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Comparative evaluation of MQL and dry machining of C45 steel using uncoated w/c inserts

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Abstract
Globally, the methods by which the products are designed and manufactured are advancing at rapid pace. In the present scenario, the identity of the lubricants and the coolants are classified as the toxic fluids not only to operators but also degrade the environment. Industries and researchers are working for the new advancement to reduce or eliminate the use of cutting fluids, both for economic and ecological reasons. Minimum Quantity Lubrication (MQL), which minimizes the use of cutting fluid proved advantages comparative to Flood cooling reduces the quantity of the lubricant to much extent, had gained popularity as a new substitute for Flood Cooling. The use of MQL in machining not only results in increase tool life, controlled temperature at chip-tool interface but provides with a cleaner environment and much amount-effectual machining technology. This paper presents a parallel analysis into the effect of temperature, roughness and tool wear at different cutting speed during turning of C45 steel. Dry cutting and minimum quantity lubrication (MQL) results are also compared and conclusions are analyzed. The experimental outcome demonstrates that the cooling and lubricating conditions influence altogether the researched procedure and surface properties which depends to a substantial degree on the connected cutting parameters, in particular the cutting speed and feed rate.

Keywords: green manufacturing, dry machining, minimum quantity lubrication (MQL)

1. Introduction

Green manufacturing is one of the major research and development theme in the industrial science and manufacturing sector from past few years due to the challenges raised by increased environmental awareness, strict protection laws and health regulations for occupational safety. The machining operations, particularly in turning extreme friction comes into role due to contact between the tool and the workpiece, i.e on the apparatus (tool) rake face and paraphernalia (tool) flank [1]. Due to such processes, a lot of heat is generated which results in increase in temperature, tool wear, surface roughness and thus leads to shorter tool life. During such operations, heat is produced at the two zones of tool i.e primary zone and secondary zone. The extent of heat produced at the primary zone cannot be controlled, but can be controlled at secondary zone. At the interface between a cutting tool edge and a metallic workpiece, the temperature show increment from 200°C to more than 1,300°C [2]. At such temperatures, the metallic structure of softer metals such as aluminum distort. This quick temperature variation or the thermal shocks decreases the tool life by increasing tool wear [3]. During dry machining, the friction and the traction between the chip and tool have a tendency to be higher, which causes higher temperatures, higher wear rates and thus shorter tool lives [4]. The new technique, flood cooling has been proved to be useful but the issue exists that in flood cooling the excessive use of lubricant, degrades the environment and workers health hazard problems in metal cutting industry [5]. Cutting fluids are used to reduce cutting forces, temperature, coefficient of friction and power, increases tool life, improve surface finish, chip removal, reduces thermal distortion and subsurface damage [6, 7]. Inappropriate disposal of the metal cutting fluid pollutes the air, land, and water and disturbs the entire environment. In addition, cutting fluid liquid particles stay dangling in the environment for short time. To conquer the disadvantages of Flood cooling, tools are microtextured for elite cutting [8]. Tool coating is the most effective in enhancing the performance of a tool. Appropriately, the consolidation of the micro-textured surface and the surface encrustation (coating) seems to take collaborative effect on the consummation (performance) of cutting [9, 10]. Friction coefficient at the rake face lowers when surface texture was brought to bear to cutting tools. Utilization of the rake-face textured tools can fundamentally reduce cutting forces and cutting temperature in contemplate with the traditional tools. For the solution, the breakthrough approach is adopted known as Minimum Quantity Lubrication (MQL), also known as "Micro lubrication," and "Near-Dry Machining" (NDM) is the current approach of providing metal cutting fluid to the tool or the work interface [11]. Utilizing this innovative approach, cutting fluid, when wisely selected and used, have a generous effect in how adequately a tool performs. In MQL maybe, secondary qualities are essential. These assimilate their invulnerability properties, (human acquaintance and environment degradation) oxidation, biodegradability and storage stability. This is vital aspect of MQL because the cutting fluid or the lubricant could not affect the environment and can use for long term because of the low consumption.

