

Study of Dimple Effect on the Friction Characteristics of a Journal Bearing using Taguchi Method

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Abstract. The effect of producing dimples using chemically etched techniques or by machining process on the surface of a journal bearing bushing to reduce the friction using Taguchi method is investigated. The data used in the present analysis is based on the results obtained by the series of experiments conducted to study the dimples effect on the Stribeck curve. It is statistically proved that producing dimples on the bushing surface of a journal bearing has significant effect on the friction coefficient when used with light oils. Also it is seen that there is an interaction effect between speeds-load and load-dimples. Hence the interaction effect, which are usually neglected should be considered during actual experiments that significantly contributes in reducing the friction in mixed lubrication regime. The experiments, if were conducted after Taguchi method, then the number of experiments would have been reduced to half of the actual set of experiments that were essentially conducted.

1. Introduction

The relation between the friction coefficient and the velocity along with the viscosity and pressure can be graphically expressed by Stribeck curve. Fig.1 shows the curve at three different regimes. To improve and enhance the life of the components used in mechanical systems, reduction in wear and friction plays a crucial role. The profile of the journal bearing surface contributes in reducing the friction apart from developing the required hydrodynamic pressure. Modifying and optimizing the surface topography of the mating surfaces therefore became a subject of interest for many researches leading them to actively investigate in this area. Fogg et al [1] showed that proper control on friction surface, speed and load considerably improved the efficiency, consistency and helped in energy conservation. Out of the different methods available, texturing of journal surface has great effect in reduction of friction and enhancing the various performance properties in tribological related systems. Sinanoglu et al [2] disclosed that the load carrying capacity of a bearing with surface texturing effects can be improved. A number of researches examined on surfaces, proved the potential advantages of altering the surface topography, for example, lower coefficient of friction and spillage issues in mechanical seals, enhanced load capacity in sliding and axial bearings, and additionally diminishes the metal to metal contact and reduced surface destruction. In the present study, an attempt is made to statically analyse the effect of different shaped dimples on improving the frictional characteristics of a journal bearing using Taguchi method.

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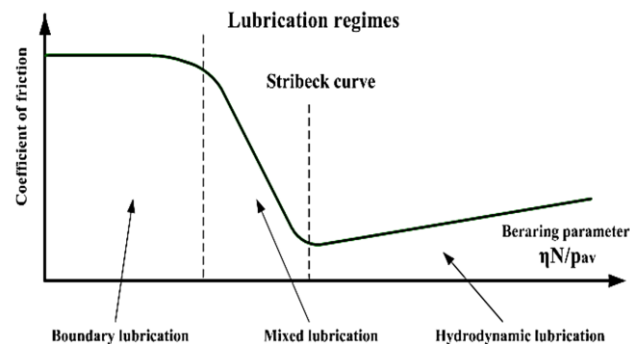


Figure 1. Stribeck curve

Etsion [3] experimentally investigated that there is significant improvement in wear resistance, load capacity, friction coefficient obtained by forming regular micro-dimples on the surface of the bearing. Laser Surface Texturing (LST) was used to obtain the desired texture on the surface. Cupillard et al. [4] numerically studied the pressure buildup due to textures in an inclined slider bearing. Numerical simulations were performed for laminar, steady, and isothermal flows. Their studies concluded that the performance of the bearing with textures was increased. Tala-Ighil et al. [5] established a numerical FDM model to study the textured surfaces with different shapes of micro cavities and at different locations of the texture zone. Their studies revealed that change in the surface texture improves the performance of the bearing. A comparative study was carried out in terms of load carrying capacity for the commonly used dimple shapes for parallel slider gas-lubricated bearings by Qiu, et al. [6]. Their results resolved that the ellipsoidal texture shape was able to give higher load carrying capacity compared to that of all the other types. Simulation were done using the compressible Reynolds equation. Meng, et al. [7] numerically investigated using fluid-structure-interaction method the load capacity of a compound dimpled surface bearing and showed that higher load carrying ability and reduced friction coefficient of the compound dimple. It was seen that the size, geometry and position/interval of compound-dimples play an important role. Sinanoglu et al. [8] studied experimentally and using ANN the topology effect on surface of the shaft on the pressure developed and load carrying capacity. The smooth and the textured surface performances were tested. The textured trapezoidal surface showed a high pressure build up and thus the load capacity. Yushan et al. [9] experimentally discovered a new method of arranging oiling dimples on the surface of axial bearings. 15 to 16 percent reduction in friction was achieved for a patterned surface.

2. Methodology

The flow chart of the methodology adapted for the present research work is as shown in fig.2 is in accordance with the one that is described in Research Methodology by Buckley and Chang [10]. Primarily the experiment is conducted in the laboratory. Later the results obtained by the simulation are used as secondary data for the statistically analysis using Taguchi approach of design of experiments. The data used in the present analysis is based on the results obtained by a series of experiments conducted to study the dimples effect on the Stribeck curve.

