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Performance Evaluation of TiAlN Coated Tungesten Carbide and CBN Tool During Hot Machining of OHNS Round Bar

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Abstract

Hot machining is one method of machining easily hard materials. Heat is added to the cutting tool, resulting in a reduction in hardness and improved machining capabilities. During the hot turning process, the surface quality of the machined component improves. Cutting speeds, feed rates, and depth of cut for both CBN and TiAlN-coated tungsten carbide insert are optimised by trial and error. The effects of CBN and TiAlN inserts on hot turning and cold turning with minimal fluid application have been analysed in terms of power consumption, surface roughness, cutting force.

Keywords: *Hot turning, Optimization, OHNS, CBN, TiAlN*

1.0 Introduction

In their research, the authors[1] analysed the influence that the shape of the cutting tool and the processing parameters had on the surface roughness of SAE 1030 steel. The performance of coated tools was analysed and forecasted during hard turning operations[2]. Research on turning operations using tool steels was conducted by Kumar and Ramamoorthy[3]. A RSM and ANN model was created by the authors to forecast the surface quality of the machined component and to compare with experimental findings[4]. In this study, surface morphology and cutting force elements were measured in high-speed turning of SAE or AISI Factor D3 cold work steel material containing CC6050 and CC650 types of ceramic inserts[5]. After conducting high-turning experiments on tempered alloy steel (AISI 4140) 56 HRC with PVD coating ceramics, the authors[6] used the RSM (Response Surface Method) to determine the best cutting conditions that resulted in the relatively low surface irregularity and cutting force elements. Hot turning was done on Inconel 625 using a carbide cutting insert, with the workpiece heated by flame heating techniques and a variety of cutting settings tested[7]. Using polyoxymethylene (PIM C) polymer, the author studied the impact of cutting parameters. After reviewing the available research, it is determined that less effort has been put into developing a CBN tool that can compete in terms of the cutting speed, depth of cut, and feed rate with a TiAlN alternative[8].

The response variables of this article are cutting force, surface roughness, and power consumption, while the input variables are cutting speed, feed, and depth of cut. A comparative performance analysis was done for CBN and TiAlN coated carbide inserts. Force measurements were carried out for output parameters. Experiment with hot turning up to 600 degree Celsius in a heat-free environment.

This research aims to assess the impact of depth of cut, cutting speed, and feed rate on surface quality and cutting force during the turning operation of OHNS (Oil-hardening,

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Table 1: Toolinserts dynamometer system

Position	Specification	Symbol	Interpretation
1	Insert shape	C	Rhombic 80^{o}
		H	Hexagonal
		S	Square
		T	Triangular
2	Normal clearance	N	0^{o}
		A	3^{o}
		B	5^{o}
		C	7^{o}
3	Tolerance class (nose height)	A	+/- 0.005
		H	+/- 0.013
		M	+/- 0.018
		E	+/- 0.025
4	Fixing and chip breaker	A	With hole, without chip breaker
		G	With hole, double sided chip breaker
		M	With hole, with one sided chip breaker
		N	Without hole, without chip breaker
5	Insert size	06	Side length (mm)
		08	Side length (mm)
		12	Side length in (mm)
		16	Side length (mm)
6	Inserts thickness	04	Thickness (mm)
		08	Thickness (mm)
		12	Thickness (mm)
		16	Thickness (mm)
7	Nose radius	04	0.4 (mm)
		08	0.8 (mm)
		12	1.2 (mm)
		16	1.6 (mm)

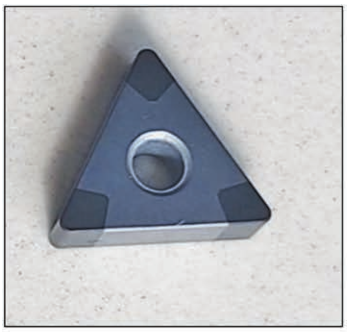
Figure 1: Six corner CBN insert


Figure 2: Six corner TiAlN coated carbide


Figure 3: Inserts tool holder

non-deforming) tool steel. The Taguchi approach is used for practical experiments to explore machining characteristics. Cubic Boron Nitride (CBN) and titanium-aluminium-nitride coating (TiAlN) type coatings on carbide tools are used to increase the wear resistance property of tool inserts. The tool and inserts are chosen based in Fig.3 on the literature; the plain carbide inserts used for lathe turning experiments have the ISO designation TNMA 160408 and are made of CBN in Fig.1 and or TiAlN in Fig.2 with coated carbide. In Table 1 described tool insert dynamometer system of TNMA 160408.

