OPTIMIZATION OF PROCESS PARAMETERS DURING GRINDING AISI-4130 STEEL USING MINIMUM QUANTITY LUBRICATION

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Abstract : ***The development of high cutting forces and high temperatures during grinding process requires the use of cutting fluids. The main function of cutting fluid is to reduce metal to metal contact and friction between them which results in less power required to revolve the work piece, less generation of heat and reduced wear of wheel. Minimum Quantity Lubrication is alternative method of applying atomized air oil mixture in grinding zone. This research study aims to investigate the effect minimum quantity lubrication parameters on the cooling and lubrication in the grinding process in order to design efficient minimum quantity lubrication system. The experiment was designed with Taguchi L9 orthogonal array. The process parameters were optimized using analysis of variance. In this study vegetable oils were found to be a replacement for high toxic cutting fluids because of their environmental friendly characteristics.***

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

I. INTRODUCTION

During grinding process, higher amount of heat is generated due to friction involved between grinding wheel and work piece. This heat generation is associated with high negative rake angle and with greater contact length (Tawakoli et al., 2010). Without using the cutting fluids the heat is not carried away too much extent from the cutting zone, resulting in an increase in tool and work piece temperature (Rajput, 2007). As friction is involved at chip tool interface, it is obvious that the temperature would increase. If cutting fluid is not used, then the temperature of work piece and tool increases to such a high value resulting in dimensional inaccuracy and thermal damage (Silva et al., 2005). This increased temperature is the main reason of change in metallurgical properties and surface quality of work piece and wear of tool (oliveira et al). Material removal rate is the main parameter on which cost of machining depends. But increasing MRR will not reduce the machining cost but it will led to various problems such as shortening of tool life, dimensional inaccuracy and change in metallurgical properties of work piece due to increase in friction and heat generation at the tool-chip interface (Dhar et al., 2006). To avoid these problems, the researches on the lubricant were done so as to get the minimum production cost as well as considering the health of the workers as excess amount of lubricant contain chemicals and toxic substances which cause health issues as well as it cause water pollution (Hadad and Sharbati, 2016). So the further research was done to find suitable lubricant. The researches are being done with using lubricant in very small quantity. These processes are known as minimum quantity lubrication MQL.

During grinding the excessive amount of heat is produced at chip tool interface. The heat leads to many problems like improper surface finish, reduction in tool life, improper chip formation (Tawakoli et al., 2010). This higher amount of heat is removed by applying cutting fluid to the work tool interface with the help of nozzle at High Pressure and fluid makes layer over the work tool interface through which heat is removed. The cutting fluid performs the functions of cooling and lubrication (Vasu and Kumar 2011). The main function of cutting fluid is to reduce metal to metal contact and friction between them which results in less power required to revolve the work piece, less generation of heat and reduced wear of wheel. Good lubricating Property, low viscosity, non-corrosive, High Flash Point, chemically stability, non toxic properties of cutting fluids make it efficient for heat transfer medium. Cutting fluids helps to reduces the temperature, Reduces friction between tool-work interface, provides Flushing action to carrying away debris and chips along with them, reduces wear of tool and Resist corrosion (Sahid et al., 2015). There are numerous advantages of the cutting fluids but inspired of them, there are also certain problems assisted with them. 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 and disposal of cutting fluid is also difficult problem because it creates water pollution (Shokrani et al., 2012). Rahman et al. (2006) evaluated the Machinability of titanium alloys which were difficult to machine materials. Different wheels were taken such as CBN, PCD and BCBM for Machining of titanium alloy. It was observed that during the machining of titanium alloy at low speed, there was high temperature at work-tool interface. This high temperature cause tool life decreases and for enhancing the tool life, BCBN Wheel was utilized. Shen and Shih (2009) investigated performance of vitrified bond CBN wheel in grinding of cast iron under dry, MQL, flood cooling conditions. It was founded that the value of surface roughness, temperature and grinding forces were improved using vitrified bond CBN Wheel under various cooling conditions. The material removal Rate was same during using MQL and Flood Method. Temperature and surface roughness were lowers in flood cooling as compared to MQL and dry grinding. Mao et al. (2012) investigated the grinding Characteristics of A1SI 52100 steel using nano fluid MQL. Al_2O_3 nano fluid was used during the research and results of Al¬2O3 nano fluid was compared with pure water as a fluid. It was found that Al_2O_3 nano fluid helps in Reducing the temperature, tangential grinding force and improve the surface finish as compared to pure MQL.

