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EXPERIMENTAL INVESTIGATION AND ANALYSIS OF SURFACE ROUGHNESS PARAMETERS IN HARD TURNING OF AISI D2 STEEL USING COATED CARBIDE TOOLS

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ABSTRACT

In the present work, hard turning of AISID2 Steel were carried out on CNC turning centre using TiCN coated carbide tools to investigate the effect of cutting parameters on surface roughness parameters (Ra, Rq, Rz) The statistical models were developed using the Taguchi method to find the effect of cutting parameters (speed, feed, and depth of cut) on surface roughness parameters. L9 orthogonal array is designed for the experiments and experiments were carried out for one, two and three passes to evaluate the optimum roughness value of the surface roughness parameters. It was observed from the results that the feed rate played an important role with surface parameters.

Keywords: AISI D2 steel, Coated carbide tool, Hard turning, Surface roughness parameter and DOE

1. Introduction

Hard turning is generally considered as a finishing operation of hard material in the range of 45-68 Rockwell hardness and it is a good alternative to grinding. As hard turning is considered as a finishing operation so, it has direct comparison with the grinding operation. Therefore, the cutting parameters of hard turning should be selected in such a way that it gives a good surface finish as compared to grinding. Turning is the most important machining operation in the metal removal process of the lathe machine, which is used to remove unwanted materials of work piece to the required size and shape. The hard turning in the present work is done at 56HRC, therefore higher precision is required as compared to grinding, it is done with a carbide tool and a CNC machine. Nowadays, Hard turning is widely used for bearing materials, Jigs, Dies etc. hence, it required advance technologies for the machining of hardened steels with high metal removal rate. Moreover, in hard turning different types of advance machine tools & cutting tools like carbide insert, CBN, ceramic tool etc. Additionally, turning with the CBN tool can replace grinding operations on such surfaces but Ra, values obtained with this tool were always lower than 0.8 microns and mixed ceramic tools are not suitable to replace grinding in such an operation [1]. Also, in advance machining operation more work has been reported on materials like SS204, 304, 201, AND EN31 alloy steel incorporation with these AISI D2 steel has very less literature reported. So, more investigation is required for AISID2 steel with varied cutting parameters such as depth of cut, feed rate, and cutting speed; analysis which reveals as a great impact on surface roughness [3,4]. Beside this coated carbide insert possess good characteristics than ceramic, which is costlier than coated carbide. These coated carbide inserts are more suitable for this type of operation due to high hardness, wear resistance ability and also possess good chemical stability. Moreover, insert nomenclature also supports high material removal rate. By contrast with these characteristics' carbide insert has high hardness than ceramic tool at both elevated and cryogenic temperature [2]. Surface roughness based on simultaneous interaction effect of three variables (V, f and r that is cutting speed, feed rate and nose radius) [5, 6]. Additionally, the Taguchi design is used to develop the statistical model of cutting parameters (speed, feed and depth of cut) on surface roughness. For this selected pattern is applied for the investigation. First, of all, the cutting speed 80m/min is taken with a feed value of 0.08, 0.12 and 0.16 later on speed change with 100 & 120 m/min but the fed is the same as 0.08, 0.12, & 0.16 to evaluate the optimum roughness value by using a carbide tool on AISID2 Steel. Moreover, investigation on the effect of cutting parameter (speed, feed and depth of cut) on various surface roughness parameters (Ra, Rq, Rz) were carried out on CNC lathe using the prefixed cutting condition. So, to analyze the specific cutting parameters to evaluate the roughness parameter of AISID2 steel, machining an experimental design plan

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adopted thereafter. For the machining CVD coated TiCN carbide insert is used because another technique is PVD which is not applicable to this investigation because in [7] found evident from the SEM images of the worn out insert, tool wear at the different regions increased with the increase in turning length. This method deposits thin films on the cutting tools through physical techniques, mainly sputtering and evaporation. The peak machined surface temperature to the white layer formation is used to determine the tool life in hard turning [8].

