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Sustainable Implementation of MQL Technique in Metal Grinding Operation Employing Conventional & Nano-Particles Enriched Metal-Working Fluids: A Conceptual Approach

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Abstract: The current drive for accomplishing the implementation of sustainability concepts in manufacturing calls for economical machining practices to be embraced. A key territory of research is the scan for ecologically benign cooling techniques. Techniques like minimum quantity lubrication (MQL) and minimum quantity cooled lubrication (MQCL) have likewise been proposed which indicated viable outcomes when contrasted with cryogenic and conventional machining. Likewise, nanofluids could be utilized to give cooling and lubrication to control thermo-physical and tribochemical properties of material processing. It is forecasted that addition of nanoparticles alongside customary cutting oil could outperform traditional cutting strategies as far as warm conductivity, convective warmth exchange coefficient, basic warmth transition, consistency, and wettability. These properties have a promising potential to prompt the advancement of new coolants and lubricants with applications in a wide assortment of materials processing technologies. This paper audits the exploration in metal grinding employing MQL technique and assesses its potential for applications in machining, concentrating on their thermal and tribological viewpoints. The expanding utilization of MQL prompts a requirement for data on their sustainability with a specific end goal to perceive and keep away from risks. Sustainability is discussed in perspective of occupational health and safety and toxicity of nanoparticles. Also a concept of automated MQL grinding setup has also been proposed in the present study.

Keywords — Minimum quantity lubrication (MQL), Metal-working fluids, Nanoparticles, Automated MQL Grinding

I. INTRODUCTION

Sustainability is a concept that has to be incorporated at all of the three social, economic and environmental levels. For the machining processes this is not complete without the cutting process lubrication taken into the account. It was seen that the role of lubricant consumption is of great importance in the sustainability assessment of machining processes. Huge amounts of metal-working fluids consumption have been recorded in countries, e.g. 100 million gallons a year in the U.S. and 75491 tons in Germany. In Japan very high consumption and disposal costs were recorded. An estimate suggests that almost 16% of the total manufacturing costs are comprised of cutting fluid costs and when it comes to the machining of hard to machine materials, they reach up to 20-30 percent. The main characteristic of grinding in comparison to other machining processes is relatively large contact area between the tool and the workpiece and the high friction between the abrasive grits and the workpiece surface, thus resulting in thermal damage to the workpiece as well as loading and wear of the grinding wheel. Thermo-mechanical processes in the contact zone are defined by tribological relationships between the grain cutting edge, the grinding wheel bonding, the workpiece and the chip as it forms, so that cooling lubrication plays a decisive role during grinding with respect to heat generation and dissipation. Over the years various research were conducted and it was found that minimum quantity lubrication (MQL) in grinding process serves the best purpose for achieving fine surface finish, reduction in tool wear, less thermal damage and curtailment of fluid consumption.

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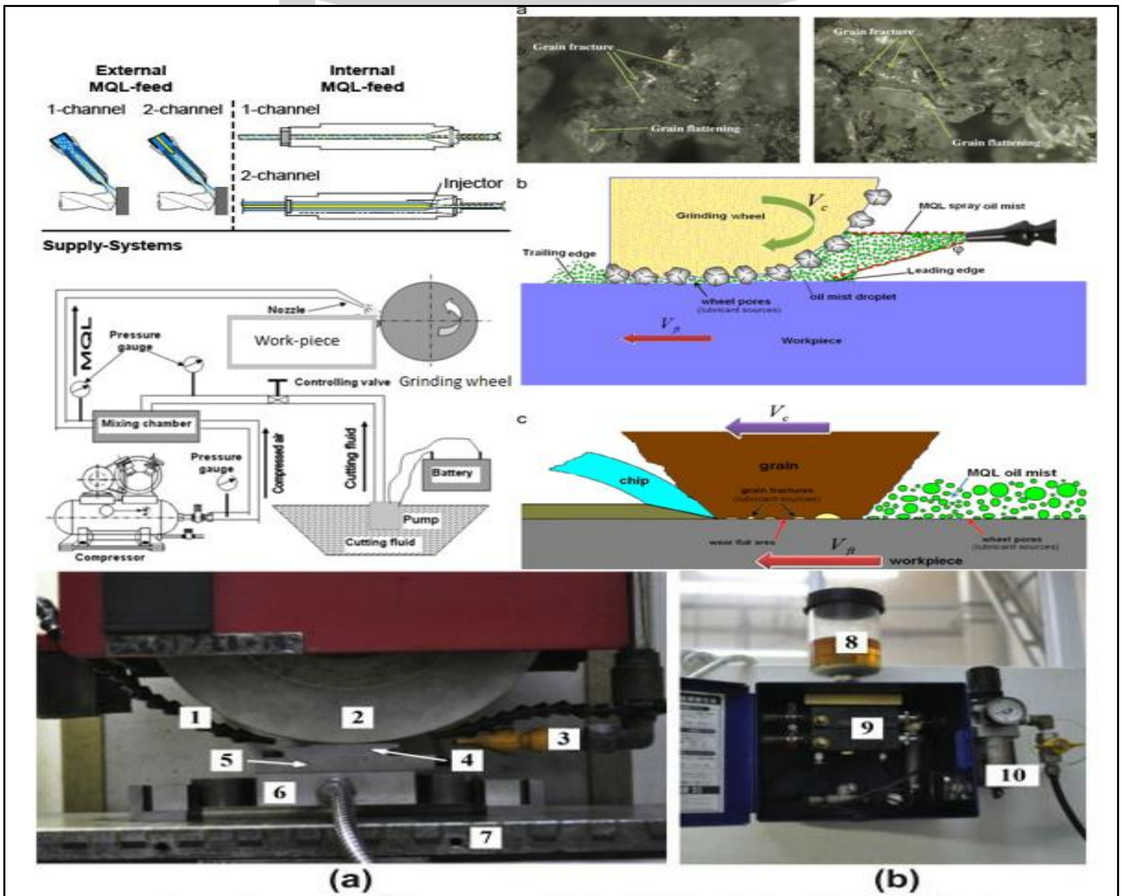
II. MINIMUM QUANTITY LUBRICATION

