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Optimization of Surface Roughness Parameters for EN 8 Steel by Tungsten Carbide Tool in Turning Operation

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***Abstract* - Better quality of the product can afford finest customer satisfaction. The purpose of this research paper is focused mainly to improve the quality of the product by considering different factors such as cutting parameters, tool wear and surface roughness. The objective was to reduce the lead time, increasing productivity and improve the surface roughness of the product. This present paper presents an experimental study by two types of cutting fluids such as vegetable oil and mineral oil, workpiece material EN8 steel and tool material Tungsten carbide. Taguchi design is used for machining parameters and optimizing the surface roughness value using desirability functions.**

Key words; surface roughness; EN 8 steel; cutting fluids; desirability functions.

I. INTRODUCTION

Machining is the process in which a tool removes material from the surface of a less resistant body, through relative movement and application of force. The mechanical energy was used to form the chip becomes heat, which generates high temperatures in the cutting region **[1]**. Machining at high cutting speed and feed, raises the temperature of the cutting tool tips and the work surface near the cutting zone which results in high tool wear rate, reduced tool life due to the changes in contact conditions and the tool wear is by thermal softening, abrasion and a built-up edge (BUE) formation, which affects the quality of the generated surface and dimensional accuracy **[2], [3]**. EN 8 is a very popular grade of medium carbon steel and it possesses good machining properties, so it is readily mechinable in any condition. Tungsten carbide tool (WC) is suitable for machining of hardened steel in wet condition. Cutting fluids are used to obtain good surface finish, tool life and dimensional accuracy. The high quality of Surface finish and dimensional accuracy fulfill customer demand.

Now-a-days rising the productivity and quality of the machined parts are the main challenges of metal cutting industry during turning processes **[4].** AISI 304 steel were applied in air craft fittings, aerospace components such as bushings, shafts, valves, special screws, cryogenic vessels and components for severe chemical environments. The majority of the components need certain machining in different machines. The machining of AISI 304 operators encounter certain difficulties such as premature tool failure and poor surface finish, so they use coconut oil as a cutting fluid to extend the tool life with a better surface finish **[5].** Cutting fluids employs higher cutting speeds which results in longer tool life and higher material removal rates **[6]**. Various types of cutting fluids are widely used in metal cutting processes i.e., straight oils, soluble oils, synthetic and semi synthetic. Bio-based cutting fluids may reduce the occupational health risks **[7].** The product quality and machining economics were increased by Optimizing machining parameters **[8].** Surface roughness pays a serious attention for several years. It imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning **[9].** Surface roughness can be reduced by employing Taguchi method in the analysis of optimum cutting conditions in CNC turning of different grades of EN materials **[10]**. In this study, five different carbon steel used for turning are SAE 8620, EN8, EN19, EN24 and EN47. As a result, it was concluded that the surface roughness increased with increased feed rate and it higher at lower speeds and vice versa.

II. MATERIALS AND METHODS

A. Cutting fluids

1)Mineral Oil: Cutting fluids are used in metal machining for a variety of reasons such as improving tool life, reducing work piece thermal deformation, improving surface finish and flushing away chips from the cutting zone. Practically all cutting fluids presently in use fall into one of four categories:

(i) Straight oils
(ii) Soluble oils
(iii) Semi synthetic fluids
(iv) Synthetic fluids

Straight oils are non-emulsifiable and are used in machining operations in an undiluted form. They are composed of a base mineral or petroleum oil and often contain polar lubricants such as fats, vegetable oils and esters as well as extreme pressure additives such as Chlorine, Sulphur and Phosphorus. Straight oils provide the best lubrication and the poorest cooling characteristics among cutting fluids.

Synthetic Fluids contain no petroleum or mineral oil base and instead are formulated from alkaline inorganic and organic compounds along with additives for corrosion inhibition. They are generally used in a diluted form (usual concentration = 3 to 10%). Synthetic fluids often provide the best cooling performance among all cutting fluids.

Soluble Oil Fluids form an emulsion when mixed with water. The concentrate consists of a base mineral oil and emulsifiers to help produce a stable emulsion. They are used in a diluted form (usual concentration = 3 to 10%) and provide good lubrication and heat transfer performance. They are widely used in industry and are the least expensive among all cutting fluids.

