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Optimization on EN8 by CNC Turning with PVD Coated Inserts Using Taguchi and D Grey Relational Analysis

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ABSTRACT: The primary goal of today's manufacturing industry is to manufacture high-quality, low-cost items in a short period of time. In order to improve the quality of machining products and lower the machining costs, the selection of suitable cutting parameters is critical. Hard turning is currently an option to grinding in the completion of work parts in hardened steels because it allows for high productivity, great flexibility, and the avoidance of coolants. En8 is machined to determine the best parameters for the CNC Hard turning process, which is the subject of this study. Experimental layout, parameter analysis, and parameter predictions are all done using Taguchi's L9 orthogonal array. Speed was 1750 rpm, Feed was 0.15 mm/rev, and DOC was -0.3 for the best Surface Roughness. Feed has a substantial impact on the percentage of surface finish that can be attributed to it.

1. INTRODUCTION

Machining of components with hardness greater than 45HRC is referred to as "hard machining," however the actual hard machining method uses items with a hardness of 58HRC to 68HRC as its hardness threshold[1]. Hardened alloy steel, tool steels, case-hardened steels, nitride irons, hard-chrome-coated steels, and heat-treated powder metallurgical components are some of the workpiece materials used in hard machining. One of the most effective approaches employed in manufacturing sectors is optimization, which is vital for sectors aiming to produce high-quality products at a cheaper cost[2]. The Taguchi technique is based on the idea that a process' variability can be minimized through the use of well-designed experiments. Its overall goal is to produce high-quality products at minimal cost for the company. Genichi Taguchi is the man behind the Taguchi technique[3]. He devised a strategy for designing experiments to study how different parameters affect the mean and variance of a process performance characteristic that describes how effectively the process is working. It is suggested that the process parameters and the levels at which they should be adjusted be organized using orthogonal arrays, according to Taguchi's recommended experimental design. In the machining process, surface roughness serves as an indicator of quality and is one of the most frequently requested client specifications. Cut depth, feed rate, and speed must all be optimized for optimal machine tool performance[4]. As a result, a method for determining the optimal cutting parameter values to minimize surface roughness must be developed. Production of high-quality goods at low cost and in a timely manner are key objectives of modern industry. For cutting and polishing machined items, turning is the most popular method of choice. Cutting parameters must also be carefully adjusted in order to generate products of the desired quality while also maximizing machining productivity. Materials, tool shape, and cutting circumstances (feed rate, cutting speed) all affect material removal rate and machining quality, such as surface roughness, in the turning process. Analyzing sample variance is a hypothesis-testing technique for determining if the means of two or more populations are equal.

1.1 HARD TURNING

Hard turning is a method that avoids the need for grinding. A suitable hard turning method results in a surface finish Ra 0.4 to 0.8 micrometre, roundness of 2-5 micrometers, and a diameter tolerance of +/-3-7 micrometres.. The equipment that does soft turning can also conduct hard turning. Hard turning begins with a material with a hardness of 47 HRC, however it is more commonly performed on materials with a hardness of 60HRC or above. Among the metals required for hard turning are elevated alloys such as Inconel, Haste alloy, stellite, and other exotic alloys like tool steel. To avoid chatter, the length to diameter (L/D) ratio for unsupported workpieces should not be greater than 4:1, even if tailstock support is available for long thin components. The degree of machine rigidity is used to determine the level of

hard turning precision. Hard turning necessitates higher levels of system rigidity than machine rigidity. In order to maximize the system's stiffness, overhangs, extensions of tools, extensions of parts, and spacers should be avoided. Keeping everything as close to the turret or spindle as feasible is the objective of this strategy. The most significant issue in hard turning is whether or not to utilize coolant. Dry hard turning is the norm in most circumstances. Without coolant, turning will be difficult and the part would become extremely hot. Process gauging will be difficult as a result of this. It is necessary to utilize high pressure coolant through the machine tool in order to cool down the machined object. The majority of hard turning is done with water-based and low concentration coolants. Because the highest amount of heat is delivered to the chip during and after cutting in hard turning, inspecting the chip will reveal whether or not the process has been properly turned. During a continuous cut, the chips should glow orange and flow like ribbon. If the cooled chip disintegrates when it is crunched, then the right amount of heat has been generated.

