Experimental Design And Analysis Using Two Level Design For Identification Of Factors Which Affect Surface Roughness On Aerospace Fasteners

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Abstract- *In order to understand the factors which affect a particular characteristic, it would be worthwhile doing an experiment method by using statistical techniques. There are varieties of techniques available to do a statistical conclusion, among them design of experiment approach using the principle of randomization, replication and blocking widely accepted and followed.*

In a machining industry where factors such as material characteristics, machine parameters (speed, feed and depth of cut) play a vital role on quality characteristics such as surface roughness, it would be easier to understand the implications these factors by using DOE approach.

*In the current work it is seen that the material and the other machine parameters plays the vital role in affecting the surface roughness. Hence in this work, a DOE based approach is considered by choosing a 2^4 design with material, depth of cut, speed and feed as factors. The experiment is run by using 80 samples (2^4*5 replicates) and various measures such Average surface roughness ,Surface roughness Range, Standard deviation for surface roughness are evaluated.*

Keywords- *Surface Roughness, Speed, feed, depth of cut, 2-level design (2^k design), Design Of Experiments, ANOVA*

1. INTRODUCTION

Traditionally, different types of materials have been used for aerospace fasteners. The choice of the materials has been based on the characteristics, quality and cost. Some of the materials which are being used in the aerospace are Titanium, Alloy steel, etc.

The aim of the paper is to reduce the defects and defectives in the production line and minimizing surface roughness using Industrial engineering tools and techniques. Surface roughness of a material has a direct impact on surface finish quality and hence surface defects. The lower the surface roughness value the better would be the surface finish quality. In aerospace, the surface finish plays a crucial role and becomes important quality characteristic, therefore a need of minimal or zero defects. To analyse and identify which combination gives better result, design of experiment approach is used.

Machining was carried out using CNC machine and material used was Titanium Alloy (Ti-6Al-4V) and Alloy steel(Al-304). To machine, Titanium alloy and Alloy steel were used with 8mm diameter and 10 mm length as shown in the figure.

Figure-1: Work piece

The chemical composition of Titanium alloy Ti-6Al-4V and Alloy steel is summarized shown in the table 1 and 2. All the work from initial preparation of work piece to final machining experiment was done at ABC Company.

Table-1: Chemical composition of Ti-6Al-4V, % wt

Element	Al	V	Fe	O	C	N	Y	H	Ni
Wt(%)	6.1	4	0.16	0.11	0.02	0.01	0.001	0.001	Bal

Table-2: Chemical composition of AISI-304, % wt

Elements	C	Si	Mn	S	P	Cr	Ni	Mo
Wt(%)	0.368	0.155	0.684	0.02	0.023	1.6	1.598	0.284

2. LITERATURE REVIEW

There have been various literatures on and carried in analysing the effects of various machining factors on material such as titanium and alloy steel.

Mohammed T. Hayajneh et al. [11], carried out a set of experimental design to understand the surface quality for End-Milling Process. Their objective was to know the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a multiple regression model.

Navneet Khanna, J P Davim [10] studied the effect of control factors i.e. cutting speed, feed rate and cutting tool temperature using taguchi technique. The output of their study was to suggesting Aerospace industry to use titanium alloys which has superior strength

Goutam Devaraya Revankara et al. [8] carried out their study on Titanium alloy (Ti–6Al–4V) and Polycrystalline Diamond Tool using different factors such as speed feed and depth of cut. The aim of their study was to know the effect of these parameters on surface roughness and hardness. The study tells, the smaller the roughness, better hardness is achieved.

Er. Manpreet Singh et al. [12] carried a literature review on different type of material to be machined. Their study showcase the importance of machining parameters like Speed Feed Depth of cut Nose radius plays a vital role in Surface Roughness.

3. EXPERIMENTAL DESIGN

A 2^4 design was considered with factors and levels as shown in Table 2. The response variables considered are shown in Table 4.

