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Investigation of the Effect of CuO Nanofluid in Minimum Quantity Lubrication Machining

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Key words
Nano-enhanced lubricant; Minimum quantity lubrication; Machining; Cutting tool.

Abstract

Nanofluid is a new class of fluids engineered by dispersing nanometer-size solid particles into base fluids such as water, ethylene glycol, engine oil, cutting fluids, etc. Researches have shown that the thermal conductivity and the convection heat transfer coefficient of the fluid can be largely enhanced by the suspended nanoparticles. Recently, tribology research shows that lubricating oils with nanoparticle additives (MoS_2, CuO, TiO_2, Diamond, etc.) exhibit improved load-carrying capacity, anti-wear and friction reduction properties. These features make the nanofluid very attractive in some cooling and/or lubricating application in many industries including manufacturing, transportation, energy, and electronics, etc. In this study, the effect of CuO nanofluid in minimum quantity lubrication machining was investigated.

Minimum Miktarda Yağlama ile İşlemede CuO Nanoakışkanın Etkisinin Araştırılması

Anahtar kelimeler
Nano-geliştirilmiş yağlayıcı; Minimum miktar yağlama; Metal ,şleme; Kesici takım.
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Özet

Nanoakışkanlar, su ve benzeri etilen glikol, makine yağı, kesme yağı vb. temel akışkanlara nano boyutta ilave edilen katı parçacıkların yeni bir mühendislik tasarımıdır. Yapılan araştırmalar nanoparçacıklar kullanılarak akışkanın ısı iletkenliği ve ısı transfer katsayısının büyük ölçüde geliştirilebileceğini göstermektedir. Son zamanlarda, tribolojik araştırmalar nanoparçacık katkılı (MoS_2, CuO, TiO_2, Diamond, vb) yağlama yağlarının daha fazla yük taşıma kapasitesi, anti-aşınma ve sürtünmeyi önemli ölçüde azaltan özellikleri gösterdiğini ortaya koymaktadır. Bu özellikler, imalat, ulaştırma, enerji, ve elektronik gibi birçok sanayi bazlı soğutma ve veya yağlama uygulamasında nanoakışkanları çok cazip hale getirmektedir. Bu çalışmada CuO nanoakışkanın metal işlemede kullanılmasının etkileri üzerinde durulmuştur.

1. Introduction

Nanofluids are dilute liquid suspensions of nanoparticles with at least one of their principal dimensions smaller than 100 nm. From previous investigations, nanofluids have been found to possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water (Kaufui and Omar, 2010)

Through preliminary investigation, it was determined that copper nanofluid produces a higher wear rate than the base fluid and this is possibly due to oxidation of copper nanoparticles. A lower wear and friction rate was seen for alumina nanofluids in comparison to the base fluid. Some interesting erosion test results from Singh et al. (2006) are shown in Tables 1 and 2.

Table 1. Erosion Test Results for 50% Ethlyene Glycol, 50% H_2O Aluminum 3003 - 50°C Rig (Singh *et.al.* 2006).

Impact Angle (*)	Velocity (m/s)	Time (hrs)	Weight Loss (mg)
90	8.0	236	0 ± 0.2
90	10.5	211	0 ± 0.2
50	6.0	264	0 ± 0.2
50	10.0	244	0 ± 0.2
30	8.0	283	0 ± 0.2
30	10.5	293	0 ± 0.2

Table 2. Erosion Test Results for Cu Nanoparticles in Trichloroethylene Glycol on Al 3003 - 50°C Rig (Singh *et.al.* 2006).

Impact Angle (*)	Velocity (m/s)	Time (hrs)	Weight Loss (mg)
90	4.0	217	0 ± 0.2
30	4.0	311	0 ± 0.2
90	7.6	341	0 ± 0.2
30	7.6	335	0 ± 0.2
30	9.6	336	0 ± 0.2

Shen et al. (2007) researched the wheel wear and tribological characteristics in wet, dry and minimum quantity lubrication (MQL) grinding of cast iron. Water-based alumina and diamond nanofluids were applied in the MQL grinding process and the grinding results were compared with those of pure water. Nanofluids demonstrated the benefits of reducing grinding forces, improving surface roughness, and preventing burning of the workpiece. Contrasted to dry grinding, MQL grinding could considerably lower the grinding temperature.