2. Experimental Procedure

2.1 Material Selection (AISI D2 Steel)

AISI D2 Steel is an air-hardening, high carbon, and high stainless steel. It has high wear and abrasion resistant properties. It is heat treatable and will offer hardness in the range of 46 to 56 HRC and it can be machined within the annealed condition [1]. AISI D2 Steel work piece was procured with a length of 1000 mm x 50 mm diameter and cut into 5 equal pieces. The material is having density 7.7g/cm³ and weight 3.24 Kg. The cutting parameters selected as cutting speed, feed, depth of cut and number of passes. The chemical compositions range available for AISI D2 Steel is shown in Table 1.

Table 1 Range of AISI D2 steel [1]

Carbon	Molybdenum	Silicon	Chromium	Vanadium
1.4-1.6	0.6-0.8	0.6-0.8	11.00-13.00	0.090-1.10

The heat treatment process was carried out on AISI D2 steel to get 50 HRC hardness. First, the annealing is done in a closed furnace at 900°C temperature and workpieces were kept in the enclosed furnace up to 4 hours of holding time and then slowly cooled at the rate of 20°/hr to bring at 500°C, then after the furnace was opened and workpieces were allowed to cool in the furnace itself. Then quenching was carried an oil tank with a capacity of storage of 10,000 litters of reusable oil for 1 hour. After this, AISID2 steel normally shows a slight amount of contraction in size. So, the tempering was done at 450°C for neutralizing the shrinkage and brings back the work pieces to its original size. The double tempering was carried out to neutralize the shrinkage [3].

2.2 Tool Selection

From the literature, it is found that Cubic Boron Nitride (CBN) and Ceramics tools are widely used to machine hardened alloy steel. CBN tools perform better for AISI 4340 harden steel than ceramic. Some researchers have also compared the performance of coated carbide inserts with CBN and ceramics [9, 10]. The cost of carbide tools is also low as compared to CBN tools [2,6,11,12]. Therefore, in present work, TiCN coated carbide insert with CVD coating of Sandvik-Coromat having insert is selected for machining AISID2 hardened steel. The insert has new petit cut geometry with 55° rhombic shape and 0° relief angle its tolerance class is with symbol M with tolerance of noise height ± 0.08-0.18 mm, inscribed circle ±0.05-0.15 mm and thickness of ±0.13 mm in additional to this insert size having diameter 12.07 mm of inscribe circle and insert corner configuration of 0.8 mm corner radius with neutral cutting direction.

2.3 Machine Tool Selection

All experiments were carried out on CNC turning centre (Make: Jyoti; Model: DX 200 3A) under dry condition with the following specification: Highest power available: 20 KW, programmable speed range: 50 to 400 rpm, chuck size: 400 mm, maximum job diameter turned: 200 mm, distance between centers: 1085 mm and CNC 828D Siemens controller. The three different input parameters (cutting speed, feed rate and depth of cut) are selected with its three different levels as shown in Table 2. Total nine experiments (L9 Orthogonal Array) are designed as per the Taguchi robust design technique. Total nine experiments carried out three times with one, two and third passes and output parameters are measured such as Ra, Rq and Rz. The total 27 experiments are shown in Table 2. The Taguchi robust design technique is used to reduce the process variation through robust design of experiments [10].

Table 2 Factors and their level

Factors	Column	Level 1	Level 2	Level 3
Cutting Speed (m/min)	A	80	100	120
Feed (mm/rev)	B	0.08	0.12	0.16
Depth of Cut (mm)	C	0.3	0.4	0.5

The surface profilometer is used to measure a surface profile of the workpiece (Make: Mitutoyo: Model: SJ-210). The surface roughness tester was used during the experiments with cutoff wave length 0.8 mm over four sampling lengths. AISID2 steel round bar was marked at 120° on its circumference to measure average surface roughness values. A diamond stylus is moved vertically in contact with a sample distance and specified contact force. It can measure small surface variation in vertical stylus displacement as a function of position. The height of the diamond stylus generates analog signal which is converted into a digital signal stored, analyzed and displayed [11].

