

Experimental Investigation of Turning of AISI 304 Stainless Steel using Green Fluids

Gaurav Gaurav^{a*}, Mohit Dubey^a, Govind Sharan Dangayach^a, Sundeep Kumar^b, Sumit Gupta^c

^aDepartment of Mechanical Engineering, Malaviya National Institute of Technology Jaipur, Jaipur, 302017, India

^bDirector, Centre for Electronic Governance, Technical Education Department, Government of Rajasthan, 302017, India

^cAmity School of Engineering and Technology, Amity University Noida, Noida, 201313, UP, India

Abstract

In order to increase the efficiency of any machining process, knowledge of the correct cutting fluid in the machining of different work piece materials is essential. The purpose of this study is to investigate the effect of green fluid i.e vegetable oil on surface roughness (Ra) and chip thickness during turning of AISI 304 Stainless Steel with carbide tool. The performance of vegetable oil (canola oil and sunflower oil) compared with semi-synthetic (chemoleum oil) at different combination of machining parameters i.e cutting speed (RPM), feed (mm/rev) and depth of cut (mm) using L₉ Taguchi design. The results show that canola oil is better than the other two cutting fluids in reducing chip thickness and improving surface finish. According to the signal-to-noise (S/N) ratio analysis, the best combinations of parameters (cutting speed, feed and depth of cut) for the best surface roughness and maximum chip thickness are 1500, 1, 0.1; 1000, 0.05 and 1.25 respectively.

Key words: Turning; AISI 304 Stainless Steel; Vegetable oil (canola oil and sunflower oil); machining; Green fluids; Carbide tool; Taguchi Method.

1. Introduction

Lubricants are used to lubricate the machine parts in all sector of the industry. A survey shows that approximately 38 million tons of lubricants were used globally in 2005, and grew by 1.2% in the next decade (Kline & Company, 2006). Nearly 85% of lubricant being used are petroleum based. In today's industry there is sudden demand of environmental friendly, bio-degradable, non-toxic and cheaper fluid is increasing. This is due to harmful effect of cutting oil on environment and workers' health. Owing to these environmental degradations some countries made strict regulations on use of mineral oil based cutting fluids as coolant. Those countries are Japan, Hungary, Canada, United States of America, European Union and Austria (Bartz, 2006).

Corresponding author *E-mail address:* 2016rme9006@mnit.ac.in

1.2 Cutting fluids

Cutting fluids have been used in machining processes to improve the performance of machining system. Interestingly, Taylor first reported the use of coolants in machining in 1907. When using high-speed steel tools to process steel with water as a coolant, cutting speeds increased by 40%. (Taylor, 1907). Cutting fluid provides lubrication between the workpiece and the tool, and also eliminates heat produce during machining (De Chiffre and Belluco, 2000). The use of conventional petroleum-based cutting fluids is potentially dangerous. The impact of a particular cutting fluid on humans, the work environment, work pieces and machine tools, and the overall life environment in general is expressed in terms of its ecological parameters. Machine operators are affected by contact with various substances in the cutting fluid. (Mijanovic and Sokovic, 2001).

1.3 Vegetable-based cutting fluids

Traditionally, mineral oil-based cutting fluids have traditionally been used in production plants due to their chemical stability and frequent reuse. However, the current trend of new cutting fluids based on vegetable oils and esters in machining obviously has higher biodegradability and lower environmental impact, which is reasonable. Ionic and non-ionic surfactants are used to prepare vegetable oil emulsions for use as metalworking fluids. Vegetable oils and fats have been used for many years and retain their importance as metalworking lubricants. Most concerned are vegetable oil-based emulsions, which are rarely used as references for metalworking fluids. The use of vegetable oils in metalworking applications can alleviate problems faced by workers, such as skin cancer and inhalation of toxic mists in the work environment. A plant-based emulsion was developed by (John, Bhattacharya and Raynor, 2004) that can be used in the metalworking industry to partially or completely replace commonly used petroleum-based emulsions. Vegetable oil has good lubricity and has been used to formulate metal cutting emulsions (Herdan, 1999). (Belluco and De Chiffre, 2002) made an investigation on the effect The effect of new vegetable oil formulations on reaming and tapping operations using AISI 316L stainless steel on surface integrity and part accuracy was investigated. The cutting fluid was found to have a significant impact on surface integrity and the thickness of the subsurface strain hardened layer, as well as the accuracy of the part. Vegetable oil-based cutting fluids show better performance than mineral oils. By measuring tool life, tool wear, cutting forces and chip formation, the

efficiency of six cutting oils was evaluated in AISI 316L austenitic stainless steel drilled holes using conventional HSS-Co tools. In terms of extending tool life and reducing thrust, all vegetable-based oils produce better results than commercially available mineral oils.