Semi-synthetic fluids are essentially combination of synthetic and soluble oil fluids and have characteristics common to both types. The cost and heat transfer performance of semi-synthetic fluids lie between those of synthetic and soluble oil fluids**.**

2) Coconut Oil: Coconut oil is a kind of vegetable oil which is used in small and tiny industries. This oil can increase the tool life; improve the surface finish during machining at low and medium cutting speed**.** Coconut oil is an edible oil extracted from the kernel or meat of matured coconuts harvested from the coconut palm (*Coco nucifera*). Throughout the tropical world, it has provided the primary source of fat in the diets of millions of people for generations. It has various applications in food, medicine, and industry. Because of its stability, it is slow to oxidize and, thus, resistant to rancidity, lasting up to two years owing to the high saturated fat content.

B.Process variables and their limits

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units are listed in Table 1.1

Table 1.1: Machining parameters

Sl.no.	Cutting speed (m/min)	Depth of cut (mm)	Feed rate (mm/rev)
1	750	0.5	0.10
2	1500	1.0	0.15
3	2250	1.5	0.20

C. Experimental plan

Orthogonal Arrays (often referred to Taguchi Methods) are often employed in industrial experiments to study the effect of several control factors popularized by G. Taguchi. Other Taguchi contributions include model of the engineering design process, robust design principle, efforts to push quality upstream into the engineering design process. An orthogonal array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. To define an orthogonal array, one must identify number of factors to be studied, levels for each factor, the specific 2-factor interactions to be estimated, the special difficulties that would be encountered in running the experiment. Orthogonal arrays are most often named following the pattern L_9 ($Levels^{Factors}$). In this study experiment L_9 (3^3) is Chosen. The following table 1.2 shows the machining parameters with L_9 orthogonal array.

Table 1.2: Machining parameters with L_9 Orthogonal array

No. of runs	Depth of cut (mm)	Feed rate (mm/rev)	Cutting speed (m/min)
1	0.5	0.10	750
2	0.5	0.15	1500
3	0.5	0.20	2250
4	1.0	0.10	1500
5	1.0	0.15	2250
6	1.0	0.20	750
7	1.5	0.10	2250
8	1.5	0.15	750
9	1.5	0.20	1500

D.Desirability Functions

The output parameters are measured for all the 9 trials. Based on this output the best trial is selected, the best trial can be selected based on the influence of the output parameter over the expected results. One of the best techniques to optimize the quality characteristics is the desirability function. Desirability function is defined as the functions which transform a set of properties into a single objective are called "desirability" functions.

Engineers design products of processes by selecting design parameters X1, x2,....,xp that will result in a desirable combination of properties or quality criteria, Y1, Y2,...Ym. For example, in arc welding the engineer must set the travel speed and torch angle of a welding robot in order to achieve desired values of convexity, undercut, and cycle-time for producing a certain type of part. The purpose of response surface methods (RSM) is to aid in the development of models of the process properties for use in optimization over the process inputs. With these models, the challenge then becomes formulating specific objectives using obtainable information so that, when these objectives are optimized, the outcome will be truly "desirable". Functions that transform a set of properties into a single objective are called "desirability" functions and are written D (Y1, Y2,..., Ym). References on desirability functions include Castillo, Montgomery, and Mc Carville (1996), Derringer and Suich (1980), derringer (1994), Harrington (1965), and Kim and Lin (2001). Without loss of generality, it is convectional to restrict the range of the desirability functions to the [0, 1] closed interval.

To define a global knit quality index, "dG", we grouped the different individual indexes into one global satisfaction degree by using the derringer and suich desirability function (phan-tan-Luu, 1993), and by according relative weight, "wi", to each individual index, calculated in accordance with equation (4) as follows:

$$d_G = \sqrt[w]{\left(d_1^{w_1} * d_2^{w_2} \ldots\ldots\ldots * d_i^{w_i}\right)} \qquad (4)$$

Where di is the individual index of the property Yi, wi is the weight of the property "Yi" in the global knit quality definition, w is the sum of the individual weights.

E.Experimental Procedure

1. First fix the workpiece (EN 8 steel) in three jaw chuck of CNC machine and tool in the tool holder.
2. Now run the machine for roughing operation in EN 8 steel for uniformity.
3. Fix the Tungsten carbide insert in the tool holder to carry out the machining operation.
4. According to Table 1.2 machining parameters are programmed in the CNC machine.
5. With reference to these machining parameters turning operations has been carried out in the CNC machine.
6. During machining process there are two types of cutting fluids are used separately for each process.
7. Mineral oil and Coconut oil are used as coolants for machining of EN 8 steel.
8. During machining of EN8 steel cutting force has been noted from digital display of CNC machine for the respective machining parameters.
9. After finishing the turning operation in CNC machine measure the surface roughness value in surface roughness tester equipment.
10. Using surface roughness tester equipment finding out the least surface roughness value of EN 8 steel.
11. To find the Optimum value of surface roughness for EN 8 steel desirability function (Optimization technique) are used.
12. By using this desirability function we are able to find out the optimum surface roughness value and also which cutting fluids (Mineral oil & Coconut oil) are giving better surface finish.