Table 3 L9 Orthogonal Array (Experiment Run with level combination)

Exp-Run	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Pass
Sr. no	A	B	C	D
1	80	0.08	0.3	1
2	80	0.12	0.4	1
3	80	0.16	0.5	1
4	100	0.08	0.4	1
5	100	0.12	0.5	1
6	100	0.16	0.3	1
7	120	0.08	0.5	1
8	120	0.12	0.3	1
9	120	0.16	0.4	1
10	80	0.08	0.3	2
11	80	0.12	0.4	2
12	80	0.16	0.5	2
13	100	0.08	0.4	2
14	100	0.12	0.5	2
15	100	0.16	0.3	2
16	120	0.08	0.5	2
17	120	0.12	0.3	2
18	120	0.16	0.4	2
19	80	0.08	0.3	3
20	80	0.12	0.4	3
21	80	0.16	0.5	3
22	100	0.08	0.4	3
23	100	0.12	0.5	3
24	100	0.16	0.3	3
25	120	0.08	0.5	3
26	120	0.12	0.3	3
27	120	0.16	0.4	3

Table 4 L9 Orthogonal Array (Experiment Runs with level)

Exp-Run	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	No of Passes	Ra (μm)	Rq (μm)	Rz (μm)
Sr. no	A	B	C	D			
1	80	0.08	0.3	1	0.603	0.489	1.978
2	80	0.12	0.4	1	0.881	1.173	4.091
3	80	0.16	0.5	1	1.56	1.939	7.056
4	100	0.08	0.4	1	1.424	1.665	5.765
5	100	0.12	0.5	1	2.377	2.838	9.754
6	100	0.16	0.3	1	1.635	1.958	6.643
7	120	0.08	0.5	1	1.675	1.994	6.998
8	120	0.12	0.3	1	0.191	0.233	0.858
9	120	0.16	0.4	1	0.291	0.378	1.483
10	80	0.08	0.3	2	1.73	2.702	7.96
11	80	0.12	0.4	2	0.622	0.753	2.576
12	80	0.16	0.5	2	1.587	1.999	7.094
13	100	0.08	0.4	2	1.837	2.785	6.635
14	100	0.12	0.5	2	1.993	2.501	8.261
15	100	0.16	0.3	2	0.951	1.229	4.329
16	120	0.08	0.5	2	0.821	1.057	4.028
17	120	0.12	0.3	2	1.627	1.9	6.604
18	120	0.16	0.4	2	0.96	1.206	4.526
19	80	0.08	0.3	3	0.735	0.922	3.405
20	80	0.12	0.4	3	1.915	2.352	7.594
21	80	0.16	0.5	3	2.501	3.072	11.352
22	100	0.08	0.4	3	2.393	2.767	9.413
23	100	0.12	0.5	3	2.258	2.74	9.743
24	100	0.16	0.3	3	1.617	2.052	6.905
25	120	0.08	0.5	3	2.031	2.475	8.842
26	120	0.12	0.3	3	0.397	0.484	1.768
27	120	0.16	0.4	3	0.765	0.97	3.635

3. Result And Discussion

The acquired R-Sq value for Ra, MRR and CC is found to be 99.4%, 99.4%, 99.27% and 98.38% correspondingly, which indicates that the regression models are greatly significant for AISI 4340 steel as observed by [12,13]. Whereas, the result obtained from the experimental investigation of hard turning is mentioned in this with the average of three readings and its statistically analysis of variance of Ra is found with feed having 0.000 P-values mentioned in table 5. This means that the model explains variation in the response, having R^2 increase with value 90% as declared in

Table 6. Hence the selected parameter proves to be good for the surface finish while hard turning of AISID-2 steel. Result for machining parameter of different roughness value of Ra, Rq and Rz on AISI D2 Steel hard turned by coated carbide tool. The result of all roughness parameters are as determined below & their value checked as significant as p value is less than 0.005. The percent contribution is obtained by summing all the sum of squares term (SS) and then taking each individual SS and dividing by the total SS and multiplying by 100.