Many problems can be found with cutting fluids, such as health and environmental issues. There is an urgent need to develop new environmentally friendly cutting fluids, such as vegetable-based cutting fluids, to reduce these harmful effects. In this study, performances of two vegetable cutting fluid (sunflower and canola oils) is compared with commercial available Semi- synthetic oil (Chemoleum oil Grade-50) during the Turning of AISI 304 Stainless Steel. The purpose of this study is to investigate the effect of green fluid i.e vegetable oil in terms of surface roughness (Ra) and Chip Morphology during turning of AISI 304L. S/N ratio and Comparative analysis of different cutting fluid conditions was performed to obtain important parameters affecting the surface roughness and chip thickness ratio (CTR).

2. Materials and methodology

For the experimental work, AISI 304 austenitic stainless steel work piece of diameter 45 mm and length 111 mm was used, and turning operation was performed under different metalworking fluids. The turning operations were performed under two different cutting environment of oil i.e. Semi- synthetic oil (Chemoleum oil Grade-50) and vegetable oil (Sunflower oil and canola oil). Properties of cutting fluids used are listed in table 1.

Table:1 Properties of cutting fluids used

Parameter	Canola oil (Vegetable oil)	Sunflower oil (Vegetable oil)	Chemoleum oil (Mineral oil)
Relative Density(gm/cm ³ ,20°C/water at 20°C)	0.914	0.918	0.8130
Viscosity (kinematic at20°C,mm ² /sec)	78.2	49.14	45.13
Cold Test(15 Hrs at 4 °C)	Passed	Passed	Passed
Flash Point,Open Cup (°C)	275	227	170
Specific Heat (J/g at 20 °C)	1.91	1.67	1.40
Thermal Conductivity (W/mK)	0.188	0.167	0.170

Turning experiments are performed with TiN coated carbide insert and MTJNL2525M16 tool holder are used to accommodate the cutting insert. In this study, turning operations are

performed on MaxTurn Plus+ CNC lathe and specification of this lathe machine is listed in table 2.

Table: 2 Specifications of MaxTurn Plus+ CNC lathe

Parameters	Value
Chuck size	165 mm
Distance Between Centers	380 mm
Maximum Turning Length	360 mm
Maximum Turning Diameter	235 mm
Swing over Bed	410 mm
Number of Axes	2
Spindle Motor Capacity	5.5 Kw

Taylor Hobson surface tester was used for quantifying surface roughness (Ra) of the machined surface. The average value of Ra is measured at four different locations to minimize the deviation. Specification of Taylor Hobson Profilometer is listed in table 3.

Table: 3 Specifications of Taylor Hobson Profilometer

Manufacturer	Taylor Hobson Ltd
Working Temperature	20 °C ± 2 °C
Least Count	5 nm
Stylus radius	5 µm

Spindle speed, feed speed and cutting depth are considered turning parameters. The range of turning parameters is selected based on the recommendations of the tool manufacturer. The machining factors and their levels are shown in table 4. Taguchi arranges experimental plans for three cutting parameters (spindle speed, cutting depth, feed rate), three levels (3^3) and one parameter (cutting fluid type). Method (L_9 orthogonal array, table 5). Minitab 16 trial version is used for Design of Experiments (DOE). Using the Taguchi method to reduce a large number of experiments is important for reliable design in experimental research. In the optimization process, there are three characteristics of signal-to-noise ratio; the lower the better, the higher the better, and nominally the better. In this study, in order to obtain the best conditions, the surface roughness and chip thickness ratio (CTR) were studied, and lower- the better quality characteristic (S/N ratio) for surface roughness, and Larger- the better quality characteristic (S/N ratio) for chip thickness ratio (CTR) are selected in the experimental plan.

Table: 4 Variables in experiments

Parameter	Unit	Level-1	Level -2	Level-3
Speed	RPM	500	1000	1500
Feed Rate	mm/rev	0.050	0.100	0.125
Depth of cut	mm	0.50	1.00	1.25

Table:5 Matrix of Design of experiment

Experiment No.	Cutting speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	500	0.050	0.50
2	500	0.100	1.00
3	500	0.125	1.25
4	1000	0.050	1.00
5	1000	0.100	1.25
6	1000	0.125	0.50
7	1500	0.050	1.25
8	1500	0.100	0.50
9	1500	0.125	1.00

3. Results and discussion

Surface roughness(Ra), and Chip Morphology were measured for both Canola oil (Vegetable oil and Sunflower oil (Vegetable oil) and reference commercial Chemoleum oil (Mineral oil) in the performance experiments during the turning of AISI 304 Stainless material.