2.0 Methods and Material Selection

OHNS is oil hardened and non-shrinking tool wear resistant, has good durability, and holds a good cutting edge. OHNS is often used to make blanks, stamping dies, shear blades, drills, threading tools, gauges, plastic molds, broaches, guide rails, and measuring tools. OHNS has an affinity to reach high hardness and has a good option to define experiment for hard to cut material, so that is used for experimentation. The size of material used is 32 mm to 300 mm in length. A round bar is used for 36 turning experiments as per the design of experimentation. OHNS is often referred to by its standard designation, 100 MnCrW4 tool steel, and its elemental composition is shown in Table 2. The chemical composition of OHNS (oil hardened and non-shrinking) is displayed in Table 3, and the mechanical characteristics of OHNS (oil hardened and non-shrinking) are displayed in Table 4.

Table 2: Tool Holder Identification System

Position	Specification	Symbol	Interpretation
1	Holding method	M S	Multiple lock Screw lock
2	Shape Insertion	C D R sS T V	80^o diamond 55^o diamond Round Square Triangle 35^o diamond
3	Tool form	A B C D J S	Straight shank 0^o angle of side-cutting Straight shank 15^o angle of side-cutting Straight shank 0^o angle of end cutting Straight shank 45^o angle of side-cutting Offset shank 3^o angle of side-cutting Offset shank 45^o angle of side-cutting
4	Insert clearance angle	C N E	7^o positive 0^o negative 20^o positive
5	Tool's hand	R L N	Right tool hand Left tool hand neutral
6	Shank size	A	Shank width
7	Shank size	B	Shank height
8	Insert size	I	Internal circle
9	Tool length	A C D	4.0 inch 5.0 inch 6.0 inch

Table 3: Chemical configuration of OHNS (oil hardened and non-shrinking)

Element	C	Si	S	Ph	Mn	Ni	Cr	Mo	V	Cu	T
Weight %	0.95	0.23	0.032	0.026	0.43	0.10	1.24	0.028	0.006	0.091	0.003

Table 4: Mechanical properties of OHNS (oil hardened and non-shrinking)

Properties	Values (metric)
Tensile strength	950 Mpa
Yield strength	465 Mpa
Impact strength	25 joule
Elongation	10%
Hardness	197(BHN)

2.1 Heat Treatment of OHNS

Heat treatment of OHNS steel is carried out up to 780–810ºC until it gets completely heated through preheating. OHNS is up to 300–490ºC for nearly 30 minutes, then the steel should be immediately quenched in oil. This is known as oil hardening. At this point, the material's hardness value is at 54.67 HRC. At the end of normalizing, hardness is 40 HRC as per the Rockwell testing machine. The specimen becomes harder than the aneling specimen after normalising due to the formation of bainatie and martensite. Figure 4 shows the material of OHNS after heat treatment.

