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The Improvement of Metal Cutting Processing Using Al_2O_3 Nanoparticles

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Abstract

Recently, the scientific researches on nano-existing metalworking fluids consistently led to improvements in processing methods. Cooling and lubricating with the addition of particles of different particles, the fluid is a method of increasing the performance of the cutting tool. In recent years, conventional metalworking fluids involved in the nano-sized particles emerges as a new method. The fluids, in which these particles are added, is called as "nanofluids". Inasmuch as the thermal conductivity of a solid metal is higher than that in the joined base from fluids, metallic particles increases the thermal conductivity of the fluid mixture into the join. This study examines the effects of Al_2O_3 nanofluids on the improvement of metal processing.

Al_2O_3 Nanopartikül Kullanarak Metal Kesme İşleminin İyileştirilmesi

Anahtar kelimeler
Nanoakışkanlar; Metal işlemenin iyileştirilmesi; Kesici takım; MQL

Özet

Son zamanlarda nano akışkanlar konusunda yapılan bilimsel araştırmalar mevcut metal işleme işleme yöntemlerinin sürekli olarak gelişmesine neden olmuştur. İş yapan akışkana farklı partiküllerin eklenmesi, akışkanın kesici takımın performansını artıran bir yöntemdir. Son yıllarda, konvansiyonel metal işleme akışkanları içerisine katılan nano boyuttaki partiküller yeni bir yöntem olarak karşımıza çıkmaktadır. İçerisine bu partiküllerin katıldığı akışkanlar "nanoakışkanlar" olarak adlandırılmaktadır. Katı bir metalin ısıl iletkenliği içine katıldığı temel akışkanınkinden daha yüksek olduğu için, metalik parçacıkların akışkan içerisine katılması karışımın ısıl iletkenliğini artırmaktadır. Bu çalışma Al_2O_3 nanoakışkanların metal işlemenin iyileştirilmesine etkilerini incelemektedir.

1. Introduction

Nanotechnology is considered to be one of the significant forces that could drive the next major industrial revolution of the century. The primary approach of nanotechnology is to manipulate the structure at the molecular or atomic aggregate level with the goal of achieving desired change in property with unprecedented precision. Though exploits of nanotechnology mostly concerns engineering solids either for functional (electronic, magnetic, optical, catalytic, etc.) or structural (strength, hardness, wear/abrasion resistance, etc.) applications, the concept of nanofluid is rather new. About a decade back, researchers in Argonne National Laboratory, USA noticed that the fluid used for collecting nanometric alumina (Al_2O_3) particles synthesized by chemical vapor deposition showed usually large thermal conductivity. Successful reproduction of this fluid with ultra fine particle dispersion in very small quantity and subsequent realization that the degree of increase in thermal conductivity was far above the level expected from the rule of average, created enough ripples to catch the imagination of scientific community and evoke a wide spread interest in synthesizing new type of nanofluids, exploring new areas of application and proposing plausible theories to explain the significant increase in thermal properties (Kaufui *et.al.* 2010).

Han et al. (2008) have used phase change materials as nanoparticles in nanofluids to simultaneously enhance the effective thermal conductivity and specific heat of the fluids. As an example, a suspension of indium nanoparticles (melting temperature, 157 ^{o}C) in polyalphaolefin has been synthesized using a one-step, nanoemulsification method. The fluid's thermophysical properties, that is, thermal conductivity, viscosity, and specific heat, and their temperature dependence were measured experimentally. The observed melting-freezing phase transition of the indium nanoparticles significantly augmented the fluid's effective specific heat.

Engine oils, automatic transmission fluids, coolants, lubricants, and other synthetic high-temperature heat transfer fluids found in conventional truck thermal systems—radiators, engines, heating, ventilation and air-conditioning (HVAC)—have inherently poor heat transfer properties. These could benefit from the high thermal conductivity offered by nanofluids that resulted fromaddition of nanoparticles (Choi *et.al.* 2001; Chopkar *et.al.* 2006).

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. More research must be conducted on the tribological properties using nanofluids of a wider range of particle loadings as well as on the erosion rate of radiator material in order to develop predictive models for nanofluid wear and erosion in engine systems. Future research initiatives involve nanoparticles materials containing aluminum and oxide-coated metal nanoparticles. Additional research and testing in this area will assist in the design of engine cooling and other thermal management systems that involve nanofluids.

Future engines that are designed using nanofluids'

cooling properties would be able to run at more optimal temperatures allowing for increased power output. With a nanofluids engine, components would be smaller and weight less allowing for better gas mileage, saving consumers money and resulting in fewer emissions for a cleaner environment.

Klocke and Eisenblatter (1997) also conducted tests on drilling using minimal cooling lubrication (MCL) and concluded that MCL offers an alternative when 100% dry machining is not technologically feasible. Another technique described as composite mist machining (Suzuki, 2000), used a mixture of a minimal amount of water mist and oil mist, and tested on aluminium wheel machining, demonstrated similar benefits, other than the cost advantage.

