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Machining Performance Optimization for Effective Turning of En31 Alloy Steel

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Abstract:
In this research the investigations have been carried out on traditional machining e.g.turning operation using DNMX150608WM1525 graded tools for dry as well as wet turning. Analysis of the influence of turning parameters on the various pre determined machining performance and optimization of machining parameters for different performance criteria are carried out using Taguchi method. The optimization of machining parameters and development of mathematical models for surface finish are also presented for dry and wet turning using specific insert. In this research investigation mathematical model is developed for the surface finish.
The research investigations will propose an effective methodology in advance for proper setting of machining parameter in practicefor effective turning of En31 alloy steel.
Key words: Tool life,En31 alloy steel, taguchi method

1. Introduction

The rapid technological acceptance of hard alloy steel in industrial application, the machining of En31 alloy steel has been of urgent importance for modern die and shaft manufacturing industries The major problems encountered during traditional machining of En-31 alloy steels are rapid tool failure, abrasive wear, flank wear of cutting tool, formation of flank build up layer on the cutting tool edge, poor surface finished etc.Keeping in view, the present research investigations have been carried out on traditional machining e.g.turning operation using different graded tools, special tooling system. The influence of continuous length of machining on the flank wear, influence of cutting time on the flank wears i.e. tool wear rate have been experimentally investigated and analyzed through various graphical representation.

Analysis of the influence of turning parameters on the various pre determined machining performance and optimization of machining parameters for different performance criteria are carried out. The optimization of machining parameters and development of mathematical models for cutting forces, tool wear and surface finish are also presented. The major problems encountered during traditional machining of En-31 alloy steels are rapid tool failure, severe abrasive wear, flank wear of cutting tool, formation of flank build up layer on the cutting tool edge, poor surface finished etc.

Although some research on traditional and non-traditional machining of hard alloy steel have been carried out by the previous

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researchers but still a lot of applied research on traditional machining process are required as to explore the successful utilization of the process parameters for effective machining of En-31 alloy steels. To explore the successful utilization of the traditional machining process experimental investigation on machinability of hard alloy steel during turning is needed to be carried out considering some major machining factors such as various tools, tooling system, cutting forces, built-up edge, chip formation, temperature generated during cutting, tool wear and surface finish criteria etc. for searching out the effective machining conditions with cost effective machining process for achieving the criterial objective fulfillment.

According to the machining requirements, the experimental investigations have been carried out in a pre planned way keeping the objective of the present research. Analysis of the influence of turning parameters on the various pre determined machining performance and optimization of machining parameters for different performance criteria are carried out.

Keeping in view, a brief review of some of the interesting and important contributors in the field as above discussed are presented here.Aggarwal Amanet al. [1] reviewed the literature on optimization of machining parameters in turning processes. Armarego E. J. A. et al.[2] presented multi constraint optimization analyses and computer aided strategies for selecting the optimal feeds and speeds in single pass rough turning operations with modern coated chip breaker tool on CNC lathe.Blais Carl et al. [3] studied on the optimization of machining parameters. Author presented new approaches to improve the P/M machinability. Chen M. C. et al.[4] studied the extensive attention regarding optimization of machining conditions for turning cylindrical stocks into continuous finished profiles.Chung Shin Chang [5] proposed force model to study the stability of the single point cutting tool during turning of stainless steel. Author validated the developed force model with the experimental data and concluded that the model is closely correlated with the theoretical values. Hui Y. V. et al. [6] studied the optimal machining conditions based on costs of quality and tool maintenance in turning. Author developed a time dynamic economic model for single pass turning.Kaye J. E. et al. [7] developed a mathematical model for on line prediction of tool wear during turning using the surface response methodology. Authors conducted different tests with varying the combination of cutting speed, feed rate, depth of cut and material hardness for development of mathematical model and to predict the flank wear.

Manna A. et al. [8] experimental investigated the influence of cutting conditions on surface finish during turning of AL/SiC-MMC. In this study, author used the Taguchi method based experiment design to optimize the cutting parameters for effective turning of AL/SiC-MMC by rhombic insert.Suresh P. V. S. et al. [9] studied on the genetic algorithm approach for optimization of surface roughness model. This approach was used for prediction of optimal machining conditions for good surface finish and dimensional accuracy.

