



Study on Mechanical and Tribological Properties of Nylon-6/Nano MgO Polymer Composites

Shiva Kumar K^{1*}
Chennakesava Reddy A²
Shankar Goud B³

^{1,2}Department of Mechanical Engineering, JNTUH University College of Engineering, Hyderabad, Telangana, 500085, India

³Department of Mathematics, JNTUH University College of Engineering, Hyderabad, Telangana, 500085, India

Abstract

In the present paper, Nylon is taken as the matrix material, and composite is made by the addition of the MgO at various percentages based upon Taguchi's design of the experiment. After fabrication of the composite material, the tensile and wear test is carried out to see the variation of the mechanical properties, and optimum process parameters are found using the Anova test and along with varying the process parameters such as normal load, sliding distance, and speed. The surface of the material after braking is studied using SEM Analysis and also the wear debris is studied, and results were obtained as there is an impact of MgO on the matrix material.

Keywords: Nylon-6, MgO; Tensile; Wear test; Taguchi; Scanning Electron Microscope

Introduction

Teflon as a filler to Nylon 6 matrix material increases the tensile and the hardness of the Nylon/Teflon polymer matrix composites. The addition of Teflon to the Nylon 6 matrix increases hardness and tensile strength while it decreases the ductility of the Nylon/Teflon polymer composites [1]. The composites enhance the mechanical properties by addition of the filler content, by addition of the 10 wt % of Al₂O₃ in the PA6 matrix exhibited the best performance in flexural strength, tensile strength, and also shows the best performance in hardness and impact strength [2]. The addition of the graphite filler into PA6 reduces the wear. The minimum wear loss was found at the filler content of 25 %wt fractions and the increase in the filler content by up to 25%wt with a decrease in the coefficient of friction [3]. Nano TiO₂ with Nylon-6 shows better mechanical properties compared to micro ones [4]. With the addition of iron oxide nanomaterial to Nylon 6/Teflon, the tensile and hardness were doubled [5]. With the addition of graphite content in the composite, there was a reduction in the strength with an increase in hardness and also Strength of the PTFE increases and stiffness [6]. Impact strength increases gradually with the increase in micro alumina wt. % up to 6 wt. % and after reduces [7]. Inorganic fillers, such as mica, when added to the polymer composite, increase the heat resistance, rigidity, and dimension stability [8]. Nylon 6/graphite powder composites increase thermal stability by adding 0-15 wt % of graphite [9]. The highest tensile strength was achieved by nano-Al₂O₃ content in the matrix material [10]. An increase in nano-SiO₂ content improves mechanical properties more compared to the Nylon-6/ABS blend [11]. The hardness of nylon composites varies by reinforcement material such as fly ash [12]. Copper nanoparticles in nylon 6 improve mechanical properties with an increase in the concentration of the copper content [13]. This review says nylon 6 is one of the best polymers for composite matrix. Fillers affect the composite's mechanical characteristics. Despite polyamide research, Graphite has a lesser affinity for PA6. More study is needed to improve graphite's PA6 affinity [14]. According to Taguchi's design of experiment, the wear conduct of Nylon-6 loaded with nanometer-measured boron nitride (BN) composites was studied for varying filler quantity, normal load, sliding distance, and speed. We studied nylon-6 and its composites using a tensile test. The Nylon-6/BN polymer composites were evaluated using a pin-on-disk erosion and wear test (ASTM G99). This work reduces extreme quality in composites by using expanding boron nitride and converts normal load to a 71.54 percent wear rate variation. Improving Nylon-6/BN composites' mechanical characteristics will boost Nylon-6's use [15]. Load contributes more (81.7%) than any other input. ABS with 8% MgO has the highest tensile strength. Without MgO, composites have limited tensile strength. MgO adds mechanical characteristics. MgO

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*Corresponding author:

Shiva Kumar K

Department of Mechanical Engineering
JNTUH University College of Engineering
Hyderabad, Telangana, 500085, India
E-mail: kskumar3456@gmail.com

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enhances composite hardness. Input load increases the wear rate. ABS/MgO fractography shows that when MgO increases, multilayer cracks appear due to MgO's strong bond with ABS. According to SEM images, micro fractures increased under load [16].

