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A STUDY OF TRIBO-CHARACTERISTICS OF DEEP DRAWING OILS

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ABSTRACT

This paper presents an attempt to study the performance of anti-wear (AW) and extreme pressure (EP) based oils used in deep drawing operations. Four ball tester was used for screening the performance of lubricants. Also an extreme pressure properties of deep drawing oils has been evaluated for its load carrying capacity. Using pin-on-disc machine, tribo-experiments were conducted employing various blends of AW/EP additives of different concentrations in mineral oil. Taguchi's analysis technique was used, as a basis for systematic evaluation of friction coefficient under different operating conditions. A total of three lubricating blends were formulated and tested for varying concentration of vegetable base ester. On the basis of experimental results and S/N ratio analysis, ranking of the parameters has been done. This paper suggests a scientific approach for evaluation of commercially available lubricants.

Keywords: Extreme Pressure Additives, Coefficient of Friction and S/N Ratio.

1. Introduction

The deep drawing process has been used widely in many industries like automobiles, aviation, electronical components etc. The quality of the formed product in metal forming is very difficult to control and depends on many of the process parameters, such as sliding velocity, contact pressure etc. Also the behavior of tribological system depends not only on process parameters but also on the complex set of factors like material of tools and workpieces, lubricant properties, contact geometries, frictional conditions and their interactions. Friction and lubrication attribute significantly in the process. In metal forming processes high pressure is generated at tool-work interface, causing deformation and strain hardening in the material; consequently affects on product quality. Friction determines the required force and energy needed for the process alongwith the flow of the metal. Reducing friction to a very low levels may not be essential, but preferable to avoid adhesive wear, or galling in most cases like forming of stainless steels [1,2]. The main role of the lubricant is to control the friction, to reduce the wear, to prevent seizure and to preserve as long as the possible integrity of the tools and work pieces with optimum frictional energ [3].In almost every rubbing surface when oil is somewhere present a lubricant film manages to get between the surface and carry part of the load. The mechanism by which it does are varied and they are boundary, mixed film, hydrodynamic, and hydrostatic etc. The modes of lubrication in metal forming process are studied by various researchers and boundary as well as mixed lubrication modes are reported by them. Under such a conditions anti-wear (AW) and extreme pressure (EP) additives have been proved their enhanced load carrying capacity. These additives formed a protective layer on the interacting surfaces and carry the load [9]. Several researchers [4,5,6,7] investigated anti-wear (AW) and extreme-pressure (EP), or more precisely extreme-temperature additive influence on friction and wear performance of a base fluid by using four-ball test equipment. Most of them have shown their interest in evaluating the performance of an engine oils, gear oils [4-6], or cutting fluids [7]. Due to diversity of applications and lubricant types, lubricant formulators are facing major challenges in recommending specific metal forming oils for particular application. It is important to have different formulation of oil with additives keeping the base oil as same for different metal forming operation so that the lubricant could be very specific to the particular operation with associated process parameters. This will result in less time of oil preparation suited to customers need and also cut down

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cost considerably. There are three groups of stainless steels commonly used to form products, austenitic group, ferritic group and ferritic-martensitic group. Tribological behaviors of stainless steels were studied by authors using pin-on-disc set-up, but under dry conditions [8]. These steels get work hardened at faster rates than carbon steels; therefore require higher pressure to form, which results in high tool wear rates than those used to form carbon steel. Under these circumstances, the authors felt the need to correlate work hardening property to frictional value.

There is a need to find an appropriate lubricant that works equally well for stainless steels and carbon steel. They differ with their work hardening property. Hardness of a metal is also an indirect measure of strain hardening and it affects the friction and wear characteristics of forming operations [10].

In the present paper the authors studied the friction characteristics of vegetable base ester as an EP/AW additive under varied concentration levels, pressure, speed and work hardening property (n-value) of different grades of steels and stainless steels with the help of Pin-on-disc tribo-tester under sliding conditions. Also load carrying capacities of different blends of lubricants were analyzed using four ball tester.

