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Mechanical and Tribological Properties of Al 6061 Alloy Reinforced with Gr – WC Particulates Using Powder Metallurgy Technique

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Abstract. There is a tremendous demand for composites based on metal matrix, as they give low density, high wear resistance, stiffness and specific strength as compared to pure aluminium. In the present work, we investigated the mechanical and tribological properties by considering metal matrix as Aluminium 6061 and reinforcements as Gr and WC. The composites were prepared based on powder metallurgy technique by varying the weight proportions of Gr particulates for 0%, 2%, 4%, 6%, 8%, and 10% with this we kept WC particulates weight proportion as 3% constant for added reinforcement specimens. From hydraulic compaction machine, compaction process was performed and specimens were sintered in a muffle furnace at 5500C. The mechanical properties were performed for BHN, compression strength of the prepared composites were improved as compared to the pure matrix material Al6061 alloy and tribological properties like wear and SEM were examined for Al 6061 alloy results in less wear resistance as compared to Aluminium 6061 with the addition of reinforcements Gr - WC.
Keyword: Aluminium 6061, Tungsten Carbide, Graphite, Wear rate, SEM.

Nomenclature - Al 6061 = Aluminium 6061, WC = Tungsten Carbide, Gr = Graphite, SEM = Scanning Electron Microscope, L = Load, S = Speed, SD = Siliding Distance, WR = Wear Resistance.

1. Introduction

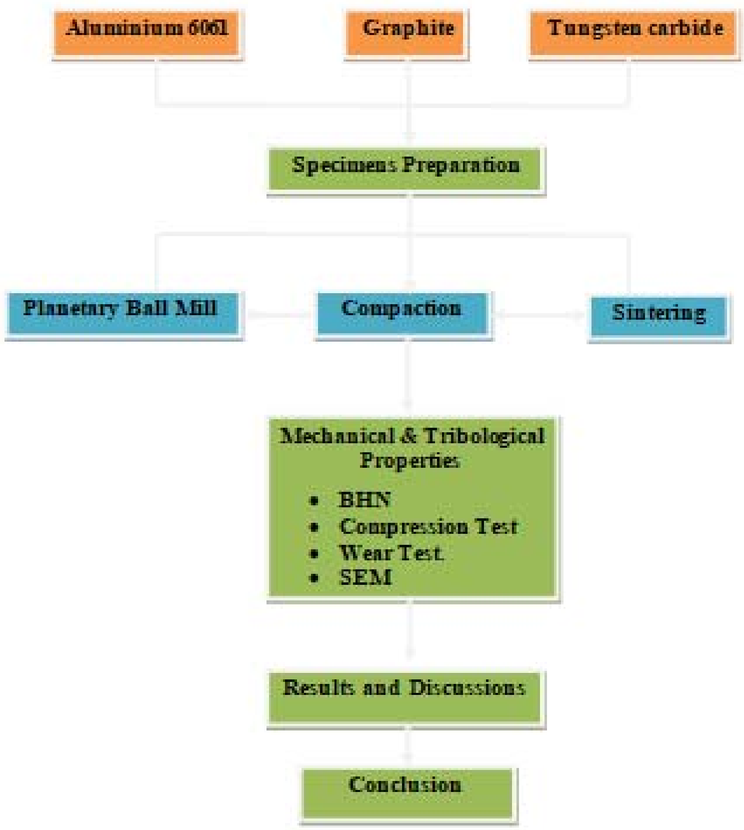
Due to its various advantages over manolithic materials are replacing conventional Engineering materials. The major developments of the new begining of composites was the creations of metal matrix composites. The MMCs is a material consisting of metal alloy reinforced with cermaic particulates, whiskers, continous fibers etc., because of their increased wear resistance and rigdity these MMCs are commonly used in automobile, marine, aerospace and transporation industries. Aluminium alloys are widely used in MMCs. The few examples of new combinations of metal matrix with reinforcements are: aluminium – silicon carbide, aluminium – graphite, aluminium – Flyash, aluminium – Bottom ash which are good in wear resistance. Powder metallurgy is a process of mixing fine powdered composite materials, pressed to form a desired shape(structure) through compacting and then prepared composite specimens are heated in a muffle furnance (sintering) at room temperature. Powder metallurgy technique basically consists of four steps: preparation of powder, powder blending, compaction and sintering.

