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ANALYSIS OF CUTTING FORCE AND SURFACE ROUGHNESS OF BOTH UNCOATED CARBIDE AND COATED CARBIDE CUTTING TOOL INSERTS USING TAGUCHI METHOD.

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Abstract- The objective of this paper is to obtain optimal setting of turning process parameters (cutting speed, feed rate and depth of cut) resulting in an optimal value of cutting force and surface roughness while machining EN-19 steel with both uncoated and coated carbide cutting tool. The effects of the selected process parameters on the cutting force and surface roughness have been accomplished using Taguchi's design of experiments approach. The results indicate that the selected process parameters significantly affect the mean and variance of cutting force and surface roughness. The percent contributions of parameters in the ANOVA table for cutting force (F_Y) on uncoated carbide cutting tool the depth of cut (74.1%) has a major contribution than that of feed rate (18.5%) and cutting speed (3.3%). The cutting force (F_Y) for coated carbide cutting tool also depicts the similar trend where in the depth of cut (86.7%) has a major contribution than that of feed rate (7.1%) and cutting speed (4.6%). The surface roughness (R_a) for uncoated carbide cutting tool the feed rate (93.7%) has a major contribution than that of depth of cut (3.0%) and cutting speed (1.6%). While in case of coated carbide cutting tool the surface roughness (R_a), the depth of cut is having significant contribution of (39%) than that of cutting speed (31.7%) and the feed rate (25.1%). The ANOVA of S/N ratio for all the cases also exhibits similar trend. The predicted optimal range of cutting force for uncoated carbide cutting tool is (332 to 76 N), while for coated carbide cutting tool is (191 to 106 N), for surface roughness of uncoated carbide cutting tool is (2.232 to 0.804 µm) and for coated carbide cutting tool is (0.939 to 0.643 µm). The results have been validated by the confirmation of experiment.
Keywords – Cutting force, Surface roughness, Taguchi, ANOVA.

1. INTRODUCTION

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface with the work piece is rotating and a single point cutting tool feeding parallel to the axis of the work piece.

Turning is carried out on lathe that provides the power to turn the work piece at a given rotational speed and feed to the cutting tool at a specified rate and depth of cut. Therefore three cutting parameters namely cutting speed, feed rate and depth of cut need to be optimized in a turning operation.

Turning produces three cutting force components as shown in figure 1. The main cutting force (F_Y) acts in the cutting speed direction, feed force (F_X), which acts in feed rate direction and the radial force (F_Z) which acts in the radial direction and which is normal to the cutting speed.

Rodriguez Kantharaj and Freitas [1] presented a method to determine the effect of the cutting parameters on cutting force in turning mild steel. Experiments were carried out using full factorial design and the ANOVA is the tool used for this study. From the ANOVA it was found that the feed rate was the most significant factor followed by cutting speed and depth of cut.

Singh and Kumar [2] studied on optimization of cutting force through setting of optimal value of process parameters namely cutting speed, feed rate and depth of cut while machining EN-24 alloy steel (0.4%C) with TiC coated carbide inserts. The effects of the selected process parameters have been accomplished using Taguchi's parameter design approach and concluded that the effect of depth of cut and feed rate in variation of cutting force were affected more as compared to cutting speed.

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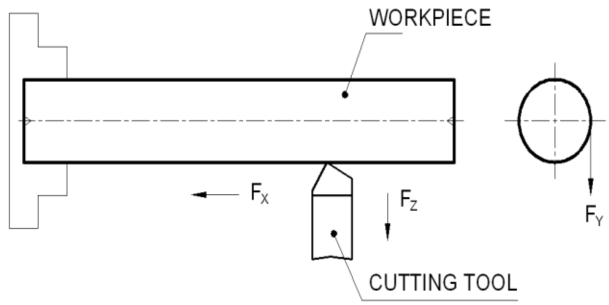

Figure 1. The block diagram showing the direction of forces.

Anirban Bhattaharya et. al., [3] investigated the effect of various machining parameters during high speed machining on the work piece surface roughness. The experiments were carried out taking AISI 1045 steel as the work piece material and coated carbide tool. The Taguchi's orthogonal arrays and analysis of variance were employed to design the experiments. It was observed from these experiments that at the higher cutting speeds (240 m/min) the best surface roughness results were observed. Cutting speed was found to be most significant factor for surface roughness and contributes up to 76%. The interactions between cutting speed and feed rate were observed to have no significant impact.