3.1 Surface finish

Nine experiments were conducted as per L₉ orthogonal array and average surface roughness (Ra) were measured for all metal working fluids. Table 6 shows the L₉ orthogonal array and Surface roughness (Ra) measurements for both vegetable oils and mineral oil. Effect of turning parameters (cutting speed, feed rate, depth of cut) on Surface Roughness are shown in figure 1-3. From the figure 1 it can be seen that the surface roughness is decreases as the cutting speed increases. In comparison to all three oil, lower surface roughness was obtained by the use of canola oil as a working fluid under different cutting speed.

Table: 6 L₉ orthogonal array and Surface roughness (Ra) measurements

Sample No.	Cutting speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Ra (µm) of Sunflower oil (Vegetable oil)	Ra (µm) of Canola oil (Vegetable oil)	Ra (µm) of Chemoleum oil (Mineral oil)
1	500	0.050	0.50	0.87	0.63	1.10
2	500	0.100	1.00	0.77	0.70	1.03
3	500	0.125	1.25	1.00	0.90	1.13
4	1000	0.050	1.00	0.90	0.76	0.93
5	1000	0.100	1.25	1.0	0.73	1.10
6	1000	0.125	0.50	0.93	0.97	0.96
7	1500	0.050	1.25	1.36	1.17	1.40
8	1500	0.100	0.50	0.67	0.43	0.68
9	1500	0.125	1.00	0.63	0.50	0.80

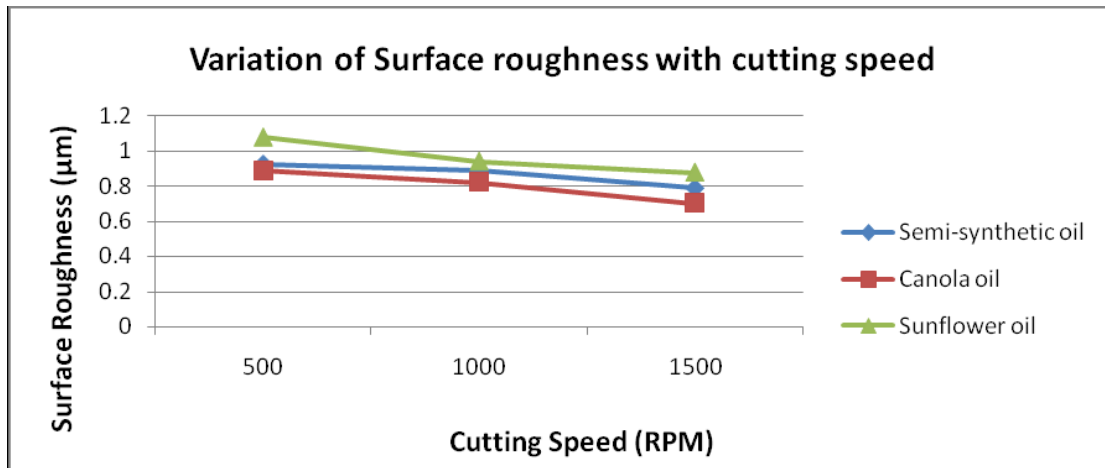


Figure: 1 Effect of cutting speed on surface roughness under different metalworking fluid.

From the figure 2 it can be seen that the surface roughness is first decrease with increase of cutting speed but on further increment in feed surface roughness increases rapidly. So the minimum value of surface finish is obtained at feed of 0.1 mm/rev. In comparison to all three oil, lower surface roughness was obtained by the use of canola oil as a working fluid under different feed.

