Optimization of Material Removal Rate and Surface Roughness in Dry and Wet Machining of En19 Steel Using Taguchi Method

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Abstract
The objective is to optimize the material removal rate and surface roughness while machining EN19 steel using ANOVA. The influence and contribution of cutting parameters such as cutting speed, feed rate and depth of cut are estimated through dry and wet machining using ANOVA. The Minitab software is used to form the design of experiments with L9 orthogonal array. The values of the material removal rate (MRR) and the surface roughness (SR) are calculated, through sum of squares the percentage contribution are calculated and by main effects plots influencing levels of cutting parameters are justified. The results of this study indicates that the depth of cut and cutting speed has the most significant effect on MRR and SR for dry machining and the depth of cut for wet machining.

Keywords
Anova, Material Removal Rate (MRR), Surface Roughness (SR).

I. Introduction

Now-a-days modern machining industries mainly emphasized on the achievement of high dimensional accuracy, good surface finish, high production rates, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact [1]. Turning process is one of the most fundamental and important machining process in which the unwanted material is removed from the surface of a rotating cylindrical workpiece by a single point cutting tool. For better performance of any machining process, high machining rate and better surface finish and good power consumption are desirable. To achieve high cutting performance, selecting of cutting parameters is very important [2-3]. Dry machining is the process where no cutting fluid is used for economic and environmental reasons. In this process, temperature of the cutting tool is very high and this induces excessive tool wear thus decreasing tool life. Also the chips generated at machining cannot wash away and these chips cause deterioration on the machined surface. The problems of cutting fluid contamination and disposal are not seen in dry machining. The advantages of dry machining include: non-pollution of the atmosphere (or water); no residue on the swarf which will be reflected in reduced disposal and cleaning costs; no danger to health; and it is non-injurious to skin and is allergy free. Moreover, it offers cost reduction in machining. However, in dry cutting operations, the friction and adhesion between chip and tool tend to be higher, which causes higher temperatures, higher wear rates and, consequently, shorter tool lives [4]. Wet machining means the cutting fluid have been introduced in the cutting process which improves the characteristics of tribological processes which are always present on the contact surfaces between the tool and the workpiece. It has the advantage of better part quality and less tool wear. The use of cutting fluids increases the tool life, contributes to a more economical cutting speed and generally improves the efficiency of the production systems when taken as a whole [5]. Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions [6]. In this paper, the S/N ratio and a statistical analysis of variance (ANOVA) are been employed to indicate the impact of process parameters on output response values. The cutting parameters are taken and both the material removal rate and surface finish are optimized by using the Taguchi method and Analysis of variance (ANOVA) [7].

II. Experimentation

A. Workpiece

En19 steel is used as workpiece for machining which offers good ductility and shock resisting properties combined with resistance to wear. With these characteristics, it is a popular high tensile engineering steel with a tensile of 850/1000 N/mm². The chemical composition of the selected workpiece is shown in Table 1.

Table 1: Chemical Composition

Carbon	.35-.45%
Manganese	0.5-0.8%
Chromium	0.9-1.50%
Molybdenum	0.2-0.4%
Silicon	0.1-0.35%
Phosphorus	0.035% max
Sulphur	0.050% max

B. Tool Material

Carbide cutting tool also known as cemented carbides is used for machining the workpiece. It is a hard material used to machining the tough materials such as carbon steel or stainless steel, also used where other tools would wear away, high-quantity production runs. Carbide tools can also withstand higher temperatures than standard high speed steel tools.

C. Surface Roughness Tester

Surface roughness is a measure of the texture of a surface. It is used to determine and evaluate the quality of a product which is one of the major quality attributes of a turning product. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough and vice versa. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Surface roughness tester is the machine which used to measure the roughness of surface using probes as shown in fig. 1.

