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Experimental Evaluation of Effect of Nose Radii and Cutting Parameters on Surface Finish in Turning EN-31 Material

Santosh Kurade¹, R. R. Malagi², S. R. Chougula³,

^{1, 2, 3}Department of Mechanical Engineering, VTU - Belagavi

Abstract: *In present day of technology development, there is big demand for light and strong materials. And in industrial sector machining these materials, and a crucial task, most goods in industry needs to go through some or the other machining operation. which demands for optimum cutting conditions with minimum amount of force generated. In the present study an attempt made to identify the optimum cutting parameters while turning most practically used industrial steel EN-31 material to collect the machining parameters, a conventional lathe fitted with a tool dynamometer is used. Cutting forces are recorded during turning operations, and surface roughness is measured afterward on various bars machined with various cutting parameters, and MRR is computed. To draw some conclusion and choose one ideal cutting condition, ANOVA analysis was undertaken. the effect of cutting parameters on the forces, surface roughness and conditions for efficient cutting, all these data are compiled and graphed. In this study low-speed turning operations gives good surface roughness, MRR is high.*

Keywords: *Cutting forces, Surface roughness, ANOVA*

I. INTRODUCTION

Metal cutting is one of the most important production activities in engineering. Highly competitive market needs items of excellent quality at minimal cost. The cost of product is determined both material cost and manufacturing cost the performance of product. Many researchers observed cutting forces during turning were analyzed. A number of researches have been done to assess the influence on surface roughness of hard turning operations of factors such as feed rate, tool nose radius, cutting speed and depth. With increasing nose radius, surface roughness decreases. Wide nose radius instruments gave a superior finish on the surface than a small tool on the nose.

In the Expertise is necessary to turn EN 31 on a conventional lathe and achieve the desired result. In our study, we aim to discover the best turning circumstances for attaining high MRR, good machining efficiency, and good surface roughness. measurement of cutting forces is part of the cutting condition measurement. Cutting factors like as speed, feed, and depth of cut all have a significant influence on performance.

In recent past, they emphasize using regression modelling in the EN 31 steel turning with (RSM) They created an empirical model with cutting parameters such cutting speed, feed rate, depth of cut, tool nose radius, and lubricant concentration as model variables and tool roughness, area as response variables [1]. On EN 8 the impact of cutting factors, on surface finish was conducted regression analysis to determine the effect of cutting parameters on surface roughness [4]. develop a force prediction model for finish machining of EN-31 steel (equivalent to AISI 52100 steel) hardened to 602 HRC with a hone edge uncoated CBN tool [11]. surface roughness does not vary considerably when the experimental depth of cut is between 0.1 and 0.3 mm [2]. the effects of various minimum quantity solid lubricant (MQSL) settings on surface roughness and tool temperature in turning EN 31 steel were investigated experimentally and the findings were compared to dry turning [10]. The optimization of machining parameters for turning various alloy steels using CNC was investigated with Taguchi and ANOVA approach were applied [3]. The test is carried out on EN 31 alloy steel with a carbide insert.

Response Surface Methodology is used to optimization, MINITAB software is utilised [5]. CNC turning of EN 24 alloy steel were investigated, and machining parameters were attempted to be optimised using a generic algorithm. They developed a mathematical model using a three-level central composite design and experimented with three machining parameters [6]. tool wear in EN-31 alloy steel turning at various cutting parameters. They used response surface technique to create a mathematical model for flank wear [8]. Analysis of Variance was used to determine the percentage contribution of each process parameter (ANOVA). Taguchi design of experiment and Analysis of Variance were used to examine the experimental data from the lathe tool dynamometer and the proposed complete bridge dynamometer [12].

II. DESCRIPTION

A. Work Piece Material

EN 31 steel was used in the experiments, which is commonly used in motive type applications such as axles, bearings, spindles, and molding dies, among others. Its chemical position and other properties are listed in the table. The experiment was carried out with a cylindrical solid bar of EN 31th dimension with a diameter of 30 mm and a length of 60 mm.

Table 1: EN 31 steel chemical composition

Constituent	(% by wt.)	specification limits as per EN 31 of BS: 970-1955
Carbon	1.069	0.90-1.20
Manganese	0.562	0.30-0.75
Chromium	1.019	1.00-1.60
Sulphur	0.068	0.050 max
Silicon	0.226	0.10-0.35
Phosphorous	0.054	0.050 max

B. Design of Experiments

By minimising product material, speeding up the design process, and reducing late engineering design modifications and labour complexity, experimental design can be employed at the point of greatest leverage to minimise design costs. When conducting the experiment, it is critical to keep a close eye on the process to verify that everything goes according to plan. In order for the results and conclusions to be objective rather than judgmental, statistical procedures should be employed to analyses the data. It's also common to describe the results of a number of experiments using MINITAB software and graphs are generated using the same software to analysis.