A.R.K Swamy.et.al the weight of reinforcement particlates in the Al – matrix ranges from 0% - 4%. The composites are fabircated through a process called ‘Vortex’. From this study results shows that, as the context of WC particlates significantly increases in hardness and tensile strength while decreasing in its ductility.

Z.Zulkoffli.et.al the author examined by considering reinforcement silicon carbide and fabricated with pre – alloyed powder AZ61. Compaction process carried in hydraulic machine with out binder agent under 200Mpa compaction pressure about 20 minutes by varying temperatures of 350^{0}C, 300^{0}C, 250^{0}C and 200^{0}C.

2. Experimental Work

The flow chart gives information about the fabrication and experimental procedure of the present work. In this Aluminium 6061 considered as metal matrix alloy and reinforcements as combinations of Graphite and Tungsten Carbide, also the specimens were prepared according to ASTM Standards. By using planetary ball milling and compaction machines mixing and compaction process was carried out and finally sintering process was done by Muffle Furnace. Here we investigated the mechanical and tribological properties like BHN Test, Compression Test, Wear Test and performed SEM. For all these tests results obtained are tabulated and graphs were plotted and ended with conclusions.



3. Materials and Methodology

3.1 Aluminium 6061

Aluminium 6061 is on the whole commonly used alloys for general purpose. It is developed in 1935 and called as “Alloy 61s”. 6061 is an aluminium alloy which contains silicon and magnesium elements as its main alloy. It has excellent properties of mechanical and shows excellent weldability and is frequently extruded.

Applications: Castings, Extrusions, Forging, Welding etc.

TABLE I. Chemical Compositions of Aluminium 6061

Chemical Compositions of Aluminium 6061

Chemical Composition	Ti	Zn	Cr	Mg	Mn	Cu	Fe	Si	Al
(%)	0.2	0.25	0.04 - 0.35	0.8 - 1.2	0.15	0.15 - 0.40	0.7	0.4 - 0.8	Bal

TABLE II. Mechanical Properties of Aluminium 6061

Sl. No	**Mechanical properties**	**Values**	**Units**
1	Density (ʃ)	2.7	(g/cm3)
2	Young's Modulus (E)	68.9	(Gpa)
3	Tensile Strength (Σt)	124 – 290	(Mpa)
4	Poisson's Ratio (V)	0.33	
5	Melting Temperature (Tm)	586	(^{0}C)
6	Thermal Conductivity (K)	151 – 203	(W(m-k))
7	Specific Warm Capacity (C)	897	(j/Kg-K)
8	Elongation Break (€)	13 – 26	(%)

3.2 Tungsten Carbide

WC is a chemical compound that contains atoms of tungsten and carbon in equal proportions. Basic form of a WC is a fine gray powder. By means of a process called sintering, where it can be pressed and shapes can be formed to used in industrial machinery's like cutting tools, Amor piercing shells, abrasives and jewellery.

Applications: Surgical Instruments, Sports equipments, Machinery cutting tools, mining tools etc.

3.3 Graphite

It is also known as "Plumbago". The crystalline shape of the carbon elements with its hexagonally arranged atoms naturally occurs in this form. Also it converts in to diamond under the conditions of high temperature and high pressure.

Applications: Batteries, Steel making, Brake linings, Foundry facings, lubricants etc.