Ramesh Karunamoorthy and Palanikumar [4] conducted a study on the effect of cutting parameters on the surface roughness in turning operations. The material used was an alloy of titanium; tool used is RCMT 10T300-MT TT3500 round insert, and tool used was response surface methodology. The input parameters were cutting speed, feed rate and depth of cut. The chip formation and scanned electron microscopic images were studied. The results showed that surface roughness was affected by feed rate.

Dr. S.S.Chaudhari et. al., [5] investigated a single characteristic response optimization model based on Taguchi technique was developed to optimize process parameters, such as cutting speed, feed rate, depth of cut and nose radius of single point cutting tool. Taguchi's L_9 orthogonal array is selected for experimental planning. The experimental analysis showed that the combination of higher levels of cutting speed, depth of cut and lower level of feed rate is essential to achieve simultaneous maximization of metal removal rate and minimization of surface roughness.

H.K. Dave et.al., [6] presented an experimental investigation of the machining characteristics of different grades of EN materials in CNC turning process using TiN coated cutting tools. They have focused on the analysis of optimum cutting conditions to get the lowest surface roughness and maximum material removal rate in CNC turning of different grades of EN materials by Taguchi method. Optimal cutting parameters for each performance measure were obtained employing Taguchi technique. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in dry turning operation. ANOVA has shown that the depth of cut has significant role to play in producing higher material removal rate and insert has significant role to play for producing lower surface roughness.

Ali Riza Motorcu [7] studied on surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools was investigated in terms of main cutting parameters such as cutting speed, feed rate, depth of cut in addition to tool nose radius using a statistical approach. Machining tests were carried out with PVD coated ceramic cutting tools under different conditions. An orthogonal design, signal-to-noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness. The obtained results indicate that the feed rate was found to be dominant factor among controllable factors on the surface roughness followed by depth of cut and tool's nose radius.

Y.Sahin and A.R.Motorcu [8] have investigated surface roughness for turning of mild steel with coated carbide tools. The model was developed in terms of cutting speed, feed rate and depth of cut, using response surface methodology. Machining tests were carried out with TiN-coated carbide cutting tools under various cutting conditions. The established equation shows that the feed rate was main influencing factor on the surface roughness.

D.L.Lalwani et. al., [9] presented the effect of cutting parameters on cutting forces and surface roughness in finish hard turning of MDN 250 steel using coated ceramic tool. The author's found that the feed rate was the dominant factor on surface roughness.

T.Ozel et.al., [10] conducted a set of ANOVA and performed a detailed experimental investigation on the surface roughness and cutting forces in the finish hard turning of AISI H13 steel. The result indicated that the effects of work piece hardness, cutting edge geometry, feed rate and cutting speed on surface roughness are statistically significant.

2. EXPERIMENTATION

The EN-19 steel is selected as the work material for turning operation. The following process parameters were selected for the present work: Cutting speed - (A), feed rate – (B) and depth of cut – (C), Tool material – uncoated carbide insert and coated carbide (WIDIA) make, environment – dry cutting.

Insert geometry – TNMG 160404TTS (uncoated and coated carbide insert)
Tool holder – MTJNR2020K16, Cutting conditions – Dry, Tool overhang – 40 mm
In selecting an appropriate orthogonal array, the prerequisites are:
i) Selection of process parameters and interactions to be evaluated
ii) Selection of number of levels for the selected parameters.
The non-linear behaviour of the process parameters if exists, can only be revealed if more than two level of the parameters along with their values at three levels are given in Table 1. It was also decided to study the two factor interaction effects on the cutting force . The selected interactions were:
i) between cutting speed and feed (AxB)
ii) between feed and depth of cut (BxC)
iii) between cutting speed and depth of cut (AxC)
The three parameters each at three levels and three second – order interactions were selected and the total degree of freedom (DOF) required is 18. Since a three level parameter has 2 DOF (number of levels – 1) and each second order interaction has 4 DOF (product of DOF of interacting parameters). As per Taguchi's method the total DOF of the selected OA must be greater than or equal to the total DOF required for the experiment. The EN-19 steel rods of 60 mm diameter and length of 300 mm was machined on HMT A28-2487 Lathe using both uncoated and coated carbide cutting tool inserts having the designation TNMG 160404TTS. The work piece is machined as per the process parameters given in Table 1. The cutting force (F_Y) was measured for each trial using lathe tool dynamometer and the surface roughness (Ra) is measured using Talysurf surface tester. For each trials the new insert is used in order to have the uniformity of cutting conditions. The results of the experiments for twenty seven trials were reported in Table 2. The ANOVA results for tangential force of uncoated carbide cutting tool insert is tabulated in Table3, and its Signal to Noise (S/N) ratio is tabulated in Table 4. Similarly for coated carbide cutting tool insert the values are tabulated in Table 5 and its S/N ratio in Table 6. For uncoated carbide cutting tool inserts, the ANOVA for surface roughness is tabulated in Table 7 and its S/N ratio in Table 8. Similarly for coated carbide cutting tool insert the values are tabulated in Table 9 and its S/N ratio in Table 10.
The Signal – to – Noise ratio for Lower the Better (LB) characteristics are calculated using

