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Experimental Study of the Parameters Affecting the Tribological Performance of Nano Lubricant Containing Multi-Walled Carbon Nano-tubes (MWCNT) using Design of Experiments (DOE)

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ABSTRACT: *The Multi-Walled Carbon Nano-Tubes (MWCNT) are gaining wide acceptability as an anti-wear lubricant additive because of their extraordinary tribological properties. However, full anti-wear potential of the MWCNT can be derived when it is used in a proper quantity with a suitable surfactant. The aim of the present research is to identify the factors that affect the tribological performance and to employ the Design of Experiments (DOE) to study the effect of four factors: MWCNT quantity, surfactant quantity, load and speed on the tribological performance of the nano lubricant. The tribological performance of the nano lubricant is measured in terms of wear of the block sliding against the disk in a block and disk test setup. Four levels of these factors are considered for use in the design of experiments. The interaction amongst these factors is also determined. The experimental results has been analyzed and reported.*

Keyword: *Design of experiments, Anti-wear additives, Multi-Walled Carbon Nano-tubes, Wear, Nano-lubricant.*

I. Introduction

The heavy load and slow speed between the two sliding surfaces causes mechanical contact resulting in wear [1]. Much efforts have been made in the past to prevent failures arising out of the such operating conditions and many alternative technologies have been suggested to separate the contacting surfaces [2–18]. Even though anti-wear lubricant additives like Zinc [19], Molybdenum Disulphide [20,21], Tungsten Disulphide etc are effective under these conditions but Multi-Walled Carbon Nano-Tubes (MWCNT) [22,23] are gaining wide acceptability as an anti-wear lubricant additive because of their extraordinary tribological properties. Extensive studies have shown that mechanical, electronic, transport, vibrational, thermal, etc., properties of MWCNT are due to its unique quasi-one-dimensional sp^2-bonded structure. However these advantages are quickly nullified with the occurrence of agglomeration of the MWCNT in the nano lubricant. The use of surfactant is thus an essential requirement but its optimal quantity is not well defined. Moreover, different researchers have used different quantities of MWCNT ranging from 0.01% to 0.1% (by weight of lubricant) and there appears to be disagreement on the required MWCNT quantity for a given surface and operating conditions. Therefore, there is a need to identify the factors that affect the tribological performance and to determine the effect of these factors on the tribological performance of nano lubricant containing MWCNT by conducting experiments. This will further the understanding and would enable the designer to arrive at a proper decision.

In the present work, Design of Experiments (DOE) is employed to study the effect of four factors: MWCNT quantity, surfactant quantity, load and speed on the tribological performance of the nano lubricant. Four levels of the influencing factors have been considered and their interactions have also been determined. The experiments have been conducted on block and disc test setup to determine the wear of the block in terms of its weight loss. The experimental results has been analyzed and reported.

II. Experimental Details

The experiments have been conducted on block and disk test setup as shown in Fig. 1. The schematic diagram is shown in Fig. 2.

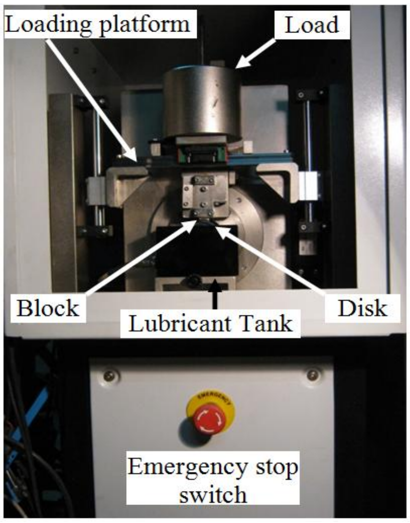

Figure 1 Photograph of block and disk test setup [24]

