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Optimisation of Drilling Parameters Using Grey Relational Grade on AA7075 Plates Using Coated and Cryogenically Treated Drills

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Abstract: ***Drilling is the one of the basic operation of machining to make holes. It is the essentially used in aerospace, automobile and medical industries. In this study, an attempt is made to study the effect of cryogenic treatment and AlTiN coating on drills by varying parameters (speed, feed, thickness of plates) on the diametrical error (De) and surface roughness (Ra) on AA7075 plates. The control factors provide better diametrical error and surface roughness were determined by the grey relational analysis. Response surface methodology (RSM) is used to develop the interactions among control parameters. In addition, analysis of variance was employed to determine the most significant control parameters on diametrical error and surface roughness. Four type of drills (conventional heat treated (H), coated drill (CO), cryogenically treated (CY) and cryogenically treated +coated (CYC),thickness of plate, feed rate and spindle speed are considered as input parameters, and L36 full factorial design with mixed orthogonal array selected for experimentation. As a result, it is found that type of drill bit used and feed rate are most significant parameters with percentage contributions 36.54% and 31.17% respectively. From the grey relational analysis, low thickness, high feed rate and low spindle speed with cryogenically treated +coated drills are found as optimal parameters combination. Confirmation test is conducted for optimal parameters combination and an error in grey relational grade found as the 3.04% when it compared to predicted value.***

Keywords: cryogenically treated +coated drill (CYC), cryogenically treated drill (CY), coated drill (CO), grey relational grade, and AlTiN coated drill

1. Introduction

Aluminium alloys are extensively used as a main engineering material in various industries such as aircraft, aerospace, and automotive industries where weight is probably the most important factor. These materials are considered as easy to machining and possess superior machinability index [1].Especially Drilling is necessary in industries for assembly related to mechanical fasteners. It is reported that around 55000 holes are drilled as a complete single unit production of the Air bus A350 aircraft [2]. Drilling of hole with good hole quality is necessary, mainly in aerospace and aircraft industries. In real time the mostof the drilled components rejected during the assembly of a product due to bad hole quality. The process of drilling is commonly used for the stabilisation and assembly of the composite parts [3]. They have stated that the main problem in the processing of MMCs is the high tool wear caused by reinforcing elements that are especially hard and abrasive [4, 5].A study on the drilling of Al356/20/SiC MMCs [6] claimed that the highest influence on the tool wear is cutting time (50%) and the next one is feed rate (24%). The next important factor affecting the tool wear is cutting tool material [7]. TiN coating on the HSS drills does not considerably increase the tool performance with respect to the uncoated ones [8,9], butTiAlN/TiN coated drills showed better dimensional accuracy than the uncoated drills under the wet cutting conditions. Which is very important parameter for assembly of components [10].Among several drill materials such as HSS, carbide and PCD, PCD tools have the best wear and BUE resistant, while PCD drills might be used for large lot production in terms of investment cost [8]. However, the high cost of the PCD tools limits the preferability of these tools. PCD drills exhibit better surface finish in the machining of hybrid MMCs compared to carbide and coated carbide drills. This is due to the increase in drill hardness which decreases the surface roughness of the drilled surface [11]. However, the high cost of the PCD tools limits its applications in manufacturing industry.

As life of cutting tools plays a major role in increasing productivity and consequently is an important economic factor. In order to increase the life of cutting tools, a common approach used in the past has been to heat-treat tool materials [12]. In tool steels, a low percentage of austenite is retained after the conventional heat-treatment. The retained austenite which is a soft phase could reduce the product life and, in working conditions, it can be transformed into martensite. Cryogenic treatment is the process of cooling materials at a temperature below room temperature [13]. Cryogenic treatment is not a kind of heat treatment in itself, but a supplementary process that complements heat treatment [14]. Cryogenic treatment is generally classified as either “Shallow Cryogenic Treatment” at temperature down to approximately −80◦C (dry ice temperature), or “Deep Cryogenic Treatment”at−196◦C(liquid nitrogen temperature) [15]. Microstructural analysis on cryogenically treated tool steels indicates that the treatment has increased the carbide population and also distributed the carbides evenly throughout the structure, resulting in improving the wear resistance [16].Cryo-tempering is process of reheating the material after the cryogenic treatment and bringing the temperature of material back the room temperature. Cryo-tempering showed a positive effect on minimising surface roughness and diametrical error, as cryo-tempering converts retained austenite to martensite [17].