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The main objective of the paper is to optimize the machining condition for the effective turning of En31 alloy steel. The taguchi design approach is utilized for experimental planning and ANOVA is employed to investigate the influence of depth of cut, feed rate, and cutting speed on the surface roughness height Ra during turning.The result was obtained from the experimental study are utilized for analyzing the effect of various input constraint at optimal point.Multiple linear regressionswere used for developing the mathematical model for optimizing the machining condition for minimum surface roughness height (Ra) during machining of En31 alloy steel.

2. SCHEME OF EXPERIMENTS

A set of experimental investigation has been carried out in a pre-planned way to study the influence of machining parameters e.g. cutting speed, feed and depth of cut on the cutting forces, cutting tool wear, surface finish criteria, and chip reduction co-efficient during turning of En31 steel. The influence of continuous length of machining on the flank wear, influence of cutting time on the flank wears i.e. tool wear rate have been experimentally investigated and analyzed through various graphical representation. The combined effect of cutting speed and feed on the cutting forces, flank wear, chip reduction co-efficient have also been investigated during experimentation. The influence of length of continuous machining on dimensional deviation during turning by different inserts at wet and dry environment are also experimentally investigated and analyzed.

2.1 Machine tools, cutting tools, work-piece materials and measuring instruments

The different sets of experiments have been performed by turning operation on a HMT-LB20 Center Lathe with and without use of cutting fluid. Table 2.1 represents the details of cutting tool used for the experimentation. Machined surfaces have been measured at different positions along the machined surface and average value is taken utilizing TSK SURFCOM-130 A surface texture measuring instrument. The cutting tools used DNMX150608WM1525, are used for conducting the experiments for both dry as well as wet turning. En31 steel are selected as work-piece materials.
Table 2.2 Represent the chemical composition of the work-piece materials obtained by Spectro analysis used for experimental investigations.

Table 2.1 Details of cutting tool used and environment for turning experiments:

Cutting tool used	Cutting tool specification	Rake angle	Clear-ance angle	Nose radius	Cutting edge angle	Environment
T-Max-P Négative insert	DNMX150608WM1525	- 6^0	0^0	0.8 mm	55^0	Wet and dry

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Table 2.2 Chemical composition of En 31 steel

Specification	%C	%Mn	%P	%S	%Ni	%Cr	%V	%Mo	%Cu	%Ti	%W
En31 steel	1.07	0.53	0.08	0.07	0.04	1.12	0.02	0.04	0.08	0.01	0.16

2.2 Taguchi method base parametric optimization for surface roughness Ra

According to the Taguchi method based design, an L_{27} (3^{13}) orthogonal array is employed for the experimentation. Three machining parameters such as cutting speed, feed and depth of cut are considered as controlling factors and each parameter has three levels, namely small, medium and large are denoted by 1, 2 and 3 respectively. Table 2.3 shows the cutting parameters and their levels considered for the experimentation.

Table 2.3 Cutting parameters and their levels

Sl. No.	Machining parameters	Level		
		1	2	3
1	A: Cutting speed, m/min.	40	100	160
2	B: Feed, mm/rev.	0.16	0.33	0.48
3	C: Depth of cut, mm.	0.50	0.75	1.25

The design of experimental plan is a methodology to study efficiently the effect of different control factors simultaneously through a matrix experimental plan called orthogonal array. An orthogonal array for a particular robust design project can be constructed on the basis of the total number of control variables and their levels. According to the Taguchi method based design of experiments L_{27} (3^{13}) orthogonal array is considered for turning experiments to study the effects of turning parameters e.g. cutting speed (m/min), feed rate (mm/rev) and depth of cut (mm). Considering three column from the L_{27} (3^{13}) orthogonal array i.e. from 13 columns

with 3-levels matrix array turning operations are performed. Three turning operations are carried out on three samples against each parametric setting as per the table 2.3. Total 81 experiments are conducted for 27 set of experiments. The degree of freedom for each factor can be evaluated as the number of levels minus one. The degrees of freedoms for interactions of the factors can also be determined as the product of degrees of freedom of all the factors considered for interactions. The total degree of freedom is the summation of degrees of freedom for the overall mean, all the factors and interactions or otherwise total number of experiments with considering repetition against each parametric setting minus one. Here, total degree of freed is 80 for 81 experiments against 27 parametric setting with three repetition against each setting.

