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Dry Sliding Wear Behavior of Epoxy Based Composites Filled With WS_2 and B_4C

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Abstract

In the recent times need is felt for newer materials that will have durable span of any component and having advantages like high wear resistance, strength-to-weight ratio and low cost. In present paper, Tribological studies were performed on the developed composite filled with $WS_2$and B_4C in epoxy resin, under condition of dry sliding. The concentration of fillers were varied from 1wt% to 2.5wt% of B_4C and 2.5wt% to 4wt% of WS_2. The wear rate is investigated by means of pin-on-disc tribometer. Experiments were carried out considering parameters like filler content, sliding velocity, normal load & time. Taguchi's design of experiments is used to design the experiments. The result shows that normal load has the most significant effect and sliding velocity has least significant effect on the specific wear rate of WS_2&B_4C filled epoxy composite. Wear mechanisms of worn surfaces were analyzed through Scanning Electron Microscopy.

Keywords: Epoxy, Tungsten Disulphide (WS_2), Boron Carbide (B_4C), Tribological characterization, Wear rate, SEM.

1.0 INTRODUCTION

Today there is a striking growth in the large scale production of fiber and particulate reinforced epoxy matrix composites because of their high strength-to-weight & stiffness-to weight ratios. Polymeric Composites are mainly used for a wide variety of structural applications as well as in aerospace, automotive & chemical industries due to its light weight, low coefficient of friction, wear resistance and self lubrication capacity. The utilization of filler in polymeric composites helps to improve Mechanical, Tribological characteristics & Thermal stability &other properties. In addition, higher mechanical strength can also be obtained by addition of fillers in polymeric composite, there is also cost reduction in terms of consumption of resin material. The final selection of filler ultimately depends up on the requirements of end user.

Polymer composites are mostly used in Tribological applications due to the possibility of changing their properties with addition of fillers & fibers. Mechanical, frictional& wear properties of many polymers have modified by investigators & researchers in the past. Emad Omrani et.al.(2015)[1] carried study on the effect of carbon fiber as reinforcement on the mechanical and Tribological properties of bio-based epoxy composite ,use of carbon fiber enhanced the bending strength and modulus of the composite and also its tribological properties. Davide Carnelli et.al.(2015)[2] studied the Flexural and Fracture toughness tests shows that composites exhibiting localized and aligned reinforcement architectures can improve 50-60% stronger ,stiffer and tougher than compositions with randomly distributed micro-platelets. K.S Srinivas et.al.(2014)[3]studied the tribological behavior of epoxy composites containing three different particulates fillers (Gr, SiC and Gr-SiC).The result shows that the synergic effect of hybrid filler Gr-SiC to improve the wear resistance which when compared with that of Gr/ SiC, the composite containing 5% Gr and 35% SiC exhibits highest wear resistance. J.S.Sidhu et.al. (2014) [4] observed that Epoxy itself has a high friction coefficient in many applications as well as poor wear resistance compared to epoxy composites. Filler additions reduce both friction coefficient and wear rate of epoxies. Tungsten disulphide (WS_2) used as filler brings improvement in Mechanical properties and Tribological properties. M.H. Shaikh et.al.(2013) [5]studied the Tribological behavior of epoxy composites filled with WS_2 particulates were studied using a pin-on-disc wear apparatus under dry sliding conditions and result shows that filler content is the most predominant factor as far as specific wear rate concerned hence filler improves the wear property.GanguluriKranthiet.al(2010)[6] reports the development and wear performance evaluation of a new class of epoxy based composites filled with pine wood dust. Effect of pine wood dust content on the wear rate of polyester composites under different test conditions is studied hence, study reveals that pine wood dust possesses good filler characteristics as it improves the sliding wear resistance of the polymeric resin. S. Basavarajappa et.al(2009)[7] studied tribological behaviour of glass epoxy polymer composites with SiC and Graphite particles as secondary fillers using a pin-on-disc wear rig under dry sliding conditions. The results showed that the inclusion of SiC and Graphite as filler materials in glass epoxy composites will increase the wear resistance of the composite greatly. Z. Rymuza et.al.(2007)[8] discussed on selection of polymers as materials for sliding (as well rolling) components of machines and devices is very important task for tribologists. Non polymer–on-polymer as well as polymer-on-polymer contacts are important nowadays in design of machines and devices in modern technology. Understanding of tribological processes is very crucial. Tribological behavior of polymeric tribo systems both for non-polymer-on-polymer and polymer-on-polymer combinations. Li Changet.al(2006)[9] investigated the influences of two solid lubricants, PTFE and graphite, were studied and compared. The transfer films established with two lubricants in sliding wear of epoxy nano composites against metallic counterparts were characterised under different sliding conditions. As a result showed a synergised effect in wear performance, especially under very severe wear conditions. This paper analyses the Tribological behavior of the epoxy with particulate B_4C &WS_2 as filler content.