The main aim of minimum quantity lubrication (MQL) is to reap the benefits of metal-working fluids without getting affected with the harmful effects of the metal-working fluids. It involves the usage of minimal quantity of metal-working fluid with a typical flow rate of 50-500 ml/h which is directly applied to the cutting zone thereby avoiding the need of fluid disposal as it happens in flood cooling. Since MQL involves significantly lesser amount of cutting fluid, this phenomenon is popularly referred to as 'near dry machining' or 'micro lubrication' or 'spatter lubrication'. This system consists of an atomizer, cutting fluid sump, discharge nozzle, etc. The atomizer works as an ejector in which high pressure air is used to atomize the coolant. Atomized coolant is then delivered to the machining zone by the air in a low-pressure distribution system. Due to the venturi effect in the mixing chamber, partial vacuum sucks the cutting fluid from the oil sump where it is maintained at a constant hydraulic load. The air passing through the mixing chamber atomizes the coolant stream into aerosol of micron-sized particles. When this aerosol is sprayed in the grinding zone as mist, it works as coolant as well as lubricant and penetrates deep into the wheel-work piece interface.

There are two methods of mixing air and lubricant in MQL method: Mixing inside the nozzle and Mixing outside the nozzle. In the first method, the lubricant and air is mixed just before reaching the nozzle in a mixing chamber. The oil-mist is then supplied through the nozzle at high pressure onto the grinding zone. The oil performs the lubricating function while highly pressurized compressed air performs the cooling action. In the second method, the mixing of oil and compressed air is done in a separate mixing chamber. The figure below illustrates the MQL techniques.



1-supply nozzle of the nanoparticle jet MQL grinding liquid, 2-wheel, 3- supply nozzle of the flood grinding liquid, 4-workpiece, 5-fixture, 6-YDM-III99 grinding 3D dynamometer, 7-workbench, 8-MQL oil tanker, 9-MQL flow control valve, 10-pressure regulating valve with pressure gage

III. USAGE OF METAL WORKING FLUIDS & NANO-PARTICLES IN MQL

Metal working fluids are widely used in machining operations to serve the purpose of reducing thermal deformation by cooling the machining zone and improving the surface finish by providing good lubrication. The application of MQL in machining has emerged as an alternative for reducing the abundant flow of metal-working fluids and achieving cleaner production. There are two broad categories into which metal-working fluids may be classified (i.e.) Water miscible metal-working fluid and Mineral-oil based metal-working fluid. Several additive compounds such as Sulphur, Phosphorous, and Chlorine based components can be added to the base cutting fluids in order to improve their cooling and lubricating properties. Also enrichment of nano-particles has shown considerable improvement in heat dissipation capacities. Under aggressive machining conditions such as high grinding speed, as soon as the small quantity of oil mist comes in contact with the machining zone, it vaporizes without

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effectively removing the heat. Thus, there arose a need to enhance the properties of the MQL fluid in such a way that it can prove to be beneficial in all the grinding conditions. One such solution provided was addition of small sized thermally conducting particles, having lubricating properties to the base fluid medium which can cool as well as lubricate the grinding zone. Nano-particles such as Molybdenum disulphide, Aluminium oxide, Carbon nanotubes and Graphite powder are widely used in MQL environment.