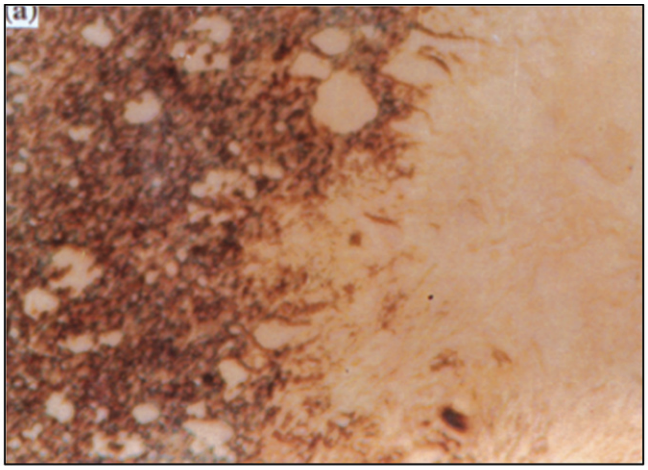

Figure 4: Hardened microstructure of OHNS

2.2 Experiment set up

In the workshop, experiments were carried out on a lathe machine without the use of cutting fluid. The dynamometer used here has a range of 0-200 kg accuracy +/- 5%. The cutting temperature was measured using an MT4 Rayteck portable infrared thermometer with a range of -30º to 900ºC. The gas burner raised the temperature of the specimen. The dynamometer shown in Figure 6 is connected to the lathe in Figure 5.

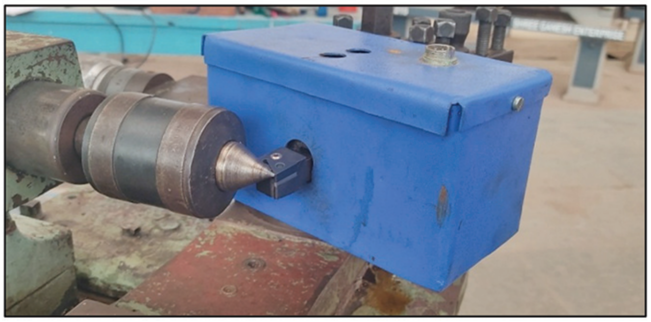

Figure 5: Dynamometer attached on lathe

Figure 6: Lathe tool dynamometer

2.3 Design of Experiments (DOE)

DOE methods lead to an accurate and standard experimental process. Here in this work, the Taguchi statistical method is carried out to define the experimental data matrix. Feed rate, cutting speed and depth of cut are the primary process input parameters; two other parameters are CBN and TiAlN coated carbide inserts and temperature. experiment is performed with and without heating. Table 5 shows the cutting parameters and their levels, which have been set to carry out experiments. Experimentation has been

Table 5: Level of input parameters

Process parameter	Levels		
Inserts material	CBN	TiAlN coated carbide	
Temperature	Without heat (room temp)	With heat (600 degree)	
Cutting speed (rpm)	300	500	800
Feed rate	0.1	0.2	0.3
Depth of cut	0.5	1.0	1.5

carried out for five different parameters with three levels. As per the Taguchi approach, a total of 2*2*3*3 = 36 experiments are to be performed..

2.4 Experimental work

Total 36 experiments is carried out in dry environment on lathe machine. First eighteen experiment is done on room temperature (without application heat) with CBN and TiAlN inserts and next eighteen experiment is done on 600ºC heat with CBN and TiAlN in Table 6 respectively. The results of the trials are depicted in Figure 7.

Figure 7: Specimen after experiments

3.0 Result and Discussion

The tool lathe dynamometer is used to measure three distinct forms of force in addition to the amount of power consumed by each experiment in Table 7.

$$P_c = F_c * V_c \quad \text{... (1)}$$

3.1 Impact of individual factors

Cutting forces, surface quality, and power usage have all been discussed in relation to this point, as have the impacts of feed rate, cutting depth and cutting speed.

3.1.1 The influence of the cutting speed on the output parameters

Figure 8 shows how cutting speed affects power consumption, cutting force and surface roughness. ANOVA one-wayanalysis in minitab generates such a graph. All response variable increase with direct relation to the rate at which the cutting speed is increased.

3.1.2 The influence of the feed rate on the output parameters

The effect that increasing the feed rate has on output variables such as cutting force, roughness, and power usage. A lower feed rate has been utilised in order to get the optimal outcome shown in Figure 9.

