Experimental Investigations into Wear Characteristics of M2 Steel Using Cotton Seed Oil

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Abstract

Vegetable oils have traditionally been applied in food uses but recent trends suggest their economic usefulness as industrial fluids. Increasing crude oil prices and emphasis on the development of renewable, environmentally friendly fluids have brought vegetable oils to a place of importance. As environment pollution and health problem became more and more seriously concerned, the use of environmentally friendly lubricants is strongly supported by political parties, regional and local governments. The objective of this work is to determine the influence of lubricant on wear and frictional force by using pin on disc machine with M2 HSS tool. Further an attempt has been made to identify the influence of cottonseed oil in reducing the wear and frictional force. The performance of cottonseed oil is also being compared with dry and wet conditions by using SAE 40 oil. The results indicated that in general, cottonseed oil performed better than the other two conditions in reducing wear and frictional force.

Keywords: Lubricant, wear, cottonseed oil

1. Introduction

The lubricants of the future have to be more environmentally adapted, should have a higher level of performance and lower total life cycle cost than commonly used lubricants today. Since we live on a planet with finite resources we have to think about coming generations and work for a sustainable development in the field of tribology.

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Over the past decade the landscape of the lubrication marketplace has significantly changed because of a combination of environmental, health, economic and performance challenges. To address these challenges it is essential to develop and use lubricants that come from natural resources. Environment friendly or “Green” lubricants are renewable and usually made from vegetable oils e.g. rapeseed, canola, corn, soybean oil, synthetic esters, severely hydro treated petroleum based oils. When compared to mineral and synthetic oils, vegetable oils have a number of distinct advantages including significantly higher lubricity and viscosity, lower volatility and higher shear stability. With better biodegradable and toxicity properties than conventional petroleum based products, vegetable oils have tremendous potential for use in the industrial sector. The ultimate motivation is to research and develop a novel green lubricant that can be used in manufacturing process in industry [1-3].

In all machining processes wear is a natural phenomenon and it leads to tool failure. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature which not only reduces tool life but also impairs the product quality. Metal working fluid changes the performance of machining operations because of their lubrication, cooling and chip flushing functions; however the use of metal working fluid has become more problematic in terms of both employee health and environmental pollution [4].

The cost of replacing cutting tools is a major portion of the total cost of machining. The wear of a cutting tool is the main parameter that determines its life span. Cutting tool wear directly affects machined part quality such as the degradation of the surface finish, dimensional accuracy, etc. It is therefore desirable to select machining conditions that will result in lower wear. Metal working fluid changes the performance of machining operations because of their lubrication and cooling but the use of metal working fluid has become more problematic in terms of both employee health and environmental pollution. The development of lubricants like metal working fluids was traditionally based on mineral oil as a base fluid. This fact is related to the good technical properties and the reasonable price of mineral oils. The two oil crises of 1979 and 1983 however, elucidated that mineral oil is in principle a limited resource. Also mineral oil has its poor biodegradability and, thus it’s potential for long term pollution of the environment and workers health.

The growing demand for biodegradable materials has opened an avenue for using vegetable oils as an alternative to petroleum-based polymeric materials. In the present work it has been tried to found that how wear test of a commonly used cutting tool material (M2 HSS Tool) will lead towards knowledge development about feasibility of bio-lubricant as a metal working fluid. Experiments have been carried out to study the wear characteristics of this material under dry condition and wet conditions using conventional and vegetable oil.