The further research is needed eliminate the use of cutting fluids by using different types of vegetable oils. Vegetable oil are biodegradable fluids which helps in reducing the environment pollution and also improve the health of operator. The different types of vegetables oils such as soybean, sunflower, palm, groundnut are used which helps in reducing the grinding temperature and also improve the surface quality of work piece. From the previous literature it was observed that the use of vegetable oils with MQL helps in reducing cutting temperature and grinding forces. So the present research is aimed at investigating the effects of minimum quantity lubrication using vegetable oil and flood cooling on the machining parameters such as cutting forces and cutting temperature.

II. EXPERIMENTATION

The first step of experiment was to select the material in this research study. We have selected the AISI 4130 (100*12*15) steel for research purpose. The main reason to use this steel was that there was less work performed on it in previous research and other reason is its availability. It have properties like hardness (90-96) and tensile strength (590-760 Mpa) which made it to have wide range of applications such as for structural work in aircraft engine mounting and welding tubing.

For grinding purpose surface grinder was utilized for performing surface grinding of AISI 4130 material. The surface grinder was available at UCOE workshop in Punjabi University Patiala. The Magnetic bed of machine plays an important role to hold the work piece during the grinding operation. The depth of cut was easily changed by providing down feed.

The next step after the selection of material and machine was the selection of various process parameters. The various process parameters were selected during the research work were flow rate, vegetable oils and pressure of oil. The vegetable oils like soybean sunflower, olive oil were selected and their effect were selected and their effect were compared with the flood coolant. The flow rates used during the experiment were 60, 100 and 140 ml/hr and pressure of oil were 1, 2 and 7 bar and the effect of flow rate and pressure of oil were also compare with flood coolant.

After selecting process parameter machine and material, the next step was to perform the experiment. The MQL setup was prepared at UCOE workshop. The setup contain, compressor, thermocouple vice and dynamometer (Fig. 1). The dynamometer was used for measuring grinding forces and thermocouple was used for measuring temperature the nozzle consists of two noses one nose was connected to compressor and other nose was dipped in vegetable oil. The pressure of compressor was adjusted to research. After the experiment, the results were noted at regular intervals.

Fig 1. Experimental setup

The surface grinding was carried out at constant wheel speed 22 m/s, table speed and depth of cut 50 um for each grinding passes. The experiment is carried out under pure flood cooling method and MQL using vegetable oils. The grinding forces, surface roughness, temperature under different conditions of cooling lubrication are measured and also their effect on work piece surface quality is analyzed. Following are the various surface grinding process parameters:

Table 1 Grinding process parameters

GRINDING MODE	Surface grinder
WHEEL SPEED	22 m/s
TABLE/WORK SPEED	0.66 m/s
DEPTH OF CUT	50 um
GRINDING PASSES	20
GRINDING ENVIORNMENT	MQL, Flood cooling
VEGETABLE OIL	Soybean oil, Sunflower, Olive oil
MQL FLOW RATE	60, 100, 140 ml/hr
AIR PRESSURE	1, 4, 7 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	FLOW RATE(ml/hr)	AIR PRESSURE(bar)
1.	Soybean oil	60	1
2.	Sunflower oil	60	4
3.	Olive oil	60	7
4.	Soybean oil	100	4
5.	Sunflower oil	100	7
6.	Olive oil	100	1
7.	Soybean oil	140	7
8.	Sunflower oil	140	1
9.	Olive oil	140	4