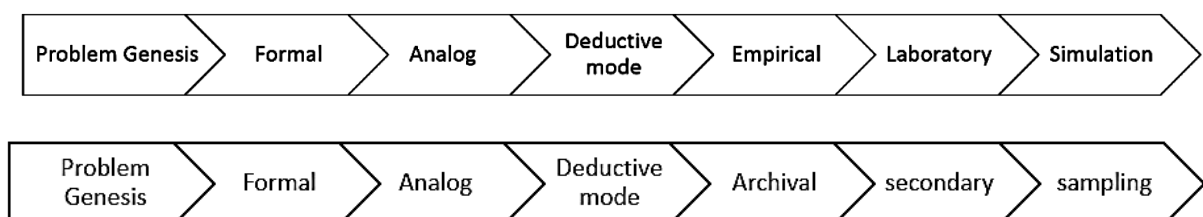


Figure 2. Flow chart of the methodology adopted

The specifications of the various elements used in the experimentation [1] are tabulated from table 1 to table 4.

Table 1. Machined bushing

Bushing	Dimple diameter (mm)	Dimple depth (mm)	Bur diameter (mm)
Conventional	0	0	0
Machined 1	2	0.165	6.223
Machined 2	4	0.448	9.373

Table 2. Etched bushing

Bushing	Dimple Shape	Dimple Depth (mm)	Etching time (h)
Etched 1	4 mm diameter circle, 360 ⁰	0.130	1.0
Etched 2	4 mm diameter circle, 180 ⁰	0.130	1.0
Etched 3	4 mm: 1 mm ellipse, 360 ⁰	1.040	8.0

Table 3. Oil Properties

Oil Type	Viscosity (cSt)		Specific Gravity at 15 °C
	40 °C	100 °C	
SAE 30	93	10.8	0.890
GT32	31.3	5.25	0.877



Figure 3. Dimpled bushings (a) machined dimpled bushings (b) etched dimpled bushings

The variation of friction coefficient in different bearing types for various loading condition with SAE 30 and GT32 oil were plotted [5] and is as shown in figure 4 to figure 10.

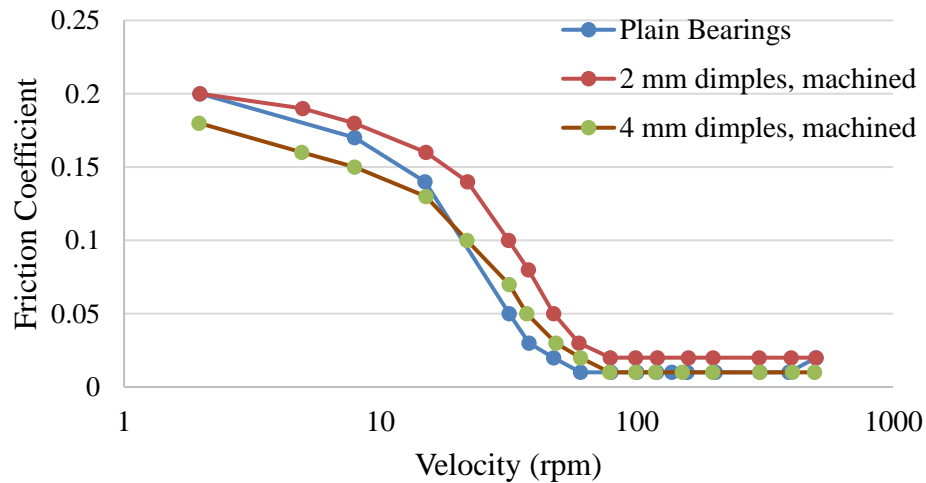


Figure 4. Coefficient of friction v/s velocity (oil – SAE 30 and Load - 667 N)

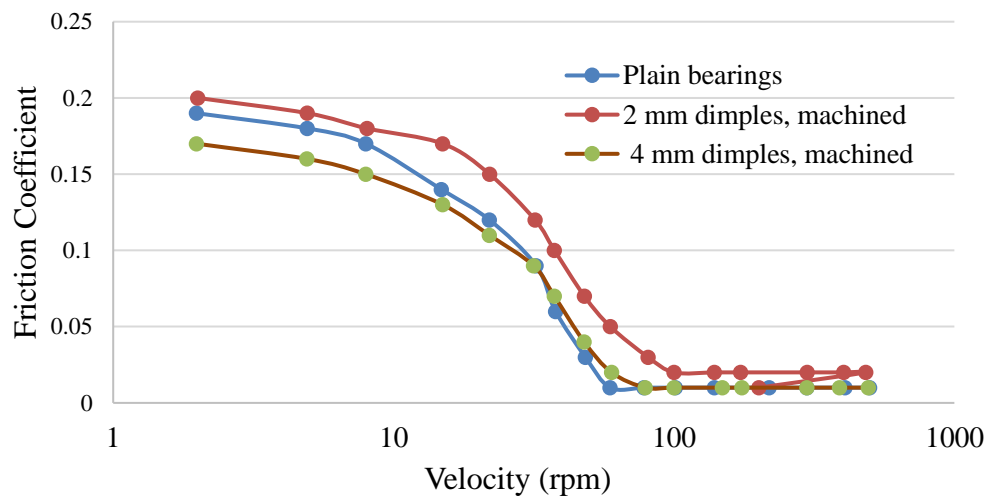


Figure 5. Coefficient of friction v/s velocity (oil – SAE 30 and Load - 890 N)

