International Journal of Research
Available at https://edupediapublications.org/journals
Special Issue on Conference Papers
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 06
March 2018

Optimization of Drilling Process Parameters on Ti-6Al-4V Alloy Using Integrated GRA - Taguchi method

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***Abstract*—The optimization of process parameters is of prime importance for the industry to be able to control and optimise the material cost and time effectively. In this paper the average thrust force on the tool, tool wear and average temperature of the work-piece are obtained from the simulation model developed using DEFORM software. The work-piece used was Ti-6Al-4V and tool used is carbide type drill. Optimisation of the values is done using Integrated GRA-Taguchi method.**

***Keywords*—Drilling, Thrust Force, Tool Temperature, Tool Wear, DEFORM Software, Integrated GRA- Taguchi Method**

I. INTRODUCTION

Drilling is a popular and widely used machining process in industries. The main considerations during the drilling are hole quality, surface finish and tool life. Industries are constantly striving for lower cost solutions to get the higher quality. Since, machining is largely an operator's skill dependant job, various methods were used in the past to quantify the impact of machining variables on the final quality of the product. Now, the CNC machinery has replaced the conventional machinery and many computer aided design based modelling tools are being used efficiently by the industries.

During the drilling, a considerable heat is generated due to the deformation and the friction at the interface. The heat generation raises the levels of temperature and this temperature generated greatly affects the material behaviour and the mechanics of chip formation. Many parameters like tool life, cutting forces, surface quality, mechanics of chip formation, etc., are also dependent on the machining temperature. In the present work, Ti-6Al-4V is considered as the work piece material because of its widespread applications in aerospace, medical, marine, and chemical processing. The main advantages of the alloy are high strength to low weight ratio and its outstanding corrosion resistance. Machining of these alloys can be treated as "hard to machine materials" because of their lower thermal conductivity and higher chemical reactivity [Zhang et al., (2010)]. The present work simulates the drilling of the chosen material for temperature and tool wear using a commercial finite element code called DEFORM-3D. The simulated results are subsequently considered to obtain optimal values of process parameters using Taguchi Integrated PCA Analysis

II. FEA SIMULATION

In this investigation, cutting speed, feed rate and drill depth are considered as the process control variables. The geometric parameters of the drill are: drill diameter 10 mm, web thickness 2 mm, helix angle 280°, point angle 180°, margin 0.4 mm, and clearance 0.2 mm. Uncoated carbide twist drill bit of 24 per cent cobalt is used to machine Ti-6Al-4V work piece at 2700°C and the convection heat transfer coefficient at the work piece – cutting insert interface is chosen as 45 N/sec/mm/°C. The model is simulated for thermal analysis by assuming the work piece as a plastic material with a diameter of 30 mm and the cutting insert is assumed as a rigid body. Geometrically identical meshes for the thermal equations are used for the computation of cutting temperature and the Usui model (1978) is used to calculate the tool wear. This model is a widely used one for estimating tool wear which was derived considering sliding velocity between chip and cutting tool, tool temperature and normal pressure on tool face.

Since, the accuracy of any FEA model is directly dependent on the number of assumptions made, as well as the effort involved in correlating the computer model and the real application, some assumptions are made to define the problem and to apply the boundary conditions such as: the work piece is a homogeneous, isotropic, and incompressible solid; the work piece is set at room temperature as reference temperature of 25°C at the beginning of simulation, the machine tool is perfectly rigid and no influence of machine tool dynamics on machining is considered; and constant friction at tool-chip interaction and tool-workpiece interaction.

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 06
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Experiments are planned based on Design of Experiments (DOE). A rotatable central composite full factorial design with two center points is chosen.

