EFFECT OF DIFFERENT PARAMETERS ON CUTTING FORCES AND TEMPERATURE DURING GRINDING PROCESS USING MINIMUM QUANTITY LUBRICATION

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Abstract : ***The requirements of high production of machining need use of high cutting velocity and feed rate. This produces high cutting forces and high temperature, which reduces tool life and lowers the product quality. The use of cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions. But the conventional cutting fluids are not that effective in such high production machining, particularly in continuous cutting of materials likes steels. Minimum quantity lubrication (MQL) presents itself as a significant alternative for other forms of lubrication. In this research work, it was proposed to investigate the effect of flow rate of vegetable oils and air pressure used in minimum quantity lubrication on cutting forces and cutting temperature during grinding of AISI 4130 steel. The effectiveness of different vegetable oils used in minimum quantity lubrication was also compared with that of flood coolant machining..***

IndexTerms - Grinding, Minimum quantity lubrication, cutting forces, temperature, Taguchi

I. INTRODUCTION

Lubrication is the process of applying metal working fluids in order to reduce the friction and wear (Vasu and Kumar, 2011). The fluids perform the various functions of cooling and lubricating the tool-work piece interface. Also it carries chips produced during grinding operation along with it. Water-soluble chemical fluids, water-soluble oils, synthetic oils, and petroleum-based oils are most commonly used. The use of fluids in a grinding process is necessary to cool and lubricate the wheel and work piece as well as to remove the chips produced in the grinding process. One of the advantages is the cooling effect which reduces the temperature in the cutting zone. One another advantage is of lubrication which decreases cutting forces and due to this the coefficient of friction between the tool and chip becomes lower as compared to dry machining (Dudzinski et al., 2004). There are numerous advantages of the cutting fluids but inspite of them, there are also certain problems assisted with them (de Jesus Oliveira et al., 2012). There high costs increases the overall production cost. Cutting fluids are also dangerous for the workers as these cause various skin diseases due to the chemicals contained in them. Proper disposal of the cutting fluids is also required as great environmental hazards are posed by them. Various modifications are done to the cutting fluids to overcome or reduce various problems of foaming, bacteria and fungi. Most widely used base oil is paraffin oil.

Minimum Quantity Lubrication (MQL) sometimes also termed as nearly dry grinding or semi dry grinding uses a minute quantity of lubrication. The quantity of the fluid used varies from 60 ml/hr. to 500 ml/hr. and this much quantity cannot be recovered from the parts (Kim et al., 2001; Silva et al., 2005). As a very little amount of lubrication is used, post cleaning of parts is not required as remaining film of lubricant vaporize by the high temperature of the cutting zone. In this process, the mixture of lubricant and compressed air in the form of aerosol or spray is sprayed directly by the nozzle to the tool-work interface at high pressure (Amrita and Shariq, 2014). This high pressure results into the penetrating of the oil to the cutting zone to reduce the cutting temperature and friction (Sadeghi et al., 2010). With respect to cutting forces, surface finish, cutting temperature and tool wear, minimum quantity lubrication gives the beneficial results as compared to results obtained with the dry machining and flood machining (Kedare et al., 2014). Minimum quantity lubrication gives the best performance of machining operations because of their lubrication, cooling and chip flushing characteristics by the high pressure varying between 5 bar to 8 bar (Vasu and Kumar, 2011). Various authors have studied the effect of MQL on machining processes. (Webster et al., 1995)) studied the influence of nozzle position, jet velocity and distance from the grinding zone and determined the percentage increase in wheel life by optimizing coolant application during grinding of an aerospace component. Zhong et al. (2001) performed an experiment on Inconel 718 and some other advanced ceramics by using a newly developed ultra-high speed grinding machine and a conventional grinding machine. The results concluded that the grinding of wheel with higher speed produces smaller cutting depth. Also, grinding forces were reduced and surface finish was improved. Uysal et al. (2015) investigated the application of MQL method on milling of Martensitic Stainless Steel by using MoS2 reinforced vegetable cutting fluids. Vegetable cutting fluid was used with 1% of MoS2 (Molybdenum Disulphide) particles during milling of AISI 420 martensitic stainless steel with uncoated Tungsten carbide (WC) cutting tool. Depth of cut, cutting speed and feed were kept constant. Results showed that MQL results in better surface finish and reduced tool wear in nano MQL milling. Jia et al. (2016) evaluated the influence of jet parameters of MQL on the lubricating property of Ni based alloy grinding by performing grinding operation on Ni based alloy using K-P36 numerical control surface grinder. Grinding forces were measured using 3-D dynamometer to calculate specific grinding energy and coefficient of friction surface roughness was also measured. Results tell us the calculated values of air pressure, gas liquid ratio and fluid flow rate. From the previous literature it had been observed that the use of vegetable oils with the minimum quantity had worked well in reducing the grinding temperature and forces. The vegetable oils like olive, soyabean, sunflower, palm, groundnut and many more had shown significant role in grinding temperature. These had shown the results for the same flow rate. They were proved as the best alternatives as in case of production cost and also that of the environmental degradation.

