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Performance assessment of CaF_2 solid lubricant assisted minimum quantity lubrication in turning

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Abstract

Machining is one of the most widely used manufacturing processes and conventional cutting fluids have been used in large quantity to tackle the effects of heat generated during metal cutting. Looking at the effects of the cutting fluids on the environment as well as an increase in total production cost, the performance of CaF_2 solid lubricant assisted minimum quantity lubrication in turning is studied. The performance of solid lubricant is judged by measuring surface roughness, chip-tool interface temperature and tool flank wear in different machining conditions. The effect of different concentration of solid lubricant is analyzed under various cutting conditions. A comparison of the results is provided with those obtained in dry, wet and minimum quantity lubrication (MQL) machining. The results indicate the improvement in process performance with the application of solid lubricant assisted lubrication. The use of the solid lubricant with MQL can be considered as a low-cost environment-friendly alternative.

Keywords: Solid lubricant; Turning; Surface roughness; tool wear

1. Introduction and literature review

Machining, specifically the turning operation has wide applications in manufacturing industries and processes. Metal cutting industries always aim to and have found the ways to improve the quality of work part; however, it is the present-day requirement to study the effects of process parameters including lubrication conditions on machining responses including surface finish [1]. The obtained work part quality is greatly influenced by cutting conditions,

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cutting mechanism, geometry of cutting tool and lubricating conditions. Further, any change in contact conditions during machining changes mechanism of machining and leading to larger cutting temperature resulting in increased tool wear, surface roughness and power requirements [2].

Conventional metal-working fluids have been used to reduce the friction in the machining area and thus to provide cooling and lubricating action during machining. However, in some countries as the result of strict environmental policies, it is vital to reduce the use of these metal working-fluids which is further affecting the health of workers associated with the process [3]. Further, the use of such fluids adds up the total production costs [4]. The use of minimum quantity lubrication and solid lubricants can be the alternatives to the cutting fluids. It is evident from the available literature that the MQL is applied to almost all machining process and the performance of the same is studied and compared with dry and wet cooling approach [5-6].

The application of solid lubricant in machining can be also viewed as efficient, environment friendly and low-cost alternative leading to sustainable lubrication process [7].

2. Experimental details and data collection

2.1. Material

The workpieces in form of round bar with dimensions Ø50 × 150 mm were used for turning operations. The workpiece material selected was EN31 steel widely used in the manufacturing of ball and roller bearings, bearing rings, ball screws, cams and pawls, gauges, forming tools, punches, etc.

2.2. Machine tool

The turning experiments were carried out on Kirloskar made Turnmaster lathe machine under dry, wet, MQL and MQSL environments. The lathe gives us a wide variety of feeds, cutting speeds and depth of cut. The spindle rotation ranges from 45 rpm to 1120 rpm. There are eight spindle rotational spindle speeds selectable. The ranges of feed rates are available by varying the arrangement of the gear train of the lathe.

2.3. Cutting inserts

The turning operation as a part of experiments was carried out by using coated carbide insert of TN4000 grade of Widia make. The insert with four-layer coating of CVD - TiN-TiCN-Al2O3-TiN and with higher cobalt content has good toughness which permits heavy depths of cut and interrupted cuts. The insert designation as per ISO code is CNMG1204085 TN4000. The inserts were rigidly mounted on a tool holder with PCLNR2020K12 I 7D designation, as per ISO Code of Widex make.

2.4. Measurements

The measurement of surface roughness was using Mitutoyo Portable Surface Roughness Tester (Model: Surftest SJ-210 – Standard Drive Unit Type), a user-friendly, compact and complies with many industrial standards. For consistency, the stylus type surface roughness tester was placed on the specially design rigid stand, whereas the cylindrical workpiece was kept on magnetic V block. The flank wear of the cutting tool inserts was observed with the use of the portable microscope and the visualization of images of the flank surface of inserts was done by stereo zoom microscope fitted with the camera and equipped with image analysis software with a magnification of 20X–50X. The chip-tool interface temperature was measured by tool work thermocouple arrangement developed and mounted on machine. This method uses workpiece and tool forming two elements of thermocouple. The generated EMF during machining was measured by the voltmeter and converted in temperature readings. The calibration of tool-work thermocouple was done by the means of furnace kept at known temperature. Continuous chip obtained by the machining of workpiece material and tungsten carbide rod is used to form the hot junction. Hot junction of thermocouple was inserted in a metal plate with k type calibrated thermocouple. The metal plate attached with a k type thermocouple and the hot junction of tool-work thermocouple was kept in a furnace, temperature reading was obtained by K type thermocouple corresponding to emf generated by tool-work thermocouple. For each value of emf average value of temperature were taken and given an input to the GraphPad software for obtaining the thermoelectric relationship.

