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An Investigation In to Sliding Wear Behaviour of Polyoxymethylene on Surface Textured Counter Face

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Abstract: Polymer and polymer composites have been increasingly used in various industrial applications such as aerospace automotive and chemical industries. This material provides high strength/weight ratio. In this work attention is given to investigate the effect of surface texturing on tribological properties of polymer composite material considering various conditions so as to observe the comparative friction and wear behavior of polymer composite with surface texturing on mating surface under varying surface texture density, surface texture depth, material and lubrication by using a pin on disc type wear tester at NTP. Experimental work is carried out by loads of 183.21 N at sliding velocity 0.12 m/s keeping this parameter constant. The test is carried out for material polyoxymethylene and its composite containing like glass fiber in dry and wet condition. In this work AISI 304 stainless steel two discs are used. One disc has plane surface on one side and other side having surface texturing and other disc has surface textured pattern on both sides. This test is carried out at ambient condition using a pin on disc Tribometer (TR-20LE).The result is tabulated and graphs are plotted for each material testing. From these graphs the effect of dimple depth and density at dry and wet sliding condition on coefficient of friction and specific wear rate of the material is studied. So for dry condition the coefficient of friction and wear of the material is higher than wet condition. Reduction is seen in wear rate and coefficient of friction for wet condition. As Dimple depth increase there is decrease in C.O.F and wear and Specific wear rate increases at dry sliding condition. The lowest coefficient of friction and wear obtained for POM + 30% G.F. from the 30% surface texturing density and Dimple depth is 50 micron at wet condition. SEM image shows that the wear of Polyoxymethylene + 30% G.F. surface is low as compared with other composite surface in wet lubricating conditions.

Keywords: Composite material, Tribometer, Dimple depth, Dimple density, SEM analysis.

I. INTRODUCTION

Tribology in a traditional form has been in existence since the beginning of recorded history. There are many well documented examples of how early civilizations developed bearings and low friction surfaces. The scientific study of tribology also has a long history, and many of the basic laws of friction, such as the proportionality between normal force and limiting friction force, are thought to have been developed by Leonardo da Vinci in the late 15th century. The oil, instead of being drained away by the hole, was now able to generate a hydrodynamic film and much lower friction resulted. The work of Reynolds initiated countless other research efforts aimed at improving the interaction between two contacting surfaces, and the efforts continue to this day. As a result, journal bearings are now designed to high levels of sophistication. Wear and the fundamentals of friction are far more complex problems, the experimental investigation of which is dependent on advanced instrumentation such as scanning electron microscopy and atomic force microscopy. This dissertation is set in this field and is oriented to give contribute to the development of strategies and methods for the improvement of tribological properties of Polyoxymethylene Composites.

Thus polyoxymethylene Composites suitable for Journal bearing of mills in the sugarcane industrial application was chosen as substrates. The guideline of the experimental works follows the different surface texturing patterns on Surface of AISI SS 304 Disc with varying Dimple depth & dimple density. Further the study of optimum combination of depth & density of dimples is studied for the varying aspect ratio to give a specific solution to the problem under study. Surface texturing is also known to have counter work due to the hydrodynamic disturbance of lubricant during sliding motions, resulting in an increased coefficient of friction. Therefore, it can be said that the surface texturing density and the shape of a hole based on the aspect ratio play a key role in surface texturing for low-friction materials. Surface texturing that has a concave shape has been widely studied because the role of surface texturing has been focused on the retention capability of a lubricant. However, surface texturing with a convex shape can be made and used in many areas; for example, surface texturing that has hemispherical pillars.

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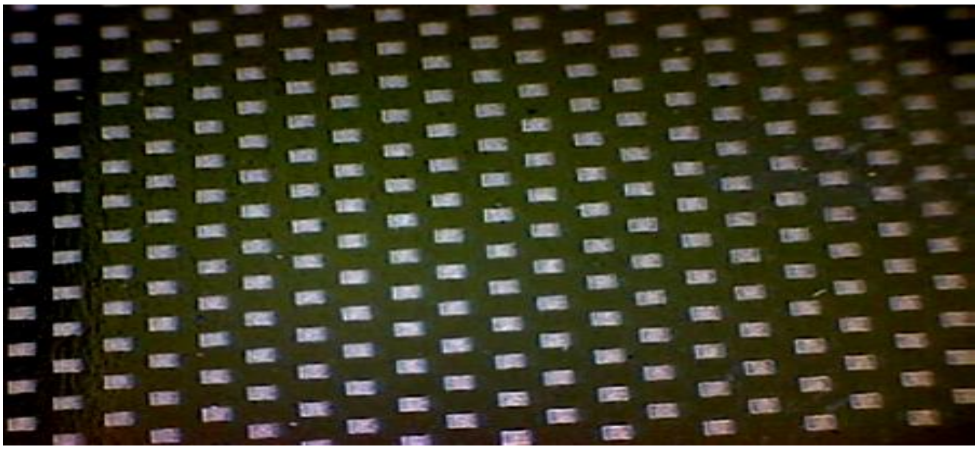

