Effect of CuO nanoparticles based vegetable oil on the machining performance of WC tool insert while turning EN 8 steel

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Abstract

Tool wear is a very unavoidable phenomenon that affects the overall performance of cutting tool during machining. Improvement in tool wear leads to deformation in surface finish and an increase in cutting force. Poor surface finishes influence the product quality and raise the product cost as well as machining cost. In this study, the copper oxide (CuO) nanoparticles have mixed with vegetable oil (coconut oil) to enhance the machining property of tungsten carbide (WC) cutting tool. The performance of WC cutting tool inserts have been investigated in, wet, vegetable oil and CuO nanoparticles based vegetable oil cutting environment. Turning of EN 8 steel has been done by keeping constant cutting parameters viz. speed, feed, and depth of cut. The tool wear has measured in terms of flank wear, and nose wear. Results reveal that the addition of CuO nanoparticles into the vegetable oil reduces the tool wear and surface roughness significantly.

Keywords
Cutting fluid, tool wear, surface roughness, nanoparticles, vegetable oil

1. Introduction

Recently, researchers are more focused on sustainable manufacturing and the development of eco-friendly solutions in manufacturing. In machining industries, turning is the most elementary manufacturing process of metal removal. The performance of the cutting tool is extensively influenced by friction and temperature, which take place between tool and workpiece (Prasanth et al., 2018). This not only reduces tool life but also affects product quality. Tool wear is a unavoidable phenomenon it can only be reduced. Tool wear domenantly effect the machining performace of cutting tool, consequently the surface quality also reduces. Tool starts wearing with the start of machining due to a high abrasion and cutting temperature. Different types of tool wears are shown in Figure 1.

Machining temperature can be regulated with the help of cutting fluid (Jhodkar et al. 2014). A significant purpose of cutting fluid is to decrease friction between tool and workpiece and tool-chip interfaces presently (Jhodkar et al. 2018). It works as a coolant and lubricant both. Conventional cutting fluid such as petroleum products and soluble oils make numerous undesirable outcomes such as environmental pollution and soil contamination during disposal (Fox et al., 2007). Petroleum-based cutting fluids contain sever harmful chemicals due to which operators suffer lots of skin disorders and eye burns problems. Shashidhara and Jayaram (2010) evaluated the performance of vegetable oil as cutting fluid. The study focuses on the physical and chemical properties of different vegetable oils such as soybean, sunflower, rapeseed, jojoba, jatropha, etc. Fox and Stachowiak (2007) described the environmental factors such as biodegradability, renewability of vegetable oil, and further elaborated about the low oxidation and thermal stability, viscosities properties of the vegetable oils. Jayadas et al. (Jayadas et al. 2007) have studied the thermo-gravimetric analysis of coconut oil. Lawal et al. (2012) described the application of vegetable oil-based metal working fluids in machining ferrous metal. In that study, authors concluded that vegetable-based cutting fluid reduces the cutting temperature, surface roughness, and tool wear. The use of nanoparticles also influences the performance of vegetable oils because it reduces cutting temperature and friction coefficient. Many researchers focused to increase the machining performance of vegetable oil by adding nanoparticles. Nguyen et al.(Nguyen et al. 2012) determined the effect of nanoplatelets based vegetable oil during MQL machining. The result indicates that the performance of the cutting tool has improved significantly.

Chen et al. (2013) prepared the water-based cutting fluid to improve the machining ability of cutting tools with the help of graphite nanoparticles. Thottackkad et al. (2012) have investigated the lubrication property of coconut oil after the addition of copper oxide (CuO) nanoparticles by weight. Results reveal that the nanoparticles improved the viscosity, friction of coefficient, and wear rate. Das et al. (2019) employed CuO nanoparticles in rice brand oil in hard turning of HSLA steel. Similarly, Vamsi Krishna et al. (2010) evaluated the effect of nano-boric acid particles in SAE-40 and coconut oil while turning AISI 1040 steel. The authors concluded that tool wear, cutting temperature, surface roughness affected significantly. Copper nanoparticles have also used for friction reduction and anti-wear additives in lubricating oils (Jatti and Singh 2015).