Figure.1 Aluminium 6061

Figure.2 Tungsten Carbide

Figure.3 Graphite

3.4 Specimens Preparation

In the existing work, Hybrid composites like Aluminium 6061 + Gr + WC were fabricated through the technique of powder metallurgy. First step is the blending of particles like Al6061 + Gr + WC in a Ball mill (Fig.4) at a speed of 260 rpm for about 2 hours at 22Hz. In the Next step extracted powder is compressed in the die under optimum load through compaction machine (Fig.5). Finally, all the prepared Specimens will be kept in the muffle Furnace (Fig.6) and heated up to 550^{0}C about 2 hours. At last all the heated specimens were cooled at room temperature.

Figure.4. Planetary Ball Mill

Figure.5 Compaction Machine

Figure.6 Muffle Furnace

Figure.7 Prepared Composite Specimens

4. Results and Discussions

The specimens had been prepared according to standards of ASTM. The experiments were carried out to investigate the mechanical and Tribological properties such as BHN, Compression, Wear and SEM.

4.1 BHN Results

The aim of experiment is to find out the Brinell Hardness Number (BHN) of the prepared composite specimens with ASTM B-925 Standards having dimensions of 20mm depth and Diameter of Φ15mm with the help of BHN testing machine. The primary test of hardness by varying the reinforcement ratio of Gr such as 0%, 2%, 4%, 6%, 8%, 10% and WC reinforcement particulates is kept constant with a ratio of 3% with aluminium alloy 6061 for all prepared composites. Hardness is found out by considering the indentations on the specimens. BHN test is commonly used to measure hardness of metals.

Table.3 Numerical Results of BHN Test

Specimen Percentages	**BHN**
Al 6061	40
Al 6061 + 2% Gr + 3% WC	43
Al 6061 + 4% Gr + 3% WC	44
Al 6061 + 6% Gr + 3% WC	44
Al 6061 + 8% Gr + 3% WC	51
Al 6061 + 10% Gr + 3% WC	54

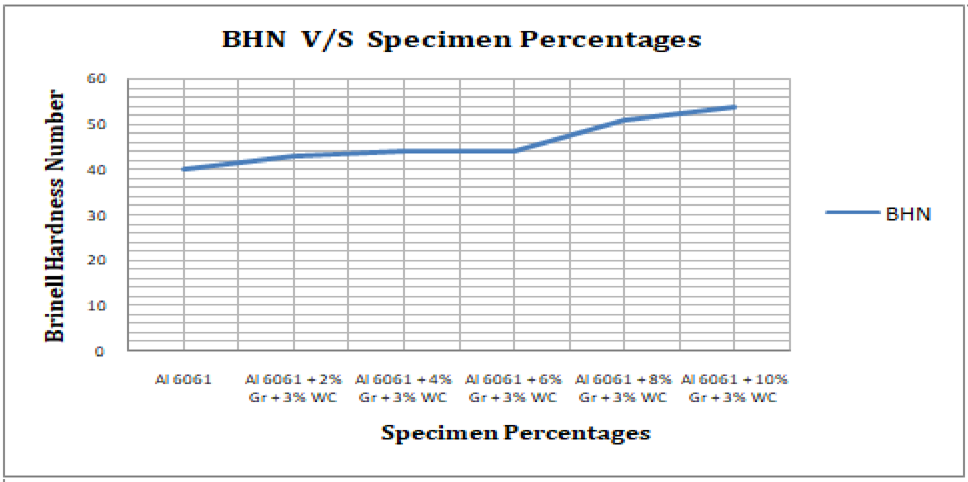


Figure.8 BHN V/S Specimen Percentages

4.2 Compression Results

The experimental aim is to investigate the compressive strength (Mpa) and observations are made to know the behaviour of the prepared specimens with ASTM E9-95 Standards having dimensions of 25mm depth and dia of Φ25mm were subjected to continually increasing uni-axial compressive force with the help of UTM machine. The tests were performed by varying the reinforcement ratio of Gr such as 0%, 2%, 4%, 6%, 8%, 10% and WC reinforcement particulates is kept constant with a ratio of 3% with base material Al - 6061 for all prepared composite specimens.

