PERFORMANCE ASSESSMENT ON APPLICATION OF SOLID LUBRICANTS IN MACHINING: AN APPROACH TOWARDS CLEANER PRODUCTION

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Abstract—*The traditional machining methods introduce cutting fluid to control the amount of heat generated by providing lubrication. However the application of fluids account for an extensive proportion of the total manufacturing cost. Further an industry is required to comply with regulations that control the use and disposal of lubrication materials that are potentially hazardous or place unacceptable burdens on natural resources and the environment. Some alternative measures are required to overcome the difficulties of cutting fluids. In this context current work aims to use solid lubricants in machining which leads to cleaner production and more cost effective alternative. The performance assessment of solid lubricants mixed with SAE 40 base oil is experimentally carried out by measuring the value of process temperature, tool wear, surface roughness and power consumption. Comparison of the effectiveness of application of solid lubricants with that of conventional cutting fluid and dry machining is presented. Based on the findings from experiments, solid lubricants mixed with oil is a cost-effective and environment friendly lubrication technique than flood cooling in machining.*

1. INTRODUCTION

Machining is considered as one of the important manufacturing process which uses a cutting tool to remove the extra amount of metal available on workpiece surface and brings it to required dimensions. Since the basic mechanism involved in machining is shear deformation of workpiece, lot of friction occurs in the contact area of tool and workpiece which results the heat generation. During machining of low strength alloys the amount of heat generated is less as compared to machining of ferrous materials. The traditional machining methods introduce high-volume or high-pressure machining fluid systems to provide cooling and lubrication between the tool and the work piece. This provides a measure of control with respect to the thermal behavior within the machining zone and enable a general 'bulk' cooling of the machining process. Nevertheless the application of fluids account for an extensive proportion of the total manufacturing cost. The costs attributed to the use of machining fluids do not only comprise of the initial purchase and delivery logistics but also the storage, energy consumption, treatment, filtration, and the end of life disposal [1, 2] The majority of fluids are semi-synthetic soluble oils that also require the use of water. In this respect, industry is required to comply with regulations that control the use and disposal of lubrication materials that are potentially hazardous to, or place unacceptable burdens on natural resources and the environment [3].

The concept of minimum quantity lubrication (MQL) has been proposed before many years as an alternative to overcome the issues related to environmental effect and employee health with the flying cutting fluid particles around machine. Minimum quantity lubrication (MQL) is the way to achieve nearly dry machining (NDM), it uses the cutting fluid in optimize and minimum quantities, which is considered very less as compared to the amount of cutting fluid which is used in fluid cooling [4, 5].

It leads to start thinking to find suitable alternative of cutting fluid like solid lubricants. The solid lubricants can be applied in powder form to the machining area or it can be mixed with oil [6] or it can be mixed with compressed air and applied to cutting zone [7, 8]. The graphite was used in paste form to apply in surface grinding operation [9]. The reported results shows the better performance of solid lubricant assisted machining in form of reduced temperature, tool wear, power consumption and improved surface finish. However it is required to develop effective solid lubricant delivery system. The solid lubricants can be applied by mixing it with cutting oil [10].

The above information reveals that the use of solid lubricants while machining can be a feasible option in order to reduce the environmental effects and develop a clear machining process [11]. Work was done by using the solid lubricants (a mixture of graphite and boric acid with SAE 40 oil) for the turning of EN8 material. Performance of solid lubricant was assessed by measuring the value of cutting force [12]. The obtained results are very encouraging in terms of reduction of cutting force.

The objective of the present work is to investigate the role of solid lubricants applied in machining on process temperature, surface finish, power consumption and tool wear in turning of EN 31 material. The other objective is the comparison of solid lubricant assisted machining with dry and wet machining under the same operating conditions.