III. RESULTS AND DISCUSSION

3.1 MQL RESULTS

During Experiments, Taguchi method with orthogonal array l_9 was used in which three parameters, three factors and three trials had been taken. Flow rate, vegetable oil, pressure of oil were taken as three parameters. The three factors such as normal grinding force, tangential force and surface temp were taken. The grinding forces were measured by dynamometer and temperature was measured by thermocouple. 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	60	Soybean	1	14.7	40.8	39.1
2	60	Sunflower	4	14.7	44.9	38.2
3	60	Olive	7	16.7	40.5	42
4	100	Soybean	4	15.3	35.9	38.4
5	100	Sunflower	7	15.9	33.5	37.6
6	100	Olive	1	11.5	37.5	41.8
7	140	Soybean	7	14.9	31.1	38.1
8	140	Sunflower	1	12.5	34.4	37.3
9	140	Olive	4	13.7	40.8	41.6

3.2 OPTIMIZATION AND VALIDATION OF PROCESS PARAMETERS

The optimization of process parameters such as flow rate, oils and pressure using taguchi method evaluates the effect of individual parameter independent of other parameters during the measurement of grinding forces and temperature. The influence of each parameter can be evaluated by determining the SN ratio for each parameter at each level. The mean effect plots for various responses are shown in following figures. From the main effect plots analysis, the optimum combination for better grinding forces and temperature are obtained. S/N ratio for smaller is better is S/N =10log$_{10}$(mean square deviation)

$$S/N = 10\log_{10}(1/n\sum 1/y_2)$$

Where n is the number of measurement in a trail/row and y is measured value. Regardless of category of the performance characterstics a greater S/N value correspondes to a better performance. Therefore optimum level of each parameter is the level with the greatest S/N value.

EFFECT OF PROCESS PARAMETERS ON TEMPERATURE

Table 4 S/N ratios for grinding temperature

Flow rate	Oil	Pressure	Temperature	SN ratio
60	Soybean	1	39.1	-31.84
60	Sunflower	4	38.2	-32.64
60	Olive	7	42	-32.46
100	Soybean	4	38.4	-31.68
100	Sunflower	7	37.6	-31.50
100	Olive	1	41.8	-32.42
140	Soybean	7	38.1	-31.61
140	Sunflower	1	37.3	-31.43
140	Olive	4	41.6	-32.38