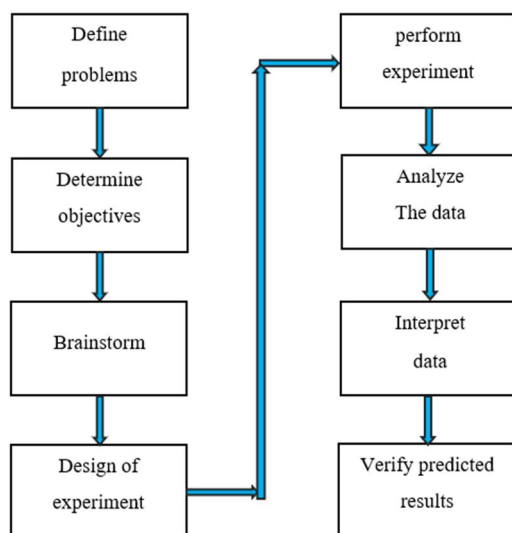
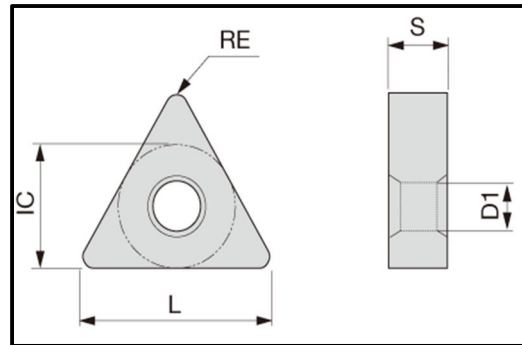


Fig.1: Flow chart of experimental design process

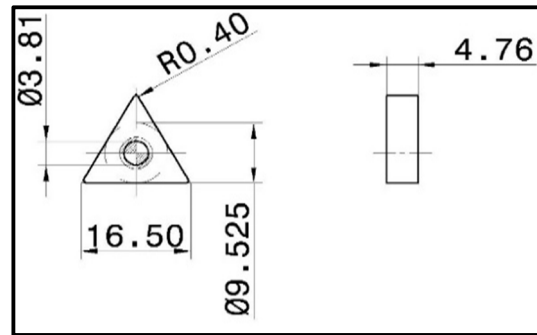
C. Cutting Tool

Coated carbide tools are known to outperform uncoated carbide tools in terms of performance. Its popularity as a tool material stems from its unique mix of wear resistance and toughness, as well as its ability to produce complex shapes. Cemented carbide with a coating is known as coated cemented carbide.

Thus, commercially available TNMG 160404-ZM or TNMG331-ZM is taken as insert and is taken as holder for conducting the experiment. The numbers and letters in the tool designations describe the shape the shape, dimensions and other important parameters. Tool used for the work is an insert carbide tool of 0.8mm and 0.4 mm nose tip radius.



(a)



(b)

Fig.2 (a) and (b): Tool insert

D. Measurement of Cutting Forces

The dynamometer is usually placed between the instrument and the object of work and the non-rotating frame of the tooling machine. This design simplifies measurement data interpretation by reducing the amount of cabling necessary to send the signal to the amplifier. This sort of dynamometer is known as a platform dynamometer. A dynamometer must be attached to the spindle in other situations, and the force must be measured in a rotating coordinate system. The weight of the dynamometer components can lower the measuring system's natural frequency to the passing frequency of the tooth in this circumstance.

Three cables at the tool post link the dynamometer to the lathe; each cable records the separate forces in the X, Y, and Z directions, which are shown on the dynamometer. F_a (horizontal, parallel to work piece, X axis), F_c (vertical, tangential force, Y axis), and lastly F_r (horizontal, perpendicular to work piece, Z axis) are the three cutting forces (along the radius of work piece, Z axis).

III. EXPERIMENTAL AND DATA COLLECTION

In the lathe machine we are consider some different cutting speed, DOC and feed are used to machining EN 31 material. In lathe operation use three-time operation in one bar to same cutting conditions. Shows the below table.

Table 2: cutting parameters

Speed (rpm)	Feed (mm/rev)			Depth of cut (mm)		
	0.2	0.24	0.28	0.3	0.5	0.7
112	0.2	0.24	0.28	0.3	0.5	0.7
180	0.2	0.24	0.28	0.5	0.7	0.3
400	0.2	0.24	0.28	0.7	0.3	0.5

A. Experimental Procedure

On a traditional lathe machine, this study is carried out. Initially, EN31 steel round bars with dimensions of $D = 30\text{mm}$, $L = 250\text{mm}$, and a number of 9 are prepared for turning and then turned on a lathe machine. Cutting forces are measured during turning and shown on a dynamometer attached to the lathe machine.

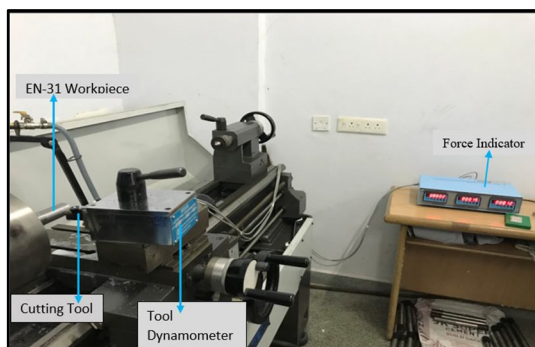


Fig.3: Conventional lathe Setup

Each EN 31 specimen is weighed using an electronic scale before and after the procedure and weighing machine that is accurate to three decimals. A total of 27 turning operations are performed on 9 bars, with the feed, speed, and depth of cut all varying. There was a total of 9 sets of different conditions, each of which was repeated three times, for a total of 27 experiments. For easier identification, each specimen is given a separate name, such as s_1 , s_2 , and so on.



