TAGUCHI DESIGN OF EXPERIMENT APPROACH TO STUDY THEIR MACHINABILITY OF TITANIUM ALLOY

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ABSTRACT

The machinability study of Titanium (Grade-5) alloy using the CBN cutting tool inserts having nose radius of 0.8 mm. This paper presents the findings of an experimental investigation into the effects of cutting speed, feed rate, depth of cut and approach angle in turning of titanium (Grade 5) alloy. The main cutting force, i.e. tangential force (F_c) and surface roughness (R_a) were the response variables investigated. The experimental results indicate that the proposed mathematical models suggested could adequately describe the performance indicators within the limits of the factors that are being investigated. The feed, cutting speed and depth of cut is the most significant factor that influences the surface roughness and the tangential force. . Taguchi design of experiment has been used for planning experiment and data analysis. An orthogonal array L27 (313), the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to investigate the cutting characteristics of Titanium alloy (grade-5) using CBN cutting tool. A plan of experiment based on the Taguchi technique is used for the performance of experiments on the Titanium alloy (Grade-5) For the elaboration of experiments plan the method of Taguchi for four factors at three levels is used, being understood by levels taken by the factors. The array chosen was the L27 (313) which have 27 rows corresponding to the number of tests (26 degrees of freedom) with 13 columns at three levels.

Keywords: Machinability, Orthogonal array, Surface Roughness, Taguchi technique.

Introduction

Titanium and its alloys are an important class of the aerospace engineering materials due to their excellent combination of strength and fracture toughness as well as low density [1-4].These materials are regarded as difficult to machine because of their low thermal conductivity and high chemical reactivity with cutting tool materials [5]. Moreover, the low thermal conductivity of Titanium inhibits dissipation of heat within the work piece causing a higher temperature at the cutting edge and generating for higher cutting speed a rapid chipping at the cutting edge which leads to catastrophic failure. In addition, chip morphology significantly influences the thermo-mechanical behavior at the work piece/tool interface, which also affects the tool life [6].Ti-6Al-

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4V will be continue to be the most-used titanium alloy. However, the machinability of the titanium alloys is difficult due to their low thermal conductivity and elastic modulus, high hardness at elevated temperature, and high chemical reactivity. Good machinability can be defined as an optimal combination of factors such as low cutting force, good surface finish, low power consumption, high material removal rate, accurate and consistent work piece geometrical characteristics, low tool wear rate and good curl or chip breakdown of chips [7-8]. In addition, chip morphology significantly influences the thermo-mechanical behavior at the work piece and tool interface, which also affects the tool life.

1.1 Categories

Titanium alloys are classified into four categories: a Alpha alloys.

b Alpha & Beta alloys.

c Beta alloys.

d Near – alpha alloys.

a. Alpha alloys: These are non-heat treatable and are generally very weld able. They have low to medium strength, good notch toughness, reasonably good ductility and have excellent properties at cryogenic temperatures. The more highly alpha or near alpha alloys offer high temperature creep strength and oxidation resistance.

b. Alpha & Beta alloys: These are heat treatable to varying extents and most are weldable with the risk of some loss of ductility in the weld area. Their strength levels are medium to high. Hot forming qualities are good but cold forming often presents difficulties. Creep strength is not usually as good as in most alpha alloy**.**

c. Beta alloys: Beta or near beta alloys are readily heat treatable, generally weldable, and offer high strength up to intermediate temperature levels. In the solution treated condition, cold formability is generally excellent.

d. Near-alpha alloys: Titanium near α-alloys contain small amount of ductile β-phase. Besides α-phase stabilizer (aluminum), Near α-Alloys are alloyed by 1-2% of β-phase stabilizers (molybdenum, silicon).