1.2 SURFACE ROUGHNESS

It is because of the growth in surface texture understanding and ongoing improvement that the current machine era has made a significant leap forward. Greater strength and bearing loads requires smoother, harder surfaces. Machine components, load carrying capacity, tool life, fatigue life, bearing corrosion and wear attributes are all directly influenced by the surface texture of the machine parts. Because of the high concentration of stress in the corners, fatigue invariably leads to a failure. Any surface irregularity begins at a sharp corner, and that's why it breaks sooner. Non-working surface irregularities might also lead to failure. Because diverse applications involve a variety of surface types, quantitative measurement of surface texture is necessary. Variations in height and spacing characterize the surface flaws that make up the surface pattern. There will always be some deviations from ideal circumstances when using the chip removal technique on any material.

1.3 METAL HARDENING

The increased hardness and improved mechanical qualities that arise from this treatment make the final product more robust and long-lasting. In order to harden and strengthen alloys, they must be heated over their critical transition temperature and then cooled quickly enough. As alloying components content varies, cooling methods can include cooling by air or cooling by quenching in oil, water, or another liquid. To increase their dimensional stability and hardness, hardened materials are often tempered or stress eased. Heat treatment is frequently required to improve the mechanical qualities of steel objects, such as enhancing their hardness or their strength. In order for the material to convert into a stronger, harder structure, it must be heated above the critical (normalising) temperature, held at this temperature for one hour per inch of thickness, and then cooled rapidly enough. Iron and carbon are the basic building blocks of steel, however additional metals can also be found in the solution. Carbon and other elements form a solid solution when the material is heated above the critical temperature. Quenching "freezes" the microstructure, resulting in stresses in the final product. Parts are then tempered in order to alter their microstructure, attain the desired hardness, and remove any residual stress.

1.4 METAL QUENCHING

Depending on the type of steel, the material is heated to the appropriate temperature and then quenched in water or oil to harden. To achieve a fully hardened structure, the material is heated to the appropriate hardening temperature and then rapidly cooled by submerging the hot section in water, oil, or another suitable liquid. Because of this, it is common for quenched parts to require additional processing to reach the desired ultimate hardness, dimensional stability, and toughness. To attain the desired mechanical properties, alloys can either be air cooled or chilled by quenching in a specific liquid, such as oil, water, or a combination of these. It is necessary to temper hardened materials in order to increase their dimensional stability and toughness.

II. MATERIAL AND METHODOLOGY

2.1 WORK PIECE MATERIAL

The carbon-chrome alloy work piece has a length of 540(60x9) mm and a diameter of 32 mm. Because of this, it has an HRC hardness rating of 40, 45, and 50 after being heat processed. Images of the alloy's material and chemical composition may be seen in this photo.