Copper-oxide brake nanofluid (CBN) is manufactured using the method of arc-submerged nanoparticle synthesis system (ASNSS). Essentially this is done by melting bulk copper metal used as the electrode which is submerged in dielectric liquid within a vacuum-operating environment and the vaporized metals are condensed in the dielectric liquid (Kao *et al.*, 2007).

In the nanofluid research applied to the cooling of automatic transmissions, Tzeng et al. (2005) dispersed CuO and Al_2O_3 nanoparticles into engine transmission oil. The experimental setup was the transmission of a four-wheeldrive vehicle. The transmission had an advanced rotary blade coupling, where high local temperatures occurred at high rotating speeds. Temperature measurements were taken on the exterior of the rotary-blade-coupling transmission at four engine operating speeds (range from 400 to 1600 rpm), and the optimum composition of nanofluids with regard to heat transfer performance was studied. The results indicated that CuO nanofluids resulted in the lowest transmission temperatures both at high and low rotating speeds. Therefore, the use of nanofluid in the transmission has a clear advantage from the thermal performance viewpoint. As in all nanofluid applications, however, consideration must be given to such factors as particle settling, particle agglomeration, and surface erosion.

In automotive lubrication applications, Zhang, Q. J. and Zhang, Z., (1997) reported that surface-modified nanoparticles stably dispersed in mineral oils are effective in reducing wear and enhancing load-carrying capacity. Results from a research project involving industry and academia points to the use of nanoparticles in lubricants to enhance tribological properties such as load-carrying capacity, wear resistance, and friction reduction between moving mechanical components. Such results are promising for enhancing heat transfer rates in automotive systems through the use of nanofluids.

Recently, tribology research shows that lubricating oils with nanoparticle additives (MoS_2, CuO, TiO_2, Diamond, etc.) exhibit improved load-carrying capacity, anti-wear and frictionreduction properties (Choi *et.al.,* 2001). These features make the nanofluid very attractive in some cooling and/or lubricating application in many industries including manufacturing, transportation, energy, and electronics, etc. In this study, the effect of CuO nanoparticles in minimum quantity lubrication machining was investigated. At last, the paper identifies the opportunities for future researches.

2. Material and Method

The CuO nanofluids were produced by dispersing CuO nanoparticles into the base fluid, distilled water (DI water). It had a spherical shape with a mean diameter of approximately 50 nm. Prior to each test, the CuO nanofluids were processed in an ultrasonic bath for 90 minutes to break any possible aggregations of CuO nanoparticles and to keep the nanofluids uniformly dispersed. The dispersing method could ensure that the nanofluids were stable for more than 24 hours without any visible sedimentations and agglomerations. After the CuO nanofluid samples were prepared, they were charged into the test cell for the machining tests.

Milling operations were performed on 7075 aluminium alloys. Cutting speeds up to 350 m/min were employed. The main objective of the present study was to analyze the effect of the coolant environment on tool wear, cutting forces and surface quality of the work-piece during miling operation. The tests were performed using uncoated carbide inserts under three different coolant environments of dry cutting, MQL and flooded coolant conditions. MQL was applied at two rates of 30 ml/h and 70 ml/h. A fully synthetic water soluble coolant (Ecocool S-CO5), containing glycol as a lubricating agent and free of chlorine and mineral oil, was used as the flood coolant in a volumetric concentration of 1:20. As coatings act as a barrier between tool and component and they posses high heat resistance to aggravate the effects of lack of coolant, uncoated carbide inserts (axial rake angle = +5°, helix angle -5°, nose radius of the insert *r* = 0.80) were selected.