1.2 Grades of Titanium alloys

Grade 5: (Ti6Al4V, Ti-6Al-4V or Ti 6-4) the most commonly used alloy. Chemical composition is 6% aluminum, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the remainder titanium. Stronger than commercially pure titanium having the same stiffness and thermal properties except thermal conductivity,which is about 60% lower in Grade 5 Ti. It is heat treatable. It has excellent combination of strength, corrosion resistance, weld and fabricability**.**

The alloy is fully heat treatable in section sizes up to 15 mm and is used up to approximately 400 °C (750 °F). Application includes Blades, discs, rings, airframes, fasteners, components. Vessels, cases, hubs , forgings, Biomedical implants.

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Grade 6: (Ti-5Al-2.5Sn) having 5% aluminium and 2.5% tin. Used in airframes and jet engines due to its good weld ability, stability and strength at elevated temperatures

2. Experimental Detail

2.1 Material used

The material used for experiments was Titanium alloy (grade -5). Thus the machining experiment were carried out in a dry cutting condition .Table 1 show the chemical composition of grade-5 alloy.CBN is cutting tool which can we used with nose radius of 0.8mm.

Table 1 Chemical composition of titanium alloys (grade-5)

Aluminium %	Vanadium %	Iron %	Oxygen %
6	4	0.25	0.2

2.2 Turning Process Experiment

Turning is very important for the machining process. which a single-point cutting tool removes material from the surface of a rotating cylindrical work piece. Turning is carried out on a SPRINT 16 CNC machine that can provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at a specified rate and depth of cut. The cutting tool is a fed linearly in a direction parallel to the axis of the rotation. Four cutting parameters cutting speed, feed rate, depth of cut, and approach angle are determined in a turning operation. A common method of the evaluating machining performance in a turning operation is based on the surface roughness and cutting force. Basically, surface roughness is strongly correlated with cutting parameters such as cutting speed, feed rate, and depth of cut. Proper selection of the cutting parameters can be obtain better surface roughness. Hence, optimization of the cutting parameters based on the parameter design of the Taguchi method is adopted to improve surface roughness in a turning operation.

2.3 Optimization Technique used in Turning of Titanium Alloy

The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. Design of experimental approach by Taguchi technique is successfully used by researchers in study of machining of titanium alloy. Taguchi technique is a powerful tool for the design of high quality systems. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations. DOE can be highly effective to Optimize product and process

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designs, study the effects of multiple factors (i.e.- variables, parameters, ingredients, etc.) on the performance, and solve production problems by objectively laying out the investigative experiments.

The information from the experiment will tell you how to allocate quality assurance resources based on the objective data. It will indicate whether a supplier's part causes problems or not (ANOVA data), and how to combine different factors in their proper settings to get the best results (Specific Objectives). Taguchi technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiments. The experiment results are analyzed using analysis of means and variance to study the influence of factors. Objective of this research is to develop a Taguchi optimization method for low surface roughness in terms of process parameters when turning of titanium alloy. Considering the process parameters of feed, cutting speed, axial-radial depth of cut and approach angle, a series of experiments were performed to measure the roughness data. Taguchi orthogonal arrays, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are used to find the optimal levels and the effect of the process parameters on surface roughness. A confirmation experiment with the optimal levels of process parameters was carried out in order to demonstrate the effectiveness of the Taguchi method.

3. Equipment used for Experiment Work

3.1 Roughness Tester

Roughness is an important parameter when trying to

find out whether a surface is suitable for a certain purpose. Roughsurfaces often wear out more quickly than smoother surfaces. Rougher surfaces are normally more vulnerable to corrosion and cracks, but they can also aid in adhesion. A roughness tester is used to quickly and accurately determine the surface texture or surface roughness of a material. A roughness tester shows the measured roughness depth (Rz) as well as the mean roughness value (Ra) in micrometers or microns (µm). Measuring the roughness of a surface involves applying a roughness filter. Different international standards and surface texture or surface finish specifications recommend the use of different roughness filters. Roughness tester show the measured roughness depth (Rz) as well as the average roughness value (Ra) in µm. Roughness testers allow a user to determine the material surface roughness quickly. The measurement of surface roughness is very easy. Roughness testers get in contact with surfaces within a few seconds and show the roughness value in Ra or in Rz. Our Roughness testers will be delivered with control cards, probe protection, accumulators and chargers inside a carrying case. Roughness testers are compatible with the following standards and regulations: DIN 4762, DIN 4768, DIN 4771, DIN 4775, and DIN 4766-1 dealing with the range of surface roughness. Some of these products have an