Hence, the standard orthogonal array, L_{27} (3^{13}) is to be selected and according to the table 2.3 parametric setting for 27 x 3(repetition) i.e. 81 experiments are to be conducted for the present research investigation. Table 3.1 exhibits the planning for experimental design is to be used for the present investigation.

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3.S/N Ratio, ANOVA and Mathematical model for Pz by DNMX150608WM1525 insert in dry environment on En31 alloy steel.

Table 3.1 shows the set of experiments of $L_{27}(3^{13})$ orthogonal array with experimental results of average surface finish and S/N ratio (dB), obtained during turning of En31 alloy steel by DNMX150608WM1525 insert in dry environment.

Expt. No	Column										
	Coded level			Actual setting values			Results				
	1	2	6				Surface Finish			Average Surface finish	S/N Ratio
1	1	1	1	40	0.16	0.50	2.06	2.01	1.99	2.02	-6.10794
2	1	1	2	40	0.16	0.75	2.21	2.16	2.17	2.18	-6.76955
3	1	1	3	40	0.16	1.25	2.5	2.49	2.54	2.51	-7.99379
4	1	2	1	40	0.33	0.50	2.77	2.68	2.74	2.73	-8.72406
5	1	2	2	40	0.33	0.75	2.89	2.87	2.91	2.89	-9.21809
6	1	2	3	40	0.33	1.25	3.2	3.24	3.19	3.21	-10.13029
7	1	3	1	40	0.48	0.50	3.07	3.06	3.11	3.08	-9.77122
8	1	3	2	40	0.48	0.75	3.24	3.26	3.22	3.24	-10.21101
9	1	3	3	40	0.48	1.25	3.59	3.58	3.54	3.57	-11.05352
10	2	1	2	100	0.16	0.75	1.81	1.83	1.79	1.81	-5.15392
11	2	1	3	100	0.16	1.25	2.11	2.15	2.16	2.14	-6.60871
12	2	1	1	100	0.16	0.50	1.65	1.64	1.63	1.64	-4.29698
13	2	2	2	100	0.33	0.75	2.58	2.57	2.56	2.57	-8.19870
14	2	2	3	100	0.33	1.25	2.91	2.94	2.85	2.9	-9.24868
15	2	2	1	100	0.33	0.50	2.38	2.43	2.42	2.41	-7.64068
16	2	3	2	100	0.48	0.75	3.03	3.07	3.02	3.04	-9.65769
17	2	3	3	100	0.48	1.25	3.39	3.34	3.38	3.37	-10.55277
18	2	3	1	100	0.48	0.50	2.84	2.86	2.88	2.86	-9.12746
19	3	1	3	160	0.16	1.25	1.86	1.88	1.84	1.86	-5.39059
20	3	1	1	160	0.16	0.50	1.41	1.39	1.37	1.39	-2.86089
21	3	1	2	160	0.16	0.75	1.53	1.56	1.53	1.54	-3.75078
22	3	2	3	160	0.33	1.25	2.48	2.46	2.44	2.46	-7.81889
23	3	2	1	160	0.33	0.50	2.39	2.43	2.41	2.41	-7.64054
24	3	2	2	160	0.33	0.75	2.64	2.54	2.56	2.58	-8.23361
25	3	3	3	160	0.48	1.25	2.89	2.91	2.93	2.91	-9.27799
26	3	3	1	160	0.48	0.50	2.42	2.47	2.43	2.44	-7.74813
27	3	3	2	160	0.48	0.75	2.62	2.57	2.61	2.6	-8.29976

Fig. 1 exhibits Signal to Noise (S/N) response graph for average surface finish

It has been observed that the average surface finish decreases with the increase of cutting velocity and increases with the increase of machining time during machining of En31 alloy steel. From the S/N Ratio graph Fig.1 it is clear that the parametric combination for higher surface finish is is A3B1C1.