The Vertical Machining Centers with a Taksan TMC 500 electronic control unit was driven by a tri-phasic asynchronous engine. Preliminary experiments were conducted to determine the machining parameters and coolant quantities. From these experiments the depth of cut and feed rate were fixed at 1.0 mm and 0.15 mm/rev respectively.

Tool wear was measured with a Nikon Eclipse ME600 optical microscope and an Omis mini optical measurement inspection system tool maker's microscope.

Surface roughness measurements were performed by using a Mitutoyo Surftest-B Profilometer with a cut-off length of 0.8 mm and sampling length of 5mm. Cutting forces were measured with a Kistler three-component dynamometer 9257B linked via a multichannel charge amplifier (type Kistler 5019B) to a chart recorder.

3. Results and Discussion

Figure 1 shows the evaluation of the tool flank wear for the uncoated carbide inserts in this paper. It is usually suggested to take several measurements of the tool wear and use the average value as the flank wear value. Nevertheless, it is seen that the flank wear is almost linearly distributed from the center of the cutter. The value of the flank wear (VB) measured at a distance of one third of the diameter from the center is considered as the representative tool flank wear in the following discussions, as shown in the figure. The value of the tool flank wear is read from the measuring system attached to the microscopic after calibration with a Standard scale. The reason for not using the largest value of tool flank wear is to avoid the measurement error due to the loss of the tool cutting edge.

The gradual tool flank wears of the cutting tools under different distances while the cutting speed is 50 m/min. for dry, flood and MQL conditions. In the figure, it is shown that the tool life decreases with respect to the decreased speed under dry, flood and MQL conditions. There was not much difference in flank were at MQL conditions of 30 ml/h and 70ml/h as seen from the figure. The maximum flank wear has occurred at both 50 m/min. and 350 m/ min. dry machining processing.

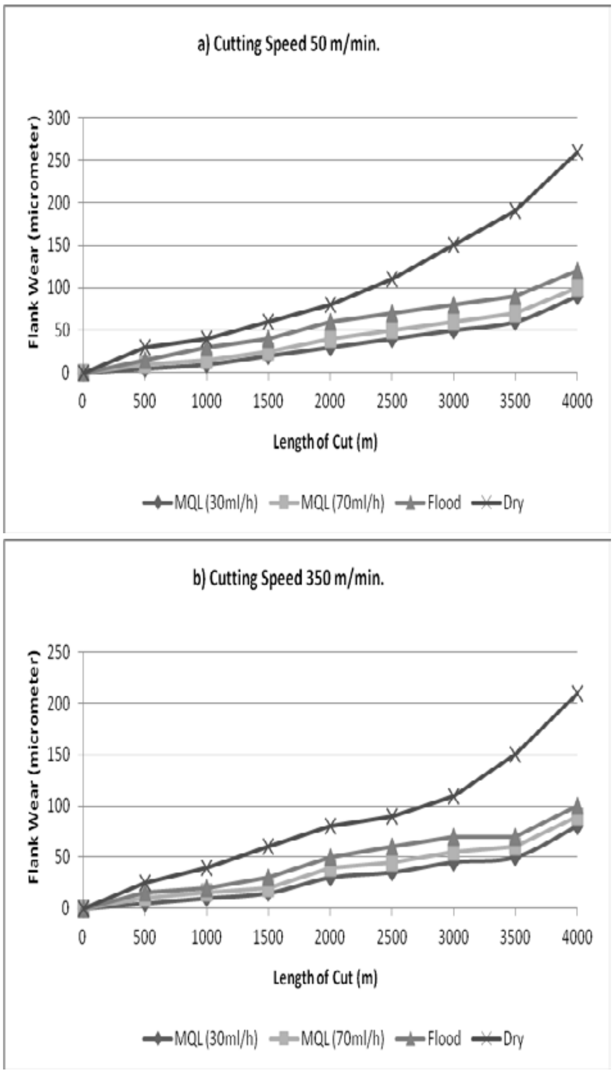

Figure 1. Change in flank wear VB with machining distance.