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Fig. 1: Surface Roughness Testing of Specimen

D. Coolants

MAK SHEROL B is used as coolant for machining. It is premium quality soluble cutting oil blended from refined mineral oil, emulsifier and other additives. It forms extremely stable milky emulsion of the "Oil in Water" type. This soluble cutting oil is recommended for use in a variety of cutting operations on ferrous and non-ferrous materials. It is used at water to oil ratios between 20:1 and 30:1.

E. Parameters of the Experiment

If there is an experiment having 3 factors which have three values as shown in Table 2, then total number of experiments is 27. Then results of all experiments will give 100 accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments is reduced to 9 instead of 27 with almost same accuracy. It will help in avoiding the unnecessary combinations, that is, it avoids repetition of combinations.

Table 2: Cutting Parameters and Levels

Level	Spindle Speed (RPM)	Feed Rate (mm/ rev)	DOC (mm)
1	500	0.048	0.3
2	770	0.059	0.5
3	1200	0.090	0.7

F. Design of Experiments

Table 3 shows the experimental results for material removal rate and surface roughness and the corresponding S/N ratio for dry and wet machining. Taguchi uses the S/N ratio to measure the quality characteristic deviating from desired value. Higher the better and lower the better quality characteristic for material removal rate and surface roughness respectively.

Table 3: Parametric Combinations

Spindle Speed (Rpm)	Feed Rate (Mm/Rev)	Depth Of Cut (Mm)
500	0.048	0.3
500	0.059	0.5
500	0.090	0.7
770	0.048	0.5
770	0.059	0.7
770	0.090	0.3
1200	0.048	0.7
1200	0.059	0.3
1200	0.090	0.5

Table 4: For Dry Machining

Mrr	S/N Ratio	R_A	S/N Ratio
0.018	-34.8945	3.8050	-11.6071
0.069	-23.2230	3.0750	-9.7569
0.139	-17.1397	3.3663	-10.5431
0.198	-14.0667	3.0903	-9.8000
0.154	-16.2496	4.1570	-12.3756
0.070	-23.0980	3.8840	-11.7856
0.045	-26.9357	2.1570	-6.6770
0.037	-28.6360	2.1343	-6.5851
0.167	-15.5457	3.5260	-10.9456

Table 5: For Wet Machining

MRR	S/N Ratio	R_a	S/N Ratio
0.104	-19.6593	3.073	-8.1410
0.157	-16.0820	3.567	-11.0461
0.298	-10.5157	2.342	-7.3917
0.047	-26.5580	1.836	-5.2775
0.164	-15.7031	3.373	-10.5603
0.086	-21.3100	3.073	-9.7513
0.169	-15.4423	3.309	-10.3939
0.109	-19.2515	1.644	-4.3180
0.138	-17.2024	3.071	-9.7456

III. Results & Analysis

A. Dry Machining

For Material Removal Rate (MRR) and Surface Roughness (SR)

Table 6: Response Table for Means of MRR

Level	Speed	Feed	DOC
1	3.415	3.017	3.274
2	3.710	3.122	3.230
3	2.606	3.592	3.227
Delta	1.105	0.575	0.048
Rank	1	2	3

Table 7: Response Table for Means of SR

Level	Speed	Feed	DOC
1	0.07533	0.08700	0.04167
2	0.14067	0.08667	0.14467
3	0.08300	0.12533	0.11267
Delta	0.06533	0.03867	0.10300
Rank	2	3	1

Table 8: Analysis of Variance for Means (MRR)

Source	DF	Seq SS	Seq MS	F Value	P Value	% contribution
Speed	2	0.007653	0.003826	1.12	0.471	22.43
Feed	2	0.002965	0.001482	0.43	0.697	8.69
DOC	2	0.016674	0.008337	2.45	0.290	48.89
Error	2	0.006817	0.003408			
Total	8	0.034108				

Table 9: Analysis of Variance for Means (SR)

Source	DF	Seq SS	Seq MS	F Value	P Value	%contribution
Speed	2	1.96287	0.981437	1.24	0.447	47.67
Feed	2	0.56210	0.281048	0.35	0.739	13.65
DOC	2	0.00422	0.002111	0.00	0.997	0.102
Error	2	1.58837	0.794183			
Total	8	4.11756				

The speed is ranked one for the MRR and depth of cut is ranked one for Surface roughness from the response Table 4 & 5 respectively. From Table 6 & table 7, the percentage contributions of the machining parameters have revealed that the influence of the Depth of Cut is significantly higher than that of Cutting speed and feed for material removal rate and the influence of speed is significantly higher than the feed and depth of cut for surface roughness respectively.