2.5. Experimental Procedure

The focus of the present investigation is to assess the performance of solid lubricants mixed in oil during turning operation. The solid lubricants mixed in oil required to be supplied to the cutting zone using minimum quantity lubrication method. Therefore, a minimum quantity solid lubrication setup (MQSL) is developed for injecting solid lubricant mixed in oil at the required pressure. The photograph of experimental setup is shown as figure 1. A stirrer, as shown in figure 1, was designed and fabricated which continuously stir the mixture of solid lubricant powder and oil. The MQSL setup was mounted on the guard of lathe machine with the nozzle fixture kept on a saddle. Figure 4.4 shows the entire MQSL setup along with the stirrer as mounted on the lathe machine. Experiments were performed under dry, wet, MQL and MQSL environments to assess the performance of CaF_2 as a solid lubricant by measuring surface roughness, flank wear and chip-tool interface temperature. The heterogeneous mixture of SAE 40 and solid lubricant is used as cutting fluid for machining. The mixture can be formed by different weight ratios of solid lubricant and SAE 40 oil. Many researchers had worked to find a proper weight ratio of the solid lubricant in heterogeneous mixture for better the surface finish and less temperature generation. Krishna and Rao [8] used 5%, 10%, 15%, 20%, 30%, and 40% solid lubricant by weight with SAE 40 oil for testing cutting fluids lubricating and cooling properties. Hence for experiments, 10%, 15% and 20% of the solid lubricant are mixed with SAE 40 oil and the same is compared with that of dry, wet and MQL machining.

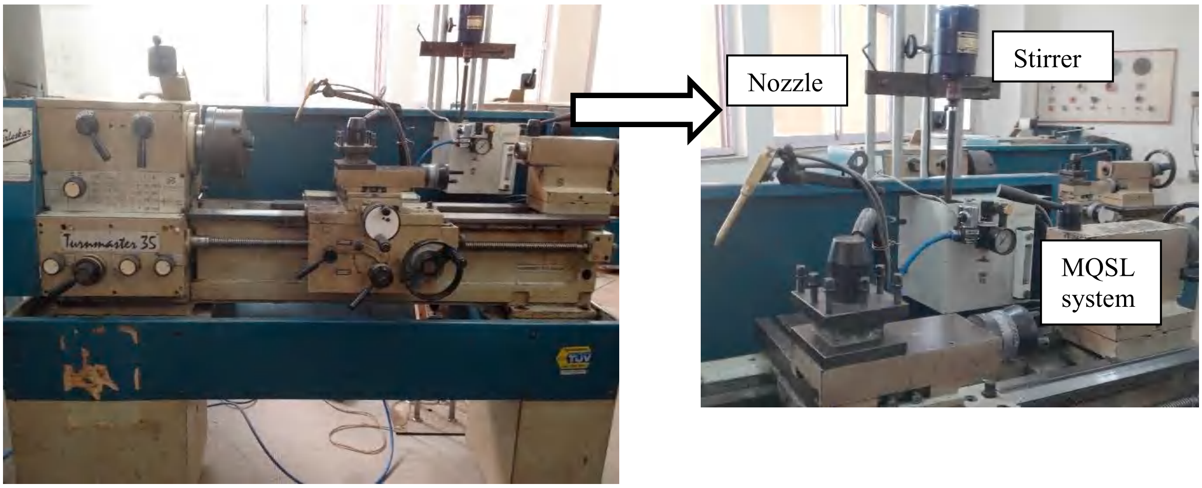

Fig. 1. Setup of MQSL mounted on Lathe Machine

Many researchers had used the graphite, molybdenum disulphide, boric acid and calcium fluoride powder however very little work has been reported with the use of calcium fluoride. Hence the calcium fluoride was chosen for preparing powder mixed cutting fluid to be applied to the machining zone. Figure 2 (b) depicts the observed powder XRD pattern of CaF_2 composition. The XRD result shows the crystalline nature of CaF_2 powder. The reflection peaks of the powder match with reflection peaks of cubic structure, confirming the cubic nature of the powder. To measure the particle size, SEM measurements were performed. It is clear from the SEM image as shown in figure 2 (a) that the particle of irregular shape and size were formed.