2.0 MATERIALS &METHODS:

2.1 Materials:

Tungsten disulphide (WS_2) of average size of 4micron which is supplied by M/S.Sajan Overseas, Vatva, GIDC(G.S), Boron carbide (B_4C) of mesh size1500provided by M/S.Gannon Norton metal & tools, Delhi& Epoxy Resin AW 106 and HV 953 IN provided by M.K Hardware's Nanded, Maharashtra, India.

Table 1: Properties of Epoxy Resin AW 106 and HV 953 IN used in the present work.

Property	Test method	AW 106	HV 953 IN	Mix
Colour	Visual	Neutral	Pale yellow	Pale yellow
Specific Gravity	ASTM D-792	1.15	0.95	1.05
Viscosity at 25^0C	ASTM D-2393	30-50	20-35	30-45
Shelf life	-------------	2 years	2 years	----------------

Table 2: Properties of Tungsten Disulphide (WS_2) used in the present work.

Properties	Description of WS_2
Color	Silver gray
Appearance	Crystalline solid
Melting point	1250°c
Density	7.5g/cm^3
Molecular weight	248
Coefficient of friction	0.03 Dyanimic, 0.07 static
Thermal stability in air	COF <0.1 Till 1100°F
Lubrication Temperature Range	Ambient -273°C to650°C
Chemical Durability	Inert substance, non toxic
Hardness	30HRc

Table 3: Properties of Boron Carbide (B_4C) used in the present work.

Properties	Description of B_4C
color	Black
Appearance	Crystalline Solid
Melting point	2763°C
Boiling point	3500°C
Density	2.52g/cm^3
Molecular weight	55.25g/mol
Knoop hardness	2750 kg/mm^2
Thermal conductivity	28w/m-k@30°C
Specific gravity	2.1

2.2 Methods:

The epoxy resin(AW106) is mixed with an hardener(HV 953 IN) in the ratio 100:90 by volume in glass beaker(borosilicate glass) the measured quantity of WS_2 and B_4C were stirred gently into the liquid epoxy resin, such a that there must be not any introduction of air bubbles and even dispersion of filler. The mixed composite is stirred gently to ensure homogeneous mixture. After mixing homogeneous mixture is poured in mould cavity which is coated with silicon release agent to yield specimens of 10mm diameter and 30mm length(C1,C2,C3,C4),as shown in Table 4. The mould is placed in an electric oven and heated at constant temperature of 150°C for 45 min for curing. These test specimens were then post cured at constant temperature of 100°c in an electric oven for one hour. Composition test specimens of the composites are varied from 1wt% & 2.5wt% to 2.5wt% & 4wt% of filler (WS_2&B_4C).

Figure1: Metallic die For Preparation of Specimen.