Fig.5: Specimen with a label



Fig.4: Single bar with turning

Out of a 250mm bar, 200 mm is twisted first to remove any rust and defects, and the diameter is decreased from 32mm to 30 mm. Each bar is turned 60mm using varied cutting settings, and surface roughness is assessed on that 60mm turned length. The surface roughness of each bar is measured using the SURFTEST SJ-210, and the results are tabulated with other data such as MRR and cutting forces.

B. Surface Roughness

Surface roughness is defined as the imperfections on the workpiece's surface caused by the manufacturing process. It is defined as the deviations from the ideal form, in the direction of a real surface's normal vector. Surface roughness measurements must be performed on a steady, insulated, and vibration-free platform to be successful. The result of a measurement taken while being exposed to a lot of vibration might be incorrect.



Fig.6: Surface tester in action



Fig.7: Work piece marked

A special surface roughness tester machine called Mitutoyo S-210 is used to test the roughness of each specimen, each specimen machined using a specific set of machining conditions, and i.e. each machined bar indicates different set of machining conditions. A probe/stylus linked to the SJ-210's detecting unit identifies minute imperfections on the surface of the work piece During the tracing, the vertical stylus displacement is analysed and digitally displayed on the SJ-210's liquid crystal display.

IV. RESULTS AND DISCUSSION

Table 3: Optimized assigned data for 0.8mm nose radius

SI no.	Speed rpm	Feed mm/rev	DOC mm	F _a N	F _c N	F _r N	MRR grams/mim	R _a μm	Time sec	Bar
1	112	0.2	0.3	0	107.91	58.86	3.4285	3.6502	140	S ₁₀
2	112	0.24	0.5	39.24	186.39	98.1	9.4488	2.45	127	S ₈
3	112	0.28	0.7	29.43	255.06	156.96	9.0566	3.5215	106	S ₇
4	180	0.2	0.5	9.81	137.34	78.48	8.1818	2.7815	88	S ₂
5	180	0.24	0.7	29.43	196.2	117.72	12.913	3.1585	79	S ₉
6	180	0.28	0.3	0	117.72	68.67	7.1641	3.805	67	S ₅
7	400	0.2	0.7	29.43	186.39	127.53	26.3414	3.819	41	S ₃
8	400	0.24	0.3	0	98.1	58.86	11.3513	4.3037	37	S ₆
9	400	0.28	0.5	19.62	225.63	176.58	23.2258	3.7167	31	S ₄

- From the graph figure (8) it is observed that the three cutting force move in a way manner and all forces rise and dip at some points.
- Cutting force high at points 3, 5, 7 and 9, the cutting parameters are DOC 0.7 and expect last point DOC 0.5.

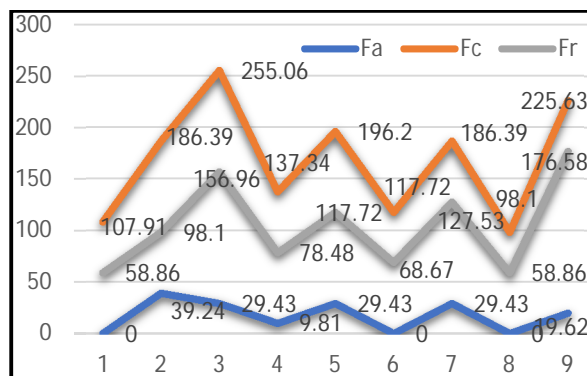


Fig.8: Cutting forces

- Low cutting force at point 1, 4, 6, 8 are observed where the depth of cut 0.3mm.

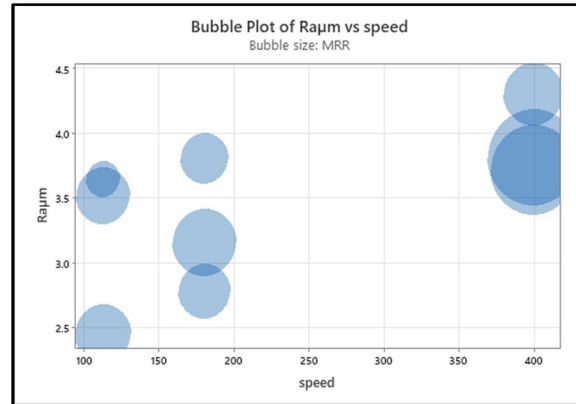


Fig.11: R_a (μm) Vs speed (rpm) and MRR

- 4) In the graph (9) surface roughness average (R_a) low at feed is 0.24 mm/rev. AT 2ND point. It will indicate the when the cutting speed is 112 Rpm, feed 0.24, DOC 0.5 respectively.