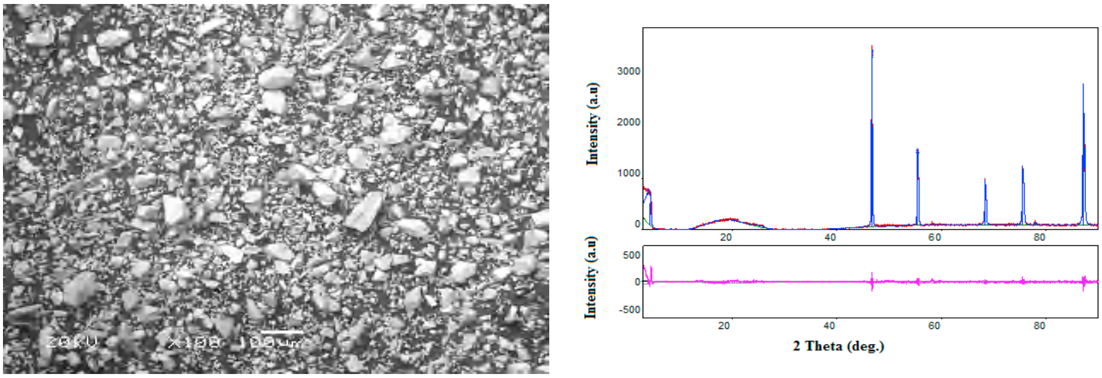

Fig. 2. (a) SEM image of CaF_2 (b) EDAX Image

The experiments are performed to study the effect of different solid lubricant concentration on surface roughness, chip-tool interface temperature and flank wear. The details of experimentation are shown in Table 1. Four machining environments are compared namely dry, wet, MQL and MQSL with the different concentration of solid lubricants. The optimized value of process parameters is obtained by grey relational analysis for the minimum quantity solid lubrication environment and same has been used for experiments.

Table 1 Experimental conditions used in machining

Work material and dimensions	EN 31 Ø50 ×150mm
Cutting conditions	Cutting speed= 130 m/min.
	Feed= 0.2 mm/rev.
	Depth of cut= 0.5 mm
Cutting tool and geometry	CNMG1204085 TN4000
	clearance angle (α) = 0°, nose radius = 0.8 mm
Surface roughness tester	Surftest SJ-210
Chip-tool interface temperature	Tool work thermocouple
Flank wear	Microscope with image analysis software
Machining conditions	Dry, wet, MQL, MQSL machining with 10%, 15% and 20% CaF_2 concentration
Air Pressure	0.2 MPa
Lubricants	Wet Cutting Environment (Cutting Fluid)
	Soluble Oil – Servo Cut oil (Indian Oil Corporation) Ratio – 1:20 in Water
	MQL- SAE 40 oil
	MQSL- Calcium Fluoride powder mixed in SAE 40 oil
	Nozzle tip diameter – 1 mm Nozzle distance from machining zone – 15 mm
	Nozzle angle - 45°

3. Results and discussion

3.1. Flank wear analysis

Tool flank wear can be viewed as the most important criteria in machining as it governs the surface finish produced and hence influence the work part quality. The assessment of tool life during machining has been carried out until the flank wear reaches to 0.25 mm to allow comparisons among all machining conditions. The flank wear increased rapidly with cutting time immediately after 7 minutes of machining however in MQL and MQSL the rapid tool wear started only after 15 minutes of machining. It has been revealed that in dry machining the flank wear reached to the desired value at the end of 13 minutes. However longer tool life and thus longer machining time is obtained in case of machining with MQSL added with 15% concentration of CaF_2 which may be due to enhanced lubrication and cooling with reduced friction resulted in lower cutting temperature during machining [9].

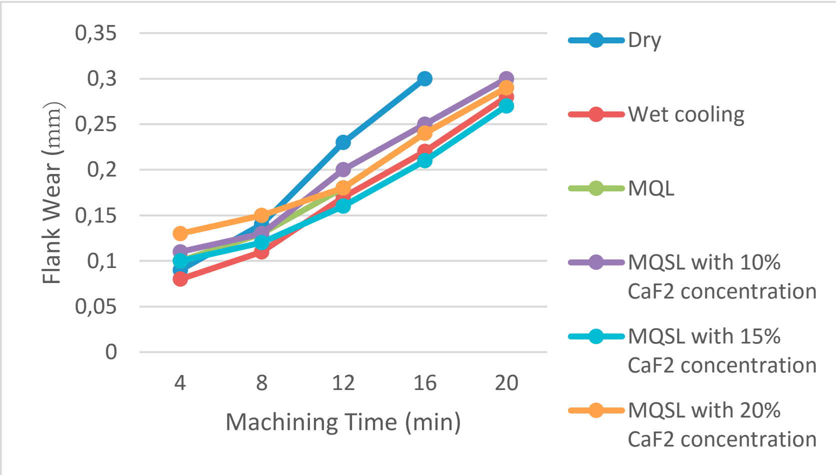

Fig. 3. Comparison of flank wear in various machining environments

Abrasion is mostly viewed as flank wear mechanism for the selected machining conditions. The similar pattern of tool flank wear is observed with wet cooling and MQL with effective machining time of 18 minutes. The Comparison of flank wear in various machining environments is as shown in Fig. 3.