WORK MATERIAL DETAILS

Work material – EN8

Work material size–32mm dia Length- 75 mm thickness

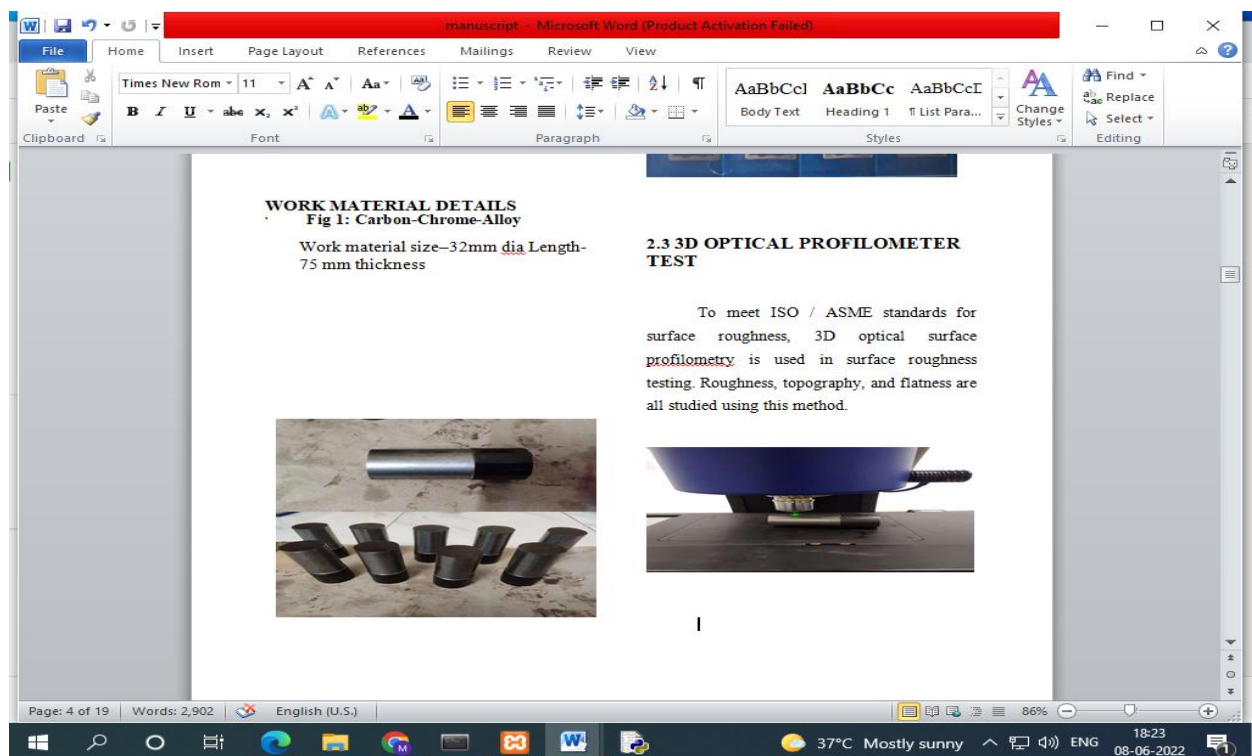


Fig 2: EN8

2.2 CUTTING INSERTS

There are a total of four cutting inserts utilized in this experiment. For nine experiments, all eight edges of the first three inserts and three edges of the last insert are employed. Each insert contains eight edges. SMG 120408 is the insert's model name. Titanium-coated carbide inserts are used.