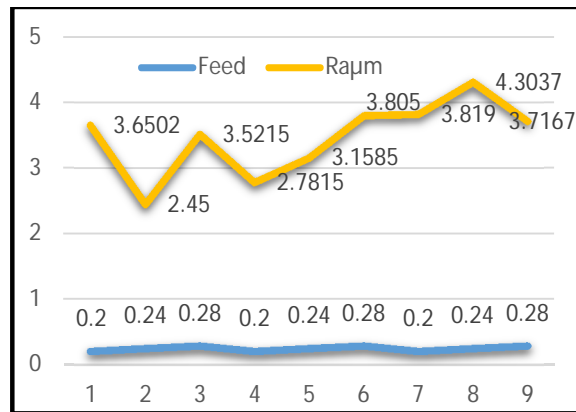


Fig.9: Feed (mm/rev) and R_a (μm) graph

- 5) MRR is high at point 8 with respect to speed 400rpm, DOC 0.4mm and Feed is 0.2mm/rev. and R_a Value also low, Feed also 0.2 mm/rev with cutting speed 400 rpm.
 6) When the cutting speed 400 rpm and R_a is 4.30 μm the MRR is high

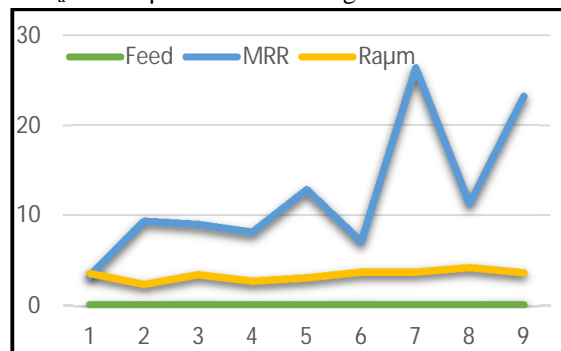


Fig.10: Graph of, Feed (mm/rev), MRR (grams/min) R_a (μm)

A. ANOVA one-way analysis by Minitab

In the single factor taking speed, feed doc are the input range factors and output range is surface roughness value.

In addition, it shows the cutting force analysis of variance. The correlation coefficient R was found to be extremely near to unity, and the tables show that the cutting force and cutting parameters have a relationship.

B. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
speed	2	1604	802.0	0.36	0.709
Error	6	13216	2202.7		
Total	8	14820			

Means				
speed	N	Mean	StDev	95% CI
112	3	104.6	49.4	(38.3, 170.9)
180	3	88.3	26.0	(22.0, 154.6)
400	3	121.0	59.1	(54.7, 187.3)

Pooled St-Dev = 46.9333

C. Analysis of variance (ANOVA) for force

The residual analysis was used to perform analytical verification of the model, and the results were given in Figure (5.9). The residuals fell on a straight line, indicating that the errors were distributed evenly. The residual with regard to the nine experimental runs is given in the following figures as a plot of residual for cutting force and residual vs run numbers for cutting force. There was no discernible pattern in the residuals, which were dispersed in both favourable and bad.

This indicates that the model was suitable and that there was no need to change it. believe that the independence or constant variance assumptions had been violated.

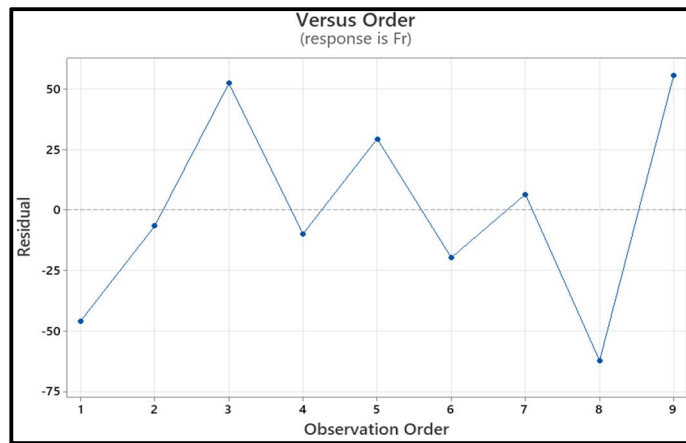


Fig.12: Residuals Vs run numbers for cutting force

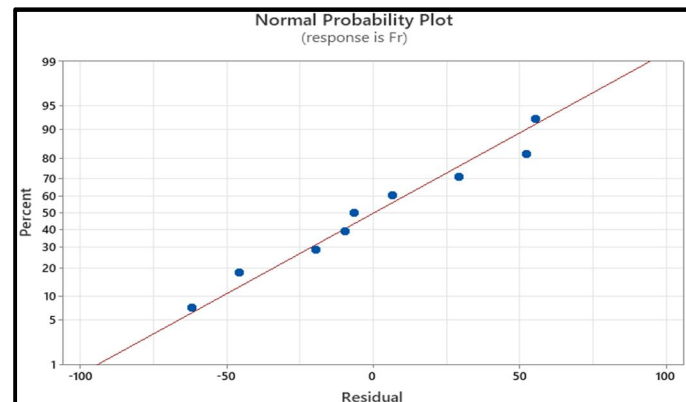


Fig.13: Normal probability plot of residual for cutting force

D. Cutting Parameters have an Effect on Forces.

To fine-tune the process for the most efficient cutting within the defined range of cutting parameters, it's important to understand the influence of cutting parameters on tool forces and surface roughness. As can be seen in the graph fig. (14 and 15) below, axial forces (F_a) increased as the depth of cut increased. Cutting speed and feed had little influence, as can be seen in the figures.