F.Experimental Setup

According to the experimental procedure mentioned in section E and machining parameters table 1.2 machining process has been carried out for EN 8 steel in CNC machine by using different types of cutting fluids such as mineral oil and coconut oil "**Fig 1.1".**

Fig 1.1. Machining of EN 8 steel in CNC machine

Before and after machining of EN 8 (workpiece) is shown in the above "Fig. 1.2 and fig 1.3

Fig 1.2 Before machining of EN 8

Fig 1.3 After machining of EN8

Fig 1.4 Measuring of surface roughness for EN 8 steel in surface roughness tester

Surface roughness value can be measured in surface roughness tester for the machining parameters mentioned in **table 1.2** . This is shown in the above **Fig 1.4**

III. RESULT AND DISCUSSIONS

Table 1.3 Surface roughness value for mineral oil

SLOTS	TEST I	TEST II	TEST III
1	1.57	1.49	1.99
2	3.77	3.49	3.58
3	1.23	1.38	1.35
4	3.50	3.09	3.39
5	1.25	1.42	1.44
6	3.48	3.63	3.37
7	1.55	1.69	1.11
8	2.44	2.12	2.64
9	1.69	1.49	1.40

The total length of EN 8 steel (workpiece) is 300 mm. The turning process has been carried out in every 30 mm by using mineral oil as cutting fluid. The surface roughness value can be measured at three different places (Test I, Test II and Test III) in slot 1. The length of slot 1 is 30mm. In similar way up to slot 9 surface roughness value can be measured in surface roughness tester equipment. The table 1.3 shows the surface roughness value for mineral oil.

Table 1.4 Surface roughness value for coconut oil

SLOTS	TEST I	TEST II	TEST III
1	2.44	2.66	2.29
2	2.85	3.10	2.88
3	2.19	2.43	2.39
4	3.06	3.03	3.76
5	0.92	0.98	0.89
6	3.28	3.08	3.92
7	1.90	1.86	1.94
8	2.44	2.99	2.57
9	1.66	1.10	1.64

The total length of EN 8 steel (workpiece) is 300 mm. The turning process has been carried out in every 30 mm by using coconut oil as cutting fluid. The surface roughness value can be measured at three different places (Test I, Test II and Test III) in slot 1. The length of slot 1 is 30mm. In similar way up to slot 9 surface roughness value can be measured in surface roughness tester equipment. The **table 1.4** shows the surface roughness value for coconut oil.

Table 1.5: Cutting force and Surface roughness value of Mineral oil

SLOTS	Cutting force in N	Roughness value in µm
1	260	1.67
2	240	3.61
3	210	1.32
4	350	3.32
5	200	1.37
6	280	3.49
7	410	1.45
8	370	2.40
9	210	1.52

According to the machining parameters machining process has been carried out. During machining of EN 8 steel how much amount of cutting force are used by the CNC machine are shown in the display. The surface roughness value are measured in surface roughness tester. The surface roughness values are in microns. These values are shown in the above **table 1.5**.

After finding out the surface roghness value we have to find the optimum surface roughness value for EN8 steel. To find the optimum value desirability functions are used. Using desirability function one of the parameter Global Knit Quality index has been calculated from the respective formulae and tabularized in the **table 1.6** . The **table** values is for machining of EN 8 steel by using mineral oil as cutting fluids.

Table 1.6 : Desirability function for Mineral oil

Trial no	SLOT	Cutting force index (d_i)	Roughness index (d_i)	Global knit quality index(d_G)
1	1	0.761	0.385	0.541
2	2	0.857	0.192	0.405
3	3	0.904	0.437	0.628
4	4	0.333	0.056	0.136
5	5	1	1	1
6	6	0.619	0	0
7	7	0	0.610	0
8	8	0.238	0.305	0.269
9	9	0.904	0.787	0.843

According to the machining parameters machining process has been carried out. During machining of EN 8 steel how much amount of cutting force are used by the CNC machine are shown in the display. The surface roughness value are measured in surface roughness tester.