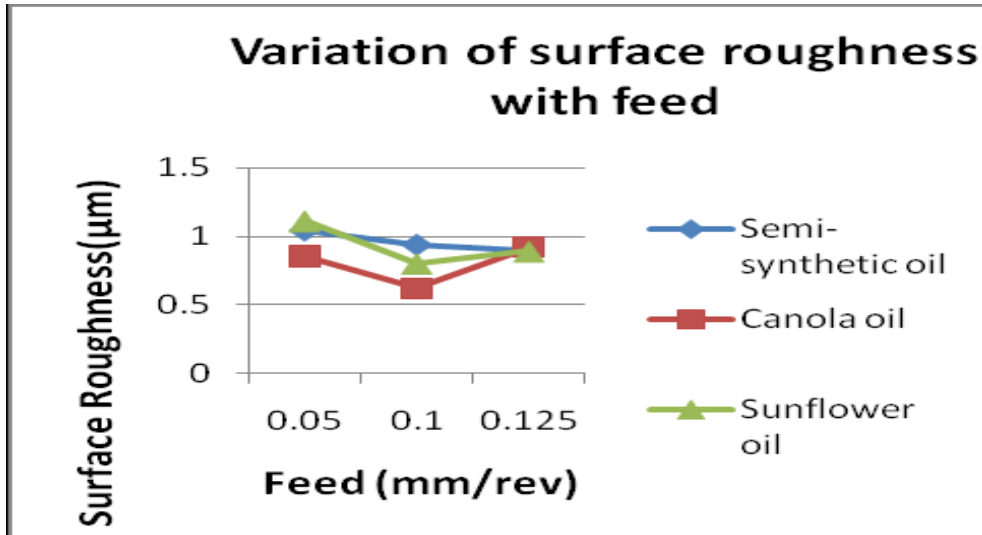


Figure: 2 Effect of feed rate on surface roughness under different metalworking fluid.

From the figure 3 it is quite clear that on increasing depth of cut, firstly surface roughness slightly decreases and then increases rapidly. So minimum value surface finish is obtained at 1 mm depth of cut. In comparison to all three oil, lower surface roughness was obtained by the use of canola oil as a working fluid under different depth of cut.

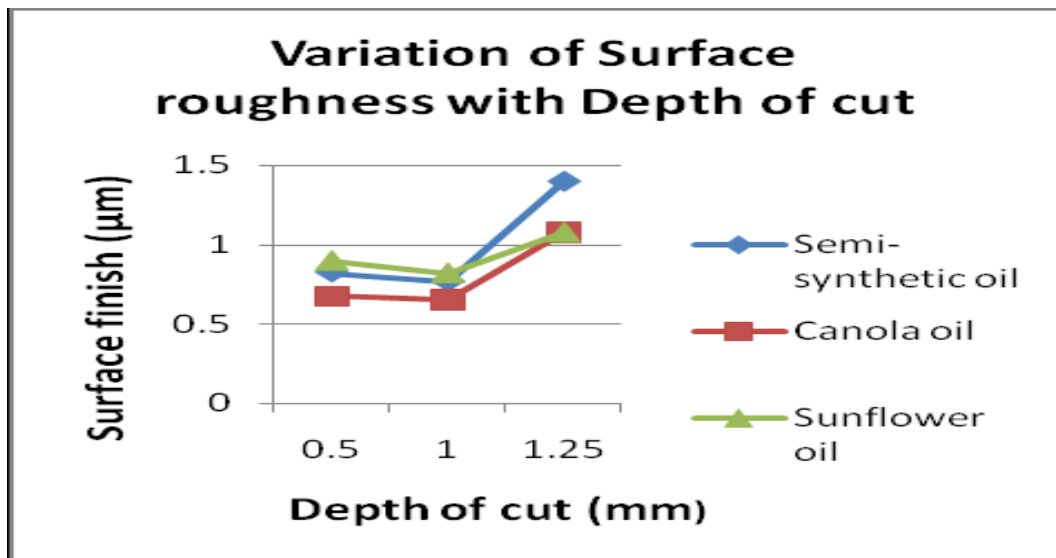


Figure: 3 Effect of depth of cut on surface roughness under different metalworking fluid.

It is quite clear that, among all three cutting fluid, canola oil shows the best results at different Speed, feed rate, depth of cut on Surface Roughness. So the canola oil comes out as a benchmarking metal working fluid among all. The performance of canola oil is further analysed by S/N ratio for surface roughness.

Taguchi analyzed the performance and optimal cutting conditions of canola oil (vegetable oil) by lower the better (signal-to-noise ratio) characteristic for surface roughness. The main effect of the signal-to-noise ratio is shown in figure 4. From the analysis of the signal-to-noise ratio, the optimal turning parameters for surface roughness are 500 rpm (level 1) of the spindle speed and 0.05 mm (level 2) of cutting depth. 2) and the feed rate is 1.25 mm / rev (level 3).