Table 6: Data of experimental parameter -1

Exp. No.	Inserts used (without heat)	Speed Cs (rpm)	Feed f (mm/rev)	Depth of cut d (mm)	Cutting force Fc (N)	Surface roughness Rs (µm)
1	CBN	300	0.3	1.5	71	3.510
2	CBN	500	0.3	1.5	81	3.241
3	CBN	800	0.3	1.5	78	2.764
4	CBN	300	0.2	1.0	51	1.876
5	CBN	500	0.2	1.0	59	2.503
6	CBN	800	0.2	1.0	67	1.783
7	CBN	300	0.1	0.5	22	1..574
8	CBN	500	0.1	0.5	17	4.71
9	CBN	800	0.1	0.5	17	7.026
10	TIAlN	300	0.3	1.5	96	2.423
11	TIAlN	500	0.3	1.5	100	2.947
12	TIAlN	800	0.3	1.5	78	2.764
13	TIAlN	300	0.2	1.0	27	3.875
14	TIAlN	500	0.2	1.0	34	3.499
15	TIAlN	800	0.2	1.0	52	3.875
16	TIAlN	300	0.1	0.5	15	1.168
17	TIAlN	500	0.1	0.5	15	1.574
18	TIAlN	800	0.1	0.5	15	4.710

Exp. No.	Inserts used (with 600°C heat)	Speed Cs (rpm)	Feed f (mm/rev)	Depth of cut d (mm)	Cutting force Fc (N)	Surface roughness Rs (μm)
19	CBN	300	0.3	1.5	84	2.520
20	CBN	500	0.3	1.5	85	2.500
21	CBN	800	0.3	1.5	85	2.304
22	CBN	300	0.2	1.0	60	1.409
23	CBN	500	0.2	1.0	58	1.244
24	CBN	800	0.2	1.0	56	1.998
25	CBN	300	0.1	0.5	33	0.644
26	CBN	500	0.1	0.5	31	0.644
27	CBN	800	0.1	0.5	29	1.752
28	TIAlN	300	0.3	1.5	75	2.914
29	TIAlN	500	0.3	1.5	72	2.742
30	TIAlN	800	0.3	1.5	76	2.872
31	TIAlN	300	0.2	1.0	38	2.050
32	TIAlN	500	0.2	1.0	39	1.524
33	TIAlN	800	0.2	1.0	37	1.616
34	TIAlN	300	0.1	0.5	17	0.630
35	TIAlN	500	0.1	0.5	17	0.819
36	TIAlN	800	0.1	0.5	17	1.161

Table 7: Tool Dynamometer Observations

Exp. No.	Inserts used (without heat)	Speed Cs (rpm)	Feed f (mm/rev)	Depth of cut d (mm)	Cutting force Fc (N)	Cutting speed Vc (m/sec)	Power consumption Pc (Kw)
1	CBN	300	0.3	1.5	71	30.144	2140.224
2	CBN	500	0.3	1.5	81	50.24	4069.44
3	CBN	800	0.3	1.5	78	80.384	6269.952
4	CBN	300	0.2	1.0	51	30.144	1537.344
5	CBN	500	0.2	1.0	59	50.24	2964.16
6	CBN	800	0.2	1.0	67	80.384	5385.728
7	CBN	300	0.1	0.5	22	30.144	663.168
8	CBN	500	0.1	0.5	17	50.24	854.08
9	CBN	800	0.1	0.5	17	80.384	1366.528
10	TIAlN	300	0.3	1.5	96	30.144	2893.824
11	TIAlN	500	0.3	1.5	100	50.24	5024
12	TIAlN	800	0.3	1.5	78	80.384	6269.952
13	TIAlN	300	0.2	1.0	27	30.144	813.888
14	TIAlN	500	0.2	1.0	34	50.24	1708.16
15	TIAlN	800	0.2	1.0	52	80.384	4179.968
16	TIAlN	300	0.1	0.5	15	30.144	452.16
17	TIAlN	500	0.1	0.5	15	50.24	753.6
18	TIAlN	800	0.1	0.5	15	80.384	1205.76