Table-3: Process control parameters and their levels

Parameters	Units	Level 1	Level 2
Speed	Rpm	2300	3700
Feed	mm/rev	04	06
Depth of cut	mm	0.2	0.3
Materials	-	Titanium	Alloy steel

3.1 Experimental procedure

The turning, Outer diameter(OD) and part off operations were carried out in CNC machine at ABC Company. The CNC machine is equipped with AC variable speed spindle motor up to 4000 rpm and regular industrial power was used for present experimental work. The cutting tool used was Carbide tool and inserts.

Figure-2: Photo of CNC machine

3.2 Response values

The response values were taken using **Surface Roughness Tester** in Advance Material science lab at MSRIT, Bangalore. Surface Roughness can be measured in µm and the cut off length is 0.25mm and 2.5mm. If we place the specimen below the tester, it automatically calculates the surface roughness of it. To check the repeatability, the readings were collected for many trials. The figure3 shows the surface testing machine.

Figure-3: Surface roughness testing machine

The response variables are tested as follows

3.2.1 Average surface roughness: In this within a part five data point's average were collected to check the variability within a part.

3.2.2 Surface roughness Range: In this the range was considered to know the variation within a part.

3.2.3 Standard deviation for surface roughness: In this the lateral side of the specimen's five data points were measured to check the variation across the part.

After collecting the responses, the data was input in run order sheet and using Minitab software, then accordingly data was analyses using Minitab software package. Table 4 shows the run orders and response values. The experiment was run for 80 runs (2^4 * 5 Replicates) based on randomization for which the details have been provided in Table 4.

Table-4: Response variables

Std Order	Run Order	Material	Depth of cut	Feed	Speed
36	1	Alloy steel	0.3	4	2300
1	2	Titanium	0.2	4	2300
17	3	Titanium	0.2	4	2300
11	4	Titanium	0.3	4	3700
14	5	Alloy steel	0.2	6	3700
26	6	Alloy steel	0.2	4	3700
60	7	Alloy steel	0.3	4	3700
64	8	Alloy steel	0.3	6	3700
51	9	Titanium	0.3	4	2300
3	10	Titanium	0.3	4	2300
39	11	Titanium	0.3	6	2300
2	12	Alloy steel	0.2	4	2300
66	13	Alloy steel	0.2	4	2300
69	14	Titanium	0.2	6	2300
79	15	Titanium	0.3	6	3700
68	16	Alloy steel	0.3	4	2300
5	17	Titanium	0.2	6	2300
28	18	Alloy steel	0.3	4	3700
65	19	Titanium	0.2	4	2300
22	20	Alloy steel	0.2	6	2300
34	21	Alloy steel	0.2	4	2300
10	22	Alloy steel	0.2	4	3700
71	23	Titanium	0.3	6	2300
40	24	Alloy steel	0.3	6	2300
12	25	Alloy steel	0.3	4	3700
76	26	Alloy steel	0.3	4	3700
20	27	Alloy steel	0.3	4	2300
47	28	Titanium	0.3	6	3700
77	29	Titanium	0.2	6	3700
48	30	Alloy steel	0.3	6	3700
15	31	Titanium	0.3	6	3700
41	32	Titanium	0.2	4	3700
52	33	Alloy steel	0.3	4	2300
23	34	Titanium	0.3	6	2300
73	35	Titanium	0.2	4	3700
30	36	Alloy steel	0.2	6	3700
78	37	Alloy steel	0.2	6	3700
27	38	Titanium	0.3	4	3700
29	39	Titanium	0.2	6	3700
63	40	Titanium	0.3	6	3700
80	41	Alloy steel	0.3	6	3700
70	42	Alloy steel	0.2	6	2300
46	43	Alloy steel	0.2	6	3700
8	44	Alloy steel	0.3	6	2300
72	45	Alloy steel	0.3	6	2300
35	46	Titanium	0.3	4	2300
38	47	Alloy steel	0.2	6	2300
59	48	Titanium	0.3	4	3700
45	49	Titanium	0.2	6	3700
67	50	Titanium	0.3	4	2300
42	51	Alloy steel	0.2	4	3700
18	52	Alloy steel	0.2	4	2300
74	53	Alloy steel	0.2	4	3700
50	54	Alloy steel	0.2	4	2300
16	55	Alloy steel	0.3	6	3700
25	56	Titanium	0.2	4	3700
13	57	Titanium	0.2	6	3700
44	58	Alloy steel	0.3	4	3700
19	59	Titanium	0.3	4	2300
43	60	Titanium	0.3	4	3700
57	61	Titanium	0.2	4	3700
58	62	Alloy steel	0.2	4	3700
54	63	Alloy steel	0.2	6	2300
37	64	Titanium	0.2	6	2300
61	65	Titanium	0.2	6	3700
62	66	Alloy steel	0.2	6	3700
7	67	Titanium	0.3	6	2300
53	68	Titanium	0.2	6	2300
31	69	Titanium	0.3	6	3700
9	70	Titanium	0.2	4	3700
32	71	Alloy steel	0.3	6	3700
75	72	Titanium	0.3	4	3700
33	73	Titanium	0.2	4	2300
4	74	Alloy steel	0.3	4	2300
56	75	Alloy steel	0.3	6	2300