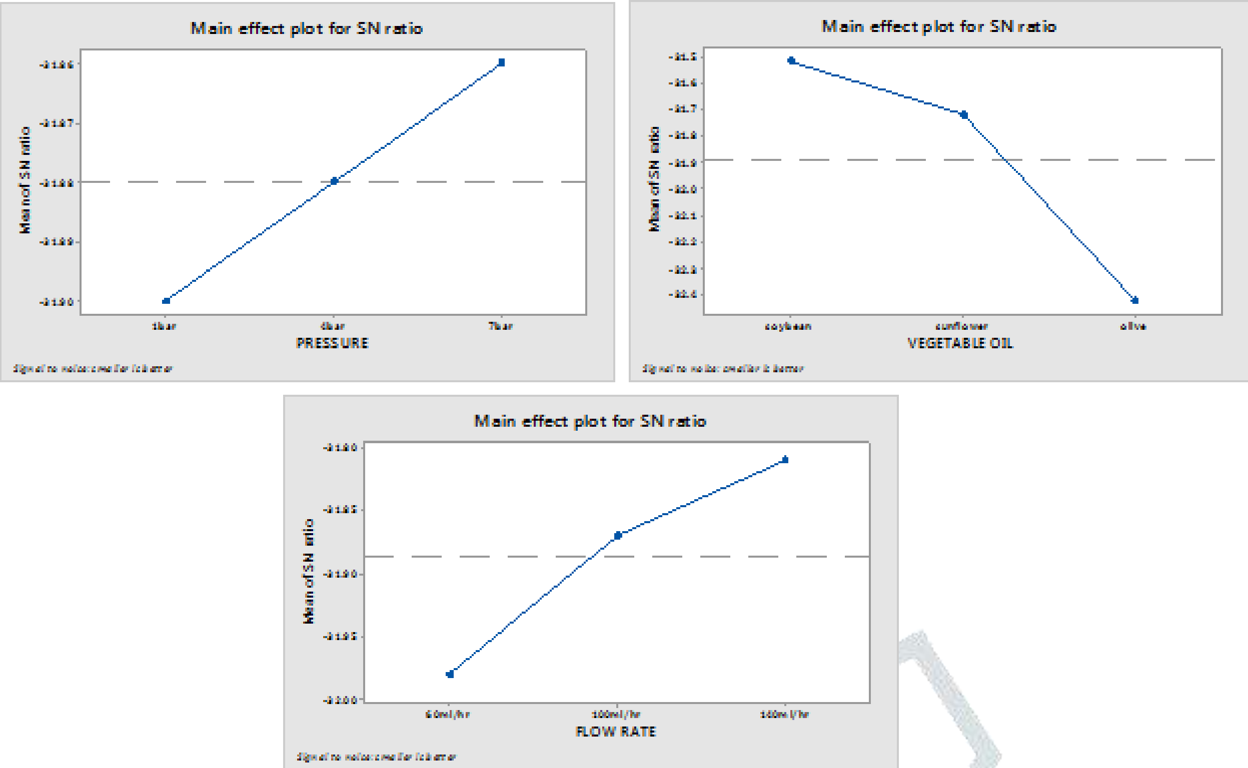

Fig 2. Mean effect plots of S/N ratios

Fig 2 shows the main effect of SN ratios for grinding temperature.The result indicated that minimum optimum grinding temperature can be achieved at flow rate 160 ml/hr, pressure 7 bar and using soybean oil. Main effect plot for grinding temperature shows that grinding temperature are minimized during the minimum quantity lubrication using 140 ml/hr flow rate, 7bar pressure and soybean oil. The response for signal to noise ratio for grinding temperature is shown in table .All three parameters are characterised according to their degree of contribution and significance.

Table 5 Response table for signal to noise ratios

Level	**Flow rate**	**Oil**	**Pressure**
1	-31.98	-31.52	-31.90
2	-31.87	-31.72	-31.88
3	-31.81	-32.42	-31.86
Delta	0.17	0.90	0.04
Rank	2	1	3

Response table shows that oil has largest degree of contribution is most significant factor for grinding temperature this may be due to reason that vegetable oils have higher heat transfer capability. Flow rate is second most significant factor for contribution of temperature. Pressure is third significant factor for contribution of temperature.

Analysis of Variance for SN ratios:

Table 6 shows the contribution of each parameter in the grinding temperature. After the analysis of ANOVA test it has been found that in improving the grinding temperature, oils have maximum contribution then flow rate and pressure have minimum contribution.

Table 6 analysis of variance for grinding temperature

Parameter	**D.F**	**S.S**	**M.S**	**F-Value**	**p-value**	**% Contribution**
Flow rate	2	0.04561	0.022804	12.76	0.076	3.27%
Oil	2	1.34093	0.670467	375.19	0.003	96.24%
Pressure	2	0.00312	0.001560	0.87	0.534	0.22%
Residual error	2	0.00357	0.001787			0.25%
Total	8	1.39324				100%

Table 6 shows the contribution of each parameter in the grinding temperature. After the analysis of ANOVA test it has been found that in improving the grinding temperature, oils have maximum contribution then flow rate and pressure have minimum contribution. oils gives the highest contribution of 96.24%. After this flow rate gives the contribution of 3.27% and pressure have minimum contribution of 0.22%.

3.3 EFFECT OF PROCESS PARAMETERS ON NORMAL FORCE

Table 7 S/N ratio for normal force

Flow rate	Oil	Pressure	Normal force	SN ratio
60	Soybean	1	40.8	-32.21
60	Sunflower	4	44.9	-33.04
60	Olive	7	40.5	-32.14
100	Soybean	4	35.9	-31.10
100	Sunflower	7	33.5	-10.50
100	Olive	1	37.5	-31.48
140	Soybean	7	31.1	-29.85
140	Sunflower	1	34.4	-30.73
140	Olive	4	40.8	-32.21