Fig.1. Surface Textured With Flat Cavities by Laser Ablation [26]

II. PROBLEM DEFINITION AND OBJECTIVES OF THE PROJECT

It is reported from one of the best sugar industry, "SahakarmaharshiBhausahebThoratSahakariSakharKarkhana Ltd., Amrutnagar, Sangamner, Maharashtra", having crushing capacity of 5000 tons per day, that in milling section number of mills are there to extract juice from sugar cane by passing and compressing fiberized sugar cane through slowly rotating (4.5 rpm to 6 rpm) heavy metal mills and These mills are supported on gunmetal or brass journal bearings. The lubrication used for these bearings is hydrostatic lubrication. The thick oil used for this hydrostatic lubrication is IPOL-3 mineral oil under oil pressures ranging from 775 psi to 900 psi. Sometimes the lubricating oil may get mixed with sugar cane juice due to leakage and may change the juice properties slightly. Juice which contains bagasse particles may enters in the bearing when the top roll moves up & down during milling, degrading the lubricant properties. The life of a bottom roller bearing is one to five seasons longer than that of top roller bearings.

A.Objectives of the Project

1) To investigate the effect of surface texturing on tribological properties.
2) To find out behavior of the material from wear and friction point of view and the effect of sliding speed and load at surface textured pattern with varying dimple density as well as depth.
3) To develop relationship between the coefficient of friction, wear, Specific wear rate by mathematical modeling by using regression analysis.
4) To suggest suitable material for sugarcane journal bearing from tested materials.

III. EXPERIMENTATION

A. Design of Experiment

Number of Experiments to be performed is decided with the help of Taguchi Method & Design experts 9 software. The factors load, velocity & dimensions of the pin are taken constant throughout the experimentation and the lubrication, material, density of dimples, dimple depth are varied at different levels.

TABLE I: LEVEL OF EXPERIMENTAL PARAMETERS

Factor Name	Type	L	1	2	3	4
Dimple Depth	Discrete	3	50 µ	100 µ	150 µ	
Dimple Density	Discrete	3	10 %	20 %	30 %	
Material	Nominal	4	Pure POM	POM+10%G.F.	POM+20%G.F.	POM+30%G.F.
Lubrication	Nominal	2	Dry	Wet		

According to above input to the Design expert software for optimum number of experiments it gives the 13 runs for various combinations of the different levels of the four factors as follows:

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TABLE II: COMBINATION OF PARAMETERS AT DIFFERENT LEVELS

Run	Dimple Depth (Micron)	Dimple Density (%)	Material	Lubrication (Condition)
1	150	10	POM	wet
2	50	30	POM +30% G.F.	dry
3	50	20	POM	dry
4	100	20	POM	wet
5	150	30	POM	wet
6	50	30	POM +30% G.F.	wet
7	150	30	POM +10% G.F.	wet
8	50	20	POM +20% G.F.	dry
9	100	20	POM +20% G.F.	dry
10	150	10	POM +10% G.F.	dry
11	100	10	POM +10% G.F.	wet
12	100	30	POM	dry
13	150	20	POM	dry