According to the researchers Anuj Kumar Sharma [1] and others when performed the machining of AISI-4140 which is also known as molybdenum steel of the dimensions (70 mm x 300 mm) using uncoated carbide inserts as a cutting tool which is achieved on HMT lathe machine under contrasting machining aura like wet, dry, conventional cutting fluid. The experimental setup consists of compressors, flow controlling unit, air-dryer and two nozzles. Supply of air pressure of cutting fluid is 4 bars. Using nanofluid as lubricant shows decrease in cutting forces in Fx, Fy & Fz. With the lubricating effect of vegetable oil this devaluation is seen due to decreased coefficient of friction between tool and workpiece. B.P. Bandyopadhyay [2], and others performed the machining of AISI-4140 steel which is a chromium molybdenum steel with Tin Coated embed CNMG 120408 which results and concludes under MQL conditions, that type of these chips was coiled-shape and were significantly brighter and smoother in appearance. This demonstrates that an apparent decrease of cutting temperature because of utilization of MQL the outcomes demonstrate that MQL has a constructive effect in enhancing the surface finish and properties. At dry machining conditions, there was the significant increase in surface roughness as the feed rate was increased. The reduction may be due to the reduced coefficient of friction between tool and workpiece because of rolling action of nanoparticles and lubricating effect of vegetable oil. The cutting execution of MQL machining is superior to that of dry cutting. MQL decreased cutting power altogether due to diminished cutting temperature due to improved tool-chip interaction. The surface finish of the turned piece was also improved with MQL cutting compared to dry cutting. The examination of chip morphology uncovers that cutting temperature was lower while cutting with MQL contrasted with dry cutting. Bikash Chandra Behera [3] and other proposed the machining of INCONEL 718 with TI AIN coated carbide tool which concludes the surface hardness lowers by 15-40 % in MQL cutting conditions contrasted with dry cutting due to tiny air suspended cutting fluid particles. Cutting forces increases on speed beyond 100m/min. under dry conditions and concludes closely coiled chips were formed during MQL turning at higher speed (0.2mm/rev.) and speed 120m/min. The effectiveness of MQL was demonstrated indirectly due to coiling of chips which happened due to effective cooling at the chip tool interface. Che Haron [9] and other proposed the machining of Titanium alloy, Ti-6Al-4V ELI φ102 X 120 mm with Carbide, ISO CNMG 120408-QM-H13A. Observations were made on Tornado T4 CNC lathe. The cutting speeds were set at 100, 135 and 170 m/min, while the feed rates were 0.15, 0.2 and 0.25 mm/rev and 0.6, 0.8 and 1.0 mm were the depth of cuts. The mode of lubrication during machining experiments was MQL. The MQL jet has been used mainly to target rake and flank region with flow rate 100 ml/hr. surface roughness ranges from 1.022 - 2.544 µm was concluded which is considered as nominal one. 100 m/min was the cutting speed which was kept constant, and variation in feed rate from 0.15 mm/rev and 0.25 mm/rev, resulted in hysterically elevated in surface roughness. Chetan N, B.C. Behera, and other [8]. Performed the machining with the study of MQL on a computer numerical machine tool (CNC) Hermle C40 for turning processes multi thickness KC9240 grade of WC inserts horsed in PCLNL 2020 k12 tool holder by Kenna metals is used. The change in Ph. value is mainly due to reduction in contact value with alumina NFs. Significant changes in intermolecular forces (reduction in Vander wall forces) is due to the charge present over alumina particles also changes the PH value of the base fluid. It is a well-known fact that contact angle has a strong relation with Vander Waals' forces Cutting fluid. It plays a very significant role in wetting and lubricating of the work surface. Littler the contact edge bigger will be the wetting area through the reverse is valid for the substantial contact edge separately. D.G. Thakur [27], and other authors, proposed the machining of Super alloy Inconel 718 with tungsten carbide tool which comes about less surface hardness while machining under MQL condition than dry condition. When parameters were set as cutting speed 40 and 60m/min feed rate – 0.05 and 0.2mm/rev. depth of cut - 5mm cutting fluid flow rate 10ml/min and concludes the high-speed machining of Inconel 718 under MQL with pulsed jet mode resulted in improved surface roughness values. Material side flow prodigy which deprecates the peculiarity of the machined surface found to be nominal in case of MQL under pulsed jet mode conditions. Domnita Frăţilă [10] and others suggested the machining of AISI 1045 carbon steel bar with exaggeration in cutting speed and lubricant dribble results in lower surface roughness. The most unfavorable combination of process parameters consists of a low level of spindle speed, high values of cutting depth, and DC condition and concludes consumption and disposal of MWF are controversies of largest significance in the machining monopoly. Relating to the use of MQL to AISI 1045 turning with carbide insert under concluding conditions, the survey conferred in this article substantiates that the environmental-friendly modus operandi, particularly MQL, can be auspiciously resolved without affecting the process results, in terms of surface quality. Diego Carou [7], and other suggested the machining of Inconel 718 with carbide inserts Nickel-base alloys the use of the MQL system in nickel-base alloys turning can be exceptional substitute to wet machining. In appropriate, it can rectify the tool life or tool wear. They also suggested that even using very small amounts of cutting fluid, the use of exclusively constructed nozzles can lead to betterment in tool life when the oil mist is dexterously recommended the turning of Inconel 718 at the cutting zone. The main decree indicates that MQL lowered the cutting temperature, cutting force, flank wear, and surface roughness higher than dry cutting. MQL also increased the tool life and provided greater dimensional accuracy. Senevirathne [26] and others preside over the MQL machining of AISI 9310 steel by adopting palm oil as cutting fluid. The use of MQL diminished the cutting temperature up to 10 °C as corelated to traditional flood cooling. The MQL procedure also provided logically upgraded outcomes in regard to surface finish, tool wear and chip formation. Puneet Sharma [24], and others suggested the machining of AISI 1040 steel with CNMG 120408, HSS Tool Nano graphite-soluble oil with dry lubrication, flood lubrication and mist application of soluble oil and concludes the use of Nano graphite-soluble oil in mist application has greatly enhanced the cutting conditions by lowering the temperature proliferate, abbreviating the tool wear and cutting forces. For both cemented carbide and HSS tools, mist application at 10 and 15 ml/min showed momentous improvement when intertwined with flood and dry lubrication with reference to chip–tool consolidate temperature, tool wear and cutting forces at the accomplished machining parameters on AISI 1040 workpiece.