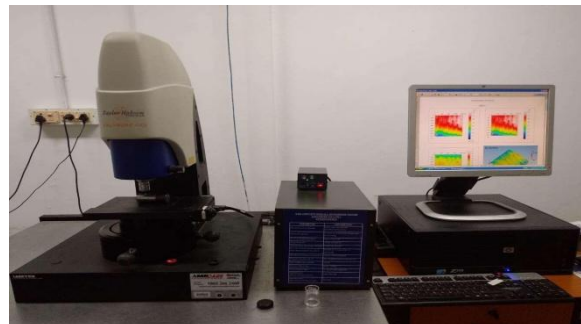
Fig 3: Titanium coated carbide inserts

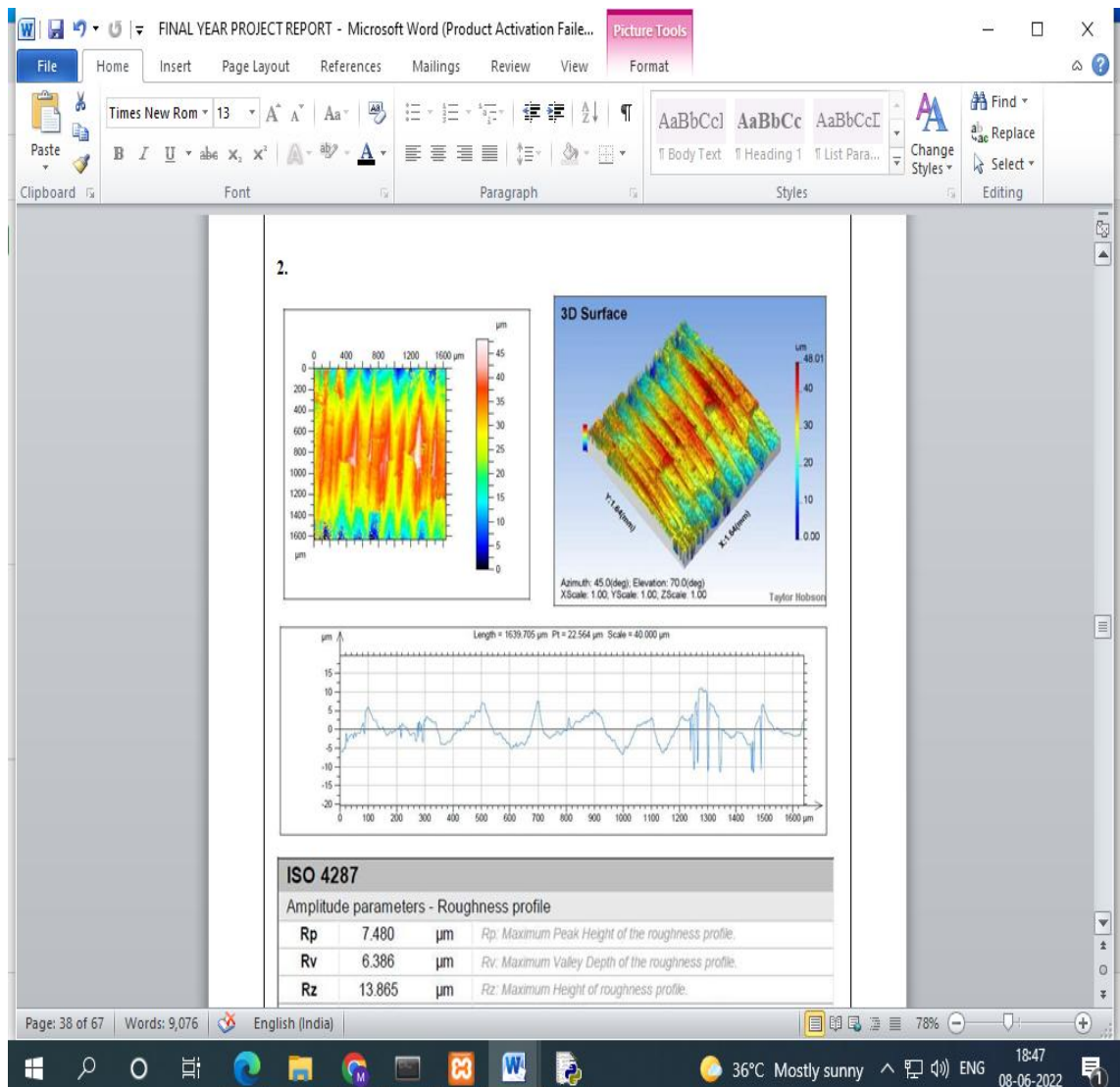
2.3 TEST OF 3D OPTICAL PROFILOMETER

To meet ISO / ASME standards for surface roughness, 3D optical surface profilometry is used in surface roughness testing. Roughness, topography, and flatness are all studied using this method.



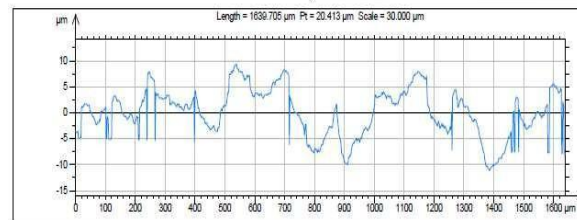
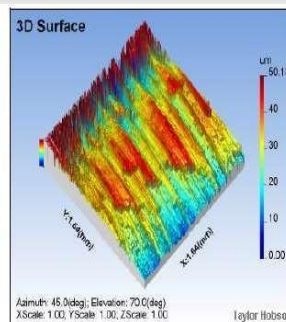
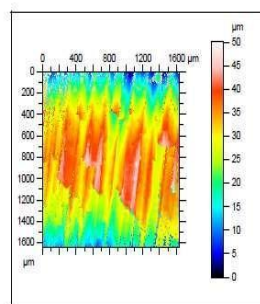
Fig 4: Optical Profilometer