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internal storage facility which helps you to save your measuring results and check and analyze them again afterwards. There are many parameters that can be measured with these instruments. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Roughness plays an important role in determining how a real object will interact with environment. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs of a component and its performance in application.

3.2 Experimental set up

The experiments were carried out under dry machining process on a SPRINT 16 CNC turning centre. Turning is carried out on a SPRINT 16 CNC machine that can provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at a specified rate and depth of cut. The cutting tool is a fed linearly in a direction parallel to the axis of the rotation. Four cutting parameters cutting speed, feed rate, depth of cut, and approach angle are determined in a turning operation. A common method of the evaluating machining performance in a turning operation is based on the surface roughness and cutting force. The SPRINT 16 CNC turning centre has maximum spindle speed of 4,000 rpm and feed rate up to 5,000mm/min.

Optimization of cutting parameters using taguchi method

Table 2 Levels and factors for present work

Process Parameters	Level 1	Level 2	Level 3	Units
Cutting Speed	40	50	60	m/min
Feed rate	0.15	0.20	0.25	Mm/rev
Depth of cut	0.2	0.3	0.4	mm
Approach Angle	45	60	75	Degree

4. Taguchi design of experiments

The general steps involved in the Taguchi Method are as follows:

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a. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.

b. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. For example, a temperature might be varied to a low and high value of 40 C and 80 C. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.

c. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.

d. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.

e. Complete data analysis to determine the effect of the different parameters on the performance measure.

Plan of the experiments **-** The first column is assigned to cutting speed (A), the second column to feed rate content (B), the fifth column to depth of cut (C) and the ninth column to approach angle (D) the third and fourth column are assigned to (A × B)1 and (A× B)2 71 respectively to estimate interaction between cutting speed (A) and feed rate (B), the sixth and seventh column are assigned to (B × C)1 and (B × C)2 respectively to estimate the interaction between feed rate (B) and depth of cut (C), the eight and eleventh column are assigned to (A × C)1 and (A × C)2 respectively to estimate interaction between the cutting speed (A) and feed rate (C) and the remaining columns are used to estimate experimental errors. After assigning appropriate level settings, the S/N analysis (signal-to-noise ratio) is needed to evaluate experiment results. In S/N analysis,the greater the S/N, the better the experimental results.

4.2 Orthogonal array

Orthogonal arrays (OAs) are objects that are most often generated via algebraic arguments. They have a number of applications in applied mathematics, and have often been studied by algebraic mathematicians as objects of interest in their own right. Our treatment will reflect their use as representations of statistical experimental designs. An OA is generally presented as a two-dimensional array, table, or matrix of N rows and k columns. Each entry in the array is one element of a set of s “symbols”, often taken to be $\{0, 1, 2, ..., s - 1\}$ or $\{1, 2, 3, ..., s\}$. From the standpoint of basic definitions, the symbols are not regarded as numerical quantities, so {a, b, c, . could work just as well. However, the use of numerals (especially the first set above) is convenient for some construction techniques. The final basic quantity required for defining the array it its strength, a positive integer t ≤ k. The single requirement that an N-by-k array of s symbols must meet to be an OA of strength t is that every subset of t columns (from among the k columns), when considered alone, must contain each of the possible s t ordered rows the same number of times. A standard notation often used to reference an OA of N rows, k columns, and s symbols, of strength t is OA (N, k, s, t). For example, the following array is an OA.

