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CFD SIMULATION OF CRYO-MQL SPRAY AND THE EFFECT OF DROPLET SIZE

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ABSTRACT

A mixture of carbon dioxide (CO_2) and minimum quantity lubrication (MQL) is being used as the coolant in this article. Then using computational fluid dynamics (CFD) a mist form was made and using the discreet phase modeling (DPM) atomization simulation was performed in a turbulent environment. Using variables like mass flow rate and pressure, we were able to calculate the jet velocity and droplet size. This study investigates the impact of spray parameters on droplet size and velocity, discovering that a medium-sized droplet, which is significantly effective in lubricating the working zone when the pressure is higher.

Keywords: CFD, DPM, Cryo-MQL, Droplet Size, Spray

INTRODUCTION

Because of the exceptional qualities of super alloys, such as their low weight, high resistance to wear and corrosion, and capacity to keep a high level of strength even when subjected to high temperatures, the fields of aerospace and biomedicine are where the vast majority of applications for this type of material have been discovered. Yet, because it has a low heat conductivity, super alloy is regarded as a material that is difficult to cut and has poor machinability. This is because of the material's low heat conductivity. During the machining process, this results in severe tool wear, which in turn mandates high machining costs. Cryogenic machining has been utilized as a promising method for enhancing machinability as a means of reducing the amount of tool wear, lowering the amount of energy consumption, and cutting the expenses associated with machining. In order to get around the problems that have been discussed; this has been done. During the machining process, approximately 80% of the heat that is generated stays in the tool, while the other 20% is taken away by the chip. This information is derived from [1]. According to the findings of [2], the limited thermal conductivity of super alloys causes the high heat concentration to have a negative impact on the surface integrity of the workpiece, which in turn causes rapid tool wear. This was found to be the case because super alloys have poor thermal conductivity. Because of this, it is quite important to appreciate the problem of heat creation during machining and locate a remedy to it because, in essence, this is the major component that chooses how long the tool will last [3]. Cryogenic machining has been increasingly popular in recent years as the optimal response to the issue of high temperatures. According to [4], cryogenic cooling is a method for the removal of material in which the cryogenic is substituted for more traditional cutting fluids. On the other hand, as compared with traditional metalworking fluids, minimum quantity lubrication presents a glaring benefit that should not be overlooked. It is possible for the digital process chain to immediately take into consideration the oil quantity, volumetric flow rate, and pressure of the MQL aerosol. In addition, the appropriate combination of MQL oil and tooling not only boosts production but also extends the life of the tools. Minimum quantity lubrication (MQL), also known as micro lubrication, is one of the solutions that has come up as one of the methods that is being used in the machining of super alloys and has been gaining popularity over the course of the past decade. This method has been one of the methods that has been used in the machining of super alloys and has been one of the methods that has been used in the machining of super alloys [5]-[9]. MQL not only offers a superior reach in these conditions in comparison to other cutting environments, but it also adheres to the green manufacturing philosophy because it is seen as a more ecologically responsible alternative to dry cutting. MQL gives a greater reach in scenarios where higher speeds are employed because the heat generated during the machining process is more noticeable at the interface of the workpiece and the tool when higher speeds are used. MQL cutting requires a very tiny amount of cutting fluid [6]-[7], making it a more cost-effective procedure overall as compared to flood cutting. However, in [10], it was suggested that a new combination of cryogenic MQL may be used to increase the life of a tool when cutting Ti6Al4V. This was done with the intention of maximizing productivity. In this study, it was discovered that both MQL and the combination of cryogenic MQL were extremely effective in terms of improving the life of a tool when compared with flood cooling, and that MQL gave the best surface roughness among all of the cooling technologies. Flood cooling was found to be less effective in terms of improving the life of a tool than either MQL or the combination of cryogenic MQL. It was discovered in a study [11] that was carried out not too long ago that the utilization of cryogenic cooling in the process of machining Ti6Al4V had no impact on the friction coefficient. This was discovered to be the case. The lubrication of the cutting process is not significantly impacted by cryogenic coolants, as their influence is negligible. However, according to the authors' understanding, the process of cutting metal might be significantly enhanced by the addition of more lubricant to cryogenic coolants. Recently, some studies have experimented with combining the fluids that are used for cooling and lubricating. It was demonstrated in [12] using supercritical carbon dioxide (scCO2)-based MQL that scCO2 with dissolved lubricant had a higher heat removal efficiency than scCO2 with no dissolved lubricant when it came to removing heat from a system. This was proved by contrasting the two varieties of scCO2 that did not have any lubricant that was dissolved in it. In addition, it was found on [13] that scCO2 with dissolved lubricant has the potential to be superior coolants and lubricants to typical metalworking fluids. This research was carried out in the context of metalworking. An examination into the turning of AISI 304 was conducted in [14]. As part of this investigation, a procedure was analyzed that incorporated the utilization of MQL as well as cryogenic liquid. In spite of the fact that MQL is better for the environment than a combination of cryogenic and MQL supply (Cryo-MQL), they discovered that by using the combined technique, it was possible to strike a compromise between the ecological and technological considerations that were involved. This was discovered despite the fact that MQL is better for the environment than Cryo-MQL. In point of fact, while using cryo-MQL as opposed to dry and MQL methods, there is a significant enhancement in tool wear qualities without sacrificing the process temperature properties. This is the case because cryo-MQL uses liquid nitrogen instead of dry air. Even though there is no difference in the amount of time it takes for the tool to wear out. Because of this, the lubricant-cooling method that we are employing in this research is called Cryo-MQL spray, and it consists of CO_2 and MQL. One of the most important things when considering a coolant or lubricant is the wettability. If the wettability is great than it will greatly decrease the tool wear increase tool life and improve the machinability. To make sure the wettability is great we need to consider the parameters of the spray which highly effects the droplet size of the spray. It is proved in the paper [15] that the droplet of a spray that has a medium size and higher pressure has the optimum ability to moisten its surroundings. So, in this paper I am going to find the medium droplet size in higher pressure of my spray using computational fluid dynamics (CFD).