21	76	Titanium	0.2	6	2300
6	77	Alloy steel	0.2	6	2300
49	78	Titanium	0.2	4	2300
24	79	Alloy steel	0.3	6	2300
55	80	Titanium	0.3	6	2300

Table-4: Run orders

Std Order	Run Order	Material	Depth of cut	Feed	Speed	Response Average	Range	Std Dev
36	1	Alloy steel	0.3	4	2300	2.31	0.99	0.42784
1	2	Titanium	0.2	4	2300	0.32	0.06	0.02449
17	3	Titanium	0.2	4	2300	0.332	0.03	0.01304
11	4	Titanium	0.3	4	3700	0.292	0.08	0.03033
14	5	Alloy steel	0.2	6	3700	1.956	0.22	0.11349
26	6	Alloy steel	0.2	4	3700	1.966	1.43	0.66418
60	7	Alloy steel	0.3	4	3700	1.954	1.17	0.50787
64	8	Alloy steel	0.3	6	3700	1.684	0.52	0.24481
51	9	Titanium	0.3	4	2300	0.356	0.06	0.02608
3	10	Titanium	0.3	4	2300	0.41	0.33	0.13323
39	11	Titanium	0.3	6	2300	1.798	0.29	0.11256
2	12	Alloy steel	0.2	4	2300	1.84	1.06	0.41689
66	13	Alloy steel	0.2	4	2300	1.662	1.24	0.51935
69	14	Titanium	0.2	6	2300	2.342	1.23	0.48874
79	15	Titanium	0.3	6	3700	0.334	0.13	0.0493
68	16	Alloy steel	0.3	4	2300	1.636	2.19	0.88506
5	17	Titanium	0.2	6	2300	0.188	0.11	0.04266
28	18	Alloy steel	0.3	4	3700	2.196	0.5	0.20852
65	19	Titanium	0.2	4	2300	0.33	0.1	0.03674
22	20	Alloy steel	0.2	6	2300	1.94	0.98	0.38079
34	21	Alloy steel	0.2	4	2300	1.112	0.75	0.3292
10	22	Alloy steel	0.2	4	3700	1.188	1.26	0.57552
71	23	Titanium	0.3	6	2300	0.348	0.1	0.03768
40	24	Alloy steel	0.3	6	2300	1.74	1.26	0.51488
12	25	Alloy steel	0.3	4	3700	0.282	0.08	0.03114
76	26	Alloy steel	0.3	4	3700	1.492	0.75	0.30351
20	27	Alloy steel	0.3	4	2300	2.094	0.36	0.13612
47	28	Titanium	0.3	6	3700	0.334	0.05	0.01949
77	29	Titanium	0.2	6	3700	0.292	0.18	0.07463
48	30	Alloy steel	0.3	6	3700	1.886	1.24	0.46474
15	31	Titanium	0.3	6	3700	0.344	0.08	0.02966
41	32	Titanium	0.2	4	3700	0.36	0.14	0.05701
52	33	Alloy steel	0.3	4	2300	1.348	0.58	0.27887
23	34	Titanium	0.3	6	2300	0.348	0.12	0.0502
73	35	Titanium	0.2	4	3700	0.272	0.08	0.0295
30	36	Alloy steel	0.2	6	3700	0.308	0.13	0.0507
78	37	Alloy steel	0.2	6	3700	1.646	0.74	0.28023
27	38	Titanium	0.3	4	3700	0.378	0.08	0.03271
29	39	Titanium	0.2	6	3700	0.32	0.04	0.01581
63	40	Titanium	0.3	6	3700	0.33	0.35	0.13802
80	41	Alloy steel	0.3	6	3700	1.538	0.93	0.42423
70	42	Alloy steel	0.2	6	2300	1.744	0.67	0.26035
46	43	Alloy steel	0.2	6	3700	1.272	1	0.45855
8	44	Alloy steel	0.3	6	2300	1.184	0.81	0.32316
72	45	Alloy steel	0.3	6	2300	2.746	2.49	0.96653
35	46	Titanium	0.3	4	2300	0.482	0.98	0.40923
38	47	Alloy steel	0.2	6	2300	1.84	0.91	0.42913
59	48	Titanium	0.3	4	3700	0.322	0.29	0.11032
45	49	Titanium	0.2	6	3700	0.416	0.12	0.0493
67	50	Titanium	0.3	4	2300	0.172	0.07	0.03114
42	51	Alloy steel	0.2	4	3700	1.494	0.57	0.2259
18	52	Alloy steel	0.2	4	2300	0.29	0.09	0.03464
74	53	Alloy steel	0.2	4	3700	1.612	0.86	0.36279
50	54	Alloy steel	0.2	4	2300	2.29	1.39	0.57676
16	55	Alloy steel	0.3	6	3700	1.566	0.9	0.35437
25	56	Titanium	0.2	4	3700	0.446	0.07	0.02702
13	57	Titanium	0.2	6	3700	0.228	0.12	0.05119
44	58	Alloy steel	0.3	4	3700	1.47	0.65	0.25417
19	59	Titanium	0.3	4	2300	2.002	0.7	0.25985
43	60	Titanium	0.3	4	3700	0.258	0.08	0.03033
57	61	Titanium	0.2	4	3700	0.32	0.13	0.04848
58	62	Alloy steel	0.2	4	3700	1.224	1.12	0.43855
54	63	Alloy steel	0.2	6	2300	2.602	1.81	0.72758
37	64	Titanium	0.2	6	2300	1.328	0.7	0.27472
61	65	Titanium	0.2	6	3700	0.43	0.68	0.28636
62	66	Alloy steel	0.2	6	3700	2.474	1.6	0.59563