2. Experimental Setup

There are various kinds of supply systems for MQL technique depending on the type of application which has been discussed in details. The MQL experimental set up consists of a fluid tank, mixing tank, compressor, and a small pump. A number of pressure gages and valves are placed at various locations to read the pressure as well as control the pressure. The fluid tank and the mixing tank are manufactured of stainless steel. Figure 1 shows the representational glimpse of the MQL unit (outermost mixing type). Coolant from the cutting fluid reservoir is sent into the fluid tank using the pump. The coolant in the fluid tank is compressed up to a pressure of 6 bar. The compressed coolant is then sent into the mixing tank where mixing of coolant and compressed air takes place. The coolant from the mixing reservoir is endowed at high pressure and intruded at high speed through the nozzle at cutting zone. The lean but eminent velocity stream of MQL was predetermined along the cutting edge of the insert so as to clinch that the coolant reaches immediate to the chip tool interface. The main advantage of the system is that the flow rate can be controlled by varying the pressure [2].

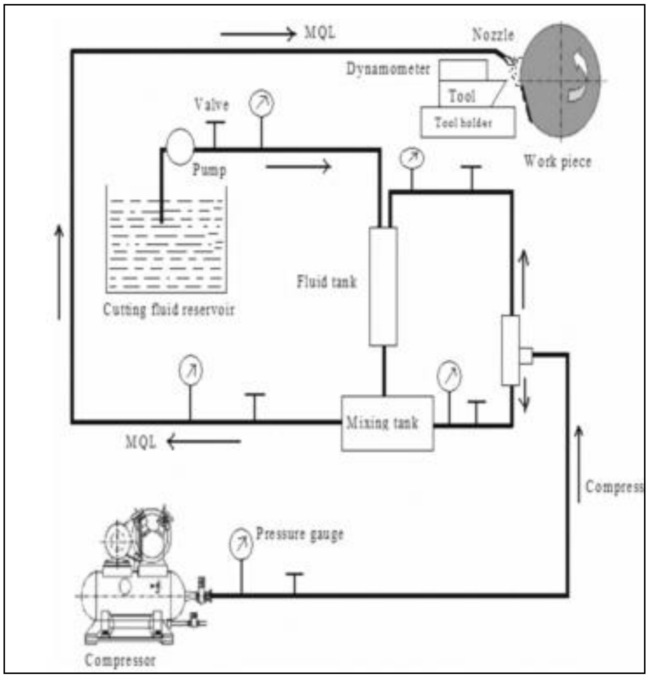

Fig 1: Schematics of Minimum Quantity Lubrication (MQL) Unit [2].

Workpiece - C45 steel is a medium carbon steel is used when superlative tenacity, durability and adherence is pined than in the "as rolled" condition. Uttermost size accuracy, straightness and concentricity conjoin to detracts wear in high speed applications. 1045 is a medium tensile low hardenability carbon steel which is turned, ground and polished customarily outfitted in the black hot rolled or periodically in the standardize state, with a quintessential tensile strength which ranges from 540 - 720 MPa and Brinell hardness range 175 – 220 in either condition.

Experiment Parameters

Above experiment is percolated at cutting speed 80,120m/min with fixed depth of cut 0.5mm, feed rate is 0.16 mm/rev. Selected lubricant is canola oil. Jet mode is uninterrupted, Flow rate of lubricant and pressure are 200ml/hr and 6 bars respectively.