ANALYSIS OF CFD

The primary goal of aerosol spray simulation is to identify the critical spray quality parameters. The spray's quality is proportional to the droplet count, droplet size, and droplet speed. By adjusting for these factors, cutting force, temperature, and roughness can be minimized, hence improving machining performance. Computational fluid dynamics (CFD) software fluent 6.3.26 was used to model the droplet's atomization. The form of the air atomizer was fashioned using the modelling and meshing software GAMBIT 2.3. Because the MQL process generates droplets with finer droplet sizes, the volume of fluid (VOF) model, which employs the Eulerian method to study the two-phase flow in fluids, is unable to effectively reproduce jet breakup (microns). The time step and mesh size needed to simulate the breakdown of micron-sized droplets will increase the cost and complexity of the computation. Hence, the VOF model of MQL fell outside the scope of this study. Hence, a discrete phase model (DPM) was used to simulate the atomization process under turbulent conditions. The Euler-Lagrange method is the basis of the DPM model, which represents air (CO2) as a continuous variable and cutting fluid (MQL) as discrete particles. Once the conservation of mass, momentum, and energy equations are solved for, the model will reveal the continuous phase, also known as the primary phase. The properties of DPM can be determined after the transportation and force balancing equations have been solved. Many distinct sub models were developed in the CFD program and utilized to calculate coalescence and particle breakage. The discrete secondary phase was simulated using the Lagrangian approach. Oil, being the secondary-discrete phase, occupies a smaller volume fraction than the other phases combined (less than 10%) due to the microliter-scale mass flow rates. This makes it an ideal candidate for the MQL model. Because it takes into account the viscosity constraints that are present in turbulent flow, the realizable *k* model was utilized for each and every simulation. It is a turbulence model that is widely utilized in all of the important computations in engineering, and it also delivers findings that are more accurate in cases where the Reynolds numbers are higher [16]. The primary and secondary phases of the mixture were determined to be the carbon dioxide gas and the cutting fluid, MQL, respectively. For the sake of computational simplicity, the model of the simulation was developed in a two-dimensional space, taking into account the structure of the nozzle and the characteristics of the spray. By providing consistent inputs for each zone, the boundary conditions of those regions might be established. Due of its steady pressure, the CO2 gas stream input boundary was selected as the "pressure intake". This led to the selection of that boundary as the “pressure inlet”. In a similar fashion, the oil stream input and the wall boundaries were chosen to serve as the mass flow entrance and the pressure exit, respectively. The “interior” boundary condition was used to divide several distinct domains, including the air and oil streams, the mixing area, and the nozzle outlet. Both the air pressure and the mass flow rate are going to be changed throughout the experiment. It has been determined how the droplet size distribution changes depending on the air pressure (0.2, 0.4, and 0.6 MPa) and the mass flow rate (60, 80, and 100 ml/h). It would be difficult to conduct a comprehensive examination of the droplet size distribution over such a vast range of data. As a result, the Sauter mean diameter (SMD) was determined; this is the value often employed by such models when simulating aerosol sprays. The SMD is defined as the diameter of a spherical droplet whose surface area to volume ratio is the same as that of the entire spray (D32).

