LUBRICATION PERFORMANCE OF CASTOR OIL BLENDED WITH OTHER VEGETABLE OILS IN GRINDING OF INCONEL 625

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Abstract. The present work is aimed to investigate the effect of mixed vegetable oils in surface quality during surface grinding of Inconel 625 by vitrified bonded alumina grinding wheel. Three different blends of vegetable oils were considered for the study in which castor oil was base oil and blending oils were soya bean oil, corn oil and rice bran oil. Castor oil has good lubricating properties but its high viscous and poor rheological properties make it directly unviable for lubrication applications. In this study, the rheological properties of the castor oil were modified to cater to the specified needs for grinding of Inconel 625 by mixing it with some other vegetable oils. The blends were prepared in 1:1 proportion. Experiments were conducted using the blends of vegetable oils in grinding of Inconel 625 under identical work conditions. The finished work piece was measured for its surface quality with respect to its average surface roughness, surface morphology and temperature generated on the work piece. The castor oil and soybean blend produced the lowest surface roughness, $Ra = 0.0738 \mu m$ & $Rz = 0.4299 \mu m$, with near absence of deep grooving and smearing of chip material on the surface, in comparison with other blends due to enhanced rheological properties.

Keywords: Grinding, Inconel 625, Vegetable based cutting fluid, Surface roughness, blended castor oil

1. INTRODUCTION

Grinding is a finishing process, which generates high temperature in the workpiece due to grit-work material interaction. The friction between grinding wheel and workpiece is the major source for heat generation, where some part of heat is lost through chips. High temperature involved in grinding process leads to large power consumption, poor surface quality and surface integrity on the workpiece [1]. Grinding process requires large amount of metal working fluids (MWF) to reduce the amount of heat generation by reducing friction with the aid of applying appropriate MWF in the grinding zone [2]. Traditionally copious amount of mineral oil-based cutting fluids is being used as MWF in grinding difficult to cut materials like Inconel 625. However, mineral oil exhibits very poor impact on environment. About 80% of occupational diseases to machine operators are due to the exposure of MWF in the working environment [3]. Dry machining is the target to eliminate the cutting fluid in the machining industry thus reduces the machining cost and ecological impact. In contrary absence of MWF increase the grinding wheel- workpiece interaction thus diminish the surface quality, tool life and
increase cutting forces. Minimum Quantity Lubrication is another approach to reduce the cutting fluid in grinding, where minute droplets of lubricants are directed to the grinding zone. Although MQL reduces the MWF consumption, it still uses them in the form of mist or droplets which increases health hazards for the workers like respiratory issues [4]. Another approach to grind hard metals by sustainable manner is cryogenic grinding. Irrespective of its eco-friendly nature, it has produced some negative effects in grinding of hard to cut materials. PP Reddy and Ghosh (2016) explored the scope of cryogenic coolant (LN2) application in surface grinding of AISI52100 using vitrified Alumina Grinding wheel [5]. In their work a high power consumption, excessive wheel wear and more tensile residual stress on the ground surface were observed for LN2 coolant when compared with soluble oils. Vegetable oils have proved to exhibit better lubricity due to its long fatty acid chains in their molecules [6]. Asadauskas et al. (1997) exhaustively investigated the castor oil, super-refined mineral oil, and high-oleic corrosive sunflower oil for understanding the thickness, oxidation security, statement age tendency, unpredictability, lubricity, and similarity with added substances [7]. The outcomes of literature study show that the castor oil displays to be potential biodegradable base oil. Although the high viscosity of castor oil provides the better lubrication in the grinding zone, it has poor rheological attributes. This restricts their usage in high speed machining operations. Further these poor properties can be balanced by mixing another vegetable oil with low viscosity such as soybean, maize, peanut, sunflower, palm, and rapeseed oils with castor oil [8]. However, its application in grinding and other metal cutting operations is not explored in detail in the past. The main aim of the present work is to investigate the role of mixed vegetable oils in surface finish of ground Inconel 625 workpiece.

2. EXPERIMENTAL PROCEDURE

The work material selected for grinding in this investigation is Inconel 625 which is used where high strength is required at elevated temperature such as aero engine. Its chemical composition is listed in Table 1. The grinding experiments were done on surface grinding machine having maximum rotation speed of 2400 rpm and Power of 1.5kW. The grinding conditions are wheel speed: 24 m/s; Feed: 3m/min and depth of cut: 7, 14 µm under dry and lubricated environment. All grinding experiments were done with Alumina grinding wheel having fine alumina grits with vitrified bond. The grinding temperature was measured with the aid of non-contact Laser Infrared Thermometer (Make: MCP, Model: Ir-20). Average surface roughness ($R_a$) and ten point average roughness ($R_z$) of the ground surface were measured using computerized surface roughness tester (Make: Surfcom, Model: 1400G). Further the selected ground region was observed under Scanning Electron Microscope (SEM) to reveal the grinding marks and surface finish features.