Exp. No.	Inserts used (with 600^{o}C heat)	Speed Cs (rpm)	Feed f (mm/rev)	Depth of cut d (mm)	Cutting force Fc (N)	Cutting speed Vc (m/sec)	Power consumption Pc (Kw)
19	CBN	300	0.3	1.5	84	30.144	2532.096
20	CBN	500	0.3	1.5	85	50.24	4270.4
21	CBN	800	0.3	1.5	85	80.384	6832.64
22	CBN	300	0.2	1.0	60	30.144	1808.64
23	CBN	500	0.2	1.0	58	50.24	2913.92
24	CBN	800	0.2	1.0	56	80.384	4501.504
25	CBN	300	0.1	0.5	33	30.144	994.752
26	CBN	500	0.1	0.5	31	50.24	1557.44
27	CBN	800	0.1	0.5	29	80.384	2331.136
28	TIAlN	300	0.3	1.5	75	30.144	2260.8
29	TIAlN	500	0.3	1.5	72	50.24	3617.28
30	TIAlN	800	0.3	1.5	76	80.384	6109.184
31	TIAlN	300	0.2	1.0	38	30.144	1145.472
32	TIAlN	500	0.2	1.0	39	50.24	1959.36
33	TIAlN	800	0.2	1.0	37	80.384	2974.208
34	TIAlN	300	0.1	0.5	17	30.144	512.448
35	TIAlN	500	0.1	0.5	17	50.24	854.08
36	TIAlN	800	0.1	0.5	17	80.384	1366.528

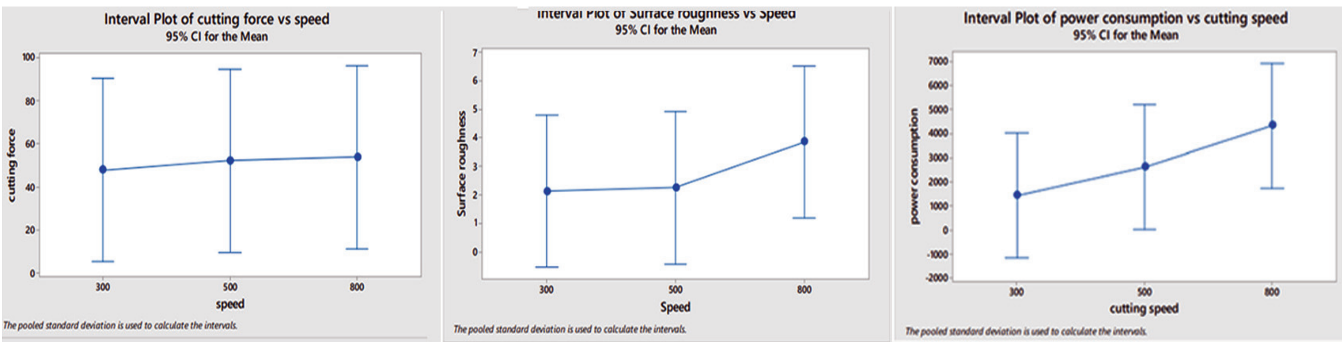

Figure 8: Impact of cutting speed on response variables: power consumption, cutting force and surface roughness

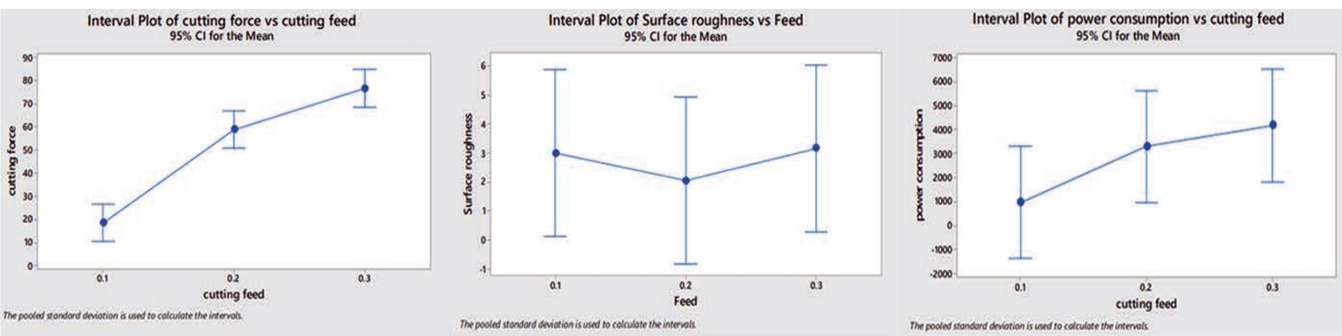

Figure 9: Impact of cutting feed rate on response variables: power consumption, cutting force and surface roughness

3.1.3 The influence of the depth of cut on the output parameters

According to the experiment's findings, the best outcomes may be obtained by lowering the depth of cut. As seen in Figure 10, the product's value increases in a direct proportion to the depth of the cut.

