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Determination of mist flow characteristic for MQL technique using Particle Image Velocimetry (PIV) and Computer Fluid Dynamics (CFD)

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Keywords: Flow pattern, MQL, Particle Image Velocimetry (PIV), Computer Fluid Dynamics (CFD).

Abstract. In recent years, minimum quantity lubrication (MQL) machining is regarded as a promising method for reducing machining cost and cutting fluid, while improving cutting performance. However the effectiveness and the working principle of MQL are still questionable with very few explanations provided. The aim of this study is to determine the optimum distance between the nozzle and tool tip and appropriate flow pattern of the mist flow for minimum quantity lubricant using Particle Image Velocimetry (PIV) and Computer Fluid Dynamic (CFD) for optimizing the spraying conditions thus reducing the lubricant consumption. The spray from the nozzle with outlet diameter of 2.5 mm is analysed using Particle Image Velocimetry (PIV) to measure the mist flow velocity and identify the flow pattern. The input pressure of 0.2, 0.3 and 0.4 MPa will be discharged throughout the experiment. Higher pressure produce more mass flow rate which helps in reducing the cutting force and cutting temperature efficiently and prolong tool life. Thus the appropriate distance can reduce lubricant consumption and increase the cooling and lubricating ability with best nozzle position. The applied distance increases the efficiencies of MQL applied during machining process.

Introduction

Due to serious concern about ecological and economical and most importantly occupational pressure, many machining industry are turning towards dry machining to eliminate the usage of metal working fluids. Multitude researches have been conducted to replace wet machining. [1] Wet machining are not highly desirable due to its affects that causes respiration and skin problems to the workers who are highly exposed during machining process. [2] Meanwhile, in dry machining metal working fluids are not used thus leaving a dry and easy to clean workplace. Despite the advantages of the dry machining, there are some limitations in dry machining that leads to the usage of metal working fluids. Dry machining can be less effective when higher machining efficiency, better surface finish quality and severer cutting conditions are required. By taking into consideration of the ecological and economical problems, implementing near dry machining or minimal quantity lubrication (MQL) would be the best technique to control or to reduce the metal working fluid consumption. Based on studies done using MQL technique have shown reduction in friction coefficient and cutting temperature compare with dry and wet machining. [3] In MQL cutting, a small amount of biodegradable oil, which is mixed with compressed air to form oil mist, generated using a process called atomization is applied to the cutting point instead of the flood supply of water-miscible or water-immiscible cutting fluids to lubricate, reduce temperature and to enhance the tool life during the machining process [4]. For example, it was assumed that the oil can penetrate the tool-workpiece interface due to high pressure of the compressed air that serves as a vehicle for the oil droplets [5,6]. No comparison was made between the contact pressure at this interface and that of compressed air. These important parameters are not reported in many research documents and papers on near dry machining. Even though MQL is known for its many benefits but

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no one was able to prove that the statement is true or no one have ever suggested a systematic procedure to prove MQL's efficiency. The effectiveness and the working principle of MQL are still questionable with very few explanations provided. The aim of this study is to determine the desirable flow pattern of the mist flow in order to choose the nozzle distance from the cutting tool for the minimum quantity lubricant in machining process using Particle Image Velocimetry (PIV) and Computer Fluid Dynamics (CFD).

Methodology

Particle Image Velocimetry. Particle Image Velocimetry (PIV) is used in measuring the instantaneous whole field velocities and can provide overall information about spray behavior. The experimental setup is illustrated in the Fig. 1. The lubricant is sprayed via a nozzle with an outlet diameter of 2.5 mm into an acrylic chamber at the pressure of 0.2, 0.3 and 0.4 MPa. The flow is seeded with smaller tracer particles and illuminated by Nd: YAG laser light sheet of 632 nm. The illuminations are recorded by a high resolution CCD-camera (resolution 1376 X 1040 pixels). The calculation of the particle displacement is carried out by cross correlation the two corresponding interrogation areas. The frames were analysed using Dentec 6.0 software. The image of the flow patterns is clearly captured and displayed on the computer.