Table 1: Chemical composition of Inconel 625

| Elements | Ni  | Cr  | Fe  | Mo  | Nb  | C   | Mn  | Si  | Ti  | S   | Al  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Percentage| 63  | 20.3| 4.31| 8.81| 3.33| 0.004| 0.03| 0.018| 0.017| 0.006| 0.17 |

Castor oil was selected as base oil for all grinding experiments. Other vegetable-based oils such as soya bean, corn oil and rice bran oil were mixed individually with base oil (castor oil) in the proportion of 1:1 to alter the rheological property. The flash point, fire point and viscosity of the mixture were tested using Cleveland open cup apparatus and Redwood viscometer respectively and listed in Table 2.
Table: 2 Flash point, Fire point and Kinematic viscosity of castor oil and other blends

| Oil Blends                  | Flash Point (°C) | Fire point (°C) | Kinematic Viscosity (cSt) at 60 °C |
|-----------------------------|------------------|-----------------|----------------------------------|
| Castor oil                  | 230              | 250             | 198.6                            |
| Castor oil + Soyabean oil   | 260              | 310             | 25.50                            |
| Castor oil + Corn oil       | 300              | 325             | 28.81                            |
| Castor oil + Rice Bran oil  | 310              | 330             | 30.45                            |

3. RESULT AND DISCUSSION

3.1 Grinding Temperature

Grinding temperature is one of the most important factors that affects the surface quality of ground workpiece. During grinding, an abrasive wheel is in contact with the workpiece causing an abrupt rise in temperature. The detrimental effects of surface cracking, burn marks and tensile residual stress are often directly related to high grinding temperature. The variations of the temperature on the ground surface of the workpiece with the different vegetable oil at similar grinding conditions are shown in Fig. 1. It is clearly evidenced that dry grinding developed a temperature to a minimum of 1.5 times higher than that of produced by other blended oil lubricating conditions. Use of blended vegetable oil based cutting fluids reduce the impact of rubbing abrasive grits with workpiece by forming a thin film of lubrication layer and reduce the wear of micro abrasives by dulling. The castor oil + rice bran oil lubricating conditions produced least grinding temperature of 350°C when compared with other combinations, which was mainly due to good thermal properties such as high flash point (310°C) and fire point (330°C) and high viscosity (30.45 cSt at 60°C). However, the impact of such low temperature of castor oil + rice bran oil lubrication was not reflected on the surface roughness and surface morphology.

![Figure 1](image.png)

Figure 1 Variation of grinding temperature during grinding of Inconel 625 at cutting speed: 24 m/s; feed: 3 m/min and depth of cut: 14 µm with different blended vegetable-based metal working fluids.
3.2 Surface Roughness

Figure 2 and 3 depicts the variations of surface roughness (Ra and Rz) of ground surface at cutting speed= 24 m/s, Feed = 3 m/min and depth of cut = 7, 14 µm. The average surface roughness (Ra) increased with increasing depth of cut in the case of grinding with dry and all other lubricated conditions. It is thus obvious that the surface roughness produced under lubricated conditions is superior to that of finish produced under dry environment. Among three vegetable blend, castor oil + Soya bean oil produced smoother surface (Ra = 0.0738) compared with its counterparts. The lowest kinematic viscosity of the blend (25.5 cSt at 60°C) allows it to reach the grit workpiece interface without any difficulty which in turn reduce the friction and average surface roughness. The poor surface quality produced under castor oil + rice bran oil is probably due to its insufficient rheological behavior even after mixing. The ten-point average roughness, Rz also followed the same trend as Ra.

![Figure 2](image1.png)
Figure 2 Variation of Ra after grinding of Inconel 625 at cutting speed: 24 m/s under different blended oil lubrication environments

![Figure 3](image2.png)
Figure. 3 Variation of ten point mean surface roughness (Rz) after grinding of Inconel 625 at cutting speed: 24 m/s under different lubrication conditions
In contrary variation of Rz observed under castor oil + rice bran oil is almost nearer to the values that are produced by other lubrication conditions.

