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Comparative Analysis of Eco-Friendly Vegetable, Petroleum and Synthetic Oil Based Cutting Fluids

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Abstract - **Cylindrical grinding is one of the important metal cutting processes used extensively in the finishing operations. Metal removal rate and surface finish are the important output responses in the production with respect to quantity and quality respectively. The Experiments have been designed by using Taguchi and conducted on Center Lathe Machine model GH-1440K of Everest make with grinding attachment with L9 Orthogonal array with input machining variables as type of fluid, work piece speed, feed rate and depth of cut. Empirical models are developed using design of experiments and response surface methodology. The adequacy of the developed model has been tested with ANOVA and Regression Analysis. The results reveal that type of fluid, feed rate, depth of cut and work piece speed influence predominantly on the output responses metal removal rate (MRR) and surface roughness (Ra).The predicted optimal values for MRR is 2.10 mm3/minwith optimum input conditions of 650 rpm as work piece speed, 0.653 mm/rev. as feed rate and 0.100 mm as depth of cut and for Ra is 3.16 µm with optimum input conditions of Palm oil based vegetable oil as cutting fluid, 60 rpm as work piece speed, 0.513 mm/rev. as feed rate and 0.150 mm as depth of cut.**
investigated.

Keywords- Cylindrical grinding, Metal removal rate (MRR), Surface roughness (Ra), Taguchi method and regression analysis.

1. INTRODUCTION

During a machining process, a substantial part of the energy is converted into heat energy through the friction generated between the tool and the work piece and the plastic deformation of the work material in the machining zone. The rapidly accumulated heat causes the temperature of the tool and the work interface zone to rise at a fast rate, directly affecting the surface finish of the product. The resulting high temperature induces metallurgical transformation such as softening of the work piece. The transformation leads to structural breakdown of the work piece and the tool material. This may adversely affect the quality of the machined products in terms of dimensional accuracy and surface finish. The heat generated during machining process is therefore critical in terms of product quality. It is therefore imperative that effective control of heat generated in the cutting zone during metal removal is crucial to ensuring good work piece surface quality (Schmid, et al. 2001). Besides controlling the heat generated during machining process, type of cutting fluid, cutting speed, feed rate, and depth of cut and tool geometry are other process parameters that influence the process to a great extent.

The selected vegetable oil (Palm oil) is an important and versatile vegetable oil which is used as a raw material for both food and non-food industries particularly soap and detergent industries. It is obtained from the fruit (both the flesh and the kernel) of the oil palm tree. Oil palms are highly efficient oil producers, with each fruit containing about 50% oil. It is also the cheapest vegetable oil in all the vegetable oils. Palm trees require ten times less land than other oil-producing crops. Palm oil and palm kernel oil are entirely genetically modified (GM) free. Vegetable oil production around the world totals over 144 million tons per year, of which over 47 million tons is palm oil. Along with soy oil, palm oil makes it 60% of the total oil production of the world.

Petroleum-based lubricants get most of their lubricity from additives, such as chlorine and sulfur. Bio-based lubricants such as palm oil which is abundantly produced worldwide have superior lubricity without the need for these chemical additives, which reduces friction. Due to less friction created, cutting forces are reduced and less heat is produced in the metal cutting process, allowing tools to be fed faster. Less friction also reduces wear on cutting tools and grinding wheels, usually extending tool life. Bio-based oils have a much higher flash point than petroleum. Flash points go down as viscosity of oils is reduced. Comparing oils at a viscosity of 40 cst, bio-based oil has a flash point of 310 degrees C (590 degrees F) and petroleum has a flash point of about 148 degrees C (300 degrees F). This increased flash point reduces smoke while cutting metal cutting and allowing higher feed rates. Complimentary bio-based oils and hydraulic oils can be introduced to maintain a pure bio-based system with the highest possible flash point to reduce smoke.

Another characteristic of bio-based lubricants is their polar attraction to metal. Petroleum based fluids have no polarity and therefore no affinity to metal. Therefore tools and work pieces, leaving surfaces without protective lubrication. The

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polarity of bio-based lubricants provides metal affinity and more effective thin film protection at the cutting tool/work piece interface.

