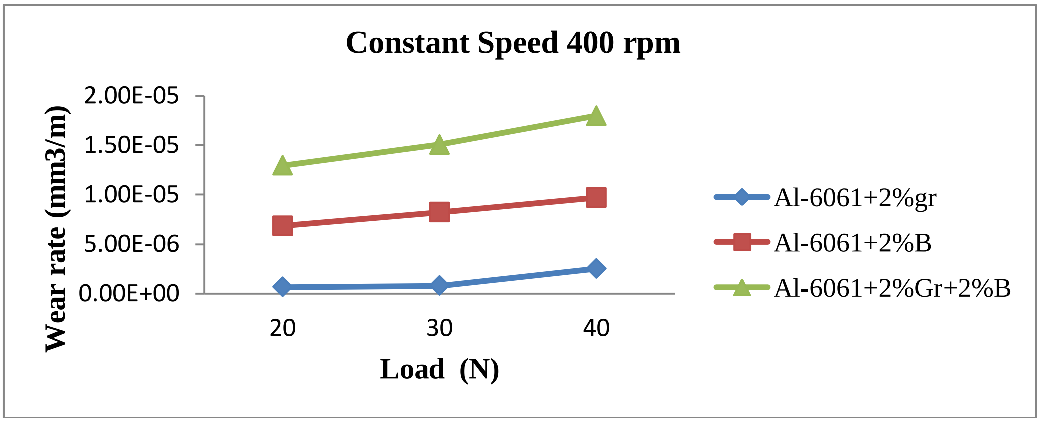

Fig.5.17: Load V/S Wear rate for constant speed of 400rpm

Table: 5.6 Constant speed 600 rpm/Wear rate (mm^3/m)

Load (N)	Al-6061+2% Graphite	Al-6061+2% Boron	Al-6061+2% Graphite+2% Boron
20	3.87E-06	9.95E-06	3.00E-05
30	6.90881E-05	0.000118573	0.000172216
40	0.000122131	0.000216373	0.000277348

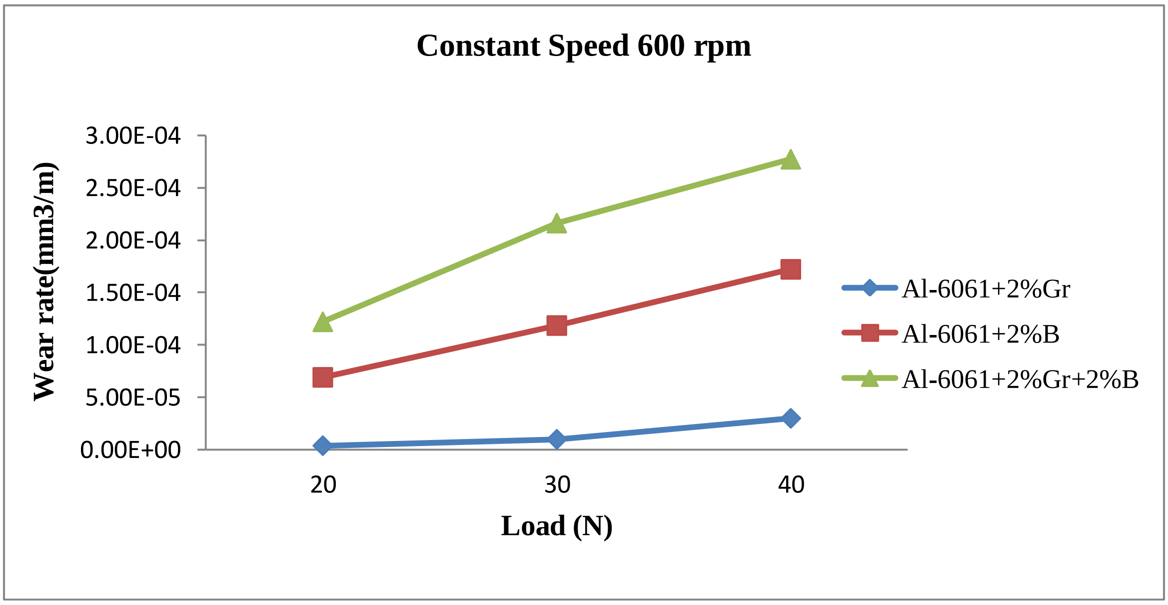

Fig.5.18: Load V/S Wear rate for constant speed of 600rpm

Table: 5.7 Constant Speed 800 rpm/Wear rate (mm^3/m)