B. Preparation of Specimen

Stainless steel 304 disc of diameter 165 mm x thickness 8 mm prepared on lathe machine by turning and facing operation. Stainless steel disc having composition C - 0.032%, Si - 0.446%, Mn – 1.463%, P - 0.012%, S - 0.009%, Cr - 18.63, Ni - 8.26%. Then by using grinding machine plane surface prepared. The disc of material AISI stainless steel 304 plates is finished by Richfield automation Industries, MIDC Satpur, Nashik. The surface roughness Ra for counter surface i.e. for disc is measured on the Shanmukha material testing laboratory Nashik. Surface texturing of square shape pattern dimples made from R.R. Laser engravers Satpur MIDC Nashik. On disc surface Square texture patterns done by using laser surface texturing. [2] After that on disc surface decided 3 different dimple density tracks from center of disc of square shape laser texture dimple. Dimple size is 450 x 450 µm. [32] Track having 10 to 30 mm diameter in that selected density 10 %. Similarly in remaining two tracks having 33 mm to 53 mm has density 20 % and 56 mm to 76 mm has density 30 % is as shown in figure 1. The calculation of number of dimple in 10% dimple density area is as follows. [26]

C. Preparation of Tracks on Stainless Steel Disc.

TABLE III: GEOMETRICAL PARAMETER OF SQUARE DIMPLE

Sr. No.	Dimple Length (mm)		Area of dimple (mm^2)	Dimple depth (micron)		
	Along X axis	Along Y axis				
1.	0.450	0.450	0.2025	50	100	150

TABLE IV: TEXTURING TRACKS ON SS DISC AT 10% DIMPLE DENSITY

Diameter	Perimeter	No of Dimple
10	31.4	35
12.5	39.25	44
15	47.1	52
17.5	54.95	61
20	62.8	70
22.5	70.65	79
25	78.5	87
27.5	86.35	96
30	94.2	105
Number of Dimple =		629

This dimple of square shape arranged in well manner in particular area. Two discs selected for configurations. Square shape dimple depth should be vary for experimentation i.e. 50 micron and 100 micron on one disc to both surface of disc and 150 micron on the other disc in only one surface and other surface is non textured. Lubricant used in sugar mill is I Pol -3 for wet lubrication condition.

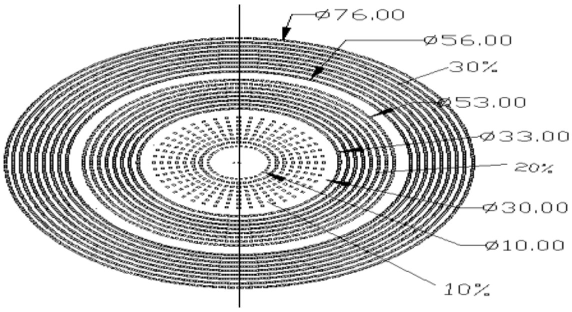

Fig.2. Drawing of Disc Specimen.

D. Experimental set up

Fig.3. Photograph of Experimental Set up Of Pin-On-Disc Tribometer

E. Material and Test Conditions

TABLE V: RUNNING PARAMETERS SELECTED FOR EXPERIMENTAL ANALYSIS

Sr. No.	Load (N)	Sliding velocity (m/s)	Test Duration (minute)
1.	183.21	0.12	60

1. Temperature:In this experimental work no such facilities were available for the test rig. So the readings are taken at the room temperature.
2. Contact Area:Contact area between the pin and disc is 113.04 mm². (Pin dia. is 12 mm.)
3. Sliding Time:Sliding time is kept 60 minutes for all mating surfaces.
4. Surface finish:Surface finish of the AISI SS 304 stainless steel disc is measured by surface tester. The disc of material AISI SS 304 stainless steel plate is finished by Richfield automation Industries, MIDC, Satpur, Nashik. While during experimentation wearing surface of the test pins are polished with the help of 2000 grit fine silicon carbide abrasive paper so as to obtain high surface finish.

F. Experimentation

Experimental data of slide wear and coefficient of friction of polyoxymethylene and its composite test pin against the tracks of densities 10%, 20%, 30% & size of dimples depth on the tracks of one side is 50 micron other side 100 micron and on next disc 150 micron of surface texturing pattern made on the AISI SS 304 stainless steel disc with time. Sliding velocity of 0.12 m/s and normal load of 183.21 N under dry & wet lubricating condition using a pin-on-disc Tribometer (TR-20LE) at NTP.

Using these tables, for each track of surface texturing pattern, graphs of variation of wear in micrometre with time and variation of coefficient of friction with time are plotted. For run 1 to 7 dry sliding tests carried out and in that 7 testing for dry condition and 6 Wet sliding test condition, all the reading is taken as follows.

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5. 1. Dry Sliding Condition:

TABLE VI: SUMMARY OF DRY SLIDING CONDITION TEST AT TIME 60 MINUTE.