5. RESULT AND DISCUSSION

The experimental results show that the approach angle and feed rate are the main parameters among the four controllable factors (approach angle, feed rate, cutting speed and depth of cut) that influence the surface roughness in turning of Titanium alloy. According to tool nose radius 0.8 mm the result shows 0.03% and 0.446% contributed by the feed rate and approach angle on the surface roughness.

The interaction between cutting speed and approach angle (A X D) is contributed 0.393 % on surface roughness. Similarly for nose radius 0.8 mm the result shows 0.006% contributed by the feed on the cutting speed.

The interaction between cutting speed and approach angle (A X D) is contributed 0.040 % on surface roughness. It is found that cutting speed 40 m/min, feed rate 0.25 mm/rev, depth of cut 0.2 mm and approach angle 60 the optimum cutting parameters for surface roughness. The analyses of the experimental data have been carried using the software MINITAB 17 specially used for design of experiment applications.

Table 3: Experimental design using l27 array

Run	Cutting Speed (Mm/min)	Feed Rate (Mm/rev)	Depth of cut (mm)	Approach angle (degree)	Surface roughness (µm)	**S/N Ratio** (dB)
1	40	0.15	0.2	45	1.42	-3.0458
2	40	0.15	0.3	60	1.06	-0.5061
3	40	0.15	0.4	75	1.13	-1.0616
4	40	0.20	0.2	60	2.45	-7.7833
5	40	0.20	0.3	75	2.71	-8.6594
6	40	0.20	0.4	45	2.51	-7.9935
7	40	0.25	0.2	75	3.15	-9.9662
8	40	0.25	0.3	45	3.20	-10.1030
9	40	0.25	0.4	60	2.83	-9.0357

10	50	0.15	0.4	45	1.47	-3.3463
11	50	0.15	0.2	60	0.98	0.1755
12	50	0.15	0.3	75	1.54	-3.7504
13	50	0.20	0.4	60	2.29	-7.1967
14	50	0.20	0.2	75	2.69	-8.5950
15	50	0.20	0.3	45	1.69	-4.5577
16	50	0.25	0.4	75	1.88	-5.4832
17	50	0.25	0.2	45	1.83	-5.2490
118	50	0.25	0.3	60	3.92	-11.8657
19	60	0.15	0.3	45	1.48	-3.4052
20	60	0.15	0.4	60	1.28	-2.1442
21	60	0.15	0.2	75	1.93	-5.7111
22	60	0.20	0.3	60	1.47	-3.3463
23	60	0.20	0.4	75	3.47	-10.8066
24	60	0.20	0.2	45	2.88	-9.1878
25	60	0.25	0.3	75	2.85	-9.0969
26	60	0.25	0.4	45	3.63	-11.1981
27	60	0.25	0.2	60	2.51	-7.9935

The experimental data for surface roughness is reported in the Table 3 for tool nose radius 0.8 mm. The overall mean for the S /N ratio of the surface roughness are found to be− 3.7653dB. The analyses of the experimental data are carried using the software MINITAB 17 specially used for design of experiment applications. Before analyzing the experimental data using this method for predicting the measure of performance, the possible interactions between control factors are considered. Thus factorial design incorporate a simple means of testing for the presence of the interaction effects. The mean response refers to the average values of the performance characteristics for each parameter at different levels i.e. of surface roughness.

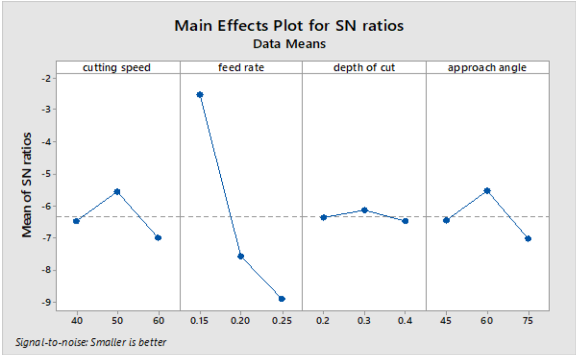


Fig. 5.1 Main effect plot of S/N ratios for surface roughness (nose radius 0.8 mm)