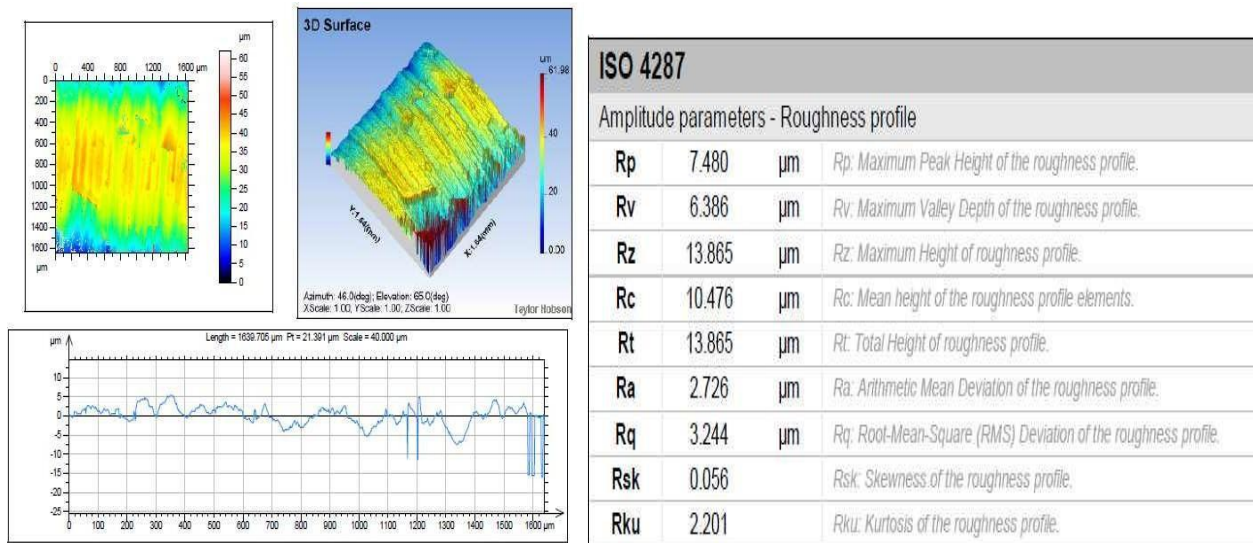




ISO 4287		
Amplitude parameters - Roughness profile		
Rp	4.517	μm Rp: Maximum Peak Height of the roughness profile
Rv	7.894	μm Rv: Maximum Valley Depth of the roughness profile
Rz	12.211	μm Rz: Maximum Height of roughness profile
Rc	6.357	μm Rc: Mean height of the roughness profile elements
Rt	13.858	μm Rt: Total Height of roughness profile
Ra	1.481	μm Ra: Arithmetic Mean Deviation of the roughness profile
Rq	1.810	μm Rq: Root-Mean-Square (RMS) Deviation of the roughness profile
Rsk	-0.437	Rsk: Skewness of the roughness profile
Rku	3.201	Rku: Kurtosis of the roughness profile

ISO 4287			
Amplitude parameters - Roughness profile			
Rp	7.004	μm	Rp: Maximum Peak Height of the roughness profile.
Rv	7.744	μm	Rv: Maximum Valley Depth of the roughness profile.
Rz	14.748	μm	Rz: Maximum Height of roughness profile.
Rc	11.161	μm	Rc: Mean height of the roughness profile elements.
Rt	14.748	μm	Rt: Total Height of roughness profile.
Ra	3.282	μm	Ra: Arithmetic Mean Deviation of the roughness profile.
Rq	3.883	μm	Rq: Root-Mean-Square (RMS) Deviation of the roughness profile.
Rsk	-0.020		Rsk: Skewness of the roughness profile.
Rku	1.938		Rku: Kurtosis of the roughness profile.





3. EXPERIMENTAL DESIGN

3.1 TAGUCHI DESIGN

The approaches of experimental design are overly complicated and difficult to utilize. This challenge is alleviated by the Taguchi technique, which use an orthogonal array design to examine the whole parameter space using only a small number of tests, which reduces the need for as many experiments as possible. An S/N ratio is calculated using experimental data in order to identify any quality features that are deviating from the target values. According to the S/N ratio study, there are usually three groups of quality characteristics: the lower, the higher and the nominal. Based on the S/N analysis, the S/N ratio for each level of process parameter is compared. The higher the S/N ratio, the better the quality features are regardless of the quality category. As a result, the highest S/N ratio represents the ideal process parameter setting. A statistically significant S/N and ANOVA analysis can also predict the optimal combination of process parameters. In order to confirm the optimal process parameters established by parameter design, a confirmation experiment is carried out last. The three most frequent Signal-to-Noise ratios to consider when trying to optimize Static Problems. So that an experimenter can always choose the biggest factor level setting, the equations for signal to noise ratio were established. As a result, we came up with a method for calculating the Signal-to-Noise ratio.

3.2 PROCESS PARAMETERS AND THEIR LEVELS

LEVELS	PROCESS PARAMETERS		
	SPINDLE SPEED (N) (RPM)	FEED (mm/Rev)	DOC
1	1500	0.10	0.1
2	1750	0.15	0.2
3	2000	0.20	0.3

Table 3.1: Process Parameters

3.2.1 EXPERIMENTAL ARRANGEMENT AND PROCESS PARAMETERS LEVELS

- Machine Tool: Batliboi smarturn CNC lathe.
- Work specimen material: EN8

- Size of material: $\Phi 32\text{mm}$ X 60 mm.
- Tool material: Carbide-TAEGUTEC-TT-5100-04 inserts.
- Environment: Coolant not used.
- Metal removal rate calculation: Through weight.
- Machining time measurement: From CNC machine.



3.2.2 PROCESS PARAMETERS AND VARIABLES

S.NO	SPINDLE SPEED (N) (RPM)	FEED (mm/Rev)	DOC
1	1500	0.10	0.1
2	1500	0.15	0.2
3	1500	0.20	0.3
4	1750	0.10	0.2
5	1750	0.15	0.3
6	1750	0.20	0.1
7	2000	0.10	0.3
8	2000	0.15	0.1
9	2000	0.20	0.2