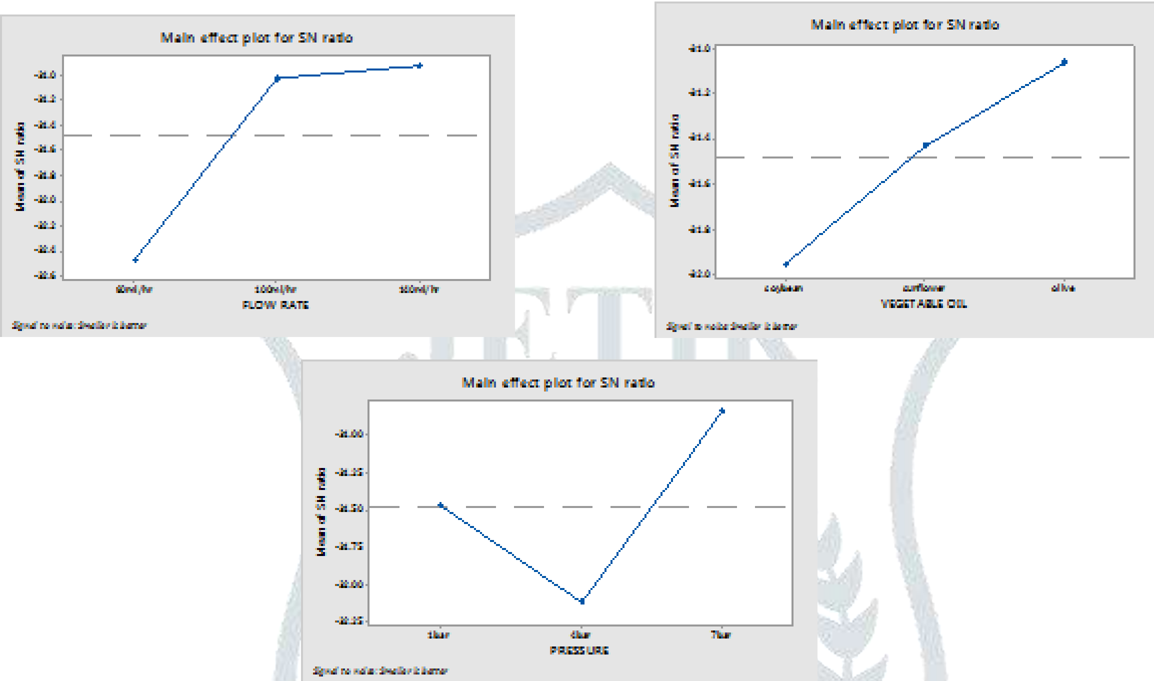

Fig 3 S/N ratio response graph for normal force

Fig 3 shows the main effect of SN ratios for normal force.The result indicated that minimum optimum normal force can be achieved at flow rate 160 ml/hr, pressure 7 bar and using olive oil. Main effect plot for normal force shows that normal force are minimized during the minimum quantity lubrication using 140 ml/hr flow rate, 7bar pressure and olive oil. The response for signal to noise ratio for normal force is shown in table..All three parameters are characterised according to their degree of contribution and significance.

Table 8 Response table for signal to noise ratio

Level	**Flow rate**	**Oil**	**Pressure**
1	-32.47	--31.95	-31.47
2	-31.03	-31.43	-32.12
3	-30.93	-31.06	-30.84
Delta	1.54	0.89	1.28
Rank	1	3	2

Response table shows that flow rate has largest degree of contribution is most significant factor for minimizing normal force. This may be due to reason that that as the flow rate increases the oil layer formed over the surface of work piece increases which results in reducing friction and provide good lubrication effect. The reduction in friction reduces the normal forces. Pressure is second most significant factor for contribution of normal force. Oil is third significant factor for contribution of temperature.

Analysis of variance for S/N ratio:

Table 9 shows the contribution of each parameter in normal force. After the analysis of ANOVA test it has been found that in improving the normal force, flow rates have maximum contribution then pressure and oils have minimum contribution.