Sr. No.	Run	Frictional Force (N)	C. O. F.	Wear (Micron)	Specific Wear rate (mm^3/N-m) x 10^{-5}
1	2	23.1	0.1254	5	0.71443
2	3	31.7	0.1722	5	0.71443
3	8	5.9	0.032	7	1.00021
4	9	20.6	0.1119	6	0.85731
5	10	10.9	0.0592	7	1.00021
6	12	32.6	0.177	5	0.71443
7	13	10.4	0.0565	5	0.71443

5. 2. Wet Sliding Condition:

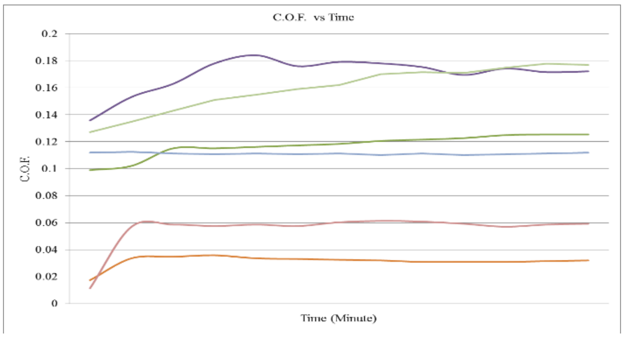
TABLE VII: SUMMARY OF WET SLIDING CONDITION TEST AT TIME 60 MINUTE.

Sr. No.	Run	Frictional Force (N)	C. O. F.	Wear (Micron)	Specific Wear rate (mm^3/N-m) x 10^{-6}
1	1	0.8	0.058	4	5.7154
2	4	16.1	0.0874	3	4.2866
3	5	1.9	0.1189	3	4.2866
4	6	5.8	0.0315	2	2.8577
5	7	6.3	0.0342	3	4.2866
6	11	6.1	0.0331	3	4.2866

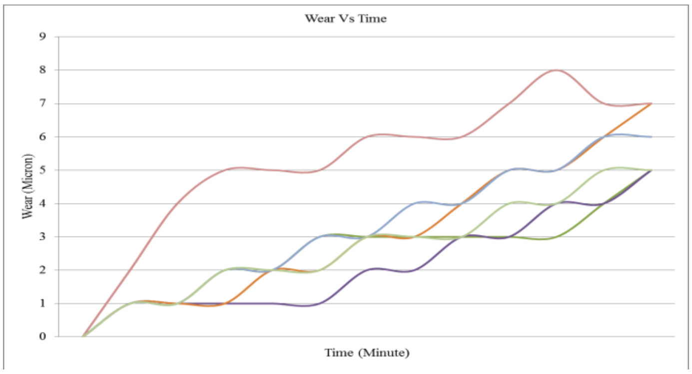
IV. RESULTS & DISCUSSION

Sliding tests in dry conditions using textured samples were first performed to investigate the effect of lubricant on friction. Results show that the wear and coefficient of friction of POM and composite material in addition with glass fiber with lubrication condition decreased. Then variation of friction as a function of texturing density was investigated, and the typical friction plots. In most cases, the coefficient of friction and wear slightly increased during the early stage, and soon it became stable.

A. Dry Sliding Condition



Graph.1.Coefficient of Friction (μ) Vs Sliding Time (Minute).



Graph.2.Wear (Micron) Vs Sliding Time (Minute)

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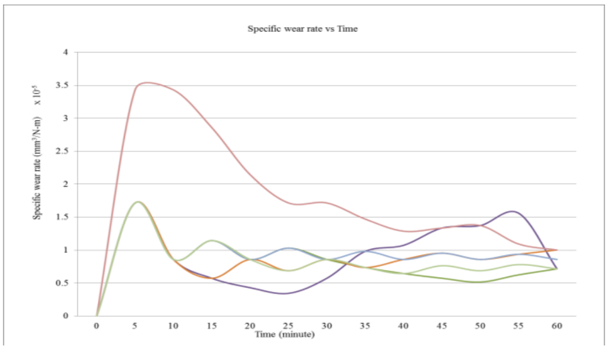
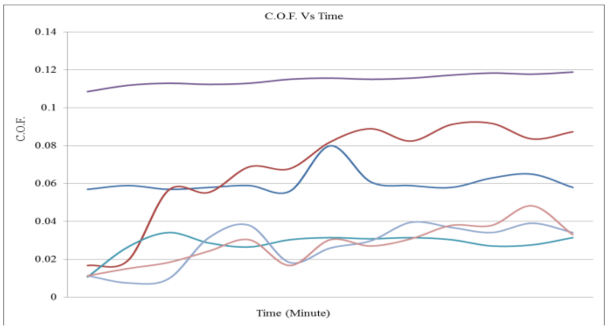


