Wear Analysis On Polyurethane Matrix Hybrid Nano Composites

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Abstract

Wear properties of Polyurethane Matrix composites have tested experimentally. The experimental results have to be compared with modeling and FEA results for identifying the optimum composition of the additive particles percentage with Polyurethane matrix. The properties to be identified for three samples obtained from varying percentage of Molybdenum disulphide particles such as 7%, 10% & 20 % of Polyurethane blended with the Tetrahydrafuron solvent. The next three samples have been synthesized and tested by adding 0.5%, 1% & 1.5% of Titanium dioxide nano particles with 7%, 10% & 20% of Molybdenum disulphide particles in the Polyurethane Matrix Hybrid Composites. The wear test has to be conducted on Pin on Disk test Apparatus. Finite Element Analysis, a model has designed for all the six samples with and without Titanium dioxide nano particles in Polyurethane matrix hybrid composites by selecting the appropriate element. The calculated wear rate has to be compared with experimental results. By Comparing the Experimental and FEA output, the optimum composition of the sample has been identified for the test and to be applied to specific application.

Keywords: *Polyurethane, X-ray diffraction, Molybdenum disulphide , Nanoparticles, Finite Element Analysis..*

1. Introduction

Mechanical and microstructural properties of Polyurethane Matrix composites have tested experimentally. The experimental results have to be compared with modeling and FEA results for identifying the optimum composition of the additive particles percentage with Polyurethane matrix. The samples have been synthesized by sol-gel process with or without the addition of Titanium dioxide nano particles in Polyurethane matrix composites. First, the samples of Polyurethane matrix composite have been synthesized without the addition of Titanium dioxide nano particles.

Commercially available Molybdenum disulphide has to be blended with the Tetrahydrafuron solvent and then polyurethane was added pellet wise to the stirred suspension of Tetrahydrafuron solvent in various concentration to obtain the feasible viscosity of the suspension. The suspended solution was stirred continuously for one hour using the mechanical stirrer and the mixing has been continued for another 10 minutes with high speed stirrer. The suspended solution was cured for layer by layer approximately for 8 hours and the samples were cut into standard specimen sizes. The different specimen from each sample has been taken for testing their mechanical properties. The properties to be identified for three samples obtained from varying percentage of Molybdenum disulphide particles such as 7%, 10% & 20 % of Polyurethane blended with the Tetrahydrafuron solvent.

The different specimen as per ASTM specification of each sample has been taken for obtaining the wear test has been conducted by Pin on Disk Test Apparatus; the wear rate of each sample has been calculated by obtaining the average values of wear rate on different specimens. The average values of wear rate of each samples have been compared for obtaining the perfect composition of composite having minimum wear rate.

Using the above procedure, the next three samples have been synthesized and tested by adding 0.5%, 1% & 1.5% of Titanium dioxide nano particles with 7%, 10% & 20% of Molybdenum disulphide particles in the Polyurethane Matrix Hybrid Composites. The wear test has to be conducted on Pin on Disk test Apparatus. The wear rate for the next three samples has been calculated by obtaining the average values of wear rate on different specimens. The average values of wear rate of each sample have been compared for obtaining the perfect composition of Molybdenum disulphide and Titanium dioxide nano particles in the Polyurethane Matrix Hybrid Composites having minimum wear rate.

Using ANSYS software, the Finite Element Analysis has to be done on each sample. For Finite Element Analysis, a model has designed for all the six samples with and without Titanium dioxide nano particles in Polyurethane matrix hybrid composites by selecting the appropriate element. The Properties of the composites has been calculated by using the Rule of Mixtures and then entered for analyzing, according to the required sample. The Boundary condition has been applied according to wear test. The load has been applied on the specific nodes by knowing the type of test to be conducted on the model. Obtain the output as stress and strain images having maximum and minimum values of the plotted result.