In this research work, it was proposed to investigate the effect of flow rate of vegetable oils and air pressure used in minimum quantity lubrication on cutting forces and cutting temperature during grinding of AISI 4130 steel. The effectiveness of different vegetable oils used in minimum quantity lubrication was also compared with that of flood coolant machining. AISI 4130 steel was selected as grinding material; because it is used for the structural work such as Aircraft engine mounting and welding tubing and requires lots of grinding.

II. EXPERIMENTATION

The research has been carried out to evaluate the effect of the various process parameters on the operation of grinding. The effect of different types of vegetable oils, flow rates and at different pressures has been studied. Groundnut oil, sunflower oil and soyabean oil were used as lubricating oils.

The experiment was performed in the workshop of UCoE department, Punjabi University, Patiala. After arranging the experimental equipment (Fig. 1) in a proper manner, the experiment was carried out. The white aluminium oxide (Al2O3) wheel was used as grinding wheel. Each equipment was placed carefully with proper connections of the wires. Nozzles were placed at the proper position, so that the mixture of oil and air flow should be in the required direction. The nozzles were supplied with a high pressure air from the compressor. One hoist of the nozzle was dipped in the beaker containing oil and the other was fastened to the compressor outlet valve. The beaker of oil was placed at upper position than the nozzle for the proper flow of oil through without any interruption. The dynamometer was placed on the magnetic bed of the surface grinder by the magnetic forces. The workpiece was clamped over the dynamometer by a vice, which is clamped over the dynamometer. The forces measured by the dynamometer were shown on the separate screen, which was having a button to switch between the measured values of x and y direction forces. The wheel was fastened to the spindle, the speed of which could not be varied and rotates at constant speed of 2820 rpm (22 m/s). The flow rate could be varied as the valve was present on the nozzle. The maximum range for the compressor was 8 bar. This pressure can be changed easily by adjusting the lever of the valve on the compressor. The sensor for sensing the temperature was made to pass through the dynamometer surface, so that it can be put inside the hole drilled in the workpiece erected. This sensor was connected to the thermocouple by a wire, which could show us the reading.

Fig 1. Experimental setup

The surface grinding was carried out at constant wheel speed 22 m/s, depth of cut 30 µm for each grinding passes. The experiments were conducted under both pure flood cooling method and MQL using vegetable oils. The grinding forces, temperature under different conditions of cooling lubrication were measured. Table 1 shows grinding process parameters used for experimentation.

Table 1 Grinding process parameters

GRINDING MODE	Surface grinder
WHEEL SPEED	22 m/s
TABLE/WORK SPEED	0.66 m/s
DEPTH OF CUT	30 µm
GRINDING PASSES	20
GRINDING ENVIORNMENT	MQL, Flood cooling
VEGETABLE OIL	Soybean oil, Sunflower oil, Groundnut oil
MQL FLOW RATE	80, 120 and 160 ml/hr.
AIR PRESSURE	4, 5 and 6 Bar
FLOOD CUTTING FLUID	Water soluble servo oil
FLOOD CUTTING FLOW RATE	8000 ml/hr.

The experimentation was designed with Taguchi L9 orthogonal array, and Table 2 shows nine combinations of input parameters used for this experimentation.