Graph.3.Specific Wear rate Vs Time

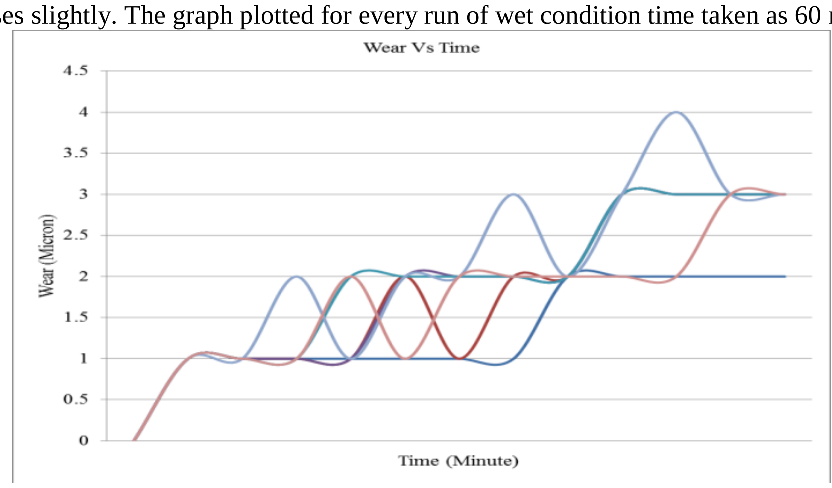
Graph 1, Shows that graph plotted coefficient of friction (μ) Vs Time. For every run of dry condition coefficient of friction increases at initial stage and later on it becomes stable. Increase fast at initial stage and later on stable and decreases slightly. For remaining run graph increase fast at initial stage and later on stable and increases slightly. The graph plotted for every run of dry condition time taken as 60 minute. It means that coefficient of friction increase with respect to time. Graph 2, Shows that graph plotted Wear (μ) Vs Time. For every run of dry condition wear increases at initial stage and later on it becomes stable. It increases at a fast rate at initial stage and later on stable and decreases slightly. For remaining run graph increase fast at initial stage and later on stable and increases slightly. The graph plotted for every run time taken as 60 minute. It means that wear increases with respect to time. Graph 3, Shows that graph plotted Specific Wear rate (μ) Vs Time. For every run of dry condition Specific wear rate increases at initial stage and later on it becomes decrease and then stable.

B. Wet Sliding Condition



Graph.4.Coefficient of Friction (μ) Vs Sliding Time (Minute).

Graph 4, Shows that graph plotted coefficient of friction (μ) Vs Time (min). For every run of wet condition, coefficient of friction increases at initial stage and later on it becomes stable. Coefficient of friction increases fast at initial stage and later on stable and decreases slightly. For remaining run graph, it increase fast at initial stage and later on stable and increases slightly. The graph plotted for every run of wet condition time taken as 60 minute.



Graph.5.Wear (Micron) Vs Sliding Time (Minute)

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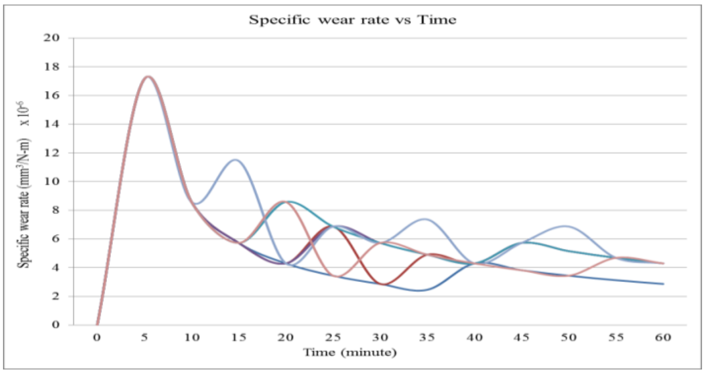

Graph.6.Specific Wear rate Vs Time

Graph 5, Shows that graph plotted Wear (µ) Vs Time. For every run of wet condition wear increases with respect to time increases. Wear increase fast at initial stage and later on stable and then decrease. For remaining run graph, it increases fast at initial stage and later on stable and increases slightly. The graph plotted for every run of Wet condition time taken as 60 minute. Graph 6, Shows that graph plotted Specific Wear rate (µ) Vs Time. For every run of wet condition Specific wear rate increases at initial stage and later on it becomes decrease and then stable.