2. Experimental Results

2.1 Wear Rate for PU / MoS_2 Composites

Wear was erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface. Wear rate was strongly influenced by the operating conditions. Specifically, normal loads and sliding speeds played a pivotal role in determining wear rate. According to ASTM D 2240 standard, the specimen's dimensions were 60x 60x 6 mm. The rate of wear for different specimens of each samples 1, 2 & 3 were calculated and tabulated in Table 1. Wear rate increased with the increase in the particles of molybdenum disulphide in the polyurethane matrix. Thus, sample 3 having 20 % molybdenum disulphide particles in polyurethane matrix had more wear rate than the other sample 1 and 2 having 7% and 10% molybdenum disulphide particles respectively.

The average values of the wear rate of different specimens of each sample 1, 2 & 3 were calculated and shown in Table 1. Wear rate increased due to the increase in percentage of molybdenum disulphide in the polymer composites. Wear for the sample of 20% molybdenum disulphide had more wear than the other samples 1 & 2.

Table 1. Rate of Wear for Samples 1, 2 & 3

S.No	Sample 1	Sample 2	Sample 3
1	2.0258	2.1755	2.4756
2	2.0926	2.2586	2.5882
3	2.1748	2.4368	2.7293
4	2.2172	2.5123	2.7981
Average	2.1276	2.3458	2.6478

The wear rate of all the samples and their four different specimens values were graphically presented in the Fig.1. The figure was having wear rate in the abscissa and number of samples in the ordinate. From the graphical presentation of samples having the wear rate, it was observed that the sample 3 had higher wear rate than the other samples 1 & 2 of 7% and 10% molybdenum disulphide respectively in the polyurethane matrix composites.

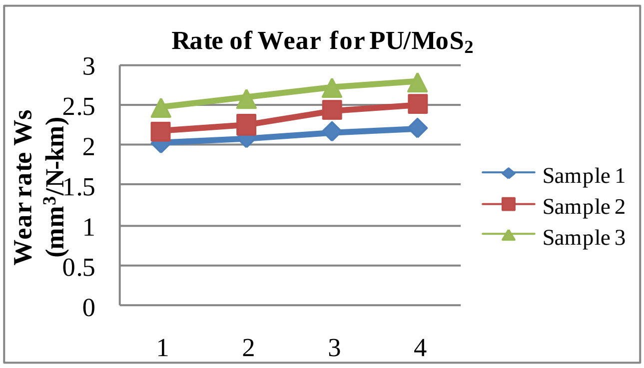

Figure 1. Rate of Wear for Samples 1, 2 & 3.

2.2 Wear Rate for PU Matrix Hybrid Composites

Each sample having different specimens were tested in Pin on Disk test to observe the wear volume based on its load and velocity. From the observed values, it was possible to calculate the wear rate on each sample. The calculated wear rate of different specimen on each sample 4, 5 and 6 were tabulated in Table 2. In Table 2, sample 4 having 7% molybdenum disulphide and 0.5% titanium dioxide had the lowest wear rate,whereas, the sample 5 had higher wear rate than the sample 4 and lower wear rate than the sample 6. Thus, wear rate also increased as the percentage of composition of molybdenum disulphide and titanium dioxide particles increased in the polyurethane matrix.

Table 2. Rate of Wear for Samples 4, 5 & 6

S.No	Sample 4	Sample 5	Sample 6
1	1.0794	1.7987	1.9823
2	1.0845	1.7863	1.9785
3	1.0899	1.7832	1.9941
4	1.1042	1.7906	2.0231
Average	1.0895	1.7897	1.9945

Wear rate calculated on different specimens on each sample were plotted in the graphical representation as shown in Fig. 2, having number of samples in abscissasand wear rate in ordinates. From the graph as shown in Fig.2, it was observed that composition percentage of molybdenum disulphide and titanium dioxide particles were increased with simultaneous increase in wear rate. Hence, sample 6 having 20% molybdenum disulphide and 1.5 % titanium dioxide particles in the polyurethane matrix had higher wear rate than the other sample 4 and having lesser percentage of particles in the polyurethane matrix.

