A Review Upon the Minimum Quantity of lubricant –Turning, Milling, Drilling and Grinding Process

Naol Dessalegn Dejene , Srinivasan Kumar , Sololo Kebede Nemomsa, Gutuofgaa

Abstract- The focus of this paper is to review the minimum quantity of lubrication in metal machining (MQL) operation. In metal machining coolant plays a crucial role by reducing the heat on the surface work piece and cutting tool. In addition, the removal of chips and surface of machined part directly affected by the fluids amount and its quality. The mis-use of cutting fluids in machining operation affects cost of manufacturing, quality of part, wastage of energy and also affects human health and the environment. That is why, now a days more attention is given to the topic to control environment and health problems caused by machiningthe development of an eco-friendly fluids has bid issue of manufacturing industries. The studies shown that technique enhances cutting performance in terms of increasing tool life and improving the quality of the machined parts. The control parameters used in various machining operations are different accordingly. In addition, alternative source of MQL, to have optimum qualities of machined part. General, this paper reviewed the effects of MQL and alternatives, control parameters in turning, milling, drilling and grinding, summarized the general concepts.

Keywords:*Minimum Quantity Lubrication, Cutting Fluids, Tool Life, cost of manufacturing.*

I. INTRODUCTION

Now a days the interest to perform study on machining operations are increasing in dry/near-dry conditions.The reason is fluid used in machining operations create many problems on health of human beings and cost of manufacturing. The character of cutting fluids is toxic so that causes dermatitis, respiratory disorder, cancer, etc.

According the study on drilling performance with minimum quantity of lubricant using fuzzy logic it's indicated as cutting is toxic and has significant on the cost of machining operations. In addition, based on German automotive companies' study, the cost of cutting operation estimated accounts up to 15% to 16% of the cost of a machined components (A. Nandi, 2006).Another, study indicates the cost of cutting fluids is several times higher than tool costs[M. Hadad, 2013, Jegatheesan, 2009].Dry machining and MQL machining have become the focus of attention of researchers and technicians in the field of machining as an alternative to traditional fluids even attempts to completely eliminate cutting fluids, but still is essential to use it to the economically feasible service life of tools and required surface qualities[Hadad et al., 2012, Sadeghi et al., 2009]. This makes the MQL an interesting alternative, because it combines the functionality of cooling with an extremely low consumption of fluids [M. Hadad 2013].The use of cutting fluids is the most common strategy to improve the tool life, the product surface finish and the size accuracy [Tawakoli 2009]. The metal cutting (Turning, milling and drilling) MQL is the objective of this paper in reviewing the work of scholars in identifying gap and forming solid compiled review paper.

II. MQL-IN TURNING OPERATION

In turning operation a number of studies have shown that compared to dry machining; MQL technique enhances cutting performance in terms of increasing tool life and improving the quality of the machined parts. In addition to MQL, there have been a few investigations about the influence of process parameters on the results, such as MQL nozzle position and cutting parameters (cutting speed, depth of cut and feed). For instance, the tool-chip interface temperature of turning AISI 4140 steel in which the oil mist is supplied from both nozzles to the rake and flank faces is approximately 350°Clower than that in dry turning. The study was aimed to show through experiment, the effects of the above parameters on turning performance such as machining forces, surface roughness and temperature. When the oil mist is supplied only to rake face, the tool temperature is about 200°Clower than that in dry turning. Additionally, in wet turning, the tool-chip interface temperature is about 300°Clower than that in dry turning[M. Hadad 2013].In turning operation, the challenging part is to supply the oil mist to the cutting point, because continuous chips prevent the oil mist being supplied to the cutting point, which differs the turning operation compared to other machining operation like milling, drilling and grinding.