Figure 2 shows the change in main cutting forces with cutting length. Main cutting forces were observed to increase with increasing cutting length and subsequent tool wear. This result is in agreement with previous findings This can be explained in terms of the high ploughing forces induced by worn tools, as a result of the increased area of the larger flank wear face of the cutting tool engaged with the workpiece compared with unworn tools. Like surface roughness, cutting forces also do not always increase with increasing cutting length and tool wear. In some cases, cutting force curves have zigzag appearance. This makes it difficult to establish a direct correlation between the cutting force and tool wear. However, this does not change the fact that worn tools result in higher cutting forces than unworn tools as the last points on all curveshave always higher values than the first points. Dry milling was found to be more sensitive to tool wear in terms of cutting forces. With dry milling, the increase in cutting forces with increasing tool wear was generally higher than that for MQL and flood at all cutting speeds.

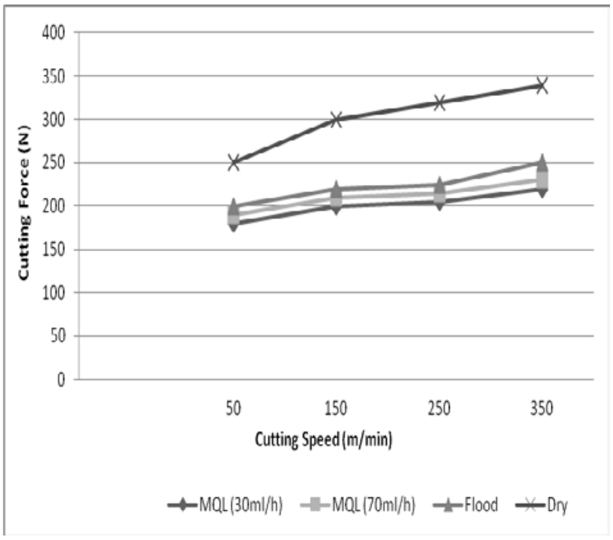

Figure 2. The relationship between the resultant cutting forces and cutting speeds

Figure 3 shows the effect of the cutting lengths and the speeds on surface roughness of the machined surfaces under dry, flood and MQL environments. It is observed in the figure that the surface roughness under MQL cutting does not change much for all cutting tests. The values of surface roughness (R_a) range at 50 m/min. cutting speed between 0.7 and 2.2 µm and at 350 m/min. cutting speed between 0.1 and 2.8 µm. The values of surface roughness do not much alter with respect to the cutting lengths or the speeds. Nonetheless, in dry milling, the values of surface roughness increase with regard to the cutting lengths under both speeds. For the case of 50 m/min. speed, the surface roughness of the machined workpiece is below 0.8 µm before cutting 1000 m long material in MQL cutting. The surface roughness is more than 2.2 µm after 1000 m after long material and suddenly increases to 1.5 µm after cutting 2000 m long in dry cutting.