Fig. 4 shows the SEM images of the tool insert captured after dry, wet, MQL and MQSL machining environment. It can be observed that the tool wear mechanism is mostly due to adhesion and abrasion. Nose wear is also observed in all inserts. For all cutting tool inserts abrasive marks on the flank are visible along with adhesive wear. No built-up edge formed in case of wet, MQL and MQSL due to better cooling and lubricating action.

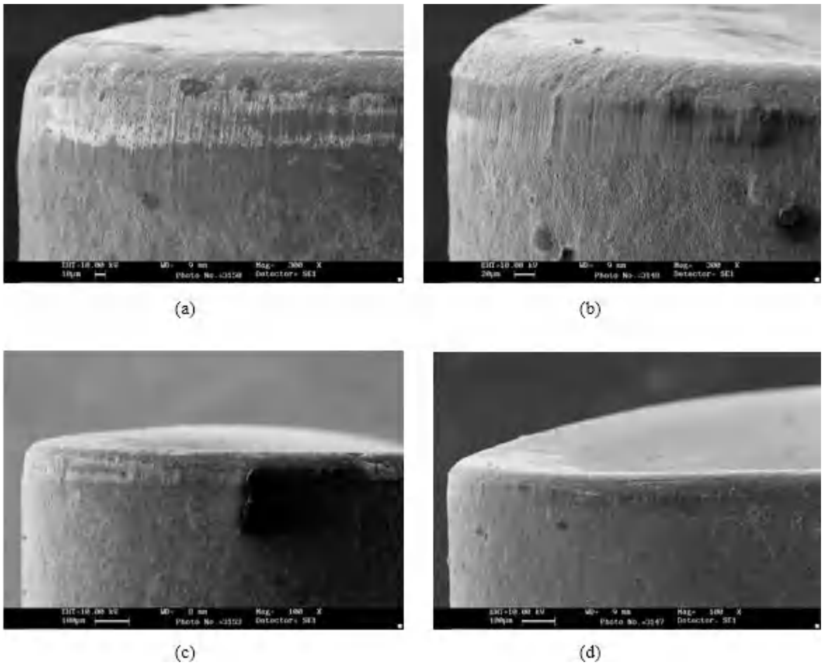

Fig. 4. SEM images of cutting tool insert in various machining environments (a) dry (b) wet (c) MQL (d) MQSL

3.2. Analysis of chip-tool interface temperature

The chip-tool interface temperature was measured with tool work thermocouple mounted on the machine. The temperature produced while machining has the large influence on tool wear and thus on surface finish produced. In experimental runs, the highest temperature produced was during dry machining, as expected, due to absence of any lubricating action in machining area. As discussed earlier with the comparison of tool wear, MQSL performed better with enhanced lubricating and cooling action, the same can be viewed as reduction in temperature with the use of solid lubricant with 15% concentration.

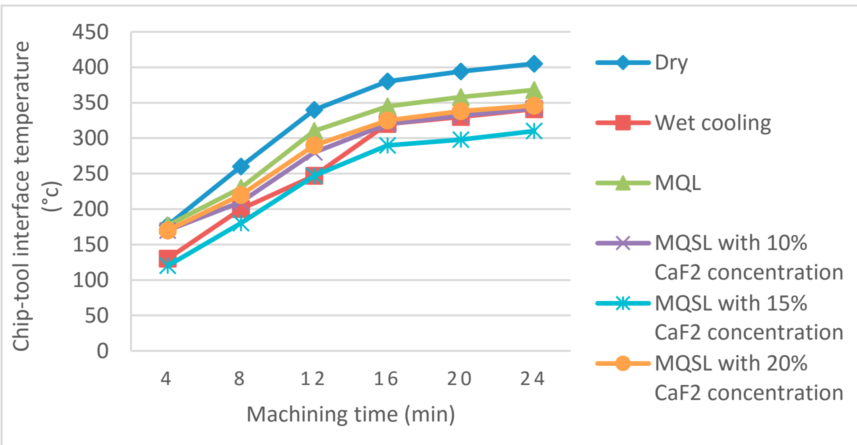

Fig. 5. Variations of chip-tool interface temperature in various machining environments