The surface roughness values are in microns. These values are shown in the above table 1.7

Table 1.7: Cutting force and Surface roughness value of Coconut oil

Trial no	Cutting force in N	Roughness value in µm
1	230	2.46
2	210	2.94
3	200	2.33
4	320	3.28
5	180	0.93
6	260	3.42
7	390	1.90
8	340	2.66
9	200	1.46

After finding out the surface roghness value we have to find the optimum surface roughness value for EN8 steel. To find the optimum value desirability functions are used. Using desirability function one of the parameter Global Knit Quality index has been calculated from the respective formulae and tabularized in the table 1.8 . The table 1.8 values is for machining of EN 8 steel by using Coconut oil as cutting fluids.

The following are the calculation for finding the optimum value of EN 8 steel using Global Knit Quality index for mineral oil and coconut oil.

Table 1.8: Desirability function for Coconut oil

Trial no	SLOT	Cutting force index (d_i)	Roughness index (d_i)	Global knit quality index(d_G)
1	1	0.714	0.847	0.777
2	2	0.809	0	0
3	3	0.952	1	0.975
4	4	0.285	0.126	0.189
5	5	1	0.978	0.988
6	6	0.619	0.052	0.179
7	7	0	0.943	0
8	8	0.190	0.528	0.316
9	9	0.952	0.912	0.931

(i) EN 8 STEEL BY MINERAL OIL

Cutting force = maximum value –minimum value
=410-200
=210 N
= maximum value-first value/210
= (410-260)/210
=0.714

Surface roughness =maximum value – minimum value
=3.61-1.32
=2.29 µm
=maximum value-first value/2.29
= (3.61-1.67)/2.29
=0.847

$$dG = \sqrt{(\text{cutting force} \ * \ \text{surface roughness})}$$

$$dG = \sqrt{(0.714 * 0.847)}$$

= 0.777

(ii) EN 8 STEEL BY COCONUT OIL

Cutting force = maximum value-minimum value
=390-180
=210 N
= maximum value-first value/210
= (390-230)/210
=0.761

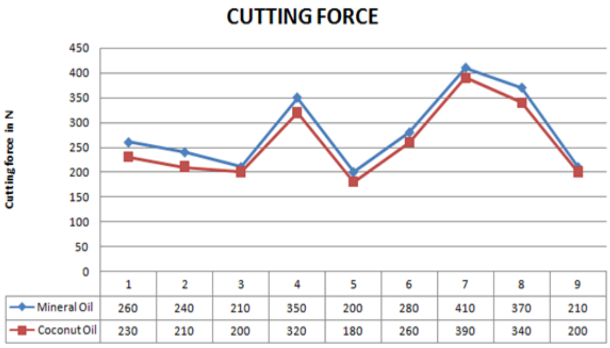
Surface roughness =maximum value-minimum value
= 3.42-0.93
=2.49 µm
=maximum value –first value/2.49
= (3.42-2.46)/2.49
=0.385

$$dG = \sqrt{(\text{cutting force} \ * \ \text{surface roughness})}$$

$$dG = \sqrt{(0.761 * 0.385)}$$

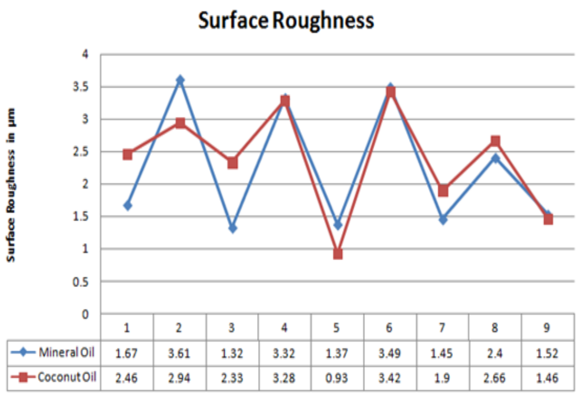
= 0.541

IX. GRAPHS



Graph 1.1 cutting force

The graph 1.1 shows the cutting force difference between mineral oil and coconut oil.



Graph 1.2 surface roughness

The graph 1.2 shows surface roughness difference between mineral and coconut oil

IV.CONCLUSION

1. From the above experimentation Optimum value can be found out by using desirability function.
2. The optimum value of mineral oil is 0.988 in 5th slot in the 5th trial.
3. The optimum value of coconut oil is 1 in 5th slot in the 5th trial.
4. By comparing the value of coconut oil and mineral oil we conclude the coconut oil is given better surface roughness than mineral oil.

5. It is suitable for conventional machines.
6. It is not suitable for continuous operation, because in conventional machine heavy smoke can be produced while the coconut oil is used as cutting fluids

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