2. Background

Many researchers studied the effects of vegetable oil on various processes parameters in machining. Their finding includes better surface finish, reduced wear, less consumption of energy by using vegetable oil. The common conclusions of all these studies suggest that the vegetable oil can be used in industry applications. Some of the crucial findings are mentioned here. Mia and Ohno investigated the aspect of vegetable oils as lubricant by comparing and examining the physical properties and studying phase diagram of mustard and coconut oil with conventional mineral oil. Lubricity of coconut oil is good and it showed lowest coefficient of friction [5]. Krishna et al. identify and provide eco-friendly and user friendly alternatives to conventional metal working fluids; they studied the application of nano solid lubricant suspensions in lubricating oil in turning of AISI 1040 steel with carbide tool. In all the cases, coconut oil based nanoparticle suspensions showed better performance compared to SAE-40 [6]. Islam et al. studied the effects of vegetable oil based metal working fluid on the cutting performance of medium carbon steel as compared to completely dry and wet conditions in terms of force, torque, chip formation mode and roundness deviation. By using vegetable based cutting oil it is possible to reduce cutting force 6% and torque 6.6 % than using conventional cutting fluid [7]. Stefanescu et al. compared the lubricating capacity of rape seed oil with usual mineral oil. From results it seems that rape seed oil has actual capacity for being used in industrial applications [8]. Kumar et al. studied three different vegetable-based cutting fluids developed from raw and refined sunflower oil
and two commercial types oils were used to determine the thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel with HSSE tool. The least surface roughness was achieved at feed rate of 0.08 mm/rev using sunflower cutting fluid [9]. Anthony and Adithan determined the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 with carbide tool. Coconut oil was found to be a better cutting fluid than the conventional mineral oils in reducing the tool wear and surface roughness [10]. Xuedong et al. studied tribological behaviors by using four-ball machine method according to ASTM D 417. It has been observed that vegetable oil, such as rapeseed oil shows good lubricity under moderate load owing to their strong tendency to form a chemico-absorption film on the metal surface [11]. Onche et al. developed different cutting fluid emulsions of about 10% concentration from fixed oils and the performance of each of the developed cutting fluid was evaluated by a direct comparison with conventional cutting fluid. The ability of each sample to perform effectively as a coolant and lubricant during turning operation has been determined. It was found that cutting fluid developed from groundnut oil performed best as coolant at all experiment speeds [12].

The need of alternative as well as biodegradable fluid has been highlighted from the review of literature. Over the years, many researchers have been working on the viability of various biodegradable fluids in metal working as well as various industrial lubrication. Coconut, mustered, palm, groundnut oils have been tested and the findings shows great promise to exploit the potential of these oils in many applications. To the best of our knowledge, however, no reports on use of cotton seed oil have been made. In context to Indian scenario cotton seed oil is available abundantly in India especially in Maharashtra and Gujrat. Moreover, cost of this vegetable oil is cheaper as compared to others. Therefore the present work is an attempt to investigate into wear characteristics of M2 steel using various lubricating conditions.

3. Experiments

To investigate the effect of wear on M2 steel cotton seed oil among various vegetable oil has been taken. Effect of different lubricating conditions on wear and frictional force at various sliding speed and load has been studied. Comparative analysis of different lubricants in terms of weight loss and coefficient of friction has been done.

3.1. Materials and test conditions

The experimentation is carried out on pin on disc wear testing machine (Figure 1). This is a study versatile machine, which facilitates study of friction and wear characteristics in sliding contacts under desired conditions. Sliding occurs between the stationary pin and a rotating disc. Normal load, rotational speed and wear track diameter can be varying to suit the test conditions. Frictional force and wear are monitored through electronic sensors. M2 steel has been used as a pin material. SiC grit paper used against M2 HSS tool pin. Grit is a reference to the number of abrasive particles per inch of sandpaper. The lower the grit the rougher the sandpaper and conversely, the higher the grit number the smoother the sandpaper. Grit papers of 80 grit size used for experimentation.

3.2. Lubrication medium

Based on literature survey and experience of industry people, Starsol SAE 40 metal working fluid used as fluid in this experiment. It is a cutting oil widely used in industry as a soluble oil.