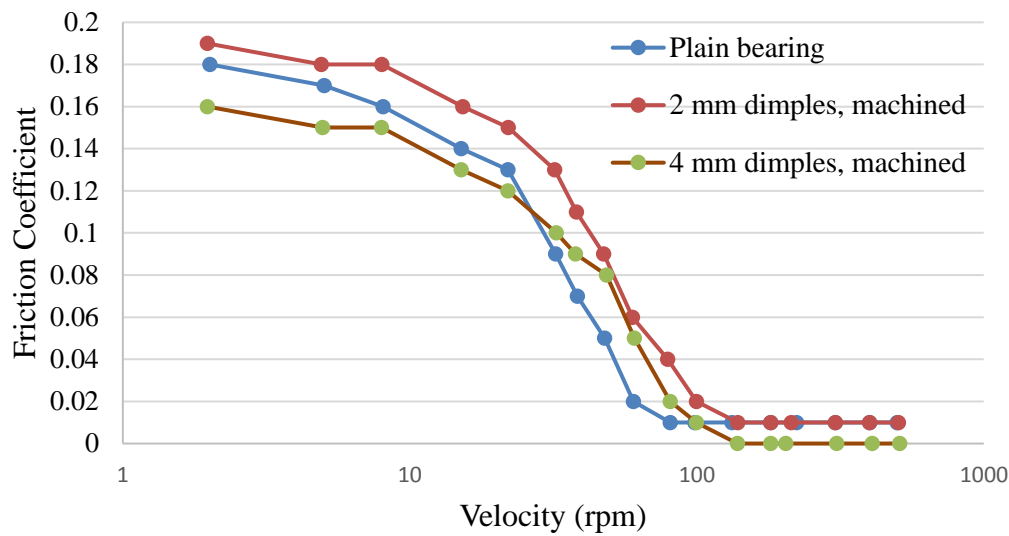


Figure 6. Coefficient of friction v/s velocity (oil – SAE 30 and Load - 1112 N)

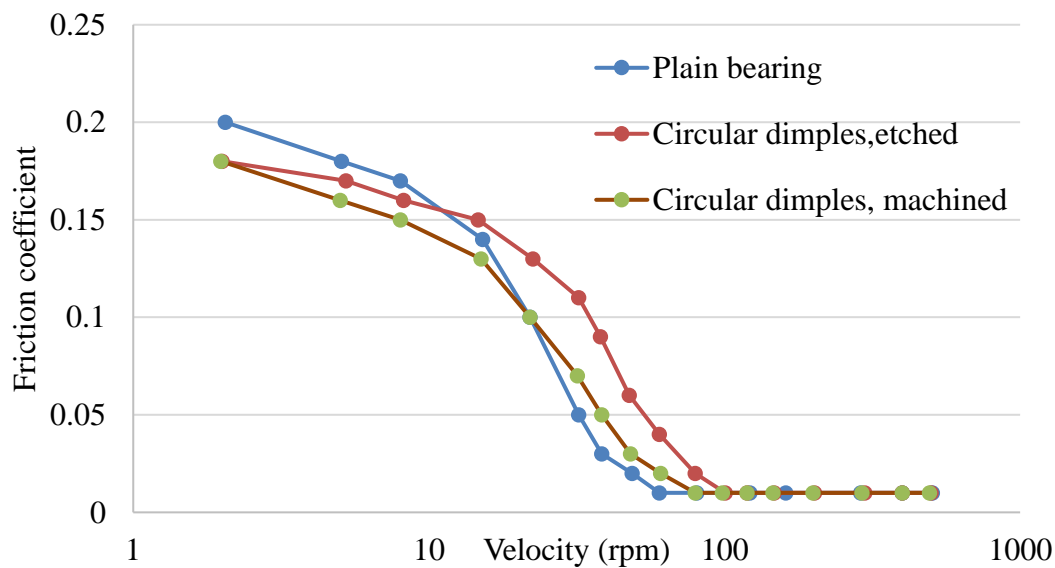


Figure 7. Coefficient of friction v/s velocity (oil – SAE 30 and Load - 667 N)

