

Wear Prediction Model for Composite Bearing Balls under Pure Sliding Contact Condition

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Abstract – In today's scenario, maintenance of any machinery is very important in view of downtime of machinery. The bearing sector is one of this examples without which any single rotating machinery work. Present work is focused on prediction of wear for ball materials in case of ball bearing under pure sliding conditions. According to ASTM G99 standard Pin on Disc Apparatus is used to determine relative wear (in micron). The wear is also calculated by measuring weight of balls in grams. Taguchi approach with L9 array is employed to conduct experiments. Engine oil 20W40 is used for lubricating condition. An orthogonal array, Signal to Noise ratio and analysis of variance were employed to investigate wear behavior of composite ball bearing. Finally a model is prepared for Silicon Nitride, Alumina Oxide and Chrome Steel balls.

Keywords – Composite Ball Bearing, ANOVA, Silicon Nitride, Taguchi Technique.

I. INTRODUCTION

The need for a ball bearing made of a material which has better performance than the standard steel ball bearing will find many applications in mechanical devices. These ball bearings can provide better performance and greater reliability. This study investigates the use of silicon nitride (Si₃N₄) in the construction of ball bearings. The scope can include using silicon nitride for the balls only or for the balls and race. Wear is measured to investigate performance of balls in case of ball bearing. The challenge is to make the silicon nitride bearings material and processing costs close to that of steel bearings.

The Alumina can be alternate material for balls in case of ball bearing. Many times bearing fails due to wear of balls, therefore this work is based on wear prediction.

II. OVERVIEW OF TAGUCHI METHODS

Taguchi methods start with an assumption that we are designing an engineering system - either a machine to perform some intended function, or a production process to manufacture some product or item. Since we are knowledgeable enough to be designing the system in the first place, we generally will have some understanding of the fundamental processes inherent in that system. Basically, we use this knowledge to make our experiments more efficient. We can skip all the extra effort that might have gone in to investigating interactions that we know does not exist.

Without going into the details, it has been shown that this can decrease the level of effort by a factor of ten or twenty and sometimes much more.

Another distinction of Taguchi methods is the recognition that there are variables that are under our control and variables that are not under our control. In Taguchi terms, these are called Control Factors and Noise Factors, respectively.

The Taguchi Method is applied in four steps.

1. Brainstorm the quality characteristics and design parameters important to the product/process.

2. Design and conduct the experiments.

3. Analyze the results to determine the optimum conditions.

4. Run a confirmatory test using the optimum conditions.

A. Design of Experiments

As per Taguchi approach the test is conducted. Depends upon the number of parameters and the no of levels, the proper L9 orthogonal array is selected.

TABLE I. TEST PARAMETER

Level	Velocity (m/s)	Load (N)	Time (min)
1	V1=7	L1=10	T1=30
2	V2=10	L2=60	T2=60
3	V3=14	L3=120	T3=90

TABLE II. L9 ORTHOGONAL ARRAY

L9 Test	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

B. Designing the Experiments

Before designing an experiment, knowledge of the product/process under investigation is of prime importance for

identifying the factors likely to influence the outcome. The aim of the analysis is primarily to seek answers to the following three questions:

1. What is the optimum condition?
2. Which factors contribute to the results and by how much?
3. What will be the expected result at the optimum condition?

III. EXPERIMENTAL SETUP

In tribometer TR-20, Counter surface of known material is to be fixed. Ball mounted on Stiff lever having frictionless force transducer. The deflection of the highly stiff elastic arm, without parasitic friction, insures a nearly fixed contact point and thus a stable position in the friction track. The friction coefficient is determined during the test by measuring the deflection of the elastic arm. Wear coefficients for the ball and disc material are calculated from the volume of material lost during the test. This simple method facilitates the study of friction and wears behavior of almost every solid-state material combination with or without lubricant. Furthermore, the control of the test parameters such as speed, contact pressure and varying time allow a close reproduction to the real life conditions of practical wear situations.

