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MICRO LUBRICATION: A WAY TO ENHANCE THE MACHINING OPERATION

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ABSTRACT:

Manufacturing industries are currently adopting many sustainable advanced manufacturing techniques to lower the rate of environmental hazards and occupational diseases. Green machining is one of such technique which uses micro lubrication method using biodegradable coolants to cool and lubricate the work piece and cutting tool interface. Micro lubrication technique minimizes the cutting fluid during the machining process, decreases the surface roughness of a work piece, and increases the tool life. From the literature survey it is found that computational Fluid Dynamics is most efficient tool to optimize nozzle design by simulating mist flow in the nozzle for micro lubrication. Optimization of oil mist in micro lubrication by improving nozzle design is one important approach to enhance the overall performance of lubrication method. Hence, the purpose of this paper is to understand the oil mist behaviour in the nozzle, to study the size of the mist droplet and nozzle channel geometry in micro lubrication.

KEYWORDS: *Micro lubrication, CFD, oil mist.*

1. INTRODUCTION

The escalating demand for sustainable manufacturing process and the fast increasing price in the disposal of coolant has increased the demand to find an alternative solution to the conventional machining which uses a large amount of cutting fluid. Green machining is one of such technique which uses micro lubrication method using biodegradable coolants to cool and lubricate the work piece and cutting tool interface, which is extensively used in manufacturing sectors and research for machining purpose to minimize the coolant also it lower the rate of environmental hazards and occupational diseases. Micro lubrication also known as minimum quantity lubrication (MQL) is extensively used in manufacturing sectors and research for machining.MQL is also called as near-dry machining. MQL is used in machining processes like drilling, milling, turning, and grinding. In MQL, a very small cutting fluid at a low rate of 50-500 ml/ hr is used. It is the mixture of small oil droplet and compressed air jet directly sprayed in the metal cutting zone, which decreases friction, cutting temperature between tool rake face and chip leads to increase in tool life. Therefore the application of micro lubrication will minimize the cost associated with the manufacturing process. Hence micro lubrication can be adapted as a substitute of dry cutting and flood lubrication. The motivation to write the paper is to evaluate the performance of MQL using computational fluid dynamics, and find the optimum flow rate of fluid in the nozzle because there is less work carried out in it .The following section describes the analysis of micro lubrication techniques used in different machining operations to enhance the machining performance, in descending order of years [5].

2. LITERATURE REVIEW

Erween Abd Rahim et al. (2018) [1] investigate the micro lubrication flow pattern and its behaviour by varying nozzle design, the distance of the nozzle from tool tip to enhance the turning performance. In this paper phase droplet anemometry(PDA) was used to understand the micro lubrication mist spray behaviour under varying pressure condition for 3.0 mm and 2.5mm nozzle diameter. Synthetic esters were used as cutting oil for AISI 1045 work piece. Nozzle distance from carbide insert selected were 9,7,6,3 mm for varying compress air pressure 0.2 to 0.4 MPa. The result shows that the generation of the cone angle of spray mist was influenced by cutting oil properties, droplet size, and compressed air pressure. From experimentation, it was observed that a bigger diameter of nozzle gave a wider cone angle of mist. Analysis of droplet size using computational fluid dynamics shows that mixing percentage of oil, air, and compressed air pressure effect droplet size. It was found larger droplet near the extreme boundaries of mist spray due to centrifugal action. Smaller nozzle diameter generates finer droplet size due to cross-section area reduction which increases the energy level of cutting oil and generating smaller size droplet.

Simulation result shows that at higher input pressure getting smaller droplet diameter because of more shear force generated between compressed air and cutting oil due to high relative between them. Like for 2.5mm nozzle diameter at 0.2, 0.4 MPa air pressure getting 24.5µm and 16.3 µm droplet size respectively. Also for 3.0 mm nozzle diameter at 0.2, 0.4 MPa air pressure getting 33 µm and 23.6 µm droplet size respectively. Analysis of cutting force for different nozzle diameter carried out at 0.15mm/rev feed rate, air pressure 0.2MPa, Nozzle distance from carbide insert was 7mm, 3mm selected. The result shows that at 3mm nozzle distance from carbide insert getting 28% more cutting force because mist could not reach metal cutting zone as it was affected by surrounding temperature, which results in the evaporation of mist before it enters the cutting zone. Hence at 7mm, 6mm nozzle distance from inserts at 0.15mm/rev,0.30mm/rev generate lesser cutting force. Also, simulation result shows that nozzle diameter 30mm produce bigger droplet size which reduces cutting force as compared to 25mm nozzle diameter.