Figure 2: Specimen for Tribo-Testing

Table 4: Material designation and its composition

Material Designation	Epoxy (Wt. %)	B_4C (Wt. %)	WS_2 (Wt. %)
C1	96.5	1	2.5
C2	95.5	1.5	3
C3	94.5	2	3.5
C4	93.5	2.5	4

3. EXPERIMENTATION

The experimental setup includes all hardware and software needed to collection of all necessary data and analysis of obtained data. The wear and friction monitor TR 20L/E/LE DUCOM Bangalore, having speed range 200-2000rpmwith force range 0-200N, It was used for dry sliding wear test**s.**Samples were made by different compositions and the end of each sample were rubbed against EN-31steel disc at different parameters.The surface samples and disc were cleaned and throughly dried before the test. Control factors its levels used for the present work as given in table 5.Every sample is indiviually weighted before and after the test in an electronic balance to measure the amount of wear.

For the purpose of analyzing the influence of control factors on performance output Taguchi's Design of experiment is a powerful analysis tool. During design of experiment the most important stage lies in the selection of the control factors. The wear tests were carried out under operating conditions i.e. Filler content, Normal Load, Sliding Velocity and Time. Accordingly L16 orthogonal array is selected and experimental observations are transformed into signal-to-noise (S/N) ratios. The S/N ratio for minimum wear rate comes under smaller is better characteristic, which can be calculated as logarithmic transformation of the loss function as shown below-
Smaller is the better characteristic: $S/N = -10\log (\sum y2)$

Where "y" is the observed data in above equation. “Smaller is better” characteristic is considered in the above S/N ratio transformation suitable for minimization of wear rate. The delta is difference between minimum &maximum values of SN ratio for an individual parameter .Highest rank indicates maximum influence on the process.

Table 5: Level of Variables used in Experiment

Parameters	Levels			
	1	2	3	4
A:Sliding velocity (m/sec)	2.512	5.024	7.536	10.048
B:Normal Load (N)	58.86	68.67	78.48	88.29
C: Filler content (wt%)	1	2	3	4
D:Time (min)	5	10	15	20

3.1 Experimental Results:

Table 6: Results Table

EXP. No.	Initial Weight (g)	Final weight (g)	Total wear (g)	Filler content	Load (N)	Sliding Speed (m/sec)	Time (min)	Density (g/cm^3)	Volume Wear (mm^3)	Specific wear rate (mm^3/Nm)	SN ratio
1	6.360	6.350	0.01	1	58.86	2.512	5	1.141	8.7642	$1.9768*10^{-4}$	74.08
2	6.050	5.960	0.09	2	58.86	5.024	10	1.139	79.0166	$4.453*10^{-4}$	67.02
3	6.770	6.660	0.11	3	58.86	7.536	15	1.132	97.173	$2.434*10^{-4}$	72.27
4	5.970	5.710	0.26	4	58.86	10.048	20	1.124	231.3167	$3.259*10^{-4}$	69.73
5	6.500	6.440	0.06	2	68.67	7.536	5	1.139	52.677	$3.393*10^{-4}$	69.38
6	6.290	5.970	0.32	1	68.67	10.048	10	1.141	280.455	$6.774*10^{-4}$	63.38
7	5.320	5.140	0.18	4	68.67	2.512	15	1.124	160.142	$1.0315*10^{-3}$	59.73
8	6.260	6.120	0.14	3	68.67	5.024	20	1.132	123.67	$2.9872*10^{-4}$	70.494
9	6.430	6.290	0.14	3	78.48	10.048	5	1.132	123.673	$5.227*10^{-4}$	65.63
10	5.700	5.430	0.27	4	78.48	7.536	10	1.124	240.213	$6.7693*10^{-4}$	63.389
11	6.280	5.960	0.14	1	78.48	5.024	15	1.141	280.455	$7.903*10^{-4}$	62.044
12	6.520	6.440	0.08	2	78.48	2.512	20	1.139	70.237	$2.968*10^{-4}$	70.550
13	6.150	5.890	0.26	4	88.29	5.024	5	1.124	231.316	$1.738*10^{-3}$	55.199
14	6.070	5.930	0.14	3	88.29	2.512	10	1.132	123.674	$9.293*10^{-4}$	60.636
15	6.410	6.260	0.15	2	88.29	10.048	15	1.139	131.694	$1.649*10^{-4}$	75.655
16	5.750	5.760	0.01	1	88.29	7.536	20	1.141	8.7642	$1.097*10^{-5}$	99.195

Table 7: S/N Ratios for Wear Rate.

