Experimental Investigations of Canola Oil Lubrication with Nano-Crystalline MoS$_2$ Additives in CNC End Milling of Aluminium Alloy

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Abstract. Since the past few decades, manufacturing operations including the milling of metals use various types of coolants and lubricants. These are composed of chemicals and other pollutant factors, which are very dangerous and hazardous to the nature and human. And also the increasing demands of high productivity for the machining requirements leaves no choice but to use high cutting velocity along with higher feed rates. These renewed machining conditions leads to the generation of high cutting temperatures, which reduces tool life with poor product quality. Hence there is a need to find the alternative coolants and lubricants, which reduces the above factors in addition to machining cost. In general lubrication is attributed for the solving of heat generation related issues at the cutting zone. Due to some inherent properties like cooling, lubrication and functions like flushing of chips, the cutting fluids leads to better performances during milling operations. As the conventional way of using fluids are less efficient during high production machining, it is observed that nano fluids have better properties in terms of transfer of heat from the cutting zone. Economic aspects are considered during the use of nano fluids by applying the phenomenon of Minimum quantity lubrication (MQL). The work is an attempt in the direction of using nano fluids as alternative lubricants in milling operations by the study of tool temperature and quality of surface finish.

Keywords: Milling, Solid lubricant, MQL, Canola oil, MoS$_2$, Nano lubrication.

1. INTRODUCTION

Radical technological changes are observed in the use of lubricants in the solid form in various machining operations, which can be attributed to the advancement in modern tribology. Many solid lubricants have been identified that have the capacity to sustain its inherent property of lubricity with the change in temperature at regular intervals. Some of the powders used are classified as lamellar solids which are being used as lubricants. They are graphite, molybdenum disulfide, tungsten disulfide and calcium fluoride [1, 2]. Experimentations have shown that solid lubricant could effectively control the machining zone temperatures by intensively removing heat during the machining process. Experimentations in order to study the end effect of the solid lubricant used were carried out by analyzing the surface finish and chip thickness after machining [3]. It is observed that heat generated during machining is dissipated when cutting fluids are introduced into the cutting zone. The conventional cutting fluids which create some problems like environmental pollution, water pollution, and keeping in mind the economic aspects [4], substitutions are being found out that ns normally meet the functional requirements by the coolants with some other means. It is found that a few other approaches are by using cryogenic coolants and lubricants which are bio-degradable [5, 6]. Keeping in mind the environmental aspects, use of environment friendly lubricants are the best alternatives. These include vegetable oils like rapeseed, corn or soybean oil, esters, etc. Considering the
economic aspects, the concept of MQL is an aspect which researchers have pondered upon keeping in mind the parameters like cutting temperature, tool wear, surface roughness and dimensional deviations. Experimentally it is found that there is a decrease in the temperature at the chip–tool interface by 10% at various cutting conditions [7].

Sharif et al. [8] investigated the use of various cutting fluids (fatty alcohol, palm oil, palm oil with additive A and palm oil with additive B) as lubricants during the end milling operation of hardened stainless steel (AISI 420) using coated carbide tool materials (TiAlN and AlTiN). Using various input parameters like cutting speed, feed rate, axial depth of cut and radial depth of cut along with the end mill diameter, he has experimentally studied its effect on Cutting forces, tool life and surface roughness. Observations revealed that the progress in the tool wear is gradual during the use of palm oil and fatty alcohol, but rapidly progressed when dry and flood type of lubrication is used. It is also observed that the flank wear progressed rapidly with machining time for dry and flood cutting, while the tool wear increased very slowly when palm oil and fatty alcohol coolant is used. It is also observed that the surface properties were not good initially with the use of palm oil and fatty alcohol which happened to improve in the later stages.

End milling process is widely being used in various industries like automobile, ship building, aerospace, textile and other manufacturing industries due to its varied applications. The present work encompasses the use of MoS2 particles in vegetable oils in order to check its machining performance with a special focus on the heat generated at the primary zone. MoS2 is characterized by its high temperature thermo physical property. Experiments are carried out on CNC Milling machine by using MoS2 as solid lubricant mixed in vegetable oil.