Table.4 Numerical Results of Compression Test

Specimen Percentage	Compression Strength
Al 6061	449.34
Al 6061 + 2% Gr + 3% WC	569.84
Al 6061 + 4% Gr + 3% WC	668.74
Al 6061 + 6% Gr + 3% WC	671.94
Al 6061 + 8% Gr + 3% WC	679.94
Al 6061 + 10% Gr + 3% WC	686.71

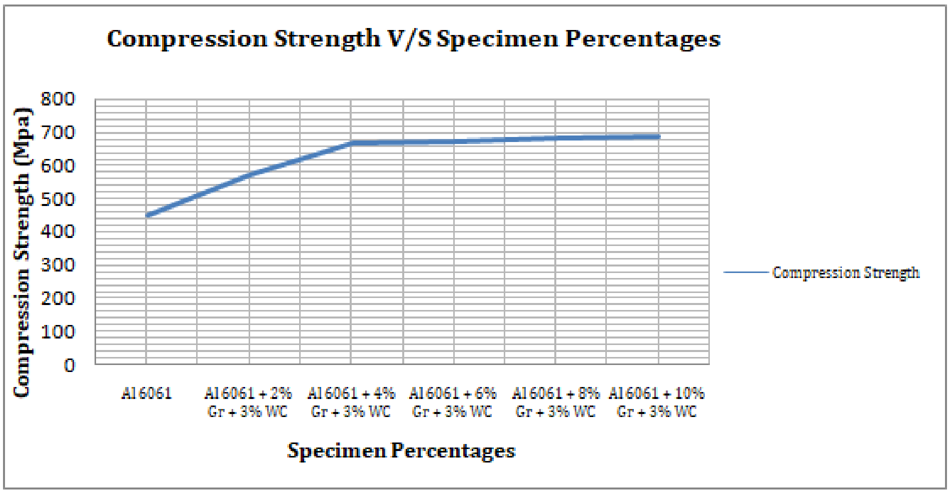


Figure.9 Compression Strength (Mpa) V/S Specimen Percentages

4.3 Wear Results

The experimental aim is to investigate the significant factors of wear mechanism, in order to achieve the minimum wear rate for prepared specimens with ASTM G99–95 Standards having dimensions of 30mm depth and dia of Φ6mm with the help of pin – on – disc apparatus. The preliminary test of wear mechanism, by varying the reinforcement ratios of Gr 0%, 2%, 4%, 6%, 8%, 10% and WC reinforcement particulates is kept constant with a ratio of 3% for all prepared specimens. Wear resistance were found out by considering parameters like load, speed, sliding distance and weight loss for composite specimens with high abrasion resistance will have less volume loss. Therefore the prepared specimens were tested by considering with different varying wear parameters.

Table.5 Numerical Results of wear

Specimens Percentages	L (N)	S (rpm)	SD (m)	WR (N - m/mm3)
	10	200	1000	6962.92
Al 6061	15	400	1500	12345.15
	20	600	2000	16701.73
	10	200	1000	6344.21
Al 6061 + 2% Gr + 3% WC	15	400	1500	7925.81
	20	600	2000	12625.75
	10	200	1000	2127.12
Al 6061 + 4% Gr + 3% WC	15	400	1500	9187.58
	20	600	2000	13982.16
	10	200	1000	2911.18
Al 6061 + 6% Gr + 3% WC	15	400	1500	9245.18
	20	600	2000	15786
	10	200	1000	7271.04
Al 6061 + 8% Gr + 3% WC	15	400	1500	12204.06
	20	600	2000	18446.09
	10	200	1000	3676.55
Al 6061 + 10% Gr + 3% WC	15	400	1500	3827.37
	20	600	2000	4235.89