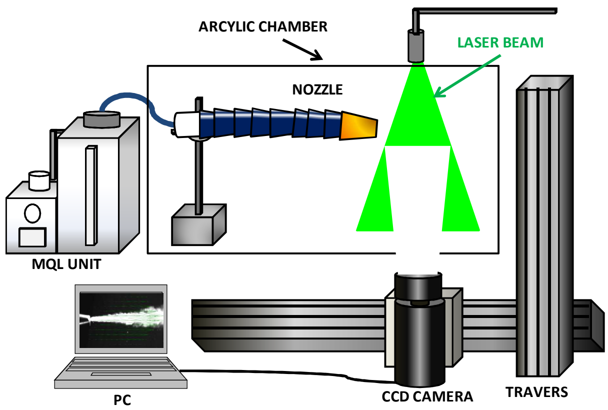

Fig. 1: Schematic illustration of PIV setup

Results and discussion

Flow Patterns. Fig. 2 (a), (b) and (c) shows the mist flow pattern obtained using PIV .The mist flow pattern was analysed only on the region of the steady state of mist flow which can be obtained in the region of smooth flowing arrows from the software which is also known as laminar region. In turbulent state, the arrows move in irregular path. The flow pattern is more concentrated in a long tube shape for a certain distance before it reaches the turbulent state. The mist is more focused in a single moving path before it starts spreading after reaching a certain length as can be seen from Fig. 2. For mist flow under 0.4 MPa, the flow rate is higher and the length of the steady flowing fluid is more than 50 mm which is longer compare to lower pressure in the laminar region before it start spreading creating wider conical shape. The mist flow is more concentrated to the centre line of the nozzle in the smooth laminar flow. When the mist starts losing its kinetic energy, it moves far from the centre line of the nozzle [7].

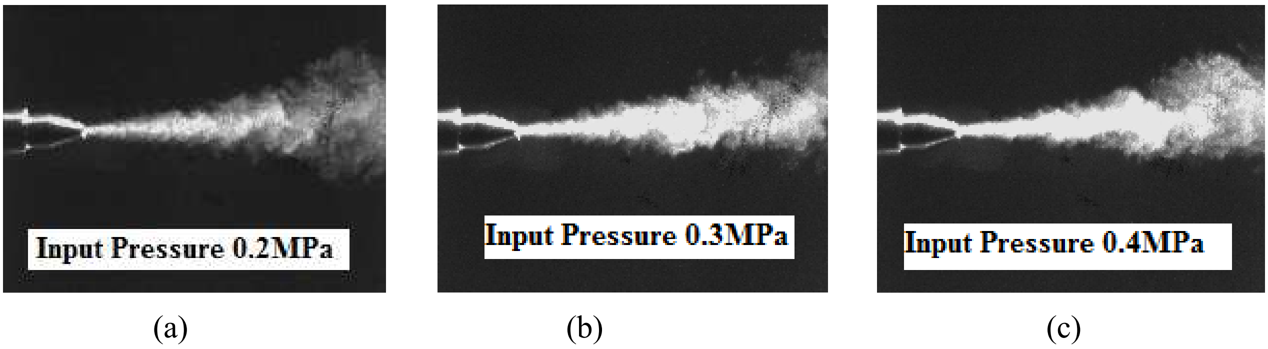

Fig. 2: Mist flow pattern under input pressure of (a) 0.2 MPa, (a) 0.3 MPa and (c) 0.4 MPa

Particle Distribution. Fig. 3, 4 and 5 shows the particle distribution under input pressure 0.2, 0.3 and 0.4 MPa for nozzle with outlet diameter 2.5 mm. From the graph it is shown the distributions of the particle are visible starting from 2 mm from the radial distance. Since it is a hollow cone spray no particle captured at the centreline of the spray. All three graphs show higher concentration of particle distribution in the area of 5 to 11 mm from the radial distance. Distance 2 mm is very close to the workpiece and this will cause rubbing between workpiece and nozzle during machining. From the observation of the machining setup and particle distribution, the nozzle distance was selected 3, 6, 7 and 9 mm from the cutting insert edge to evaluate the performance of MQL using different nozzle distance.