From the above literature cryogenically treated drills give best tool life but along with tool life we need to take care about the hole quality parameters like diametrical error, surface roughness and exit burr height. In this paper an attempt is made to study weather coated drill bit or cryogenically treated drill or combination of these two gives minimum diametrical error and surface roughness. This paper also presents grey relational analysis to optimise control parameters and developing the mathematical models for output values using response surface methodology (RSM).

2. Materials and Methodology

2.1 Work piece material

AA7075 is high strength aluminium alloy with zinc as major alloying element mostly found its applications in aerospace, marine, defence industries because of high strength to weight ratio and good corrosion resistance. Presence zinc made aluminium heat treatable. Magnesium improve strength of alloy. AA7075 is known as aerospace alloy because of wide applications in aerospace industry. The chemical composition of AA7075 is shown in the table 1. The properties of the AA7075 are shown in the table 2

Table 1: Chemical composition of AA7075

Element	Al	Cu	Mg	Cr	Zn
%	90	1.6	2.5	0.23	5.6

Table 2: Properties of AA7075

Property	Value
Density	2800kg/m^3
Hardness(HB500)	60
Thermal conductivity	130W/m-k

In this study, AA7075 plates of dimensions 60mm*80mm with three different thickness 6mm, 10mm and 14mm are taken for drilling.

2.2. Tool material

High-Speed Steels (HSS) are the cutting tool materials used for machining of materials. The HSS will be used for machining of materials. The General use of HSS is 18-4-1.

- 18% of Tungsten or Molybdenum, used for increasing hot hardness temperature of tool material.
- 4% of Chromium, used for increasing the strength of resistance to deformation of the cutting tool material.
- 1% of Vanadium, used for increasing the wear resistance of the cutting tool material or for maintaining the keenness of cutting edge.

In addition to these 2.5 to 10 %, cobalt is used to increase the red hot hardness of tool. In this study HSS M2 grade material is chosen as tool material. The chemical composition of tool material HSS M2 grade steel is given in table 3. The properties of HSS M2 grade steel is given in the table 4.

Table 3: Chemical composition of HSS (M2)

Element	C	Cr	Co	Mo	W	V	Fe
%	0.9	4.2	4.8	5	6.5	2	Rem

Table 4: Properties of HSS (M2)

Property	Value
Density	8138kg/m^3
Thermal conductivity	41.5W/m-k
Hardness(Rockwell C)	62
Abrasion	25.8mm^3

2.3 Heat treatment of drills

1) Normal heat treatment

M2 material is heated upto the melting point temperature and dropped in water until room temperature is reached. Total of 36 drills are undergone normal heat treatment process.

2) Cryogenic treatment

After the normal heat treatment 18 drills are soaked in cryogenic liquid at -100^{0}C for 2 hours and then these drill bits tempered to a temperature of 540^{0}C for 2 hours.

2.4 Drill bit specifications

Drill bit geometry plays very important role in the performance of drill, in this study twisted drill bits with following specifications are prepared after the heat treatment of M2 material and drilling is conducted.

- Drill bit: Twisted drill
- Diameter of drill bit: 6mm
- Total length of drill:50mm
- Flutes lengh:20mm
- Flute angle:30^0
- Point angle: 135^0

2.5 Coating on drill bits

- Coating material: AlTiN
- Coating colour: Black
- No. of drills coated: 18

Total of 18 drills (9 normal heat treated and 9 cryogenically treated) are coated with AlTiN material.

2.6. Types of drill bits used (HT)

After preparation and coating on drill bits, now they are four different types of drill bits are there. They are

1) Normal heat treated drill bit (H)
2) Coated drill bit (CO)
3) Cryogenically treated drill bit (CY)
4) Cryogenically treated+ coated drill bit (CYC)

Now using these four different types of drill bits, drilling is carried out on AA7075 plates according to the design of experiments (DOE).

Figure 1: Cryogenically treated and normal heat treated (quenched) drill bits

2.7. Levels of input parameters

The three input parameters are varied in three different levels are shown in the table 5.

