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A Taguchi Approach on Influence of Extreme Pressure Additive on Performance of Lithium Based Grease

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ABSTRACT

The aim of paper is to study the influence of extreme pressure additives on the properties of plane lithium based grease, by adding Molybdenum Disulphide as a additive. This have been added to grease having the micron particle mesh sizes of additive with best percentages and proportions that improve the properties of grease such as load carrying, wear resistance and friction resistance. The purpose of this study is to determine the optimum design parameters and indicate which of the design parameters those are statistically significant for obtaining a high load carrying capacity with Molybdenum Disulphide microparicles, dispersed in conventional lithium base grease used in journal bearings. Tribological testing was conducted using a four-ball tester according to ASTM standard D2596 procedures. Weld load is determined in this study by statistical evaluation. Design of experiment (DOE) was constructed using the Taguchi method, which consists of L_{27} orthogonal arrays. According to the analysis of signal-to-noise (S/N) ratio and analysis of variance (ANOVA), weld point optimized significantly by dispersing several concentrations of MoS_2 with several micron particle sizes of MoS_2. It was found that a Molybdenum Disulphide with particle size 0.5micron and 5% in proportion used in plane lithium base grease as additive showed high load carrying capacity than other combinations. The predicted values of weld load point by utilizing the levels of the optimal design parameters (0.5µ particle size of MoS_2, 5% vol. MoS_2), as made by Taguchi optimization method, was consistent with the confirmation test, will within 95% CI.

Keywords— **ASTM D 2596, Extreme pressure, Four-ball tester, Grease, MoS_2, Taguchi method.**

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I. INTRODUCTION

For the journal bearing it is required to sustain heavy loads and shock loading in addition to mechanical misalignment. Under these adverse conditions, the lubricant in use has to maintain a continuous film between the wear components of these bearings. Generally the lubricant forms a tenacious continuous lubricating film, which reduces the operating temperatures and sustains heavy loads. For lubrication in journal bearing generally grease is used as lubricant. The grease should have appropriate consistency to take the loads on the bearing and should not thin throughout during the entire operation and the grease consumption should be minimal for providing lubrication to the parts. This paper discusses the preparation of grease to be used in boundary or mixed regime which is found in journal bearings. Grease is a complex multi-phase material. Grease consists of oil and or other fluid lubricant that is mixed with another thickener. Greases generally cannot satisfy the requirements of high performance lubricants without using the benefits of modern additive technology. Additives are natural or synthetic chemical substances that can improve lots of different parameters of lubricants. Anti-wear and extreme pressure additives improve, in general the load bearing capacity in most rolling contact bearing and greases. Fillers are used as fine solids in grease formulations to improve grease performance. The filers are graphite, molybdenum disulphide, etc. The important properties which affect the characteristics of grease are amount and type of thickener, oil viscosity, additives and low or high temperature performance. Additives enhance performance and protect the grease [6]. Podornik *et al.* [1] investigated that h-BN is a solid lubricant capable of successfully replacing graphite as being a "clean" additive, not leaving dark stains on formed surface. The tribological performance, including friction and wear, lubrication film stability and the quality of the contact surfaces, greatly depend on the h-BN particle size and concentration. By increasing the h-BN particle size and concentration the friction and wear under a mild steel contact are reduced as long as the concentration in the grease does not exceed 10%, with the largest h-BN powder of 30µm showing approximately 25% lower wear than pure grease and graphite containing grease. In terms of load carrying capacity in highly loaded contacts, typical for forming operations, a high concentration of h-BN solid lubricant of at least 20% and particles larger than 5µm are required in order to provide good lubrication stability and improved surface quality of the formed part. Zhenyu *et al.* [2] studied lubricant additives, based on inorganic nanoparticles coated with organic outer layer, can reduce wear and increase load carrying capacity of base oil remarkably, indicating the great potential of hybrid nano particle as anti-wear and extreme pressure additives with excellent level of performance. The organic part in the hybrid materials improves their flexibility and stability, while the inorganic part is responsible for hardness. Marquart *et al.* [3] studied molybdenum disulphide (MoS_2) as a one kind of solid lubrication for ball bearings has been known for 60 years. Min *et al.* [17] investigated friction characteristics solid lubricants graphite and MoS_2 in the brake friction material. Author showed that the friction material containing graphite improved friction stability and fade resistance.