Load (N)	Al-6061+2% Graphite	Al-6061+2% Boron	Al-6061+2% Graphite+2% Boron
20	6.09849E-06	1.57367E-05	4.12E-05
30	3.44474E-05	6.35791E-05	9.54484E-05
40	8.52131E-05	0.000115308	0.000124484

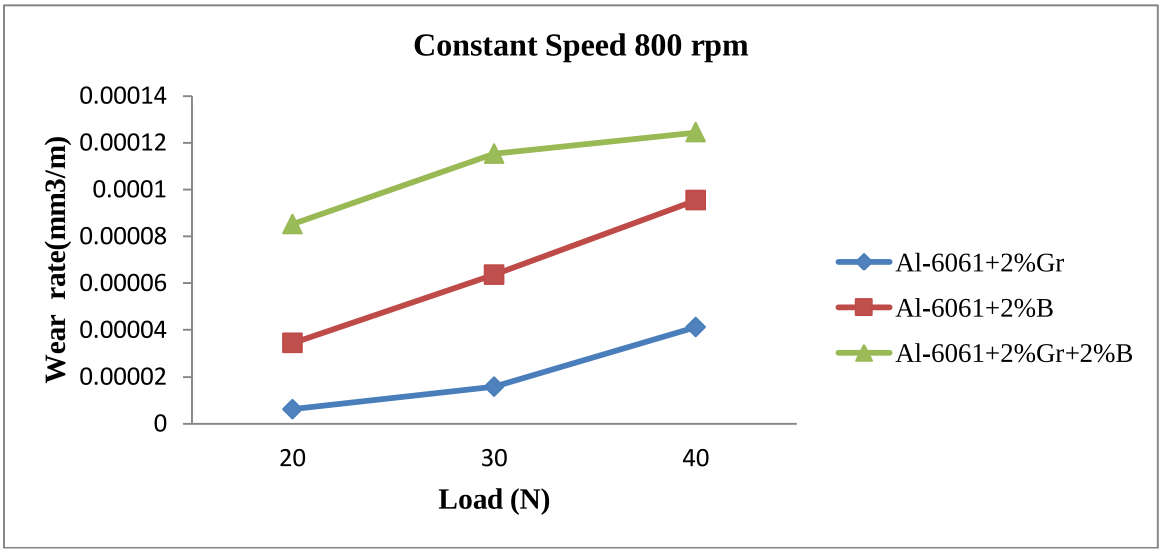

Fig.5.19: Load V/S Wear rate for constant speed of 800rpm

Table: 5.8 Constant Load 20N/Wear rate (mm^3/m)

Speed (rpm)	Al-6061+2% Graphite	Al-6061+2% Boron	Al-6061+2% Graphite+2% Boron
400	3.93E-06	8.95E-06	1.11364E-05
600	2.06528E-05	2.61E-05	2.90783E-05
800	8.10E-06	1.57367E-05	1.92E-05

5.7.1 Effect of applied load on wear rate

Applied load has also been one of the major factors influencing the wear rate of the composites. Figs 5.17, 5.18 and 5.19 illustrate the effect of applied load on wear rate of Al-6061 with 2% Graphite, Al-6061 with 2% Boron and Al-6061 with 2%Graphite and 2% Boron particulates respectively of different compositions tested for 10 minutes. At constant speed, the wear rate of the composites and the matrix increased with increase in load. The wear rate of the composites was less than that of the matrix alloy for all loads. The composites with hard particles thus exhibit better wear resistance than matrix material. Which may be due to the fact that the surface of the composite material tends to reduce delaminating because Graphite acts as self lubrication and Boron acts as hard reinforcement thus reduce wear rate.