Further, cotton seed oil was used, as it is cheaper compared to other vegetable alternate and it is available abundantly in India. Cotton grown for oil extraction is one of the big four genetically modified crops grown around the world, next to soy, corn, and rapeseed (canola). The properties/specifications of cotton seed oil and SAE 40 oil are given in Table 1.
Table 1 Specifications of cotton seed oil

| Properties                                      | Cotton seed oil | SAE 40 oil |
|-------------------------------------------------|-----------------|------------|
| Viscosity (cSt at 40°C)                         | 33.86           | 29.0       |
| Viscosity (cSt at 100°C)                        | 7.75            | 5.0        |
| Viscosity Index                                 | 211             | 96         |
| Flash point °C                                  | 252             | 150        |
| Heat transfer coefficient (W/m²K) at 700 °C     | 2190            | 587        |
| Heat transfer coefficient (W/m²K) at 450 °C     | 1970            | 1790       |
| Lubricity (HFRR) (mic. M)                       | 295             | ---        |
| WSD (mic. M)                                    | 139.5           | ---        |

The important factors for selecting the vegetable oils as a feasible choice are:

- Molecules being long, heavy and dipolar in nature create a dense homogeneous and strong lubricating film which gives vegetable oil greater capacity to sustain under high pressure.
- Lubricating film layer provided by vegetable oils, being intrinsically strong and lubricious, it improves work piece quality and overall process productivity by reducing friction, wear and heat generation.
- Higher flash point yields opportunities for increased rates of metal removal because of reduced smoke formation and fire hazard.
- Higher boiling point and greater molecular weight of vegetable oil result in considerably less loss from vaporization and misting.
- Vegetable oils are nontoxic to the environment and biologically inert and do not produce significant organic disease and toxic effect.
- Moreover, ACGIH (2001) reported no sign and symptom of acute and chronic exposure to vegetable oil mist in human.
- It is produced locally to cut transport cost and supply difficulty to free foreign currency for other uses, and to reduce local under-employment [5].
4. Results and discussion

Analysis of results of wear and friction test has been undertaken for dry, by using conventional lubricant and by using vegetable oil at various speeds and loads. Correlation of wear is formulated and comparison of actual and predicted value has also been done. Analysis of Variance (ANOVA) was used to find the significance and relative influence of each factor.

\[ Y = C + m_1X_1 + m_2X_2 \]  

(4.1)

Following values obtained by using above formula.

Putting these values in above equation it becomes the generalized equation for wear resistance.

For dry condition

\[ Y = 0.04337 + 0.000537 X_1 + 0.04165 X_2 \]  

(4.2)

For wet condition

\[ Y = 0.57878 + 0.000831 X_1 + 0.037295 X_2 \]  

(4.3)

From the equation 4.2 and 4.3, predicted value for wear has been calculated for each observation and it is compared with actual value of wear. It has been found that there is very insignificant difference between the both values. It can be observed from the above equations that \( X_2 \) i.e. load has significant effect on the wear as compared to \( X_1 \) i.e. speed.

Total 09 trials have been conducted (Table 2) for dry lubricating condition. In addition each experiment was repeated twice to eliminate the pure error.

Table 2 Influence of input parameter on wear characteristics by using various lubricating condition

| Sr. No. | X1 (Speed) | X2 (Load) | Time (min) | Wear (gm) | COF | Wear (gm) | COF | Wear (gm) | COF |
|---------|------------|-----------|------------|-----------|-----|-----------|-----|-----------|-----|
|         | Dry SAE 40 oil | Cotton seed oil |
| 1       | 300        | 10        | 5.1        | 0.4913    | 0.61 | 0.2572    | 0.53 | 0.2136    | 0.51 |
| 2       | 300        | 20        | 0.7        | 0.8569    | 0.42 | 0.3682    | 0.37 | 0.3013    | 0.34 |
| 3       | 300        | 30        | 1.8        | 1.8963    | 0.39 | 0.8562    | 0.33 | 0.7834    | 0.29 |
| 4       | 600        | 10        | 5.1        | 0.7164    | 0.68 | 0.3152    | 0.56 | 0.2169    | 0.51 |
| 5       | 600        | 20        | 0.7        | 1.1243    | 0.49 | 0.6245    | 0.42 | 0.5247    | 0.38 |
| 6       | 600        | 30        | 1.8        | 1.1564    | 0.42 | 1.013     | 0.38 | 0.9868    | 0.35 |
| 7       | 900        | 10        | 5.1        | 0.8243    | 0.72 | 0.4576    | 0.65 | 0.3568    | 0.78 |
| 8       | 900        | 20        | 0.7        | 1.7562    | 0.44 | 1.246     | 0.41 | 1.145     | 0.40 |
| 9       | 900        | 30        | 1.8        | 1.8983    | 0.43 | 1.251     | 0.39 | 1.215     | 0.36 |