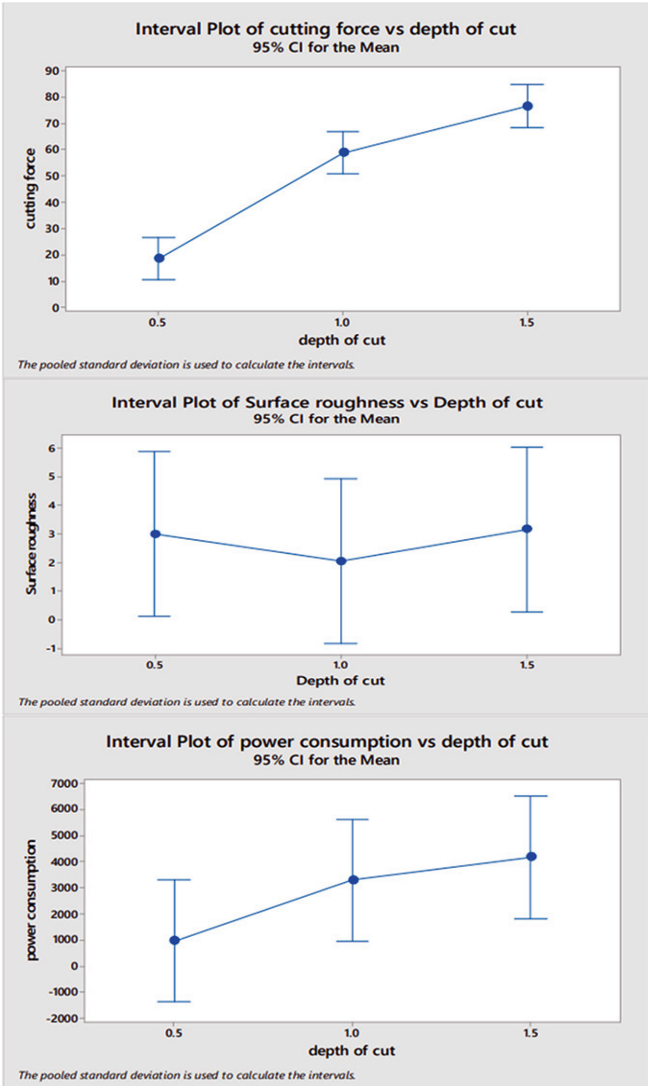

Figure 10: Impact of depth of cut on response variables: power consumption, cutting force and surface roughness