Materials and Methodology

For improving the wear resistance, the constituent material MgO with a particle size of approximately 80 nm is taken along with the matrix material Nylon-6 thermoplastic powder. The constituent material magnesium oxide is added to matrix material in various percentages such as 4%, 8%, 12%, 16%, and 20% by weight. To maintain homogeneity, MgO nanoparticles are mixed in a ME100LA mixer with Nylon-6 thermoplastic powder at a Temperature of 190°C. The mixing is carried out for 20 min, maintaining the 200rpm speed of the mixing blades. To fabricate, the Nylon-6/MgO polymer composites specimens in the injection molding machine were employed. In a hopper, the mixture of Nylon-6 and MgO was placed. To make the mixture soft and smooth the mixture was heated in the barrel. To remove material shrinkage the blend of liquid Nylon-6 and MgO nanoparticles was then forced under pressure for a particular time inside a mold cavity with a constant injection pressure of 70 Mpa. The melt flow index of Nylon-6 was 12 g per 10 min. And it is a melting point of the MgO utilized was 230°C. For all experiments, the heating temperature of the charging barrel, injection pressure, and the cooling time of moldings were kept consistent. The initial temperature of the mold was 25°C. Below the glass transition temperature, (105 °C) of the MgO material would solidify. After an adequate time, the material was solidified into the mold shape and got ejected. Standard tensile specimens were fabricated under different injection pressures and packing pressures. A standard tensile test model was manufactured under various injection pressures and packing pressures. The specimens used for the tensile test was shown in (Figure-1). The instrument used to test the tensile test of the specimen was Tensometer Model PC-2000 (Figure 2). This test specimen was investigated by scanning electron microscope (S-3000N Toshiba SEM) to study the tensile specimen fracture surfaces at room temperature.

To evaluate the wear behaviour of Nylon-6/MgO polymer composites, A wear monitor (ASTM G99) and pin-on-disc type friction were employed. On a hardened ground steel (En32) disc, Emery paper (grade size of 400) was fixed. For the selection of experiments, Taguchi's design of experiments was used. The factors MgO (%wt.), Normal Load (N), Sliding Speed (rpm), Sliding distance (m), chosen and levels are summarized in Table 1. The orthogonal array, L9 was preferred to carry out wear experiments (Table 2). To know the hardness the Vickers microhardness was



Figure 2: Tensometer

Factor	Symbol	Level-1	Level-2	Level-3
MgO, %wt.	A	4	12	20
Normal Load, N	B	10	15	20
Sliding Speed, rpm	C	100	200	300
Sliding distance, m	D	500	750	1000

Table 1: Design factors with different levels

Treat No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2: Orthogonal array (L9) and control parameters

conducted for Nylon-6/MgO polymer composites and results were drawn using Scanning electron microscopy analyses and found a consequence of wear test of Nylon-6/MgO polymer composite specimens.

Results and Discussion

Wear and tensile tests for the specimens with varied compositions (4%, 8%, 12%, 16%, 20%wt MgO) were conducted.

Mechanical behaviour of N/MgO polymer composites

Figure 3 describes the stress-strain curves for various compositions of Nylon 6/MgO. Maximum stress is exhibited by 8%wt MgO, and the maximum strain rate is exhibited by 4%wt MgO when compared to other combinations of N/MgO composites. From figure 4(a), it is observed that the ultimate strength increases drastically from 4%wt to 8%wt MgO where the highest ultimate strength is exhibited at 8%wt of MgO (32.74 MPa). From 8% to 16%, tensile strength follows the trend of gradual decrease which resulted in the lowest ultimate strength at 16%wt of MgO (20.52 MPa). It is seen the ultimate strength increases slightly from 16% to 20%wt MgO. The ultimate strength