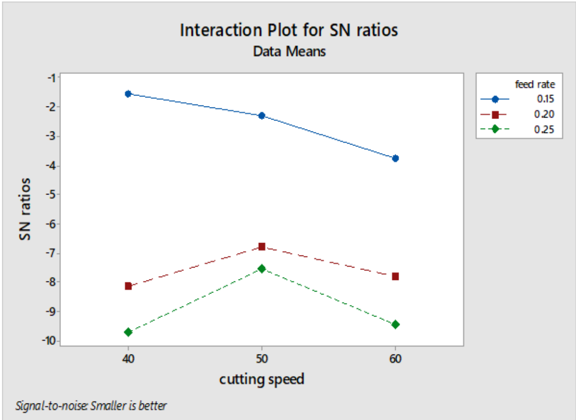


Fig. 5.1 (a) Interaction graph for A X B for surface roughness (nose radius 0.8 mm)

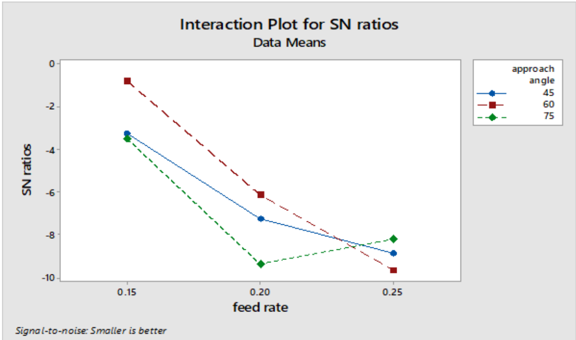


Fig. 5.1 (b) Interaction graph for A X D for surface roughness (nose radius 0.8 mm

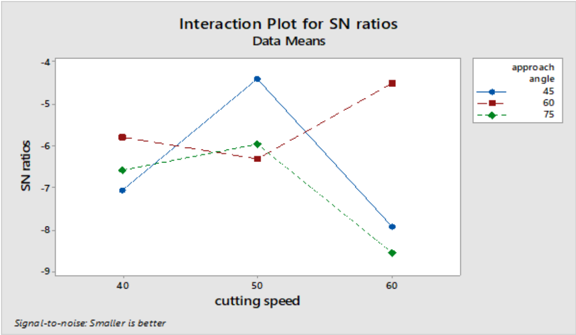


Fig. 5.1 (c) Interaction graph for B X D for surface roughness (nose radius 0.8 mm)

5.2 ANOVA and Effects of Factors

In order to understand the impact of various control factors and interaction on the response of experimental data it is desirable to develop the analysis of variance (ANOVA) to find the significant factors as well as interactions. ANOVA allows analyzing the influence of each variable on the total variance of the results. The last column of table shows the percentage contribution (P) of each variable in the total variation indicating the influence on the cutting force. The purpose of the analysis of variance (ANOVA) is to which design parameters significantly affect the quality characteristic. This is too accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio ηm can be calculated .Where *n* is the number of experiments in the orthogonal array and η*i* is the mean S/N ratio for the *i* th experiment. $SST=\sum_{i=1}^{n}((\eta i-\eta m)^2)$.

Table 5.2 S/N response for surface roughness (nose radius 0.8 mm)

Factors	Level 1	Level 2	Level3	Delta	Rank
Cutting Speed	-6.462	-5.541	-6.988	1.447	3
Feed rate	-2.533	-7.570	-8.888	6.355	1
Depth of cut	-6.373	-6.143	-6.474	0.331	4
Approach Angle	-6.454	-5.522	-7.014	1.493	2

Table 5.2.1 Result of the analysis of variance for surface roughness(nose radius 0.8 mm)