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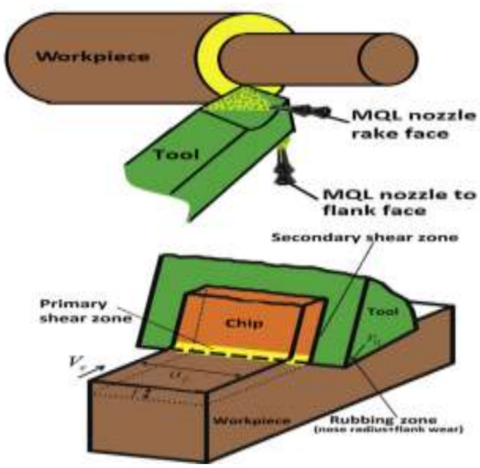

Figure 1: Illustration of MQL nozzle positioning and cutting parameters during turning process[M. Hadad 2013].

To overcome the problems of finding cutting point in turning operation two nozzles were used to supply oil mist to tool rake and flank face. This is by using the Tayler equation the important parameter of tool wear calculation is temperature and to consider heat distribution thickness, width and lengthis considered.For instance, M.Madad et.al the thermal analysis in considering the three thermal sources of the process namely heat due to deformation, heat due to friction (tool-chip) and rubbing (workpiece – nose radius).The results of applying dry, wet and MQL technique indicated that, the application of cutting fluid with MQL to the turning processresulted in a performance superior to that of the conventional methods, possibly by providing greater lubricant penetration efficiency into the machining zone. In addition, the nozzle position has important influences on the effects of MQL turning process of control parameters like machining forces, surface roughness, and temperature distribution. The advantage of MQL in turning operation is not limited to have good surface finish or tool life. According to theStudy results ofRebinder'sshowed that during cutting process, the absorbed fluid filmsprevent micro cracks from closing (healing due to plastic deformation of the work material). Because each micro crack in themachining zone serves as a stress concentrator, a lower energy wasrequired for cutting[Davim, 2008].The effects MQCL on tool wear characterizations in finish turning of AISI 1045 carbon steel study were shown on P25 cemented carbide for different cooling conditions: dry cutting, MQCL and MQCL with phosphate ester-based EP/AW additive. It's proven that the wear of the inserts using MQCL + EP/AW method is reduced by about 40% compared to dry cutting and about 25% compared with MQCL. The same analysis revealed that active compounds contained in this tribo-film reduce the rate of adhesion and diffusion of tool wear processes [R. W. Maruda, 2016].

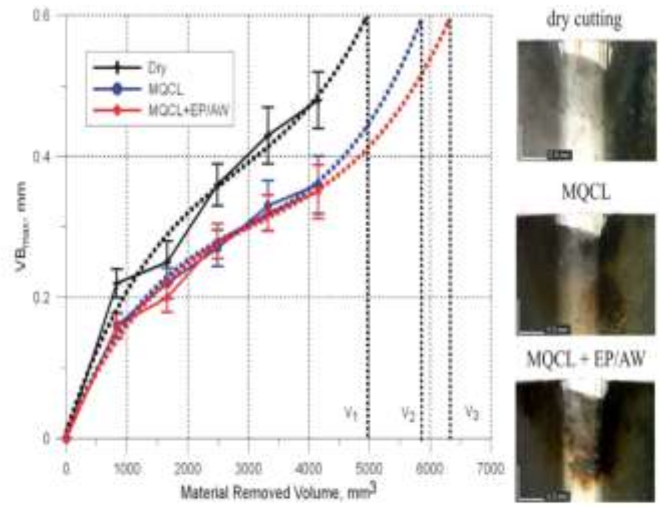

Figure 2. Changes in the maximum flank face wear bandwidth VB $_{max}$ depending on the cooling method for v_c=250 m/min and images of the cutting blade flank wear at the end of the cutting process [R. W. Maruda, 2016].

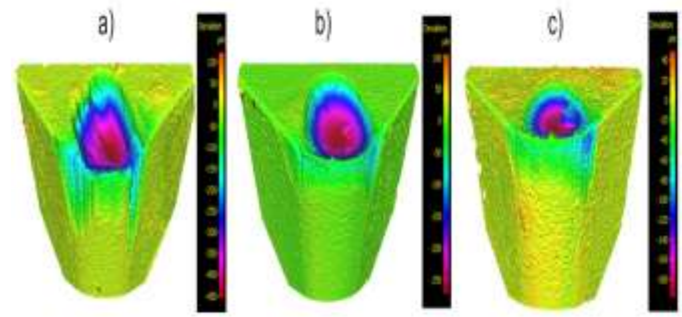

Figure 3. Topography of the cutting tool wear areas depending on the method of cooling: a) dry cutting; b) MQCL c) MQCL þ EP/AW [R. W. Maruda, 2016].