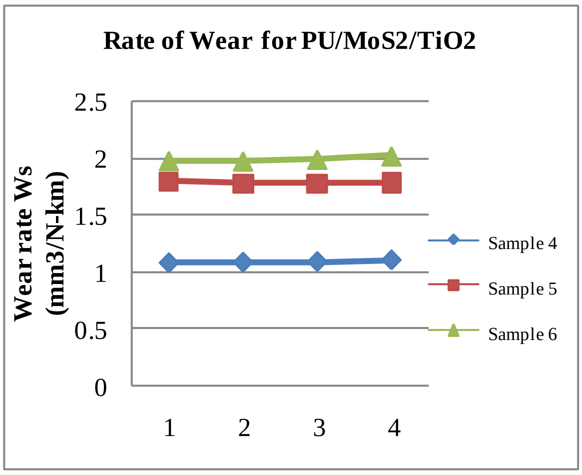

Figure 2. Rate of wear for Samples 4, 5 & 6

3. Modeling and FEA Results

3.1 Wear rate for PU / MoS_2 Composites

In Finite element analysis, the wear rate for different samples was calculated by using ANSYS software. In ANSYS, selected solid 8node 185 as the element type and entered the value of their material properties, which were calculated by using the rule of mixture. A model of specified specimen size that had been used on Pin on disk test was designed and then applied the mesh, by selecting the degrees of freedom. The load was applied on the specified nodes and the solution was plotted. From the nodal solution, the maximum stress and maximum strain on each sample were observed and applied using the formula as given below andthen calculated the rate of wear using the formula as;

Wear Rate, $K = (e \times h) / (\sigma \times L)$

Where,

e- Maximum strain

h- Height of the sample,

σ- Maximum stress on each sample,

L- Sliding Distance.

Fig. 3 showed the modeling of 50mm diameter disk and a pin 0f 4.76mm slides around the disk with a force on it. The maximum stress induced on the contact surface of pin on disk for the sample 1 was observed as 26.134 MPa. The maximum strain identified from the Fig.4 for the sample 1 was 0.000925. By applying the values in the above formula, the wear rate was calculated for the sample 1 as 1.606 mm^3/ N-Km.

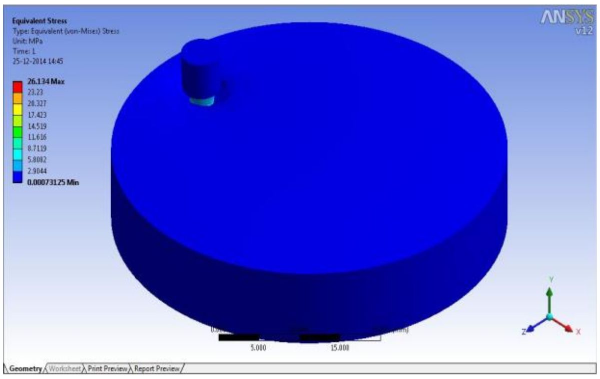

Figure 3. Wear Stress of PU / MoS_2 (93/7)

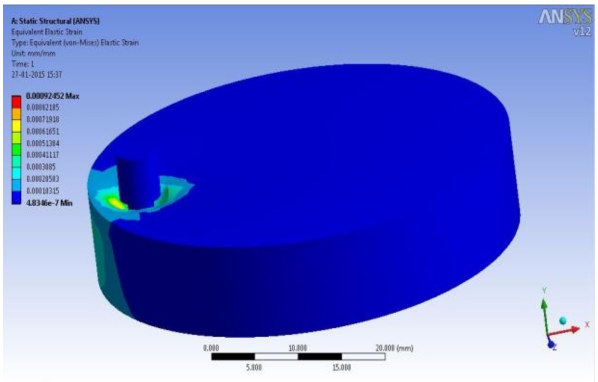

Figure 4. Wear Strain of PU / MoS_2 (93/7)

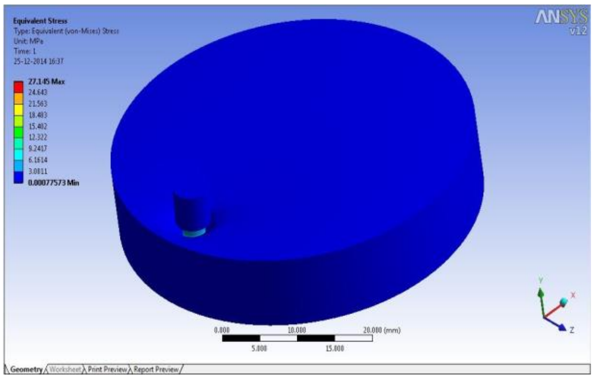

Figure 5. Wear Stress of PU / MoS_2 (90/10)