C. Design Expert Software Analysis

In experimental work select four factors Dimple depth, Dimple density, material and Lubrication at different levels. Two factors Dimple depth and dimple density has three level, and for material seven level, as well as for lubrication two levels selected. By using design expert software we get 13 runs. After experimentation we put the value of C.O.F. wear and Specific wear rate and then perform ANOVA and optimization. ANOVA of C.O.F. Wear as well as Specific Wear Rate calculated and various parameters were calculated by using regression analysis by Design expert 9 Software. In software plotted various graphs and analysis of variance done so S/N ratio of that parameter calculated and according to that the conclusion was recommended.

TABLE VIII: NO. OF COMBINATIONS FROM TAGUCHI METHOD ORTHOGONAL ARRAY & THEIR RESULTS

R	Dim. Dep. (micron)	Di. Den. (%)	Material	Lub.	C. O. F.	W (micron)	SWR (mm^3/N-m) x 10^{-5}
1	150	10	POM	wet	0.05	4	0.571
2	50	30	POM +30% G.F.	dry	0.117	5	0.7144
3	50	20	POM	dry	0.170	5	0.7144
4	100	20	POM	wet	0.06	3	0.428
5	150	30	POM	wet	0.11	3	0.428
6	50	30	POM +30% G.F.	wet	0.031	2	0.2857
7	150	30	POM +10% G.F.	wet	0.027	3	0.4286
8	50	20	POM +20% G.F.	dry	0.031	7	1.0002
9	100	20	POM +20% G.F.	dry	0.110	6	0.8573
10	150	10	POM +10% G.F.	dry	0.055	7	1.0002
11	100	10	POM +10% G.F.	wet	0.027	3	0.4286
12	100	30	POM	dry	0.15	5	0.714
13	150	20	POM	dry	0.04	5	0.714

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D. Confirmation Report

TABLE IX: TWO-SIDED CONFIDENCE = 95% N = 1

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Dimple depth	50.00	50.00	150.00	0.000	Actual
B	Dimple density	30.00	10.00	30.00	0.000	Actual
C	Material	POM+30%GF	POM	POM+30%G.F.	N/A	Actual
D	Lubrication	Wet	Dry	Wet	N/A	Actual

Response	Predicted Mean	Predicted 1Median	Std. Dev.	SE Pred.	95% PI low	95% PI high
C.O.F.	0.056145	0.056145	0.0424851	0.053	-0.062	0.17
Wear	2.02717	2.02717	0.754674	0.94	-0.072	4.13
S.W.R.	0.289598	0.289598	0.107823	0.13	-0.010	0.59

TABLE X: LOWER BOUNDCONFIDENCE = 95%N = 1

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Dimple depth	50.00	50.00	150.00	0.000	Actual
B	Dimple density	30.00	10.00	30.00	0.000	Actual
C	Material	POM+30%G.F.	POM	POM+30%G.F.	N/A	Actual
D	Lubrication	Wet	Dry	Wet	N/A	Actual

Response	Predicted Mean	Predicted [1]Median	Std. Dev.	SE Pred.	95% PI low
C.O.F.	0.056145	0.056145	0.04248	0.053	-0.04
Wear	2.02717	2.02717	0.75467	0.94	0.32
S.W.R.	0.2895	0.2895	0.1078	0.1	0.0

TABLE XI :UPPER BOUND CONFIDENCE = 95% N = 1

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Dimple depth	50.00	50.00	150.00	0.000	Actual
B	Dimple density	30.00	10.00	30.00	0.000	Actual
C	Material	POM+30%GF	POM	POM+30%GF	N/A	Actual
D	Lubrication	Wet	Dry	Wet	N/A	Actual

Response	Predicted Mean	Predicted [1]Median	Std. Dev.	SE Pred.	95% PI high
C.O.F.	0.05	0.0561	0.042	0.053	0.15
Wear	2.02	2.0271	0.754	0.94	3.73
S.W.R.	0.28	0.2895	0.107	0.13	0.53

After analysing the models the results are plotted in the form of graphs & tables. Mathematical modelling from the observations is done & afterwards with the help of graphs it is validated for predicted & actual values of response R1, R2 and R3 Due to negative COF & higher readings of Wear as well as specific wear rate in higher dimple density tracks they were not present in the optimized patterns. From Design expert software Report the optimized pattern observed is 30% dimple density, 50 μ dimple depth and material POM + 30% G.F.at Wet lubrication as it has the lower wear & COF compared with others. So, it is selected for the sugar mill bearing application.