In addition to the environmental challenges of managing a used cutting fluid waste stream, cutting fluids also introduce several health/safety concerns. The National Institute for Occupational Safety and Health (NIOSH) estimates that 1.2 million workers involved in machining, forming, and other metalworking operations are exposed to metal working fluids annually (NIOSH, 1998). Dermal exposure to these fluids represents a health concern, as does the inhalation of airborne fluid particulate. The application of cutting fluids within a machining operation often produces an airborne mist, and medical evidence has linked worker exposure to cutting fluid mist with respiratory ailments and several types of cancer (Mackerer, 1989; Thorneet al., 1996). This makes the use of cutting fluids a health issue with the potential of both long and short-term consequences.

2. EXPERIMENTATION AND OBSERVATION

Taguchi method

Taguchi methods systematically reveal the complex cause and effect relationship between design parameter and performance. These lead to building quality performance into process and product before actual production begins .Taguchi method have rapidly attained prominence because wherever they have been applied, they lead to the major reductions into process and products before actual production begins.

Signal-to-noise (S/N) ratio

In the Taguchi experiment design, a loss function is used to calculate the deviation between the experimental value and the desired value. The loss function is further transformed into utility function. The utility function developed by Taguchi is called the Signal-to-Noise (S/N) ratio to determine the statistical performance characteristic deviating from the desired value.There are several type of S/N ratios available based on the characteristic namely lower is better (LB), nominal is the best (NB), higher is better (HB).The optimal level of the process parameters is the level with highest S/N ratio. A statistical analysis of variance (ANOVA) and regression analysis has been performed to determine the significant process parameters.

Lower is better $S/N = -10 \log [1/n (\Sigma y_i^2)]$
Higher is better $S/N = -10 \log [1/n (\Sigma 1/y_i^2)]$
Nominal is better $S/N = 10 \log [\bar{y}/S_y^2]$

Where n is the number of observations, y is the observed data, S_y^2 is the variance of y.

The objective of S/N analysis is to determine the most optimum set of the operating conditions, from variations of the influencing factors within the results. The signals are those factors which are invariant and Noise is those influencing factors that are active.

Regression analysis

Regression analysis is used to determine the relationships of the variables which influences the output responses

The multiple regression analysis equations are in the following form

$$Y = a_1 + b_1x_1 + b_2x_2 + b_3x_3 + \text{----------} + b_kx_k$$

Where Y is independent variable and x_1, x_2, x_3----x_k are the known variables from which independent variable will be determined .a_1, b_1, b_2, b_3----b_k are regression coefficients which can be determined by the method of least squares. The regression analysis was done by MINITAB15 statistical software.

Table 1 Machining parameters and their levels

Level	Cutting fluid	Cutting speed (rpm)	Feed rate (mm/rev.)	Depth of cut (mm)
1	Palm oil	60	0.373	0.050
2	Petroleum oil	230	0.513	0.10
3	Synthetic oil	650	0.653	0.150

3. EXPERIMENTAL RESULTS

Table 3 Experimental values of material removal rate (MRR)

Sample No.	Weight before grinding (kg.)	Weight after grinding (kg.)	Grinding time (sec.)	MRR mm3/min.
1	0.416	0.413	102.69	0.224
2	0.427	0.424	19.97	1.15
3	0.448	0.446	07.98	1.92
4	0.413	0.409	49.52	0.62
5	0.424	0.421	26.78	1.15
6	0.446	0.445	26.78	1.24
7	0.409	0.405	74.91	0.41
8	0.421	0.417	18.88	1.63
9	0.445	0.441	10.05	3.06

Note: Conversion formulae used for converting MRR (gm/sec) into MRR (mm3/min.)

$$MRR = (W_1 - W_2)/t \text{ gm/sec}$$

$$= \frac{(W_1 - W_2)/t}{\text{Density of EN 31(kg/m3)}} * 1000 * 60 \text{ mm3/min.}$$