Total 18 trials have been conducted for wet lubricating condition. In addition each experiment was repeated twice to eliminate the pure error. It has been observed from Figure 2, under dry condition, trend for actual and predicted values of wear is overlapping each other except few readings, similarly from Figure 3, it can be observed that there is no significant difference in actual and predicted value of wear for wet condition using cotton seed oil. Correlations are in good agreement with experimental results for wet conditions as compare to dry.
4.1. Comparison of wear and coefficient of friction under different lubricating conditions using various load and various speeds.

The wear was found to be less under wet condition using cotton seed oil as compared to SAE 40 oil (Figure 4). Wear was found to increase with applied load in dry as well as wet conditions, it shows significant difference initially, while no significant at higher load. Better performance of cotton seed oil might be attributed to long, heavy and dipolar nature of cotton seed oil. It is capable of providing a dense, homogeneous and strong lubricious film which provides better support to varying load, moreover, higher flash point and greater molecular weight of cotton seed oil result in considerably less loss from vaporization and misting. It has been also noted that wear at dry condition was comparatively higher than wet conditions using SAE 40 oil and cotton seed oil. At dry condition heat generated was higher which leads to higher material removal from contacting surface [20].
Wear was found to increase with applied load (Figure 5). At dry condition it was much higher than wet conditions using SAE 40 oil and cotton seed oil. It has been noted initially from 300 to 600 rpm under dry condition change in wear was not significant, however it reached up to 1.45 gm at 900 rpm. Besides, SAE 40 oil showed better result compared to cotton seed oil at 300 rpm, however at higher speed cotton seed oil perform better. It might be attributed to higher viscosity of cotton seed oil owing to which it cannot penetrate the sliding zone completely at low speeds. However, cotton seed oil exhibited overall better result than dry and conventional lubricant. The high lubricating property of cotton seed oil is due to the fundamental composition of the vegetable oil molecules as well as the chemical structure of oil. Lubricity of vegetable oils arises from the oiliness property of its constituents, and its properties are the result of long, heavy and dipolar molecules [21].

The Coefficient of friction decreased gradually from 10 N to 30 N of applied load (Figure 6). Higher friction has been observed at dry conditions as compared to both wet conditions. Initially no significant difference in coefficient of friction was found between SAE 40 oil and cotton seed oil, however as load increased cotton seed oil showed better results, it might be happened as lubricating film layer provided by cotton seed oil being intrinsically strong and lubricious which leads to reduction in friction and heat generation. Moreover, viscosity of vegetable oil has vital effect on friction.

Figure 4 Comparison of wear under different conditions

Figure 5 Comparison of wear under different lubricating conditions at various speeds
If the lubricating oil is too thick or too thin friction increases. The higher viscosity index of vegetable oil ensures more stable lubricity across the operating temperature range. The drop in viscosity of vegetable oil with the increase in temperature is relatively slow compared to mineral oil. Conversely as the temperature falls vegetable oil remains more fluid than mineral oil [22].