IV. DISCUSSION

This section is systematically discussing the use of conventional metal-working fluids and nanoparticles using MQL technique showing its influence on metal grinding performance parameters (grinding force, temperature, grinding wheel-life, surface roughness) based on available literatures.

Surya et al. [1] carried out grinding experiments by taking zirconia as workpiece, synthetic oil as metal working fluid and found that there is considerable reduction in friction resulting in better surface finish.

Guo & Liu et al. [2] took nickel based alloy and performed grinding using castor oil and soya-bean oil and found optimal lubrication effect.

Zhang et al. [3] used Al_2O_3SiC as nano-fluid with different particle sizes which resulted in better surface integrity.

Rabiei et al. [4] performed grinding on mild carbon steel (CK45) in dry, flood & MQL environment and found that MQL reduced the friction coefficient and reduced the tangential forces. MQL was more useful for grinding of hard steels.

Balan et al. [5] performed grinding operation on Inconel 751 super alloy minimum grinding force and surface roughness could be achieved by increasing the MQL oil flow rate and air pressure. MQL considerably reduced the grinding forces, temperature and surface roughness.

Mao et al. [6, 7 ,8] investigated the suspension stability of Al_2O_3 nano fluid which is applied in minimum quantity lubricant grinding. It was found that the nanofluid had poor suspension stability under short time ultra-sonic vibrations. The suspension stability could be improved by using 0.5% nanoparticles and increasing the ultrasonic vibrations to about 1 hour. Due to better dispersing characteristics under these conditions the resulting nanofluid has got better heat dissipating and lubricating properties. He also investigated the role of the nanofluid in grinding operation by conducting friction and wear experiments which can establish various tribological properties of the nanofluid. They observed that nanoparticle based fluid showed a superior anti wear characteristic which led to a reduction in tangential cutting forces and improved the surface texture. After that he studied the effect of nozzle spraying direction during surface grinding of hardened AISI 52100 steel. An angular position of the nozzle towards the grinding wheel provided the most optimal grinding performance. Increase in air pressure resulted in reduction in grinding forces, surface roughness and grinding temperature. Better grinding performance was obtained with shorter spraying direction.

Silva et al. [9] carried out grinding experiments on ABNT 4340 steel using aluminium oxide and super abrasive cubic boron nitride (CBN) grinding wheels. The analysis indicated that surface roughness and grinding wheel wear reduced significantly when the experiment was carried out under MQL lubricating condition. The performance of aluminium oxide wheel was better than that of CBN wheel under MQL condition. However, surface roughness was less when aluminium oxide wheel was used. The tangential cutting forces were also reduced under MQL environment.

Hadad et al. [10] carried out investigation for temperature and energy partition in the MQL grinding using Al_2O_3 and CBN super abrasive grinding wheels and hardened 100Cr6 (AISI 52100) steel as the work piece material. The output responses considered for investigation were grinding forces, grinding temperature and surface finish. It was observed that grindability of 100Cr6 hardened steel increased significantly by employing the MQL technique in the grinding process. Grinding forces were reduced considerably and the surface finish was found to improve in comparison to other grinding conditions.

Setti et al. [11] carried out Taguchi and Response surface analysis in the grinding of Ti-6Al-4V using Al_2O_3 nano fluid. As expected nanofluid MQL reduced the grinding force and improved the surface finish. It was also observed that increasing the volumetric percentage of nano particles did not result in increasing the efficiency proportionally.

Kalita et al. [12] used MoS2 nano particles in paraffin and soybean oils in the grinding process using cast iron and EN24 steel as the work piece materials. It was concluded that MQL grinding using nanofluids reduced the specific energy consumption and frictional losses and increased the G ratio.

Tawakoli et al. [13, 14] made a comparison of performance characteristics for grinding process on 100Cr6 hardened steel under dry, wet and MQL lubrication conditions. It was found that tangential forces were reduced considerably under MQL environment possibly due to better penetration of the lubricant in the grinding zone under high air pressure. Due to better lubrication friction coefficient and specific energy consumption was also reduced between the rubbing surfaces which resulted in a better surface finish. He also investigated the effect of various process parameters such as oil flow rate, air pressure, MQL nozzle position and distance from the wheel–work-piece contact zone was investigated thoroughly in the process of grinding. It was observed that the position of nozzle during the process has significant effect on the overall performance. An angular position of the nozzle at 10º- 20º to the surface of the work-piece resulted in the most optimal performance. Also, the distance of the nozzle from the grinding zone was also critical in deciding the process performance. The oil mist needed to be applied to the work-piece surface in order to achieve maximum efficiency in the performance.