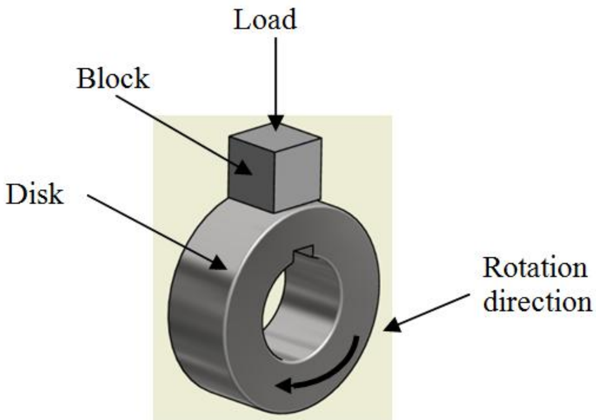

Figure 2 Schematic diagram of block and disk test setup [23]

The block is made of phosphorus bronze material and the disk is made of hardened steel. The disk is of 40 mm diameter and width of 15mm. It is driven by an induction motor. The block is fixed in a holder that is attached to the loading platform. The static load is applied on the loading platform that causes the contact between the flat face of the block with the disk. The flat face of the block slides against the disk. The disk is partially immersed in the lubricant which is maintained at a temperature of 70°C by the help of heaters and a thermal cut-off switch [25]. All the tests were conducted for one hour duration.

Table 1 Factors and levels used in the DOE

Factor	Level 1	Level 2	Level 3	Level 4
MWCNT quantity (weight %)	0%	0.01%	0.05%	0.1%
Surfactant quantity (weight %)	0%	0.1%	0.25%	0.5%
Load (N)	20	30	50	65
Speed (rpm)	25	35	45	55

The factors, affecting the tribological performance, which are considered in the present work, are: MWCNT quantity, surfactant quantity, load and speed. Four levels of these factors are considered for conducting the experiments. The factors and their levels are given in Table 1.

The experiments were conducted using an orthogonal array which facilitates the determination of effect of several factors in a most comprehensive manner. The orthogonal array and the corresponding matrix of experiments are given in Table 2.

Table 2 Orthogonal array

	Factor A	Factor B	Factor C	Factor D
Experiment No.	**MWCNT quantity**	**Surfactant quantity**	**Load**	**Speed**
1	1	1	1	1
2	2	2	1	2
3	3	3	1	3
4	4	4	1	4
5	3	2	2	1
6	4	1	2	2
7	1	4	2	3
8	2	3	2	4
9	4	3	3	1
10	3	4	3	2
11	2	1	3	3
12	1	2	3	4
13	2	4	4	1
14	1	3	4	2
15	4	2	4	3
16	3	1	4	4

The experimental plan consists of 16 experiments corresponding to 16 rows of the orthogonal array. The columns indicate the factors at different levels for each set of experiments. Based on the orthogonal array, table 2, 16 lubricant samples were prepared by dispersing the MWCNT in a commercial lubricant with TX-100 as a surfactant by ultrasonic homogenization for duration of one hour as per the quantities given in table 1.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The Table 3 gives the result of the wear tests conducted on block and disk test setup as per the experimental plan given in table 2.

Table 3 Experimental results

Experiment No.	Wear (mg)	Experiment No.	Wear (mg)
1	1.2	**9**	1.1
2	0.7	**10**	0.2
3	0.4	**11**	0.8
4	0.8	**12**	0.8
5	0.5	**13**	1.6
6	3.1	**14**	2.9
7	0.8	**15**	0.0
8	1.1	**16**	0.0

Based on the experimental results the contribution of each factor is determined and the same is shown in Fig. 3.