Table 2 MQL parameters according to orthogonal L9 array

S.NO	VEGETABLE OILS	OIL FLOW RATE	PRESSURE OF FLUID
1.	SOYABEAN	80	4
2.	SUNFLOWER	80	5

3.	GROUNDNUT	80	6
4.	SOYABEAN	120	5
5.	SUNFLOWER	120	6
6.	GROUNDNUT	120	4
7.	SOYABEAN	160	6
8.	SUNFLOWER	160	5
9.	GROUNDNUT	160	4

III. RESULTS AND DISCUSSION

3.1 MQL RESULTS

Table 3 shows the results of nine experimental runs.

Table 3 Mean value of process parameters

S.No	Flow rate (ml/hr.)	Vegetable oil	Pressure(bar)	Tangential forces(N)	Normal forces(N)	Temperature
1	80	Soybean	4	14.60	52.43	42.8
2	80	Sunflower	5	14.70	50.56	42.3
3	80	Groundnut	6	15.48	53.60	45.7
4	120	Soybean	5	12.15	42.90	41.4
5	120	Sunflower	6	11.46	40.76	42.0
6	120	Groundnut	4	13.23	49.29	44.9
7	160	Soybean	6	9.80	38.12	40.8
8	160	Sunflower	4	10.48	38.90	42.1
9	160	Groundnut	5	11.07	41.74	44.1

3.2 EFFECT OF PROCESS PARAMETERS ON GRINDING TEMPERATURE

The mean value for different parameters at each level is shown in Table 4. In case of flow rate, Level 1, Level 2 and Level 3 represent the mean value of grinding temperature at 80 ml/hr., 120 ml/hr. and 160 ml/hr. respectively. In case of pressure, these three levels represent the mean value of grinding temperature at 4 bar, 5 bar and 6 bar pressure respectively. Similarly in case of vegetable oil the three levels represent the mean value of grinding temperature under soyabean, sunflower and groundnut oil respectively.

Table 4 Average temperature for different factors

LEVELS AND FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
FLOW RATE	38.4	38.1	37.7
VEGETABLE OILS	37.9	37.8	38.4
PRESSURE	38.1	38.1	37.9

Effect of Vegetable Oils

The Fig. 2 shows the variation of grinding temperature with different kind of vegetable oils that were used in the experiment. It is clear from the figure that sunflower oil exhibited lowest grinding temperature. The grinding temperature is a very important factor as it affects the operation the most. High temperature results in the thermal cracks occur on the surface of the work piece. Poor surface finish and the work piece breakdowns are the worst effects of the increased temperature. Grinding temperature can be reduced by effective cooling or removal of heat from the surface. Proper transmission of heat from the contact surface is required with the help of cutting fluid.

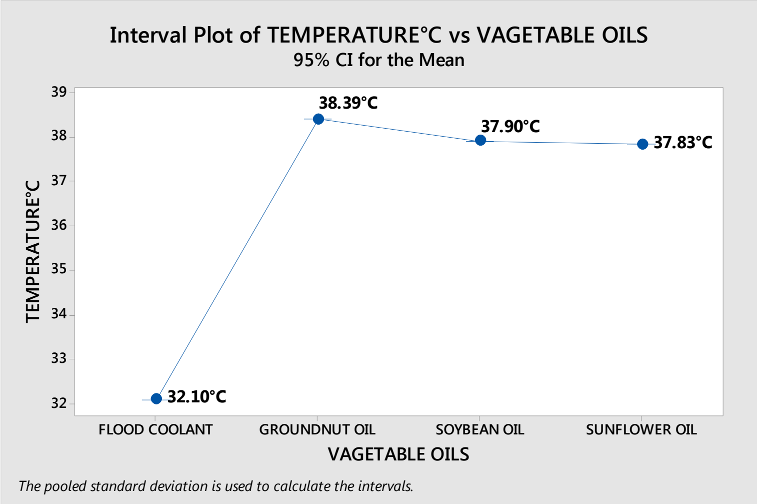

Fig 2 Individual Plot of Temperature v/s Vegetable oils

Effect of Flow Rate

Fig. 3 shows plot of temperature vs flow rate. It is clear from the plot that increase in flow rate leads to decrease in temperature. It happens because in the case of higher flow rate, the fluid penetrates deep into the tool work piece contact and produces the lubrication effect. More fluid in high flow rate transfers the more heat to the surroundings.