3.1 Analysis of Variance Ra

Table 5 Analysis of Variance for Ra

Source	DF	Adj sum of Square	Adj mean square	F-Value	P-Value	% Contributi	Remark
Regression	3	3.35298	1.11766	25.109	0.002		Significant
Speed	1	0.43148	0.43148	9.72	0.026	12.07	Significant
Feed	1	2.92043	2.92043	65.82	0.000	81.70	Significant
DOC	1	0.00107	0.0010	0.02	0.883	0.03	Non-Significant
Error	5	0.22187	0.04437	*	*		
Total	8	3.57485	*	*	*		

Table 6 Model Summary for Ra

R^2	R^2 (adj)	R^2 (pred)
93.79%	90.07%	76.36%

Regression Equation

$$Ra = -2.032 + 0.01341 \times S + 17.44 \times F - 0.133 \times DOC \quad (1)$$

The regression equation - 1 is a linear model which takes the form $Y = b_0 + b_1X_1$. In the regression equation, Ra = response variable, -2.03 is constant or intercept, 0.01341(S) is the estimated co-efficient for the linear term, 17.44 (f) is the intercept and -0.133(f) is value of term with depth of cut to obtain the surface roughness (Ra) response. The ANOVA analysis indicates that the feed rate is the most significant parameter for surface roughness followed by cutting speed, and contributes about 81.70% and 12.07% respectively in total variability.

The surface finish is continuously decreased with increasing in cutting speed as observed by [13]. For AISID2 steel, the surface finish little improved with increasing feed rate (0.08 to 0.12mm/rev) and then decreasing with increase in feed rate from 0.12 mm/min to 0.16 mm/min. Furthermore, table no. 6 depicts that the R2 = 93.79% means model used to determine the maximum surface roughness is closely related to R2 (adj) = 90.07% and it is more affected by feed than depth of cut with model terms at 95% confidence level.