TABLE I
PARAMETERS AND THEIR LEVELS

Factors	**Levels**		
	1	**2**	**3**
Speed (S) (rpm)	500	750	1000
Feed(F) (mm/rev)	0.1	0.15	0.2
Depth of cut(D) (mm)	1	3	5

TABLE 2
DESIGN OF EXPERIMENTS

Trial No	**S**	**F**	**D**
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

The simulation runs were conducted for the design of experiments table and the temperatures were tabulated. The interface of simulation software after loading the tool and the work-piece from its library is given in the Fig.1 below

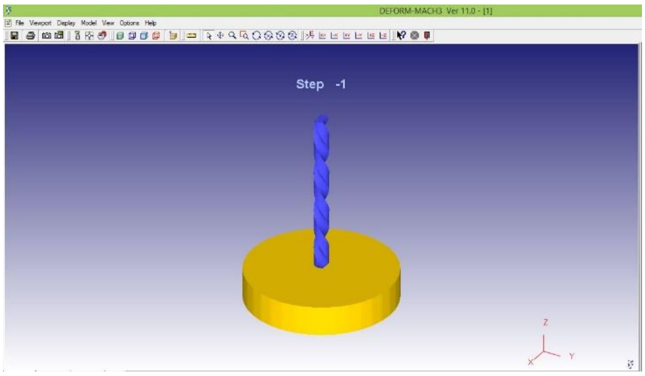

FIG 1: Deform Interface

The experimental results of Thrust force, tool wear and simulation temperature for all the trails are tabulated in Table 3 as shown below.

TABLE 3
RESPONSES FOR TRIALS

Exp No	***S***	***F***	***D***	***Temperature (°C)***	***Tool Wear (mm)***	***Thrust Force (N)***
1	500	0.1	1	246	0.00244	2280
2	500	0.1	3	499	0.00364	2572
3	500	0.1	5	695	0.0044	2818
4	500	0.15	1	178	0.00473	3111
5	500	0.15	3	437	0.00599	3369
6	500	0.15	5	615	0.0068	3707
7	500	0.2	1	156	0.00642	3987
8	500	0.2	3	390	0.00773	4360
9	500	0.2	5	561	0.00859	4682
10	750	0.1	1	259	0.00789	5001
11	750	0.1	3	524	0.00906	5379
12	750	0.1	5	699	0.00978	5727
13	750	0.15	1	216	0.01013	6099
14	750	0.15	3	461	0.01135	6511
15	750	0.15	5	618	0.01212	6953
16	750	0.2	1	211	0.01176	7348
17	750	0.2	3	424	0.01303	7814
18	750	0.2	5	588	0.01386	8299
19	1000	0.1	1	309	0.01331	8803
20	1000	0.1	3	539	0.01445	9292
21	1000	0.1	5	710	0.01514	9748
22	1000	0.15	1	243	0.01549	10227
23	1000	0.15	3	492	0.01668	10734
24	1000	0.15	5	666	0.01742	11266
25	1000	0.2	1	220	0.01707	11848
26	1000	0.2	3	441	0.01831	12427
27	1000	0.2	5	606	0.01911	12962

III. RESULTS AND DISCUSSION

A. Analysis of Variance (ANOVA)

e-ISSN: 2348-6848
p-ISSN: 2348-795X
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March 2018

Analysis of Variance is carried out on the obtained experimental data to check the significance of the model.

TABLE 4
ANOVA- TEMPERATURE

Source	**Sum of Squares**	**df**	**Mean Squares**	**F Value**	**p-value**
Model	833260.5278	9	92584.503	981.1722	<0.0001
A-s	11200.05556	1	11200.055	118.6935	<0.0001
B-f	43316.05556	1	43316.055	459.0456	<0.0001
C-d	768800.000	1	768800.00	8147.424	<0.0001
AB	147.000000	1	147.0000	1.557845	0.22890
AC	546.750000	1	546.7500	5.794230	0.02772
BC	1240.333333	1	1240.3333	13.14453	0.00209
A^2	0.166666667	1	0.166666	0.001766	0.96697
B^2	937.5000000	1	937.5000	9.935236	0.00582
C^2	7072.666667	1	7072.666	74.95319	<0.0001
Residual	1604.138889	17	94.36111		
Cor Total	834864.6667	26			

From the above analysis it was found that feed and depth of cut are the most significant terms affecting the Tool Temperature as their p-values are <0.0001. R2=0.9450 which is 94.5%. The desirable value is close to 1 which indicates that the model has a variance of 5.5% and hence is within the acceptable limits.