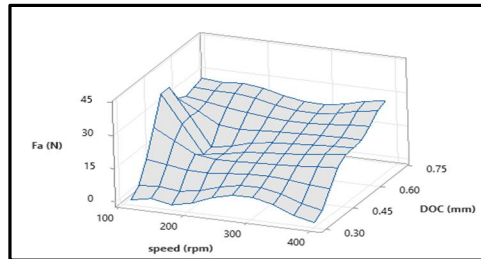


Fig.14: Variation in axial force (F_a) surface plot F_a Vs DOC, speed

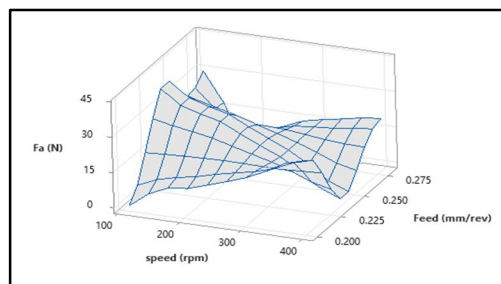


Fig.15: Variation in axial force (F_a) surface of plot of F_a Vs feed, speed

As the cut depth increased, the radial force increased as well (fig. 16). It increased as the speed increased at lower feeds (fig 16), but when the speed grew at higher feeds and deeper cuts, the radial force dropped at first, then increased somewhat (fig 16). In the United States, the tendency is more obvious (fig 17). This might be because of high depths of cut and the workpiece has been sufficiently softened thermally that it may be fed subsequent increases in cutting speed have minimal effect on the operation. This might happen if the cutting speed is between 112 and 250 rpm. The radial and axial graphs demonstrate this.

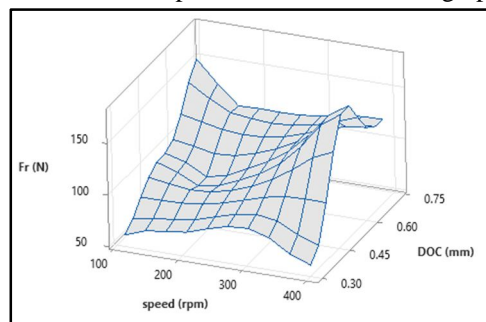


Fig.16: Variation in radial force (F_r) surface plot of F_r Vs DOC, speed

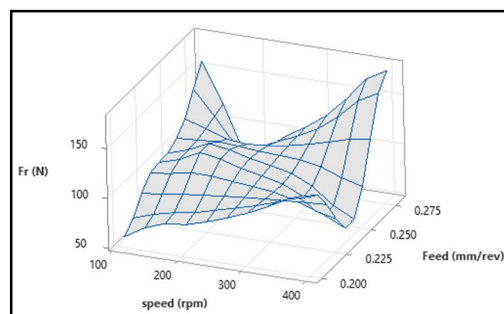


Fig.17: Variation in radial force (F_r) surface plot of F_r Vs Feed, speed

Cutting force component (F_c) rose as feed and cut depth increased (fig 18). However, in a predetermined set of machining settings, it exhibited indifference to cutting speed (fig 19). This might be because the work piece becomes thermally softened and hence more machinable at high feed and speed.

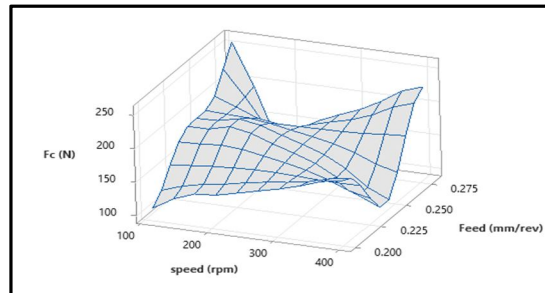


Fig.18: Variation in cutting force (F_c) surface plot of F_c Vs feed, speed

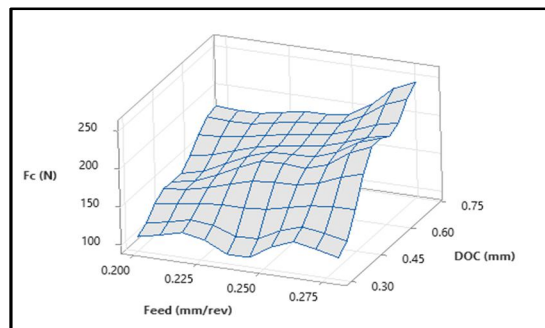


Fig.19: Variation in cutting force (F_c) surface plot of F_c Vs DOC, feed

E. Surface Roughness as a Result of Cutting Parameters

The change in surface roughness as a function of cutting settings is shown in the diagram. For the majority of the range's feed values, the surface roughness increased as the depth of cut rose. However, with low depth cuts, it first dropped and then rose as feed increased. While the surface roughness reduced with increased feed for high depths of cut in the specified range, the surface roughness increased with increased feed for low depths of cut in the selected range. Fig. (20 and 21)