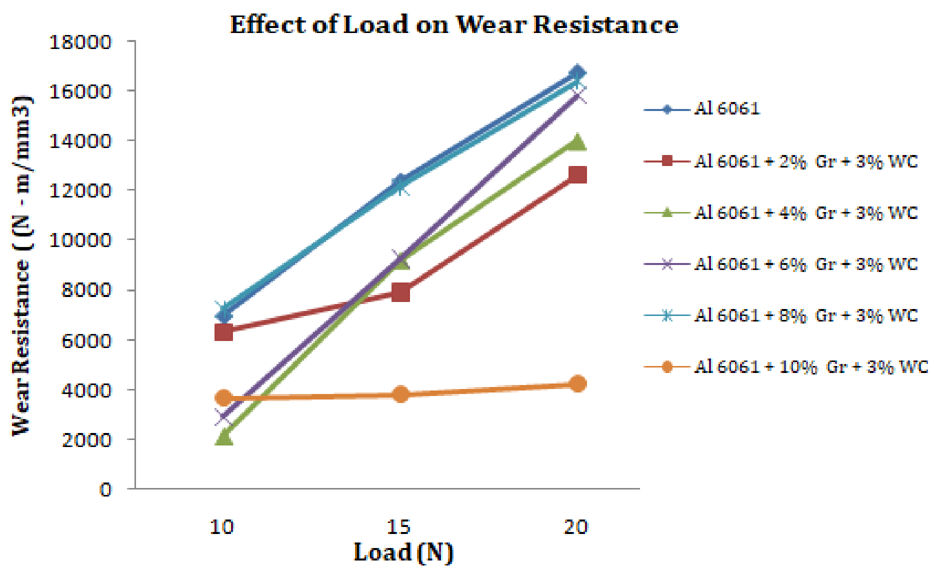


Figure.10 Wear Resistance (N –m/mm3) V/S Load (N)

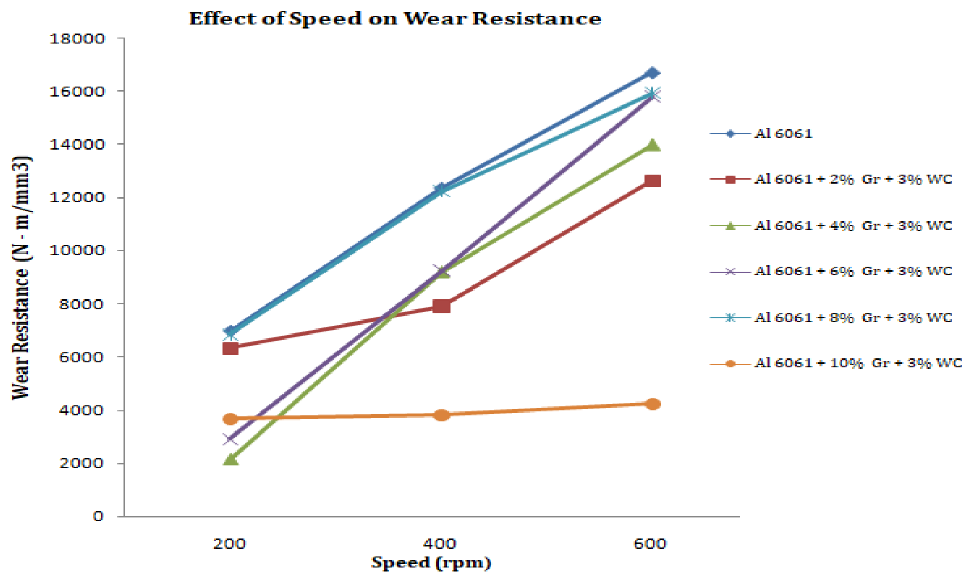


Figure.11 Wear Resistance (N –m/mm3) V/S Speed (rpm)