Result analysis of cutting temperature for different nozzle diameter carried under different air pressure and nozzle distance. It was observed that cutting temperature decreases at higher cutting speed. Also for nozzle diameter 25mm at 0.2MPa air pressure, 0.15mm/rev feed rate and 9 mm,7 mm,6 mm,3 mm nozzle distance found increased temperature 24%, 28% 50%, 48% as nozzle distance increases. At higher feed rate more cutting temperature, longer chip length found which result in burr formation and built up edges. A S S Balan et al.(2017) [3] investigate the significant parameters of spray to enhance the grinding performance by reducing cutting force and surface roughness. The computational fluid dynamic technique was used to optimize the process parameters of micro lubrication. For analysis Inconel751 work piece, diamond grinding wheel with resin bond(126 grit size, 13mm width, 150 diameter) was used. For Computational fluid dynamic analysis discrete phase model was selected and droplet size was studied under different air pressure ranging from 0.2 to 0.6 MPa, 60 to 100 ml/hr mass flow rate. Spray analysis shows that at higher compressed air pressure and mass flow rate getting smaller droplet size due to increase in shear force among cutting oil and compressed air. It was found that 24.9µm droplet size at 60 ml/hr flow rate at 2 bar air pressure. And 2.78µm droplet size at 100ml/hr at 6 bar air pressure.

It was observed that effective penetration of mist at a minimum flow rate and maximum air pressure 0.6MPa giving the good grinding performance, minimum grinding force and surface roughness, lesser cutting temperature. Moderate droplet size ranging from 6 to 16.3 µm easily penetrating the metal cutting zone and reducing cutting forces and surface roughness.

N. Verma et al.(2017) [4] studied the parameter affecting grindability and optimized mist using computational fluid dynamics. Also, residual stresses and grinding force analysed. The study was carried out on AISI521000 harden steel and AK60K5V8 grinding wheel. For analysis volume fluid model was used and for spray formation analysis discrete phase model was used. Air pressure selected in the range of 2 to 6 bar, 50 to 500 ml/hr rate of fluid flow, 50 mm and 100mm nozzle distance from a tool. Simulation result shows that by decreasing droplet size, atomizing pressure increases. Also increasing flow rate and pressure leads to increased heat transfer coefficient. Experimental result shows that increasing pressure and flow rate decreases. Residual stresses influenced by atomizing pressure, almost 63% reduction in residual stresses found in micro lubrication as compared to dry cutting when 200 ml/hr flow rate and 6 bar atomizing pressure.

Patrick Bollig et al.(2015) [5] presented a modelling method for a metal cutting process for drilling in tempered steel AISI 4140 using micro lubrication in two dimensional and three dimensional FEM simulations. By applying multiphase simulation code INSFLA, inputs needed for the FEM simulation were found. For friction modelling: CETR UMT3 tribometer was use to load cycle test. Test was conducted at room temperature sliding speed varying from 0 to 10m/s within 5 sec and then held for that time continuously taking temperature of tool by thermocouple. Test was conducted for dry cutting and flood cutting using MAG CYCLO COOL 20 MU coolant, pure distilled water and hexadecane. In MQL and dry machining coefficient of friction was measured experimentally with reference to the contact pressure, temperature, and relative sliding velocity. Result show that for friction modelling of every sliding pair, the coefficient of friction was indirectly proportional sliding speed and temperature. In dry condition, tool with PVD coating reduced coefficient of friction for 3 m/s above sliding speed, it also reduced temperature. In lubricating condition for coated tool result were same as compared to uncoated tool. Also, result show that in two and three dimensional simulation for micro lubrication, gets lower temperature level than dry machining.

M. S. Najiha et al.(2014) [6] conducted simulation for two-dimensional steady-state incompressible of flow field of micro lubrication for milling operation having four teeth cutter rotating at 2000rpm.Mass flow rate was constant. 2 mm Nozzle diameter was used and kept at 0^0 to the axis of rotation of the tool. The maximum size of 0.004 mm unstructured triangular meshes were selected. For simulation K-ε, realizable turbulence model was computed using ANSYS Fluent software. The result shows that turbulence near tool can't penetrate nozzle flow into the cutting zone because of less mass flow rate and centrifugal effect developed near the tool which obstructs a flow of lubrication towards cutting zone. Also result of flow field vector plot and velocity contour shows that mist flow was not evenly distributed because of vortex generation near cutter rotation throw away oil drops from cutting zone. Which result in uneven lubrication leads to heat generation in cutting zone and increasing cutting force. So uneven lubrication problem can be avoided by increasing mass flow rate which forces mist spray through vortex. Also by increasing the number of nozzle uneven distribution of lubrication problem can be solved. The nozzle distance with respect to the feed direction was important to optimize the effect of micro lubrication.