54	63	Alloy steel	0.2	6	2300	2.602	1.81	0.72758
37	64	Titanium	0.2	6	2300	1.328	0.7	0.27472
61	65	Titanium	0.2	6	3700	0.43	0.68	0.28636
62	66	Alloy steel	0.2	6	3700	2.474	1.6	0.59563
7	67	Titanium	0.3	6	2300	1.616	0.44	0.17516
53	68	Titanium	0.2	6	2300	0.336	0.1	0.03912
31	69	Titanium	0.3	6	3700	0.322	0.27	0.11628
9	70	Titanium	0.2	4	3700	0.294	0.02	0.00894
32	71	Alloy steel	0.3	6	3700	1.898	1.05	0.45191
75	72	Titanium	0.3	4	3700	0.408	0.1	0.04382
33	73	Titanium	0.2	4	2300	0.326	0.06	0.02793
4	74	Alloy steel	0.3	4	2300	0.334	0.11	0.04037
56	75	Alloy steel	0.3	6	2300	1.602	0.98	0.36141
21	76	Titanium	0.2	6	2300	0.358	0.1	0.03633
6	77	Alloy steel	0.2	6	2300	1.102	0.27	0.10826
49	78	Titanium	0.2	4	2300	0.334	0.12	0.04506
24	79	Alloy steel	0.3	6	2300	1.674	0.73	0.28343
55	80	Titanium	0.3	6	2300	0.266	0.05	0.01949