$$S/N_{LB} = -10\log\left(\frac{1}{r}\sum_{i=1}^{r} y_i^2\right) \quad (1)$$

A confidence interval for the predicted mean on a confirmation run can be calculated using the following equation

$$CI = \sqrt{F_\alpha(1,f_e)(V_e)\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad (2)$$

where $F_\alpha(1,f_e)$=F ratio required for α, α is the risk factor, f_e = error DOF , V_e = error variance
R = Number of repetitions, N = Number of trials

$$n_{eff} = \frac{N}{1+[\text{Total DOF associated with items used in } \mu \text{ estimate}]}$$

Table-1 Process parameters used for cutting EN-19 material using both coated and uncoated carbide cutting tool insert

No	Process parameters	Level - 1	Level - 2	Level - 3
1	Cutting speed (m/min) (A)	101.8	171.5	222.4
2	Feed rate (mm/rev) (B)	0.125	0.187	0.218
3	Depth of cut (mm) (C)	0.5	1.0	1.5

3. ANALYSIS OF RESULTS

Table-2 Experimental values of cutting force at different cutting speed, feed rates and depth of cut for both uncoated and coated carbide cutting tool.

Sl. No.	Cutting speed (m/min) - (A)	Feed rate (mm/rev) - (B)	Depth of cut (mm) - (C)	Cutting force (N)		Surface roughness R_a (µm)	
				Uncoated	Coated	Uncoated	Coated
1	101.8	0.125	0.5	270	180	2.29	0.95
2			1.0	490	260	2.21	1.13
3			1.5	620	400	2.30	1.54
4		0.187	0.5	360	200	4.57	1.21
5			1.0	650	320	4.36	1.39
6			1.5	870	470	5.32	1.65
7		0.218	0.5	400	210	6.88	1.35
8			1.0	700	360	6.96	1.50
9			1.5	1000	500	8.14	1.72
10	171.5	0.125	0.5	300	190	1.75	0.73
11			1.0	520	280	1.96	0.95

12			1.5	650	410	2.12	1.20
13		0.187	0.5	380	210	4.20	0.94
14			1.0	670	330	4.00	1.21
15			1.5	900	480	5.00	1.35
16		0.218	0.5	420	220	5.92	1.11
17			1.0	740	370	6.14	1.32
18			1.5	1050	520	6.94	1.43
19	222.4	0.125	0.5	380	220	2.10	1.23
20			1.0	590	320	2.30	1.23
21			1.5	720	480	2.51	1.54
22		0.187	0.5	450	240	4.41	1.36
23			1.0	750	370	4.33	1.40
24			1.5	970	550	5.36	1.69
25		0.218	0.5	490	260	6.47	1.51
26			1.0	810	410	7.27	1.60
27			1.5	1120	590	8.02	1.77

Table-3 ANOVA for cutting force (F_Y) on machining of EN-19 material using uncoated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS$_E$	Ftab 95% CI	P=(SS/SS$_T$)*100
A	2	49696.30	24848.15	8.35	3.49	3.3
B	2	276318.52	138159.26	46.44	3.49	18.5
C	2	1104585.19	552292.59	185.66	3.49	74.1
Error	20	59496.30	2974.81			4.1
Total	26	1490096.30				100

Table-4 ANOVA for cutting force (F_Y) using Signal to Noise ratio on machining of EN-19 material using uncoated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS$_E$	Ftab 95% CI	P=(SS/SS$_T$)*100
A	2	11.51	5.75	38.33	3.49	3.8
B	2	51.68	25.84	172.27	3.49	17.0
C	2	238.21	119.10	794.00	3.49	78.2
Error	20	3.07	0.15			1.0
Total	26	304.47				100