RESEARCH AND DISCUSSION

The results of the simulation were generated for every possible combination by using the three different levels for the two input conditions (air pressure and mass flow rate). It is assumed that the standoff distance will remain the same (80 mm) throughout the entirety of the case. The following is a summary that was acquired for each of the simulation conditions that were discussed before after post-processing for DPM. Under varying conditions of CO_2 pressure (0.2, 0.4, and 0.6 MPa) and mass flow rate (60, 80, and 100 ml/h), the droplet size distribution has been investigated and studied and the results are shown on Table 1. At a standoff distance of 80 millimeters (mm) from the nozzle tip in the spray jet, it is measured. It would be difficult to conduct a comprehensive examination of the droplet size distribution over such a vast range of data. The SMD(D32) has been the sole device utilized.

TABLE 1:DIAMETER AND VELOCITY FOR DIFFERENT CONDITIONS

PRESSURE (IN MPA)	FLOW RATE (ML/H)	SAUTER MEAN DIAMETER SMD (µM)	VELOCITY OF DROPLET (M/S)
0.2	60	13.2	20.1
0.2	80	8.2	25.2
0.2	100	3.1	29.4
0.4	60	12.89	21.4
0.4	80	7.83	26.4
0.4	100	2.6	40.5
0.6	60	11.5	22.3
0.6	80	2.8	31.9
0.6	100	2.4	43.5

As shown in Figure 1, the situation in which the CO_2 pressure was 0.2 MPa and the mass flow rate was 60 ml/h produced the largest droplets, measuring 13.2 µm and the mean velocity is 20.1 m/s shown in Figure 2

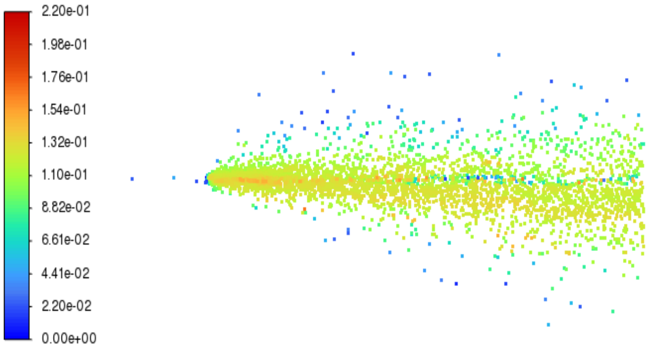

Figure 1: Largest droplet diameter 13.2 µm.

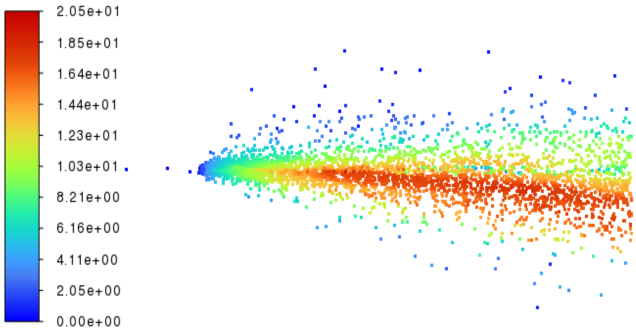

Figure 2: Mean velocity of largest droplet 20.1 m/s.

In Figure 3 the CO_2 pressure is 0.4 MPa and the mass flow rate is 80 ml/h which produces the medium droplet size 7.83 µm and the mean velocity shown in Figure 4 26.4 m/s.

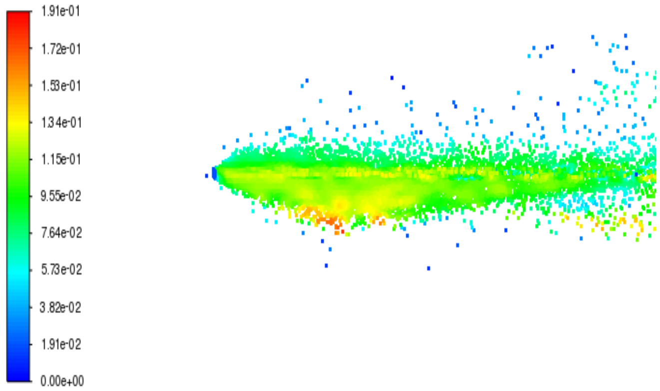

Figure 3:Medium droplet diameter 7.83 µm.