As the case study on application of MQL shows the size of droplets affects the machined part. In the research applied to commercially available powder form of alumina (Al_2O_3) and colloidal solution of silver (Ag) nanoparticles were mixed with water to prepare the nano -fluids (NFs) of different concentrations. The prepared NFs have been used under MQL mode during the machining of nickel based alloy. The results obtained with NFs have been compared with biodegradable emulsion and dry machining. The small contact angle, more spread ability and tiny droplets size of alumina NFs provided reduced cutting forces, tool wear and chip curling during machining. The phenomenon of tribo-film formation has also been observed with alumina NFs which protected the rake face[P.V. Rao, 2016]. The application of MQL in turning operation is very important to improve tool life in which it will be very easily degraded. For instance, the turbine blade materials are super alloys and they undergo high temperature during machining process in between cutting tool and work piece. So, that it causes failure of cutting tool and affect the work piece surface roughness. Therefore, using cutting fluids are very important to reduce the effect of temperature in the cutting zone. The same investigation shown on turbine blade of AISI 410 material in turning operation with Tungsten carbide tool under the dry, wet and menthol mixed with water cutting conditions. The result shows in dry lubrication the air passes in the cutting zone at room temperature 250℃, and in wet lubrication water flows on cutting zone with different temperature say 100℃,150℃ and 250℃. In the third is condition small quantity of crystalline menthol powder added to water and used as a cutting fluid. The cutting fluid pressure, velocity maintained constant in all three cutting conditions. A comparison between dry, wet and minimum quantity of menthol is investigated. Finally the results obtained that menthol mixed with water act as a better coolant and it concluded that sustainability of machining process has been increased by replacing conventional cuttingfluids with developed eco-friendly cutting fluids [Madan Mohan Reddy Nune, 2017].In order to obtain the positive effect of MQL in turning operation, it is very important tosupply the oil mist to the cutting point correctly and precisely.

III. MQL-in Milling operation

As seen in the case of turning operation, in order to obtain the positive effect of MQL, it is very important to supply the oil mist to the cutting point correctly, because it is difficult to supply the oil mist to the cutting point in turning, since continuous chips prevent the oil mist being supplied to the cutting point. Therefore, it is important to establish the oil mist supplying method in which oil mist stably reaches to the cutting point at the first time, which is not true in the case of milling operation (end Mill). In intermittent cutting like end-milling, MQL seems to be effective because the oil droplets are easy to penetrate into cutting point. That is why scholarsare interested mostly in application of MQL for milling operation. As in the case of turning the size of MQL droplets matters for better response. Therefore, before practical implementation, applying numerical simulation results and comparing with the experimental response is the method in which researchers follows. For instance, The experimental and numerical simulations of liquid film formation for different rotating velocities of milling tool and the numerical model on an unsteady Reynolds- Average Navier–Stokes (RANS) formulation and multiphase Lagrange model for liquid film formation by the droplet impingement model on a solid surface. The details of spray–wall interaction are presented and the model was used to simulate the liquid film formation in the MQL coolant process for different milling tool velocities. The shape and the size of the liquid film obtained by the calculation and the experiments were compared to improve understanding of the MQL cooling process. Overall, good agreement was observed between the numerical and the experimental measurements of liquid film size from an estimated numerical film thickness border. This study provided greater understanding of oil mist behaviour. The impingement analyses predicted better lubrication when highly oriented channels and high inlet pressure used, especially in High Speed Machining[Arnaud Duchosal, 2014]. The emerging and promising portable manufacturing technology are practicing the application of MQL to have good surface integrity. It’s required in producing parts for industries of nuclear, aerospace and power generation. The study on Robotic milling with MQL to have the suitability of cooling and lubrication is the indicator. According to L.TunerTunc et al. 2016 the effects of MQL condition on the surface in robotic milling of austenitic stainless steel AISI316L were discussed experimentally. The surface integrity is assessed in terms of surface residual stress(XRD) and surface roughness (optical metallography), where MQL conditions for improved tool life also investigated [Lutfi TanerTunc, 2016]. The lubrication conditions such as duty cycle, i.e. oil flow rate, the air flow rate and air pressure adjusted. The cutting conditions were selected based on stability analysis and tool manufacturer. The experiments showed that the surface roughness is not affected by the MQL settings. However, the surface residual stresses can be decreased by well controlled MQL Oil flow. The oil flow rate significantly affected the surface residual stress, whereas the air flow rate did not have a significant effect. The tool condition, i.e. flank wear and cutting heat affected zone, is significantly affected by lubrication settings. The most significant parameter was observed to be the duty cycle, which controls the oil flow rate. It was seen that increasing number of strokes per minute, i.e. increasing the oil flow rate, decreases the width of the cutting heat affected zone on the flank face. This can be associated with the heat barrier effect of thickened oil film, so that the heat transfer to the flank face decreases, where the amount of heat staying at the work piece increases. The tool wear progression after 20 minutes of cutting with high and low number of strokes per minute showed a big difference. Under poor lubrication conditions the flank wear was significant[Lutfi TanerTunc, 2016].