Table 3.2: Process Parameters and Variables

3.3 EXPERIMENTAL DATA

3.3.1 EXPERIMENTAL DATA ANALYSIS AND OPTIMIZATION

SL. NO	DESIGN	SPEED (N) (RPM)	FEED (mm/Rev)	DOC	MT min	RA micron	MRR gm/min
1	A ₁ B ₁ C ₁	1500	0.10	0.1	1.33	2.283	2.299
2	A ₁ B ₂ C ₂	1500	0.15	0.2	1.21	2.868	2.737
3	A ₁ B ₃ C ₃	1500	0.20	0.3	1.16	2.910	3.185
4	A ₂ B ₁ C ₂	1750	0.10	0.2	1.26	2.771	2.426
5	A ₂ B ₂ C ₃	1750	0.15	0.3	1.17	2.671	2.940
6	A ₂ B ₃ C ₁	1750	0.20	0.1	1.13	3.646	2.142
7	A ₃ B ₁ C ₃	2000	0.10	0.3	1.23	1.721	2.381
8	A ₃ B ₂ C ₁	2000	0.15	0.1	1.15	2.283	2.548
9	A ₃ B ₃ C ₂	2000	0.20	0.2	1.12	2.827	2.730

Table 3.3: Machining Time (Analysis of Result)

3.3.2 MACHINING TIME AND S/N RATIOS VALUES FOR THE EXPERIMENTS

TRIAL	DESIGN	SPEED	FEED	DOC	MT	SNRAI
1	A ₁ B ₁ C ₁	1500	0.10	0.1	1.33	-2.47703
2	A ₁ B ₂ C ₂	1500	0.15	0.2	1.21	-1.65571
3	A ₁ B ₃ C ₃	1500	0.20	0.3	1.16	-1.28916
4	A ₂ B ₁ C ₂	1750	0.10	0.2	1.26	-2.00741
5	A ₂ B ₂ C ₃	1750	0.15	0.3	1.17	-1.36372
6	A ₂ B ₃ C ₁	1750	0.20	0.1	1.13	-1.06157
7	A ₃ B ₁ C ₃	2000	0.10	0.3	1.23	-1.79810
8	A ₃ B ₂ C ₁	2000	0.15	0.1	1.15	-1.21396
9	A ₃ B ₃ C ₂	2000	0.20	0.2	1.12	-0.98436

Table 3.4: Machining Time and S/N Ratios Values

3.3.3 MT RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER

LEVEL	SPEED	FEED	DOC
1	-1.807	-2.094	-1.584
2	-1.478	-1.411	-1.549
3	-1.332	-1.112	-1.484
DELTA	0.475	0.982	0.101
RANK	2	1	3

Table 3.5: Response Table for Signal to Noise Ratios-Smaller is better

LEVEL	SPEED	FEED	DOC
1	1.233	1.273	1.203
2	1.187	1.177	1.197
3	1.167	1.137	1.187
Delta	0.067	0.137	0.017
rank	2	1	3

Table 3.6 : Response Table for Means

FACTOR	TYPE	LEVELS	VALUES
SPEED	fixed	3	1500,1750,2000
FEED	fixed	3	0.10,0.15,0.20
DOC	fixed	3	0.1,0.2,0.3

Table 3.7: General Linear Models: MT versus SPEED, FEED And DOC

SOURCE	DF	SEQ SS	ADJMS	F	P	%OF CONTRIBUTION
Speed	2	0.007022	0.003511	12.64	0.073	19
Feed	2	0.029622	0.014811	53.32	0.018	79
Doc	2	0.000422	0.000211	0.76	0.568	1
Error	2	0.000556	0.000278			1
Total	8	0.037622				100

Table 3.8: Analysis of Variance for MT, using Adjusted SS for Tests

3.3.4 SN RATIO GRAPHS FOR MACHINING TIMING



Fig 3.2: Graph for SN ratio

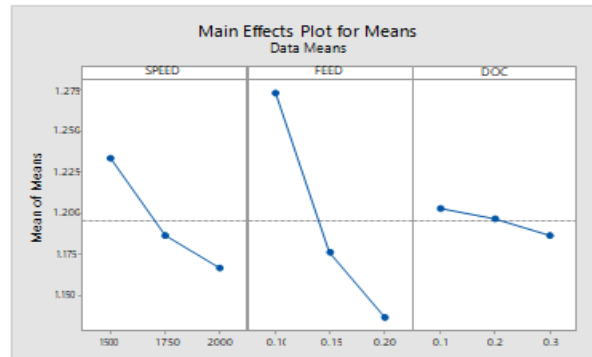


Fig 3.3: Graphs for means

3.4 SURFACE ROUGHNESSES (ANALYSIS OF RESULT)

TRIAL	DESIGN	SPEED	FEED	DOC	RA	SNRA1
1	A ₁ B ₁ C ₁	1500	0.10	0.1	2.283	-7.1701
2	A ₁ B ₂ C ₂	1500	0.15	0.2	2.868	-9.1516
3	A ₁ B ₃ C ₃	1500	0.20	0.3	2.910	-9.2779
4	A ₂ B ₁ C ₂	1750	0.10	0.2	2.771	-8.8527
5	A ₂ B ₂ C ₃	1750	0.15	0.3	2.671	-8.5335
6	A ₂ B ₃ C ₁	1750	0.20	0.1	3.646	-11.2363
7	A ₃ B ₁ C ₃	2000	0.10	0.3	1.721	-4.7156
8	A ₃ B ₂ C ₁	2000	0.15	0.1	2.283	-7.1701
9	A ₃ B ₃ C ₂	2000	0.20	0.2	2.827	-9.0265