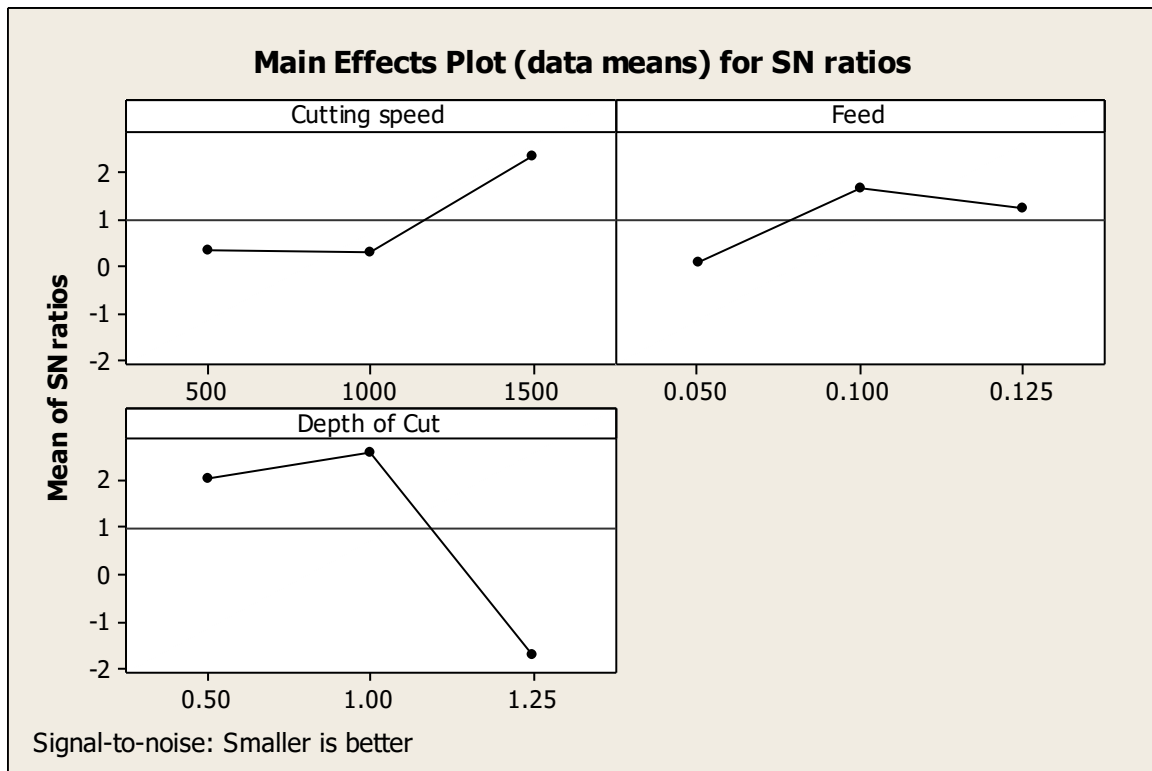


Figure: 4 Main effects plot of S/N ratios for surface roughness.

3.2 Chip Morphology

During Machining, chip formation usually depends on the type of metal to be machined, namely toughness or brittleness, and the temperature of the machining region. This temperature is attributed to the friction that exists between the cutting tool and the workpiece. During machining, chips may break due to overheating of the work piece and tool. Friction and chattering in the work piece can be minimized by using metal working fluid that absorbs a huge amount of heat. So, it can be used as a good coolant by absorbing heat, but because of its low dynamic viscosity and strong adhesion, petroleum base oils cannot be lubricated in a very effective way Therefore friction and temperature are seen in the workpiece and tool

during machining. The different chip at various condition using Semi-synthetic and vegetable oil (Canola and sunflower) oil are shown with their Chip thickness (CT).

The reliability of the lubricant can be determined by measuring the chip thickness ratio, which is defined as the ratio of the cutting depth to the chip thickness. In previous study (Childs, 2000), it was observed that chip thickness is greatly affected by lubrication. In dry conditions, the chips formed are thicker, but the addition of a lubricant will make the chips thin and curl. That is, the addition of a lubricant causes a reduction in friction between the chips and the tool. The increase in chip thickness ratio is usually related to the reduction of cutting force, cutting temperature and power consumption. This can be understood by following relations:

$$\text{Chip thickness ratio (CTR)} = \frac{d}{t}$$

Where, d = Depth of cut (mm), t = Chip thickness

From the above relation we can see that chip thickness ratio is inversely proportional to the chip thickness, i. e. higher the chip thickness lowers the CTR and vice versa.

Table: 7 L9 orthogonal array and Chip Thickness (CT) and Chip Thickness Ratio (CTR) measurements

Sample No.	Cutting speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Sunflower oil (Vegetable oil)		Canola oil (Vegetable oil)		Chemoleum oil (Mineral oil)	
				CT	CTR	CT	CTR	CT	CTR
1	500	0.050	0.50	0.78	0.641	0.63	0.793	0.80	0.625
2	500	0.100	1.00	1.55	0.645	1.40	0.714	1.70	0.588
3	500	0.125	1.25	1.70	0.735	1.64	0.762	1.80	0.694
4	1000	0.050	1.00	1.30	0.769	1.10	0.909	1.22	0.819
5	1000	0.100	1.25	1.90	0.657	1.70	0.735	1.95	0.641
6	1000	0.125	0.50	0.70	0.714	0.85	0.588	1.00	0.500
7	1500	0.050	1.25	1.65	0.757	1.50	0.833	1.60	0.781
8	1500	0.100	0.50	1.20	0.416	0.95	0.526	1.19	0.420
9	1500	0.125	1.00	1.95	0.513	1.80	0.555	2.10	0.476