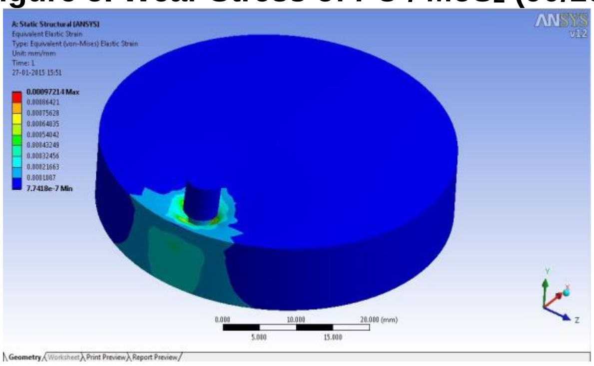

Figure 6. Wear Strain of PU / MoS_2 (90/10)

For the sample 2, the maximum stress values from the plotted solution as shown in Fig. 5 was observed as 27.145 MPa and the maximum strain value was taken as 0.000972 from Fig. 6. Applying the values of maximum stress and strain in the given formula K = (e x h) / (σ x L), height of the sample was taken from the geometry of modeling and its sliding distance L. Then the wear rate for the sample was calculated as 1.6250 mm^3/N-Km.

The maximum stress values from the plotted solution for the sample 3 as shown in Fig. 7 was observed as 32.534 MPa and the maximum strain value for the same sample was taken as 0.001417 from Fig.8. Applying the values of maximum stress and strain in the given formula K = (e x h) / (σ x L), height of the sample was taken from the geometry of modeling and its sliding distance L then the wear rate for the sample was calculated as 1.9765mm^3/N-Km.

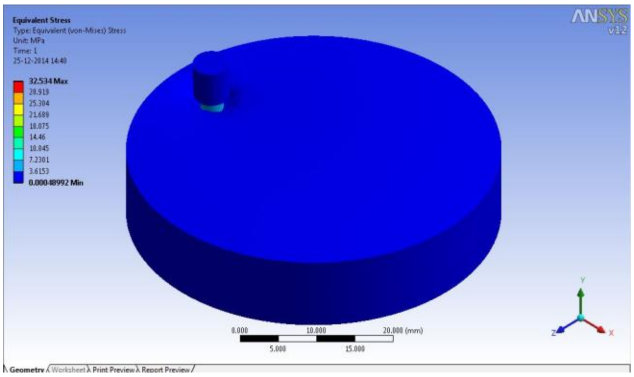

Figure 7. Wear Stress of PU / MoS_2 (80/20)

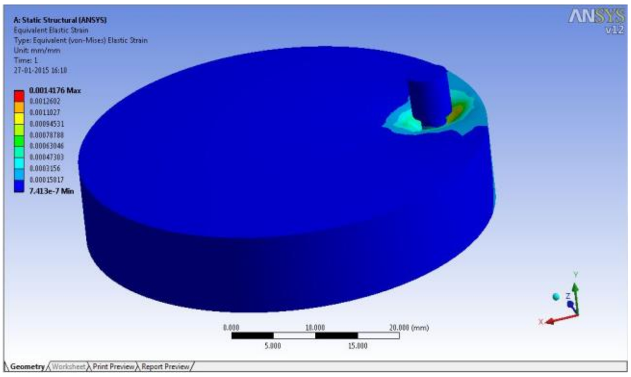

Figure 8. Wear Strain of PU / MoS_2 (80/20)

Table 3. Wear Rate Analysis of Samples 1, 2 & 3

Properties	Sample 1	Sample 2	Sample 3
Maximum Stress	26.134	27.145	32.534
Maximum Strain	0.000925	0.000972	0.001417
Calculated Wear Rate in mm3/N-Km	1.6062	1.6250	1.9765

The wear rate of sample 1, 2 and 3 were calculated from their maximum stress and strain values, which was observed from FEA solution using ANSYS Software. The calculated wear rate was tabulated as shown in Table3. From the Table3, it was understood that the rate of wear was increasing with the increase in the additive particles such as molybdenum disulphide particle in the polyurethane matrix. The wear rate was higher for the sample 3 having 20% molybdenum disulphide in polyurethane matrix than other samples 1 and 2. Whereas, the sample 2 had more wear rate than the sample 1due to the addition of molybdenum disulphide alone and then further addition of molybdenum disulphide with polyurethane matrix increased the rate of wear.