Y. Iskandar et al.(2014) [7] investigate the flow characteristic of micro lubrication over CFRP milling operation such that it reduces tool wear, cutting tool temperature and cutting force. For analysing the flow characteristic of micro lubrication jet phase doppler anemometry (PDA) and particle image velocimetry (PIV) were used. Slotting test was performed to machine CFRP laminates using Mecagreen 550 lubricant using CNC milling machine. After every 90mm surface, removal length result was recorded for cutting force, cutting temperature and tool wear. To get mean droplet diameter air flow rate varying in between range 20 to 35 l/min and oil flow rate 10 to 25 m/min for an optimum operating condition. Particle image velocimetry result shows that for increasing air flow rate gives increasing peak velocity with symmetrical mist spray around an axis of the nozzle. Also, it shows that increasing value of air flow rate and the decreasing value of the oil flow rate generates coherent jet with minimum vortex formation and greater axial velocity over a longer distance from the nozzle outlet. The experimental result shows that the ratio of lower air flow to higher oil flow gives a slightly lesser temperature than a ratio of higher air flow to lower oil flow. It was observed that 17% decrease flank wear in micro lubrication than flooded lubrication due to a larger velocity of a droplet, smaller droplet size and minimum vorticity generation which result in proper penetration mist in metal cutting zone leads to lesser cutting force.

Ming Chen et al.(2012) [8] optimized the micro lubrication process parameter by investigating the behaviour of droplet, pressure, and velocity of flow in a metal cutting zone by varying the flow rate of compressed air for thread turning operation. In this paper 30mm nozzle distance from tool was selected and a nozzle is perpendicular to rake face of the tool, cutting speed was 70 m/min for 3mm thread pitch, compressed air pressure 0.1 to 0.6 MPa, 80 to 180 l/min flow rate.

The simulation result shows that high-velocity droplet gathered near the aerosol zone and near the cutting edge decreased velocity droplet found because bigger diameter droplet having more inertia than atmospheric air which makes reducing droplet velocity lesser than atmospheric air. Also found that droplet not reaching cutting zone due to a blocking of cutting chip. It was examined that at 209m/s air stream velocity around nozzle creates

5000Pa pressure in a metal cutting zone. And vortex was found in a metal cutting zone and a low-pressure area which helped in heat dissipation. Also, it was observed that a larger flow rate cannot penetrate in the metal cutting zone.

Mohammadjafar Hadad et al.(2012) [9] studied grinding zone temperature and heat flux by developing an analytical thermal model. They validated the same result by experimentation. In thermal model, convection heat transfer coefficient of micro lubrication in the grinding zone and outside the grinding was considered. To predict the convection coefficient of conventional lubrication, and micro lubrication in grinding process, the different process parameters like air pressure, properties of oil droplet, mist flow rate of oil had considered in nusselt number. This process was used to compute the subsurface temperature distribution, heat flux profile of grinding surface in the cutting zone. The result shows that at the trailing edge heat transfer convection could not decrease the peak temperature. Micro lubrication in grinding process could not meet the requirement of cooling as compared to the conventional flooded grinding but it providing some cooling at trailing edge.

Y. Kamata et al.(2004) [10] investigate the pressure in between clearance face of a tool and machined surface and mist spray behaviour for turning operation were analysed. For simulation, ANSYS/FLOTRAN software was used. And k-ε model turbulence model used. Simulation result shows that mist flow pattern depends on cutting speed, blowing angle and blowing speed. It was found that mist changes its orientation parallel to cutting end edge when blowing velocity selected in between range 5 to 300 m/s and 4m/s cutting speed and 20^0 blowing angles. It was observed that greater blowing velocity leads to good lubrication even at constant oil consumption with respect per unit time. At higher cutting speed effectiveness of mist supply decreases and decreasing pressure drop found towards the end of cutting edge which gives a machined surface with force convection mist flow.

3. CONCLUSION AND FUTURE SCOPE

In this work, the effectiveness of micro lubrication is observed using different techniques like computational fluid dynamics, PIV, PDA etc. In which, It found that droplet size and velocity are influenced by air pressure and mass flow rate. Also high compressed air pressure and mass flow rate leads to decrease in droplet size due to the effective penetration of droplet in metal cutting zone which further decrease in metal cutting temperature; cutting forces and improves the surface texture, on the other hand. Medium size droplet diameter with larger pressure effectively penetrates in a metal cutting zone. Higher compressed air pressure and nozzle diameter provides larger cone angle of mist spray and finer droplet can be produced with smaller nozzle diameter. Bigger nozzle diameter reduces cutting force, vortex generation in metal cutting zone resulted better heat dissipation. Bigger size droplet having more velocity was able to reach in metal cutting zone. Optimum micro lubrication spray can be obtained with the maximum air flow rate and minimum oil flow rate. And quantity of mist spray near to cutting edge depends on cutting speed, blowing angle and mist velocity.

Referring to current advancements in the respective field of machining science, there is huge scope for development of the mathematical modelling on cutting parameter, tool life, temperature characteristics and effects on tool performance using Micro lubrication.

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