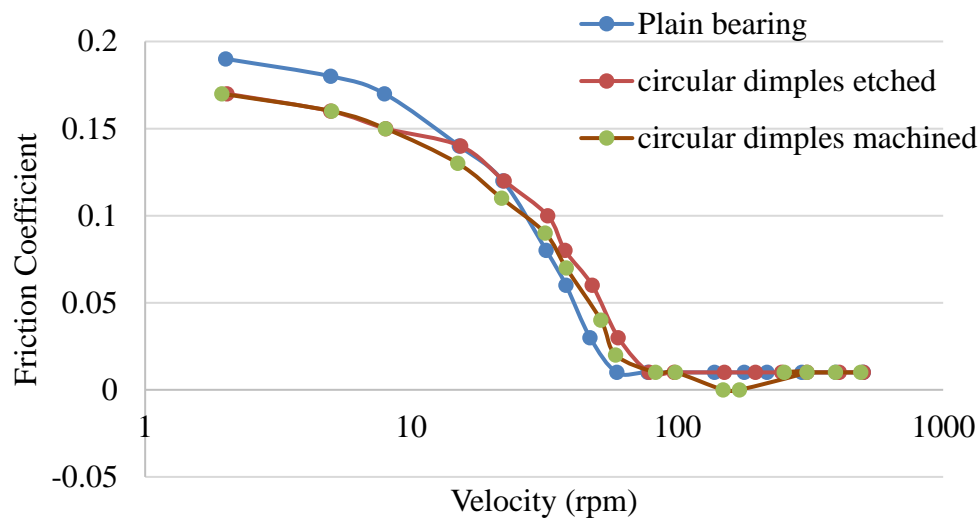


Figure 8. Coefficient of friction v/s velocity (oil – SAE 30 and Load - 890 N)

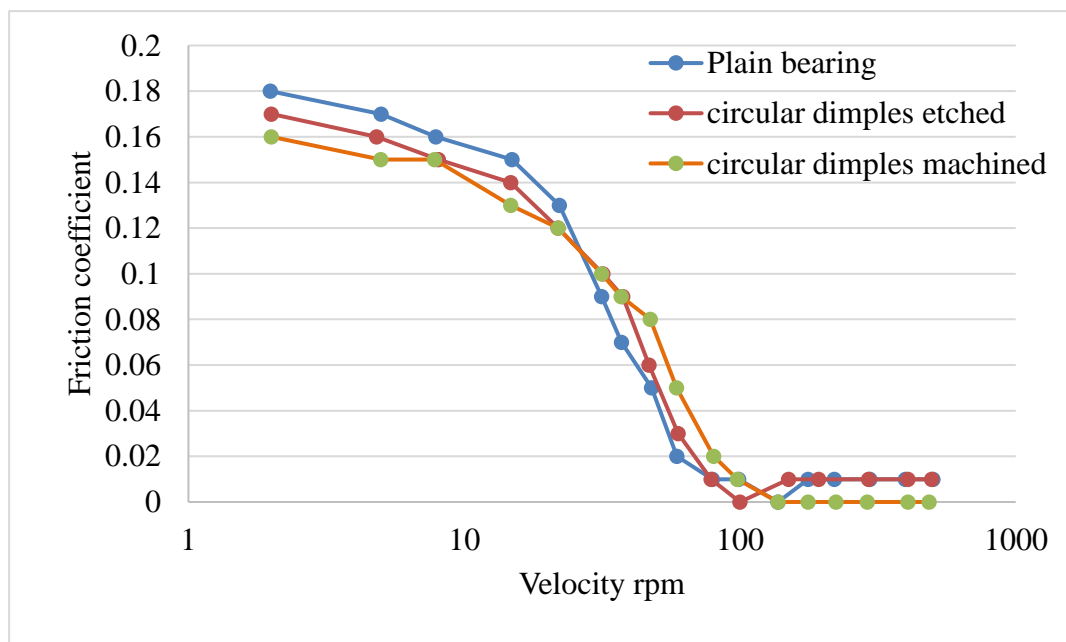


Figure 9. Coefficient of friction v/s velocity (oil – SAE 30 and Load - 1112 N)

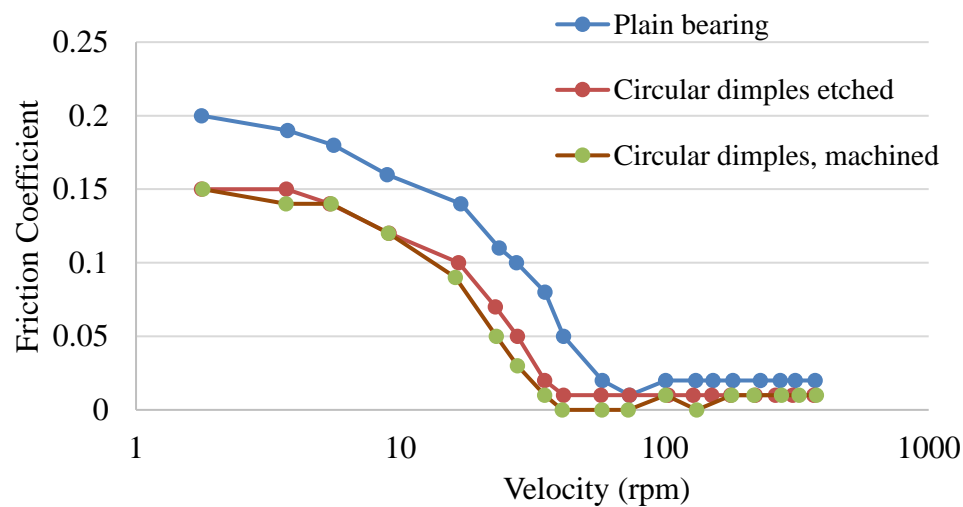


Figure 10. Coefficient of friction v/s velocity (light oil – GT32 Oil and Load - 667 N)