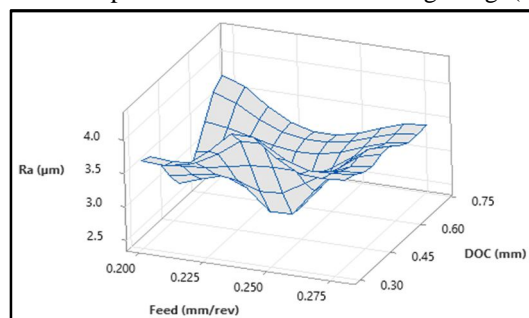


Fig.20: Variation in surface roughness (R_a) surface plot of R_a Vs DOC, feed

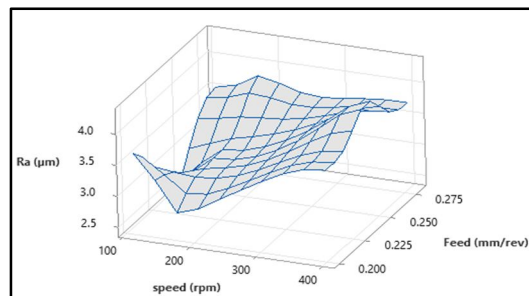
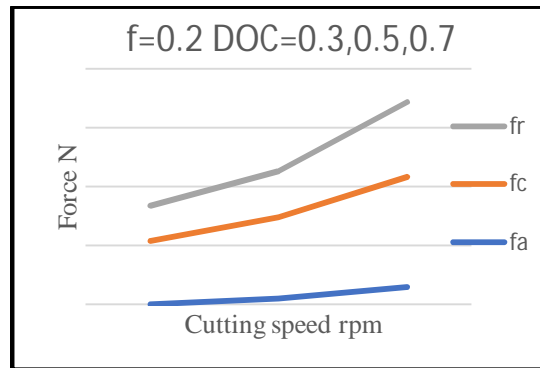


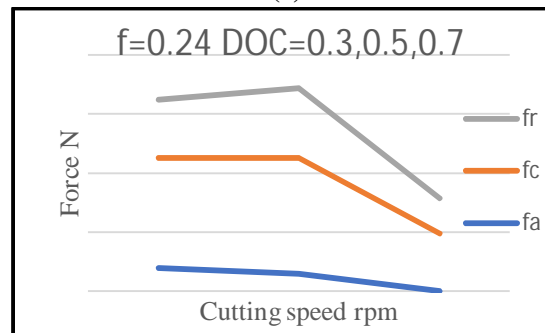
Fig.21: Variation in surface roughness (R_a) surface plot of R_a Vs feed, speed

F. Cutting Conditions for Effective Cutting

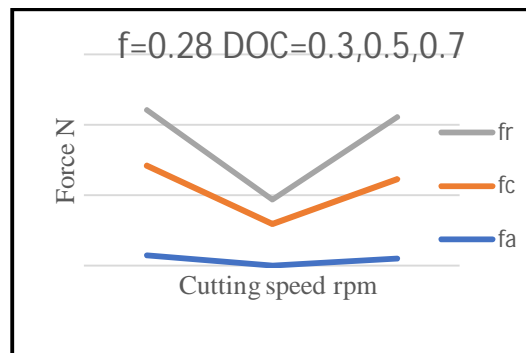
The figure made it easier to spot the instances when the levels of cutting force were almost identical to the radial force. These were the most efficient cuts since they demonstrated that cutting used more power than holding the tool in a transverse orientation. In the graphs shows the taken different three feed rate value in each graph and depth of cut value are taken in same in all graphs. and Cutting may Low and moderate cutting speeds within the prescribed range, as well as a reasonable depth of cut, will yield the best results. as shown in Fig. 22 (a) (b) (c).



(a)



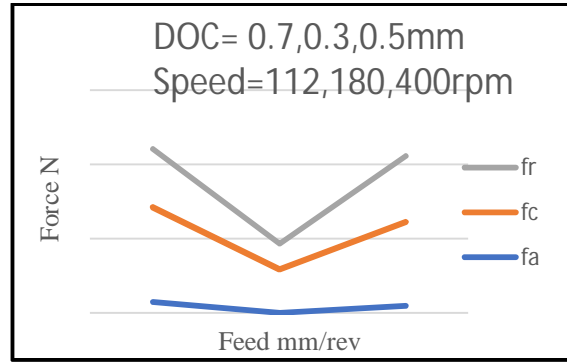
(b)