Figure 9 shows that coefficient of friction increased as speed increased from 300 to 600 rpm under dry and wet conditions; however at 900 rpm coefficient of friction decreased in case of dry and wet condition using SAE 40 oil, while using cotton seed oil it showed increase in coefficient of friction. Vegetable oils especially poly-unsaturated oils are known to possess low oxidative stability the properties of vegetable oils are determined by their fatty acid composition. A high content of linolenic acid decreases thermal and oxidative stabilities which might be attributed to increase in coefficient of friction at higher temperature. However, overall performance of cotton seed oil shows less friction as compared to the other lubricating conditions [23].

5. Drilling Test

In this study viability of cotton seed oil as a lubricant has been assessed and compared with dry and wet (SAE 40 oil) conditions. To check its performance in actual machining, drilling operation has been selected. High production machining and drilling is inherently associated with generation of large amount of heat and high cutting temperatures [24, 25]. In dry condition, such high cutting temperatures reduces dimensional, geometrical accuracy
and tool life. Hence, the present study has been carried out to study the effects of vegetable oil based cutting fluid on the cutting performance of mild steel in terms of wear. Compared to the dry and wet, vegetable oil based cutting fluid performed superior mainly due to reduction in cutting zone temperature [26-30].

The coolant used was water soluble cutting oil and vegetable oil based cutting fluid which has been applied. Drilling of metals by HSS is a major activity in the manufacturing industries. Hence, M2 steel drill bit has been used for drilling process. Wear has been measured in terms of weight loss.

The drilling tests have been carried out on a drill machine (Electronica Argo) by M2 drill bit under dry and wet conditions by conventional cutting fluid and vegetable oil conditions. Water is mixed with both lubricants in ratio of 1:20 and their method of application is same. Plate of M.S. has been taken as work piece of 8 mm thickness and 200 mm in length. Six holes has been drill on M.S. plate by keeping feed rate, material properties constant.

![Graph](image)

Figure 8 Effects of speed and lubricating condition on wear

Wear was found to increase with increased speed. Compared to mineral oil, the cotton seed oil exhibited superior performance in terms of tool wear. These drilling results have found to be in agreement with the findings of wear test.

6. Conclusions

The experiments were carried out on M2 high speed steel under different lubricating conditions. Speed and load have been varied in a wide range to study their combined effect on the wear behavior of this material under dry, wet (SAE 40 oil and cotton seed oil) conditions. Based on this, following conclusions can be drawn:

- It is revealed from the experiment that wear was increased with sliding speed. The time available for the heat dissipation is short and the surface temperature at the interference is significantly higher which leads to increase in wear.
- Wear was found to be increased with the increased load for all the wear test conditions. This is attributed to the decreased separation in the contacting sliding area on which opposite asperities compresses each other.
- The cotton seed oil performed better than dry and wet (SAE 40 oil) condition under varying load; however, no significant difference has been found at higher loading between both wet conditions. It might be
attributed to capacity of cotton seed oil for providing a dense, homogeneous and strong lubricious film which provides better support to varying load.

- At low speed SAE 40 oil performed better as compared to dry and cotton seed oil however as speed increases cotton seed oil showing better result it might be attributed to high lubricating property of cotton seed oil.
- It is observed that at initial loading, coefficient of friction at wet conditions by using cotton seed oil is higher or equal to coefficient of friction by using conventional SAE 40 oil but overall performance of cotton seed oil is better as compared to SAE 40 oil and dry condition.
- Under varying load frictional force values by using cotton seed oil showed better result comparatively reason might be lies in the high lubricating property of cotton seed oil is due to the fundamental composition of the vegetable oil molecules as well as the chemical structure of oil itself.
- Mathematical correlation is developed. The predictions have found to be in good agreement with the actual results.
- During drilling operation it has been observed that cotton seed oil performed better as compared to SAE 40 oil and dry conditions in terms of weight loss at both high and low speed, it has been also noticed that weight loss increased with speed of drilling.
- Hence, it can be concluded that cotton seed oil can be proposed as a metal working fluid in industry as it showed comparatively good result in terms of wear and coefficient of friction at various loads and speeds. Also it is biodegradable, less pollutant, easily available and cheaper as compared to conventional metal working fluid.

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