2.1 Taguchi method

The factors that affect the bearing performance are speed, load, surface texture of the bearing, shaft surface texture, geometry of the bearing, viscosity of the oil, temperature of the oil, and type of fluid used as lubricant. During operating conditions of the bearings, it has to be taken care that all these parameters are well balanced so as to produce high load carrying capacity, reduced friction and wear which results in highly stable system.

In the present work, three main independent factors namely speed, surface texture on the bearing bush and load are considered. These are set at three different levels to study their significance on dependent variable i.e., coefficient of friction using Taguchi method.

Case 1: Comparison of friction co-efficient of circular dimples with 2 mm and 4 mm diameter with that of the plain bearing for (SAE 30 Oil)

Three levels and three factors are considered. The details are tabulated in table 4.

Table 4: Setting of factors and levels

Factors	Level 1	Level 2	Level 3
Dimples (type)	1	2	3
Speed (rpm)	30	60	90
Load (N)	445	890	1112

Here dimples are designated as 1 – Plain bearing; 2 – 2 mm circular dimples (machined); 3 – 4 mm circular dimples (machined). For each run, data for coefficient of friction is recorded. In a typical case say for 3 factors and 3 levels each one may have to perform, $N = L^F = 3^3 = 27$ experiments. But using

The L9 orthogonal array, as given by Taguchi, the number of experiments or runs to be performed would be 9 which covers all the possible random combination. Table 5 shows the combinations as generated by Minitab for given levels and factors

Table 5. Combinations as generated by Minitab for given levels and factors

Dimples	Speed	Load	Co-efficient of friction
1	30	667	0.03
1	60	890	0.01
1	90	1112	0.01
2	30	890	0.12
2	60	1112	0.06
2	90	667	0.02
3	30	1112	0.11
3	60	667	0.02
3	90	890	0.01

Case 2: Comparison of friction co-efficient of etched and machined circular dimples with that of the plain bearing for (SAE 30 Oil)

Table 6 gives the details of three levels and three factors are considered for finding the friction coefficient effect on the etched and machined type of dimple bearings. Table 7 shows the combinations as generated by Minitab for given levels and factors

Table 6: Setting of factors and levels

Factors	Level 1	Level 2	Level 3
Dimples (type)	1	2	3
Speed (rpm)	30	60	90
Load (N)	445	890	1112

1 – Plain bearing; 2 – circular dimples (etched) ; 3 – circular dimples (machined)

Table 7. Combinations as generated by Minitab for given levels and factors

Dimples	Speed	Load	Co-efficient of friction
1	30	667	0.05
1	60	890	0.01
1	90	1112	0.01
2	30	890	0.10
2	60	1112	0.03
2	90	667	0.01
3	30	1112	0.10
3	60	667	0.02
3	90	890	0.01

Case 3: *Comparison of friction co-efficient of elliptical etched dimples with that of the plain bearing for light oil (GT32 Oil)*

L16 array is used in this case. Two types of dimples, three loading conditions and three different speeds are considered the details are tabulated as shown in table 8. Since with lighter oils the friction performances can be distinguished better for dimple bushing, the oil is now changed to light oil (GT32 oil). Dimple types are 1 – Plain bearing; 2 – Elliptical etched dimple. Table 9 shows the combinations as generated by Minitab for given levels and factors

Table 8: Setting of factors and levels

Factors	Level 1	Level 2	Level 3
Dimples (type)	1	2	
Speed (rpm)	30	60	90
Load (N)	445	890	1112

Table 9. Combinations as generated by Minitab for given levels and factors

Dimples	Speed	Load	Co-efficient of friction
1	30	445	0.225
1	30	560	0.210
1	30	667	0.200
1	60	445	0.160
1	60	560	0.140
1	60	667	0.125
1	90	445	0.110
1	90	560	0.090
1	90	667	0.054
2	30	445	0.150
2	30	560	0.150
2	30	667	0.160
2	60	445	0.100
2	60	560	0.125
2	60	667	0.120
2	90	445	0.060
2	90	560	0.090
2	90	667	0.120

3. Results and Analysis

3.1 Case 1: *Comparison of friction co-efficient of circular dimples with 2 mm and 4 mm diameter with that of the plain bearing for (SAE 30 Oil)*

Data for coefficient of friction are tabulated in table 5 for case 1. The Taguchi analysis is carried out and the statistical results obtained are tabulated in table 10. The response table for case 1 is shown in table 11