Table 9 Analysis of variance for normal force

Parameter	**D.F**	**S.S**	**M.S**	**F-Value**	**p-value**	**% Contribution**
Flow rate	2	4.4452	2.22258	29.61	0.033	53.72%
Oil	2	1.2022	0.60110	8.01	0.111	14.52%
Pressure	2	2.4766	1.23831	16.50	0.057	29.93%
Error	2	0.1501	0.07505			1.81%
Total	8	8.2741				

Flow rate gives the highest contribution of 53.72%. After this pressure gives the contribution of 29.93% and oils have minimum contribution of 14.52%.

3.4 EFFECT OF PROCESS PARAMETERS ON TANGENTIAL FORCE:

Table 10 S/N ratio for tangential force

Flow rate	Oil	Pressure	Tangential force	SN ratio
60	Soybean	1	14.7	-23.34
60	Sunflower	4	14.7	-23.34
60	Olive	7	16.7	-24.45
100	Soybean	4	15.3	-23.69
100	Sunflower	7	15.9	-24.02
100	Olive	1	11.5	-21.21
140	Soybean	7	14.9	-23.46
140	Sunflower	1	12.5	-21.93
140	Olive	4	13.7	-22.73

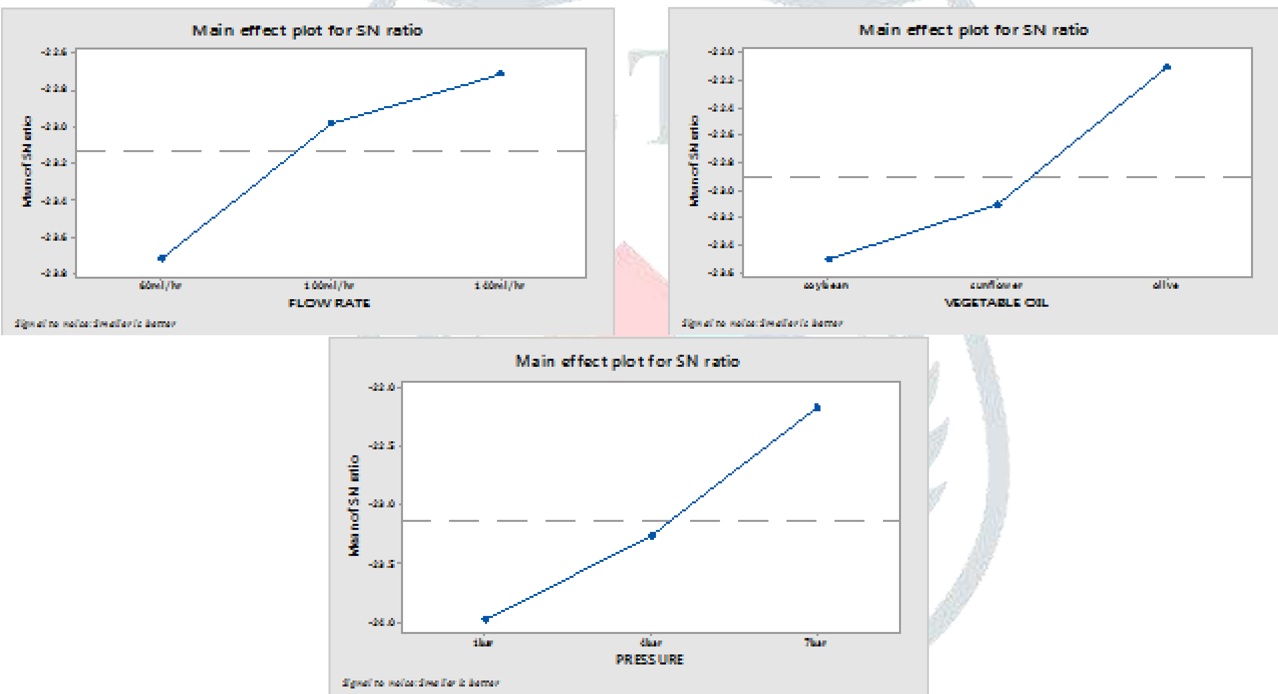

Fig.4 S/N ratio response graph for tangential force

Fig 4 shows the main effect of SN ratios for tangential force.The result indicated that optimum tangential force can be achieved at flow rate 160 ml/hr, pressure 7 bar and using oilve oil. Main effect plot for tangential force shows that tangential force are minimized during the minimum quantity lubrication using 140 ml/hr flow rate, 7bar pressure and olive oil. The response for signal to noise ratio for tangential force is shown in table.All three parameters are characterised according to their degree of contribution and significance.