Density of EN 31 = 7810 kg/m3

Table 4 Experimental values of surface roughness (Ra)

Type of fluid	Work piece speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev.)	Ra1	Ra2	Ra3	Ra avg.(µm)
Palm oil	60	0.05	0.373	302	3.16	3.1	3.09
Palm oil	230	0.1	0.513	346	3.56	3.88	3.63
Palm oil	650	0.15	0.653	1.3	3.35	3.34	3.33
Petroleum oil	60	0.1	0.653	438	3.97	3.96	4.1
Petroleum oil	230	0.15	0.373	327	4.65	3.09	3.67
Petroleum oil	650	0.05	0.513	404	3.78	3.66	3.82
Synthetic oil	60	0.15	0.513	351	3.31	3.61	3.47
Synthetic oil	230	0.05	0.653	358	4.63	4.16	4.12
Synthetic oil	650	0.1	0.373	14.27	12.09	12.33	12.89

Ra (Surface roughness total mean value) = 4.68 µm
S/N (Surface roughness *S/N* ratio total mean value) = –12.44 dB

Table 7 Regression Analysis: Ra versus Work piece sp, Depth of cut, feed rate mm

Predictor	Coef.	SE Coef.	T	P
Constant	8.061	5.562	1.45	0.207
Work piece speed (rpm)	0.005592	0.004184	1.34	0.239
Depth of cut (mm)	-1.87	25.41	-0.07	0.944
Feed rate (mm/rev.)	-9.643	9.076	-1.06	0.337

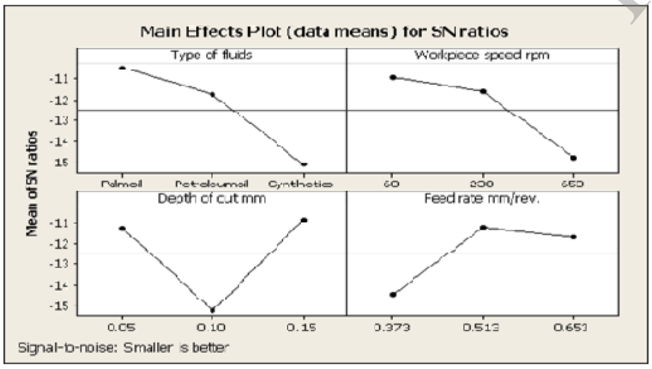

Fig. 1 Main Effects Plot (data means) for S/N ratios for surface roughness

Optimal value of surface roughness

The optimum value of surface roughness (Ra) is calculated using regression equation and optimal parameters are taken from main effects plot. The optimum position is achieved with the following parameters.
Type of fluid: Palm oil
Work piece speed (rpm): 60
Feed rate (mm/rev.): 0.513
Depth of cut (mm): 0.15
Optimal value of Ra (µm) = 8.06+0.00559Work piece speed rpm-1.9 Depth of cut mm - 9.64
Feed rate mm/rev. = 3.17

Table 8 Response Table for Signal to Noise Ratios for MRR (Larger is better)

Level	Type of Fluids	Work piece Speed (rpm)	Depth of cut mm	Feed rate Mm/rev.
1 (Palm oil)	-2.0384	2.2239	-2.2943	-0.6889
2 (Petroleum oil)	-0.3566	-8.2972	2.2587	-1.5540
3 (Synthetic oil)	2.0713	5.7496	-02881	1.9192
Delta	4.1096	14.0468	4.5530	3.4732
Rank	3	1	2	4

Table 9 Response Table for Means

Level	Type of fluid	Work piece speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)
Palm oil	1.098	1.31	1.0313	1.478
Petroleum oil	1.0033	0.418	1.61	0.9333
Synthetic oil	1.7	2.0733	1.16	1.39
Delta	0.6967	1.6553	0.5787	0.5447
Rank	2	1	3	4

Table 10 Regression Analysis: MRR versus Work piece speed (rpm), Depth of cut (mm), feed rate (per rev.) mm