Nine tests were conducted according to L₉ orthogonal array and CT and CTR were measured for all metal working fluids. Table:7 shows the L₉ orthogonal array and CT and CTR

measurements for both vegetable oils and conventional (mineral) oil. Outcome of turning parameters (cutting speed, feed rate, depth of cut) on CTR are shown in fig 1-3. From the fig 1. It can be understood that the CTR is decreases as the cutting speed increases. In comparison to all three oil, higher CTR was obtained by the use of canola oil as a metal cutting fluid under different cutting speed.

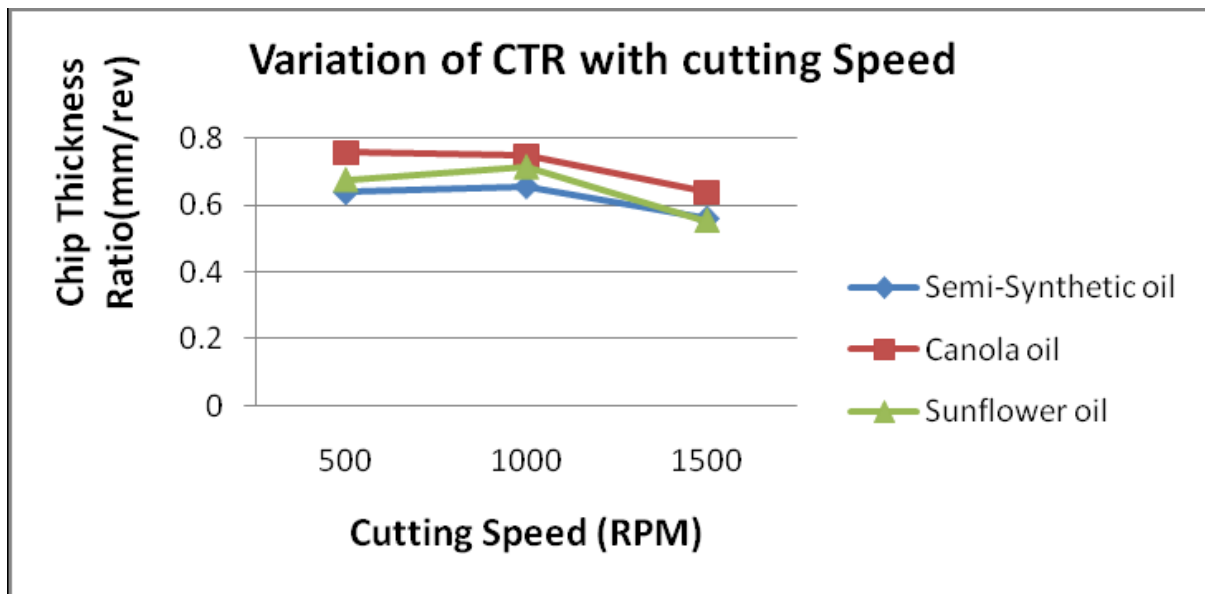


Figure: 5 Effect of cutting speed on CTR under different metalworking fluid

From the figure 5 it can be seen that the CTR is decreases as the feed increases.in case of mineral oil and canola oil whereas increases in case of sunflower oil at 0.125 mm feed. In comparison to all three oil, higher CTR was obtained by the use of canola oil as a metal cutting fluid under various feed.