It can be also seen from the comparison that the chip-tool interface temperature rapidly increases up to 16 minutes of machining and then following almost a steady trend. This is due to the fact that after few minutes of machining, a thin lubricating film is created between tool and workpiece and it has reduced friction and so as maintained the chip-tool interface temperature to steady state. According to GuoChen et al. [10], the enhanced lubricating property of solid lubricant reduces the friction between tool and work and thus lowering the cutting temperature and increasing tool life resulting in an enhanced surface finish of work part.

3.3. Analysis of surface roughness

One of the important criteria to judge the quality of machining is the analysis of surface roughness values produced after machining. From the comparison of results shown in Fig. 5, the highest surface roughness value is observed in dry machining followed by MQL and wet cooling. The tool has experienced earlier wear cycle leading to the larger tool wear in dry and MQL machining and the same can be confirmed from the flank wear and chip-tool interface temperature analysis. As expected, better surface finish is obtained in machining with solid lubricant with difference 15% concentrations of CaF_2. However, larger surface roughness value is observed in machining with 20% concentrations which may be because of difficulty to retain the solid lubricant particles in the machining zone due to larger volume. Smaller % concentration performed efficiently by creating a thin layer of lubricant film and thus by reducing friction in the machining zone.

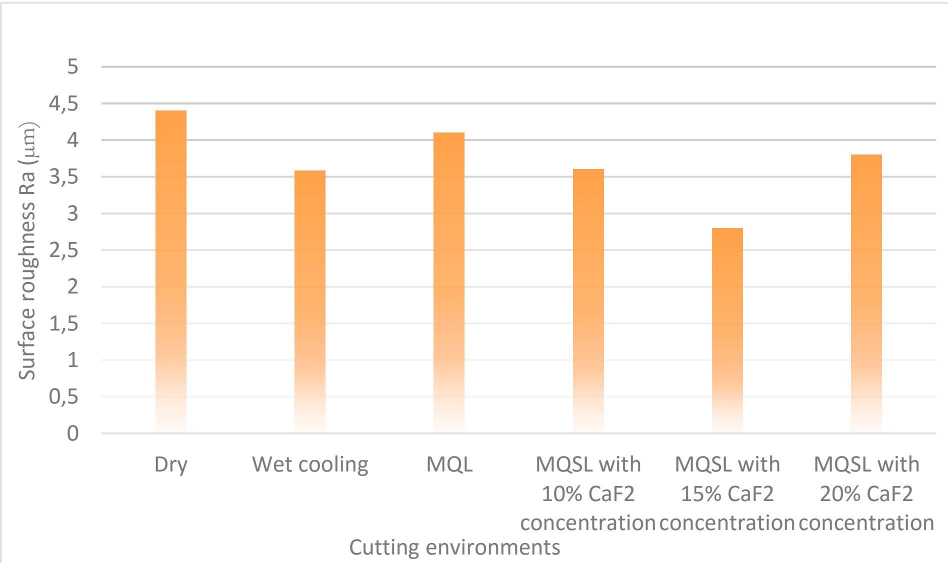

Fig. 6. Variations of surface roughness in various machining environments

The effects of MoS_2 as solid lubricant is observed in machining of plain carbon steel and almost 20% and 40% reduction in surface roughness as compared to wet and dry cutting respectively [7]. The experimental results are in agreement as it is reported in the available literature that the machining carried out with the application of solid lubricant has improved the process performance as compared to other machining environments like dry and wet in many ways including surface finish. [11-12-13].

4. Conclusion

In the present study, an effort has been made to assess the performance of solid lubricant assisted minimum quantity lubrication system in turning operation. Improvement in process performance is observed in the form of the reduction in surface roughness, tool flank wear and chip-tool interface temperature. The effect of various concentration of solid lubricant is studied and results are compared with dry, wet and MQL lubrication. For all measured parameters CaF_2

mixed with 15% concentration has performed better by reducing surface roughness, chip tool interface temperature and tool flank wear due to its excellent lubricating properties and tendency to adhesion in the machining zone. Larger concentration may decrease the overall thermal conductivity of lubricant mixture and result in higher chip-tool interface temperature leading larger tool flak wear. The result obtained can be utilized by related industries to develop and establish a sustainable process. The use of solid lubricant and MQL can be a viable alternative as compared to conventional fluid.

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