Level	A Sliding velocity	B Normal load	C % Filler content	D Time
1	70.775	66.07	**74.674**	66.249
2	65.746	63.606	70.65	63.689
3	65.403	67.423	67.257	**76.05**
4	**72.671**	**77.492**	62.012	68.597
Delta	7.268	13.886	12.662	12.361
Rank	4	1	2	3

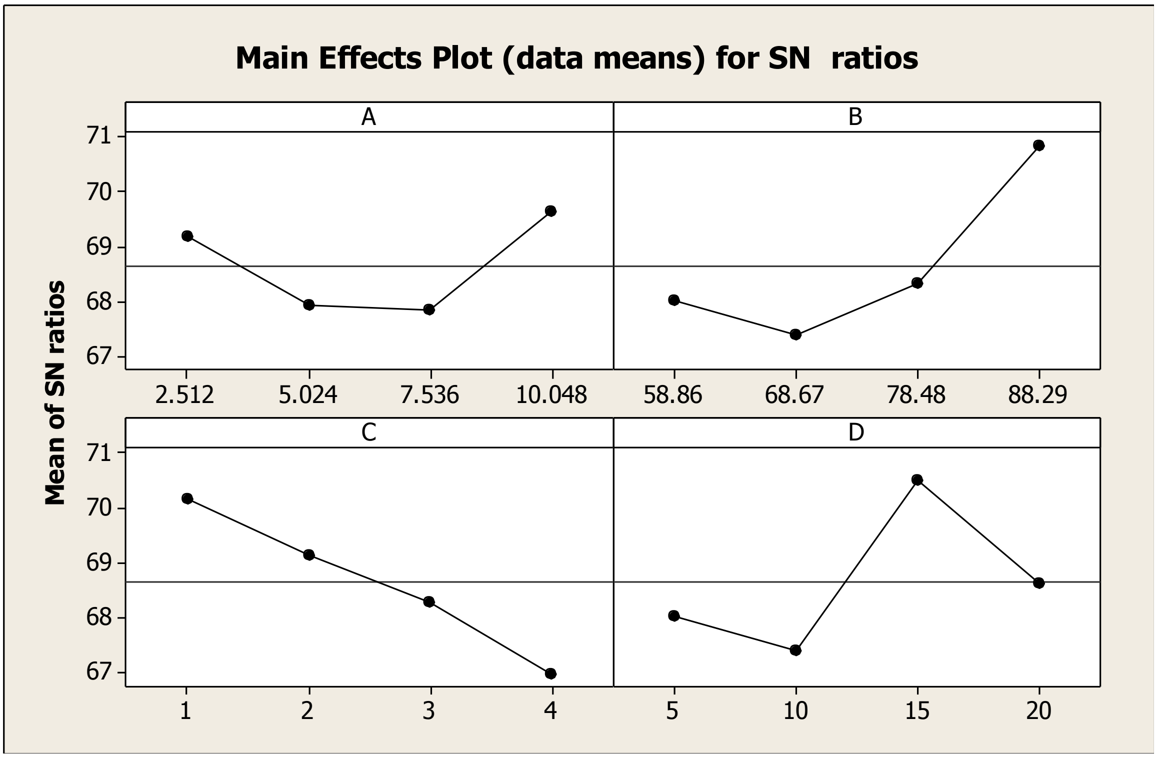


Figure3: S/Ncurve

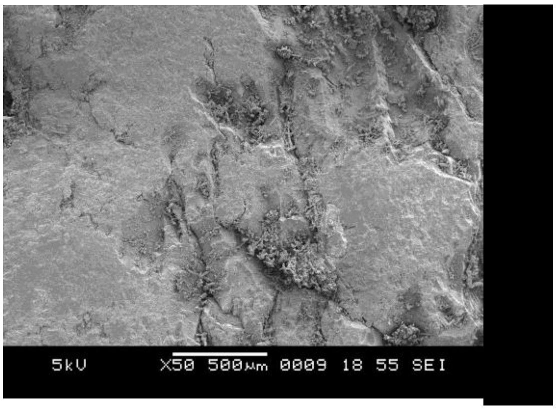
4. RESULTS AND DISCUSSION

Four control parameters and four levels are identified, accordingly array "L16"orthogonal array is selected. The wear of polymer composites with varying Filler content, Time, Normal load and Sliding velocity are reported in Table6.The SN ratios obtained are shown in Table 7for wear rate. The S/N ratio response analysis shows that most significant parameter on wear rate is Normal Load followed by Filler content, Time and Sliding velocity as per Table 7.The delta of SN ratio of particular parameter highest rank 1 that has the maximum influence on the process. Calculating the response assess the effect of individual control factor & the results of response analysis lead to conclusion that factor combination A4 B4 C1 D3 gives minimum wear rate. Thus, Increase of load on pin cause to increase of wear rate. The wear rates obtained for all the 16 test runs along with the corresponding S/N ratio are presented in Table 7.From this Table the overall mean of the S/N ratio of wear rate is found to be 68.64.This is done using MINITAB software used for Design of experiments application fig.3.which shows that as Sliding Velocity and Normal Load increases there is increase in wear rate in A & B graph plot and in case of C graph plot shows that as increase in Filler content cause to decrease of wear rate , At D graph plot shows there is zig zag plot that shows wear rate changes with every interval of time period.