2. Experimental Work

2.1 Lubricant description

In metal forming operations, the frictional resistance can be reduced by adding a lubricant between the surfaces. A lubricant separates the sliding surfaces by forming a film, and thereby reduces the frictional resistance and wear.

The lubricants used in this study contain base fluid (mineral based oil of kinematic viscosity 89.47 mm^2/sec at 40^0 C) and a mixture of sulfur and vegetable base ester. Sulfur is known for its contribution towards lubricity due to its own structure, also authors tried to find out synergistic effect of sulfur with Vegetable Base Ester. A description of the lubricants is given in Table 1.

Table 1: Lubricant Description

Lube Type	Additive Concentration	
	Sulfur	Vegetable Base Ester
A	2%	0.75%
B	2%	3.00%
C	2%	5.25%

2.2 Anti-wear (AW) characteristics of deep drawing oils

Common test methods of friction and lubrication in laboratories include the four ball test rig testing the load carrying capacity of the lubricant, on Pin-on-disc. Wear tests were performed using a four-ball test machine (TR-30L, by DUCOM) with standard 12.7 mm diameter, hardened E-52100 bearing-steel balls, as per ASTM D-4172 standard. Three 12.7mm diameter steel balls are clamped together and covered with the lubricant to be evaluated. A top ball is pressed with a force 392 N [40 kgf]. The temperature of the test lubricant is regulated at 75ºC [167 ºF] and then the top ball is rotated at 1200 rpm for 60 min. Test Conditions for anti-wear test are shown in Table 2.

Table 2: Test Conditions for AW Test

Temperature	75^0 C
Speed	1200 rpm
Duration	60 min
Load	392 N (40 Kgf)

Lubricants were compared by using the average size of the scar diameter worn on the three lower clamped balls (Fig. 1). The scar diameter was measured with an accuracy of 0.01 mm with the help of an optical microscope.

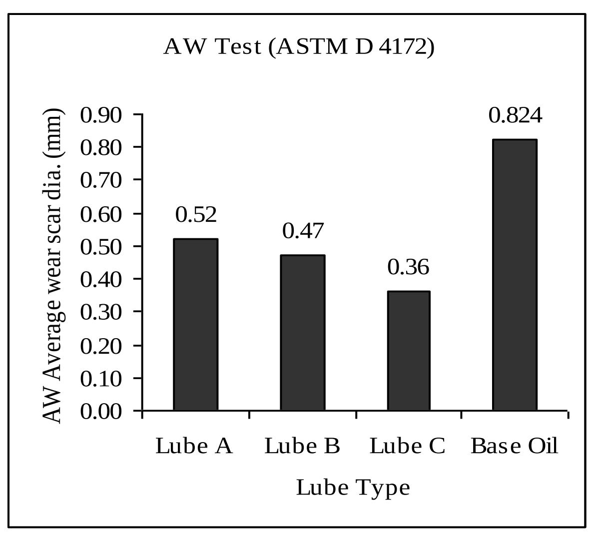

Fig. 1 Lube Type Vs Average Wear Scar Diameter

2.3 Extreme-Pressure (EP) characteristics of deep drawing oils

Extreme Pressure (EP) test were carried out as per ASTM D 2783 standard on the same machine. The rotating speed is 1760 rpm, a series of tests of 10-s duration were made at increasing load until seizure occurs. A ball-cup assembly is cleaned with acetone and a fresh lubricant is placed for each test All four balls were replaced every time and average scar diameter is measured on lower three balls to the nearest 0.01mm, along the striation marks as well as perpendicular to the striation marks.

Fig.2 depicts the relationship between the increasing loads and variation in wear scar diameter for the formulated lubricants. In fig.2 , it is clear that the wear scar diameter increases with the load, also it is observed that 5.25 % vegetable base ester stands good in all type of lubricants. Also weld load is noted and is shown in fig. 3