2. MATERIALS AND METHODS
Machining experiments are conducted on 7011H ALUMINIUM steel with the application of nano crystalline MoS2 powder as a lubricant. Nano crystalline MoS2 powder with size ranges of 30-35 nm, 65-70 nm and 85-90 nm are used. CNC Milling machine is used for the purpose of machining. The experiments are conducted using 6mm diameter HSS material Type-A, Type-N, Flat ball end mill bit. The input parameters which are varied are speed, depth of cut, feed and particle size of the nano crystalline powder. Full Factorial Design of experiments are conducted to analyze the output parameters- Temperature and Surface Roughness.

3. EXPERIMENTATION
Initial experimentations involved the finding of minimum quantity lubrication, and later experimentations were conducted. The temperature was measured during the machining process using a Infra-red thermometer. Surface roughness is measured off line after experimentation using a portable stylus-type TALYSURFF. The evaluation length of 2.5mm is used to measure response Ra value in µm. The complete methodology adopted in carrying out the experimental work is illustrated in Fig. 3.1. An indigenously developed liquid particulate dispensing system is attached to the machine for dispersing the lubricant mixture and to take care of agglomeration of the MoS2 powder mixed in the carrying unit. A CNC Milling Machine is used for the experimentation. Specifications of the Milling Machine are as follows:

(i) Make: CNC MILL HYTECH
(ii) Rapid feed rate in each axes: 600mm/min
(iii) Minimum increment: 0.005mm
(iv) Milling head : Spindle speed - 200-3000rpm
    Power - 2HP
    Spindle motor - DC Motor, 2HP
The behavior of MoS₂ powder in the nano-crystalline form as a lubricant which is mixed in a carrying medium Canola is studied. The size of the nano-crystalline MoS₂ powder considered are 30-35 nm, 65-70 nm and 85-90 nm. Preliminary tests are conducted to find out the optimal weight percentage of the nano-crystalline MoS₂ powder to be mixed in the carrying medium. It is found that a 0.5 wt. % is optimal for the purpose of experimentation. The evaluating parameters of temperature and the surface roughness are considered while machining Aluminium. The temperatures are measured while the experimentation is being carried out and the surface roughness is found out off-line at the end of each machining process.

4. RESULTS & DISCUSSIONS

To compare the performance of the measured parameters, a base line is followed in which the experimental values are plotted against the cutting speed for all the sizes of the nano-crystalline MoS₂ powder. Machining is performed for 6 minutes for each sample. The flow rate of the lubricant is maintained at 5 ml./min. The values plotted are the average of the values obtained while machining for 6 minutes. Fig. 2 represents the values with respect to Tool temperature.

Fig. 2 (a) illustrates the change in Tool temperature values at a depth of cut of 0.50 mm and feed rate of 50 mm/min while Fig. 2 (b) and Fig. 2 (c) represents the Tool temperature at a feed rate of 70 mm/min and 90 mm/min respectively. It is observed that the Tool temperature at 0.50 mm depth of cut and if the feed rate is changed from 50 to 90 mm/rev., it increases from 38 °C to 74.5 °C for a crystalline size of 85-90 nm when the speed is increased from 1000 to 2000 rpm. This clearly shows that the Tool temperature changes with the increase in the cutting velocity and change in the depth of cut.

At higher cutting speeds and when the depth of cut is increased, there is a drastic increase in the Tool temperatures. The temperatures increases to a maximum of 175 °C for a crystalline size of 85-90 nm and 210 °C for a crystalline size of 30-35 nm. This clearly shows that with the increase in the size of nano-crystalline MoS₂, there is a decrease in the Tool temperature. While comparing the average increase in the Tool temperature with respect to the crystalline size of the MoS₂ particles, the increase is 1.09 times of the average temperature when using 30-35 nm crystalline particles than by using 85-90 nm nano-crystalline

Fig. 1: Experimental setup
particles. The temperature developed is the maximum when the smallest crystalline particles (30-35 nm) are used. The nano sized particles that enter into the contact interface between the tool and the work piece gets agglomerated. At higher temperatures, Canola oil loses its viscosity and only MoS₂ particles remain in the contact interface. Since, MoS₂ powder has high friction coefficient than that of Canola oil, the friction between the chip-tool interface increases thus increasing the temperature.