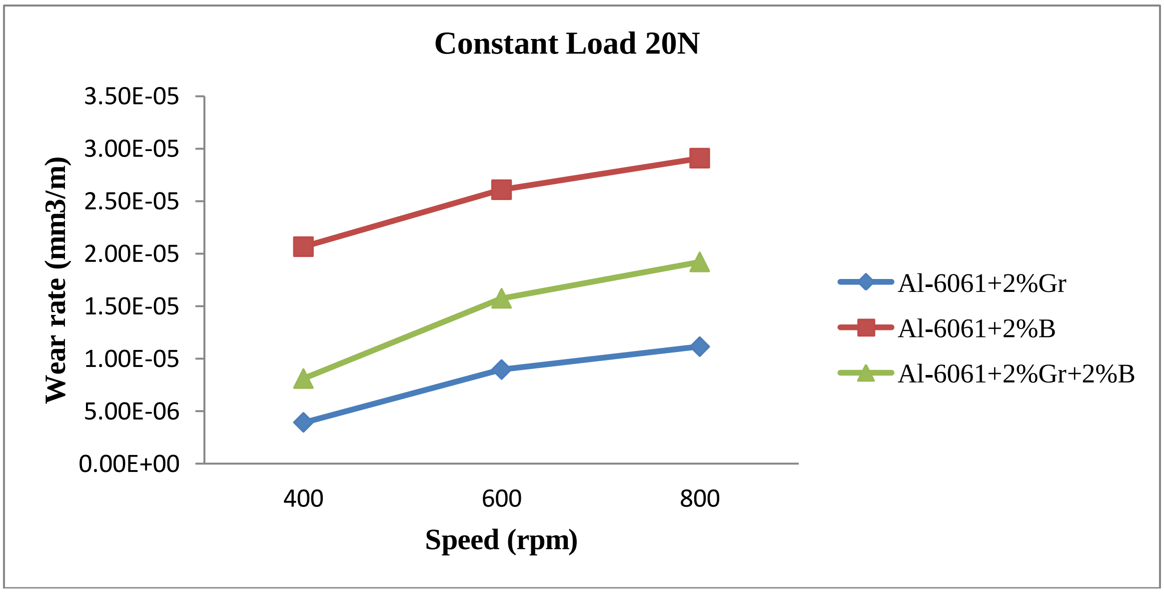

Fig.5.20: Speed V/S Wear rate for constant load of 20N

Table: 5.9 Constant Load 30N/Wear rate (mm^3/m)

Speed (rpm)	Al-6061+2% Graphite	Al-6061+2% Boron	Al-6061+2% Graphite+2% Boron
400	6.83E-05	7.62311E-05	8.29E-05
600	0.000127319	0.000148573	0.000172216
800	0.000114474	0.000135791	0.000154484

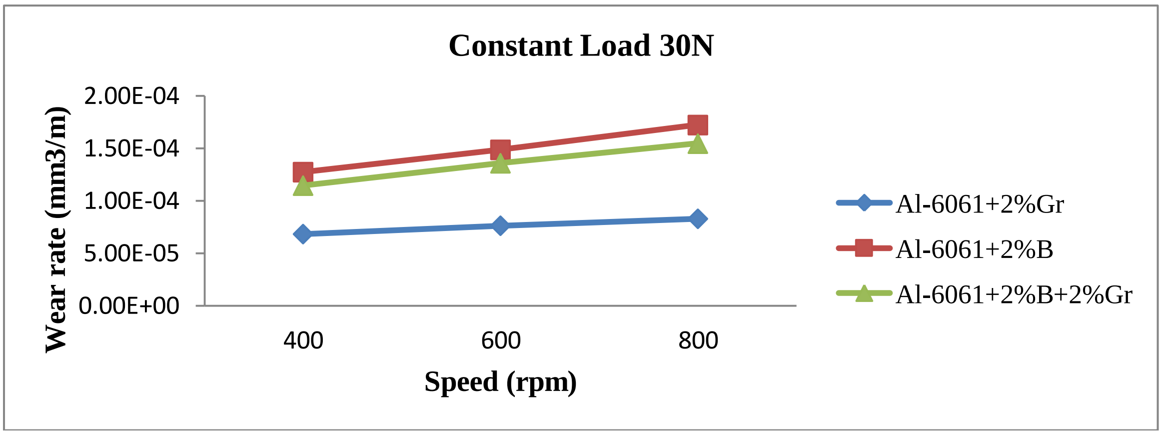

Fig.5.21: Speed V/S Wear rate for constant load of 30N

Table: 5.10 Constant Load 40N/Wear rate (mm3/m)