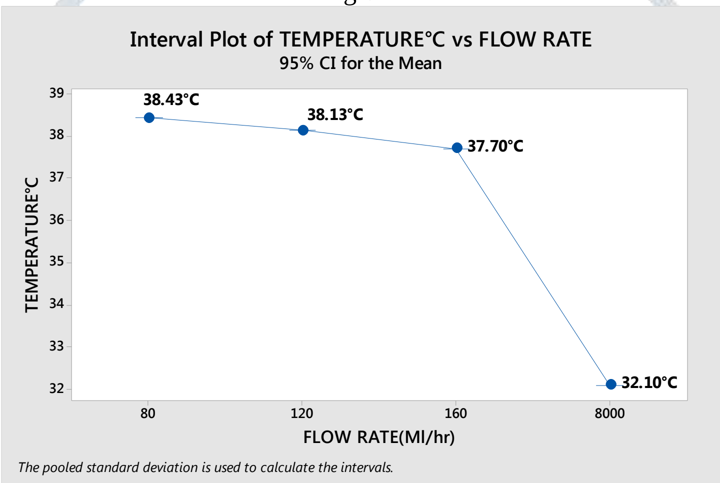

Fig. 3 Individual Plot of Temperature v/s Flow rate

Effect of Pressure

Effect of pressure was evaluated on the temperature on the various values of the pressure of 4, 5 and 6 bar and is shows in Fig. 4. It can be studied from the graph that with increase in the pressure, the value of the temperatures reduces. The value of the temperature is least for the 6 bar. The main reason behind it is that higher the pressure value, more will be the penetrating power of the lubricant. As the lubricant penetrates well into the grinding zone, it can transfer the more heat from the cutting zone which can be well shown in the graphs.

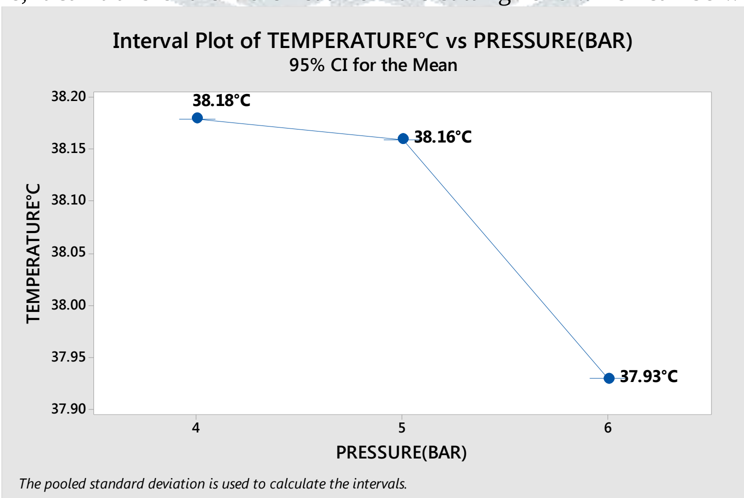

Fig. 4 Individual Plot of Temperature v/s Pressure

3.3 EFFECT OF PROCESS PARAMETERS ON GRINDING FORCES

Normal Forces

Normal grinding forces act perpendicular to the work-tool interface. The mean value for different parameters at each level is shown in Table 5. In case of flow rate, Level 1, Level 2 and Level 3 represent the mean value of normal force at 80 ml/hr., 120 ml/hr. and 160 ml/hr. respectively. In case of pressure, these three levels represent the mean value of normal force at 4 bar, 5 bar and 6 bar pressure respectively.

Similarly in case of vegetable oil, the level 1, level 2, and level 3 represent the mean value of normal forces under soyabean, sunflower and groundnut oil respectively.