2.LITERATURE REVIEW

Research has been reported in the area of application of lubricants by using the concept of minimum quantity lubrication and solid lubricants. Minimum quantity lubrication states to the supply of small quantities of fluid via an aerosol to the machining area. The mixture of air and oil can be prepared in a tank or on the nozzle tip [13]. The amount of fluid quantity required in case of grinding can be found based on the width of wheel. It is suggested as 1 L/min of fluid per 1 mm of wheel width [14]. In general, MQL fluid usage and supply is typically 30–100 ml/h [15].
The experiments were conducted during machining of AISI 4140 steel to analyse the performance of dry, wet and MQL techniques [16]. It was reported that the least value of cutting force was found in case of minimum quantity lubrication and in wet condition. The water and vegetable oil used as cooling medium during machining through a jet. The MQL application causes better surface finish, reduced tool wear and temperature as compared with dry machining. And as a result of this the performance of process was also improved [17]. The effects of grinding parameters on ABNT 4340 steel using minimum quantity lubrication method explored [18, 19]. The analysis carried out to study the effect and behavior of the minimum quantity lubricant (MQL) method and compared the same with fluid cooling method Surface roughness, residual stresses, micro structure and micro hardness was analyzed in order to conclude the effect of MQL method in grinding.

The use of solid lubricant in machining is one effort to avoid the use of cutting fluids [20]. Graphite was used as a solid lubricant in grinding process which resulted the decrease in heat generation. The value measured for various process parameters has been reported to be reduced as compared to the values with normal lubrication [21]. During the machining of hardened AISI 52100 steel with ceramic inserts, it has been found that solid lubricants are more effective at higher cutting speeds [22]. The performance of solid lubricant assisted end milling machining investigated by comparing it with wet lubrication. Graphite and molybdenum disulphide were used as lubricants to obtain the values of surface roughness, cutting forces and specific energy during machining of AISI 1045 steel. The performance of solid lubricant assisted machining has been studied in comparison with that of wet machining. It has been reported that the use of solid lubricants resulted better process performance [6]. Graphite and molybdenum disulphide applied as solid lubricants, in order to reduce heat generated and friction in grinding [23]. The setup has been developed for the application of solid lubricants and studied the effects of solid lubricants on tangential grinding force, specific energy and surface roughness while grinding Sic. The effect of graphite and MoS_2 has been reported on the tangential grinding force. The variation of specific energy with dry grinding, grinding with graphite and MoS_2 lubricants has been studied and it was found that specific energy value was less in case of solid lubricants as compared to dry grinding.The concept of minimum quantity lubrication was used by adding 10% of boric acid by weight with SAE 40 base oil. In different machining situations the value of cutting force, cutting temperature, chip thickness and surface roughness were studied for lubrication. MQL in machining performed better as compared to dry machining [24]. In this field, an optimized method of the application of solid lubricants named electrostatic solid lubrication experimental setup was developed which can supply the solid lubricants at machining zone with slow flow rate and high velocity jet. The performance of process is measured by considering thrust force, rate of tool wear, chip thickness, diameter of hole and surface roughness of material by putting the other conditions constant. They had also compared the results with dry and wet machining. The results indicated that the solid lubricants were more efficient in reducing of the cutting zone temperature as compared to dry machining and machining with fluid lubricants. It was also noted that it improved the chip and tool interaction [25]. The possibility of the application of solid lubricants has been assessed for machining of AISI 1040 steel material [26]. The reduced chip thickness ratio and value of surface roughness was reported by using uncoated cemented carbide inserts. It was also reported the increased machinability of material and quality of work.The above study indicates that the use of solid lubricant can be a new lubrication technique for pollution free environment. In above studies, the power consumption was not considered while scrutinizing the effectiveness of solid lubricant which is more important to analyze the machining cost. In the present work, solid lubricants with different concentration are mixed with SAE-40 base oil for machining of EN-31 steel material and the parameters measured are compared with the dry machining and machining with fluid lubricants.

3. EXPERIMENTAL PROCEDURE

The machining tests were carried out on heavy duty lathe machine KIRLOSKAR TURNMASTER 35.The cutting tools used during experiments were cemented carbide inserts. The work piece has a dimension of 100mm in length and 50mm in diameter. The chemical composition of work piece is shown in Table I.EN-31 alloy steel material was used and the machining parameters considered were cutting speed (v) m/min, feed rate (f) mm/rev, depth of cut (d) and tool nose radius (r) mm. The values of chip tool interface temperature, power consumption, surface roughness and tool wear during steel turning in dry and wet condition and solid lubricants mixed with SAE-40 base oil were obtained. The experimental details are given in Table II. The cutting tests were carried out on EN-31 steel using tungsten carbide insert under dry and wet and solid lubricant assisted lubrication. Surface roughness is measured by surface roughness tester and tool wear is measured on a sensitive single pan balance. Two solid lubricants namely boric acid and molybdenum disulphide (MoS_2) were mixed with SAE-40 base oil in different concentrations. The experiments were conducted by keeping different concentrations of solid lubricants.