The application of nanofluids as metalworking cutting fluid has widely increased globally. Researchers are more focusing to prepare suitable nanofluids as a better alternative of conventional cutting fluids or petroleum-based cutting fluids. Therefore, use of vegetable oil to prepare the nanofluid is a better idea, because vegetable oil posses high biodegradability and lesser environmental impact. Literature review indicates that CuO nanoparticles have been used to prepare the lubricant and additives rather than cutting fluids. However, few articles have been published in which the capability of CuO nanoparticles have been examined with vegetable oil to enhance the cooling and lubrication properties. Hence, in the present study, CuO integrated coconut oil that possesses prominent characteristic such as biodegradability, high thermal stability, better heat dissipation, good lubricating, and cooling ability, has been used for turning of EN8 steel. The performance of nanoparticles based vegetable oil compared with conventional cutting fluid (wet cooling) and plain vegetable oil (coconut oil) for tool wear and surface roughness.

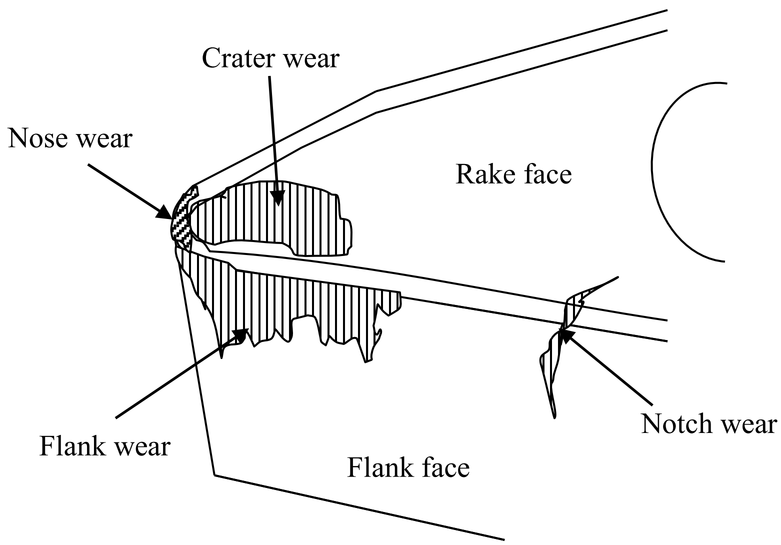

Figure 1. Different types of tool wear mechanisms

2. Experimental Procedure

The objective of this research work is to understand the influence of CuO nanoparticles on vegetable oil during the machining performance of carbide insert under three different cutting conditions (wet, vegetable oil, nanoparticles based vegetable oil). The machining experiment was carried out in 4 jaws conventional lathe(China lathe) with the power of 18.5 kW .EN8 steel workpiece of size of ø65 x 400 mm was considered as the work material. The chemical composition of EN 8 steel is C 0.36-0.44; Mn 0.55-1.00; P 0.06; S0.004; Si 0.10-0.045. The EN 8 steel widely used in manufacture a high strength engineering parts such as gears, axels, nut-bolts, studs, spindles, and various automotive engineering components. The turning operations were performed by using tungsten carbide inserts of specification WIDIA DCMT11T308. The insert was clamped with the help of screw on the rigid tool holder SDJCR 2020 K11 WIDAX recommended by the insert manufacturer. The schematic layout of experimental setup has shown in Figure 2. The CuO nanoparticles of size 20-30 nm average diameter, 97 % purity and having a length of 10-30 µm length. The CuO nanoparticles have mixed by weight in coconut oil with the help of ultrasonic mixture processer (Johnson Plasto) for 60 minutes. The machining parameters are kept unchanged viz. speed 640 rpm, feed 0.1 mm/rev and depth of cut 1.5 mm for all experiments. The cutting parameters were selected based upon literature survey and tool manufacturer recommendation. In this study, the flank wear (Vb) and nose wear (Vn) were measured with the help of optical microscope. In wet cutting conditions, soluble oil has used as a cutting fluid with the flow rate of 5L/hr. The surface roughness(Ra) was measured using Rugosurf 10G tester at three different locations of the workpiece and average value was recorded.