3.2 Wear Rate for PU Matrix Hybrid Composites

Fig. 9 showed the modeling of 50mm diameter disk and a pin of 4.76mm slides around the disk with a force on it. The maximum stress induced on the contact surface of pin on disk for the sample 4 having 7% molybdenum disulphide and 0.5% titanium dioxide with polyurethane matrix was observed as 36.172 MPa. The maximum strain identified from the Fig.10 for the sample 4 was 0.00061635. By applying the values in the above formula, the wear rate was calculated for the sample 4 as 2.2690 mm^3/ N-Km.

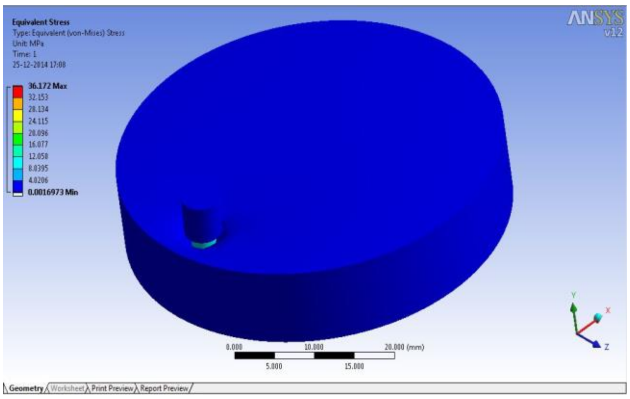

Figure 9. Wear Stress of PU/MoS_2/TiO_2 (92.5/7/0.5)

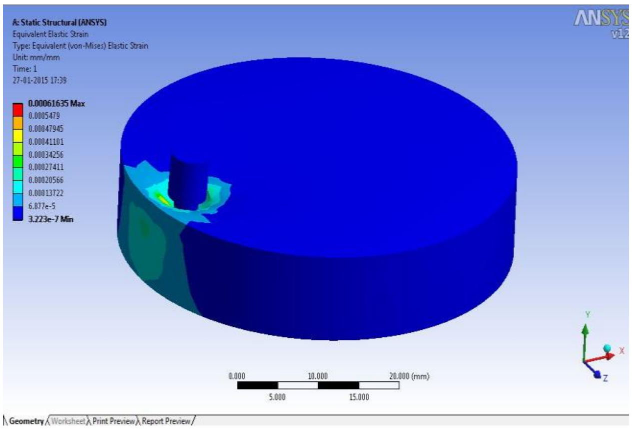

Figure 10. Wear Strain of $PU/MoS_2/TiO_2$ (92.5/7/0.5)

For the sample 5, the maximum stress values from the plotted solution as shown in Fig. 11 was observed as 28.937 MPa and the maximum strain value was taken as 0.000847 from Fig.12. Applying the values of maximum stress and strain in the given formula K = (e x h) / (σ x L), height of the sample was taken from the geometry of modeling and its sliding distance L. Then the wear rate for the sample 5 was calculated as 1.3283 mm3/ N-Km.

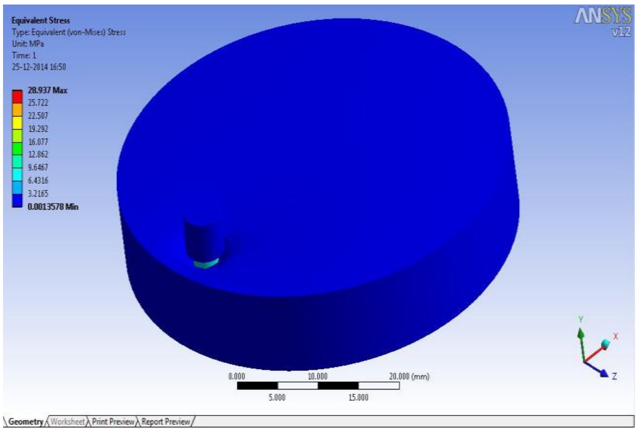

Figure 11. Wear Stress of $PU/MoS_2/TiO_2$ (89/10/1)