IV. MQL-In Drilling operation

Now a days the increasing interest to perform machining operations in dry/near-dry environments. The reason includes health and safety of operator, cost, ease of chip recyclability, etc. However, one important process, which is difficult to perform in dry, is drilling. Without coolant, drilling leads to excessive thermal distortion and poor tool life. In order to tackle these conflicting requirements, the essentiality of study on machining performances with MQL becomes important[Arup Kumar Nandi, 2008]. According A.K. Nandi the machining performance of drilling Aluminium AA1050 investigated with lubricant and the flow rate of lubricant is an important factor and the output as surface roughness and cutting speeds, power/specific cutting force. The results analysed with different lubricant flow rates for different cutting speeds and feed rates are described. After critical analysis the experimental values as well as the model of fuzzy logic results, it revels the observed surface roughness is improved with increasing the flow rate for lower values of cutting speed and constant feed rate. But, for higher values of cutting speed, the surface roughness deteriorated with increasing flow rate. In contrast, for a constant cutting speed, the rate of change of surface quality with flow rate is minimized as feed rate increases. It is also found that for fixed values of cutting speed and feed rate, the cutting power increases to certain values of lubrication flow rate.

In the other study comparison of MQL and other coolant-lubricant conditions were checked to know their effects on drilling of the part. For examplea series of experimental investigations of the effects of various machining conditions [dry, flooded, MQL), and cryogenic] and cutting parameters (cutting speed and feed rate) on thrust force, torque, tool wear, burr formation, and surface roughness in micro-drilling of Ti–6Al–4V alloy. A set of uncoated carbide twist drills with a diameter of 700 mm were used for making holes in the workpiece material. Both machining conditions and cutting parameters were found to influence the thrust force and torque. The thrust force and torque are higher in cryogenic cooling. It was found that the MQL condition produced the highest engagement torque amplitude in comparison to the other coolant–lubrication conditions. The maximum average torque values were obtained in the dry drilling process. There was no substantial effect of various coolant–lubrication conditions on burr height. However, it was observed that the burr height was at a minimum level in cryogenic drilling. Increasing feed rateand decreasing spindle speed increased the entry and exit burr height. The minimum surface roughness values were obtained in the flood cooling condition. In the dry drilling process, increased cutting speed resulted in reduced hardness on the subsurface of the drilled hole. This indicates that the surface and subsurface of the drilled hole were subjected to softening in the dry micro-drilling process. The softening at the subsurface of drilled holes under different cooling and lubrication conditions are much smaller compared to the dry micro-drilling process [M.Percin, 2016]. The challenges of practicing MQL in drilling and Milling operations are further subjected for temperature measurement. For that new temperature measuring system for rotating cutting tools proposed. The new system is composed firstly of a thermocouple integrated into the drill or into the mill and positioned as close as possible to the cutting face and near the cutting edge. To achieve the collection and the transmission of the temperature signals to the acquisition system, a data conditioning system and a wireless transmitter unit were incorporated into a special tool-holder. A Radio Frequency Antenna placed in the proximity of the tool holder completes the measuring system.This system was used with success in studies for aeronautic industry. The first one consisted tooptimize the cutting conditions during drilling of Ti6Al4V titanium alloy with a minimal quantity of lubricant (MQL). The objective of the second one was to test the thermal behaviour of three different coated tools during dry milling of an aeronautic aluminium alloy [G.Le Coz, 2011]. In the other case different source of MQL for drilling were proposed to improve the effects of lubricants on the health of operators, quality of part and to minimize the cost of manufacturing due to less lubricant. For instance, the study on the potency of minimum quantity lubricant palm oil (MQLPO) as lubricant in the high speed drilling of Ti-6AL-4V to compare MQL Synthetic Easter (MQLSE), air blow and flood conditions. It was found that MQLSE and MQLPO gave comparable performance with the flood conditions. In addition, MQLPO outperformed MQLSE on the cutting forces, temperature, power and specific cutting energy. It is shown that palm oil can be used as a viable alternative to synthetic ester for MQL lubricant (E.A Rahim, 2010).