TABLE I. CHEMICAL COMPOSITION OF (EN-31) WORK PIECE.

Com posit i on	C	Si	Mn	Cr	Co	S	P
Wt %	0.95-1.2	0.10-0.35	0.30-0.75	1	0.025	0.040	0.04

TABLE II. EXPERIMENTAL DETAILS.

Machine tool	10 HP lathe machine
Work specimen material	EN-31 steel alloy
Process parameters	Cutting speed V=8, 18, 44, 112 m/min Feed f=0.4 mm/rev Depth of cut d=0.4 mm Tool nose radius R=0.8 mm
Lubricants	(i) Dry (no lubricant)
	(ii) Wet (soluble oil mixed with water in the ration of 1:20)
	(iii) Minimum quantity lubrication (a) 10% MoS_2 + SAE-40 base oil (b) 10% boric acid + SAE-40 base oil (c) 15% MoS_2 + SAE-40 base oil (d) 15% boric acid + SAE-40 base oil

There are various methods to measure the cutting temperature like tool work thermocouple, embedded thermocouples, radiation pyrometers, temperature sensitive paints and indirect calorimetric technique. From these methods the tool work thermocouple method is used to measure the cutting temperature. Surface roughness is measured by surface roughness tester and the R_a measurement is taken perpendicular to the machining direction.

4. RESULTS AND DISCUSSION

A. *Temperature Analysis*

The value of measured cutting temperature during the turning of EN-31 high carbon alloy steel using tungsten carbide tool for various cutting speeds, feed rate, and different cutting lubricants is shown in Fig. 1.

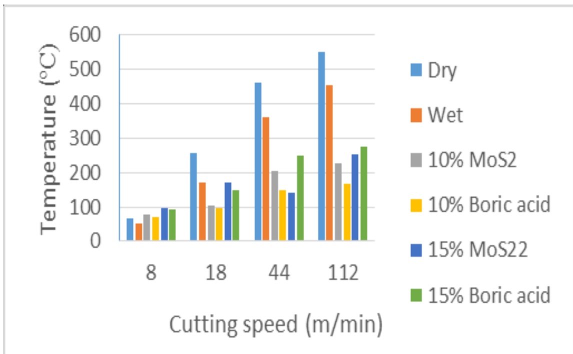

Fig. 1. The variation in temperature with different speed and constant feed rate at same depth of cut under different lubricating condition

In machining, the tool wear is sensitive to the cutting temperature. Thus the higher value of temperature results higher tool wear which further results in reduced tool life and poor surface quality. It is clear from the comparison that with the increase in cutting speed, the cutting temperature is increased due to increase in cutting energy input. Solid lubricating assisted turning operation produced lower values of cutting temperature compared to the dry and wet turning. The cutting temperature is higher in the dry turning, followed by cutting with wet turning and with 10% and 15% proportion of boric acid and MoS_2 mixed with SAE 40 base oil. From these solid lubricants 10% boric acid added with SAE-40 base oil performed best as coolant at various cutting speed. This is because of excellent a cooling properties in form of thermal conductivity and kinematic viscosity of boric acid at higher speeds.

B. *Power Consumption Analysis*

The variation of power consumption with respect to cutting speed for dry, wet and solid lubricant assisted turning is shown in the Fig. 2. From the results it can be concluded that the power consumption increases with increase in cutting speed. But solid lubricant assisted turning consumed low power compared to dry and wet machining due to better sliding action and reduction of friction during machining. Which resulted the lower value of cutting forces and ultimately the power consumption.

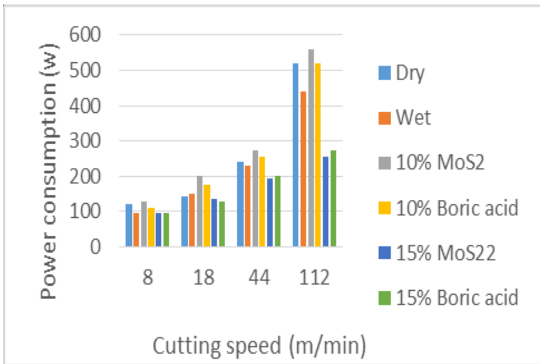

Fig. 2. The variation in power consumption with different speed and constant feed rate at same depth of cut under different lubricating condition

C. *Surface Roughness Analysis*

The variation of surface roughness with respect to cutting speed for dry, wet and solid lubricant assisted turning is shown in the Fig. 3.