Table 5: Levels of input parameters

Input parameter	Level 1	Level 2	Level 3
Thickness of plate (T)	6mm	10mm	14mm
Feed (F) mm/rev	0.1	0.2	0.3
Spindle speed (S) (rpm)	1000	1500	2000

mm-mille meters, rpm-rotations per minute, rev- revolution

2.8 Design of experiment

In this study three numerical (T, F, S) and one categorical input parameter (HT) are taken. Numerical parameters are varied at three levels (as shown in table 4.5), categorical parameter is varied at four levels (H, CO, CY and CYC). First three numeric inputs are varied at three levels, so it gives a L9 orthogonal array then this L9 orthogonal array is repeated for four categorical levels (H, CO, CY and CYC), so a total of 36 experiments need to be conducted.

Table 6: Basic L9 orthogonal array

EX.NO	T	F	S
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.9 Measuring of the diametrical error and surface roughness of hole

Diameters of the holes are measured using “ZEISS PRISMO ULTRA Coordinate Measuring Machine” supplied by CENTRAL INSTITUTE OF TOOL DESIGN (CITD), Hyderabad. Diameters of hole is checked at both entry and exit and the average is taken as actual diameter of hole. Then deviation of hole diameter from the nominal size is calculated as diametrical error.Surface roughness tester is used to measure the surface roughness of the specified surfaces, in this study the surface roughness holes is measured by bisecting the holes along the hole axis with Wire cut machine. For one hole two values are taken and mean of the two values is taken as surface roughness of the hole.

Figure 3: CMM at CITD Balanagar, Hyderabad

Figure 4: Surface roughness tester

2.10 Methods of analysis

(i) Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques which are useful for modelling and analysing engineering problems and developing, improving, and optimizing processes. It also has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs, and it is an effective tool for constructing optimization models [18]. RSM consists of the experimental strategy for exploring the space of the process or input factors, empirical statistical modelling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the levels or values of the process variables that produce desirable values of the response outputs [18]. Response surface method designs also help in quantifying the relationships between one or more measured responses and the vital input factors (DESIGN-EXPERT® software, version 6.0.1).

(ii) Grey Relational Analysis

The grey relational analysis (GRA) associated with the Taguchi method rather represents a rather new approach to optimization. The grey theory is based on the random uncertainty of small samples which developed into an evaluation technique to solve certain problems of system that are complex and having incomplete information. A system for which the relevant information is completely known is a ‘white’ system, while a system for which the relevant information is completely unknown is a ‘black’ system. Any system between these limits is a ‘grey’ system having poor and limited information. Grey relational analysis (GRA), a normalized evaluation technique, is extended to solve the complicated multi performance characteristics optimization effectively.

3. Results and Discussions

After conducting the drilling operation on AA7075 with coated and cryogenically heat treated drill bits the output values are measured are noted in table 7.

Table 7: Design of experiments with output values

Ex. No	Type of Drill Bit	T	F	S	Surface Roughness (Ra) µ	Diametrical Error(De) µ
1	H	6	0.1	1000	1.20	44
2	H	6	0.2	1500	1.08	48
3	H	6	0.3	2000	0.925	38
4	H	10	0.1	1500	1.485	49
5	H	10	0.2	2000	1.60	45
6	H	10	0.3	1000	1.27	33
7	H	14	0.1	2000	1.26	57
8	H	14	0.2	1000	1.475	45
9	H	14	0.3	1500	1.645	41
10	CO	6	0.1	1000	1.2	56
11	CO	6	0.2	1500	1.1	61
12	CO	6	0.3	2000	0.82	57
13	CO	10	0.1	1500	1.625	76
14	CO	10	0.2	2000	1.355	61
15	CO	10	0.3	1000	1.158	58
16	CO	14	0.1	2000	1.353	70
17	CO	14	0.2	1000	1.495	62
18	CO	14	0.3	1500	1.70	60
19	CY	6	0.1	1000	1.138	34
20	CY	6	0.2	1500	1.040	31
21	CY	6	0.3	2000	0.955	32
22	CY	10	0.1	1500	1.430	39
23	CY	10	0.2	2000	1.700	44
24	CY	10	0.3	1000	1.400	31
25	CY	14	0.1	2000	1.4800	45
26	CY	14	0.2	1000	1.700	40
27	CY	14	0.3	1500	1.764	34
28	CYC	6	0.1	1000	0.715	48
29	CYC	6	0.2	1500	1.070	39
30	CYC	6	0.3	2000	0.895	34
31	CYC	10	0.1	1500	1.185	52
32	CYC	10	0.2	2000	1.47	44
33	CYC	10	0.3	1000	1.05	39
34	CYC	14	0.1	2000	1.56	58
35	CYC	14	0.2	1000	1.4	41
36	CYC	14	0.3	1500	1.78	43