Speed (rpm)	Al-6061+2% Graphite	Al-6061+2% Boron	Al-6061+2% Graphite+2% Boron
400	8.52131E-05	0.000115308	0.000158182
600	0.000193958	0.000254744	0.000287964
800	0.000151136	0.000183731	0.000253485

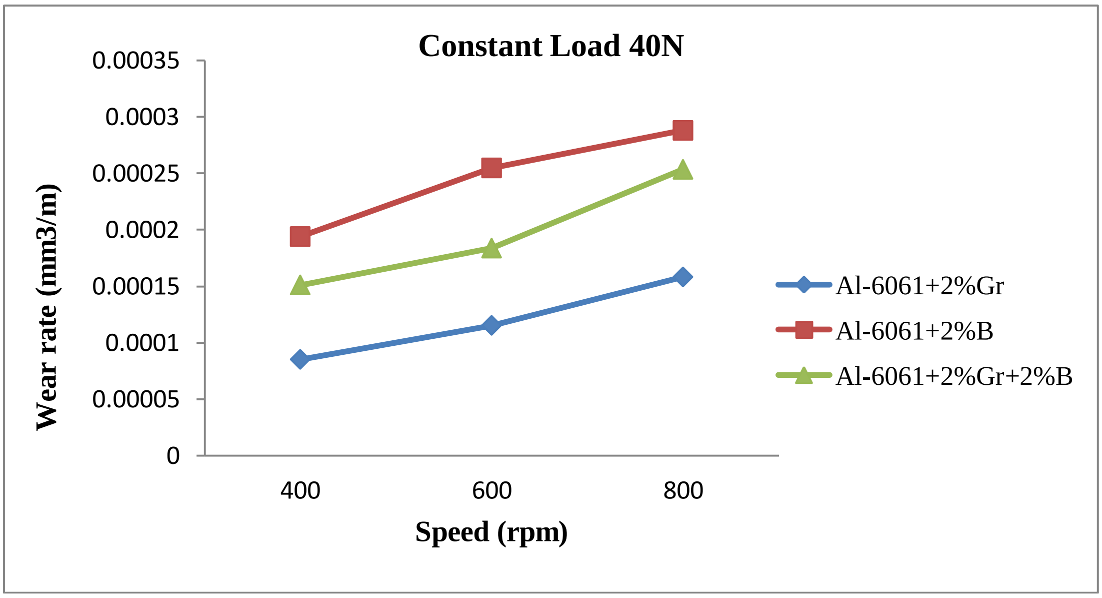

Fig.5.22: Speed V/S Wear rate for constant load of 40N

5.7.2 Effect of applied Speed on wear rate

Applied speed has also been one of the major factors influencing the wear rate of the composites. Figs 5.20, 5.21 and 5.22 illustrate the effect of applied speed on wear rate of Al-6061 with 2% Graphite, Al-6061 with 2% Boron and Al-6061 with 2%Graphite and 2% Boron particulates respectively of different compositions speed (400,600,800)rpm tested for 10 minutes. At constant load of 20N, 30N and 40N, the wear rate of the composites and the matrix increased with increase in speed. The wear rate of the composites was less than that of the matrix alloy for all loads. The composites with hard particles thus exhibit better wear resistance than matrix material. Which may be due to the fact that the surface of the composite material tends to reduce delaminating because Graphite acts as self lubrication and Boron acts as hard reinforcement thus reduce wear rate.