Table 1: Parameters classified

Cutting Speed	Depth of Cut	Feed Rate	Jet Mode	Fuel Pump	Lubricant	Flow rate of lubricant	Pressure
80,120 m/min	0.5mm	0.16	Continuous	P-6	Canola Oil	200ml/hr.	6 bars

C-45 is used broadly by approximately all industry divisions for pertinence requiring more strength and wear resistance when compared to low carbon mild steels. It also consummates those applications amalgamates flame or induction hardening.

Table 2: Mechanical properties of C-45 [28].

Tensile strength (N/mm²)	Young Modulus (GPa)	Poisson's ratio	Shear modulus (GPa)	Melting temperature (°C)	Specific heat capacity (J/Kg K)	Thermal expansion	Thermal conductivity (W/m K)
650-800	Min 14	0.3	80	1540	500	11.7	46

Table 3: Chemical Properties of C-45 [28].

Chemical Composition	C	Si	Mn	P	S	Cr	Mo	Ni	Cr+Mo +Ni
(%)	0.42-0.50	<0.40	0.50-0.80	<0.045	<0.045	<0.04	<0.10	<0.40	<0.63

MQL – Canola Oil

Selection is made between canola oil and soybean oil. Properties like viscosity and thermal conductivity is compared. It is found that thermal conductivity of oil increases with increase in temperature. So, oil with lesser thermal conductivity is preferred. Viscosity behaves differently for liquids and gases. The gas viscosity increases with temperature. Bestowing (according) to KTG (Kinetic theory of gases) viscosity is commensurate (proportional) to square root of absolute temperature. In liquids cohesive forces tween (between) the molecules of a liquid which are much near than gas. The cohesion and molecular interchange contribute to liquid viscosity. With increment in temperature of liquid the cohesive forces recede (reduces) and surge (increase) the molecular interchange. The cohesive forces result in decrease in shear stress but latter leads it to increase. This shows reduction in viscosity for higher temperature of liquid.

Table 4: Chemical Properties of Canola oil [29].

Relative density (gm/cm³)	Refractive index (nd40°C)	Crismer value	Viscosity (Kinematic at 20°C, mm²/sec)	Cold test (15 hrs at 4°C)	Smoke point (°C)	Flash point (°C)	Thermal conductivity (W/m°K)
0.914-0.917	1.465-1.467	67-70	54	Passed	220-230	275-290	0.179-0.188

Table 5: Chemical Properties of Soybean oil [24].

Relative density (gm/cm³)	Refractive index (nd40°C)	Viscosity (Kinematic at 20°C, mm²/sec)	Cold test (15 hrs at 4°C)	Moisture content	Thermal conductivity (W/m°K)
0.917	1.4736	78.3	Passed	13.2	0.192-0.198

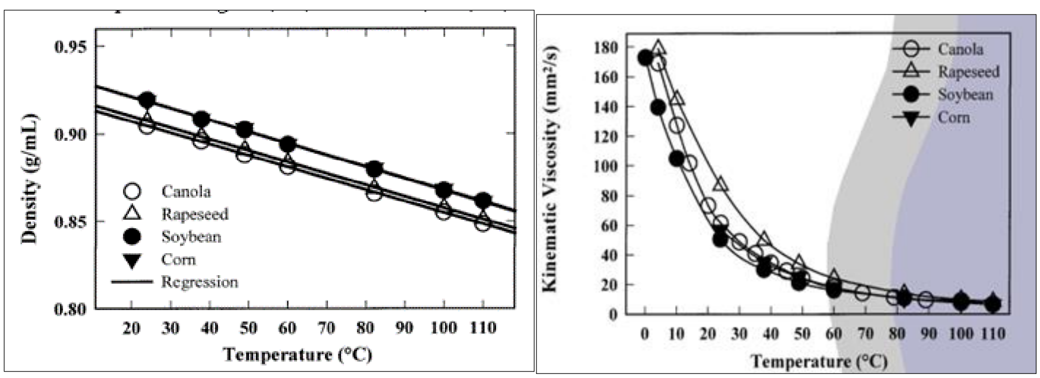

Fig 2: comparison of density and kinematic viscosity b/w canola oil and soybean oil [29].