Table 10: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F
DIMPLES	2	0.003800	0.003800	0.001900	8.14
SPEED	2	0.008867	0.008867	0.004433	19.00
LOAD	2	0.002067	0.002067	0.001033	4.43
Residual Error	2	0.000467	0.000467	0.000233	
Total	8	0.015200			

Table 11: Response Table for Means

Level	DIMPLES	SPEED	LOAD
1	0.01667	0.08667	0.02333
2	0.06667	0.03000	0.04667
3	0.04667	0.01333	0.06000
Delta	0.05000	0.07333	0.03667
Rank	2	1	3

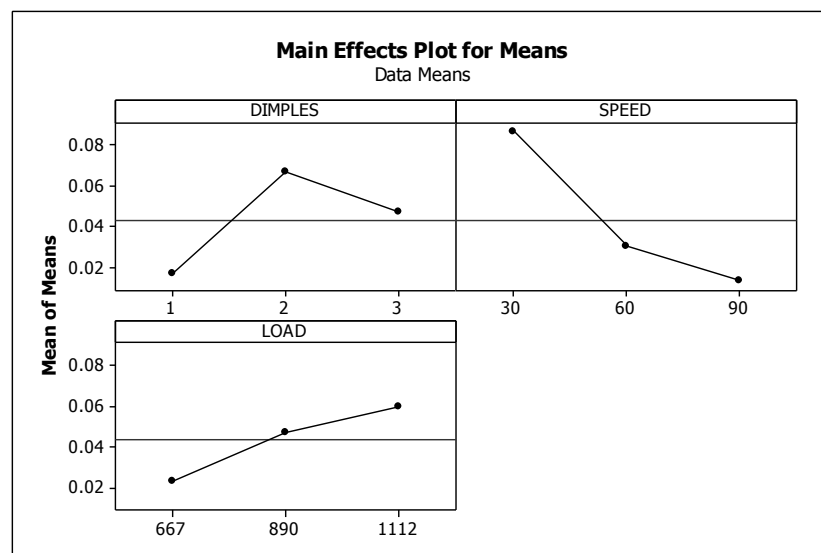


Figure 11. Mean effects plot for friction coefficient

From the above figure 11 it is seen that dimples of type 3 i.e. 4mm circular shaped dimples machined type results in lower value of friction coefficient than compared to the type 2 i.e. 2 mm circular dimples machined type. Also from the response table 11 it is seen that, creating dimples have effect on friction coefficient.

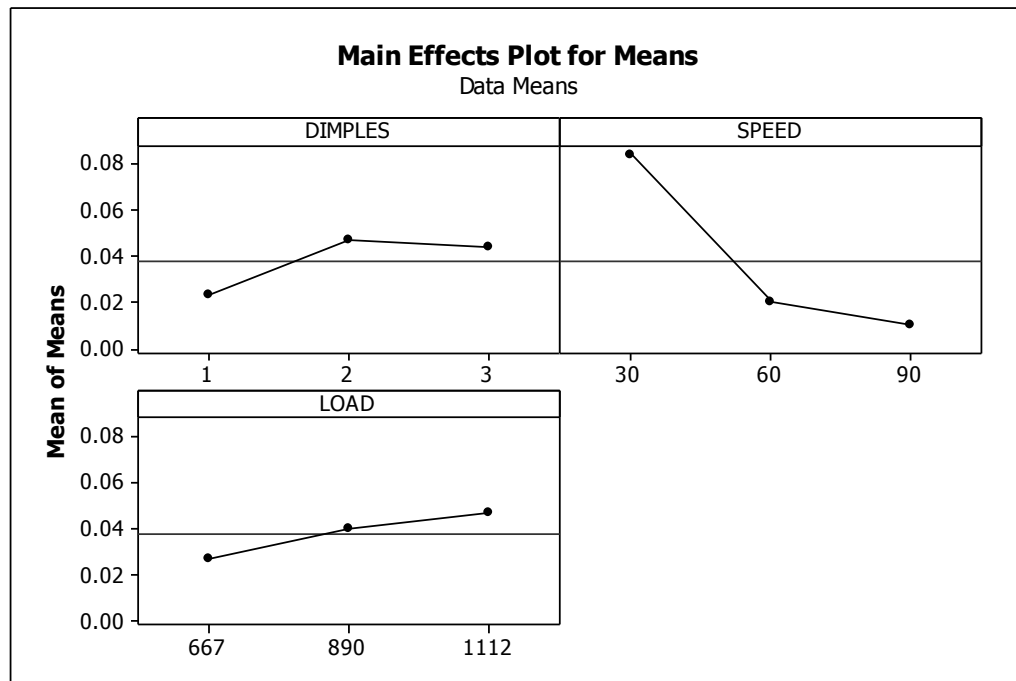
3.2 Case 2: Comparison of friction co-efficient of etched and machined circular dimples with that of the plain bearing for (SAE 30 Oil)