Fig. 2: Graphs related to Temperature

Agglomeration of nano particles at the interfacing zone of the tool and work piece increases the tool temperature, thus increasing the temperature at the cutting zone. This shows that with an increase in cutting speed, the temperature increase is drastic. The effect of cutting speed on Tool temperature is predominant when compared to the other parameters like depth of cut and feed rate. At higher cutting speeds and at higher depth of cuts, more amount of material comes in contact with the tool thus leading to stagnation of the tiny nano particles between the asperities. This in turn impairs the heat transfer mechanism from the cutting zone leading to increase in temperature. The increase in temperature in turn decreases the viscosity of the carrying medium thus leading to further increase in temperature at the cutting zone.
Fig. 3 depicts the values of the Surface roughness which are experimentally found out. The graphs represent the values at a particular cutting speed with various crystalline sizes of the solid lubricant. It is to be noted that these values are obtained after the machining process is carried out. When considered at a particular speed, the quality of the surface is better when 85-90 nm sized crystalline MoS₂ powder is used when being compared to smaller crystalline sizes of the solid lubricant. It is observed from the experimental values that the quality of surface is poor when smaller crystalline nano sized solid lubricant is used and better when large sized nano particles are used.

Fig. 3: Graphs related to Surface Roughness

It is observed that built up edges are formed when the cutting speeds are lower which is the reason for poor surface quality. These built up edges disappear when the cutting speeds are increased. This phenomenon is visible in the experimentation process where it is found out that the surface quality improves when the cutting speeds are increased. There is a proven work where the quality of surface finish depends on the size of the particle when the particle size used ranges from micron level to the nano level. It is observed during the experimentation that surface finish is better during the use of larger particle size in the nano regime which is contrary to the experimental findings when micron sized particles are used.
The surface quality deteriorates more with the increase in the feed rate which is a dominating factor when compared to other cutting parameters considered for the experimentation. Experimentally it is a proven fact that the quality of surface depends on the feed. It is also proven that the quality of surface, which is a function of feed at a particular nose radius, which changes with the square of the feed rate value. At higher cutting speeds, the built up edges disappear and there is a direct contact between the tool and the work piece with the lubricating layer between the machining parts. The nano particles act as good thermal conductors which dissipates heat from the cutting zone. As the built up edges disappear, the surface quality improves due to the fact that the nano particles act as lubricants between the machining components.

CONCLUSIONS

The present experimental investigations considering the input parameters like feed rate, cutting speed, depth of cut and size of the nano-level MoS2 powder. It is experimentally proved that the said input parameters greatly influence the output factors like the tool temperature and the quality of the machined surface. The results obtained experimentally can be used for developing analytical models which can be used to predict the surface quality and the tool temperature. The data obtained gives a scope for analyzing the effect of nano-level variation in the particle size of MoS2 powder while machining Al.

i. It is observed that the tool temperature is depends on the size of the particle. As the particle size decreases, the tool temperature increases. It implies that more heat is generated at the tool chip interface as a result of greater rubbing action at the interface.

ii. The other observation is with respect to the surface quality. The experimental investigation revealed an inverse phenomenon with respect to the change in the particle size at the nano level of MoS2 powder during the machining process of Al. This phenomenon can be because of the increase in the cutting forces, higher tool temperature and greater physical interaction at the tool – chip interface.

It can be concluded that the particle size plays a dominant role in the nano regime with respect to the quality of surface finish and the temperatures generated in the machining zone.

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