Table 5 Average normal forces for different factors

LEVEL / FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
FLOW RATE	52.1	44.3	39.6
VEGETABLE OILS	44.5	43.4	48.2
PRESSURE	46.8	45.0	44.1

Effect of Vegetable Oil

Fig. 5 shows the effect of the vegetable oil on the normal forces of the grinding. It can be seen that the normal forces for the groundnut oil is maximum whereas for sunflower oil, these forces are minimum. Li et al. (2015) had reported that higher the viscosity of the vegetable oil lower will be the normal force. In this case the viscosity of sunflower oil is more than that of soyabean oil and groundnut oil. This is the reason that the normal force for sunflower oil is lower than the soyabean oil and that of the sunflower oil. The viscosity played an important role as the higher viscosity fluid had lower fluidity therefore it can form a strong protecting film over the work piece. As the film was thick so the friction was less between work piece and the tool(Shashidhara and Jayaram, 2010). This reduction in friction leads to the reduction in normal force.

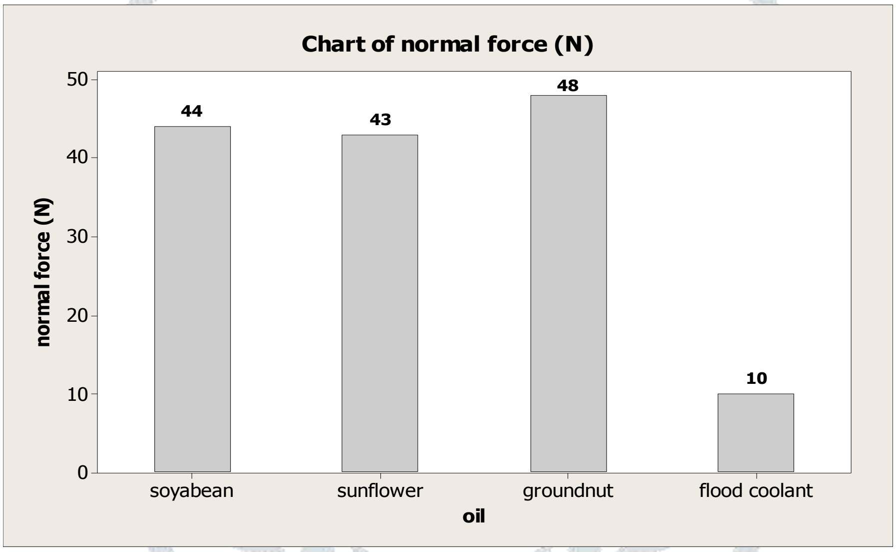

Fig 5 Chart of Normal Forces v/s Vegetable oils

Effect Of Flow Rate

Fig. 6 shows the effect of flow rate on the normal forces of the grinding. It can be seen that as the flow rate of vegetable oil increase, the normal forces decreases proportionally. This is due to the reason that as the flow rate increased the layers of the film formed over the surface of work piece increases. This results in formation of strong bonds leading to reduction in friction (Li et al., 2015). This reduction in friction was the reason for reduction in normal forces.