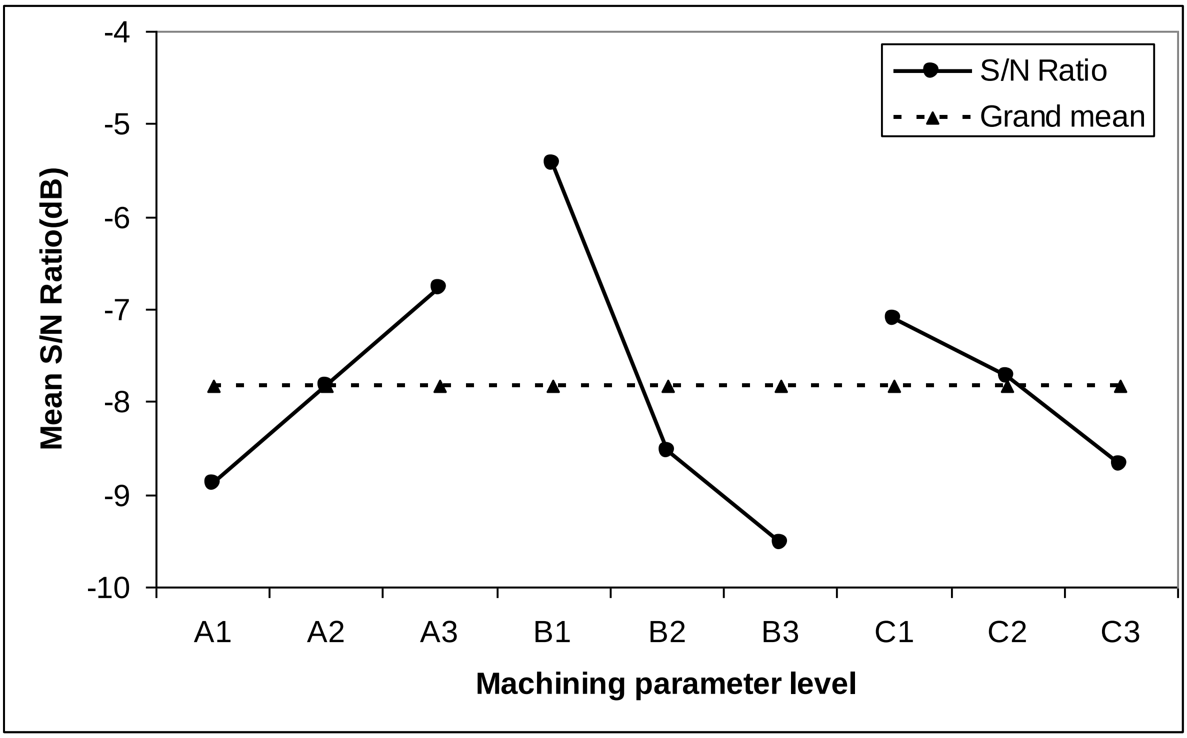

Fig. 1 S/N Ratiofor surface finish while cutting of En31 steel by DNMX150608WM1525 insert in dry environment.

3.2 Analysis of Variance (ANOVA) for surface finish while cutting of En31 steel by DNMX150608WM1525 insert in dry environment.

Table 3.2 shows the Analysis of Variance (ANOVA) and 'F' test for average surface finish. It has been observed from table that the cutting speed and feed rate are the most significant and significant parameter respectively.

Table 3.2 ANOVA for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in dry environment

Parameters	Degree of freedom	Sum of square,SS	Variance,V	'F' test value	% of contribution
X1	2	4.5774	2.28868	721.68	17.92
X2	2	17.6764	8.83821	2786.91	69.18
X3	2	2.6571	1.32854	418.92	10.4
X1.X2	4	0.2436	0.06091	19.21	0.95
X1.X3	4	0.104	0.02599	8.2	0.40
X2.X3	4	0.0881	0.02203	6.95	0.34

Error	62	0.1966	0.00317		0.77
Total	80	25.5432			100.00

3.3 Mathematical Model for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in dry environment

Considering most significant and significant parameters as identified from Table 3.2 and using the Gauss elimination method, the mathematical model for average surface finish has been developed with notation of X_1, X_2 and X_3 which represent the cutting speed, feed rate and depth of cut respectively. The mathematical model for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in dry environment as follows.

$Y_{,E0300,18}$=0.52110560344160-0.00373789341388X_1+8.36363026282609 X_2 +1.01623822596515 X_3 +0.00002528536339 X_1 X_2-0.00186507936508X_1X_3-0.01863892501083 X_2X_3 +0.00000216049383 X_1^2 -7.61165577342045 X_2^2-0.13629629629630X_3^3-----------------Eq.1

R^2 = 0.99

4. S/N Ratio, ANOVA and Mathematical model for average surface finish by DNMX150608WM1525 insert on En31 alloy steel.

4.1S/N ratio (dB) for average surface finish, obtained during turning of En31 alloy steel by DNMX150608WM1525 insert in wet environment.