4. RESULTS

4.1 Main effects plot of average surface roughness for Ti-Al steel

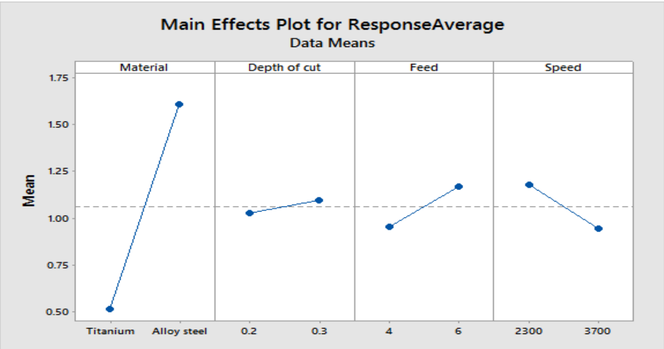

Chart-1: Main effects plot of average surface roughness for Ti-Al steel

It is seen from the main effects plot of Average surface roughness of titanium alloy that, there is a change in surface roughness value in titanium and alloy steel from 0.50 to 1.70. It infers that material plays an important role. Where in, the other factors the slope values are minimal.

4.2 Main effects plot of surface roughness range for Ti-Al steel

Chart-2: Main effects plot of surface roughness range for Ti-Al steel

It is seen from the main effects plot of Average surface roughness of titanium alloy that, there is a change in surface roughness value in titanium and alloy steel from 0.2 to 1.0. It infers that material plays an important role. Where in, the other factors the slope values are minimal.

4.3 Main effects plot of standard deviation for surface roughness for Ti-Al steel

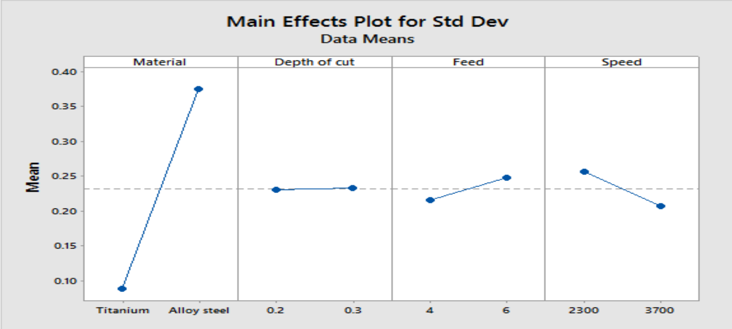

Chart-3: Main effects plot of standard deviation for surface roughnness of Ti-Al steel

It is seen from the main effects plot of Average surface roughness of titanium alloy that, there is a change in surface roughness value in titanium and alloy steel from 0.2 to 0.4. It infers that material plays an important role. Where in, the other factors the slope values are minimal.

4.4 Interaction plot for average surface roughness for Ti-Al steel

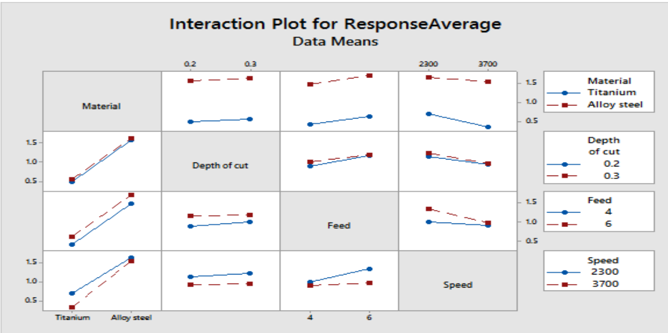

Chart-4: Interaction plot for average surface roughness for T-Al steel

It is seen from the plot that the lines are parallel. Hence there is no lines are intersecting between any of the combinations. This indicates that there is no interaction effect between them.

4.5 Interaction plot for range of surface roughness for Ti-Al steel

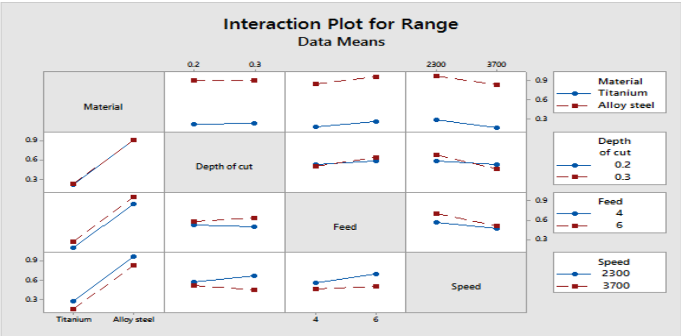

Chart-5: Interaction plot for range of surface roughness for Ti-Al steel

It is seen from the plot that the lines are parallel for material and depth of cut, material and ffeed, speed and material. Hence there is no lines are intersecting between them. But for depth of cut and feed, depth of cut and speed the lines are intersecting. This shows interaction effects between them.