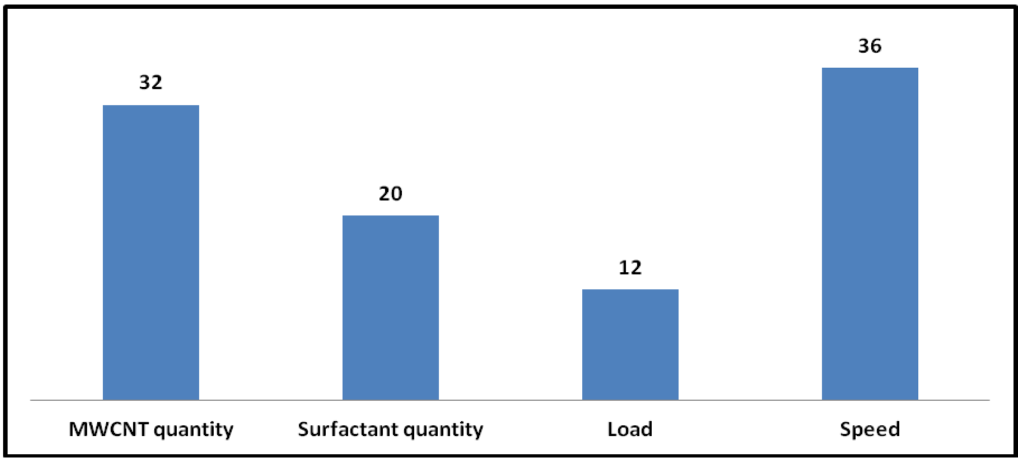

Figure 3 Contribution of various factors

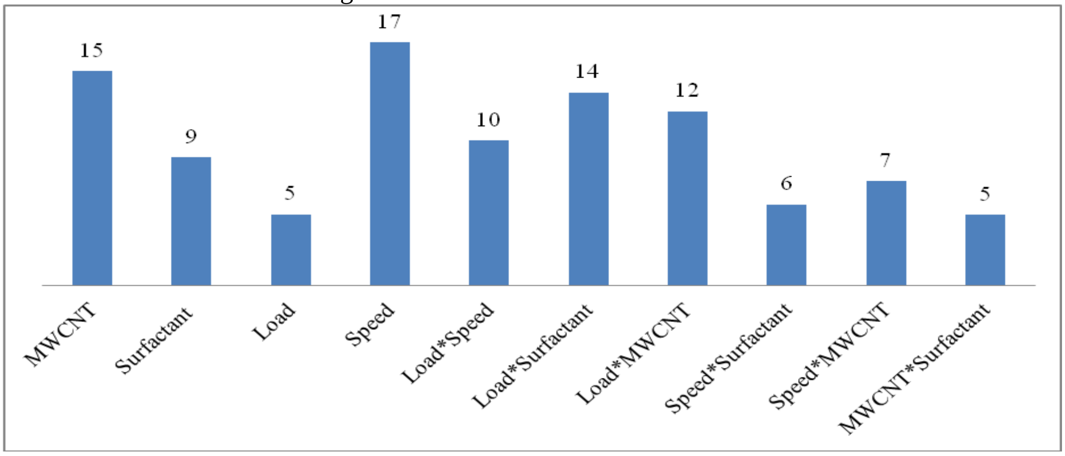

Figure 4 Interaction of various factors

It is observed from the Fig. 3 that there is substantial effect of speed on the wear of the block closely followed by the MWCNT quantity. Since the sliding velocity significantly affects the operative lubrication regime of the block and disk test set up, therefore its contribution to the wear is in right consonance. The next highest contribution is of the MWCNT quantity followed by surfactant quantity and load. The MWCNT being anti-wear additive forms a protective and sacrificial layer on the contacting surfaces and thus significantly affects the wear of the block. The interactions of the various factors were also determined and the same are depicted in Fig. 4.

It is observed from Fig. 4 that the highest interaction is between the load and surfactant followed by load and MWCNT. This indicates that the load, MWCNT and surfactant significantly affect the wear of the block. The effect of load with surfactant and MWCNT is significant as the increase in the load shifts the mixed lubrication regime to elastohydrodynamic lubrication regime and then the role of anti-wear additive becomes more pronounced.

IV. Conclusion

Based on the observations of the experimental studies, following conclusions are drawn:

- The use of MWCNT as anti-wear additive is able to reduce wear of the sliding surfaces.
- The sliding speed and MWCNT quantity significantly affects the wear performance of the nano lubricant.
- The interaction of the load with the surfactant quantity and that of load with MWCNT is significant as compared to other interactions.
- The wear is significantly reduced by the addition of 0.05% quantity of MWCNT in the nano lubricant under different load and speed conditions.
- Further theoretical and experimental studies are required to incorporate the effects of other parameters on the wear of the siding surfaces under varying surface and operating conditions.

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