V.MQL-In Grinding Operation

As seen in previous section the importance of MQL in grinding operation is also crucial. It is indicated the work of M.k.Sinha and his co-authors on the application of eco-friendly Nano fluids (NF) during grinding of Inconel 718 through small quantity of lubrication. From the study it’s concluded that the application of NFs resulted in minimization of grinding forces, coefficient of friction, and improvement in the ground surface integrity. Zinc oxide based NFs have shown better grinding responses mainly because of improved lubrication behaviour. It is primary due better spread ability that has induced stable lubricious film at the contacting surfaces even at a higher temperature. The findings of work can be regarded as a first step towards the green and sustainable grinding of higher strength superalloys[Manoj Kumar Sinha 2016]. High attention is given to environment and health problems caused by machining; the development of an environmental-friendly grinding fluid has become an urgent task. As in the case of drilling scholars worked in preparing alternative source of MQL. Those grinding cutting fluids are vegetable oil (i.e. soybean, peanut, maize, rap seed, palm, castor and sunflower oil) were used as MQL for experimental investigation and the control factors considered were grinding force, friction coefficient, specific grinding energy and grinding ratio, and friction properties wheel/work piece (surface morphology and surface roughness) as a response [Yaogang Wang, 2016]. The experimental result indicated that MQL vegetable oil achieved ata lower friction coefficient, specific grinding energy, and grinding wheel wear than flood grinding. Among the mentioned, castor oil achieved the best lubrication property and the best surface quality of workpiece.

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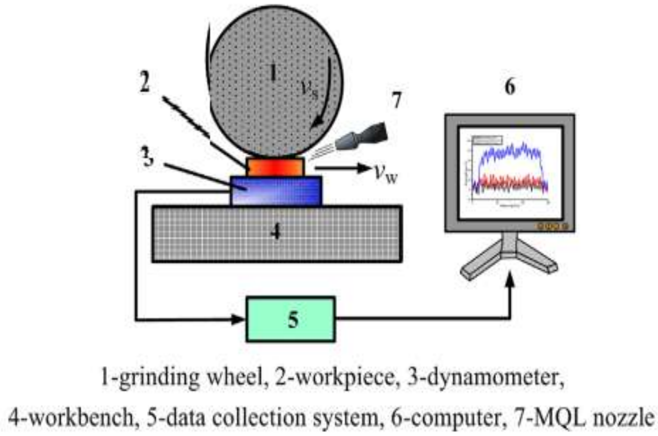

Figure 4: Grinding experiment diagram[Yaogang Wang, 2016]

The surface morphology and surface roughness quality obtained by MQL of vegetable oil is better than that of flood lubrication. In particular, MQL grinding using castor oil results in the best surface morphologyand minimum surface roughness (Ra = 0.366 and RSm = 0.0324)[Yaogang Wang, 2016]