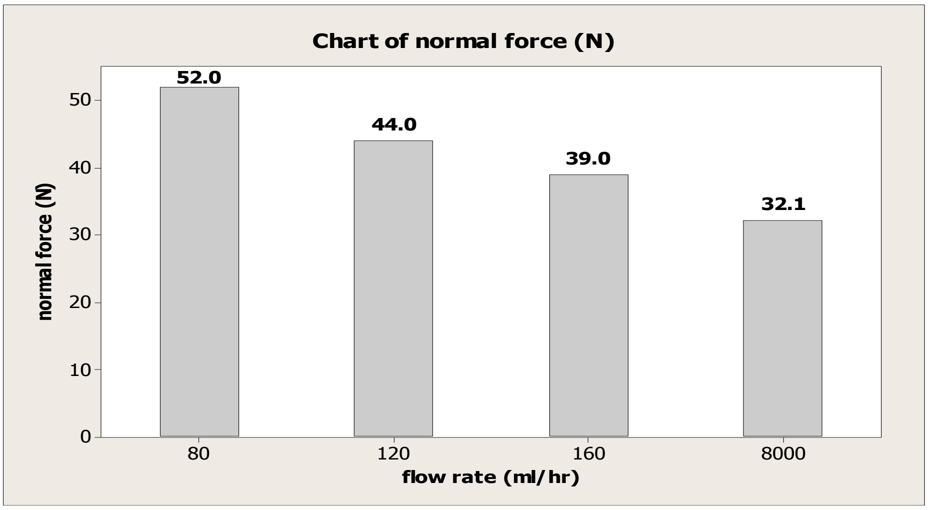

Fig 6 Chart of Normal Forces v/s Flow rate

Effect of Pressure

Fig. 7 depicts the change in normal forces with the change of the pressure of vegetable oils. The normal forces varies inversely proportional to the pressure at which the vegetable oil is supplied. Normal force is least for the 6 bar pressure. The more the value of the pressure, the more will be the penetrating power of the vegetable oil inside the cutting zone. This will make the oil to lubricate the entire contact zone more efficiently, reducing the normal forces.

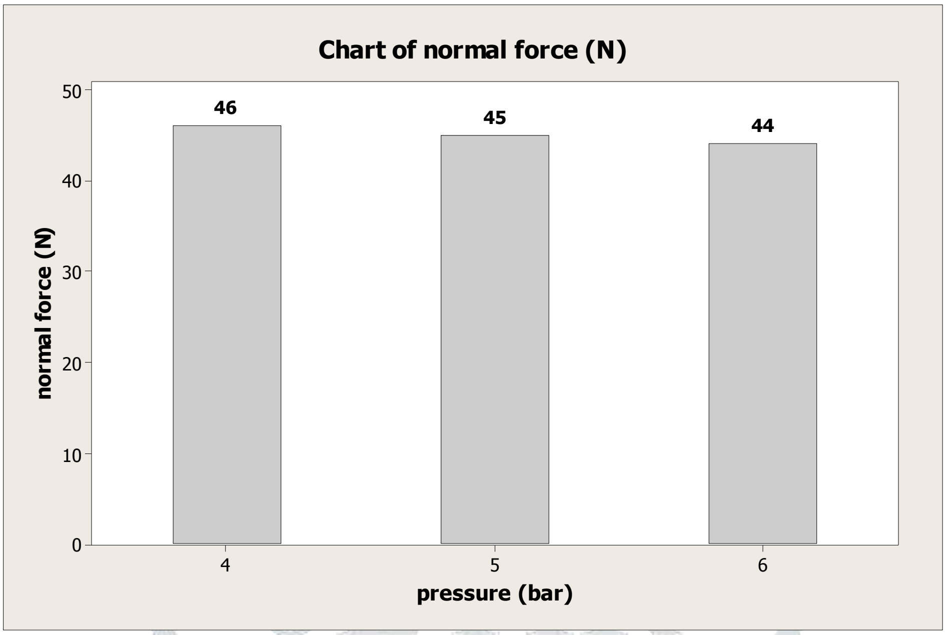

Fig 7 Chart of Normal Forces v/s Pressure

Tangential Forces

The tangential forces are those which act along the axis of the movement of the wheel. Tangential forces mainly effect the power consumption, heat generation, and service life of grinding wheel. As the experimental design was orthogonal array L_9, therefore it distinguishes the effect of each parameters at different levels. So the mean value for each parameters at each level is shown in Table 6. In case of flow rate, the Level 1, Level 2 and Level 3 represent the mean value of the tangential forces at 80 ml/hr., 120 ml/hr. and 160 ml/hr. respectively. In case of pressure, these three levels represent the mean value of normal force at 4 bar, 5 bar and 6 bar pressure respectively. Similarly in case of vegetable oil the level 1, level 2, and level 3 represents the mean value of tangential forces under soyabean, sunflower and groundnut oil respectively.

Table 6 Average tangential forces for different factors

LEVEL / FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
FLOW RATE	14.9	12.2	10.0
VEGETABLE OILS	11.8	12.1	13.2
PRESSURE	12.7	12.6	11.8

Effect of Vegetable Oils

Effect of different vegetable oils has been shown in Fig. 8, and it can be seen that soyabean and sunflower almost results in same tangential forces. As earlier explained, this is due to the fact that the viscosity is almost same of that of the soyabean and sunflower oil.