4.6 Interaction plot for standard deviation of surface roughness for Ti-Al steel

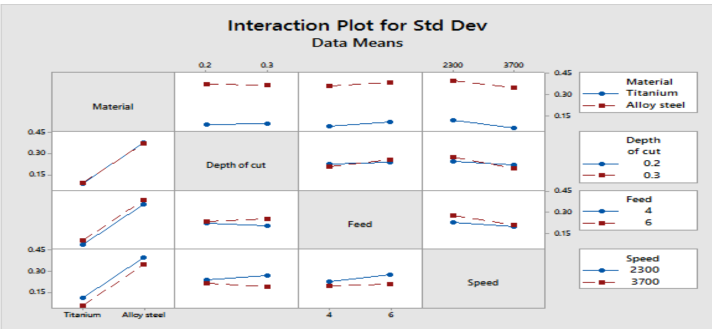

Chart-6: Interaction plot for standard deviation of surface roughness for Ti-Al steel

It is seen from the plot that the lines are parallel for material and deptth of cut, material and feed, speed and material. But feed and depth of cut, septh of cut and feed are intersecing, this shows an interaction effects between them.

4.7 Analysis of variance (ANOVA)

The main purpose of the analysis of variance (ANOVA) is the application of a statistical method to identify the effects of individual parameters and their significance for the response variable. Results from ANOVA can determine very clearly the impact of each of parameters on the process results at desired confidence level.

4.8 ANOVA for average surface roughness for Ti-Al steel

Table-5: ANOVA for Averrage of surface roughness for Ti-Al stteel

Factorial Regression: ResponseAverage versus Material, Depth of cut, Feed, Speed

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	26.8942	1.7929	5.58	0.000
Linear	4	25.7160	6.4290	20.00	0.000
Material	1	23.6575	23.6575	73.60	0.000
Depth of cut	1	0.0858	0.0858	0.27	0.607
Feed	1	0.8972	0.8972	2.79	0.100
Speed	1	1.0756	1.0756	3.35	0.072
2-Way Interactions	6	0.8312	0.1385	0.43	0.856
Material*Depth of cut	1	0.0028	0.0028	0.01	0.926
Material*Feed	1	0.0069	0.0069	0.02	0.884
Material*Speed	1	0.3522	0.3522	1.10	0.299
Depth of cut*Feed	1	0.0382	0.0382	0.12	0.731
Depth of cut*Speed	1	0.0146	0.0146	0.05	0.832
Feed*Speed	1	0.4164	0.4164	1.30	0.259
3-Way Interactions	4	0.3468	0.0867	0.27	0.896
Material*Depth of cut*Feed	1	0.0572	0.0572	0.18	0.674
Material*Depth of cut*Speed	1	0.0627	0.0627	0.20	0.660
Material*Feed*Speed	1	0.0478	0.0478	0.15	0.701
Depth of cut*Feed*Speed	1	0.1790	0.1790	0.56	0.458
4-Way Interactions	1	0.0003	0.0003	0.00	0.976
Material*Depth of cut*Feed*Speed	1	0.0003	0.0003	0.00	0.976
Error	64	20.5722	0.3214		
Total	79	47.4664			

The above table shows that the p-value for linera model is less than 0.05 for material. It infers that linear model is signficant. The 2-way interaction and for 3-way interaction are greater than 0.05. There fore it infers that all the factors for all the combination of interaction are insignificant.