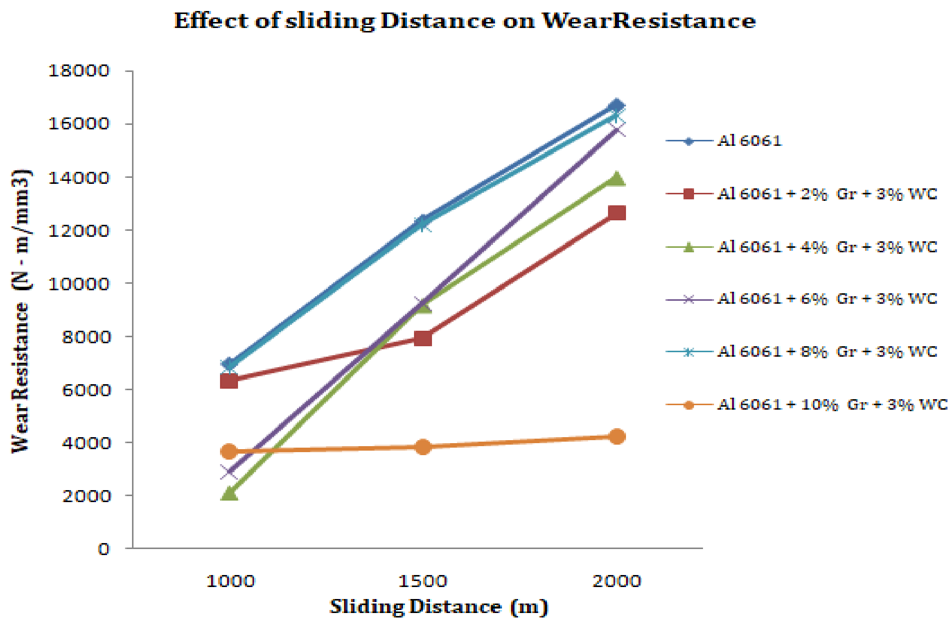


Figure.12 Wear Resistance (N –m/mm3) V/S Sliding Distance (m)

Fig. 10 shows the effect of load on wear resistance, Fig.11. shows the effect of speed on wear resistance and Fig.12 shows the effect of sliding distance on wear resistance for different weight proportions of reinforcements. The various levels of wear rate for prepared composites as shown in the above Figures. Wear rate will significantly increase by the effect of load, speed and sliding distance. It can be notice that plastic deformation is greatly increased which leads to higher wear at different levels. Usually plastic deformation leads to splits in the material surface, which in turn leads to removal of more material. As the load, speed and sliding distance increases with the sliding movement of prepared composite specimens on the top of the pin – on – disc apparatus. It develops interfaces of sliding for Al6061 + 8% Gr + 3% WC exhibits less frictional co –efficient on loads related to alloy materials.

4.4 SEM Results

The worn surfaces were examined by SEM to understand the wear mechanism of the prepared composites after performing the preliminary wear test for 6 Specimens with ASTM E407-07 Standards having dimensions of 20mm depth and dia of Φ15mm. During sliding the pin's surface area will be in contact with the steel disc's surface, and machine marks can be observed.