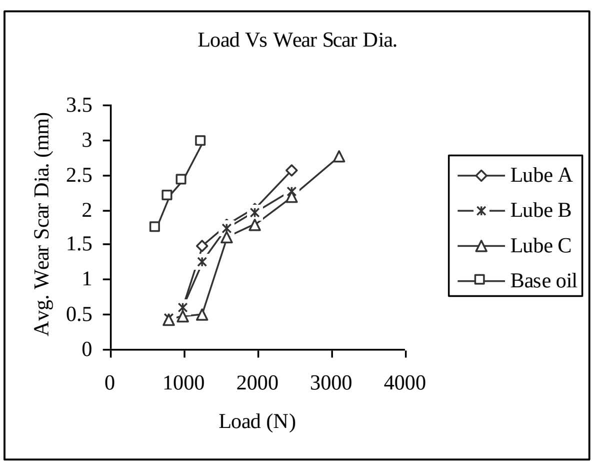

Fig. 2 Load Vs Average Wear Scar Diameter

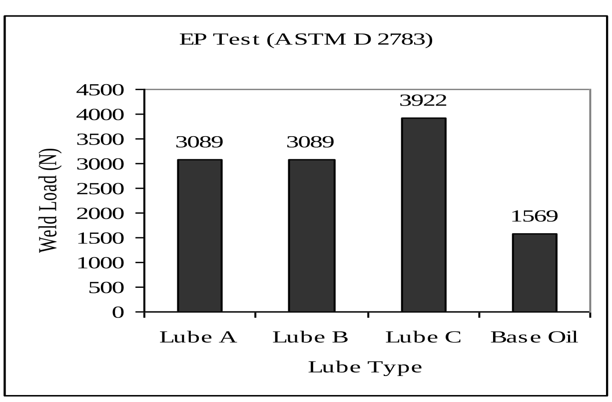

Fig. 3 Lube Type Vs Weld Load

2.4 Frictional characteristics of deep drawing oils

Experiments were conducted using DUCOM (TR-20LE) pin-on-disc equipment under lubricated condition, at room temperature. A schematic diagram for Pin-on-disc set-up is shown in Fig. 4. Process parameters which corresponds to actual forming operation like sliding speed of punch, blank holding pressure, type of lubricant, and strain hardening exponent (n-value) were taken into consideration for the above mentioned experimental study.

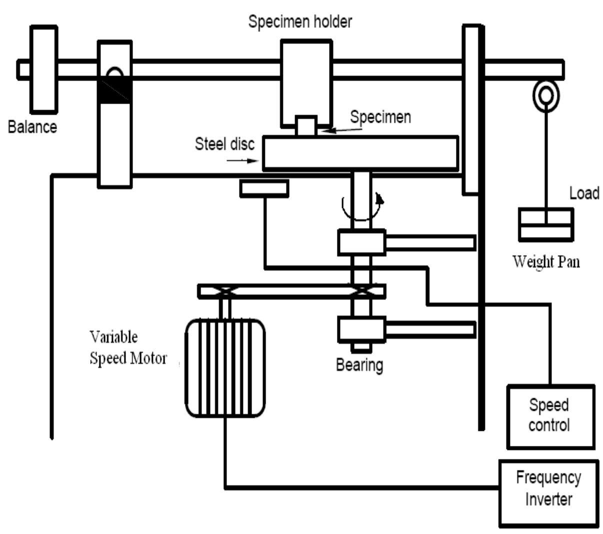

Fig. 4 Schematic Diagram of Pin-On-Disc Set-Up

Pin is of diameter 5 mm, ground on its bottom surface. The counterface disc used is of steel hardened to 62 HRC, 165 mm diameter and 8 mm thick with a surface roughness of 0.1μm. Schematic diagram of Pin-on-disc is shown in fig. 4., in which a disc is rotating through a driven spindle, a lever arm device to hold the pin, and attachments to allow the pin to be forced against the revolving disc with a controlled load.

The tangential force exerted by the disc on the pin is measured by the beam type load cell connected to the indicator. This arrangement avoids any interaction between normal force pressing the pin on the disc and the tangential force arising from friction, thus ensuring accuracy in the measurement of friction force.

2.5 Experimental design

In the deep drawing, metal to metal contact often occurs during relative motion of mating parts, though lubricated, and is subjected to friction and wear. As such, their performance characteristics in metal-to-metal contact are very important from selection point of lubricating oils.