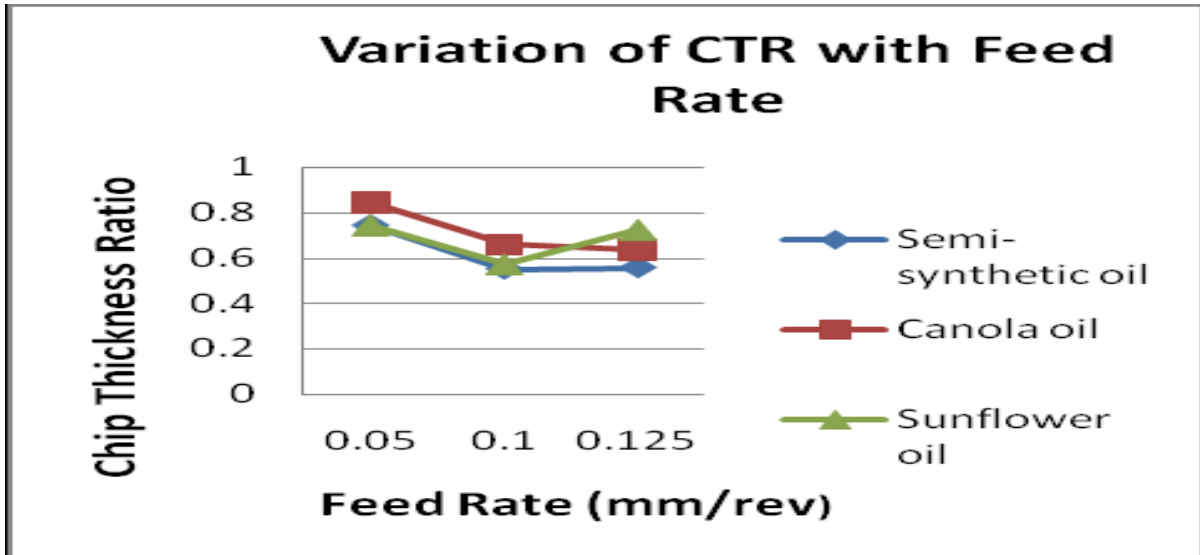


Figure: 6 Effect of feed on CTR under different metalworking fluid

From the figure 6 it is quite clear that on increasing depth of cut, CTR decreases in all case. In comparison to all three oil, Higher CTR was obtained by the use of canola oil as a metal cutting fluid under various depth of cut.

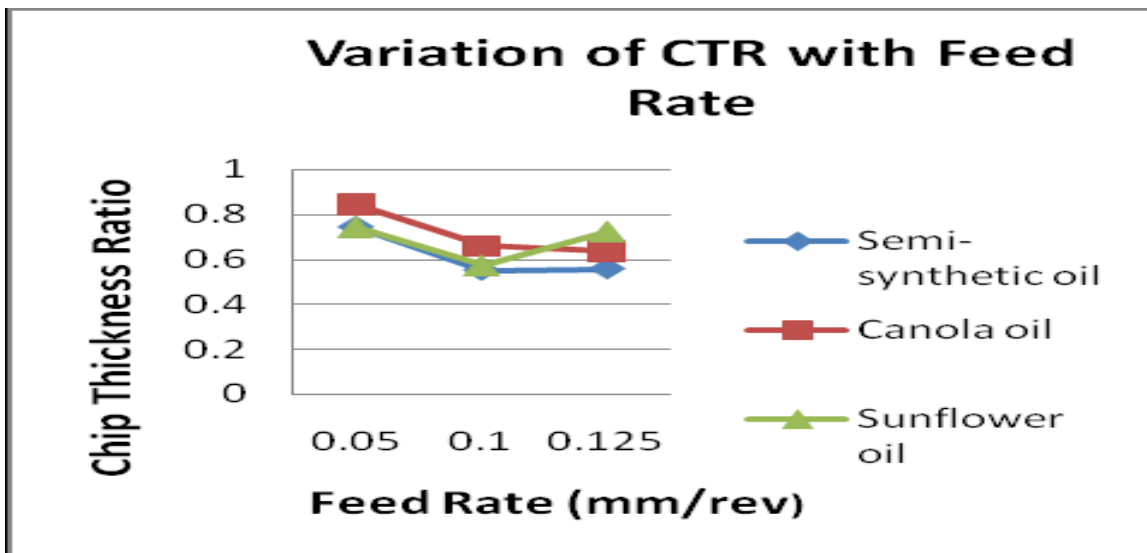


Figure: 7 Effect of depth of cut on CTR under different metalworking fluid

It is quite clear that, among all three cutting fluid, canola oil shows the best results at different Speed, feed rate, depth of cut on CTR. So the canola oil comes out as a benchmarking metal working fluid among all. The performance of canola oil in term of surface roughness is further analysed by S/N ratio analysis.

The performances of various cooling medium (vegetable oil and mineral oil) and best cutting conditions are analysed by Taguchi's, the Larger- the better quality characteristic (S/N ratio) for chip thickness ratio (CTR). The main effect plots for S/N ratios are shown in figure 8. From the analysis of the signal-to-noise ratio, the optimal turning parameters for the chip thickness ratio (CTR) are 1000 rpm (level 2) of the spindle speed and 0.05 mm (level 2) of cutting depth. and the feed rate is 1.25 mm / rev (level 3).