Table 11response table signal to noise ratio

Level	**Flow rate**	**Oil**	**Pressure**
1	-23.72	-23.50	-23.98
2	-22.98	-23.10	-23.26
3	-22.71	-22.10	-22.17
Delta	1.00	0.70	1.82
Rank	2	3	1

Response table shows that pressure has largest degree of contribution is most significant factor for minimizing tangential force. This may be due to reason that higher air pressure produces more number of higher velocity smaller droplets which provides good cooling and lubrication effect which helps in reducing the tangential forces. Flow rate is second most significant factor for contribution of tangential force. Oil is third significant factor for contribution of tangential force.

Analysis of Variance for SN ratios:

Table 12 shows the contribution of each parameter in tangential force. After the analysis of ANOVA test it has been found that in improving the tangential force, pressure have maximum contribution then flow rate and oils have minimum contribution.

Table 12 Analysis of variance for tangential force

Parameter	D.F	S.S	M.S	F-Value	p-value	% contribution
Flow rate	2	1.6215	0.8107	1.70	0.371	19.46%
Oil	2	0.7402	0.3701	0.77	0.563	8.88%
Pressure	2	5.0137	2.5068	5.25	0.160	60.18%
Error	2	0.9555	0.4778			
Total	8	8.3309				

Air pressure gives the highest contribution of 60.18%. After this flow rate gives the contribution of 19.46% and oils have minimum contribution of 8.88%.

IV. CONCLUSIONS

This research study aims to investigate the effect minimum quantity lubrication parameters on the cooling and lubrication in the grinding process in order to design efficient minimum quantity lubrication system. In this study vegetable oils were found to be a replacement for high toxic cutting fluids because of their environmental friendly characteristics. The main conclusions which are obtained from the results of present research are summarized follows:

1. It has been observed that as the flow rate increases from 60 to 140 ml/hr there is reduction in grinding forces and grinding temperature due to large quantity of oil penetrates at the work-tool interface from where heat is carried away which provides cooling effect leads to reduction in grinding forces and temperature.

2. It has been observed that the soybean oil has shown good results in reducing the temperature due to its low viscosity which increases the heat transfer capability of oil, and olive oil has shown good results in the reduction of grinding forces due to its higher viscosity which helps in providing good lubrication effect leads to reduce the grinding forces.

3. It has been observed that as the pressure of air increases there is reduction in grinding temperature and forces due to reason that higher air pressure produces more number of higher velocity smaller droplets which provides good cooling and lubrication effect which helps in reducing the grinding forces and temperatures. It has been also observed that air pressure at 4 bar pressure produces optimum results as compared to 1 bar and 7 bar.

4. It has been observed that vegetable oils shows good result with regards to cutting temperature near to flood cooling.

5. Minimum quantity lubrication proves to be environment friendly and cost effective as cutting fluids required for machining is comparatively less than the flood cooling.

6. Optimum value of each parameters using taguchi SN ratio analysis have found that optimum grinding temperature can be achieved by using 160 ml/hr flow rate, 7 bar pressure and soybean oil.

7. It has been observed that optimum normal forces can be achieved by using 160 ml/hr flow rate, 7 bar pressure and using olive oil and also found that optimum tangential force can be achieved by using 160 ml/hr flow rate, 7 bar pressure and using olive oil.

8. Significance of different parameters has been also observed by using ANOVA method and founded that for grinding temperature oils have maximum significance and for normal forces flow rate have maximum significance and for tangential force pressure have maximum significance.

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