Table-5 ANOVA for cutting force (F_Y) on machining of EN-19 material using coated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS$_E$	Ftab 95% CI	P=(SS/SS$_T$)*100
A	2	18096.30	9048.15	27.67	3.49	4.6
B	2	27696.30	13848.15	42.34	3.49	7.1
C	2	340496.30	170248.15	520.58	3.49	86.7
Error	20	6540.73	327.04			1.6
Total	26	392829.63				100

Table-6 ANOVA for cutting force (F_Y) using Signal to Noise ratio on machining of EN-19 material using coated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS$_E$	Ftab 95% CI	P=(SS/SS$_T$)*100
A	2	11.53	5.77	96.17	3.49	4.4
B	2	16.96	8.48	141.33	3.49	6.5
C	2	230.34	115.17	1919.50	3.49	88.6
Error	20	1.27	0.06			0.5
Total	26	260.10				100

Table-7 ANOVA for surface roughness (R_a) on machining of EN-19 material using uncoated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS_E	Ftab 95% CI	P=(SS/SS_T)*100
A	2	1.76	0.88	9.46	3.49	1.6
B	2	103.69	51.85	557.53	3.49	93.7
C	2	3.32	1.66	17.85	3.49	3.0
Error	20	1.87	0.093			1.7
Total	26	110.64				100

Table-8 ANOVA for surface roughness (R_a) using Signal - to – Noise ratio on machining of EN-19 material using uncoated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS_E	Ftab 95% CI	P=(SS/SS_T)*100
A	2	7.07	3.54	22.12	3.49	1.4
B	2	474.97	237.48	1484.25	3.49	95.9
C	2	10.06	5.03	31.44	3.49	2.0
Error	20	3.29	0.16			0.7
Total	26	495.39				100

Table-9 ANOVA for surface roughness (R_a) on machining of EN-19 material using coated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS_E	Ftab 95% CI	P=(SS/SS_T)*100
A	2	0.562	0.281	70.25	3.49	31.7
B	2	0.445	0.223	55.75	3.49	25.1
C	2	0.693	0.347	86.75	3.49	39.0
Error	20	0.075	0.004			4.2
Total	26	1.775				100

Table-10 ANOVA for surface roughness (R_a) using Signal - to - Noise ratio on machining of EN-19 material using coated carbide cutting tool.

Factor	DOF	SS	MSS = SS/DOF	Fcal=MSS/MSS_E	Ftab 95% CI	P=(SS/SS_T)*100
A	2	27.496	13.748	42.043	3.49	31.2
B	2	22.265	11.132	34.043	3.49	25.3
C	2	31.848	15.924	48.697	3.49	36.1
Error	20	6.548	0.327			7.4
Total	26	88.157				100

Table 3 indicates that the depth of cut has a significant contribution (74.1%), compared to feed rate (18.5%) and cutting speed (3.3%). The S/N ratio for cutting force (F_Y) of uncoated carbide cutting tool also exhibits similar trends and these are tabulated in Table 4.
Table 5 indicates that the depth of cut has a significant contribution (86.7%), compared to feed rate (7.1%) and cutting speed (4.6%). The S/N ratio for cutting force (F_Y) of coated carbide cutting tool also exhibits similar trends and these are tabulated in Table 6.
Table 7 indicates that the feed rate has a significant contribution (93.7%), compared to depth of cut (3.0%) and cutting speed (1.6%). The S/N ratio for surface roughness (R_a) of uncoated carbide cutting tool also exhibits similar trends and these are tabulated in Table 8.
Table 9 indicates that the depth of cut has a significant contribution (39%), compared to cutting speed (31.7%) and feed rate (25.1%). The S/N ratio for surface roughness (R_a) of coated carbide cutting tool also exhibits similar trends and these are tabulated in Table 10.

Estimating the optimal cutting force and surface roughness of both uncoated carbide and coated carbide cutting tool.
The optimal cutting force (μ_{CF}) is predicted at the selected optimal setting of process parameters. The mean values of cutting force of uncoated carbide cutting tool for various cutting speed, feed rate and depth of cut are shown in Table 11. The average value of cutting force ($\overline{T_{cf}}$) is determined from Table 2 i.e., 639.63 N. In order to determine the estimated mean of the response characteristics (μ_{CF}) of cutting forces on individual process parameter is Lower the Better (LB) characteristic is considered. Hence the cutting speed (A_1) 101.8 m/min, feed rate (B_1) 0.125 mm/rev and depth of cut (C_1) 0.5 mm respectively. The corresponding mean values of the cutting forces are 595.6 N, 504.4 N and 383.3 N respectively.
The estimated mean of the response characteristics can be computed as