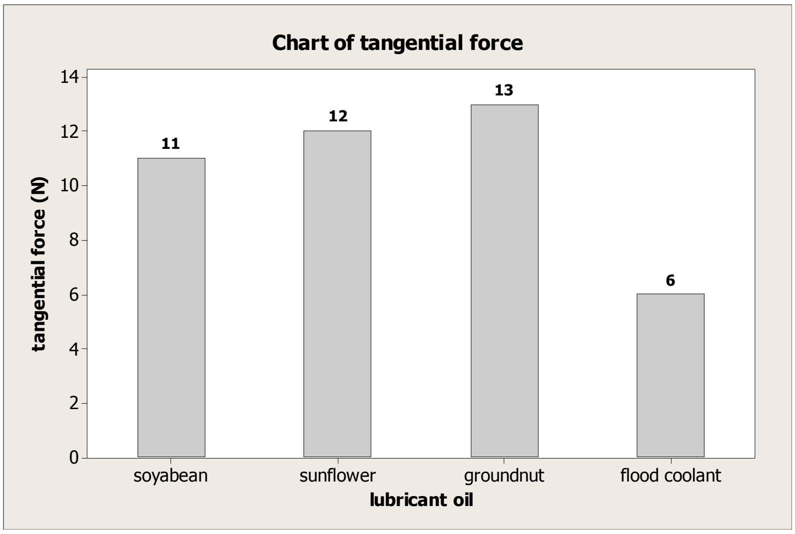

Fig. 8 Chart of Tangential Forces v/s Vegetable oils

The tangential force for the soyabean is the less than that of the other two lubricating oils. The film formed by the vegetable oil reduces friction which again reduces the grinding forces.

Effect of Flow Rate

Fig. 9 compares the effect of the different values of flow rates on the tangential forces which acts almost in the same manner as they were in the normal forces.

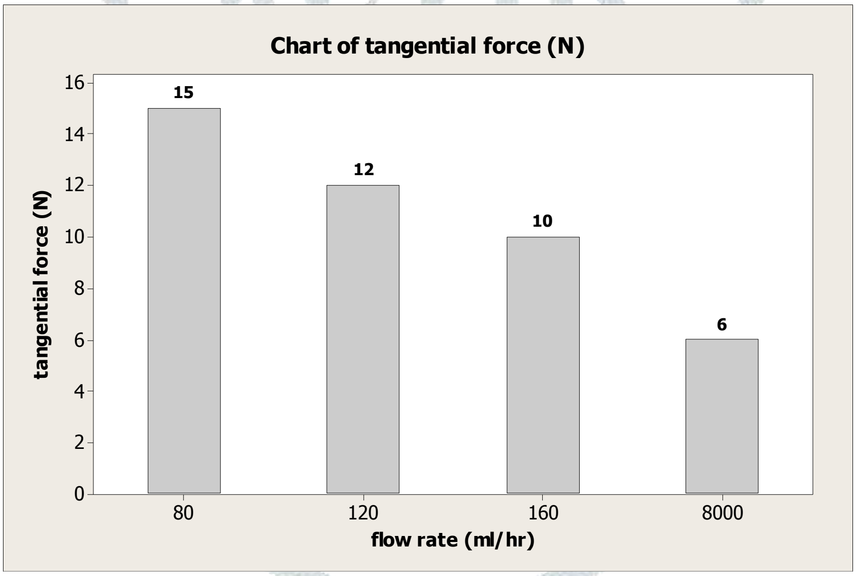

Fig. 9 Chart of Tangential Forces v/s Flow rate

The value of flow rates taken were 80, 120 and 160 ml/hr. The graph shows that increasing the flow rate, decreases the value of tangential forces. The value of tangential force is lowest for flood coolant. Comparing the three flow rates which we took as input process parameters, the value of tangential force is least for the 160 ml/hr. and hence giving us the most suitable value from the other two.

Effect of Pressure

Fig 10 shows the effect of pressure on the tangential force. The more the value of the pressure, the lubricant will make to move with more force into the cutting zone, which aids the grinding operation both in cases of the reducing forces and that of the reducing temperature.