ANOVA result	DOF	Adj SS	Adj MS	F value	P value
Cutting Speed	2	9.653	4.826	0.87	0.464
Feed Rate	2	202.484	101.242	18.35	0.003
Depth of cut	2	0.516	0.258	0.05	0.955
Approach angle	2	10.234	5.117	0.93	0.446
Cutting speed*Feed rate	4	9.300	2.325	0.42	0.789
Cutting Speed *Approach angle	4	26.970	6.743	1.22	0.393
Feed rate *Approach angle	4	22.402	5.600	1.02	0.469
Error	6	33.620	5.517		
Total	26	314.663			

Where

DF: Degree of Freedom

Adj.SS: Adjacent Sum of Square

Adj.MS: Adjacent Mean square

F: Variance ratio (Vm/Ve)

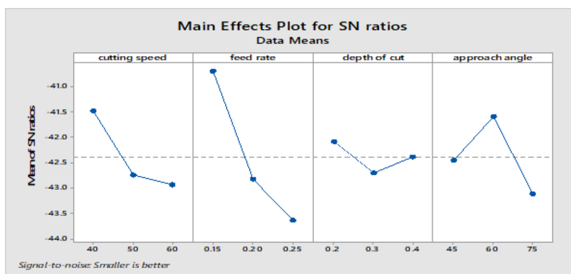
P: Percentage contribution ratio (PCR)

Table 5.2.1 shows the results of ANOVA for surface roughness. The Cutting speed, feed rate, and depth of cut are the significant cutting parameters for affecting surface roughness. However, the contribution order of the cutting parameters for surface roughness is approach angle (P=0.446 %), feed rate (P=0.003 %), the interaction between (A × D) cutting speed and approach angle (P= 0.393%) has significant influence on the surface roughness. However the interaction between feed rate and approach angle (0.469%). It is observed that the cutting speed, approach angle and interaction of (A × D) have major impact on surface roughness. Table 4.1 shows the S/N ratio for surface roughness, it is observed that approach angle has major impact on surface roughness followed by cutting speed, feed rate and depth of cut.

Table 5.3 Experimental Design using L27 array (nose radius 0.8 mm)

Run	Cutting Speed (Mm/min)	Feed Rate (Mm/rev)	Depth of cut (mm)	Approach angle (degree)	Cutting Force	S/N Ratio (dB)
1	40	0.15	0.2	45	75	-37.5012
2	40	0.15	0.3	60	88	-38.8897
3	40	0.15	0.4	75	162	-44.1903
4	40	0.20	0.2	60	82	-38.2763
5	40	0.20	0.3	75	141	-42.9844
6	40	0.20	0.4	45	191	-45.6207
7	40	0.25	0.2	75	126	-42.0074
8	40	0.25	0.3	45	161	-44.1365
9	40	0.25	0.4	60	96	-39.6454
10	50	0.15	0.4	45	79	-37.9525
11	50	0.15	0.2	60	111	-40.9065
12	50	0.15	0.3	75	155	-43.8066
13	50	0.20	0.4	60	134	-42.5421
14	50	0.20	0.2	75	118	-41.4376
15	50	0.20	0.3	45	156	-43.8625
16	50	0.25	0.4	75	128	-42.1442
17	50	0.25	0.2	45	154	-43.7504
18	50	0.25	0.3	60	260	-48.2995
19	60	0.15	0.3	45	77	-37.72

						98
20	60	0.15	0.4	60	115	-41.2140
21	60	0.15	0.2	75	159	-44.0279
22	60	0.20	0.3	60	106	-40.5061
23	60	0.20	0.4	75	148	-43.4052
24	60	0.20	0.2	45	219	-46.8089
25	60	0.25	0.3	75	159	-44.0279
26	60	0.25	0.4	45	171	-44.6599
27	60	0.25	0.2	60	159	-44.0279



Main effect plot of S/N ratios for cutting force (nose radius 0.8mm)