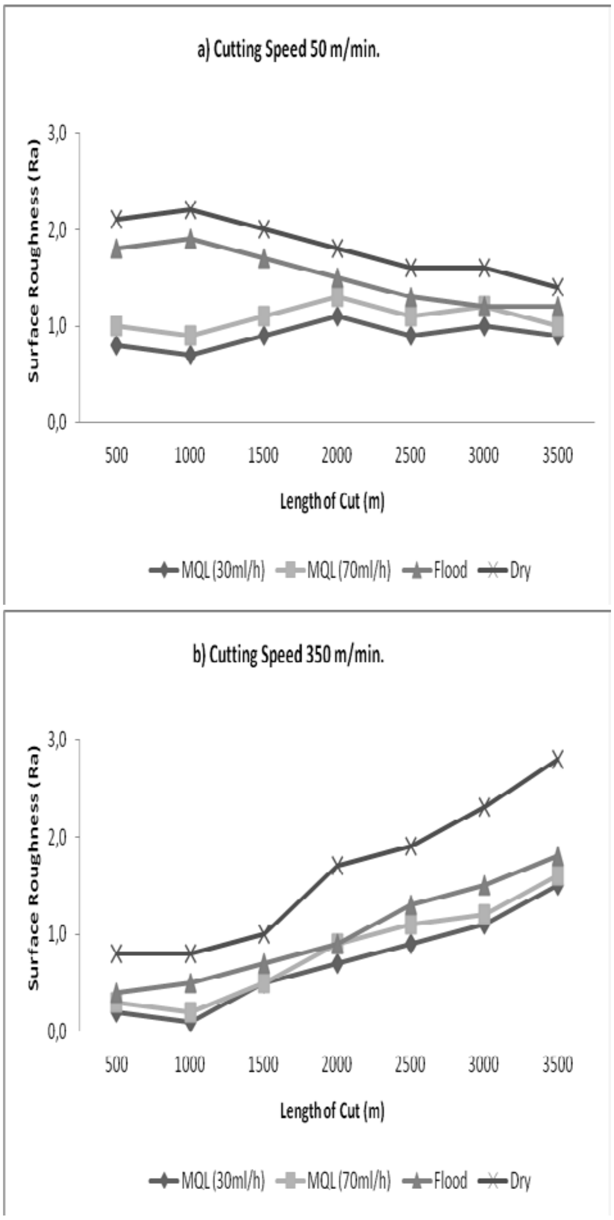

Figure 3. The surface roughness (R_a) values of the work-piece

The surface roughness were seen to increase up to 500 m of cut for dry and MQL with 30 ml/h, whereas the Ra value increased approximately till 1000 m of cut for MQL 70 ml/h and flood conditions. After the length of cut mentioned above, the Ra values registered a decreasing trend.

At dry machining condition, there was marked increase in the surface roughness as the length of cut increased. Adhesion plays an important role in determining the machined surface quality at higher cutting speeds. At 350 m/min, the material adhered on to the tool would have continuously ploughed on the machined surface.

4. Discussions and Conclusions

The negative impact of cutting speed on tool wear is obvious in Figure 1. As the cutting speed increases, all tools undergo higher flank wear. This is more pronounced for dry milling than the other three. At lower speeds for dry milling and at all speeds for MQL and flood millind, more steady increases in flankwear rates are observed with increasing cutting speed. Flank wear rates for MQL (30ml/h) and MQL (70ml/h) remain almost constant at all cutting speeds.

At all cutting speeds the best surfaces were produced with MQL (30ml/h), which was the best performing tool in terms of flank wear. MQL (70ml/h) and flood milling produced surfaces having similar qualities at all cutting speeds. The superior performance of MQL (30ml/h) in terms of producing better surfaces becomes more apparent at 350 m/min. These results show that nanofluid in MQL perform better than dry and flood milling as far as surface quality is concerned. The fact that MQL and flood milling produced better surfaces than dry milling indicates that nanofluid in MQL machining helps in improving the quality of machined surfaces.

When the four millings are compared, it can be seen that the average cutting forces obtained with dry milling were higher than those obtained with MQL and flood at all cutting speeds. The results obtained with MQL and flood were nearly the same at 150 and 250 m/min. At all cutting speeds, on the other hand, MQL resulted in a lower average cutting force than dry and floood. This indicates that Nonofluid in MQL results in higher cutting forces at low cutting speeds and lower cutting forces at high cutting speeds.

The wear behaviour of nanofluid in MQL and flood machining are nearly the same in the studied cutting speed of 50 and 350 m/min, with that of the former being slightly better than the latter. Dry machining exhibits a slightly worse wear behaviour than that of nanofluid in MQL and flood machining at all cutting speeds.

The main cutting force generated by nanofluid in MQL machinings are less than those generated by dry and flood machining at all cutting speeds indicating that millind with former processes is more economical than the latter in terms of energy and power requirements.

The best surface quality is obtained with nanofluid MQL machining at all cutting speeds. This is obvious at 50 and 350 m/min. The surface qualities

obtained with nanofluid MQL, flood and dry machining are comparable, with that obtained with the latter being slightly better than the former. This

indicates that nanofluid in MQL adversely affects the quality of machined surfaces.

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