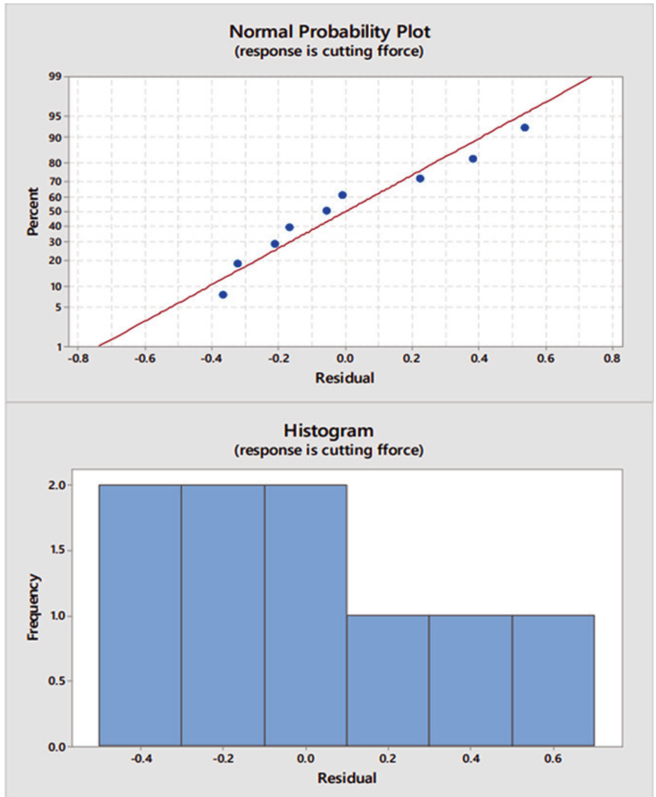

Figure 11: Normal Probability plot and Histogram : Effect of cutting forces

3.2 ANOVA analysis with general linear model

3.2.1 Cutting forces vs. cutting speed, feed, cut depth

Due to their inability to be quantified, the following were eliminated: Cut depth. Histogram and Normal Probability plot depicting the effect of cutting forces in Figure 11. Table 8 provides a detailed analysis of the variation in the transformed response of the cutting force.

According to the analysis, the feed force has the greatest influence on cutting force (97%). The P value of feed is less than 0.05, indicating that feed has the greatest influence on cutting force.

Table 8: Response Variance Analysis for Transformed Cutting Force

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	P-Value
speed	2	0.1322	0.40%	0.1322	0.0661	0.737
feed	2	32.1611	97.18%	32.1611	16.0806	0.001
Error	4	0.8015	2.42%	0.8015	0.2004	
Total	8	33.0948	100.00%			

Table 9: Response Variance Analysis for Transformed surface roughness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	P-Value
speed	2	0.05609	16.09%	0.05609	0.02805	0.626
feed	2	0.07988	22.91%	0.07988	0.03994	0.529
Error	4	0.21270	61.00%	0.21270	0.05318	
Total	8	0.34867	100.00%			

Table 10: Response Variance Analysis for Transformed power consumption

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	P-Value
speed	2	0.000178	26.51%	0.000178	0.000089	0.001
feed	2	0.000488	72.64%	0.000488	0.000244	0.000
Error	4	0.000006	0.85%	0.000006	0.000001	
Total	8	0.000672	100.00%			