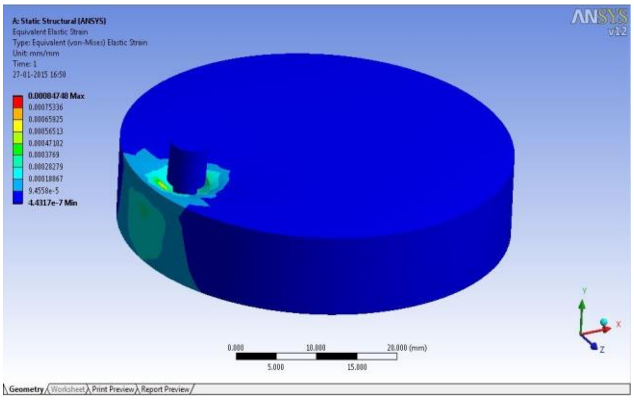

Figure 12. Wear Strain of PU/MoS_2/TiO_2 (89/10/1)

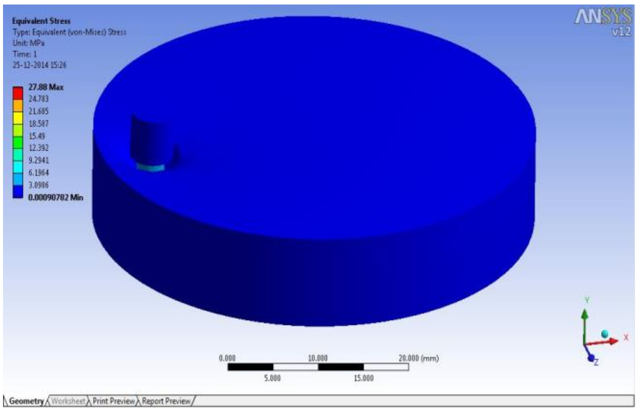

Figure 13. Wear Stress of PU/MoS_2/TiO_2 (78.5/20/1.5)

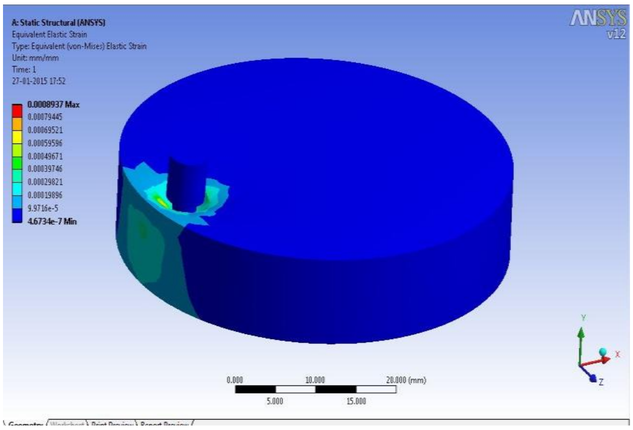

Figure 14. Wear Strain of PU/MoS_2/TiO_2 (78.5/20/1.5)

The maximum stress values from the plotted solution for the sample 6 having 20% Molybdenum disulphide and 1.5% Titanium dioxide with Polyurethane matrix as shown in Fig.13 was observed as 27.880 MPa and the maximum strain value for the same sample was taken as 0.000893 from Fig.14. Applying the values of maximum stress and strain in the given formula K = (e x h) / (σ x L), height of the sample was taken from the geometry of modeling and its sliding distance L then the wear rate for the sample 6 was calculated as 1.4536 mm^3/ N-Km.