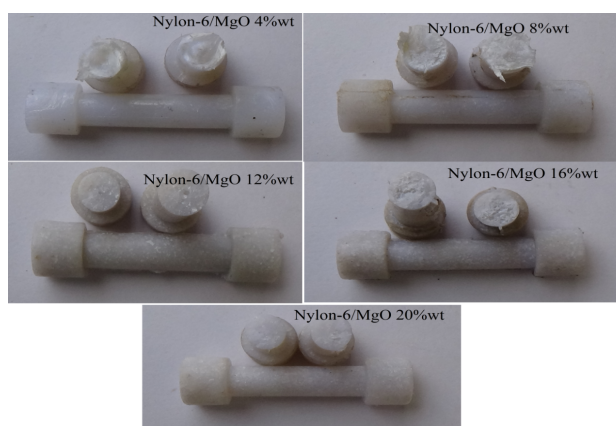


Figure 1: The specimens used for the tensile test

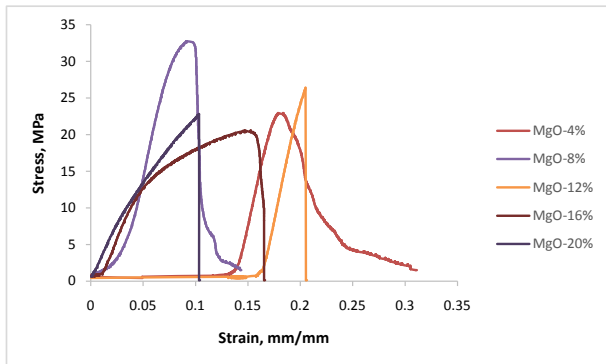


Figure 3: Stress-strain curves of N/MgO polymer composites.

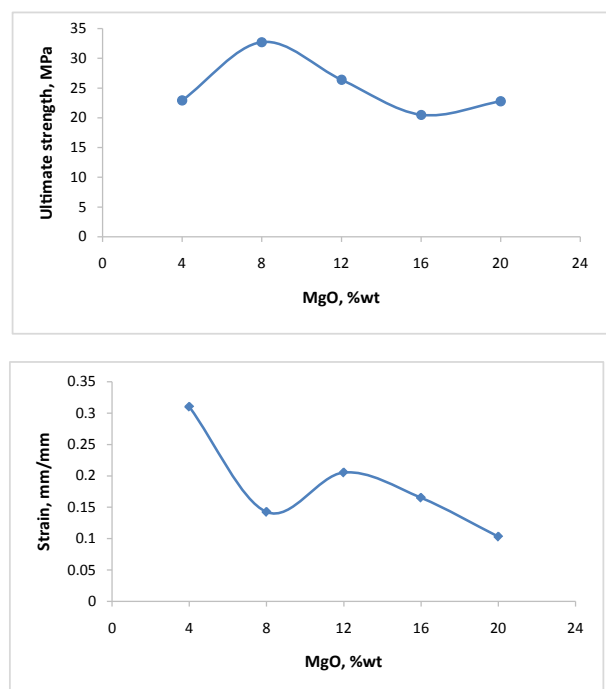


Figure 4: Ultimate strength (a) and corresponding strain (b) as a function of MgO.

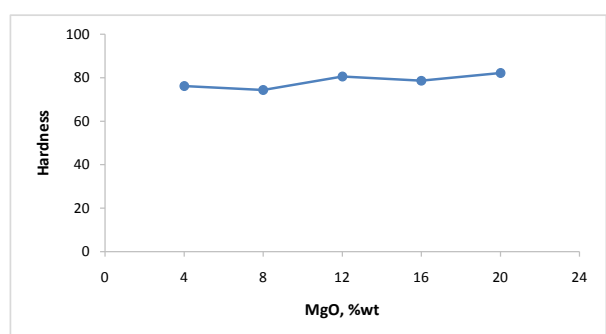
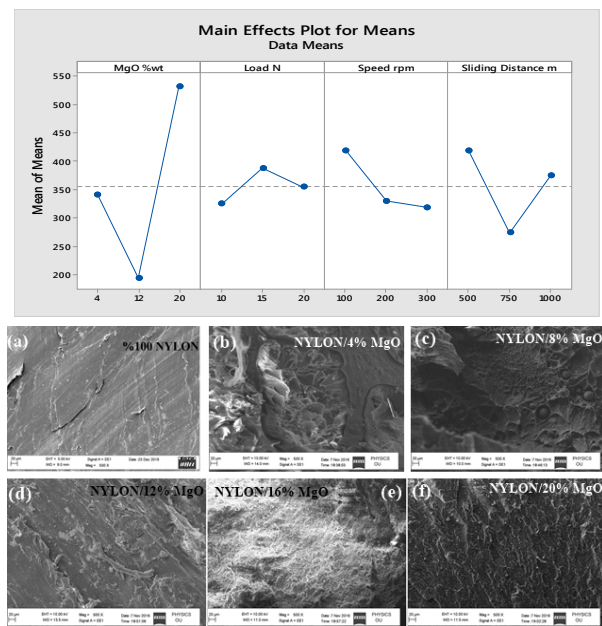