V. CONCLUSION

1. The C.O.F, wear and Specific wear rate of the textured surface at wet lubrication condition is less than dry sliding condition.
2. Load carrying capacity of textured surface is increased in higher dimple depth & density (Run no. 4 & 6) due to that it shows less C.O.F at wet lubrication.
3. As Dimple depth increase there is decrease in C.O.F and wear and Specific wear rate increases at dry sliding condition.
4. The design expert software analysis shows that the Run no.6 (30% dimple density, 50 μ dimple depth & wet lubrication) as an optimized pattern for the mill bearing application.
5. Suitable material for sugarcane journal bearing from tested materials is POM + 30% G.F.
6. SEM images show that the wear of Polyoxymethylene + 30% Glass fiber surface is low as compared with other composite surface in wet lubricating conditions.

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REFERENCES

[1]. J.R. Gomes, O.M. Silva , C.M. Silva , L.C. Pardini , R.F. Silva "The effect of sliding speed and temperature on the tribologicalbehaviour of carbon - carbon composites" Wear 249 (2001) 240 - 245.
[2]. H. Benabdallah "Friction and wear of blended polyoxymethylene sliding against coated steel plates" Wear 254 (2003) 1239 - 1246.
[3]. S.E. Franklin, A. de Kraker "Investigation of counter face surface topography effects on the wear and transfer behaviour of a POM - 20% PTFE composite" Wear 255 (2003) 766 - 773.
[4]. H. Unal, A. Mimaroglu "Friction and wear behaviour of unfilled engineering thermoplastics" Materials and Design 24 (2003) 183 - 187.
[5]. H. Unal, U. Sen , A. Mimaroglu" Dry sliding wear characteristics of some industrial polymers against steel counter face" Tribology International 37 (2004) 727 - 732.
[6]. H. Unal, U. Sen, A. Mimaroglu "Abrasive wears behaviour of polymeric materials" Materials and Design 26 (2005) 705 - 710.
[7]. AndriyKovalchenko, OyelayoAjayi, Ali Erdemir, George Fenske, IzhakEtsion "The effect of laser surface texturing on transitions in lubrication regimes during unidirectional sliding contact" Tribology International 38 (2005) 219 – 225.
[8]. John A. Williams "Wear and wear particles - some fundamentals" Tribology International 38 (2005) 863 - 870.
[9]. H. Unal, A. Mimaroglu, V. Serdar "Dry sliding performance of thermoplastics against reinforced unsaturated polyester (BMC): In use in electrical contact breakers components" Wear 261 (2006) 841 - 847.
[10]. BekirSadık U¨ nlu¨, EnverAtik "Determination of friction coefficient in journal bearings" Materials and Design 28 (2007) 973 – 977.
[11]. Lan-Hui Sun, Zhen-GuoYang , Xiao-Hui Li "Study on the friction and wear behavior of POM/Al2O3 Nano composites" Wear 264 (2008) 693 - 700.
[12]. ErolFeyzullahoglu, ZehraSaffak "The tribologicalbehaviour of different engineering plastics under dry friction conditions" Materials and Design 29 (2008) 205 - 211.
[13]. Wan Yi, Xiong Dang-Sheng "The effect of laser surface texturing on frictional performance of face seal" journal of materials processing technology 1 9 7 (2 0 0 8) 96 - 100.
[14]. K.H. Hua, J. Wangc, S. Schraubed, Y.F. Xua, X.G. Hua, R. Stenglerd "Tribological properties of MoS2 Nano-balls as filler in polyoxymethylene-based composite layer of three-layer self-lubrication bearing materials" Wear 266 (2009) 1198 -1207.
[15]. P. Flores "Modeling and simulation of wear in revolute clearance joints in multibody systems" Mechanism and Machine Theory 44 (2009) 1211–1222.
[16]. M. Harrass, K.Friedrich, A.A.Almajid "Tribological behavior of selected engineering polymers under rolling contact" Tribology International 43 (2010) 635 - 646.
[17]. Jianliang Li, DangshengXiong, JihuiDai, Zhongji Huang, RajneshTyagi "Effect of surface laser texture on friction properties of nickel-based composite" Tribology International 43 (2010) 1193 - 1199.
[18]. K.O. Low, K.J.Wong "Influence of ball burnishing on surface quality and tribological characteristics of polymers under dry sliding conditions" Tribology International 44 (2011) 144 - 153.