Table 4. Wear Rate Analysis of Samples 4, 5 & 6

Properties	Sample 4	Sample 5	Sample 6
Maximum Stress	36.172	28.937	27.880
Maximum Strain	0.000616	0.000847	0.000893
Calculated Wear Rate in mm3/N-Km	2.269	1.328	1.453

The wear rate of sample 4, 5 and 6 were calculated from their maximum stress and strain values, which were observed from finite element analysis solution using ANSYS software. The calculated wear rate was tabulated as shown in Table 4. From the Table 4, it was understood that the rate of wear increased with the increase in the additive particles such as molybdenum disulphide and titanium dioxide particles in the polyurethane matrix. The wear rate was higher for the sample 4 having 7% molybdenum disulphide and 0.5% titanium dioxide in polyurethane matrix than other samples 5 and 6, whereas, the sample 5 had lesser wear rate than the sample 6 due to 10% of molybdenum disulphide and 1% titanium dioxide in the polyurethane matrix and then further addition of molybdenum disulphide and titanium dioxide particles with polyurethane matrix increased the rate of wear.

4. Conclusion

The wear rate of each sample was done experimentally by pin on disk test and their values were tabulated in Table 5. From the experimental values, it was observed that wear rate was higher for the first three samples and lesser for other three samples. The samples had a higher wear rate due to the addition of molybdenum disulphide particles in the polyurethane matrix. Whereas,the wear rate decreased by the addition of titanium dioxide nano particles with molybdenum disulphide in the polyurethane matrix and a further addition of the particles in the matrix increased the wear rate.

Table 5. Correlations of Wear Properties

S.No	Experimental Values in mm^3/ N-Km	FEA Analysis in mm^3/ N-Km
Sample 1	2.1276	1.6062
Sample 2	2.3458	1.6250
Sample 3	2.6478	1.9765
Sample 4	1.0895	0.7635
Sample 5	1.7897	1.3283
Sample 6	1.9945	1.4536

In FEA, the wear rate of each sample was calculated by using pin on disk setup. By the addition of molybdenum disulphide in the polyurethane matrix increased the wear rate of the first three samples and then by adding titanium dioxide nanoparticles with molybdenum disulphide in the polyurethane matrix, the wear rate decreased. Thus, wear rate was optimum for the sample 5 having 10% molybdenum disulphide and 1% titanium dioxide.

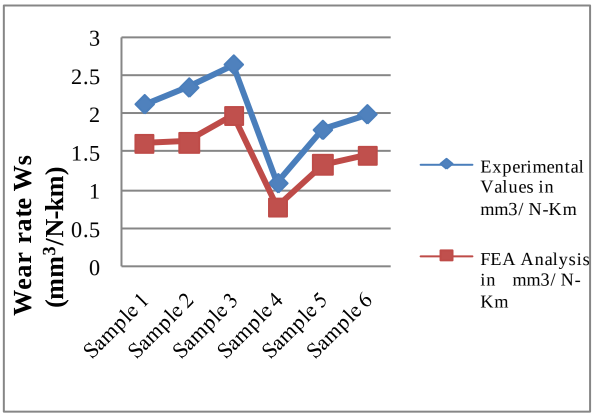

Figure 15. Correlations of Wear Properties

The graphical representation of wear rate in both experiments and FEA was shown in Fig.15. In this figure, X-axis represented the sample number and the Y-axis represented the wear rate in mm^3/N-Km. The experimental values of wear rate showedthe gradual increase in wear rate with the increase of molybdenum disulphide. The wear rate was lower than the first three samples by the addition of titanium dioxide nano particles with molybdenum disulphide in the polyurethane matrix. The further addition of titanium dioxide particles increased the wear rate, whereas, on FEA, the sample 5 having 10% molybdenum disulphide and 1% titanium dioxide had minimum wear rate than the other samples.