The experimental data generated has been reported in table. Polymer composite wear sample were prepared by use of filler material WS_2 with density 7.5 g/cm^3 Hardness 30HRC & B_4C with density 2.57 g/cm^3 hardness 81HRC in Epoxy AW106&HV953IN .Increased Hardness & Tensile strength with increase filler percentage provide relatively better mechanical properties (hardness &tensile strength), From the experimental data it is revealed that normal load is most predominant factor contributing to resistance against the wear, across the given Sliding velocity, Filler content & Time.

The obtained results are attributed to better mechanical properties observed improvement in wear resistance with load content has been in present investigation. Hardness is most important mechanical properties dictating performance of the material during service. Improved hardness exhibited better wear resistance in investigation; higher hardness that is higher wear resistance has been pointed out through study.

5. MORPHOLOGICAL ANALYSIS



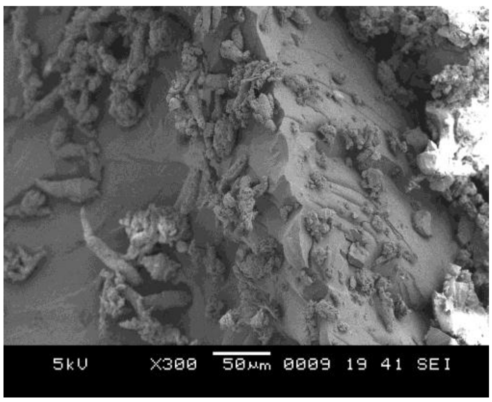


Figure 4: SEM micrograph of the worn surface of specimen C1 with 50x &300x magnification.

The SEM images are taken at VNIT, Nagpur, Maharashtra. In fig. 4 the SEM morphology of the worn surface with 1wt%B_4C and 2.5wt%WS_2 as fillers and tested under 78.48 N load with time of 15 min. In fig 4.shows with minimum filler content the wear and damage is maximum. Further adhesive and abrasive wear is predominant. Plough marks are noticed with some adhesive wear surfaces adhere to the surface in 50x magnification .In higher magnification micrograph shows adhesive wear of surface with deposition of wear particles on the surface. There is severe deterioration of the composite surface when applied load is higher and sliding speed gets higher. Small sized platelets and debris is produced on the surface which gradually changes to smaller particles, at beginning abrasive wear dominates then adhesive wear occurs which is visible at higher magnifications.