Table 3.9: surface Roughness and S/N Ratios Values

3.4.1 RA RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER

LEVEL	SPEED	FEED	DOC
1	-8.533	-6.913	-8.526
2	-9.541	-8.285	-9.010
3	-6.971	-9.847	-7.509
DELTA	2.570	2.934	1.501
RANK	2	1	3

Table 3.10: Response Table for Signal to Noise Ratios-Smaller is better

LEVEL	SPEED	FEED	DOC
1	2.687	2.258	2.737
2	3.029	2.607	2.822
3	2.277	3.128	2.434
DELTA	0.752	0.869	0.388
RANK	2	1	3

Table 3.11: Response Table for Mean

FACTOR	TYPE	LEVELS	VALUES
SPEED	fixed	3	1500,1750,2000
FEED	fixed	3	0.10,0.15,0.20
DOC	fixed	3	0.1,0.2,0.3

Table 3.12 : General Linear Models: RA versus SPEED, FEED, DOC

SOURCE	DF	SEQ SS	ADJ MS	F	P	% OF CONTRIBUTION
Speed	2	0.85130	0.42565	24.47	0.039	37
Feed	2	1.14829	0.57414	33.01	0.029	50
Doc	2	0.24972	0.12486	7.18	0.122	11
Error	2	0.03478	0.01739			2
Total	8	2.28409				100

Table 3.13 : Analysis of Variance for RA, using Adjusted SS for Tests

3.4.2 SN RATIO GRAPHS FOR SURFACE ROUGHNESS

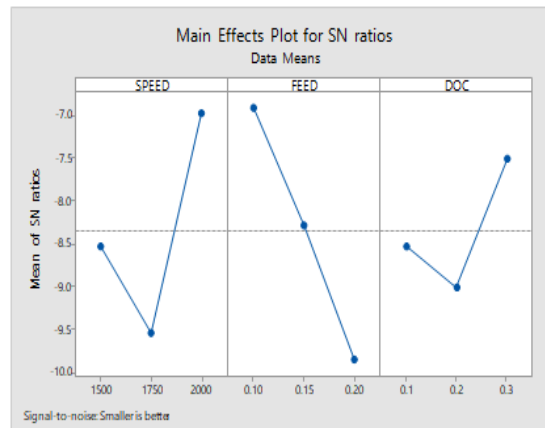


Fig 3.4 : Graph for SN ratio

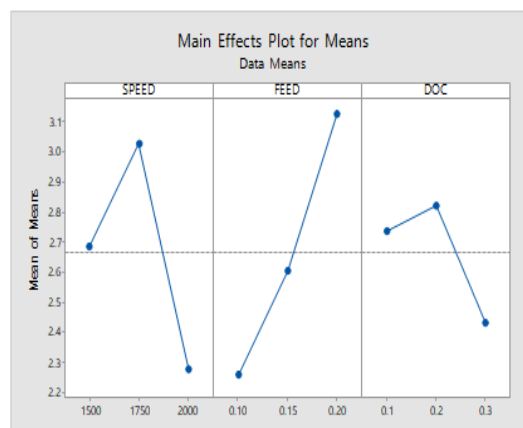


Fig 3.5: Graphs for means

5. MRR (ANALYSIS OF RESULT)

TRIAL	DESIGN	SPEED	FEED	DOC	MRR	SNRA1
1	A ₁ B ₁ C ₁	1500	0.10	0.1	2.299	7.2308
2	A ₁ B ₂ C ₂	1500	0.15	0.2	2.737	8.7455
3	A ₁ B ₃ C ₃	1500	0.20	0.3	3.185	10.0622
4	A ₂ B ₁ C ₂	1750	0.10	0.2	2.426	7.6978
5	A ₂ B ₂ C ₃	1750	0.15	0.3	2.940	9.3669
6	A ₂ B ₃ C ₁	1750	0.20	0.1	2.142	6.6164
7	A ₃ B ₁ C ₃	2000	0.10	0.3	2.381	7.5352
8	A ₃ B ₂ C ₁	2000	0.15	0.1	2.548	8.1240
9	A ₃ B ₃ C ₂	2000	0.20	0.2	2.730	8.7233