Table: 5.11 Al-6061+2% Graphite

	Constant Load (20N)	Constant Load (30N)	Constant Load (40N)
400	3.93E-06	6.83E-05	8.52131E-05
600	2.06528E-05	0.000127319	0.000193958
800	8.10E-06	0.000114474	0.000151136

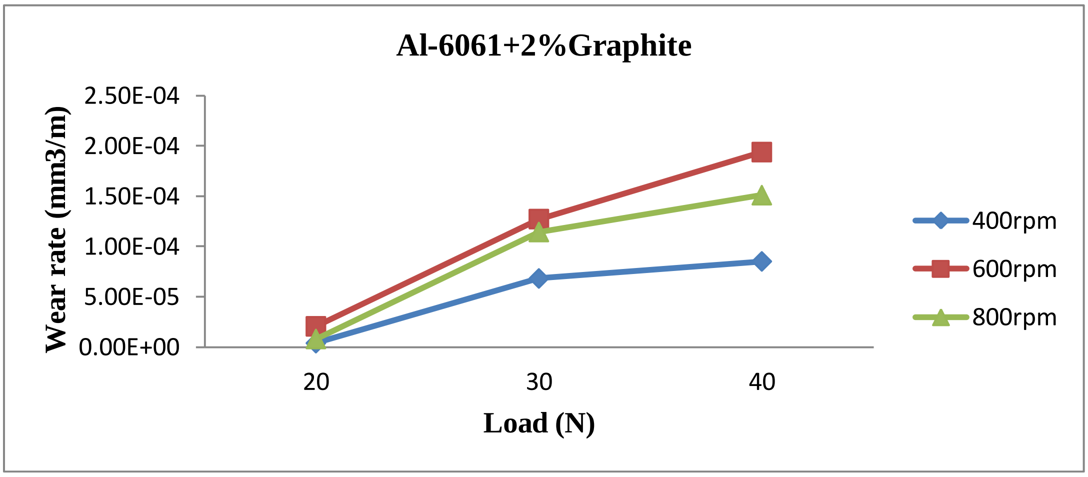

Fig.5.23: Load V/S Wear rate of Al-6061+2%Graphite for various speed

Table: 5.12 Al-6061+2% Boron

	Constant Load (20N)	Constant Load (30N)	Constant Load (40N)
400	3.93E-06	7.62311E-05	0.000115308
600	2.06528E-05	0.000148573	0.000254744
800	8.10E-06	0.000135791	0.000183731

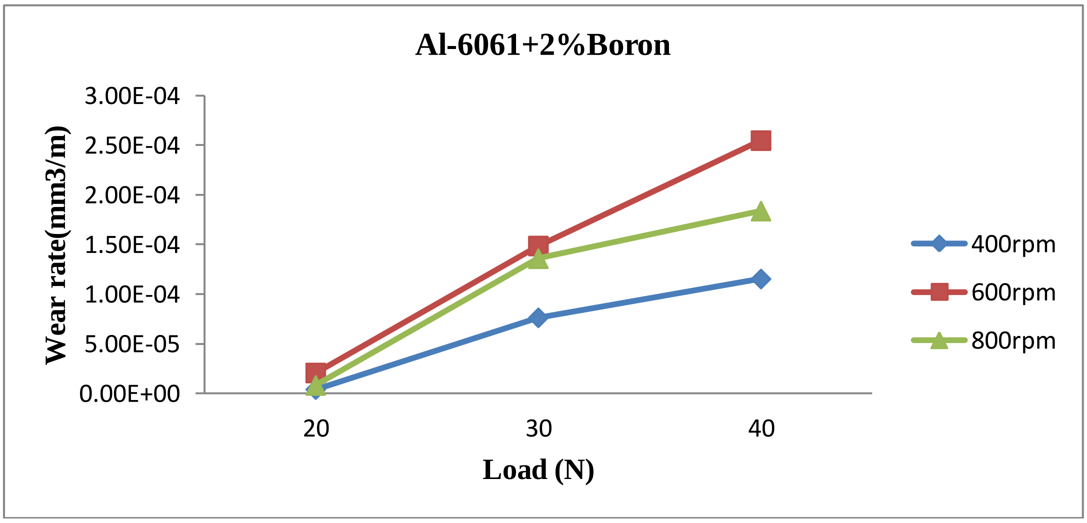

Fig.5.24:Load v/s wear rate of Al-6061+2%Boron for various speed

Table:5.13 Al-6061+2% Graphite+2% Boron

	Constant Load (20N)	**Constant Load (30N)**	**Constant Load (40N)**
400	3.93E-06	7.62311E-05	0.000115308
600	2.06528E-05	0.000148573	0.000254744
800	8.10E-06	0.000135791	0.000183731