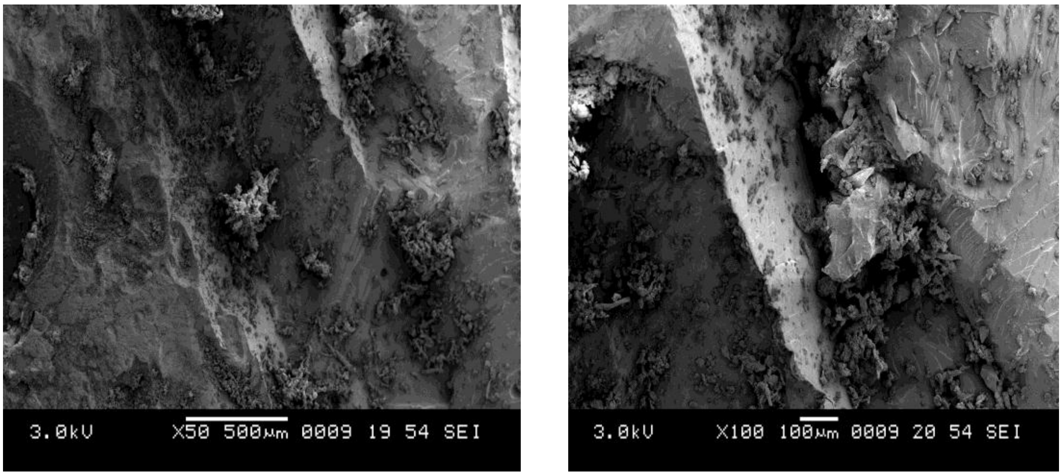


Figure 5: SEM micrograph of the worn surface of specimen C2 with 50x &100x magnification.

In fig.5 the micrograph at higher magnification of the worn surface ,with1.5wt%B_4C and 3wt%WS_2 fillers and tested under 88.29N load with time of 15min shows micro fracture regions and smeared wear debris particles, with increased with increasing temperature. As the normal load on the particles increased the load distributed over all asperities and each asperity goes deeper in to the surface that means a larger depth of grooves were created as seen in the micrograph. Higher wear rate caused due to deeper grooving. This result in more material removal by a severe plastic deformation, which appeared as a series of grooves parallel to direction to sliding in SEM micrograph.

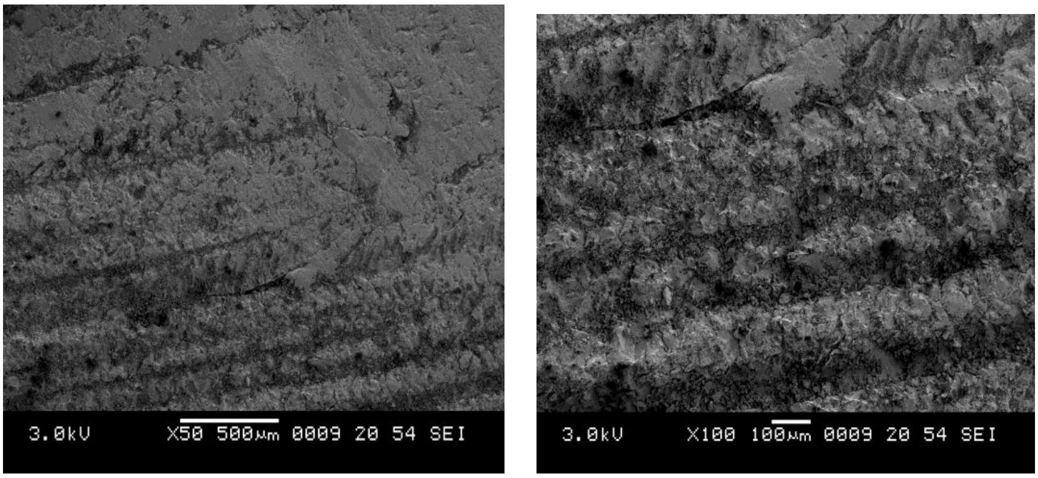


Figure 6: SEM micrograph of the worn surface of specimen C3 with 50x &100x magnification

In fig.6 the micrograph at higher magnification of the worn surface, with 2wt%B_4C and 3.5wt%WS_2 fillers and tested under 78.48N load with time of 5min.shows that scratches produced on the surface parallel to the sliding direction. Due to destruction and transfer of the material from the surface, ploughed marks are seen at higher magnification which indicates that adhesive wear is the dominant wear mechanism. As the filler content in the composite was more, the dispersion of filler particles in the epoxy was sufficient. Probably due to more filler content the resin is unable to hold them together, so wear registered here is more, there is destruction of the matrix surface, this may be due to improper mixing of fillers with the matrix in stir casting.