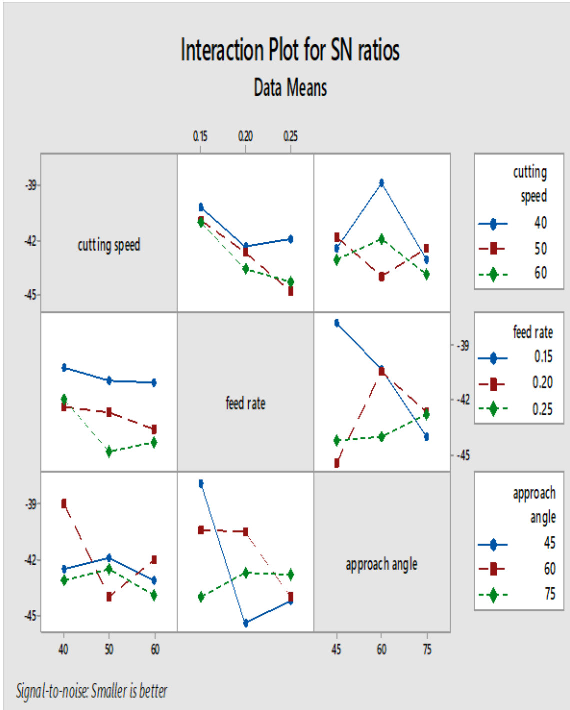


Fig 5.5.1 Interaction graph for A X B, A X D, B X D for cutting force (nose radius 0.8 mm)

5.4 Analysis of Variance ANOVA and Effects of Factors

In order to understand the impact of various control factors and interaction on the response of experimental data it is desirable to develop the analysis of variance (ANOVA) to find the significant factors as well as interactions. ANOVA allows analyzing the influence of each variable on the total variance of the results. The last column of table shows the percentage contribution (P) of each variable in the total variation indicating the influence on the cutting force. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic.

The total variability of the S/N ratios,which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio ηm can be calculated

Table 5.4.1 S/N response for cutting force (nose radius 0.8 mm)

Factors	Level 1	Level 2	Level3	Delta	Rank
Cutting Speed	-41.47	-42.74	-42.93	1.46	3
Feed rate	-40.69	-42.83	-43.63	2.94	1
Depth of cut	-42.08	-42.69	-42.37	0.61	4
Approach Angle	-42.45	-41.59	-43.11	1.52	2

Table 5.4.2 Result of the analysis of variance for Cutting force (nose radius 0.8 mm)

ANOVA result	DOF	Adj SS	Adj MS	F value	P value
Cutting Speed	2	11.374	5.6869	3.68	0.090
Feed Rate	2	41.610	20.8052	13.46	0.006
Depth of cut	2	1.681	0.8404	0.54	0.606
Approach angle	2	10.518	5.2591	3.41	0.103
Cutting speed*Feed rate	4	5.837	1.4593	0.95	0.499
Cutting Speed *Approach angle	4	31.270	7.8176	5.06	0.040
Feed rate *Approach angle	4	90.519	22.6297	14.66	0.003
Error	6	9.264	1.5440		
Total	26	202.073			

Table 5.4.2 shows the results of ANOVA for Cutting force. The Cutting speed, feed rate, and depth of cut are the significant cutting parameters for affecting surface roughness. However, the contribution order of the cutting parameters for surface roughness is approach angle (P=0. 103%), feed rate (P=0.006 %), the interaction between (A × D) cutting speed and approach angle (P= 0.040%) has significant influence on the surface roughness. However the interaction between feed rate and approach angle (0.003%). It is observed that the cutting speed, approach angle and interaction of (A × D) have major impact on Cutting force.

Conclusion

The Taguchi design of experiment and analysis is successfully used for optimizing the titanium alloy (grade-5) for CBN cutting tool. These techniques have been utilized widely in engineering

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analysis to optimize the performance characteristics of design parameters. Taguchi technique is also a powerful tool for the design of high quality systems. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance, and computational cost. In Taguchi technique, three-stages such as system design, parameter design, and tolerance design are employed. System design consists of the usage of scientific and engineering information required for producing a part. Tolerance design is employed to determine and to analyze tolerances about the optimum combinations suggested by parameter design.

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