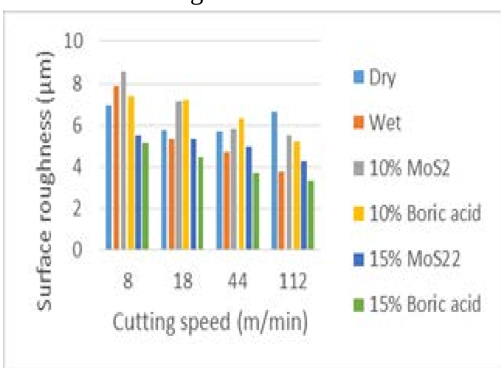

Fig. 3. The variation in surface roughness at different speed and constant feed rate at same depth of cut under different lubricating condition

The effectiveness of machining process can be evaluated from the surface finish achieved. Though, many factors are affecting the surface quality and hence it is difficult to achieve better surface finish during machining. It is concluded that the surface finish can be improved by reducing the cutting forces and heat generated during machining [27]. It was also reported that the application of graphite as solid lubricant had reduced the surface roughness as compared to dry machining and machining with fluid cooling [28].

Fig. 3. shows the variation of surface roughness with different cutting speed under different machining environments. The obtained value of surface roughness with the use of solid lubricant is lower as compared to dry and wet machining. Among of the two variants (boric acid and MoS_2) of the solid lubricant assisted turning, boric acid assisted turning gives better result as compared to molybdenum disulphide assisted turning operation. The surface finish is improved with solid lubricant due to the property of lubricant to minimize the friction force between cutting tool and workpiece surface. The good lubricating action of boric acid has resulted the improvement in surface finish.

The surface roughness is lower in machining using solid lubricant than dry and wet machining operation because of better lubricating action.

D. Tool Wear Analysis

Tool wear occurs in machining due to the rubbing action of workpiece surface and tool edge. It is found that, in case of dry and wet environment the rate of tool wear is comparatively high compared to solid lubricant environment with different proportion with base oil. Fig. 4 shows the tool wear at different cutting environment, cutting speed and feed. Tool wear has important role and it is affecting to the cutting and the quality of the machined surface. Generally, in the machining process the tool has been gradually wearing.

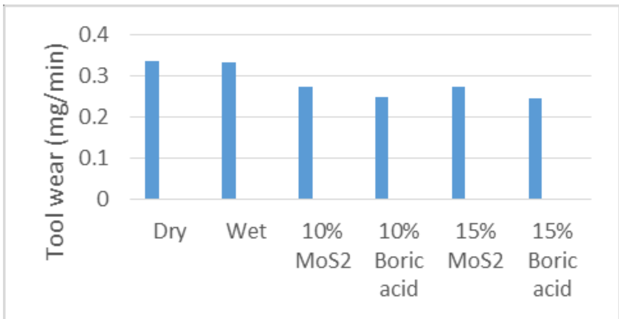

Fig. 4. The variation in tool wear under different lubricating condition

Using solid lubricant assisted machining the effective temperature is controlled so that the plastic deformation is reduced. The reasons for reduction of tool wear are low coefficient of friction, sliding action and low shear resistance within the contact interface.

5. CONCLUSION

With the use of solid lubricant assisted machining significant improvement in product quality and therefore overall machining economy, longer tool life, better work surface finish is achieved. Up to certain quantity the use of solid lubricants environmentally safer, healthier for the workers as compared to fluid machining.

Using solid lubricant the chip-tool interface temperature had reduced by 20 to 30%. The reduction in cutting temperature using wet lubricant is high at lower level of machining parameters and low at high level machining parameters. Surface finish is improved due to significant reduction in wear and damage at the tool tip by the application of solid lubricant. Use of solid lubricant improved the machinability with the reduction in frictional forces between the tool and workpiece. Power consumption is also reduced compared to dry and wet machining. This work also highlights that solid lubricant assisted machining is necessary for making it an important alternative to eliminate the use of cutting fluids in metal cutting and thus making the machining cleaner and pollution free.

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