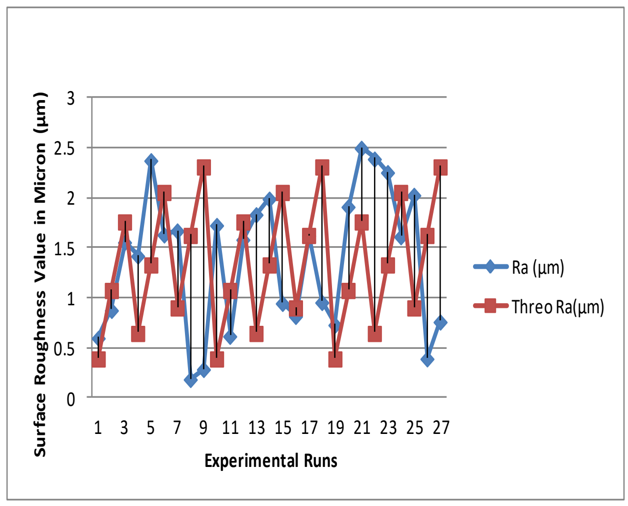

Fig. 1 Ra (Theo) Vs Ra (Actual) Comparison

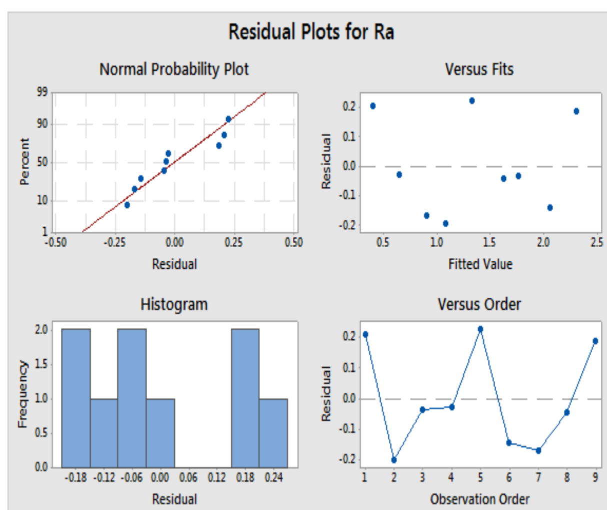

Fig. 2 Residual plot for Ra

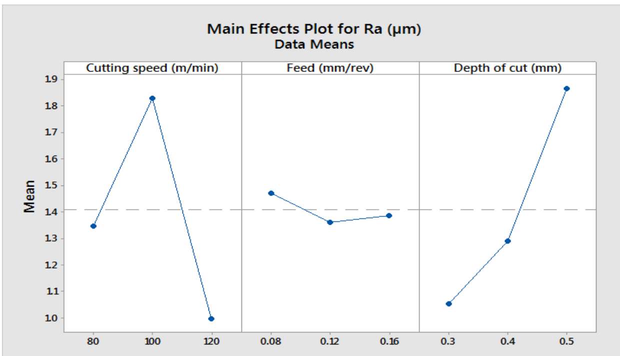

Fig. 3 Main Effect Plot Ra

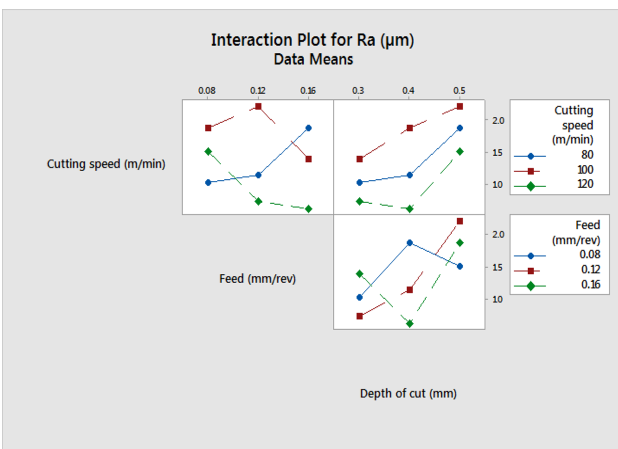

Fig. 4 Interaction Plot for Ra

From the fig.1 it was analyzed that there is a close tolerance between Ra experimental (Actual), theoretical and by regression equation. Fig. 2 shows the residual plot of observed y-value and predicted y-value with small vertical distance from the actual plotted point to the point on the regression line shows very little error. Normal plot can also result in the data fitting in a normal distribution. While the main effect plot indicates the roughness value of Ra with feed and cutting speed in Fig 3, which shows the mean response of each level factors connected with the parameters. Similarly, it also compared interaction with the depth of cut and feed which show combine relationship with roughness parameter in Fig.4 and also represents the effect of input parameters with Ra.

Table 7 Analysis of Variance for Rq

Source	DF	Adj sum of Square	Adj mean Square	F-Value	P-Value	% Contribution	Remark
Regression	3	6.45364	2.15121	43.10	0.001		Significant
Speed	1	0.44227	0.44227	8.86	0.031	6.60	Significant
Feed	1	5.92424	5.92424	118.68	0.000	88.38	Significant
DOC	1	0.08712	0.08712	1.75	0.244	1.30	Non-Significant
Error	5	0.24959	0.04992	*	*		
Total	8	6.70322	*	*	*		

Table 8 Model Summary for Rq

R^2	R^2 (adj)	R^2 (pred)
96.28%	94.04%	85.37%

Regression Equation

$$Rq = -3.109 + 0.01358 \times S + 24.84 \times f + 1.205 \times DOC \quad (2)$$

Here, the value of R^2 value is shown table 8 is 96.28% and table 7 represents the feed value of P-Value significant with strongly agreed to reject null hypothesis. Moreover, R^2 adj (94.04%) is also close to each other which prove that the feed having a high contribution in Rq with strongly agrees to reject the null hypothesis. The response variable Rq from equation 2 interpreted as Rq is the response of analysis, -3.109 is a constant, 0.01358 X S is constant with intercepts speed, 24.84 X f is the estimated coefficient for the estimated coefficient for linear intercepts feed and 1.205 X doc is for the depth of cut. Fig 5 shows close value of experimental and theoretical value of Rq. Here, the feed 0.08 and 0.12 with speed 120m/min are in better agreement while other parameters are less in conciliation.