Table 12: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
DIMPLES	2	0.0009556	0.0009556	0.0004778	3.31	0.232
SPEED	2	0.0094889	0.0094889	0.0047444	32.85	0.030
LOAD	2	0.0006222	0.0006222	0.0003111	2.15	0.317
Error	2	0.0002889	0.0002889	0.0001444		
Total	8	0.0113556				

Table 13:Response Table for Means

Level	DIMPLES	SPEED	LOAD
1	0.02333	0.08333	0.02667
2	0.04667	0.02000	0.04000
3	0.04333	0.01000	0.04667
Delta	0.02333	0.07333	0.02000
Rank	2	1	3

**Figure 12.** Mean effects plot for friction coefficient

From the above figure 12 it is seen that dimples of type 3 i.e. circular dimples machined type results in lower value of friction coefficient than compared to the type 2 i.e., circular dimples etched type. Also from the response table 13 it is seen that, creating dimples have effect on friction coefficient.

3.3 Case 3: Comparison of friction co-efficient of elliptical etched dimples with that of the plain bearing for light oil (GT32 Oil)

Table 14: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
DIMPLES	1	0.0031734	0.0031734	0.0031734	4.93	0.046
SPEED	2	0.0273434	0.0273434	0.0136717	21.24	0.000
LOAD	2	0.0000751	0.0000751	0.0000376	0.06	0.944
Error	12	0.0077257	0.0077257	0.0006438		
Total	17	0.0383176				

Table 15:Response Table for Means

Level	DIMPLES	SPEED	LOAD
1	0.14600	0.18250	0.13417
2	0.11944	0.12833	0.13417
3		0.08733	0.12983
Delta	0.02656	0.09517	0.00433
Rank	2	1	3