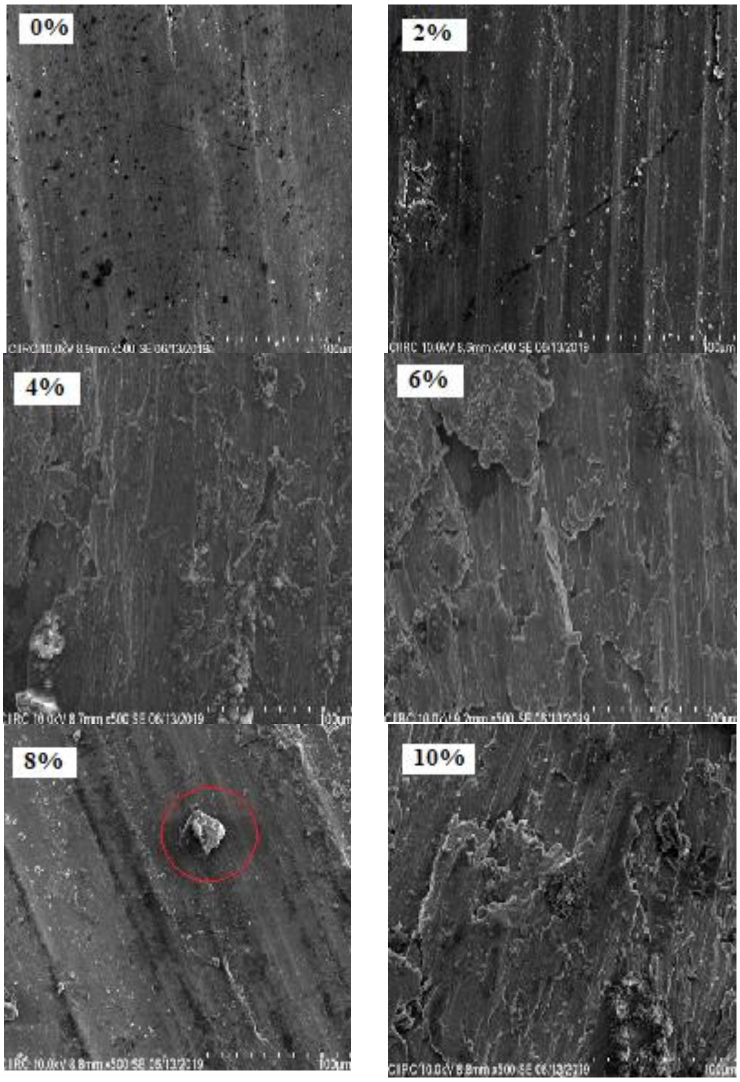


Figure.13. Wear Suface of SEM of prepared wear specimens at 500X

In this study we investigated the wear of particulate reinforced MMCs under varying applied loading conditions were identified. At lower loads (10N), the particles support the applied load in which MMCs wear resistance is better than alluminium alloy in the order of magnitude. At higher loads (20N), transition of severe wear takes place. We can notice the wear debris will be in the size of the order of micrometers, at lower loads it is of the order of a few hundred micrometers as the load increases the proportion of metallic wear debris also increases. Wear debris includes coarse metallic particles of the surfaces, WC and Gr particles, which acts as a abrasive particles between the specimen and disc. Figure.8 shows the SEM photographs of wear specimens with the varaition of reinforcement porportions of Gr with 0%, 2%, 4%, 6%, 8% and 10% by keeping WC as a constant proportion of 3% with the base metal at a load of 20N , with a speed of 600 rpm and with siliding distance of 2000m. The crack exhibits randomized longitudnal hollows, parallel towdards sliding distance. This indicates voids on the surface found to be damaged. It can be notice, that a little amount of material was removed from the prepared specimens. The surface displays different appearance with a percentages rising in reinforcements.

5. Conclusions

- The successful fabrication between base material aluminium 6061 with particulates of reinforcements including WC and Gr by using a powder metallurgy technique.
- By varying weight proportions of reinforcements with aluminium 6061 alloy, where we observed a good mechanical and tribological results.
- As increasing the context of reinforcements with in the base material has been found to results in significant improvements in its mechanical properties such as BHN and compression.
- At Al 6061 + 10% Gr + 3% WC, the properties of mechanical such as BHN and Compressive strength were found to be high.
- The properties of wear behaviour can be improved by increasing the reinforcement ratio of Graphite. The results of preliminary test shows highest wear resistance for Al 6061 + 8% Gr + 3% WC.
- Wear loss is minimum at load 10N, with a speed of 200rpm and with siliding distance of 1000m for each wear rate.
- The most affected specific wear rate were observed at applied load 20N, speed 800rpm and siliding distance 2000m for Al6061 + 8%Gr + 3%WC.
- Images of SEM clearly reflects the microscopically worn surface such as microcracking due to its applied loads, speed and siliding distances.

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