The aim of this work is to study the influence of some additives on properties of (Lithium baseg) grease by adding additive molybdenum disulphide. This additive was added having different particle size which are like in micron particle sizes, 0.5µ, 1µ and 1.5µ and in different proportions, 5%, 10% and 15%. So from that we got the best combination of additives in grease which carries the heavy load in lubrication film in journal bearing. For this research tribological testing of lubricant was done on four ball testing machine. And the tests were carried out by ASTM (ASTM D 2596) standards [23]. Kothavale in 2011 [12] used the four ball testing machine for is research work as per ASTM D 2783-82 standards. Author investigated from these testing that load carrying capacity of EP lubricating oil is important parameter for their application. The test was carried out on four ball testing model under atmospheric pressure of lubricant at different loads and at room temperature. Critical seizure load, weld load, wear index are determined by him in his study. In this work the design of experimentation of input and output parameters was done by Taguchi method for getting best combination. Minitab statistical software was used for DOE. The four ball EP tester is designed to evaluate performance under much higher unit loads than applied on the wear test, hence designed as Extreme Pressure. One steel ball is rotated against the other three stationary balls at constant speed, with controlled temperature rise. The load was increased at specified intervals until the rotator ball seizes and welds to the other balls. At the end of each interval, the scar diameter is measured and recorded. Two values from EP test are generally reported, load wear index and weld point. Load wear index is a measure of the ability of the lubricant to prevent wear at applied loads. Weld point is the lowest applied load at which either the rotary ball seizes and welds to the three stationary balls. It indicates the point at which the extreme pressure limit of the lubricant is exceeded [8].

Here experimental report of nine samples are carried out on test rig developed four ball tester using ASTM D 2596 standard [23] method up to getting weld load point we was repeated test with another next successive standard load and weld load point as result of load carrying capacity of grease calculated. These nine samples were prepared with combination of three particle sizes and adding in three different proportions. These nine samples were tested repeatedly till the weld point appeared on test balls. And the optimum best combination is evaluated from Taguchi method as Design of Experimentation.

I. Experimental Procedure

A. Design of Experiment (DOE)

The Taguchi [23] approach was built on traditional concept of design of experiments (DOE) is a body of statistical techniques for the effective & efficient set of data for a number of purposes. Two significant ones are the investigation of research hypotheses and the accurate resolve of the relative effects of the many different factors that influence the quality of a product or process. DOE can be employed both in product design phase and production phase. In this study, the Taguchi method consisting of L_{27} orthogonal arrays was used, with 27 rows (corresponding to the number of tests), and two columns at three levels. This array has twenty six degrees of Freedom (DOF). In order to observe the degree of significant of the design parameters % by vol. and Particle sizes µ contributions, two factors (each at three levels), were taken into account (as shown in Table 1). Table 2 shows the DOE with L_{27} orthogonal arrays using Minitab statistical software.

TABLE 1
MoS_2 contents and experimental condition: two parameters and three levels

Level	Parameters	
	Particle size in µ	Vol. %
1	0.5	5
2	1	10
3	1.5	15

TABLE 2
DOE with L_{27} orthogonal array

Test no.	Factors	
	MoS_2 Particle size in µ	MoS_2 Vol. %
1	1	1
2	1	1
3	1	1
4	1	2
5	1	2
6	1	2

7	1	3
8	1	3
9	1	3
10	2	1
11	2	1
12	2	1
13	2	2
14	2	2
15	2	2
16	2	3
17	2	3
18	2	3
19	3	1
20	3	1
21	3	1
22	3	2
23	3	2
24	3	2
25	3	3
26	3	3
27	3	3

B. Preparation of Sample For Test

Based on the DOE shown in Table 2, samples are prepared approximately 18 ml by grease and additive molybdenum disulphide powder with three particle sizes and in three proportions, as per volume capacity of ball pot. The sample vol. was to be taken as % by weight on digital weighing machine having accuracy in milligrams. As given in Fig. 1.

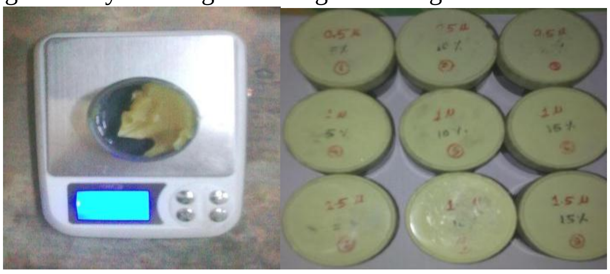

Fig. 1 Preparation of Samples for Test

C. Four-Ball Extreme Pressure Lubricant Tester

The four ball testing machine shown in Fig. 2 was used for tests and ASTM D 2596 standard procedure is followed to find out load carrying capacity of lubricants [23]. The Ducom four ball testers is widely accepted as the industry standard for conducting EP, AW and SS property test of lubricants. The Ducom four ball testers has the unique capability of evaluating lubricants for their wear preventive, extreme pressure frictional properties and shear stability properties, all in one machine. The test system is capable of carrying out a number of standards applicable to lubricant characterization and its capabilities extend beyond the scope of these standards, allowing users to perform a variety of customized tests. This instrument uses four balls, three at the bottom and one on top. The bottom three balls are held firmly in a ball pot containing the lubricant under test and pressed against the test ball. The top ball is made to rotate at the desired speed wile the bottom three balls are pressed against it. The lubricant under test is characterized by evaluating the wear scar formed on the balls after the test and evaluating the load at which the lubricant fails and the four balls weld together.