Figure 5: Hardness is a function of %wt MgO

of 4%wt MgO composite and 20%wt MgO are almost the same. From figure 4(b), it can be illustrated that the strain rate observes a drastic decrease from 4%wt to 8%wt MgO. The maximum strain rate is observed at 4%wt MgO. The strain rate increases from 8%wt to 12%wt followed by a gradual decrease trend from 12%wt to 20%wt where it attains the minimum value.



From the table, it was found that the MgO shows a higher contribution

Figure 6: Fractography of Pure Nylon-6 and Nylon-6/MgO polymer composites

Figure 5 Rockwell Hardness of Nylon 6/MgO polymer composites with different compositions were studied. The hardness of Nylon 6/MgO composites at different compositions follows a linear trend with only a slight difference between each other. Hardness is maximum at 20%wt MgO with a value of 82.16 HRM and a minimum at 8%wt MgO with a value of 74.33 HRM. The hardness decreases slightly from 4%wt to 8%wt, later increases from 8%wt to 12%wt followed by a slight decrease from 12%wt to 16%wt, and finally increases from 16%wt to 20%wt to attain the maximum.

From the table, it was found that the MgO shows a higher contribution. The percentage contribution of the MgO is 75.09% .so; the filler material shows a greater impact on mechanical properties. The second most influencing process parameter is the sliding distance with a percentage contribution of 14.29% - other process parameters such as the speed and the load show very less impact on the output response. The optimum solution was found -12%, load-10 N, speed-300 RPM, and sliding distance-750M.

Development of the mathematical models

Using Minitab, mathematical models are developed to measure the wear rate of the material using input parameters such as filler content, normal load, sliding distance, and speed. The regression equation was developed using the stepwise regression method. The equation is in the form of a coded value. ANOVA test is conducted to know the reliability of the equation and found R^2 as 96.03% and R^2 (adj) as 89.42%. As R^2 values are greater than 95% percentage we can adopt the equation for estimating the wear rate.

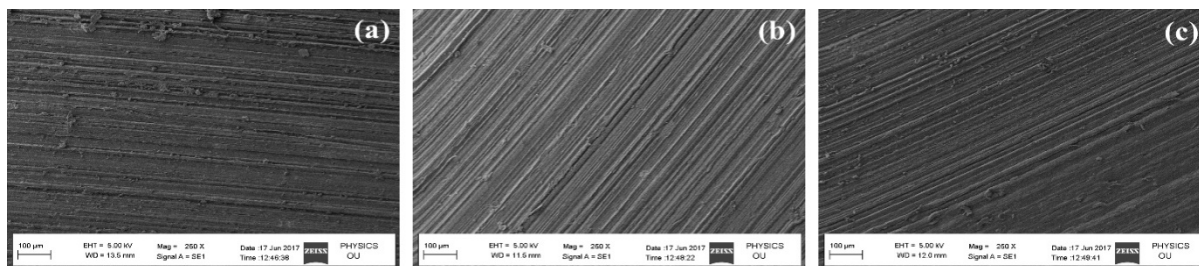
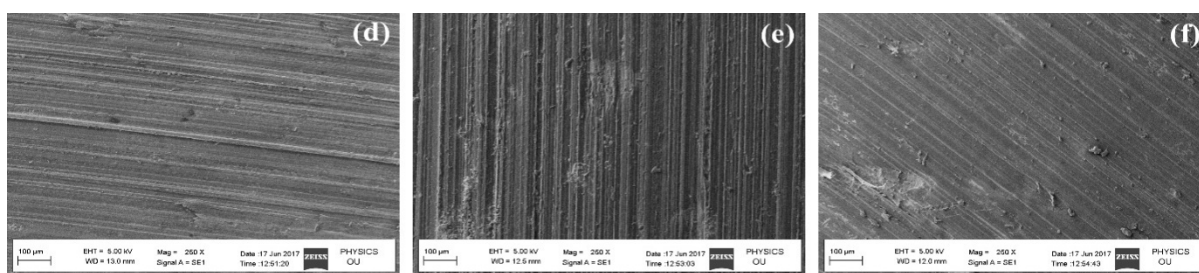
Confirmation test