4.9 ANOVA for range of surface roughness

Table-6: ANOVA for range of surface roughness for Ti-Al steel

Factorial Regression: Range versus Material, Depth of cut, Feed, Speed

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	11.4642	0.76428	4.05	0.000
Linear	4	10.0639	2.51597	13.34	0.000
Material	1	9.4875	9.48753	50.29	0.000
Depth of cut	1	0.0053	0.00528	0.03	0.868
Feed	1	0.1777	0.17766	0.94	0.335
Speed	1	0.3934	0.39340	2.09	0.154
2-Way Interactions	6	0.1999	0.03331	0.18	0.982
Material*Depth of cut	1	0.0009	0.00091	0.00	0.945
Material*Feed	1	0.0021	0.00210	0.01	0.916
Material*Speed	1	0.0011	0.00105	0.01	0.941
Depth of cut*Feed	1	0.0285	0.02850	0.15	0.699
Depth of cut*Speed	1	0.1178	0.11781	0.62	0.432
Feed*Speed	1	0.0495	0.04950	0.26	0.610
3-Way Interactions	4	1.1742	0.29355	1.56	0.197
Material*Depth of cut*Feed	1	0.8883	0.88831	4.71	0.034
Material*Depth of cut*Speed	1	0.0437	0.04371	0.23	0.632
Material*Feed*Speed	1	0.0738	0.07381	0.39	0.534
Depth of cut*Feed*Speed	1	0.1684	0.16836	0.89	0.348
4-Way Interactions	1	0.0263	0.02628	0.14	0.710
Material*Depth of cut*Feed*Speed	1	0.0263	0.02628	0.14	0.710
Error	64	12.0734	0.18865		
Total	79	23.5376			

The above table shows that the p-value for linear model is less than 0.05, it inferse material plays a role and hence it is significant. In 2-way interactions and 3-way interaction p-values are greater than 0.05. There fore it infers that factors for combination of interaction are insignificant.

4.10 ANOVA for standard deviation of surface roughness for Ti-Al steel

Table-7: ANOVA for standard deviation of surface roughness for Ti-Al steel

Factorial Regression: Std Dev versus Material, Depth of cut, Feed, Speed

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	1.95595	0.13040	4.22	0.000
Linear	4	1.71838	0.42959	13.89	0.000
Material	1	1.64723	1.64723	53.27	0.000
Depth of cut	1	0.00011	0.00011	0.00	0.953
Feed	1	0.01979	0.01979	0.64	0.427
Speed	1	0.05125	0.05125	1.66	0.203
2-Way Interactions	6	0.03143	0.00524	0.17	0.984
Material*Depth of cut	1	0.00087	0.00087	0.03	0.868
Material*Feed	1	0.00014	0.00014	0.00	0.947
Material*Speed	1	0.00003	0.00003	0.00	0.977
Depth of cut*Feed	1	0.00537	0.00537	0.17	0.678
Depth of cut*Speed	1	0.01887	0.01887	0.61	0.438
Feed*Speed	1	0.00616	0.00616	0.20	0.657
3-Way Interactions	4	0.20538	0.05135	1.66	0.170
Material*Depth of cut*Feed	1	0.14920	0.14920	4.82	0.032
Material*Depth of cut*Speed	1	0.00580	0.00580	0.19	0.666
Material*Feed*Speed	1	0.01214	0.01214	0.39	0.533
Depth of cut*Feed*Speed	1	0.03824	0.03824	1.24	0.270
4-Way Interactions	1	0.00076	0.00076	0.02	0.876
Material*Depth of cut*Feed*Speed	1	0.00076	0.00076	0.02	0.876
Error	64	1.97913	0.03092		
Total	79	3.93508			

The above table shows that the p-value for linear model is less than 0.05, hence it inferse that significant. The 2-way and 3-way interactions are greater than 0.05. It inferse that insignicant for all the factors of combinations.

5. CONCLUSION

The important conclusions drawn from the present work are summarized as follows:

1. ANOVA table shows material plays an important role, since the p-values is less than 0.05. This infers significant role.
2. The main effects plot shows that material is significant.
3. The best process of optimal parameters are as shown
    a. Titanium alloy with Depth of cut with 0.2mm, Speed with 3700rpm and feed with 04mm/rev.
    b. Titanium alloy with Depth of cut with 0.2mm, Speed with constant with o4mm/rev.
    c. Titanium alloy Depth of cut with 0.3mm, speed with constant with 06mm/rev
    d. Titanium is considered as best suited material.

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