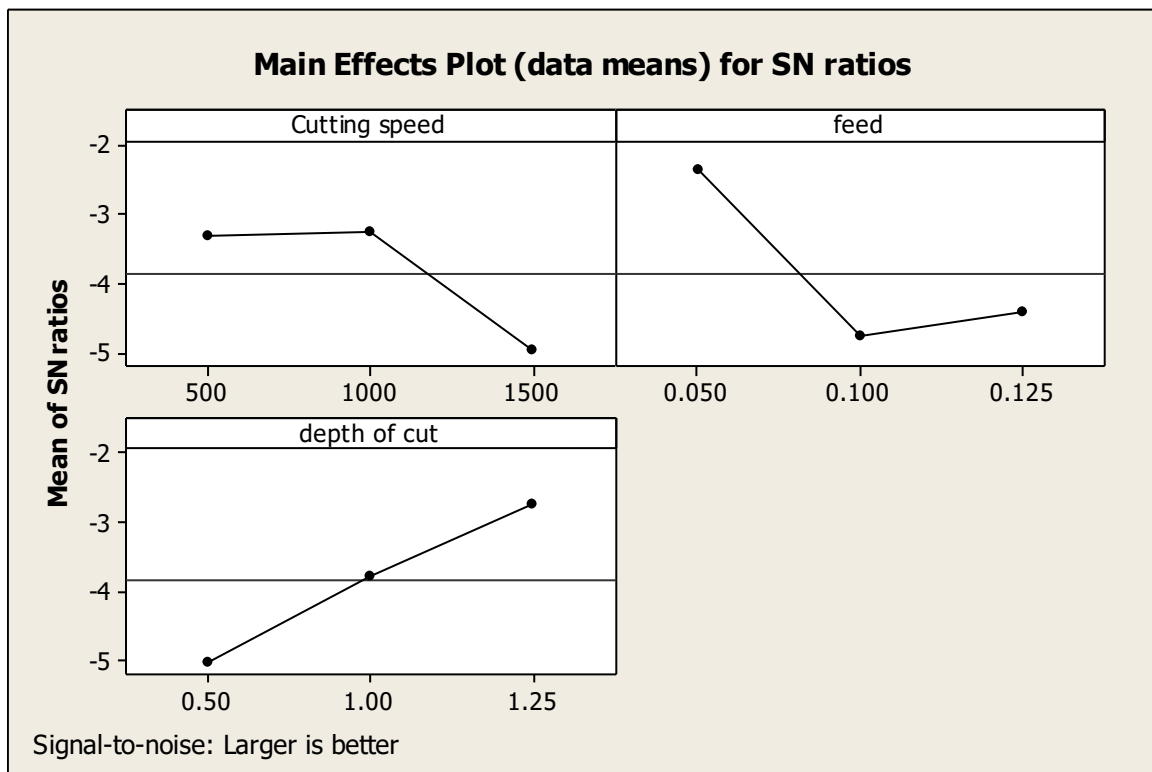


Figure: 8 Main effects plot of S/N ratios for chip thickness ratio (CTR)

4 Conclusion

1. From the experimental result, it is also found that Canola oil lubrication gives high chip thickness ratio which indicate low cutting force, low temperature generated in the cutting zone, hence low cutting power consumption
2. From the experimental results, best surface roughness was obtained under the lubrication of Canola oil (Vegetable oil) and it can be concluded that Canola oil has been found to be best cutting oil in comparison of mineral oil and sunflower oil for the machining of AISI 304 stainless steel.

3. This experimental research clearly shows that mineral based cutting oil might be replaced by vegetable based cutting oil since vegetable based oil reduce occupational health risks, lower costs towards waste treatment due to their inherently higher biodegradability and better performance rate.

References

- Bartz, W. J. (2006) 'Ecotribology: Environmentally acceptable tribological practices', 39, pp. 728–733. doi: 10.1016/j.triboint.2005.07.002.
- Belluco, W. and De Chiffre, L. (2002) 'Surface integrity and part accuracy in reaming and tapping stainless steel with new vegetable based cutting oils', *Tribology International*, 35(12), pp. 865–870. doi: 10.1016/S0301-679X(02)00093-2.
- De Chiffre, L. and Belluco, W. (2000) 'Comparison of methods for cutting fluid performance testing', *CIRP Annals - Manufacturing Technology*, 49(1), pp. 57–60. doi: 10.1016/S0007-8506(07)62895-9.
- Herdan, J. (1999) 'Rolling fluids based on vegetable oils', *J. Synth. Lubr.* Elsevier B.V. doi: 10.1016/j.wear.2014.12.044.
- John, J., Bhattacharya, M. and Raynor, P. C. (2004) 'Emulsions containing vegetable oils for cutting fluid application', *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 237(1–3), pp. 141–150. doi: 10.1016/j.colsurfa.2003.12.029.
- Kline & Company, I. (2006) *Competitive intelligence for the global lubricants industry, 2004–2014*.
- Mijanovic, K. and Sokovic, M. (2001) 'Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes', 109, pp. 181–189.
- Taylor, F. (1907) 'On the art of metal cutting', *Trans. ASME*.