TABLE 5
ANOVA- THRUST FORCE

Source	Sum of Squares	df	Mean Squares	F Value	p-value
Model	2.79E+08	9	3.10E+07	7.74E+04	<0.0001
A-s	2.45E+08	1	2.45E+08	6.12E+05	<0.0001
B-f	2.72E+07	1	2.72E+07	6.78E+04	<0.0001
C-d	3.09E+06	1	3.09E+06	7.72E+03	<0.0001
AB	1.36E+06	1	1.36E+06	3.39E+03	<0.0001
AC	1.34E+05	1	1.34E+05	3.35E+02	<0.0001
BC	2.53E+04	1	2.53E+04	6.32E+01	<0.0001
A^2	1.83E+06	1	1.83E+06	4.56E+03	<0.0001
B^2	3.59E+04	1	3.59E+04	8.98E+01	<0.0001
C^2	4.63E+01	1	4.63E+01	1.16E-01	0.73796
Residual	6.80E+03	17	4.00E+02		
Cor Total	2.79E+08	26			

From the above analysis it was found that speed and feed are the most significant terms affecting the Tool Temperature as their p-values are <0.0001. R2=0.9546 which is 95.46%. The desirable value is close to 1 which indicates that the model has a variance of 4.54% and hence is within the acceptable limits

B. *Grey Relational Analysis*

Data processing must be performed before Grey correlation coefficients can be calculated. A series of various units must be transformed to be dimensionless. Data pre-processing converts the original sequence to a comparable sequence. Several methodologies of pre-processing data can be used in Grey relation analysis, depending on the characteristics of the original sequence.

1) *Normalisation of data:* The normalized values are calculated using the formula given below.

$$x_t(k) = \frac{\max y_t(k) - y_t(k)}{\max y_t(k) - \min y_t(K)}$$

TABLE 6
NORMALISED DATA

Trial No	**Temperature**	**Tool Wear**	**Thrust Force**
1	0.837545	1	1
2	0.380866	0.928014	0.972664
3	0.027076	0.882424	0.949635
4	0.960289	0.862627	0.922206
5	0.49278	0.787043	0.898053
6	0.17148	0.738452	0.866411
7	1	0.761248	0.840198
8	0.577617	0.682663	0.80528
9	0.268953	0.631074	0.775136
10	0.814079	0.673065	0.745272
11	0.33574	0.602879	0.709886
12	0.019856	0.559688	0.677308
13	0.891697	0.538692	0.642483
14	0.449458	0.465507	0.603913
15	0.166065	0.419316	0.562535
16	0.900722	0.440912	0.525557
17	0.516245	0.364727	0.481932
18	0.220217	0.314937	0.436529
19	0.723827	0.34793	0.389347
20	0.308664	0.279544	0.343569
21	0	0.238152	0.30088
22	0.84296	0.217157	0.256038
23	0.393502	0.145771	0.208575
24	0.079422	0.10138	0.158772
25	0.884477	0.122376	0.104288
26	0.48556	0.04799	0.050084
27	0.187726	0	0

2) *Grey Relational Coefficients and Grey Relational Grades:*

After data pre-processing is carried out, a grey relational coefficient can be calculated with the pre-processed sequence. It expresses the relationship between the ideal and actual normalized experimental results.