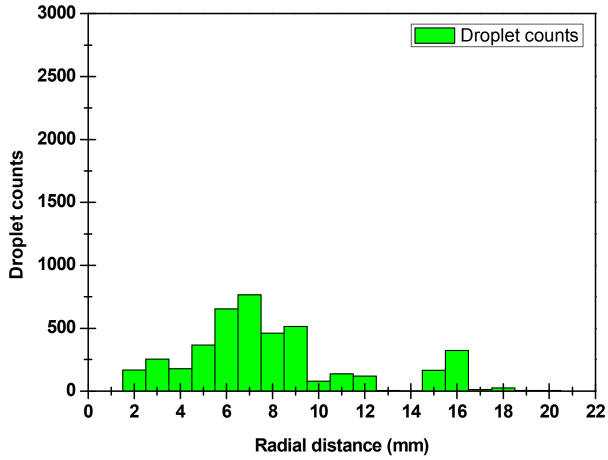

Fig. 3: Particle distribution under input pressure 0.2 MPa

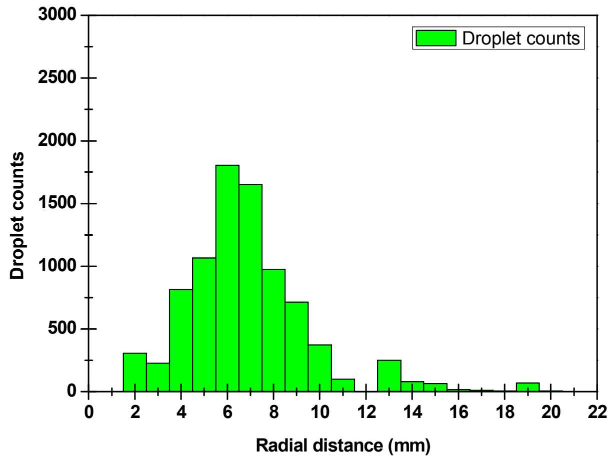

Fig. 4: Particle distribution under input pressure 0.3 MPa

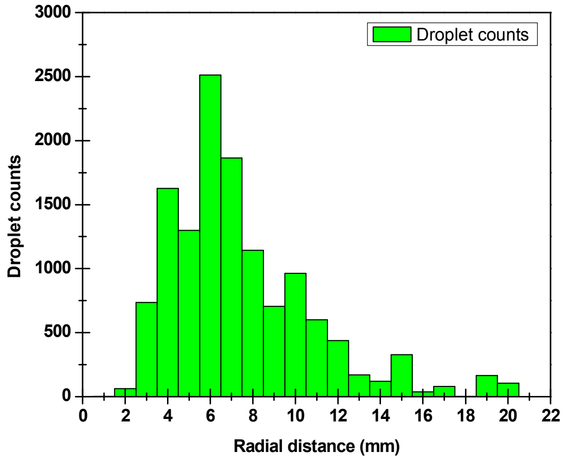

Fig. 5: Particle distribution under input pressure 0.4 MPa

Computer Fluid Dynamics. The geometry was constructed using Solid Work drawing then converted into IGES format. The external geometry was then exported in the ANYSY CFX 15.0 software. Every part was named accordingly then meshed using fine meshing with 1029200 nodes and 4875001 elements. Workpiece, insert and tool holder was selected as solid domain with boundary conditions no slip wall. Meanwhile, nozzle and enclosure was selected as fluid domain of air and synthetic ester with the ratio of 0.6 and 0.4. The fluid domain with the mixture with compressed air and synthetic ester is a homogenous mixture. For the boundary condition, the inlet of the nozzle was given stable input pressure of 0.2, 0.3 and 0.4 MPa. And at the outlet the surrounding pressure was applied zero pressure to enable the spray to flow and spread. Meanwhile Fig. 6 and 7 shows the results obtained for spray pattern under different nozzle distance and input pressure. From the results, with the inclination of 45^0 the spray pattern is more clearly visible to cover the cutting edge and machined area.

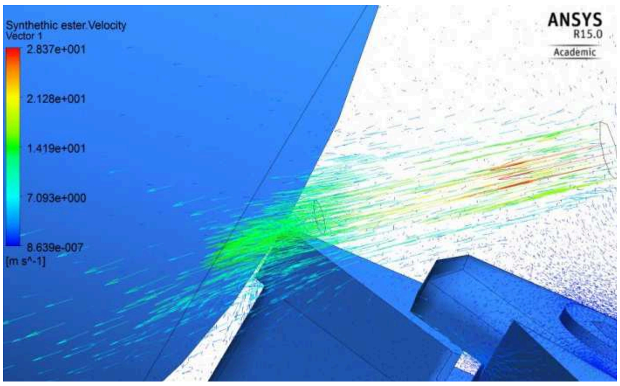

Fig. 6: Model geometry (Side view)

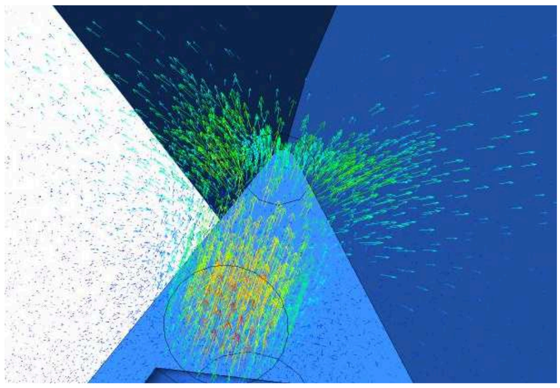

Fig. 7: Model geometry (Top view)

Conclusion

i. The influences of flow pattern and nozzle distance in oil mist supplied during the turning process are investigated. The flow pattern was analysed using Particle Image Velocimetry (PIV) and the turning process was carried out with external nozzle with outlet diameter 2.5 mm to supply cutting fluid.

ii. The nozzle distance of 6 and 7 mm from the cutting edge enable to save the cutting fluid from not splattering and directed the flow to the cutting zone. Meanwhile the selected nozzle distance shows more concentration of mist flow near the centre line of the nozzle compare to nozzle distance further than 10 mm. The selected distance enables mist particles to penetrate into the cutting zone. Control of the flow of oil mist and applying the appropriate distance from the nozzle to the tool tip increases the efficiency of oil spraying drastically and makes the MQL machining more stable [8].

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