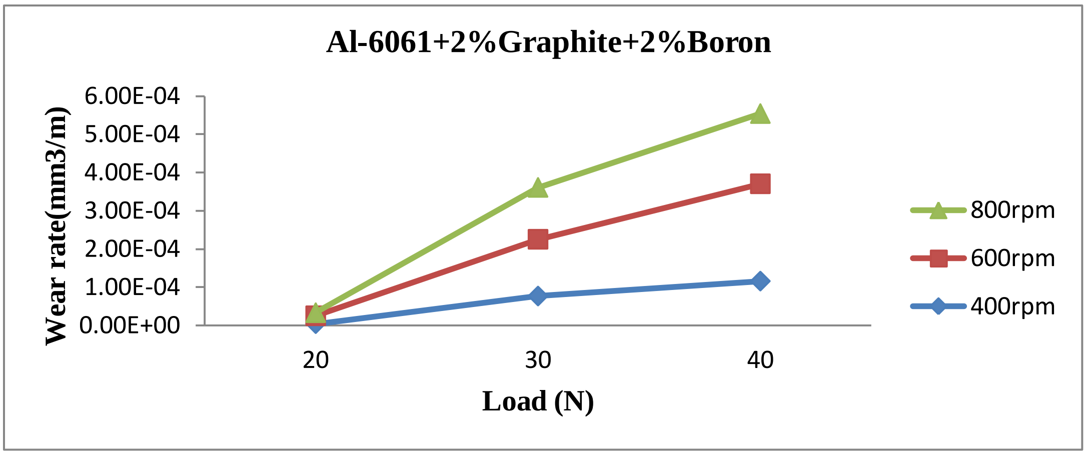

Fig.5.25 Load V/S Wear rate of Al-6061+2%Graphite+2%Boron for various speed

5.9 SEM Photographs of Worn Surface

The microstructures of stir cast Al-6061 with 2% Graphite, Al-6061 with 2% Boron and Al-6061 with 2% Graphite and 2% Boron composites wear specimen wear surface are studied by SEM (Figs 5.30 to 5.32). Fig. 5.30 shows the worn tracks observed using Scanning Electron Microscopy in Al6061 with 2% Graphite against steel disc under sliding speed of 800 rpm, load 40 N on the morphology of worn surface of the alloy in room temperature. A non uniform wear consisting of grooves, micro cuttings and scratch marks, formed by the reinforcing materials have been observed in composite specimens after wear. This indicates that the wear of the composites may be due to the abrasion wear. Delamination was also observed on the wear surface of the composites which induces sub surface cracks that gradually grow and eventually shear to the surface forming long thin wear sheets. The morphological changes on the worn surface of the composite samples was studied under different parameters like applied load of 40N, sliding speed of 800rpm and sliding time of 10 min and Al-6061 with 2% Graphite particulate reinforcement. Fig. 5.30 shows the SEM worn surface micrograph of Al-6061 with 2% Graphite have a smooth surface nature with more tribolayers formed. The examination shows that the worn surface of the composite is generally less rough than that of the other combinations.