A. Specification of Tribometer

- Ball Size 10 mm diameter
- Ball holder for 10 mm diameter ball
- Disc Size 165 mm dia. X 8 mm thick
- Wear Track Diameter (Mean) 10 mm to 140 mm
- Sliding Speed Range 0.5 m/sec. to 15 m/sec.
- Disc Rotation Speed 200-2000 RPM
- Sensor Proximity Sensor
- Normal Load 200 N maximum.
- Frictional Force 0-200 N, digital readout, recorder output
- Wear Measurement Range 4 mm, digital readout, and recorder output
- Wear Sensor Spec. LVDT
- Power 230 V, 15A, 1 Phase, 50 Hz
- Power for motor 1.5 kw
- Lubrication Motor 0.1 Hp, 0.48A, 230V.
- Oil Recirculation Unit 3 liter capacity with gear pump, 0.1Hp



Fig. 1 Top View of Tribometer

B. Test Procedure

This test is conducted as per G99 Standard of ASTM. Chrome Steel discs are polished with metallographic abrasive papers (C-400) and (C-600) respectively. Chrome Steel disc

rotating at a selected speed slide against a ball according to velocity track diameter of ball on disc is varied accordingly. This pre-rubbing process ensured a full contact of the ball and disc surfaces. The surface roughness Ra of disc specimens is 0.09–0.11 μ m. All the specimens were manually cleaned in petrol and then thoroughly dried. The friction and wear tests were performed at room temperature (280 C) in atmosphere. Applied loads ranged from 10 N to 120N and rotation speeds of discs ranged from 7m/s to 14m/s, time ranged from 30 to 90 minute, and the sliding distance was varied accordingly. The Servo engine oil (20W40) oil is used at flow rate of 50 ml/min on the rubbing surfaces using oil lubrication system during the wet test. It is ensured that lubrication will be continuously between Pin and counterface during the wet test.

IV. EXPERIMENTAL RESULTS

The trials are conducted as per orthogonal array L9 for dry and wet conditions separately. Following results are obtained & the same are used for ANOVA.

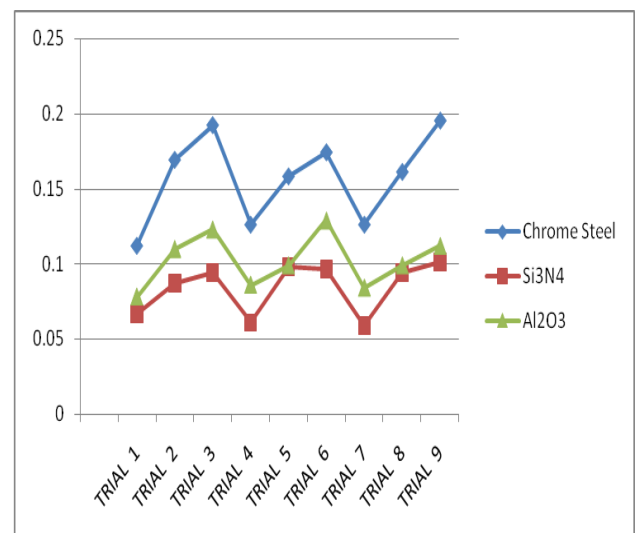


Fig. 2 Wear Results of various Trials

It is observed that wear of chrome steel ball is much greater than Silicon Nitride and Alumina balls.

V. ANALYSIS OF VARIANCE

A. Chrome Steel ball Material

ANOVA is done in MINTAB R15 software. Following results were obtained. This analysis was carried out for level of confidence 95%.

The regression equation is,

$$W = 0.105 + 0.00051 V + 0.000591 L + 0.000161 T$$

$$S = 0.0105521 \quad R\text{-Sq} = 92.1\% \quad R\text{-Sq(ajd)} = 87.4\%$$

TABLE III. MODEL ANOVA FOR CHROME STEEL

Source	DF	SS	MS	F	P
<i>Regression</i>	3	0.0065093	0.0021698	19.49	0.003
<i>Residual Error</i>	5	0.0005567	0.0001113		
<i>Total</i>	8	0.0070660			

TABLE IV. PARAMETER ANOVA FOR CHROME STEEL

Source	DF	SS	% Contribution
V	2	0.000098	1.3860
L	2	0.006613	93.589
T	2	0.000321	4.5428