Fig.2 Four Ball Tester

D. Preparation of Apparatus

Thoroughly clean four new test balls, ball pot, and chuck assemblies by first washing with acetone and then dry in atmosphere. Three balls are held in cup and locked by a locking ring as given in Fig. 3(a).

Fig. 3 (a) Ball Assembly (b) Ball Assembly with Grease

Then grease is completely filled in ball pot such that avoiding the inclusion of air pockets, scrap off the excess grease pushed onto the lock nut, as given in Fig. 3(b).

Press one ball into the ball chuck and mount the chuck into chuck holder, and install the ball pot assembly on the test apparatus in contact with the fourth ball. Place the mounting disk between ball pot and thrust bearing, as given in Fig. 4.

Fig. 4 Installation of Ball Assembly

E. Tribological Testing

According to Table 2, tribological testing was carried to determine the weld load using four-ball tester. Testing performed as per ASTM standard D2596 procedures [23]. The speed and temperature were 1770 ± 60 rpm and 27 ± 8 ºC, respectively. Within the four-ball tester, three 12.7 mm diameter carbon-chrome steel balls were clamped together and covered with lubricant for evaluation. Fourth steel ball (of the same diameter), referred to as the top ball, was held in a special collect inside a spindle, and rotated by an AC motor. The top ball was rotated in contact with the three fixed balls, which were immersed in the sample grease. The weld load point was record using a digital meter. The motor was run for 10 to 12 seconds duration at increasing loads as per ASTM D 2596 [23] standard successive loads until welding occurs. The testing on four ball tester for each individual sample is very costly. Weld point can be detected by noise of motor, smoke or sudden drop in pressure.

II. Result and Discussion

A. Analysis of the S/N ratio

According to Taguchi method studies, response variation using the S/N ratio is important, because it can result in optimization of quality characteristic variation, due to uncontrollable parameters. The weld load was considered as being the quality characteristic, using the concept of "the larger-the-better". The S/N ratio used for this type response was given by:

$$\frac{S}{N} = -10\log_{10}\left(\sum \frac{w^2}{n}\right) \qquad (1)$$

Where, n is the number of measurement values in a test, in this case, n=1, and w is the measured value in the test. S/N ratio values are calculated by taking into consideration Eqn. (1).The weld loads are given in table 3. For those load the welding occurred on the balls as shown in Fig. 5.

Fig. 5 Welding done on test balls

And the graph for weld load Vs vol. % and particle sizes in micron are given in fig. 6.

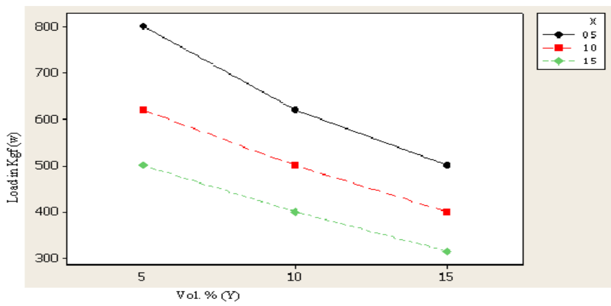

Fig. 6 Graph for weld load (kgf) Vs Vol. (%) and particle size (μ)

The weld load point values measured from the test, and their corresponding S/N ratio values, are shown in Table 3. According to the category of the performance characteristic, a smaller S/N value corresponds to a better performance. Therefore, the optimal level of Weld load parameters is the level with the smallest S/N value. Based on the analysis of the S/N ratio, the optimal weld load point for the vol. % contribution was obtained as 5 vol.% MoS_2 and 0.5 micron particle size (as shown in Fig. 7).