Anticipating better lubrication in milling owing to intermittent cutting, this study is limited to end milling with a view to finding out the performance of the MQL technique in terms of tool wear, cutting force, surface finish, and chip shape using a rated flow rate of 42 l/min as the flood coolant bench mark.

2. Material and Method

The Al_2O_3 nanofluids were produced by dispersing Al_2O_3 nanoparticles into the base fluid, distilled water (DI water). The Al_2O_3 nanoparticles were provided from Center for Production and Applications of Electronic Materials and had a spherical shape with a mean diameter of 50 nm. Prior to each test, the Al_2O_3 nanofluids were processed in an ultrasonic bath for 90 minutes to break any possible aggregations of Al_2O_3 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 Al_2O_3 nanofluid samples were prepared, they were charged into the test cell for the metal cutting 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, Al_2O_3 nanoparticle powder 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.

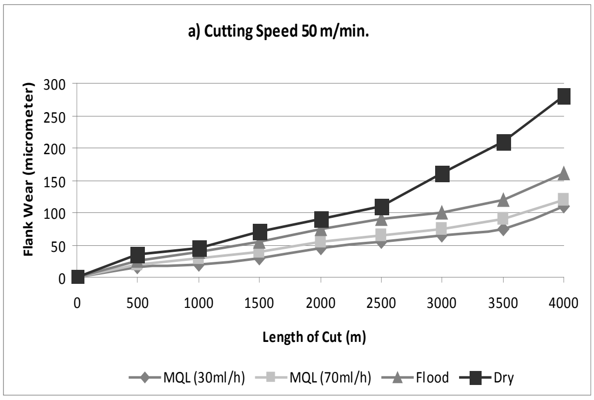
The Vertical Machining Centers with a Taksan TMC 500 electronic control unit was driven by a tri-phasic asynchronous engine. Preliminary experiments were conducted to determine the machining parameters and coolant quantities. From these experiments the depth of cut and feed rate were fixed at 1.0 mm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

Surface roughness measurements were performed by using a Mitutoyo Surftest-B Profilometer with a cut-off length of 0.8mm 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

During machining, at all cutting environments, work material adhered to the edges of the tool; but the quantity of the adhered material varied with the type of coolant environment. As the speed of machining increased from 50 to 350 m/min, the adhesion between the tool and the chip also increased correspondingly. This could be due to the increase in thermal softening of the chip as the temperature increased with the increase in cutting speed. The adhesion of the work material to the tool was observed to be having the highest rate during dry cutting. The material adhesion was seen all over the tool surfaces like flank, rake and clearance surfaces especially when the speed of machining was increased from 200 to 350 m/min. The quantity of the adhered material reduced considerably with flooded coolant compared to the dry cutting operation.

Figure 1 depicts the change in flank wear VB with machining distance. The flank wear was shown for 2 different cutting speeds of 50 m/min and 350 m/min. It was found that increasing the cutting speed from 50 to 350 m/min resulted in a significant increase in the flank wear. There was not much difference in flank were at MQL conditions of 30 ml/h and 70ml/h as seen from the figure.



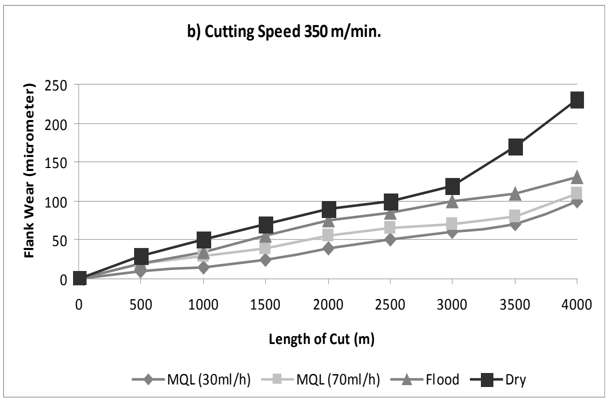


Fig. 1. Change in flank wear VB with machining distance.

Figure 2 clarifies the relationship between the resultant cutting forces and cutting speeds measured under various machining environments. As expected, the resultant cutting force was the highest under dry cutting conditions. The higher cutting forces were due to the effect of adhesion of the work material on the tool. The cutting forces were lower when the tool was sharp during the initial stages of machining and was seen to increase as adhesion on the tool progresses.