To test the regression equation experiment was conducted and wear rates are recorded. The same input values are taken and wear rate was found using the developed equation, and the error percentage compared was found that the error percentage is 7.01 %. The test was conducted by taking input values as MgO -12%, load-20 N, speed-100 rpm, and sliding distance-750 M.

Parameter	Symbol	SUM-1	SUM-2	SUM-3	SS	v	V	P
MgO %wt	A	1023	582.9	1257	171659	2	85829	75.09%
LOAD(N)	B	974.1	1164	1062.9	6025	2	3012	2.64%
SPEED(RPM)	C	1257	989.1	954.9	18243	2	9121	7.98%
SLIDING	D	1254.9	822.9	1122.9	32672	2	16336	14.29%
Error	E					1		0
Total	T				228598	9		100.00%

Table 3:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	219531	43906	14.53	0.026
Linear	3	72635	24212	8.01	0.061
A	1	54531	54531	18.04	0.024
C	1	15201	15201	5.03	0.111
D	1	2904	2904	0.96	0.399
Square	2	146896	73448	24.3	0.014
A*A	1	117128	117128	38.76	0.008
D*D	1	29768	29768	9.85	0.052
Error	3	9067	3022		
Total	8	228598			

Table 4: $\text{WEAR}/\mu\text{m}=1523 - 873 \text{ A} - 50.3 \text{ C} - 510 \text{ D} + 242.0 \text{ A}^2 + 122.0 \text{ D}^2$ **Figure 7:** Worn surfaces of specimens for trial conditions of 1, 2, and 3.**Figure 8:** Worn surfaces of specimens for trial conditions of 4, 5, and 6.

The wear rate was found that 175 μm and the predicted value is 162.7. There is little variation in the experimental values and the predicted values so the equation can be adopted.

Fantagraphics of Nylon-6/MgO and nylon 6 polymer composites are shown in figure 6. For pure Nylon-6 there are Voids and fibrillation which were formed due to the debonding in the Nylon-6. Figures 6(b), 6(c), 6(d), 6(e) and 6(f) Nylon-6/MgO polymer composites are shown; there are micro damages. These micro-damages were found until the interface degradation was reached. MgO nanoparticles have been observed on the damaged surface. When a material is broken it was observed that there is a little breakdown of the MgO particles. Rougher surfaces and

more crack branching for Nylon-6/4%MgO, Nylon-6/8%MgO, and Nylon-6/20%MgO composites.

For trials conditions 1, 2, and 3 with 4% MgO nanoparticles, there are small grooves of worn surfaces appearing as shown in figures 7-9. Deformation and cracking were observed on the surface in Figures 10b and 10c due to the increase in the load and sliding distance. Figure 11c, the situation was difficult for 20 N normal load and 1000 m sliding distance. For trials 4, 5, and 6 with 12% MgO nanoparticles, the high strain experienced by the specimens result in worn surfaces. As the load was increasing worn surfaces were higher. For trials 7, 8, and 9 with 20% MgO nanoparticles, the worn surface is less as compared to trial 9. Large plastic deformation was found for trail 9.

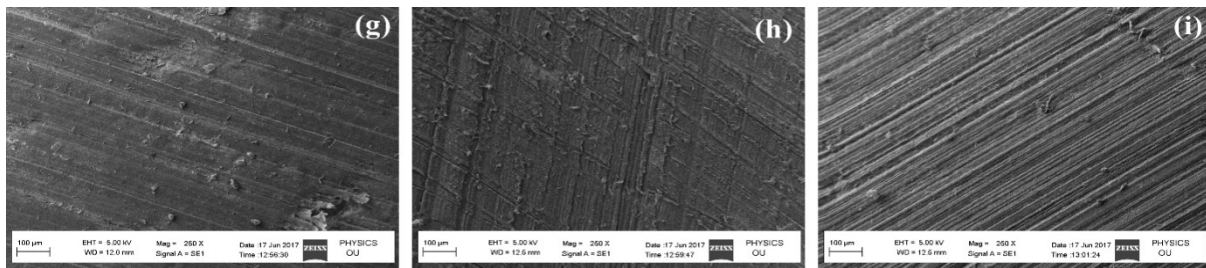


Figure 9: Worn surfaces of specimens for trial conditions of 7, 8, and 9.