TABLE 3

Weld load values and S/N Ratio values for run

Test no.	Weld load in Kg f	S/N ratio (dB)	Test no.	Weld load in Kg f	S/N ratio (dB)
1	800	-29.0308	15	500	-26.9897
2	800	-29.0308	16	400	-26.0205
3	800	-29.0308	17	400	-26.0205
4	620	-27.9239	18	400	-26.0205
5	620	-27.9239	19	500	-26.9897
6	620	-27.9239	20	500	-26.9897
7	500	-26.9897	21	500	-26.9897
8	500	-26.9897	22	400	-26.0205
9	500	-26.9897	23	400	-26.0205
10	620	-27.9239	24	400	-26.0205
11	620	-27.9239	25	315	-24.9831
12	620	-27.9239	26	315	-24.9831
13	500	-26.9897	27	315	-24.9831
14	500	-26.9897			

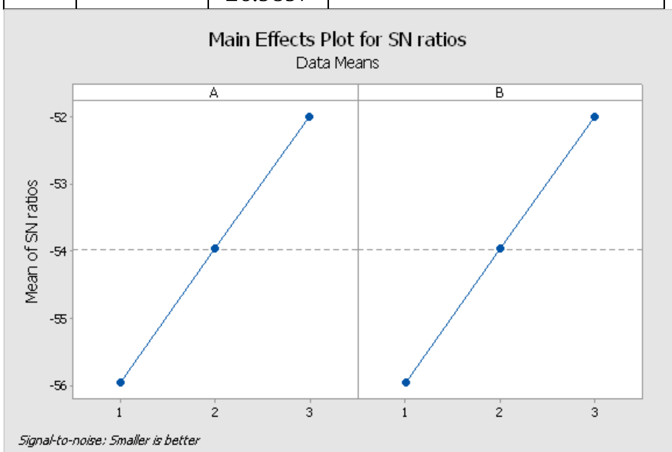

Fig. 7 Main effect plot for S/N ratio's effect on weld load

Although grease containing 0.5 micron particle size powder in 5 % showed a greater influence on the S/N ratio, it affected negative impact as particle size and proportion increases, where the weld load point becomes less means the load carrying capacity decreases as either of one parameter increases. These results showed that the grease containing a certain amount of additive of having certain particle size could increases the heavy load carrying capacity.

B. Analysis of Variance (ANOVA)

ANOVA is statistically based, used for detecting differentials occurring in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. First, the total sum of squared deviations SS_T from the total mean S/N ratio n_m is calculated as follows:

$$SS_T = -\sum_{i=1}^{n}(n_i - n_m)^2 \qquad (2)$$

Where, n is the number of experiments in the orthogonal array and n_m is the mean S/N ratio for the experiment. The Percentage contribution P can be calculated as:

$$P = \frac{SS_d}{SS_T} \qquad (3)$$

Where, SS_d is the sum of the squared deviations. By minitab software, the ANOVA results are shown in Table 4.

TABLE 4
ANOVA for Weld Load

Source of variation	D-O F	(SS)	(V)	F	P	Contri bution %
Particle size µ (A)	2	250017	125008	249.26	0.00	48.92
Vol. %(B)	2	250017	125008	249.26	0.00	48.92
Error	22	11033	502			2.16
Total	26	511067				100

A function known as the F test, which was named after Fisher [25], uses F to see the most significant effect on design parameters, based on the quality characteristic. The F-ratio is a ratio of the mean square error to the residual error, and is traditionally used to determine the significance of a factor.

The P-value usually reports the significance level, which shows either a suitable or an unsuitable level for the optimization (as shown in Table 4). Contribution (in unit %) is defined as the significance particle size and vol. % parameters on weld load point performance. Tables 4 show that the contribution percentage of both gave a more significant S/N ratio, which obtained 48.92%.

C. Confirmation Test

The confirmation test was the final stage to verify the results obtain from the Taguchi design approach. The confirmation test is a crucial step and is highly recommended by Taguchi to verify test results [24]. In this study, several confirmation tests were performed by utilizing the levels of the optimal design parameters (0.5 micron particle size, 5 vol. % additives). The average value of load (762.778) falls within 95% CI. Therefore the predicted value of load made by Taguchi optimization method was consistent with the confirmation test. The CI calculated as:

$$CI = \pm\left[\frac{F(f_1, f_2)\times V_e}{N_e}\right]^{05} \qquad (4)$$

Where, F (f_1, f_2) variance ratio for DOF f_1 and f_2 at the level of significance, V_e Variance of error term and N_e number of replications:

$$N_e = \frac{\text{Number of trials}}{[\text{DOF of mean (always=1)} + \text{DOF factors used in estimate}]} \qquad (5)$$

CI = ± 43.9711 at 95 % confidence level. Therefore the result at the optimum condition is = 762.778 ± 43.9711.

III. Conclusions

Weld load point that mean the load carrying capacity of grease have been increased significantly by dispersing several proportions of additives with several particle size powder. Because of the micron particle size powder made load carrying between contact surfaces in journal bearing. It was found that a Molybdenum Disulphide with particle size 0.5micron and 5% in proportion used in plane lithium base grease as additive showed high load carrying capacity than other combinations. The predicted values of weld load point by utilizing the levels of the optimal design parameters (0.5µ particle size of MoS_2, 5% vol. MoS_2), as made by Taguchi optimization method, was consistent with the confirmation test, will within 95% CI.

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