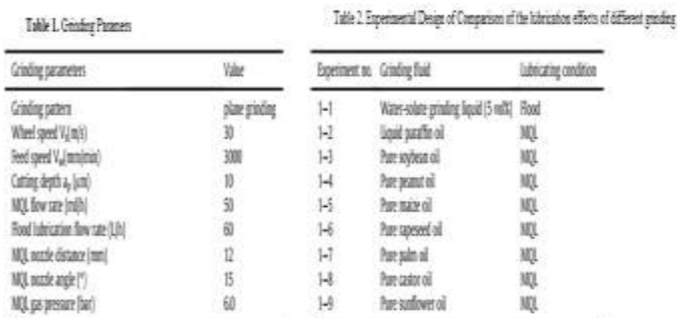

Table 1. Grinding Parames

Grinding parameters	Value
Grinding pattern	plane grinding
Wheel speed V_s (m/s)	30
Feed speed V_w (mm/min)	3000
Cutting depth a_p (μm)	10
MQL flow rate (ml/h)	50
Flood lubrication flow rate (L/h)	60
MQL nozzle distance (mm)	12
MQL nozzle angle (°)	15
MQL gas pressure (bar)	6.0

Table 2. Experimental Design of Comparison of the lubrication effects of different grinding

Experiment no.	Grinding fluid	Lubricating condition
1-1	Water-solute grinding liquid (5 wt%)	Flood
1-2	Liquid paraffin oil	MQL
1-3	Pure soybean oil	MQL
1-4	Pure peanut oil	MQL
1-5	Pure maize oil	MQL
1-6	Pure rapeseed oil	MQL
1-7	Pure palm oil	MQL
1-8	Pure castor oil	MQL
1-9	Pure sunflower oil	MQL

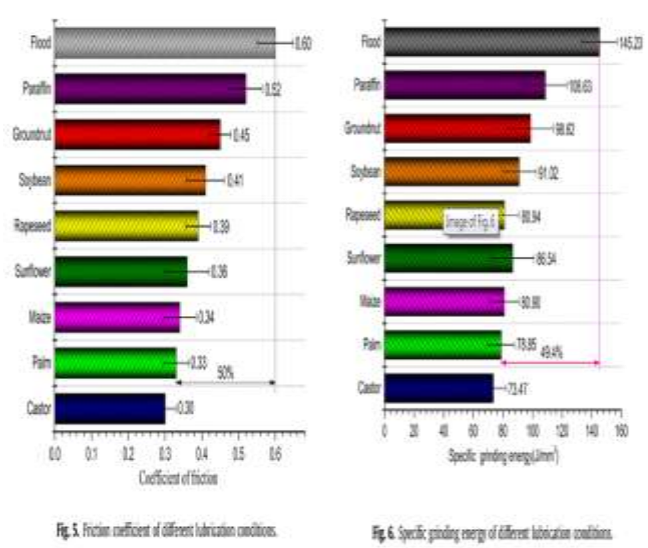

Fig. 5. Friction coefficient of different lubrication conditions.

Fig. 6. Specific grinding energy of different lubrication conditions.

Ra – Mean Average Rsm -- Arithmatic Mean value (Overall)

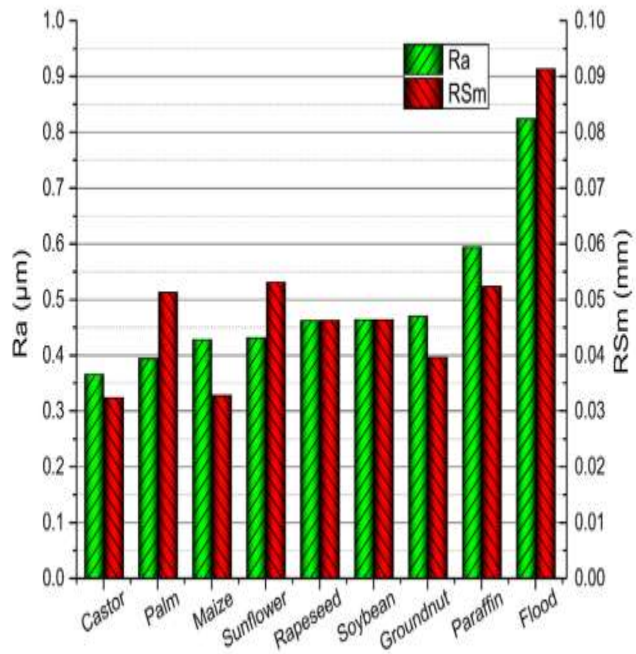

Figure 7. Surface roughness under different working conditions [Yaogang Wang, 2016].