References

[1] *Bhimaraj, P, Burris, DL, Action, J, Sawyer, WG, Toney, CG, Siegel, RW & Schadler, LS 2005, 'Effect of matrix morphology on the wear and friction behavior of alumina nanoparticle/poly(ethylene) terephthalate composites',Wear, vol. 258, pp. 1437–1443.*

[2] *Bhimaraj, P, Burris, DL, Action, J, Sawyer, WG, Toney, CG, Siegel, RW & Schadler, LS 2005, 'Effect of matrix morphology on the wear and friction behavior of alumina nanoparticle/poly(ethylene) terephthalate composites',Wear, vol. 258, pp. 1437–1443.*

[3] *Guofang, G, Huayong, Y & Xin, F. 2004, 'Tribological Properties of Kaolin Filled UHMWPE Composites in Unlubricated Sliding', Wear, vol. 256, pp. 88-94.*

[4] *Nuruzzaman, DM & Chowdhury, MA 2012, Friction and Wear of Polymer and Composites, INTECH Open Access Publisher.*

[5] *Pettarin, V, Churruca, MJ, Felhos, D, Karger-Kocsis, J & Frontini, PM 2010, 'Changes in tribological performance of high molecular weight high density polyethylene induced by the addition of molybdenum disulphide particles', Wear, vol. 269, no. 1-2, pp. 31–45.*

[6] *Song, HJ, Zhang, ZZ, Men, XH & Luo, ZZ 2010, 'A study of the tribological behavior of nano-ZnO-filled polyurethane composite coatings', Wear, vol. 269, pp. 79–85.*

[7] *Sudheer, M, Madhyastha, NK, Amanna, MK, Jonthan, B & Jayaprakash, KM 2013, 'Mechanical and abrasive wear behavior of metal sulphide lubricant filled epoxy composites', ISRN Polymer Science.*

[8] *Suresh, B, Chandramohan, G, Samapthkumaran, P & Seetharamu, S 2007, 'Investigation of the friction and wear behavior of glass-epoxy composite with and without graphite filler', Journalof Reinforced Plastics and Composites, vol. 26, no. 1, pp. 81–93.*

[9] *Luis carral, Jose angel fraguela and Jose de troya alvarez feal," Influence of the towline material: Steel or high modulus polyethylene on towing gear design & tug deck fittings", Sage journal, (2015), pp.57-69.*

[10] *Unal, H, Mimaroglu, A, Kadıoglu, U & Ekiz, H 2004, 'Sliding friction and wear behavior of polytetrafluoroethylene and its composites under dry conditions', Materials and Design, vol. 25, no.3, pp. 239–245.*

[11] *Elsevier B.V," Redesign & manufacturing of metal towing hook via laser additive manufacturing with powder bed", IJSRD - International Journal for Scientific Research & Development, (2017), pp.851-862.*

[12] *Ahmed Ibrahim Razooqi, Hani Aziz Ameen and Kadhim Mijbel Mashloosh, "Compression and impact characterization of helical and slotted cylinder*

springs", IJSRD - International Journal for Scientific Research & Development, *(2016), pp.155-167.*

[13] *Anbazhagan, R & Rajamani, GP 2014, 'Modeling and Analysis of Impact Properties on Polyurethane Composites using FEA',* International Journal of Chem Tech Research, *vol. 6, no.1, pp. 114-123.*

[14] *Anbazhagan, R & Rajamani, GP 2014, 'Fabrication, Modeling and Impact Analysis of Polyurethane matrix composites'* International Journal of Applied Engineering Research, *vol. 9, no.22, pp.16837-16848.*

[15] *Juan Wanga,b and ShuLiua,"* Dynamics shakedown analysis of slab track sub *structures with reference to critical speed", IJSRD* - International Journal for Scientific Research & Development, *(2018), pp.420-432 .*

[16] *Amir M. Kayniaa and Joonsang Parka," Effect of track defects on vibration from high speed train", IJSRD* - International Journal for Scientific Research & Development, *(2017), pp.163-173.*

[17] *G Prithviraj and Ganesha B,"* Assessment of train speed impact on the *mechanical behavior of tool materials", IJSRD* - International Journal for Scientific Research & Development, *(2016), pp. 154-165.*

[18] *David A. Ehrhardt and Thomas L. Hill (2018)",* Veering and nonlinear *interactions of a tow hook in bending and torsion", IJSRD*-International Journal for Scientific Research & Development, *pages 45-55.*

[19] *R.Anbazhagan, G.P.Rajamani, K.Arumugam, V.Sathiyamoorthy, R. Suresh (2017), "A Critical Review on Polyurethane Polymer Hybrid Nano Composites",* Journal of Advances in Chemistry, *Vol.13, Issue-6, pp.6236-6242.*