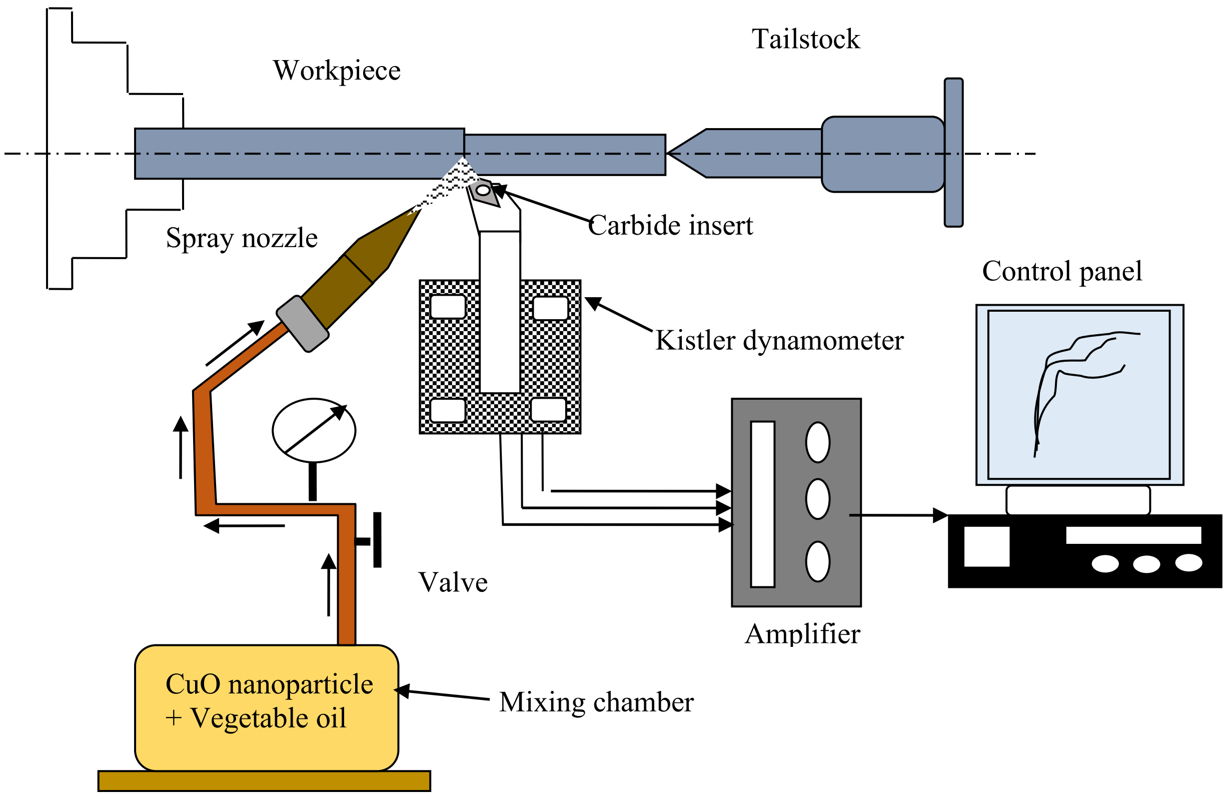

Figure 2. Schematic representation of the experimental setup.

3. Results and Discussion

3.1 Flank and nose wear

In this paper, the machining performance of CuO nanoparticles based vegetable oil is investigated through comparing the tool wear results with wet and plain vegetable oil cutting environment. Tool wear refers to abrasion on the flank below the cutting edge and abrasion of tool face just back of cutting edge. The tool performs satisfactorily when average tool wear range (flank wear and nose wear) must not exceed 0.4 mm. The rise in the cutting temperature between tool-chip interfaces is also a significant factor that affects the performance of the cutting tool. Researchers claim that the application of cutting fluid cool down the tool and workpiece. As well the other important function of cutting fluid is to flow away the chips, and cleaning of tool, workpieces and fixtures. As per Figures 3 and 4, wet cutting is showing maximum flank wear and nose wear because during high-speed machining the cutting fluids do not reach to the shear zone properly. The relative friction between the cutting tool and the workpiece results high break-in wear in the wet cutting condition.

The lack of effective penetration and high temperature generated near the shear zone responsible for higher flank wear and nose wear recorded in wet cutting conditions. In this study, vegetable oil is showing lower flank wear and nose wear as compared to wet cutting conditions. Because the application of vegetable oil reduces the coefficient of friction and plastic deformation of tool edges significantly as compared to the conventional cutting fluid. the nanoparticles based vegetable oil has worked effectively and produced with lesser flank wear and nose wear as compared to wet machining and plain vegetable oil. The addition of CuO nanoparticle into the vegetable oil has improved the thermal conductivity and heat transfer capacity of vegetable oil. The combined effect of nano particles and vegetable oil reduced the coefficient of friction and shear resistance that resulted reduction in flank and nose wear of cutting tool insert. Furthermore, flank wear and nose wear were higher in WC insert in wet cutting condition due to insufficient penetration and improper lubrication. Calculation and analysis show that the average flank wear was recuced upto 53% and average nose wear was reduced upto 83% after mixing CuO nano particles in the vegetable oil.