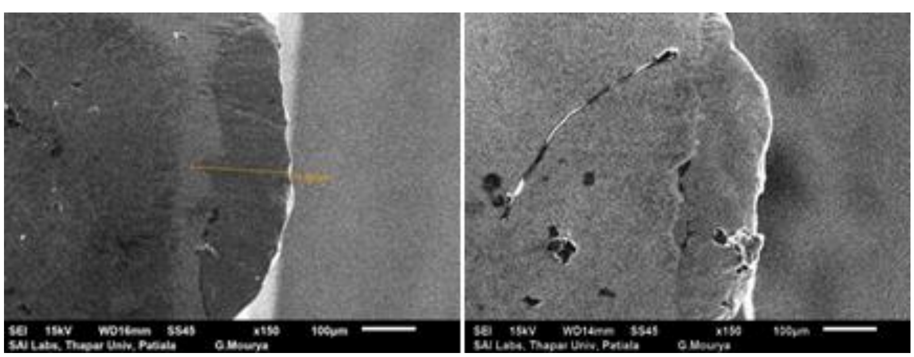

Fig 3: scanning electron microscope (SEM) of tool.

3. Results and Discussions

Effect on temperature

Experiment is performed on Centre lathe at CIHT institute where initial conditions mentioned above were set up. Results are calculated on two different speed 80 m/min and 120 m/min. feed rate, depth of cut and other cutting conditions are kept constant. The tabular data concludes between the dry and MQL conditions. The process of turning is performed for continuous 1, 2, 4, 6, 8 mins respectively. Making use of MQL strategies decreases the temperature at secondary zone and enhances tool life. Graphical interpretation is analyzed using Origin Pro 2017. This tool clearly indicates the step decrement in temperature under DRY and MQL conditions.

Table 6: comparison of temperature under dry and MQL at cutting speed 80m/min & 120m/min.

Cutting speed 80m/min	Temperature (°C)		Cutting speed 120m/min		
Time (min)	DRY	MQL	Time (min)	UT	UTMQL
1	41.6	29.5	1	55.4	37.5
2	52.6	31.5	2	61.8	45.9
4	60.9	46.6	4	73.4	49.5
6	66.5	49.5	6	90.8	61.2
8	69.5	56.1	8	104.8	84.5

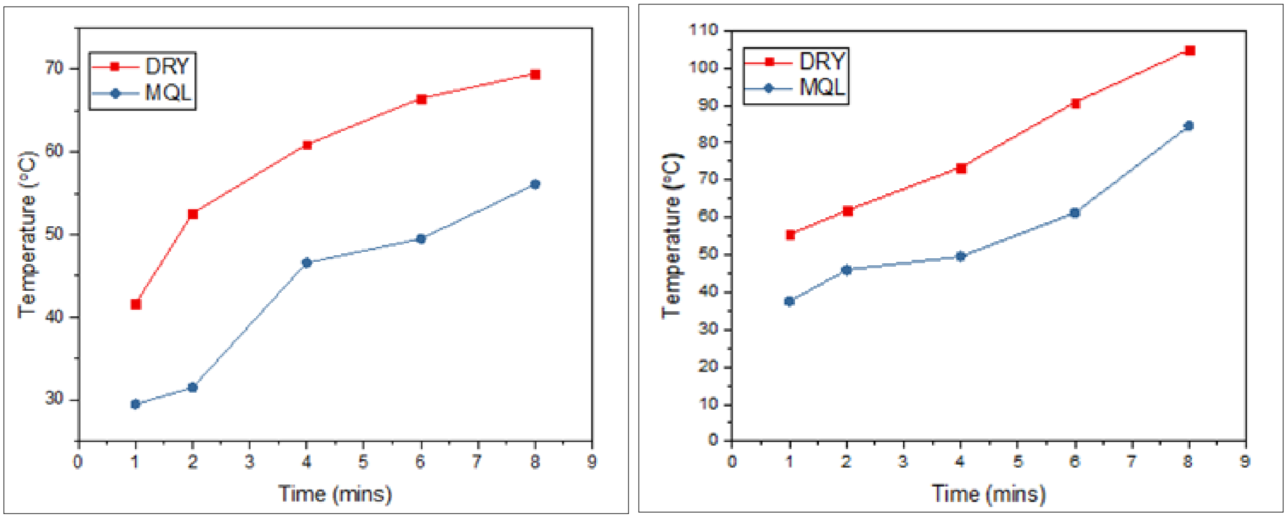

Fig 4: Graphical representation.

Effect on Surface Roughness

Surface roughness is described as fundamental of surface texture. It is evaluated by the aberration in the sight of the normal vector of a substantial surface from its optimal form. If these aberrations are huge, the surface is rough; if they are meager, the surface is smooth. In surface computation, roughness is frequently contemplated to be the immense-frequency, short-wavelength elemental of a measured surface. However, in proceeding it is generally necessary to perceive both the amplitude and frequency to confirm that a surface is correspondent for a purpose.

Table 7: comparison of surface roughness under dry and MQL at cutting speed 80m/min & 120m/min.