Table 4.1 shows the set of experiments of L_{27} (3^{13}) orthogonal array with experimental results of average surface finish and S/N ratio (dB) for average surface finish, obtained during turning of En31 alloy steel by DNMX150608WM1525 insert in wet environment.

Table-4.1Experimental results and S/N ratio of surface finish (En31, DNMX150608WM1525, Wet)

Expt. No	Column										
	Coded level			Actual setting values			Results				
	1	2	6				Surface Finish			Average Surface finish	S/N Ratio
1	1	1	1	40	0.16	0.50	1.71	1.73	1.69	1.71	-4.66031
2	1	1	2	40	0.16	0.75	1.89	1.88	1.84	1.87	-5.43741
3	1	1	3	40	0.16	1.25	2.23	2.19	2.21	2.21	-6.88808
4	1	2	1	40	0.33	0.50	2.51	2.53	2.49	2.51	-7.99365
5	1	2	2	40	0.33	0.75	2.68	2.64	2.69	2.67	-8.53050
6	1	2	3	40	0.33	1.25	2.98	2.99	2.97	2.98	-9.48435

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7	1	3	1	40	0.48	0.50	2.93	2.94	2.98	2.95	-9.39667
8	1	3	2	40	0.48	0.75	3.13	3.12	3.08	3.11	-9.85541
9	1	3	3	40	0.48	1.25	3.41	3.51	3.49	3.47	-10.80726
10	2	1	2	100	0.16	0.75	1.57	1.59	1.52	1.56	-3.86403
11	2	1	3	100	0.16	1.25	1.89	1.92	1.89	1.9	-5.57531
12	2	1	1	100	0.16	0.50	1.41	1.44	1.38	1.41	-2.98569
13	2	2	2	100	0.33	0.75	2.2	2.16	2.21	2.19	-6.80930
14	2	2	3	100	0.33	1.25	2.56	2.54	2.49	2.53	-8.06299
15	2	2	1	100	0.33	0.50	2.02	2.06	2.01	2.03	-6.15041
16	2	3	2	100	0.48	0.75	2.61	2.62	2.63	2.62	-8.36606
17	2	3	3	100	0.48	1.25	2.99	2.98	2.97	2.98	-9.48435
18	2	3	1	100	0.48	0.50	2.49	2.42	2.47	2.46	-7.81932
19	3	1	3	160	0.16	1.25	1.55	1.54	1.59	1.56	-3.86332
20	3	1	1	160	0.16	0.50	1.04	1.09	1.08	1.07	-0.58944
21	3	1	2	160	0.16	0.75	1.21	1.22	1.26	1.23	-1.79944
22	3	2	3	160	0.33	1.25	2.22	2.27	2.29	2.26	-7.08290
23	3	2	1	160	0.33	0.50	1.78	1.74	1.79	1.77	-4.96011
24	3	2	2	160	0.33	0.75	1.85	1.98	1.96	1.93	-5.71495
25	3	3	3	160	0.48	1.25	2.68	2.72	2.73	2.71	-8.65966
26	3	3	1	160	0.48	0.50	2.21	2.19	2.26	2.22	-6.92782
27	3	3	2	160	0.48	0.75	2.38	3.37	2.39	2.38	-8.79543

4.2 S/N Ratio for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in wet environment.

Fig. 2 exhibits Signal to Noise (S/N) response graph for average surface finish It has been observed that the average surface finish decreases with the increase of cutting velocity and increases with the increase of machining time during machining of En31 alloy steel. From the S/N Ratio graph Fig.2 it is clear that the parametric combination for higher surface finish is A3B1C1.