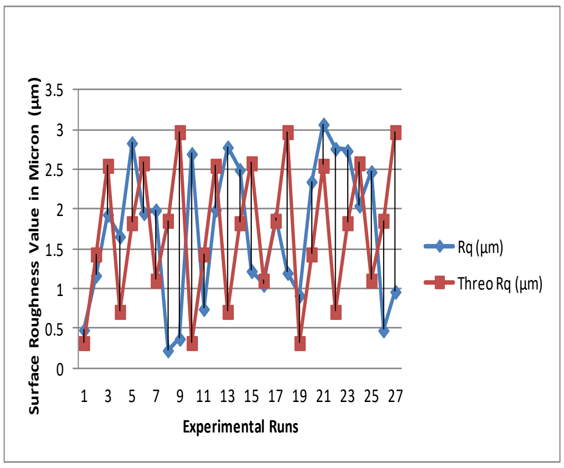

Fig. 5 Rq (Theo) Vs Rq (Actual) Comparison

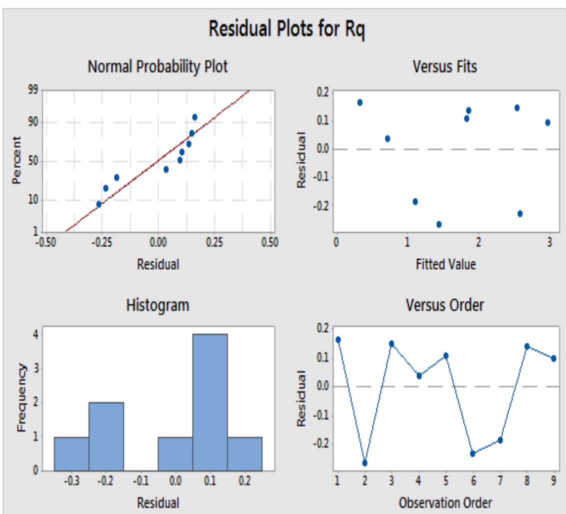

Fig. 6 Residual plot for Rq

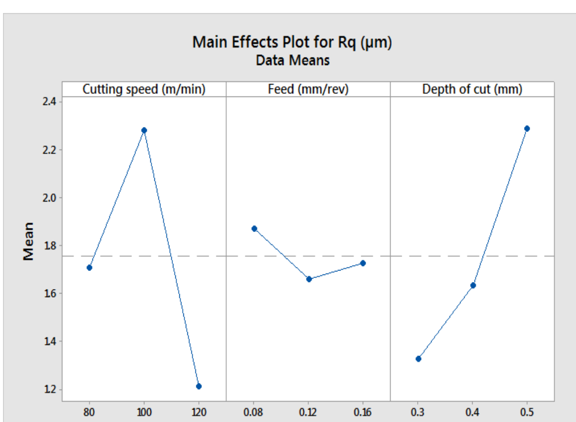

Fig. 7 Main Effect Plot Rq

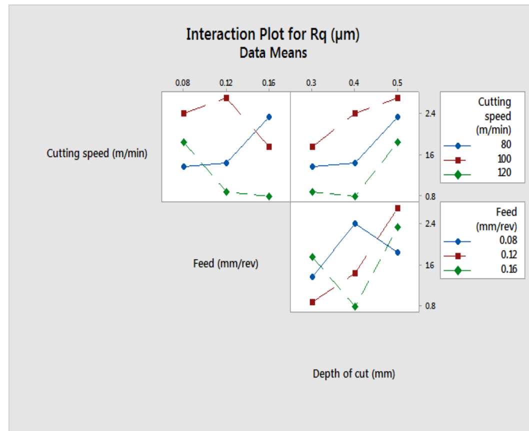

Fig. 8 Interaction Plot for Rq

Roughness term Rq called as root mean square height has the effect of cutting speed is minor but feed will highly affect the Rq as per the observation in table 7 & 8. Likewise, Fig 6 represents the residual plot showing close to the mean line with less observed error and fit to the normal distribution. In Fig 7 the surface response of Rq mean with the related effect of feed, depth of cut (DOC) and cutting speed respectively. Additionally, in Fig 8, interaction of three parameters of data plotted with respect to Rq to shows contribution in Rq.