Cutting speed 80m/min		Surface Roughness (µm)		Cutting speed 120m/min	
Time(min)	DRY	MQL	Time (min)	DRY	MQL
1	4.11	3.04	1	3.2	3.01
2	4.39	3.47	2	4.4	4.11
4	4.61	4.06	4	5.01	4.21
6	5.03	4.23	6	5.52	4.58
8	5.49	4.79	8	5.6	4.86

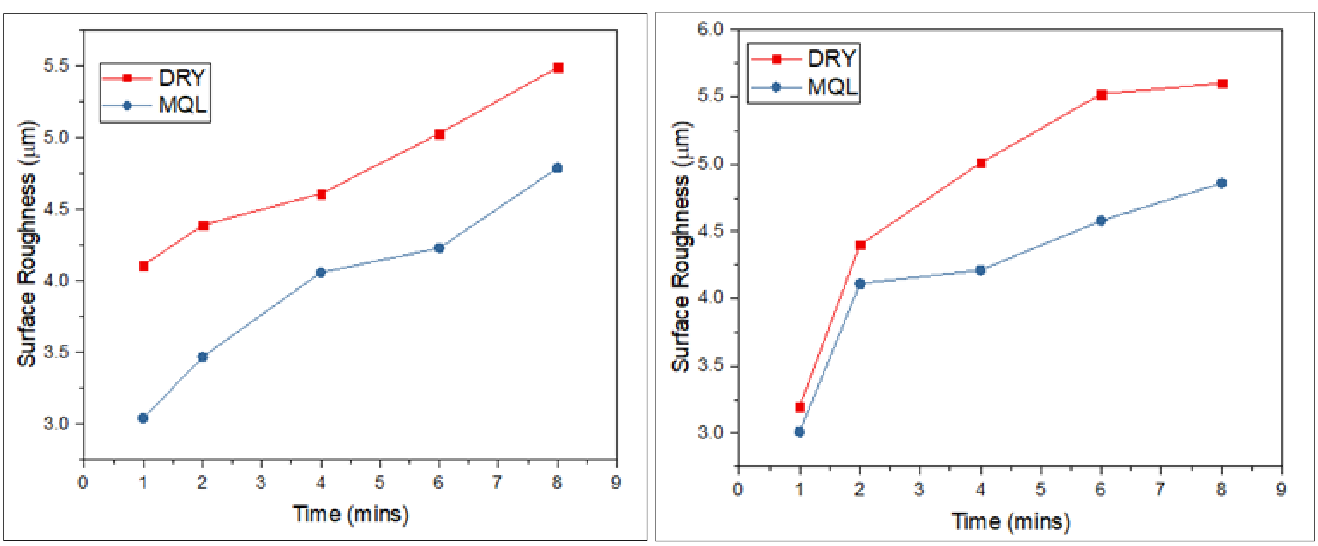

Fig 5: Graphical representation.

Effect on Tool Wear

Tool wear implies the bit by bit distortion of cutting tools due to unfaltering operation. It is a terminology which is often affiliated with tipped tools, tool bits, or drill bits that are employed with machine tools. Flank wear and crater wear are two subdivisions of tool wear. Flank wear means that moiety (portion) of the tool which is in influence with the accomplished part erodes and can be particularize using the Tool Life Expectancy equation. Crater wear means the rake face is crumbled when comes in influence with chips. This happening of tool wear is adequately normal and does not deteriorate the tool before it metamorphoses critically abundant to cause a cutting-edge failure. Below the tabular data of flank wear is analyzed at cutting speed 80 m/min and 120 m/min for different cutting conditions i.e at DRY and MQL. These results are analyzed for 1, 2, 4, 6, 8 mins respectively. More tool wears more tendency of cutting forces to develop and elevated temperatures and may also lead to tool breakage.

Table 8: comparison of tool wear under dry and MQL at cutting speed 80m/min & 120m/min.

Cutting speed 80m/min		Tool wear		Cutting speed 120m/min	
Time(min)	**DRY**	**MQL**	**Time (min)**	**DRY**	**MQL**
1	120	103	1	284.46	237.09
2	156	132	2	335.89	289.5
4	357	305	4	370.59	311.2
6	471	401	6	451.14	418.3
8	569	489	8	532.4	440.6