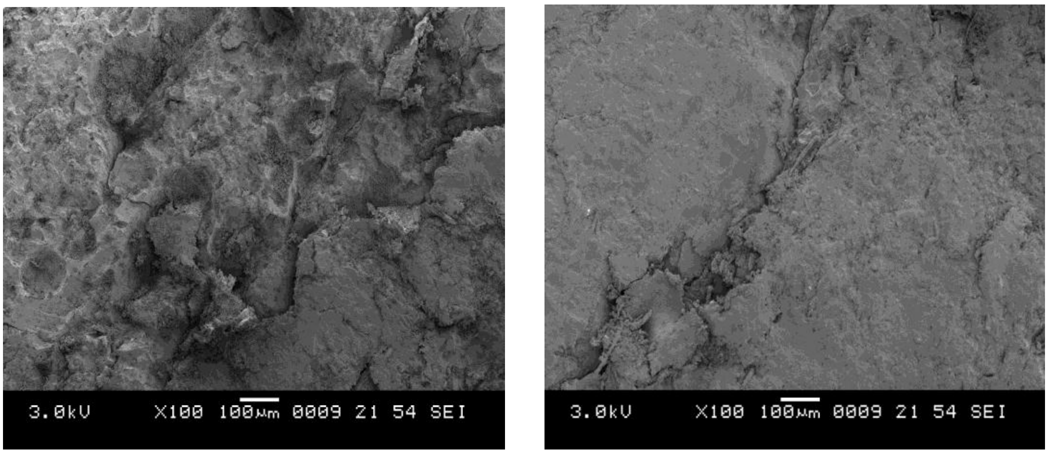


Figure 7: SEM micrograph of the worn surface of specimen C4 with 100x magnification.

In fig.7 in which the micrograph at higher magnification of the worn surface, with 2.5wt%B_4C and 4wt%WS_2 fillers and tested under 88.29N load with time of

5min.shows that no localized damage is seen due to higher load, the same composite don't show any crack or measurable wear. Further looking at micrograph it is clear that the filler is well bonded with the matrix. Due to more load and good resistance to wear is offered by the filler particles, no appreciable wear is seen. But as the material is worn against a steel disc for a considerable time, signs of fatigue in the material can be seen. So fatigue wear is dominant here. The presence of fillers have reduced the wear of the polymer to a great extent.

6. CONCLUSIONS

Taguchi's method of experimental design is used for dry sliding wear of WS_2&B_4C filled epoxy composites. Following conclusions were drawn out of the investigation:

1) Fabrication of WS_2&B_4C filled epoxy composites is possible by simple stir casting process.
2) Sliding wear characteristics of WS_2& B_4C filled epoxy composites were successfully analyzed using Taguchi's design of experiments.
3) Out of the influencing parameters affecting the specific wear rate, most dominant is the Normal load followed by Filler content, Time &Sliding velocity.
4) WS_2 and B_4C filled epoxy composite shows better hardness i.e., abrasion resistance and wear under different varying compositions, so different composites can be made for different applications.
5) SEM images revealed that at low filler content and lower loads, the dominant wear mechanisms were adhesive and abrasive wear. As the filler content increased, the material being on the harder side and more brittle exhibited fatigue wear as the dominant wear mechanism.
6) Present study lead to conclusion that polymer composites suitable for engineering components subjected to wear environments can be successfully prepared by filling in micro WS_2&B_4Cas promising filler in epoxy resin.

7. ACKNOWLEDGEMENTS:

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