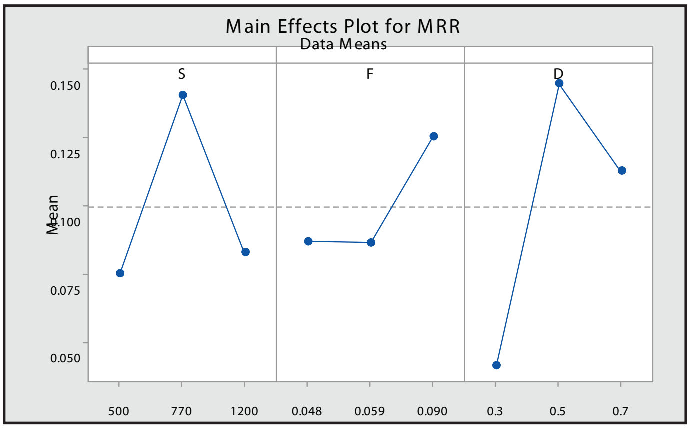

Fig. 2: Main Effects Plot for Mean

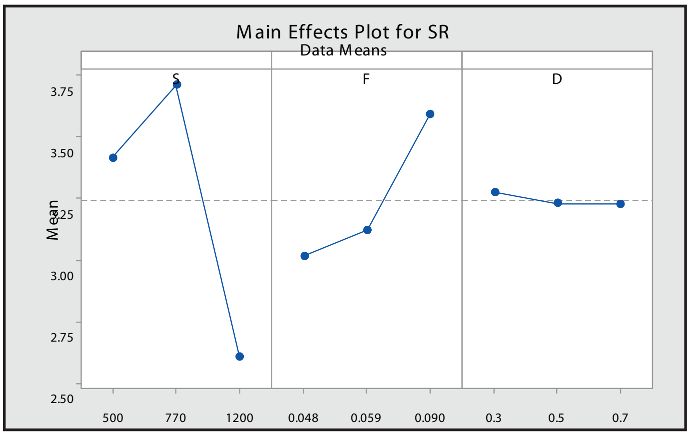

Fig. 3: Main Effects Plot for Mean

Fig. 2 shows the main effects of MRR of each factor for various level conditions, it increases and then decreases with increase in spindle speed, the increase in feed rate increases, increase in depth of cut increases and then decreases the material removal rate respectively. The main effects of SR of each factor for various level conditions, it increases and then decreases with increase in spindle speed, the increase in feed rate increases, increase in depth of cut decreases the surface roughness respectively from fig. 3.

B. Wet Machining

For Material Removal Rate (MRR) and Surface Roughness (SR)

Table 10: Response Table for Means MRR

Level	speed	feed	DOC
1	0.18633	0.10667	0.09967
2	0.09900	0.14333	0.11400
3	0.13867	0.17400	0.21033
Delta	0.08733	0.06733	0.11067
Rank	2	3	1

Table 11: Response Table for Mean SR

Level	speed	feed	DOC
1	2.821	2.566	2.423
2	2.761	2.861	2.825
3	2.675	2.829	3.008
Delta	0.146	0.295	0.585
Rank	3	2	1

Table 12: Analysis of Variance for Means (MRR)