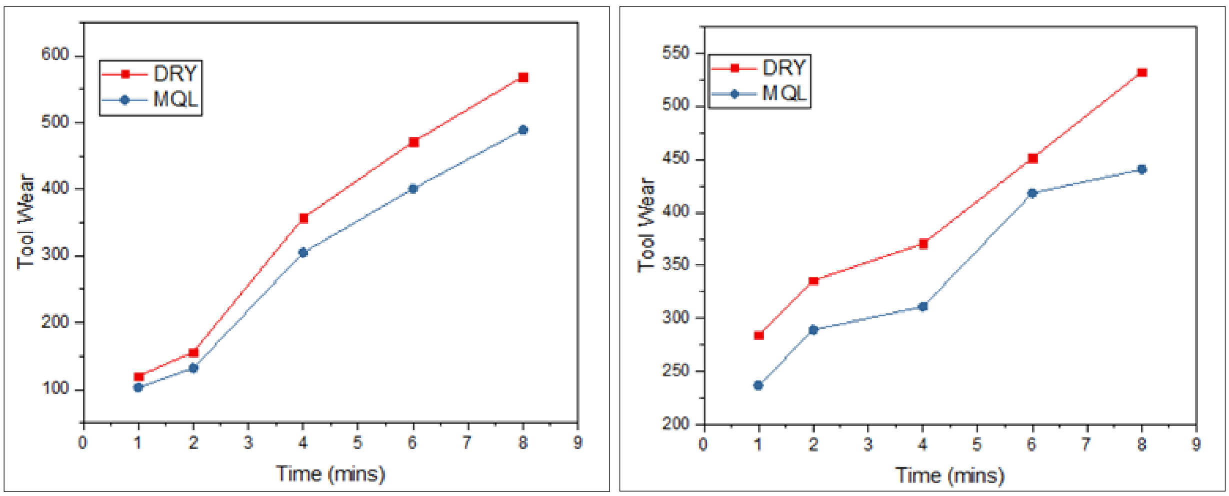

Fig 6: Graphical representation.

4. Conclusion

- Traditionally the increase in temperature at secondary zone distorts the microscopic structure of tool but as far now with use of MQL tool life is enhanced.
- Flood cooling which not only degrades the environment but also affects the operator's health, such problems are minimized by the use of MQL.
- The problem of non-degradability of cutting fluid is also minimized to large extent.
- Results concludes that finally near dry machining (NDM) and minimum quantity lubrication (MQL) replaced flood cooling and minimizes its adverse effects.
- Surface roughness is evaluated by the aberration in the sight of the normal vector of a substantial surface from its optimal form. Results concludes by providing MQL conditions during machining surface roughness also get decreased.
- Tool wear implies the bit by bit distortion of cutting tools due to unfaltering operation. Flank wear is reduced because the friction between tool and workpiece is reduced with the use of MQL.

References

1. Anuj Kumar, Rabesh Kumar, Amit Rai, Arun Kumar. Science Direct Characterization and Experimental Investigation of Al 2 O 3 Nanoparticle Based Cutting Fluid in Turning of AISI 1040 Steel under Minimum Quantity Lubrication MQL. Materials Today: Proceedings http://dx.doi.org/10.1016/j.matpr.2016.04.090. 2016; 3(6):1899-1906.
2. BP Bandyopadhyay, KR Endapally. Experimental Evaluation of the Effect of Minimum Quantity Lubrication in Turning AISI-4140 Steel. 2009 International Conference on Computers & Industrial Engineering, 2009, 1905-10.
3. Bikash Chandra Behera, Chetan, Dinesh Setti, Sudarsan Ghosh, P. Venkateswara Rao. Spreadability Studies of Metal Working Fluids on Tool Surface and Its Impact on Minimum Amount Cooling and Lubrication Turning. Journal of Materials Processing Technology, http://dx.doi.org/10.1016/j.jmatprotec.2017.01.016, 2017; 244: 1–16.
4. Barczak LM, Batako ADL, Morgan MN. A study of plane surface grinding under minimum quantity lubrication MQL con- ditions. Int J Mach Tools Manuf. 2010; 50(11):977-985.
5. Boubekri, Nourredine. A Technology Enabler for Green Machining: Minimum Quantity Lubrication MQL, 2012.
6. Çakır A *et al.* The Effect of Minimum Quantity Lubrication under Different Parameters in the Turning of