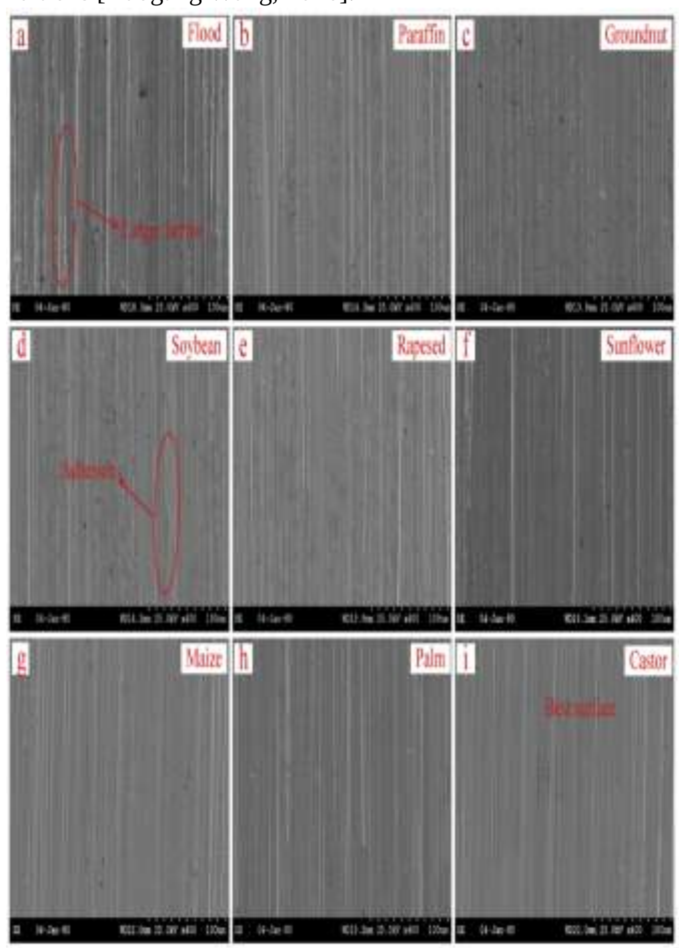

Figure 8. Surface morphology of GH4169 under flood, paraffin oil, and vegetable oils using MQL techniques.[Yaogang Wang, 2016]

VI. Conclusion

In general, a number of studies have shown that compared to dry machining; MQL technique substantially enhances cutting performance in terms of increasing tool life and improving the quality of the machined parts. The effects of MQL on different machining operation such as turning, milling, drilling and grinding are not the same. The advantage of using MQL in different machining operation is almost the same. But the parameters to be used in controlling the response of the machined part could be different. For example, the application of nano fluids resulted in minimization of grinding forces, coefficient of friction, and improvement in the ground surface integrity. It is also indicated the cost of cutting fluids is several times higher than tool costs.Asinvestigations show the process parameters in turning operation, affected by MQL nozzle position and cutting parameters (cutting speed, depth of cut and feed). On the other hand, the effects of MQL have been performed, and most of them are focused on the reduction of tool wear and improvement of surface roughness of work materials. The requirement of MQL- not only for the purpose of enhancing the tool life and cost of fluids but also the quantity of fluids increased in machining process the property of adhesion in between tool and workpiece developed because of amount of fluid is reduced substantially which results good surface finish. Those small amount of fluid suffices to reduce friction in cutting, diminishing the tendency of adhesion in materials with such characteristics. The challenges of implementing MQL in machining operation also different. For instance in turning operation, the challenging is to supply the oil mist to the cutting point, because continuous chips prevent the oil mist being supplied to the cutting point, which differs the turning operation compared to other machining operation like milling, drilling and grinding.

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