Predictor	Coef.	SE Coef.	T	P
Constant	0.479	1.189	0.40	0.703
Work piece speed (rpm)	0.0026182	0.0008941	2.93	0.033
Depth of cut (mm)	1.287	5.431	0.24	0.822
Feed rate (mm/rev.)	-0.314	1.940	-0.16	0.878

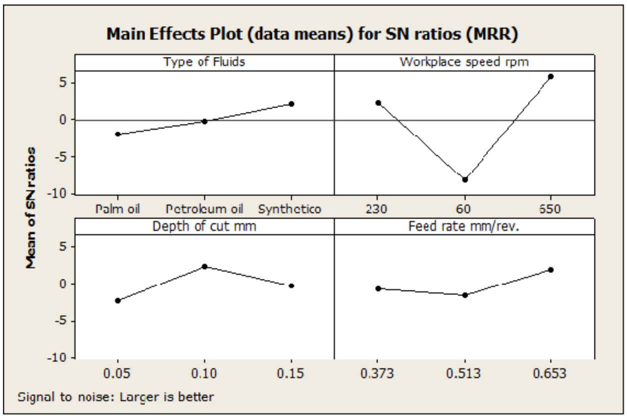

Figure 2 Main Effects Plot (data means) for SN ratio for MRR

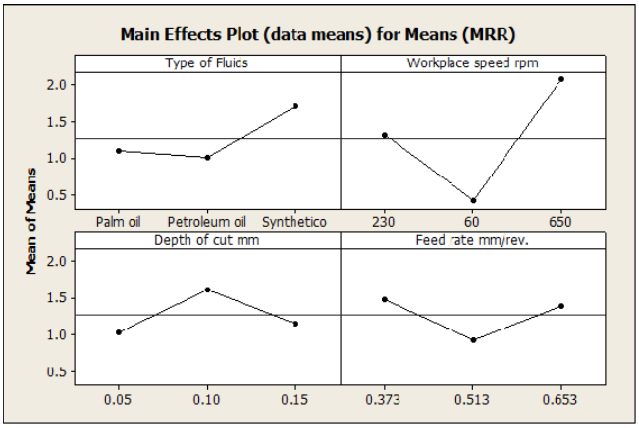

Figure 3 Main Effects Plot (data means) for data means for MRR

OPTIMAL VALUE OF MRR (MM3/MIN.):

The optimum value of MRR is calculated using regression equation and optimal parameters are taken from main effects plot for S/N ratio. The optimum position is achieved with the following parameters.

Work piece speed (rpm): 650

Feed rate (mm/rev.): 0.653

Depth of cut (mm): 0.100

Optimal value of MRR (mm3/min.) = 0.48 + 0.00262 work piece speed (rpm) + 1.29 depth of cut (mm) - 0.31 feed rate (mm/rev.)

= 2.10967.

CONCLUSION

The results from this research lead to the following conclusions:

- The optimal machining condition for surface roughness as is evident from figure 1 is 60 rpm cutting speed (level 1), 0.513 mm/rev feed rate (level 2), 0.150 mm depth of cut (level 3) and Palm oil cutting fluid (level 1).
- The results prove our hypothesis that type of fluid and depth of cut influence surface roughness predominantly as shown at Table (Analysis of Surface roughness using ANOVA) and it is concluded that palm oil produces lower surface roughness as compared to petroleum and synthetic oil based cutting fluids.
- The high viscosity and flash point of palm oil gives the cutting fluid an oiliness aspect and lubricant properties. The water presence increases the cooling capacity. This way the palm oil based cutting fluid makes possible the presence of the two main cutting fluids characteristics: good lubricant and good coolant, in only one product.
- In The optimal machining condition of material removal rate as is evident from figure 2 is 650 rpm cutting speed (level 3), 0.100 mm depth of cut (level2) and 0.653 mm/rev. feed rate (level 3).

The results indicate that type of cutting fluid does not influence material removal rate. Only work piece speed influences MRR predominantly and is a significant factor while other machining parameters are non-significant.

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