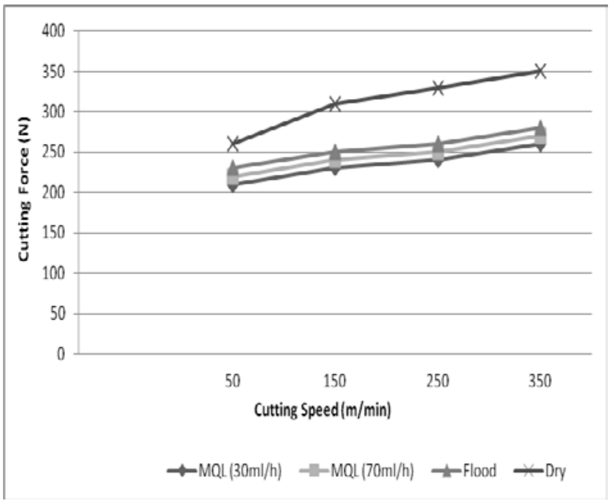


Figure 2. The relationship between the resultant cutting forces and cutting speeds

Figure 3 shows the surface roughness (R_a) values of the work-piece measured parallel to the feed direction. A total of three measurements were taken for each case and the average was plotted to obtain the graphs. During machining, very little material adhered onto the workpiece.

At a speed of 50 m/min the graphs on surface roughness do not show any specific trend. 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 R_a values registered a decreasing trend. This may be due to the filling up of cavities on the work-piece surface due to the adhesion of the material on the work surface.

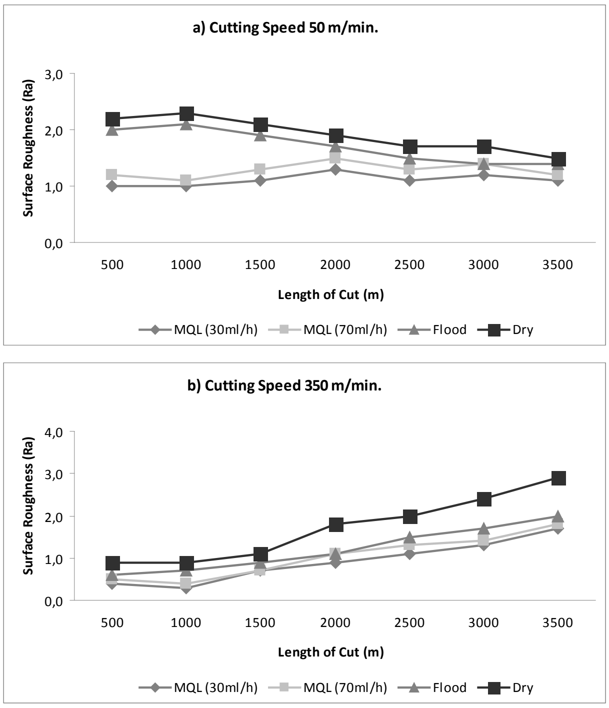


Figure 3. The surface roughness (R_a) values of the work-piece

The R_a values were seen to be increasing at a higher cutting speed of 350 m/min for all the cases of lubricant conditions (Figure 3). 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. When the adhered material became unstable, it would have detached from the tool and adhered on to the work surface increasing the surface roughness of the machined surface. These defects would have given rise to a high R_a value at high cutting speeds.

During MQL machining, the amount of material adhered was seen to be more compared with flooded coolant and less compared to dry machining. As the quantity of the lubricant was increased from 30 ml/h to 70 ml/h during MQL, there was not any considerable reduction in the adhered material. The larger amount of adhered material during MQL conditions may be due to the tool geometry. By reducing the nose radius of the tool, and geometrical modifications, the amount of adhered material can be brought down.

Investigations have to be carried out in this direction by changing the tool geometry for MQL conditions. The wear land width is seen to be almost same with MQL and flooded coolant application. This suggests that the coolant application has very little influence on flank tool wear. But the coolant has a significant effect on the amount of material adhesion on the tool. The resultant force was seen to be the lowest with flooded coolant system. This is because due to the flooded cooling, the adhesion on the tool is lowest. This lower adhesion produces lower frictional force. MQL machining also reduces the frictional forces like flooded conditions, but for getting a lower resultant force like flooded system, a further investigation on the constituents of the coolant has to be carried out.

4. Conclusion

Nanofluids are important because they can be used in numerous applications involving heat transfer, and other applications. At all the cutting speeds, it was observed that the surface roughness could be improved by the application of coolant. The improvement in surface finish can be attributed to the reduction in the material transfer onto the machined surface. At a higher speed of 350 m/min, it was clear from the graphs that the quantity of the coolant was not a deciding factor for surface roughness but there has to be MQL conditions which can reduce the surface roughness.

7075 aluminium alloy has been machined under different conditions of dry, MQL and flooded coolant/lubricant using diamond-coated carbide inserts. The process of machining was successful. Since MQL conditions can be applied to the machining, it seems that this process has got economic advantage. It was seen that the application of coolant does not necessarily reduce tool wear since at MQL conditions the tool wear was found to be lower, but the amount of coolant determines the material adhesion on the tool surface. The tools used for machining experienced nose wear and flank wear with deformation of the coating. The cutting forces were found to be dependent on the coolant system. For improving the quality of the work-piece surface, coolant is necessary. 7075 aluminium alloy has been machined under different conditions of dry, MQL and flooded coolant/lubricant using uncoated carbide inserts. The process of machining was successful using Al^2O_3 nanofluid.

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