TABLE 8
DEVIATION SEQUENCE TABLE

Trial No	PC_1	PC_2	PC_3
1	0.162454874	0	0
2	0.039711191	0.137372525	0.077794421
3	0	0.23875225	0.159801535
4	0.619133574	0.071985603	0.027335705
5	0.972924188	0.117576485	0.0503651
6	0.507220217	0.212957409	0.101947201
7	0.185920578	0.326934613	0.254727579
8	0.108303249	0.461307738	0.357517319
9	0.422382671	0.317336533	0.19472009
10	0.828519856	0.26154769	0.133589216
11	0.099277978	0.559088182	0.474442988
12	0.731046931	0.368926215	0.224864258
13	0.664259928	0.397120576	0.290114211
14	0.157039711	0.782843431	0.743961805
15	0.115523466	0.877624475	0.895712413
16	0.276173285	0.652069586	0.610653436
17	0.550541516	0.534493101	0.396086875
18	0.980144404	0.440311938	0.32269238
19	0.483754513	0.635272945	0.518067778
20	0.833935018	0.580683863	0.437464894
21	0.779783394	0.685062987	0.56347126
22	0.69133574	0.720455909	0.65643138
23	0.606498195	0.854229154	0.791424827
C24	0.514440433	0.952009598	0.949915746
25	1	0.76184763	0.699120015
26	0.920577617	0.898620276	0.841228234
27	0.812274368	1	1

The grey relational coefficient is defined as followsfollowing the data pre-processing, a Grey relational coefficient can be calculated using the pre-processed sequences. The Grey relational coefficient is defined as
The grey relational coefficient is

$$\xi_i(k) = \frac{Y(k)_{min} + \varepsilon Y(k)_{max}}{Y_i(k) + \varepsilon Y(k)_{max}}$$

If all the performance characteristics are given equal preferences then Ɛ taken as 0.5

Grey Relational Grade

$$\gamma_i = \frac{\xi_i(1) + \xi_i(2) + \xi_i(3)}{3}$$

TABLE 9
GREY RELATION COEFFICIENT AND RANK

Exp No	Temperature	Tool Wear	Thrust Force	Grey Relation Coefficient	Rank
1	**0.754768**	**1**	**1**	**0.918256**	**1**
2	0.446774	0.874148	0.948163	0.756362	4
3	0.339461	0.809616	0.908488	0.685855	5
4	0.926421	0.784471	0.86536	0.858751	2
5	0.496416	0.701304	0.830638	0.676119	6
6	0.376359	0.656558	0.789155	0.607357	10
7	1	0.676817	0.757804	0.81154	3
8	0.542074	0.611743	0.719714	0.624511	9
9	0.406158	0.575423	0.689784	0.557122	12
10	0.728947	0.604643	0.662491	0.66536	7
11	0.429457	0.557339	0.63282	0.539872	13
12	0.337805	0.531738	0.607761	0.492435	18
13	0.821958	0.520125	0.583079	0.641721	8
14	0.475945	0.483329	0.557982	0.505752	17
15	0.374831	0.46267	0.533353	0.456951	20
16	0.834337	0.472104	0.513114	0.606518	11
17	0.508257	0.440423	0.491126	0.479935	19
18	0.390691	0.421919	0.470158	0.427589	21
19	0.644186	0.434002	0.450185	0.509458	16
20	0.419697	0.409683	0.432365	0.420582	22
21	0.333333	0.396244	0.416972	0.382183	25
22	0.760989	0.389759	0.401942	0.517563	14
23	0.451876	0.369214	0.387169	0.402753	23
24	0.35197	0.357495	0.372793	0.360752	26
25	0.812317	0.362944	0.35824	0.511167	15
26	0.492883	0.34435	0.344848	0.394027	24
27	0.381018	0.333333	0.333333	0.349228	27

IV. CONCLUSION

The optimal values of Temperature, Tool wear and Thrust Force 246°C, 0.00244mm and 2280N respectively were obtained at a cutting speed of 500 rpm, feed rate of 0.1 mm/rev, Drill depth of 1 mm.

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