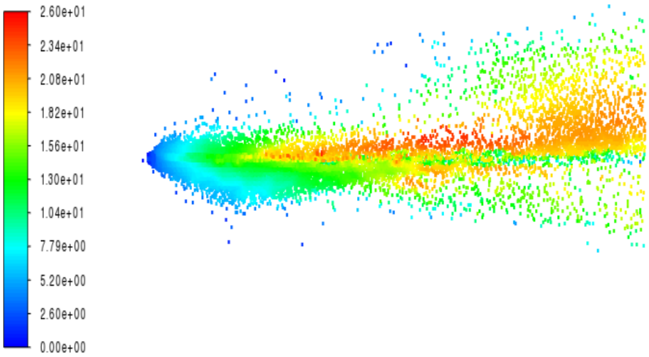

Figure 4:Mean velocity of medium droplet 26.4 m/s.

And at last shown in Figure 5 and Figure 6 is the smallest droplet size which was found when the CO_2 pressure is 0.6 MPa and the mass flow rate is 100 ml/h and the respective mean velocity 43.5 m/s.

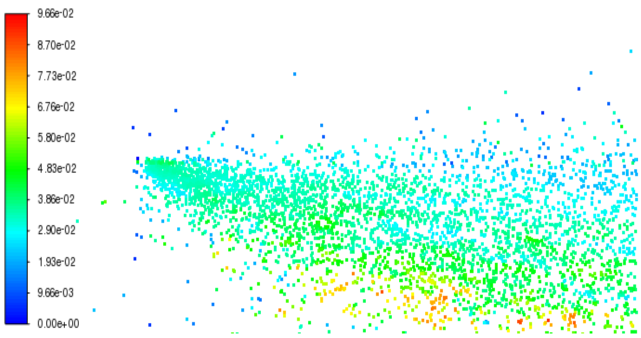

Figure 5:Smallest droplet diameter 2.4 µm.

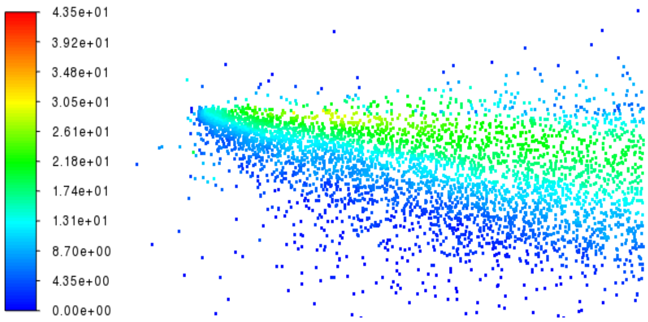

Figure 6: Mean velocity of smallest droplet 43.5 m/s.

The properties of the droplets are mostly determined by the main phase, which in a two-phase (gas–liquid) jet of MQL is carbon dioxide gas. Both an increase in the pressure at which the CO_2 gas is supplied, which leads to a reduction in droplet size, and an increase in the mass flow rate, which also leads to a reduction in droplet size. When the pressure and the mass flow rate are both increased, the velocity of the particle also increases. Because of this, the shear forces between the air (CO_2) and the oil (MQL) will be increased, which will result in the production of droplets of a smaller size. The effectiveness of MQL is reliant on the ease with which oil droplets can be accessed, as well as the degree to which the tool–workpiece interface can be moist. As was mentioned in [15], larger droplets cannot travel to the working zone because of having high inertia and may get dropped out, and very small droplets, for having low mass, are unable to travel to the working zone and will get diverted from the spray path. So, in both of the cases the droplet cannot travel to the working zone. Therefore, the medium size droplet found in the simulation will be better in lubricating the working zone.

CONCLUSIONS

From the results of the simulation conducted on the Cryo-MQL spray it is proved that the parameters of a spray which are the pressure and mass flow rate are very important factors. The increasing of the pressure and mass flow rate increases the velocity of the spray and decreases the droplet size. As the spray containing medium droplet with higher pressure is known to have the best wettability and good at increasing tool life and machinability and decreasing the tool wear the Cryo-MQL spray with 7.83 µm droplet size found in this paper with 0.4 MPa pressure and 80 ml/h mass flow rate and 26.4 m/s velocity will have the best wettability.

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