Shen and Shih [15] mixed multi walled carbon nano tubes in soybean oil and performed grinding using vitrified bond CBN grinding wheel on Dura-Bar 100-70-02 ductile iron as work material. It was observed that addition of CNT in soybean oil could not significantly reduce the grinding forces. Maximum temperature reduction and improvement in surface finish was obtained with flood cooling.

Shen et al. [16] applied water based Al_2O_3 and diamond nanofluids in the grinding of cast iron under MQL conditions and compared the results with dry and wet

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lubricating conditions. Nanofluid lubrication helped in reducing the grinding forces, improving surface roughness and preventing the burning of workpiece by providing an efficient cooling system.

Gopal and Rao [17] used graphite as a solid lubricant in grinding of Silicon carbide. Tangential cutting force, temperature, specific energy and surface roughness were found to be reduced as compared to when grinding was done under dry environment. This resulted in a greater material removal rate and a lesser wheel wear. Thus, grinding under graphite environment resulted in a greater productivity and a better product quality.

V. AUTOMATED MQL GRINDING SETUP: A CONCEPT

Essentially, Minimum quantity lubrication employed in industries are semi-automatic type i.e. flow rate of the coolant fluid is controlled manually during grinding operation. Due to this reason the fluid flow is constant whether the requirement of coolant is high or low during the machining operation. This problem can be tackled by employing automation technique in the existing typical MQL setup for grinding.

Just like engine control unit used in modern day automobiles for fuel injection, an automatic controller is required to control the flow of coolant fluid as per the requirement during the grinding operation.

Fuzzy knowledge based controller (FKBC)

A fuzzy knowledge based controller is a control system works on the principle of fuzzy logic which is a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1 which operates on discrete values of either 1 or 0 (true or false, respectively). Fuzzy controllers are very simple theoretically. They consist of an input stage, a processing stage, and an output stage. The input stage atlases sensor or other inputs, such as switches, thumbwheels, and so on, to the suitable membership functions and truth values. The processing stage appeals each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

Automated MQL grinding setup using FKBC

In typical MQL setup, response parameters are measured only after the machining run completed but the coolant flow is always constant and it is not present as per instant requirement. But in automated MQL setup, after every run of experiment, the response parameters will be measured simultaneously and the coolant flow rate will be controlled as per the requirement.

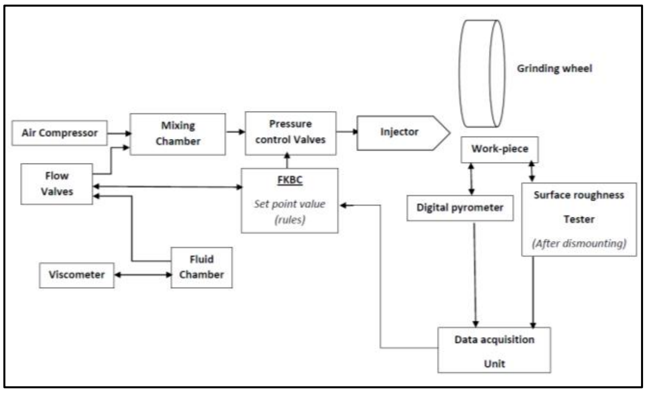

Fig. 2: A conceptual Automated MQL Grinding setup layout

Fig. 2 shows the conceptual Automated MQL Grinding setup layout. As compared to traditional MQL setup, the automated one consist of digital pyrometer and surface roughness tester attached with the workpiece. These measuring instruments constantly measures the response parameters i.e. workpiece temperature and surface roughness of the grinded area respectively. These instruments are then attached with a data acquisition system which regularly monitors the responses and sends feedback to a Fuzzy Knowledge Based Controller (FKBC). It gives digital output according to the predefined fuzzy rule set to the flow valve and pressure valve fitted with actuators to control the flow of coolant fluid. An injector is fitted at the outlet so as to bear the uneven pressure of the fluid and to deliver it on the workpiece. Initially this setup is not so cost effective. But for long run it can be beneficial and cost effective during the machining process since it reduces the use of expensive coolant and nano-particles. Overall this can be useful in industries where grinding and surfacing operations are carried out in large scale.

VI. CONCLUSION

It is interesting to observe that most of the experimental studies showed that MQL machining can be a viable alternative to wet machining and can facilitate environment-friendly machining. Mostly research has been carried in the application of mineral oils, vegetable oils and nanofluid-based metal-working fluids with the help of MQL technique during metal grinding operations. Hence, nano-lubricant powder-mixed MQL would be highly recommended for the application where cooling is more stringent requirement compared to lubrication effect for example for machining materials with low thermal conductivity like stainless steel, titanium alloy or nickel-based super alloys. A conceptual automated grinding technique is also suggested which can be beneficial in the machining process used in industries. Further research and development can be done in MQL machining by introducing different cryogenic gas mixed with nano-lubricant powder.

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