Table 9 Analysis of Variance for Rz

Source	DF	Adj sum of square	Adj mean square	F-Value	P-Value	% Contribution	Remark
Regression	3	70.5421	23.5140	23.58	0.002		Significant
Speed	1	10.1973	10.1973	10.23	0.024	13.50	Significant
Feed	1	59.8315	59.8315	60.00	0.001	79.22	Significant
DOC	1	0.5133	0.5133	0.51	0.505	0.68	Non-Significant
Error	5	4.9860	0.9972	*	*		
Total	8	75.5281	*	*	*		

Table 10 Model Summary for Rz

R^2	R^2 (adj)	R^2 (pred)
93.40%	89.44%	73.40%

Regression Equation

$$Rz = -11.26 + 0.0652 \times S + 78.9 \times f + 2.93 \times DOC \quad (3)$$

The ANOVA and model summary for Rz (Mean roughness depth) are shown in table 9 and 10 respectively. The model is significant and shows that feed is dominant parameter and contribute 79.22 of total variability whereas cutting speed is the second parameter influences the Rz and contribute 13050% of total variability. From table 10, it can be seen that R^2 is 93.40% which is close to R^2adj (89.445) value hence the feed has a significant effect to reject the null hypothesis. Regression equation 3 mentioned is also derived for Rz as a mean square depth -11.26 is constant, 0.0652 X S is an estimated coefficient for speed while other are for feed and depth of cut. In Fig 9 uses regressions equation with the actual value for close comparison which accord that the experimental runs have greater closeness with the theoretical value. Moreover, the surface roughness value mostly depends on the feed rate, whereas the cutting-speed and work-piece hardness are the secondary factors in the analysis.