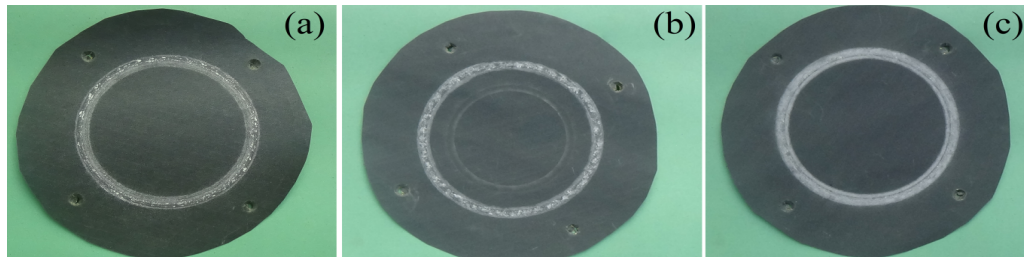


Figure 10: Wear debris was found during the wear tests

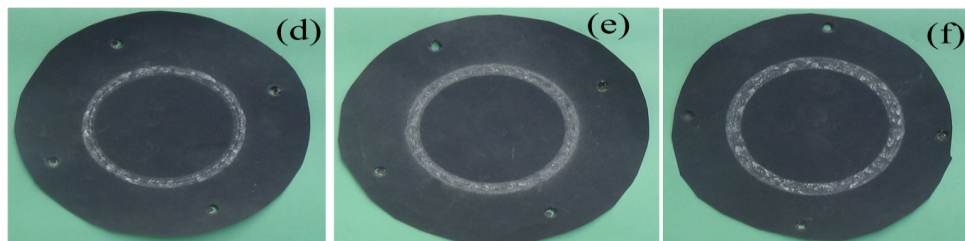


Figure 11: Wear debris was found during the wear tests

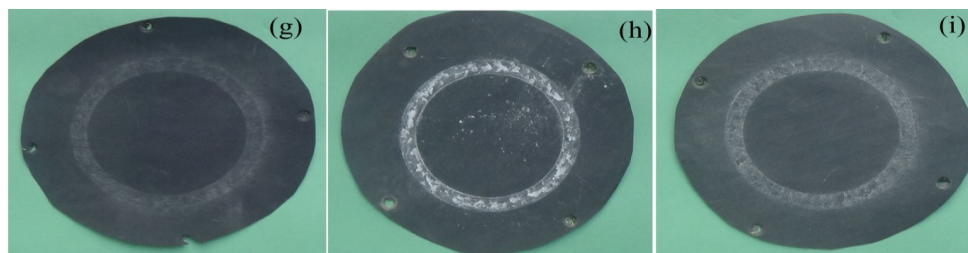


Figure 12: Wear debris was found during the wear tests

Wear debris was found during the wear tests given in figures 11-12. When load and sliding distance is increased, there is an increase in the size of the platelets or flakes. When the volume fraction of MgO at lower loads there is also found an increase in the flakes.

Conclusion

The composite is made by the addition of the MgO at various percentages based upon Taguchi's design of the experiment along with varying the process parameters such as normal load, sliding distance, and speed.

- During the tensile test, the ultimate tensile strength is increased with an increase in the MgO at 8% of filler content, then decreases.

- During the wear test, it was found that the optimum process parameters to minimize the wear were found, 12% MgO, 10 N load, 300rpm Speed, and 750m sliding distance.
- The regression equation for the wear rate is generated from the 9 trails, and a confirmation test is done to validate the equation.
- The hardness of the specimens was found to be varying slightly with an increase in the MgO fraction volume.
- SEM analysis is done to study the Factographics and worn surface of the broken specimens and found to increase in the worn surface are high with an increase in load and MgO concentration.

- When Sliding distance and load increase there is an increase in the flakes and wear debris.

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