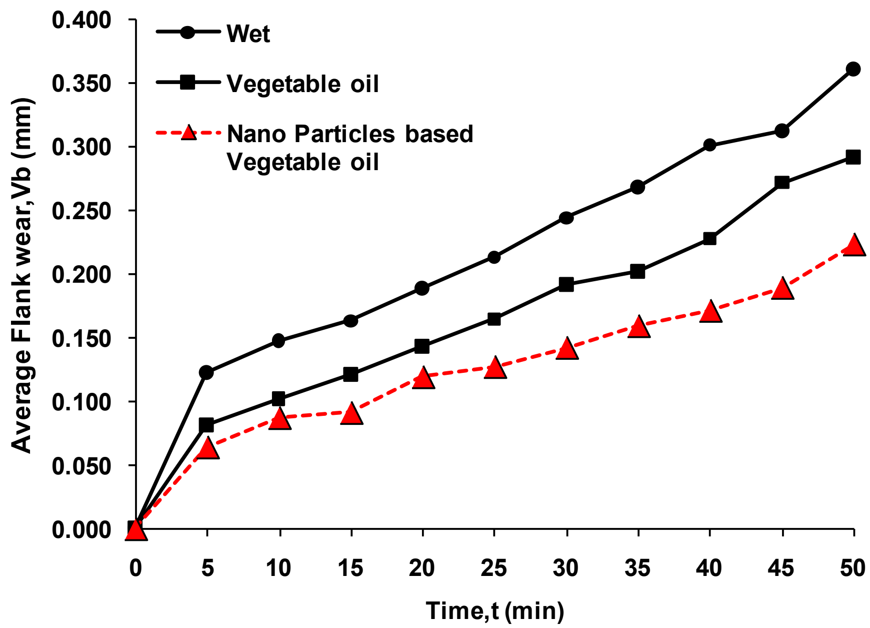

Figure 3. Average flank wear (Vb) vs machining time for all three conditions

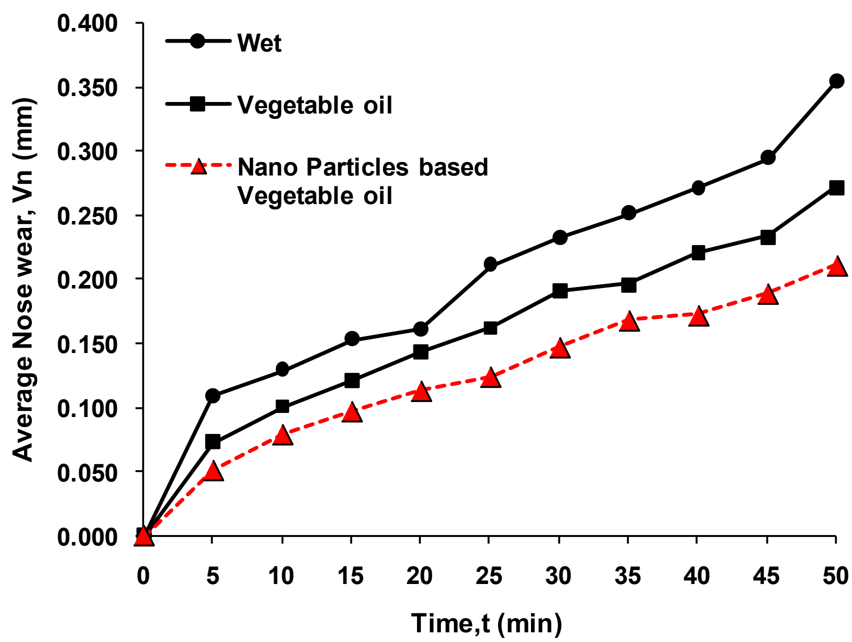

Figure 4. Average nose wear (Vn) vs machining time for all three conditions

3.2 Surface roughness

During machining, the cutting tool marks are left behind on the workpiece in the form of microirregularities as replica of tool nose. For moving surfaces, the finish affects both frictions and wear whether they are lubricated or not (Jhodkar et al. 2018). The machining conditions such as speed, feed, and depth of cut, the geometry of chip, cutting fluids, tool geometry and cutting environment greatly effect the quality of surface produced (Vardhaman et al. 2018). Therefore, in this work surface roughness was observed as key factor to evaluate the performance of the WC tool insert under different cutting environment viz. wet, vegetable oil and nanopracticals based vegetable oil.