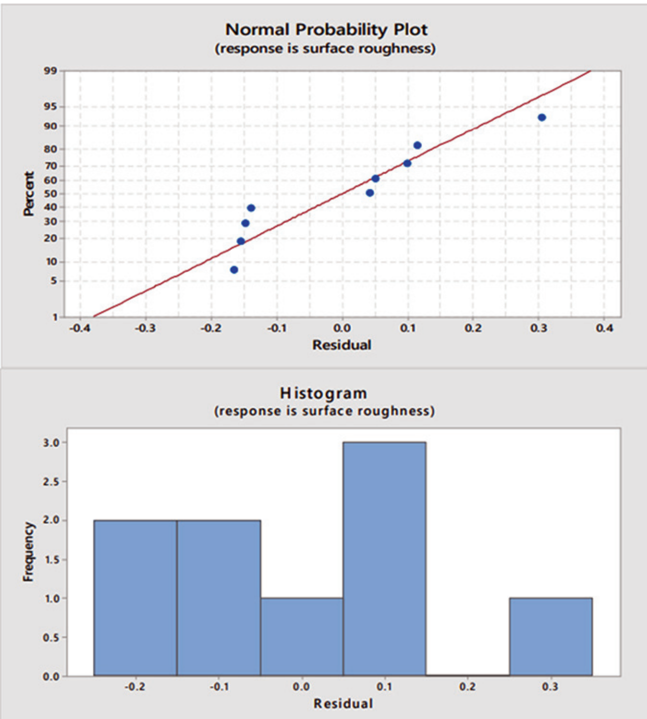

Figure 12: Normal Probability plot and Histogram : Effect of Surface Roughness

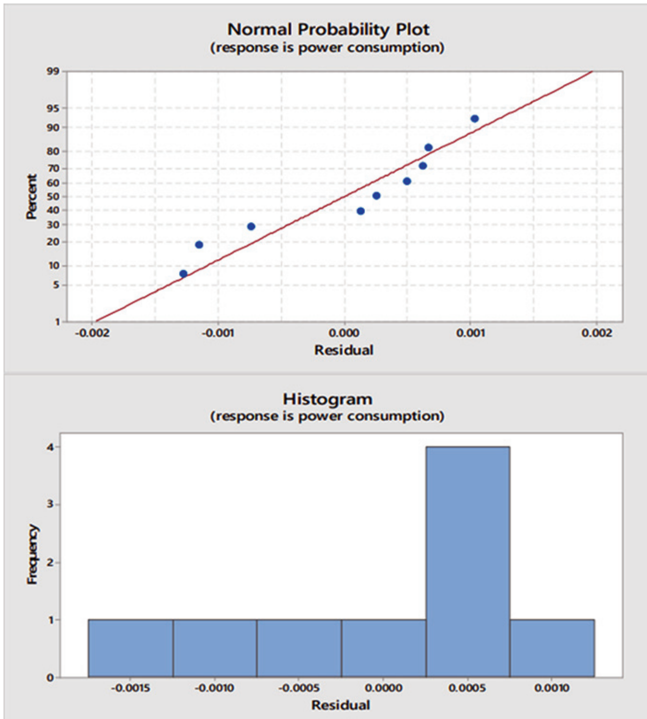

Figure 13: Normal Probability plot and Histogram : Effect of Power Consumption

3.2.2 Surface roughness vs. cutting speed, feed, cut depth

Figure 12 shows a histogram and a normal probability plot demonstrating the influence of surface roughness. Table 9 examines the variance in the transformed response of the surface roughness in extensive detail. Anova analysis reveals that feed force has the greatest influence on surface roughness (22.91%). Speed has a 16% effect on roughness.

3.2.3 Power consumption vs. cutting speed, feed, cut depth

Figure 13 shows a power usage histogram and the normal probability plot. Table 10 analyses the transformed power consumption response variation. ANOVA analysis shows that feed affects power usage by 72.6%. The feed parameter's frequency histogram peaks at 0.0005.

4.0 Conclusions

In order to determine how variations in input parameters affect power consumption, cutting forces and surface roughness during the machining of material that is difficult to cut, it is necessary to analyse the process parameters of cutting speed, feed rate and cut depth. The observation of an OHNS bar with dimensions ranging from 32 millimetres in diameter to 300 millimetres in length was taken into consideration. Analyses were done to determine how response variables were affected by varying these three factors. The findings of this study lead us to the conclusion that each of the three input factors had some degree of influence on the variables that were evaluated as outputs. In addition, individuals have endeavoured to identify the input parameters that produce the optimum results for each variety of intended output response.

Power consumption, cutting forces and surface roughness are all significantly impacted when cutting speed, feed rate and cut depth are changed. Out of all input factors, the influence of feed is the most important. As the speed rises, there is a minute increase in the amount of force being applied. The forces are at their highest value and their mid-speed (after 500 metres per second, the forces begin to decrease for other speeds). The cutting force valve is constantly adjusted so that it provides a greater cutting force in direct proportion to the input value and the cut depth. The optimum cutting force value, given the cut depth and feed, with values of 0.1 and 0.5 respectively. When the surface roughness is measured at 800 revolutions per minute, the peck value is maximised. The cut's surface finish value will initially decrease in response to an increase in either the cut depth or the feed rate. The feed rate and cut depth must be set to 0.2 and 1.0 respectively. The roughness value has become more severe as the feed rate and cutting depth have both been increased. When the feed rate, cutting speed, and cutting depth are all cranked up to their maximum, the amount of power that is consumed simultaneously increases as well.

When the speed, feed and cutting depth are set to 300, 0.1 and 0.5 respectively, the observation produces the lowest possible cutting force.The ideal value for the amount of cutting force, with a feed rate of 0.1 and a depth of cut of 0.5. Setting the feed rate to 0.2, the depth of cut to 1.0 and the minimum surface roughness to 30 results in the lowest power usage at a speed of 300 revolutions per minute.

According to the findings of the research, the feed force is responsible for 97% of the total influence on the cutting force. The fact that the feed's P-values is more than 0.05 indicates that it significantly affects the cutting force. Besides cutting speed and depth, the ANOVA shows that the feed rate affects every other factor significantly. Roughness on the workpiece's surface is affected by the feed rate and cutting force respectively by 97% and 22% and by 72.6% in terms of the quantity of power used.

5.0 References

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