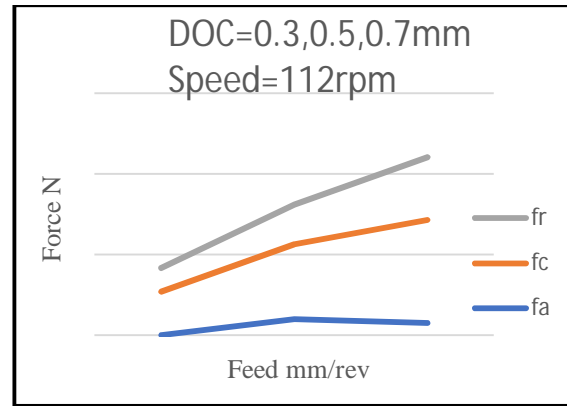
(c)

Fig. 22 (a) (b) (c): Variation in forces with cutting speed for different DOC and feed rate

Figure illustrates that by keeping speed and depth of cut in the specified range at moderate levels, the for almost all feeds, the most efficient cut can be achieved. It may be deduced that the provided parameter range should be cut at lower to moderate speeds with medium depths of cut, utilised to accomplish energy efficient machining. In the graph shows the taken parameters cutting speed 112,180,400rpm and feed 0.2,0.24,0.28mm/rev and DOC 0.7,0.3,0.5mm. the depth of cut 0.3mm in that point the all three forces values are low. another graph cutting speed 112rpm and DOC is 0.3,0.5,0.7mm. F_r and F_c forces are high at feed 0.28 and DOC is 0.7. Fig. 23 (a) and (b) shown the Forces change as the feed rate and depth change.



(a)



(b)

Fig.23: Variation in forces with feed at different speed and depth of cut

Table 4: Optimized assigned data for 0.4 mm nose radius

Sl No.	Speed rpm	Feed mm/rev	DOC mm	F _a N	F _c N	F _r N	MRR grms/min	R _a μm	Time sec	Bar
1	112	0.2	0.3	9.81	117.72	98.1	2.5714	6.233	140	V2
2	112	0.24	0.5	39.24	196.2	147.15	5.238	7.363	126	V3
3	112	0.28	0.7	58.86	274.68	196.2	7.9245	8.933	106	V6
4	180	0.2	0.5	29.43	196.2	156.96	7.5	4.077	88	V4
5	180	0.24	0.7	58.86	235.44	186.39	11.392	7.191	79	V7
6	180	0.28	0.3	9.81	156.96	117.72	6.3636	6.223	66	V10
7	400	0.2	0.7	58.86	215.82	176.58	23.414	5.099	41	V9
8	400	0.24	0.3	9.81	98.1	88.29	11.351	6.351	37	V1
9	400	0.28	0.5	29.43	206.01	196.2	23.225	6.601	31	V8

- 1) It is observed from the graph fig. (24) that the three cutting force move in a wavy manner, all forces dip and rise at same points.
- 2) The points 3, 5, 7 and 9 are the points where the cutting forces are high, where the DOC=0.7mm except point 9 where it is 0.5mm.
- 3) And the points 1, 4, 6 and 8 are the points where the cutting forces are low where the depth of cut is small i.e., 0.3 mm.
- 4) It is observed that the DOC is directly proportional to the cutting forces in the experiment we conducted, the bigger the DOC the higher the cutting forces.