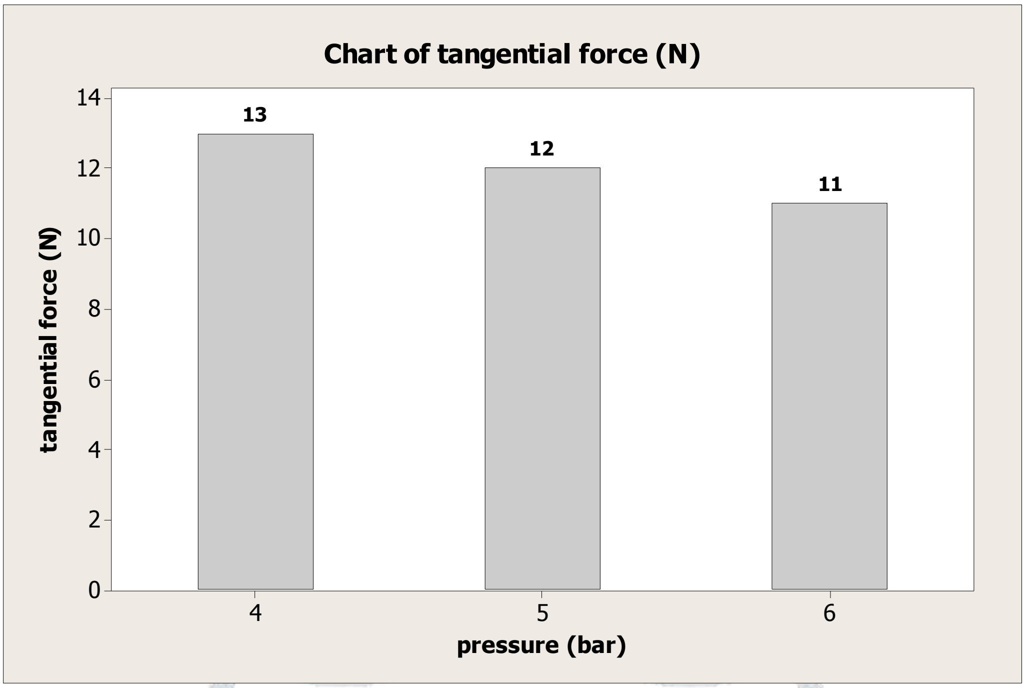

Fig. 10 Chart of Tangential Forces v/s Pressure

The value of tangential forces is less at the higher pressure of 6 bar and the highest value of the force is at the 4 bar which is the least value of the pressure taken. Hence the optimum conditions are provided with the lowest tangential forces are at 6 bar pressure, which will be the adopted pressure as compared to that of the 4 or 5 bar.

IV. CONCLUSIONS

In this study, the MQL grinding performances of sunflower oil, soyabean oil and groundnut oil are compared at the different values of process parameters of flow rate and pressure. The effects of the minimum quantity lubrication parameters are investigated on the surface grinding operation in order to design efficient minimum quantity lubrication system. The main conclusions which are obtained from the results are:

- Among the three vegetable oils, sunflower generates the lowest grinding force and also exhibits the lowest grinding temperature. Soyabean oil yields the second lowest grinding force. Therefore the sunflower oil is obtained as the better oil among the three oils.
- It has been observed that as the flow rate increases from 80 to 120 ml/hr. there is reduction in grinding forces and grinding temperature due to more quantity of oil makes a lubricating film over the surface of the work piece and heat is transferred to the surroundings. This provides cooling effect which leads to reduction in grinding forces and temperature.
- The reduction in the grinding temperature and the forces has also been observed with increase in pressure. This was due to the increased force on the vegetable oil to penetrate into the grinding zone and perform the required effect of lubrication and reducing temperature.
- Minimum quantity lubrication proves to be environment friendly and cost effective as cutting fluids required for machining is comparatively less than the flood cooling.
- It has been observed that MQL gives satisfactory results and may replace the flood coolants considering all the factors of environmental degradation and their performance in grinding process.

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