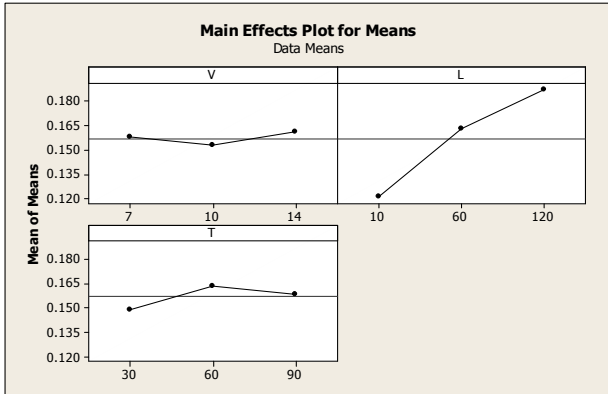


Fig. 3 Effect of Parameter on Wear of Chrome Steel

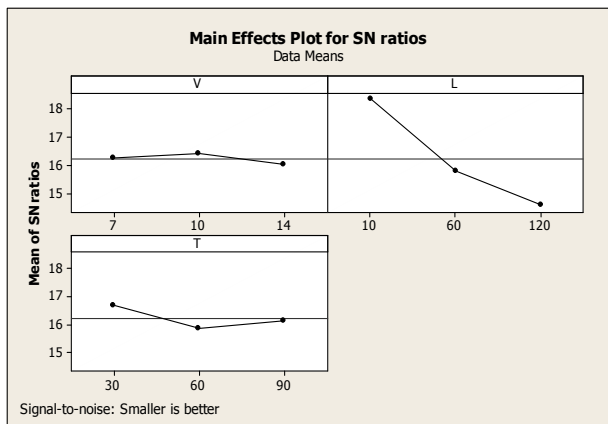


Fig. 4 S/N Ratio for Chrome Steel

B. Aluminium Oxide

ANOVA is done in MINITAB R15 software. Following results were obtained. This analysis was carried out for level of confidence 95%.

The regression equation is,
 $W = 0.0884 - 0.000806 V + 0.000350 L + 0.000000 T$
 $S = 0.00674703$ R-Sq = 90.9% R-Sq(adj) = 85.5%

TABLE V. MODEL ANOVA FOR ALUMINA

Source	DF	SS	MS	F	P
Regression	3	0.00227994	0.00075998	16.69	0.005
Residual Error	5	0.00022761	0.00004552		
Total	8	0.00250756			

TABLE VI. PARAMETER ANOVA FOR ALUMINA

Source	DF	SS	% Contribution
V	2	0.000070	2.7910
L	2	0.002244	89.473
T	2	0.000001	3.98

C. Silicon Nitride

Following results were obtained. This analysis was carried out for level of confidence 95%.

The regression equation is,
 $W = 0.0639 + 0.00027 V + 0.000307 L - 0.000033 T$
 $S = 0.0105336$ R-Sq = 75.7% R-Sq(adj) = 61.1%

TABLE VII. MODEL ANOVA FOR SILICON NITRIDE

Source	DF	SS	MS	F	P
Regression	3	0.0017261	0.0005754	5.19	0.054
Residual Error	5	0.0005548	0.0001110		
Total	8	0.0022809			

TABLE VIII. PARAMETER ANOVA FOR SILICON NITRIDE

Source	DF	SS	% Contribution
V	2	0.000010	0.43840
L	2	0.002158	86.88
T	2	0.000012	0.52608