3.3 Surface Morphology of ground surface

The surface of the ground specimens was observed under SEM to reveal the grinding marks and other surface features at higher magnification. Figure 4. depicts the magnified view (2000X) of ground surface after grinding at speed = 24 m/s, Feed = 3 m/min and Depth of cut: 7, 14 µm. It is observed that in all lubrication conditions grinding marks were visible. But the severity of the marks and other features determine the quality of ground surface. Deep grooving and smearing were observed on the surface under dry environment (Figure. 4(a)) which may be due to the increased rubbing action of abrasive grits with work material. Castor oil + soya bean oil blend produced almost flaw free surface which was mainly due to very smooth interaction of grit over workpiece during grinding.

Figure. 4 SEM images of ground surface at cutting speed: 24 m/s table feed: 3 m/min and depth of cut: 14 µm under (a) dry (b) castor oil + soya bean oil (c) castor oil + corn oil (d) castor oil + rice bran oil environments
There is a redeposited layer on the surface produced by castor oil + corn oil blend. In contrast castor oil + rice bran oil produced irregular grooving on the work surface. It is evidenced that there is a lack of penetration of high viscous castor oil + rice bran oil combination particularly at depth of cut = 14 µm.

4. CONCLUSION

Three different blends of Castor oil mixed with other vegetable oils (i.e., soybean, corn and rice bran oil) were prepared, each at a ratio of 1:1. Castor oil was taken as point of comparison and nickel based super alloy Inconel 625 was chosen as workpiece material. The lubrication performance of blended oils during grinding was experimentally investigated. From the investigated results obtained, the following conclusions were construed.

On comparison, the flash and fire point of castor and soya bean oil blend was least at 260°C and 310°C respectively. But rice bran and castor mixture show the highest flash and fire point which are 310°C and 330°C. As the rice bran shows the highest value in flash and fire point, it is best suitable for grinding at high temperature.

The viscosity of rice bran and castor oil blend shows higher value (30.5 cST) than castor and corn oil mixture (28.81 cSt) or castor and soya bean oil blend (25.5 cSt). So higher viscosity oils will have flow problems and lesser viscosity is good for lubricant in flood lubrication.

Among three blends, castor oil + soya bean oil produced lower average roughness (Ra = 0.0766 µm) when compared with the results of blends, castor oil + corn oil (0.0959 µm) and castor oil + Rice bran oil (0.1312 µm), but the variation is very marginal.

Many deep grooves, rough surfaces were observed in dry grinding environment. Meanwhile, the surface morphology of the workpiece under the blended oil environment was found enhanced. Therefore, the blend of soybean and castor oil produced the best surface quality with nearly free from deep grooving and smearing of chip material on the surface, when compared with other blends.

References

[1] Brinksmeier, E., Meyer, D., Huesmann-Cordes, A. G., & Herrmann, C. (2015). Metalworking fluids—Mechanisms and performance. CIRP Annals, 64(2), 605-628. Katna, R., Suhaib, M., & Agrawal, N. (2020).
[2] Nonedible vegetable oil-based cutting fluids for machining processes—a review. Materials and Manufacturing Processes, 35(1), 1-32. Shashidhara, Y. M., & Jayaram, S. R. (2010). Vegetable oils as a potential cutting fluid—an evolution. Tribology international, 43(5-6), 1073-1081.
[4] P. Sreejith, B. Ngoi, Dry machining: machining of the future, Journal of Materials Processing Technology 101 (2000) 287–291.
[5] Reddy, P. P., & Ghosh, A. (2016). Some critical issues in cryo-grinding by a vitrified bonded alumina wheel using liquid nitrogen jet. Journal of Materials Processing Technology, 229, 329-337.
[6] Iyappan, S. K., & Ghosh, A. (2019). Small quantity lubrication assisted end milling of aluminium using sunflower oil. International Journal of Precision Engineering and Manufacturing-Green Technology, 1-9.
[7] Asadauskas, S., & Erhan, S. Z. (1999). Depression of pour points of vegetable oils by blending with diluents used for biodegradable lubricants. Journal of the American Oil Chemists' Society, 76(3), 313-316.
[8] Guo, S., Li, C., Zhang, Y., Wang, Y., Li, B., Yang, M., Z Xianpeng & Liu, G. (2017). Experimental evaluation of the lubrication performance of mixtures of castor oil with other vegetable oils in MQL grinding of nickel-based alloy. Journal of Cleaner Production, 140, 1060-1076.