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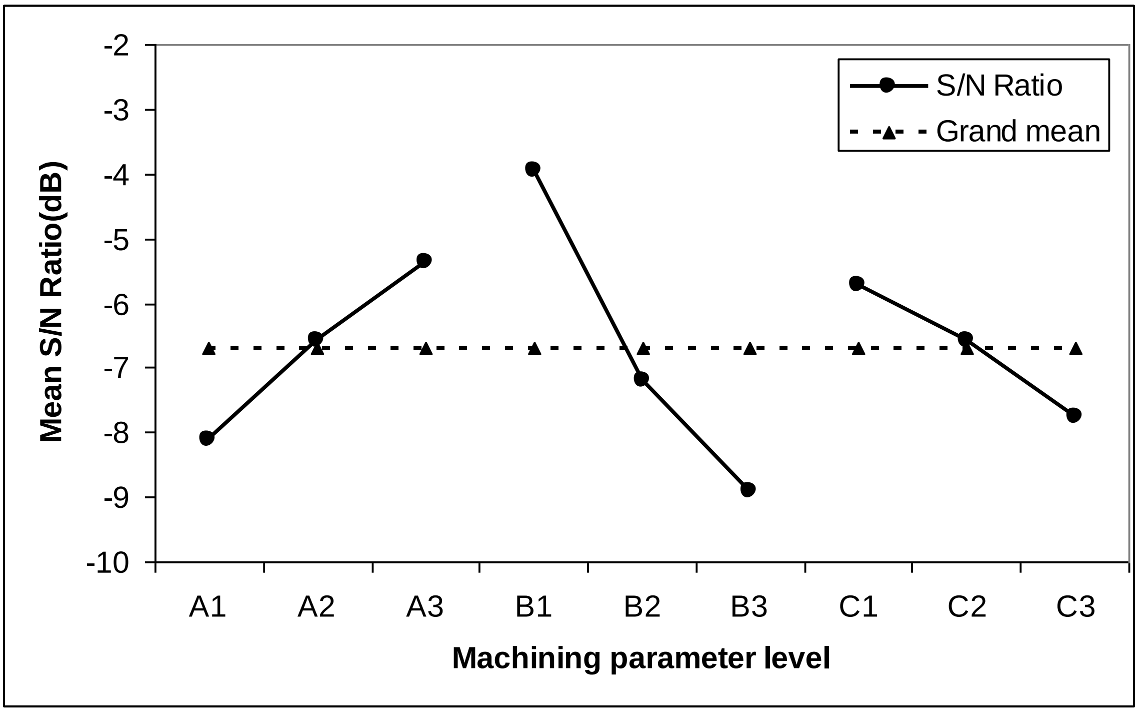

Fig. 2 S/N Ratiofor surface finish while cutting of En31 steel by DNMX150608WM1525 insert in wet environment

4.2 Analysis of Variance (ANOVA) for surface finish while cutting of En31 steel by DNMX150608WM1525 insert in wet environment

Table 4.2 shows the Analysis of Variance (ANOVA) and 'F' test for average surface finish. It has been observed from Table 4.2 that the cutting speed and feed rate are the most significant parameter.

Table 4.2 ANOVA for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in wet environment.

Parameters	Degree of freedom	Sum of square	Variance	'F' test value	% of contribution
X1	2	6.1727	3.08633	238.04	20.61
X2	2	19.3485	9.67426	746.15	64.61
X3	2	3.3796	1.68979	130.33	11.28
X1.X2	4	0.1399	0.03497	2.7	0.35
X1.X3	4	0.056	0.014	1.08	0.18
X2.X3	4	0.0437	0.01092	0.84	0.14
Error	62	0.8039	0.01297		2.68
Total	80	29.9442			100.00

4.3 Mathematical Model for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in wet environment.

Considering most significant and significant parameters as identified from Table 4.2 and using the Gauss elimination method, the mathematical model for

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average surface finish has been developed with notation of X_1, X_2 and X_3 which represent the cutting speed, feed rate and depth of cut respectively. The mathematical model for average surface finish while cutting of En31 alloy steel by DNMX150608WM1525 insert in dry environment as follows.

$$Y_{,E0300,20} = 0.79913893139654-0.01025862387611X_1+5.55310389555813X_2 +1.13102235432535X_3 +.00027031257525X_1X_2-0.00034391534392X_1X_3 -0.02852601812290X_2X_3+0.00002443415638X_1^2-2.86946259985476X_2^2-0.24296296296296X_3^2$$ ---------------------------------------Eq. 2

$R^2=0.97$

5. Conclusions

On the basis of experimental results, optimal parametric combinations for better surface finish using Taguchi design concept the following points can be concluded as listed below:

1. Most significant parameter influencing the surface finish Ra is cutting speed as compared to depth of cut and feed rate.For better surface finish the recommended parametric combination is A3B1C1
2. The developed mathematical model for surface roughness height Ra is successfully proposed

For proper selection of machining parameters. Mathematical model developed can be useful in evaluating the Ra value under various machining condition during turning.

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