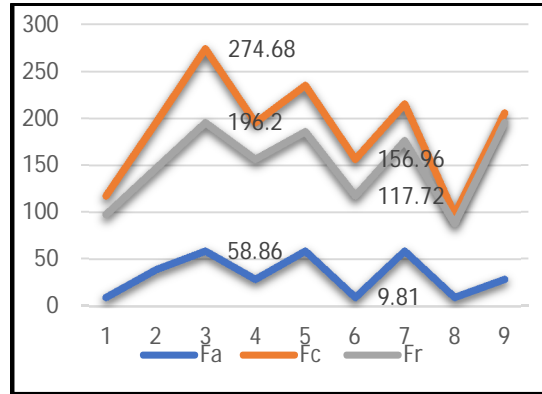


Fig.24: Cutting forces

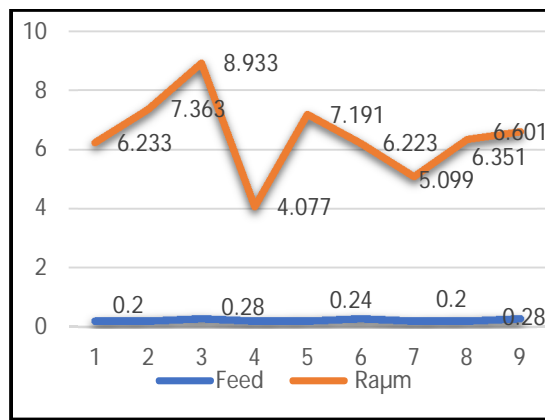


Fig.25: Feed (mm/rev) and Ra (µm) graph

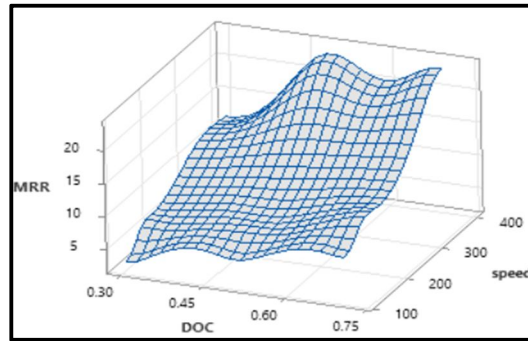


Fig.26: Surface plot of MRR Vs DOC, speed

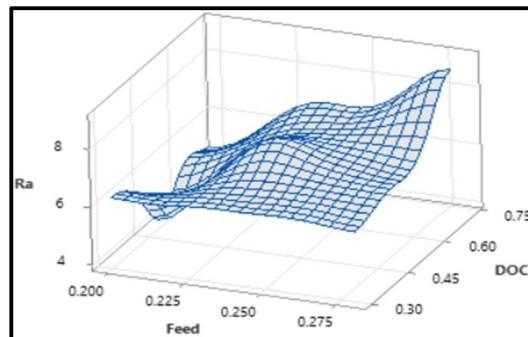


Fig.27: Surface plot of Ra Vs DOC, feed

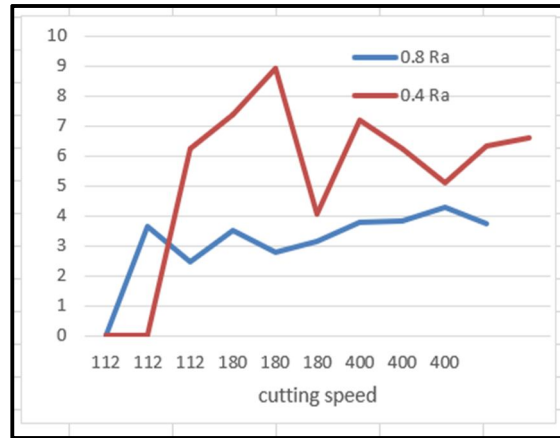


Fig.28: surface roughness Vs speed

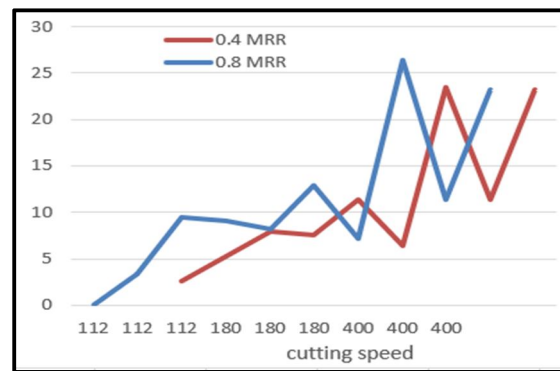


Fig.29: MRR Vs speed

- 5) From the fig. (28 and 29) shows the 0.8mm tip and 0.4 mm tip radius tool shows the roughness values and MRR plotted graphs respectively.
- 6) Surface roughness is high at point 3 for 0.4 mm tip and 0.8mm tip high at point 8.
- 7) Surface roughness is low at point 4 for 0.4 mm tip and 0.8mm tip low at point 2.
- 8) MRR is high at point 7 for 0.8 mm tip and 0.4mm tip high at point 9.

V. CONCLUSION

A. Effect of tool tip nose radius 0.8mm

- 1) High MRR rate is observed on bar S_3 which has the following cutting conditions speed 400 rpm, feed 0.2 rev/sec and DOC 0.7 mm.
- 2) Lowest cutting force is observed at speed 400 rpm, 0.24 feed rev/sec and DOC 0.3 mm.
- 3) Lowest surface roughness (R_a) value is observed at speed 112 and feed 0.24 and DOC 0.5mm.
- 4) It can be concluded that lower the feed rate smoother the surface roughness value.
- 5) MRR is observed to be high at higher speed.
- 6) F_c is larger than F_r and F_a in terms of cutting force.
- 7) It is observed the higher the depth of cut higher the MRR.
- 8) It is also observed that surface roughness will be smooth when the tip radius of tool is large.
- 9) Keeping surface roughness, MRR and cutting speed are view the optimum condition to turning EN 31 material on conventional lathe at low speed is observed to be
 - Speed = 400 rpm
 - Feed = 0.28 mm/rev
 - DOC = 0.5 mm
- 10) 0.8 mm tip radius tool is always preferable for turning operation as it yields good results under specified condition.

B. Effect of tool tip nose radius 0.4mm

- 1) Lowest roughness value is obtained at speed= 180, feed= 0.2 mm/rev and DOC = 0.5 mm but the MRR is too low and that is not considered to be optimum condition.
- 2) Keeping the forces, MRR and roughness values in view and all the data and the work results in view it is concluded that the optimised condition to perform the turning operation on EN 31 material for low speed turning operations is the following set.
 - Speed = 400 rpm
 - Feed = 0.2 mm/rev
 - DOC = 0.7 mm
- 3) The above parameters are ideal to get moderate cutting force, good MRR and good surface roughness value.
- 4) The most significant parameter impacting the three cutting forces was determined to be the depth of cut, followed by the feed.
- 5) In the range of parameters specified, the most energy efficient cut can be accomplished for virtually all feed values set for comparatively Cutting speeds should be low to moderate, with a reasonable depth of cut.

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