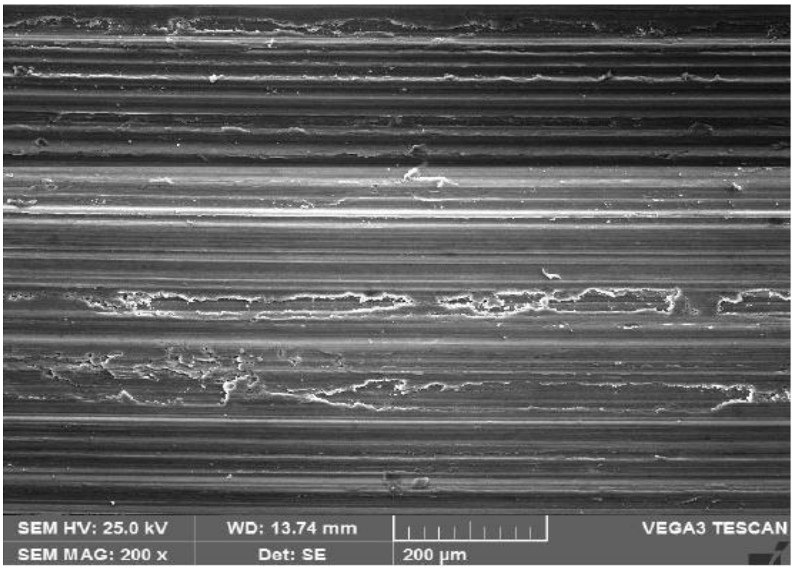

Fig. 5.30: Worn out surface micrograph for wear rate of Al-6061 with 2% Graphite for sliding Speed 800rpm, load 40 N.

Fig. 5.31 shows the worn tracks observed using Scanning Electron Microscopy in Al6061 with 2% Boron against steel disc under sliding speed of 800 rpm, load 40 N on the morphology of worn surface of the alloy at room temperature. The worn surface on the specimen observed using Scanning Electron Microscopy in Al-6061 with 2% Boron against a steel disc under sliding speed 800rpm, load 40N and Al-6061 with 2% Boron particulate reinforcement on the morphology of worn surface of composite is shown in Fig. 5.31. The large number of parallel grooves in case of stir cast indicates material loss during wear is high which is quite evident from worn surface as shown in figure. Also, surface showed large extent delamination.

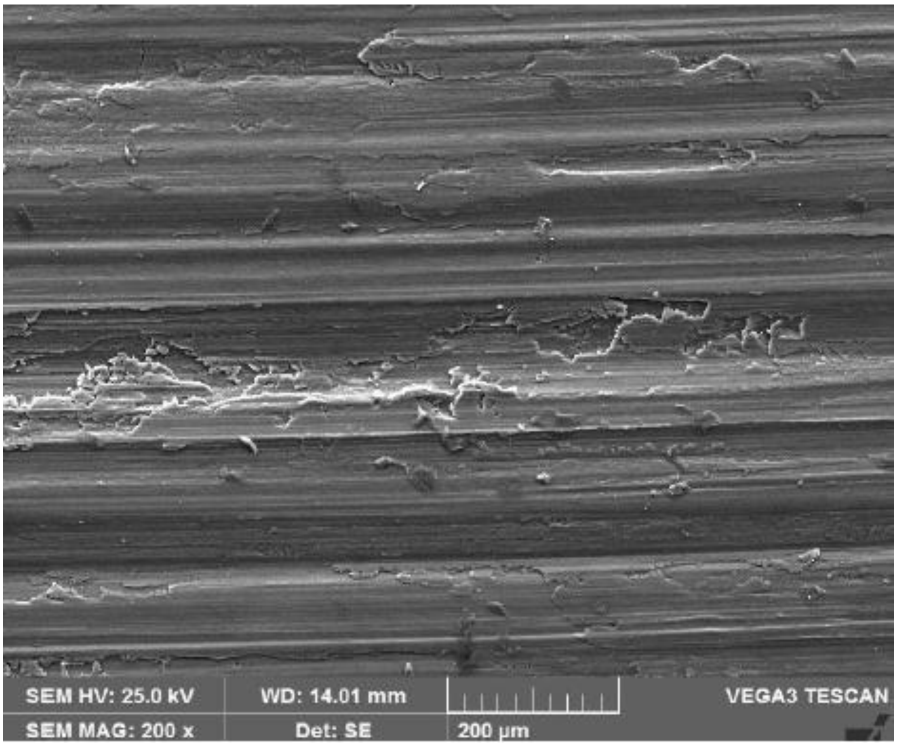

Fig. 5.31: Worn out surface micrograph for wear rate of Al-6061 with 2% Boron for sliding Speed 800rpm, load 40 N.