$$\mu_{CF} = \overline{A_1} + \overline{B_1} + \overline{C_1} - 2^* \overline{T_{cf}} \quad (3)$$

and co-efficient of $\overline{T}$ in the equation is one less than the number of items added to estimate the mean, and the mean value (μ_{cf}) is 204 N.
The confidence interval is a maximum and minimum value between which the true average should fall at 95% confidence. The Confidence Interval (CI) is computed from equation 2 and the value is ± 127.64.
The 95% confidence interval of the predicted optimal cutting force is

$$(\mu_{CF} - CI) < \mu_{CF} < (\mu_{CF} + CI) \quad (4)$$

The predicted optimal cutting force is determined from equation. The maximum value (μ_{cf} + CI) is 332 N and the minimum value (μ_{cf} - CI) is 76 N respectively.

Table-11 The mean values of cutting force (F_Y) on various process parameters by machining on EN-19 material using uncoated carbide cutting tool

$\overline{A_1}$	595.6	$\overline{B_1}$	504.4	$\overline{C_1}$	383.3
$\overline{A_2}$	625.6	$\overline{B_2}$	666.7	$\overline{C_2}$	657.8
$\overline{A_3}$	697.8	$\overline{B_3}$	747.8	$\overline{C_3}$	877.8

In a similar way the optimization of cutting force of coated carbide cutting tool insert is determined. The average value of cutting force ($\overline{T_{cf}}$) is determined from Table 2 i.e., 346.3 N. The mean value of the individual process parameters of cutting force are tabulated in Table 12. In order to determine the estimated mean of the response characteristics (μ_{CF}) of cutting force on individual process parameter is Lower the Better (LB) characteristic is considered. Hence the cutting speed (A_1) 101.8 m/min, feed rate (B_1) 0.125 mm/rev and depth of cut (C_1) 0.5 mm respectively. The corresponding mean values of the cutting forces are 322.2 N, 304.4 N and 214.4 N respectively.
The estimated mean of the response characteristic is computed and the mean value (μ_{CF}) is 148.4 N. The confidence interval is a maximum and minimum value between which the true average should fall at 95% confidence. The Confidence Interval (CI) is computed and the value is ± 42.3.
The predicted optimal cutting force is determined. The maximum value (μ_{CF} + CI) is 191 N and the minimum value (μ_{CF} - CI) is 106 N respectively.

Table-12 The mean values of cutting force (F_Y) on various process parameters by machining on EN-19 material using coated carbide cutting tool

$\overline{A_1}$	322.2	$\overline{B_1}$	304.4	$\overline{C_1}$	214.4
$\overline{A_2}$	334.4	$\overline{B_2}$	352.2	$\overline{C_2}$	335.6
$\overline{A_3}$	382.2	$\overline{B_3}$	382.2	$\overline{C_3}$	488.9

The average value of surface roughness ($\overline{T_{Ra}}$) of uncoated carbide cutting tool is determined from Table 2 i.e., 4.586 µm. The mean value of the individual process parameters of surface roughness are tabulated in Table 13. In order to determine the estimated mean of the response characteristics (μ_{Ra}) of surface roughness on individual process parameter is Lower the Better (LB) characteristic is considered. Hence the cutting speed (A_2) 222.4 m/min, feed rate (B_1) 0.125 mm/rev and depth of cut (C_1) 0.5 mm respectively. The corresponding mean values of the surface roughness are 4.23 µm, 2.17 µm and 4.29 µm respectively.
The estimated mean of the response characteristic is computed and the mean value (μ_{Ra}) is 1.518 µm. The confidence interval is a maximum and minimum value between which the true average should fall at 95% confidence. The Confidence Interval (CI) is computed and the value is ± 0.714.
The predicted optimal surface roughness is determined. The maximum value (μ_{Ra} + CI) is 2.232 µm and the minimum value (μ_{Ra} - CI) is 0.804 µm respectively.