AA7075 and AA2024 Aluminium Alloys. International Journal of Advanced Manufacturing Technology. 2016; 84(9-12):2515-21.
7. Diego Carou, Eva M Rubio, J Paulo Davim. A Note on the Use of the Minimum Quantity Lubrication MQL System in Turning. 2015-2014; 3:256-61.
8. Chetan BC, Behera S, Ghosh, PV Rao. Application of Nanofluids during Minimum Quantity Lubrication: A Case Study in Turning Process. Tribology International 2016; 101:234-46.
9. CheHaron CH, Ghani JA, Ibrahim GA, Said AYM. Surface integrity of Inconel 718 when finish turning with PVD coated carbide tool under MQL. Procedia Engineering, 2011; 19:396-401.
10. Domnita Frăţilă, Cristian Caizar. Investigation of the Influence of Process Parameters and Cooling Method on the Surface Quality of AISI-1045 during Turning." Materials and Manufacturing Processes. 2012; 27(10):1123-28.
11. Debnath, Sujan, Moola Mohan Reddy, Qua Sok Yi. Environmental Friendly Cutting Fluids and Cooling Techniques in Machining: A Review. Journal of Cleaner Production http://dx.doi.org/10.1016/j.jclepro.2014.07.071, 2014; 83:33–47.
12. Davim J, Paulo PS, Sreejith, J Silva. Turning of Brasses Using Minimum Quantity of Lubricant MQL and Flooded Lubricant Conditions." Materials and Manufacturing Processes. 2007; 22(1):45-50.
13. Frăţilă, Domnita, Cristian Caizar. Investigation of the Influence of Process Parameters and Cooling Method on the Surface Quality of AISI-1045 during Turning. Materials and Manufacturing Processes. 2012; 27(10):1123-28.
14. Guo, Yansong, Jef Loenders, Joost Duflou, Bert Lauwers. Optimization of Energy Consumption and Surface Quality in Finish Turning. Procedia CIRP. 2012; 1(1):512-17.
15. Haron CH Che *et al.* The Effect of Minimal Quantity Lubrication MQL on the Surface Roughness of Titanium Alloy Ti-6Al-4V ELI in Turning Process, 2011; 147:1750-53.
16. Han ZL, Li CH. The summarize of grinding fluid application methods. Abrasives Commun, 2010; 10:7-12.
17. Hadad, Mohammadjafar, Banafsheh Sadeghi. Minimum Quantity Lubrication-MQL Turning of AISI 4140 Steel Alloy. Journal of Cleaner Production, 2013; 54:332-43.
18. Heisel U, Lutz D, Wassmer R, Walter U. The minimum quantity lubricant technique and its application in the cutting pro- cess. Mach Met Mag, 1998; 386:22-38.
19. Jia, Dongzhou *et al.* Experimental Research on the Influence of the Jet Parameters of Minimum Quantity Lubrication on the Lubricating Property of Ni-Based Alloy Grinding. International Journal of Advanced Manufacturing Technology. 2016; 82(1-4):617-30.
20. Leppert, Tadeusz. International Journal of Machine Tools & Manufacture Effect of Cooling and Lubrication Conditions on Surface Topography and Turning Process of C45 Steel. International Journal of Machine Tools and Manufacture http://dx.doi.org/10.1016/j.ijmachtools.2010.11.001. 2011; 51(2): 120–26.
21. Maruda, Radoslaw W *et al.* International Journal of Machine Tools & Manufacture A Study on Droplets Sizes, Their Distribution and Heat Exchange for Minimum Quantity Cooling Lubrication MQCL. International Journal of Machine Tools and Manufacture 100: 81–92. http://dx.doi.org/10.1016/j.ijmachtools.2015.10.008, 2016.
22. reference http://www.tandfonline.com/doi/full/10.1080/10426914.2014.994759, http://www.astmsteel.com/product/c45-round-bar-aisi-1045-din-jis-s45c/
23. Morgan MN, Barczak L, Batako A. Temperatures in fine grinding with minimum quantity lubrication MQL. Int J Adv Manuf Technol. 2012; 60(9-12):951-958.
24. Talkit, Kailas M, DT Mahajan, VH Masand. Physicochemical Properties of Soybean Oil and Their Blends with Vegetable Oils for the Evaluation of Lubrication Properties. Journal of Chemical. Biological and Physical Sciences. 2013; 3(1):490-97.
25. Puneet Sharma, Balwinder Singh Sidhu, Jagdeep Sharma. Investigation of Effects of Nano fluids on Turning of AISI D2 Steel Using Minimum Quantity Lubrication." Journal of Cleaner Production, 2015; 108:72-79.
26. S. WMAI Senevirathne, HKG Punchihewa. Effect of Minimum Quantity Lubrication Aerosol Temperature on Tool Life in Machining AISI P20 and D2 Steels Using Coated Tungsten Carbide Tool Inserts." In 2nd International Moratuwa Engineering Research Conference, MERCon, 2016, 186-91.
27. Vishal Sharma, Gur Raj Singh, Knut Sørby. A Review on Minimum Quantity Lubrication for Machining Processes. Materials and Manufacturing Processes. 2015; 30(8):935-53.
28. Dr. Raman. Przybylski. Canola Oil: Physical and Chemical Properties. Canola Council of Canada, 2011, 1-6.