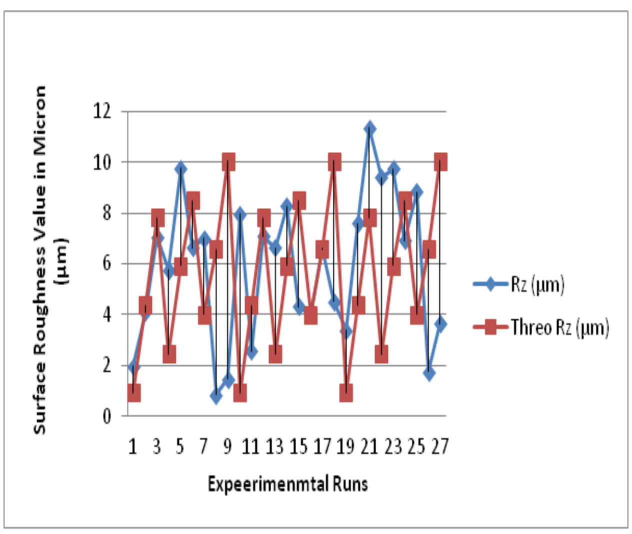

Fig. 9 Rz (Theo) Vs Rz (Actual) Comparison

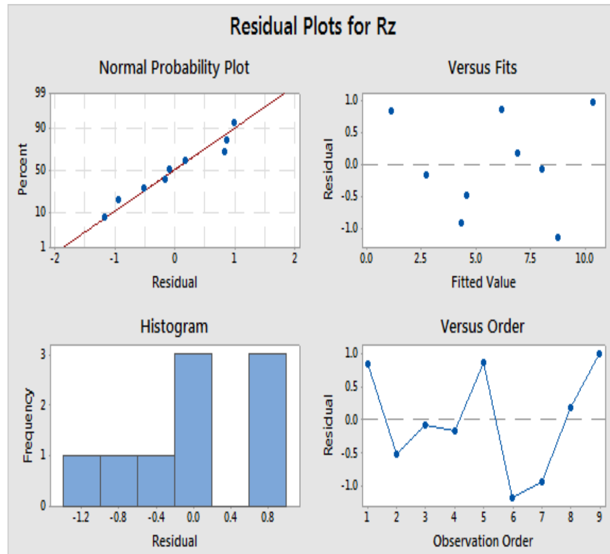

Fig. 10 Residual Plot for Rz

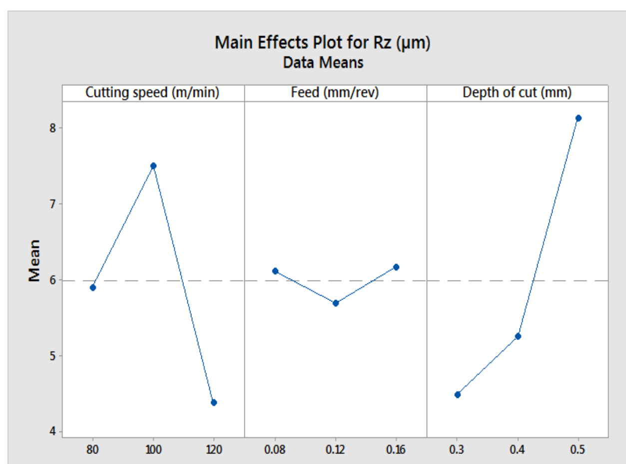

Fig. 11 Main Effect Plot for Rz

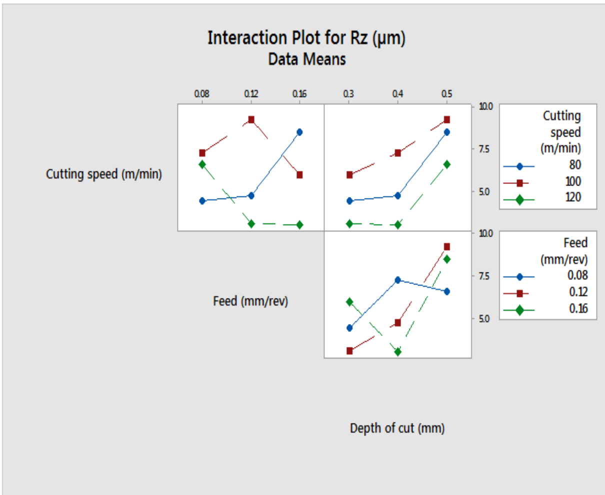

Fig. 12 Interaction Plot for Rz

The numerical optimization finds a point that maximizes the desirability function as mentioned in [14]. Fig 10 is for the residual plot for close tolerance in observed error leads to a normal distribution. The Fig 11 and Fig.12 depict for the Rz deviation with different comparison of the cutting parameters. After comparing all the results, it can conclude that the surface properties improved in hard turning (dry medium) with the depth of cut parameter range from 0.3 to 0.5 mm. If the depth of cut is more than 0.5, the roughness value increases. Optimum parameter for AISI A2 steel observed at 150m/min speed, 0.05 mm/rev feed, 0.2 mm depth of cut and similar observation is made by [15,16]. However, for AISI D2 steel 100 to 120 m/min speed ranges are proved to be optimum as per the investigation Carried out. In Fig 11 the trend of mean stands for the Rz while in Fig, 12 interaction plots decide close comparison of all three parameters with the response.

4. Conclusion

From the investigation, it has been concluded that the coated carbide tool out performs well with selected parameters. It is found that feed rate is a principle parameter that influences the surface finish significantly. The surface roughness slightly improves as feed increases from 0.12 to 0.16 mm/rev with depth of cut 0.4 to 0.5 mm after that surface finish deteriorates with increase in feed rate. For Ra, Rq, Rz analysis, it can be said that the null hypothesis is strongly rejected which means that feed matters more in the investigation with 82 - 93.07% contribution in the total variability as derived from the analysis. For roughness values, it is seen that cutting speed is the second influence parameter after feed rate. The cutting speed in the range of 100 to 120 m/min proved to be the best requirement to get good surface finish comparable with grinding for hard turning of AISI D2 steel using TicN coated carbide tools.

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