Table-13 The mean values of surface roughness (R_a) on various process parameters by machining on EN-19 material using uncoated carbide cutting tool

$\overline{A_1}$	4.78	$\overline{B_1}$	2.17	$\overline{C_1}$	4.29
$\overline{A_2}$	4.23	$\overline{B_2}$	4.62	$\overline{C_2}$	4.39
$\overline{A_3}$	4.75	$\overline{B_3}$	6.97	$\overline{C_3}$	5.08

The average value of surface roughness ($\overline{T_{Ra}}$) of coated carbide cutting tool is determined from Table 2 i.e., 1.334 µm. The mean value of the individual process parameters of surface roughness are tabulated in Table 14.
In order to determine the estimated mean of the response characteristics (μ_{Ra}) of surface roughness on individual process parameter is Lower the Better (LB) characteristic is considered. Hence the cutting speed (A_2) 222.4 m/min, feed rate (B_1) 0.125 mm/rev and depth of cut (C_1) 0.5 mm respectively. The corresponding mean values of the surface roughness are 1.138 µm, 1.167 µm and 1.154 µm respectively.
The estimated mean of the response characteristic is computed and the mean value (μ_{Ra}) is 0.791µm. The confidence interval is a maximum and minimum value between which the true average should fall at 95% confidence. The Confidence Interval (CI) is ± 0.148.
The predicted optimal surface roughness is determined, the maximum value (μ_{Ra} + CI) is 0.939 µm and the minimum value (μ_{Ra} - CI) is 0.643 µm respectively.

Table-14 The mean values of surface roughness (R_a) on various process parameters by machining on EN-19 material using coated carbide cutting tool

$\overline{A_1}$	1.382	$\overline{B_1}$	1.167	$\overline{C_1}$	1.154
$\overline{A_2}$	1.138	$\overline{B_2}$	1.356	$\overline{C_2}$	1.303
$\overline{A_3}$	1.481	$\overline{B_3}$	1.479	$\overline{C_3}$	1.543

3.1 Confirmation Experiment

The confirmation experiment after performing the machining operation for the optimal process parameters selected from the optimization of cutting force is A_1, B_1 and C_1 i.e., for cutting speed of 101.8 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm using uncoated carbide cutting tool on EN-19 material, the value of cutting force measured is 270 N, as shown in Table 2, which is within the range of predicted optimal cutting force having the maximum value (μ_{cf} + CI) is 332 N and the minimum value (μ_{cf} - CI) is 76 N respectively.
In a similar way the optimization of process parameters selected for cutting force is A_1, B_1 and C_1 i.e., for cutting speed of 101.8 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm using coated carbide cutting tool on EN-19 material, the value of cutting force measured is 180 N as shown in Table 2, which is within the range of predicted optimal cutting force having the maximum value (μ_{cf} + CI) is 191 N and the minimum value (μ_{cf} - CI) is 106 N respectively.
The optimization of process parameters selected for surface roughness is A_2, B_1 and C_1 i.e., for cutting speed of 171.5 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm using uncoated carbide cutting tool on EN-19 material, the value of surface roughness measured is 1.75 µm, as shown in Table 2, which is within the range of predicted optimal surface roughness having the maximum value (μ_{Ra} + CI) is 2.232 µm and the minimum value (μ_{Ra} - CI) is 0.804 µm respectively.
The optimization of process parameters selected for surface roughness is A_2, B_1 and C_1 i.e., for cutting speed of 171.5 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm using coated carbide cutting tool on EN-19 material, the value of surface roughness measured is 0.73 µm, as shown in Table 2 which is within the range of predicted optimal surface roughness having the maximum value (μ_{Ra} + CI) is 0.939 µm and the minimum value (μ_{Ra} - CI) is 0.643 µm respectively.

4. CONCLUSION

1. The depth of cut has a signification contribution in cutting force of both uncoated and coated carbide cutting tool, while the feed rate is having a significant contribution for surface roughness of uncoated carbide cutting tool and in case of coated carbide cutting tool the depth of cut is having a significant contribution.
2. The confirmation of experiment after conducting the trials, the cutting force (F_Y) measured is 270 N for uncoated carbide cutting tool. By using the Taguchi technique for setting the optimal process parameters for cutting force (F_Y) are cutting speed 101.8 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm.
3. The confirmation of experiment after conducting the trials, the cutting force (F_Y) measured is 180 N for coated carbide cutting tool. By using the Taguchi technique for setting the optimal process parameters for cutting force (F_Y) are cutting speed 101.8 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm.

4. The confirmation of experiment after conducting the trials, the surface roughness (R_a) measured is 1.75 µm for uncoated carbide cutting tool. By using the Taguchi technique for setting the optimal process parameters for surface roughness (R_a) are cutting speed 171.5 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm.
5. The confirmation of experiment after conducting the trials, the surface roughness (R_a) measured is 0.73 µm for coated carbide cutting tool. By using the Taguchi technique for setting the optimal process parameters for surface roughness (R_a) are cutting speed 171.5 m/min, for feed rate of 0.125 mm/rev and for depth of cut 0.5 mm.

5. REFERENCES

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