[19]. Y. Qiu, M.M. Khonsari "Experimental investigation of tribological performance of laser textured stainless steel rings" Tribology International 44 (2011) 635 - 644.
[20]. M.H. Cho ,Sangil Park "Micro CNC surface texturing on polyoxymethylene (POM) and its tribological performance in lubricated sliding" Tribology International 44 (2011) 859 – 867.
[21]. Yang Gao, Shuangyue Sun, Yadong He, Xiaodong Wang, Dezhen Wu "Effect of poly(ethylene oxide) on tribological performance and impact fracture behavior of polyoxymethylene/polytetrafluoroethylene fiber composites" Composites: Part B 42 (2011) 1945 -1955.
[22]. AndriyKovalchenko, OyelayoAjayi, Ali Erdemir, George Fenske "Friction and wear behavior of laser textured surface under lubricated initial point contact" Wear 271 (2011) 1719 - 1725.
[23]. Se-Min Park, Gi-Hoon Kim, Young-Ze Lee "Investigation of the wear behaviour of polyacetal bushings by the inflow of contaminants" Wear 271 (2011) 2193– 2197.
[24]. Yuncai Zhao, GaoJieHao, Chunming Deng, Wenyou Ma "Study of Orthogonal Test of the Tribological Properties of the Surface Texturing Coating" Procedia Engineering 24 (2011) 53 – 58.
[25]. A.Pogacnik, M.Kalin "Parameters influencing the running-in and long-term tribologicalbehaviour of polyamide (PA) against polyacetal (POM) and steel" Wear 290 - 291 (2012) 140–148.
[26]. J. Sampedro , R. Ferre, E. Fernández, I. Pérez, B. Cárcel, T. Molina, J.A. Ramos "Surface Fictionalization of AISI 316 Steel by Laser Texturing of Shaped Micro cavities with Picosecond Pulses" Physics Procedia 39 (2012) 636 – 641.
[27]. AuezhanAmanov, Ryo Tsuboi, Hironobu Oe, Shinya Sasaki "The influence of bulges produced by laser surface texturing on the sliding friction and wear behavior" Tribology International 60 (2013) 216 – 223.
[28]. MingfengQiu, Bret R. Minson, Bart Raeymaekers "The effect of texture shape on the friction coefficient and stiffness of gas-lubricated parallel slider bearings" Tribology International 67 (2013) 278 – 288.
[29]. Hongtao Zhu, QiangZhu, AnhKietTieu, BuyungKosasih, CharlieKong "A simulation of wear behaviour of high-speed steel hot rolls by means of high temperature pin-on-disc tests" Wear 302 (2013) 1310–1318.
[30]. Daniel Braun, Christian Greiner, Johannes Schneider, Peter Gumbsch "Efficiency of laser surface texturing in the reduction of friction under mixed lubrication" Tribology International 77 (2014) 142 - 147.
[31]. DangshengXiong, Yongkun Qin, Jianliang Li, Yi Wa, Rajneesh Tyagi "Tribological properties of PTFE/laser surface textured stainless steel under starved oil lubrication" Tribology International 77 (2014) 308 - 315.
[32]. Hengzhong Fan, TianchangHu, Yongsheng Zhang, YuanFang, Junjie Song, LitianHu "Tribological properties of micro-textured surfaces of ZTA ceramic Nano composites under the combined effect of test conditions and environments" Tribology International 78 (2014) 134 –141.
[33]. Dewan Muhammad Nuruzzaman, Mohammad Asaduzzaman Chowdhury, Md. Mostafizur Rahman, Md. ArefinKowserb and Biplov Kumar Roy "Experimental investigation on friction coefficient of composite materials sliding against SS 201 and SS 301 counter faces" Procedia Engineering 105 (2015) 858 – 864.