Figure 5 shows the variation in surface roughness observed during turning of EN 8 steel under the aforementioned cutting condition. During initial experiments, the surface roughness was recorded minimum. The value of roughness starts increasing gradually after every cut due to an increase in tool wear. It was observed that the surface roughness was higher (5.12 µm) during machining in wet cutting condition at 50 minutes. However, in vegetable oil and nanoparticles based vegetable oil, cutting condition surface roughness was recorded 4.13 µm and 3.32 µm respectively. The 63.4% reduction in surface roughness was recorded after mixing CuO nanoparticles in the vegetable oil. Turning with conventional cutting fluid resulted in the maximum surface roughness as compared to other cutting conditions.

The cooling and lubrication property of vegetable oil is much better than conventional cutting fluid. It also has high thermal stability and good viscosity(Xavior and Adithan 2009). The performance of vegetable oil has furthermore increased by adding CuO nanoparticles into it that results in increase in thermal conductivity and heat dissipation rate. Results show that roughness has significantly improved as compared to wet cutting and vegetable oil cutting conditions. The CuO fluid film produced on the surface of the workpiece protected it from tool feed marks. The cushioning effect of nanoparticle resisted micro damping, deburring on the surface, and reduced surface roughness.

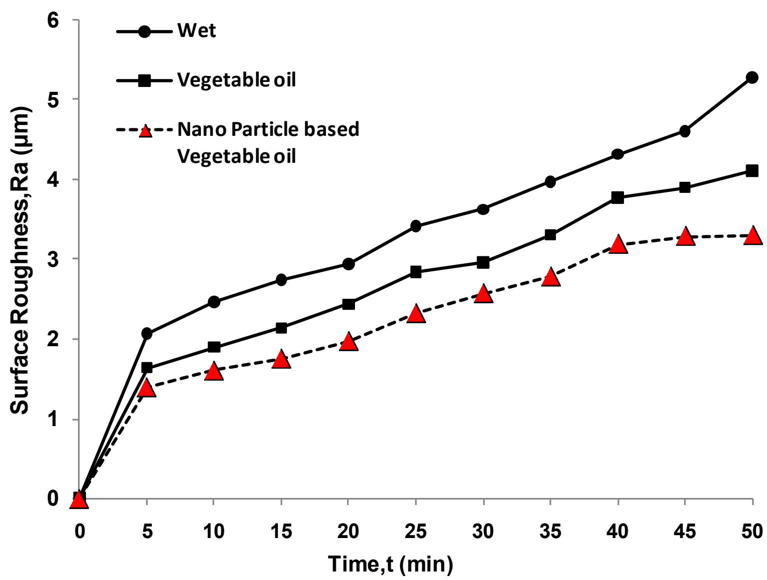

Figure 5. Surface roughness Ra (µm) vs machining time for all three conditions.

4. Conclusions

In the present work, the experimental investigation has been carried out to evaluate the influence of CuO nanoparticles based vegetable (coconut) oil on the performance of WC tool insert during turning of EN 8 steel. Results reveal that CuO nanoparticles improve the cooling and lubrication properties of vegetable oil. The following conclusions can be drawn from this research work-

- The addition of CuO nanoparticles into the vegetable oil improves the machining performance of WC inserts significantly due to a reduction in friction, low tool tip temperature, high spreadability and further heat dissipation due to that.

- The application of nanoparticles based vegetable oil reported more than 50% reduction in both flank and nose type tool wear as compared to conventional cutting fluid and vegetable oil.
- Improved cooling and lubrication property of vegetable oil by employing CuO nanoparticles results in a reduction in surface roughness 40-60% due to the formation of combine thin layer fatty acids and CuO nanoparticles.
- The avenues for future research could possibly be investigating the cutting forces and chip morphogoly under the influence of CuO nanoparticles in coconut oil, a comparative study on using these particles in other lubrication systems, and machining process life cycle analysis etc.

This study will motivate researchers and tool engineers to develop eco-friendly cutting fluid.

Acknowledgements

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