Steels as well as stainless steels are characterized by yield strength, strain hardening, % elongation and high impact strength. Typically, a more high performance lubricant is required for materials exhibiting higher n-value. Author tried to evaluate the performance of same based oil plus sulfur with different concentration of vegetable based ester for materials commercially used for forming operations having different work hardening index (n-value).

The experimental layout for evaluation of lubricants was planned using Taguchi's L_9 orthogonal array. This array consists of four control parameters and three levels, as shown in Table 3. The four parameters were n-value, sliding speed, pressure and type of lubricant, and the out-put response is coefficient of friction under sliding conditions. Each experimental trial was performed at ambient temperature and with three simple replications at each set values.

Table 3: Different Level of Variables

	Levels			
Factors	**I**	**II**	**III**	**Units**
n-value	0.10	0.314	0.45	
Sliding Speed	0.157	0.314	0.417	m/s
Pressure	1	3	5	N/mm^2
Lube Type	A	B	C	

2.6 Analysis of the S/N ratio

The signal to noise ratio (S/N) expresses the scatter around a target value. The larger the ratio, the smaller the scatter. Taguchi's loss function can be expressed in terms of Mean Square Deviation (MSD), and thus S/N ratios. Here in deep drawing operation the coefficient of friction has to be smaller, hence the S/N ratio for smaller is better condition is considered, and the equation for the same is given below.

$$S/N = -10 \log (MSD) \quad (1)$$

Where MSD = Mean Square Deviation.
For smaller is better:

$$MSD = (y_1^2 + y_2^2 + y_3^2 + \cdots y_n^2)/n \quad (2)$$

Where n is the number of observations and y is the observed data.

Using Qualitek-4, Taguchi Design Software, S/N ratios for coefficient of friction, ranking of parameters and ANOVA are calculated and are shown in Table 4, Table 5 and Table 6 respectively.

The mean effects plot for the S/N ratios are plotted for the various parameters namely n-value, sliding speed, pressure and type of lubricant and are shown in Fig.5,6,7,8.

Table 4: L_9 Orthogonal Array with Experimental Results and S/N Ratio.

Test Run	n-value	Sliding speed (m/s)	Pressure N/mm^2	Type of oil	S/N Ratio
1	0.1	0.157	1	A	25.169
2	0.1	0.314	3	B	23.915
3	0.1	0.471	5	C	24.577
4	0.26	0.157	3	C	24.151
5	0.26	0.314	5	A	25.782
6	0.26	0.471	1	B	26.90
7	0.45	0.157	5	B	23.347
8	0.45	0.314	1	C	26.289
9	0.45	0.471	3	A	24.995

3. Results and Discussion

3.1 Analysis of S/N ratios

The results of the response and ranking of parameters are shown in Table. 5.

Table 5: Response Table for S/N Ratios

Levels	n-Value	Sliding speed	Pressure	Lube Type
I	24.55	24.22	26.12	25.26
II	25.61	25.33	24.30	24.72
III	24.82	25.44	24.57	25.01
Delta	1.06	1.21	1.82	0.54
Rank	3	2	1	4