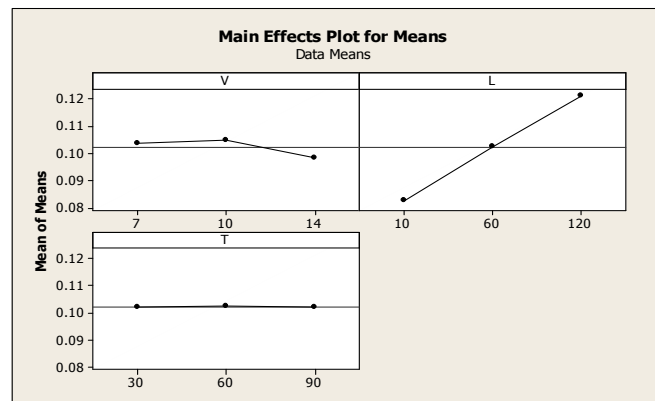


Fig. 5 Effect of Parameter on Wear of Alumina

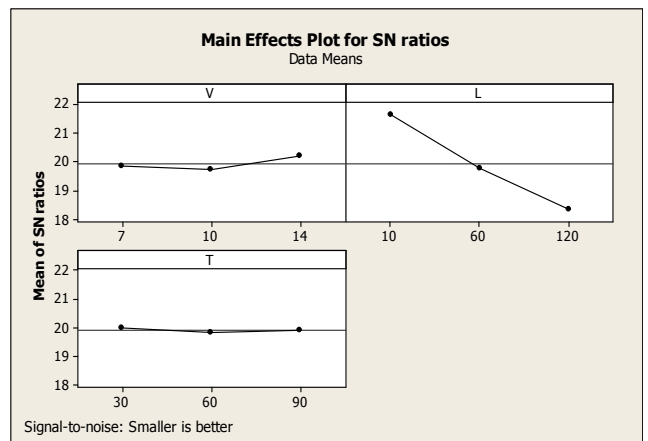


Fig. 6 S/N Ratio for Alumina

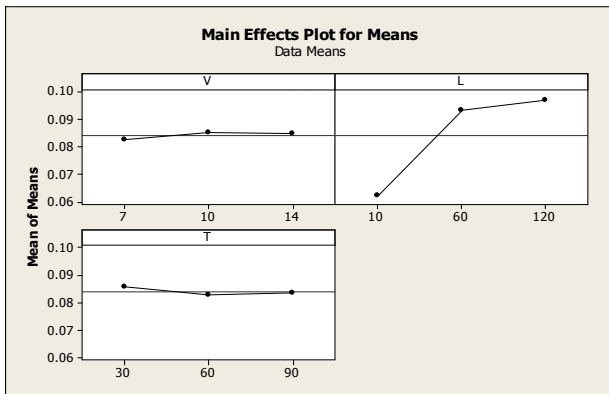


Fig. 7 Effect of Parameter on Wear of Silicon Nitride

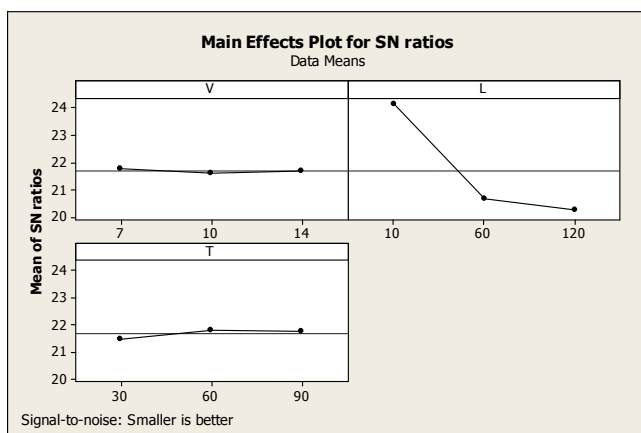


Fig. 8 S/N Ratio for Silicaon Nitride

VI. CONFIRMATION TEST

After successful development of model a confirmation test is carried out for validation.

Material	V (m/s)	L (N)	T (min)	Wear by Expt. (gm)	Wear by regression (gm)
Chrome Steel	14	10	60	0.1310	0.12771
Al ₂ O ₃	14	10	60	0.1035	0.1031
Si ₃ N ₄	14	10	60	0.0690	0.06877

VII. CONCLUSION

1. The DOE technique was successfully used to study the dry and wet sliding wear of ball bearing materials.
2. The analysis of variance shows that the load (93.58%) and time (4.54%) have significant influence on wear of chrome steel ball in wet condition.

3. The analysis of variance shows that the load (89.47%) and time (3.98%) have significant influence on wear of Aluminium Oxide ball in wet condition.
4. The analysis of variance shows that the load (86.88%) and time (0.52608%) have significant influence on wear of Silicon Nitride ball in wet condition.
5. The regression equation gives the best results for various parameters. This means a considerable saving in cost and time, which could benefit the industry to build more general and particular databases of material properties.

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