Source	DF	Seq SS	Seq MS	F Value	P Value	% contribution
speed	2	0.011473	0.005736	25.16	0.038	28.34
feed	2	0.006819	0.003409	14.95	0.063	16.84
doc	2	0.021733	0.010866	47.66	0.021	53.68
Error	2	0.000456	0.000228			
Total	8	0.040480				

Table 13: Analysis of Variance for Means (SR)

Source	DF	Seq SS	Seq MS	F Value	P Value	%contribution
speed	2	0.03231	0.01616	0.01	0.990	0.841
feed	2	0.15728	0.07864	0.05	0.952	4.09
DOC	2	0.53651	0.26826	0.17	0.853	13.97
Error	2	3.11323	1.55661			
Total	8	3.83934				

The Depth of Cut is ranked one for the Material removal rate (MRR) and Surface roughness (SR) from the response Table 8 & 9 respectively. From Table 10 & Table 11, the percentage contributions of the machining parameters have revealed that the influence of the Depth of Cut is significantly higher than that of feed and cutting speed for Material Removal Rate (MRR) and Surface Roughness (SR) respectively.

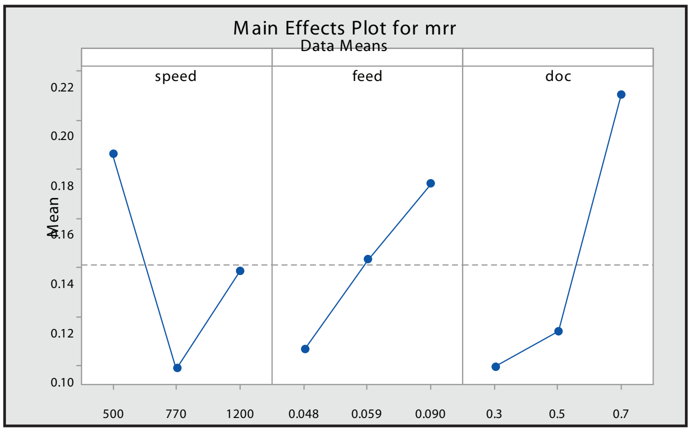

Fig. 4: Main Effects Plot for Means MRR

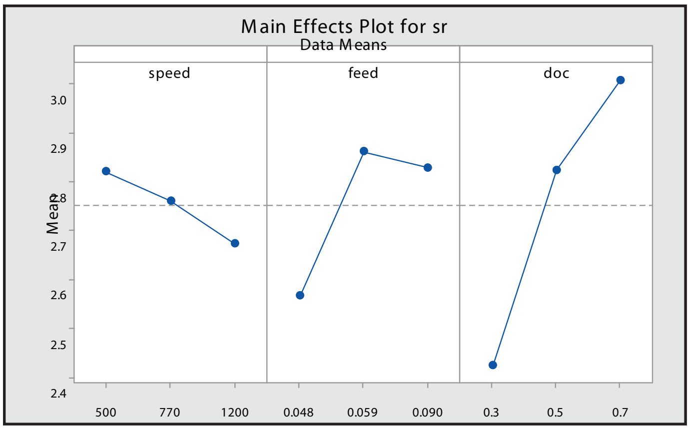

Fig. 5: Main Effects Plot for Mean SR

Fig. 4 shows the main effects of Material Removal Rate (MRR) of each factor for various level conditions, it decreases and then increases for increase in spindle speed, the increase in feed rate increases, increase in depth of cut increases the material removal rate respectively. The main effects of SR of each factor for various level conditions, it decreases with increase in spindle speed, the increase in feed rate increases and then decreases, increase in depth of cut increases the Surface Roughness (SR) respectively from fig. 5.

IV. Conclusion

The influence of the cutting parameters on the dry machining and wet machining is known through percentage contribution. The percentage contribution is obtained by following the analysis of variance (ANOVA). For dry machining the depth of cut (level 2) and cutting speed (level 2) are ranked one because of their high influence over material removal rate and surface roughness. For wet machining the depth of cut (level 3) is ranked one because of its high influence over material removal rate and surface roughness.

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