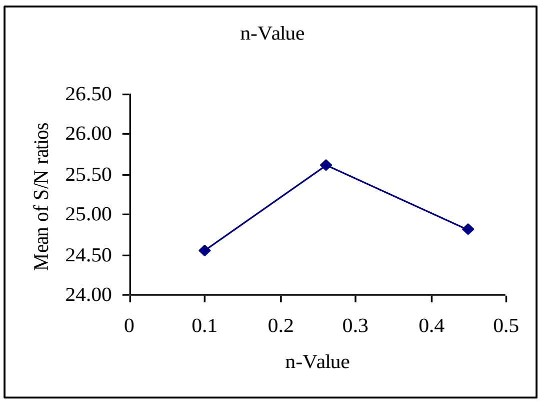

Fig. 5 Effect of n-Value

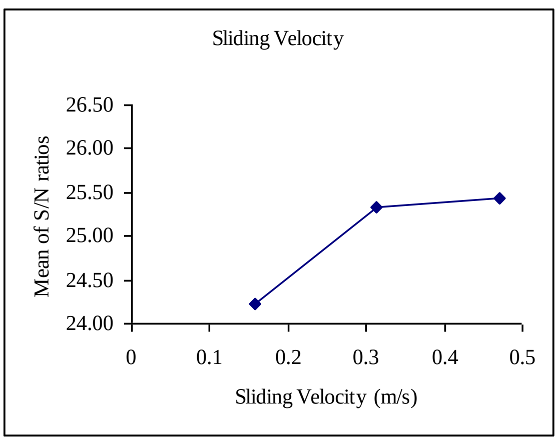

Fig. 6 Effect of Sliding Velocity

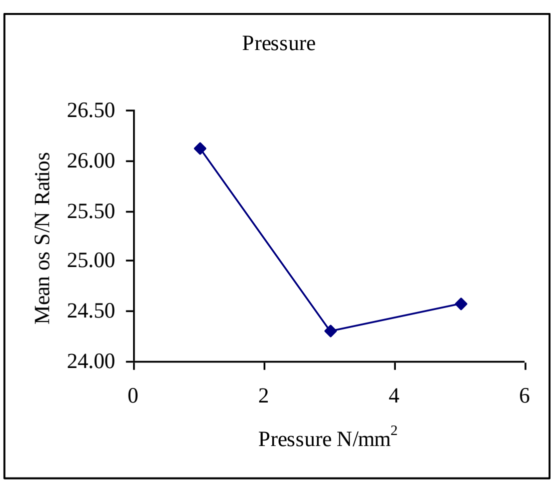

Fig. 7 Effect of Pressure

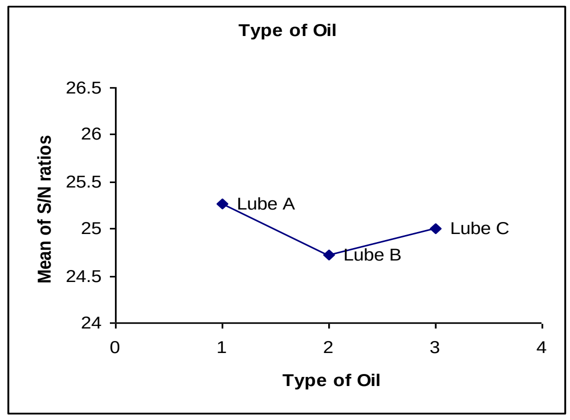

Fig. 8 Effect of Type of Oil

Analysis of the results leads to the conclusion that among all the factors pressure is the most significant followed by sliding speed, n-value of a material, and lubricant type on friction coefficient. Thus pressure, which corresponds to the blank holding pressure in actual deep drawing process is the most significant parameter and needs to be controlled under lubricated conditions.

3.2 Analysis of variance (ANOVA)

ANOVA was used to determine the significance of parameters influencing on friction coefficient. The interaction between the parameters was found to be negligent through factorial experiments. Table 6 shows the analysis of variance for coefficient of friction.

Table 6: Analysis of Variance

Factors	DOF	Sum of Squares	Variance	Percentage Contribution (%)
n-value	2	1.812	0.906	16.856
Sliding Speed	2	2.706	1.353	25.175
Pressure	2	5.794	2.897	53.891
Type of oil	2	0.437	0.218	4.072
Error	0			
Total	8	10.752		100

4. Conclusions

Based on the experimental results following conclusions were drawn**.**

i. Out of study under four-ball Anti-wear (AW) test, it was observed that lubricant C, which contains higher percentage of vegetable base ester showed very good anti-wear characteristics, since showing smallest wear scar diameter.
ii. Base oil without containing any additive shows welding of the balls at very lower load at 1569 N, while, vegetable base ester showed most promising additive with higher concentration and can withstand a load around 3922 N without seizure.
iii. Design of experiments approach by Taguchi method enabled us to analyze successfully the frictional characteristics of deep drawing oils under different conditions with n-value, pressure, sliding speed, and type of lubricant as test parameters. Effect of variables, i.e. pressure and sliding speed are more pronounced on the coefficient of friction, rather than materials exhibiting different n-values and variation in additive concentration for a blended lubricant.

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