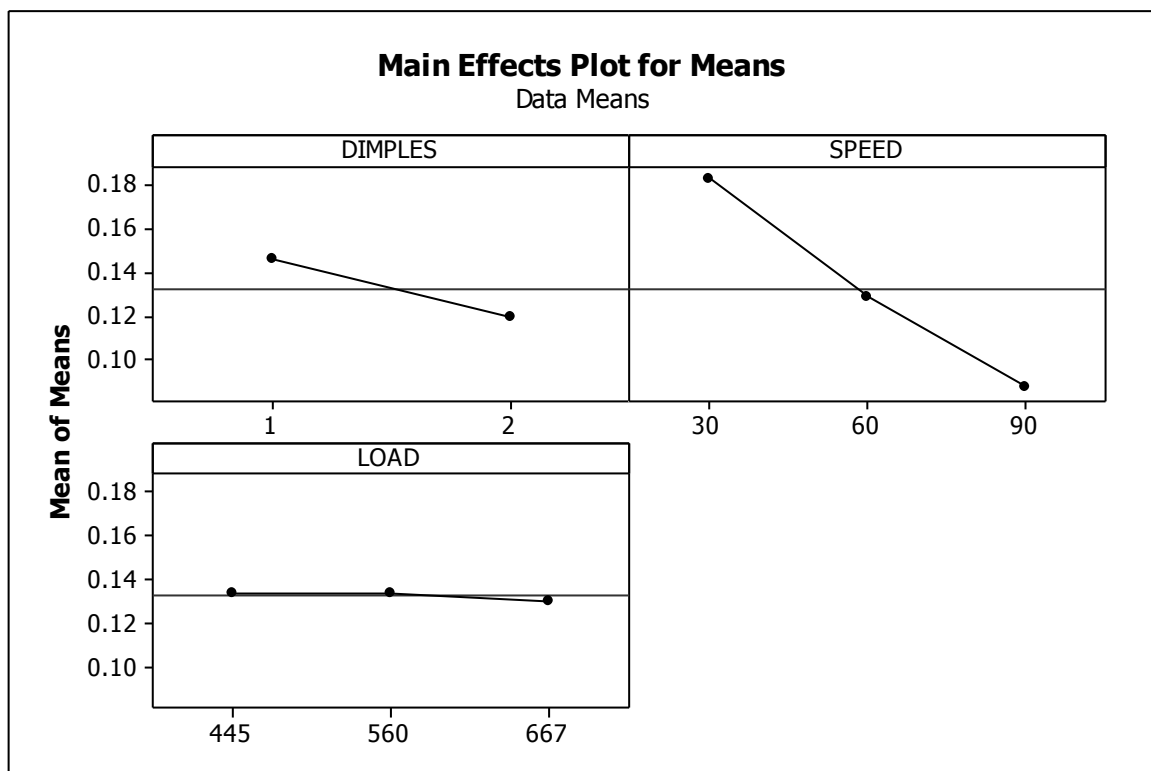


Figure 13. Mean effects plot for friction coefficient

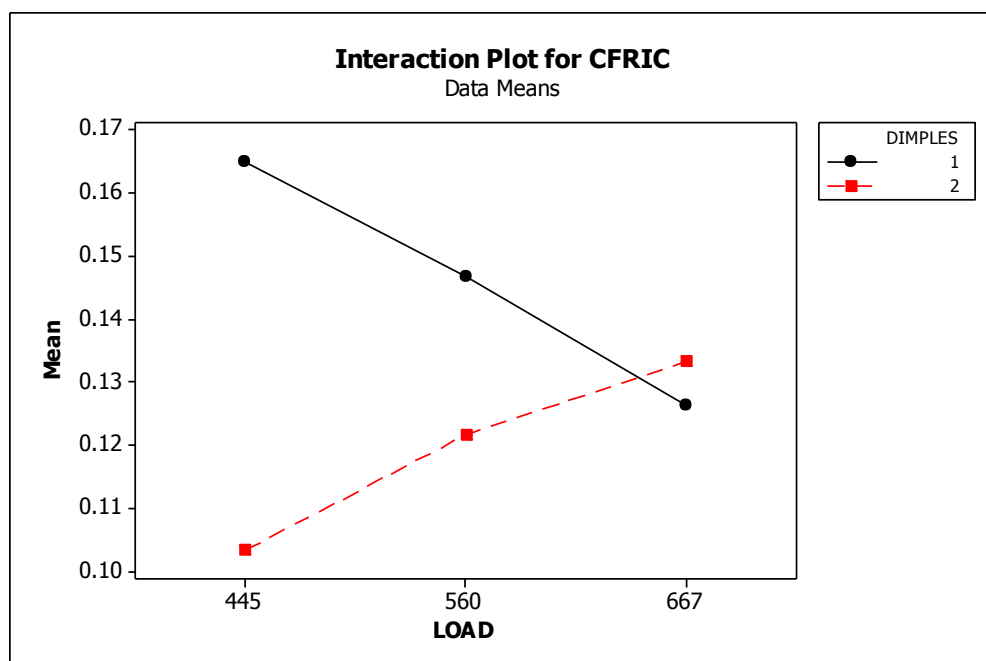


Figure 14. Interaction effect plot for coefficient of friction between dimples and load

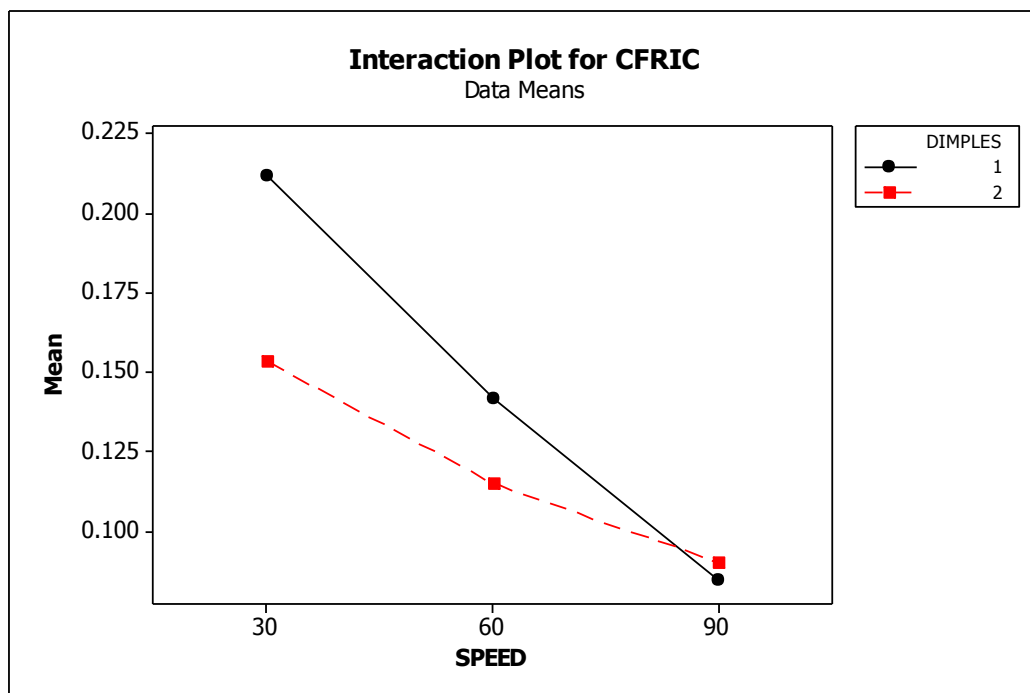


Figure 15. Interaction effect plot for coefficient of friction between dimples and speed

From figure 13 it is seen that dimples of type 2 i.e. elliptical dimples etched type results in lower value of friction coefficient than compared to the type 1 i.e., plain bearing bushing. The lower P-Value for speed indicate that this factor has a greater significance on the coefficient of friction. Figure 14 and figure 15 shows that there is interaction effect between load and dimple also between speed and dimples.

Conclusions

- Producing dimples on bearing bushing has significant effect in reducing the friction coefficient in the mixed lubrication regime.
- The elliptical etched dimples has lower value of friction coefficient than that of conventional plain bearing which can be easily distinguished with lighter oil like GE32 oil.
- Taguchi method gives accurate results as that obtained by experimentation in limited number of runs. Thus if this analysis is carried out before experimentation then it would save the time.

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