Table 3.14: MRR AND S/N RATIOS Values for the Experiments

MRR FORMULA: Before weight-After weight/Time taken X Density

DENSITY-7.85/gmcc

B. Weight	483	482	482	481	482	479	482	482	482
A. Weight	459	456	453	457	455	460	454	459	458

3.5.1 MRR RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER

LEVEL	SPEED	FEED	DOC
1	8.679	7.488	7.324
2	7.894	8.745	8.389
3	8.127	8.467	8.988
DELTA	0.786	1.258	1.664
RANK	3	2	1

Table 3.15: Response Table for Signal to Noise Ratios-Smaller is better

LEVEL	SPEED	FEED	DOC
1	2.740	2.369	2.330
2	2.503	2.742	2.631
3	2.553	2.686	2.835
DELTA	0.238	0.373	0.506
RANK	3	2	1

Table 3.16: Response Table for Means

FACTOR	TYPE	LEVELS	VALUES
SPEED	fixed	3	1500,1750,2000
FEED	fixed	3	0.10,0.15,0.20
DOC	fixed	3	0.1,0.2,0.3

Table 3.17: General Linear Models: MRR versus SPEED, FEED and DOC

SOURCE	DF	SEQ SS	ADJ MS	F	P	%OF CONTRIBUTION
Speed	2	0.09411	0.04706	0.63	0.614	11
FEED	2	0.24275	0.12138	1.62	0.381	28
Doc	2	0.38825	0.19413	2.59	0.278	44
Error	2	0.14966	0.07483			17
Total	8	0.87478				100

Table 3.18: Analysis of Variance for MRR, using Adjusted SS for Tests

3.5.2 SN RATIO GRAPHS FOR MATERIAL REMOVAL RATE

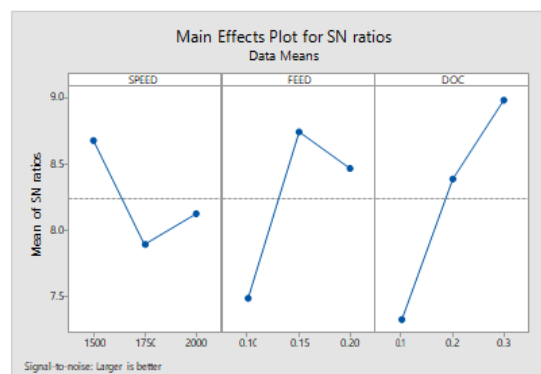


Fig 3.6: Graph for SN ratio

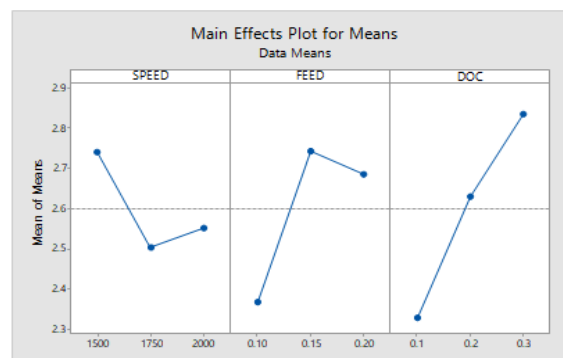


Fig 3.7 : Graphs for means

IV. CONCLUSION

Taguchi and ANOVA were employed in this study to find the best turning parameters for EN8 throughout dry conditions. Surface roughness, parametric optimization, and Taguchi analysis in hard turning with coated carbide inserts are examined extensively in this paper. The investigations may lead to the following conclusions.

1. Good surface quality of roughness about 1.721 micron is obtained during hard turning operation.
2. The Minimum surface finish was obtained when depth of cut of 0.3 mm, Spindle speed of 2000 RPM and feed 0.10 mm.

OPTIMAL CONTROL FACTOR

1. Surface Roughness- A_2 (Speed - 1750) B_1 (Feed - 0.15) C_3 (DOC - 0.3)
2. Machining Timing- A_2 (Speed - 1750) B_1 (Feed - 0.15) C_3 (DOC - 0.3)
3. Material Removal Rate- A_3 (Speed - 2000) B_2 (Feed - 0.15) C_1 (DOC - 0.1)

Percentage of contribution of Process parameter

1. Surface Roughness- Feed- 50%
2. Machining Timing- feed- 79%
3. Material Removal Rate-DOC- 44%

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