Fig. 5.32 shows the worn tracks observed using Scanning Electron Microscopy in Al-6061 with 2%Graphite and 2% Boron composites against steel disc under sliding speed of 800 rpm, load 40 N on the morphology of worn surface of the composite in room temperature. The worn surface on the specimen observed using Scanning Electron Microscopy in Al-6061 with 2% Graphite and 2% Boron composites against a steel disc under sliding speed 800rpm, load 40 N and Al-6061 with 2%Graphite and 2% Boron composites particulate reinforcement on the morphology of worn surface of composite is shown in Fig. 5.32. The large number of parallel grooves in case of stir cast indicates material loss during wear is high which is quite evident from worn surface as shown in figure. Also, surface showed large extent delamination.

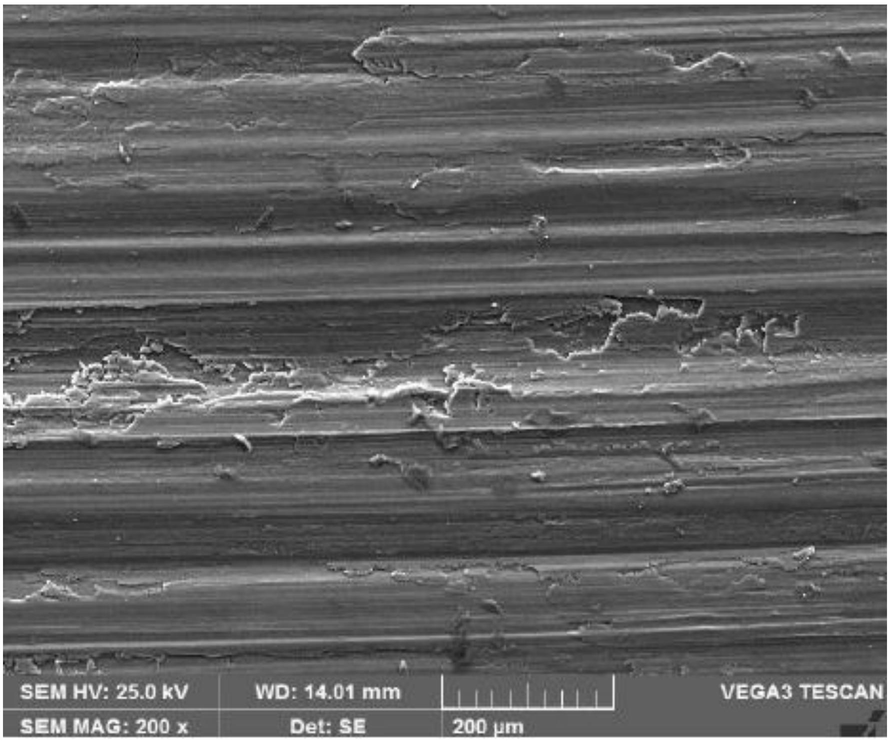

Fig. 5.32: Worn out surface micrograph for wear rate of Al-6061 with 2%Graphite and 2% Boron for sliding Speed 800rpm, load 40 N.

IV. Conclusions

Based on experimental results, the following conclusions are drawn.

- Metal matrix mono (Al-6061/2% B), (Al-6061/2% Gr) and Hybrid (Al-6061/2% B/2% Gr) composites can be effectively produced by stir casting technique.
- The Taguchi method employed in this study is an effective tool for modeling the wear behavior of composites.
- The hybrid composite showed better wear resistance under the parameters tested and compared to mono composites.
- Based on results, load and sliding speed were found to have more significant effect on the sliding wear of the specimens.
- The addition of Boron reinforcement in mono composite increases the hardness and strength. But, adding Graphite particles in hybrid composites leads to reduction in defects level and improvement in wear resistance and also results in improved lubrication of the wear surface.

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