3.1 Grey Relational Analysis

To know input parameters combination for optimised outputs, grey relational analysis is used and the results calculated by following the standard procedure and the values are tabulated in table 8.

Table 8: Grey relational analysis

Ex.no	Normalized Ra	Deviation Ra	GRC Ra	Normalizd De	Deviation De	GRC De	GRG	Rank
1	0.5446	0.4553	0.523	0.4444	0.5558	0.473	0.490	24
2	0.6572	0.3427	0.593	0.3333	0.6667	0.428	0.500	22
3	0.8028	0.1971	0.717	0.4222	0.5778	0.463	0.590	11
4	0.2769	0.7230	0.408	0	1	0.333	0.371	36
5	0.1690	0.8309	0.375	0.3333	0.6667	0.428	0.402	34
6	0.4788	0.5211	0.489	0.4	0.6	0.454	0.472	27
7	0.4882	0.5117	0.494	0.1333	0.8667	0.365	0.430	32
8	0.2863	0.7136	0.411	0.3111	0.6889	0.420	0.416	33
9	0.1267	0.8732	0.364	0.3555	0.6444	0.436	0.400	35
10	0.5446	0.4553	0.523	0.7111	0.2889	0.633	0.578	13
11	0.6384	0.3615	0.580	0.6222	0.3778	0.569	0.575	15
12	0.9014	0.0985	0.835	0.8444	0.1556	0.762	0.799	5
13	0.1455	0.8544	0.369	0.6	0.4	0.555	0.462	29

14	0.3990	0.6009	0.454	0.6889	0.3111	0.616	0.535	17
15	0.5840	0.4159	0.545	0.9556	0.0444	0.918	0.732	7
16	0.4009	0.5990	0.454	0.4222	0.5778	0.463	0.459	30
17	0.2676	0.7323	0.405	0.6889	0.3111	0.616	0.511	21
18	0.07511	0.9248	0.350	0.7778	0.2222	0.692	0.521	19
19	0.6028	0.3971	0.557	0.6222	0.3778	0.569	0.563	16
20	0.6948	0.3051	0.620	0.8222	0.1778	0.737	0.679	8
21	0.7746	0.2253	0.689	0.9333	0.0667	0.882	0.785	6
22	0.3286	0.6713	0.426	0.5333	0.4667	0.517	0.472	28
23	0.0751	0.9248	0.350	0.7111	0.2889	0.633	0.492	26
24	0.3568	0.6431	0.437	0.8222	0.1777	0.737	0.587	12
25	0.2816	0.7183	0.410	0.4	0.6	0.454	0.432	31
26	0.0751	0.9248	0.350	0.7778	0.2222	0.692	0.521	19
27	0.0150	0.9849	0.336	0.7333	0.2667	0.652	0.494	25
28	1	0	1.000	0.9333	0.0667	0.882	0.941	1
29	0.6667	0.3333	0.600	1	0	1	0.8	4
30	0.8309	0.1690	0.747	0.9778	0.0222	0.957	0.852	2
31	0.5586	0.4413	0.531	0.8222	0.1778	0.737	0.634	9
32	0.2910	0.7089	0.413	0.7111	0.2889	0.633	0.523	18
33	0.6854	0.3145	0.613	1	0	1	0.806	3
34	0.2065	0.7934	0.386	0.6889	0.3111	0.616	0.501	23
35	0.3568	0.6431	0.437	0.8	0.2	0.714	0.575	14
36	0	1	0.333	0.9333	0.0667	0.882	0.607	10

From above grey relational analysis experiment number 28 is ranked as number one experiment. The input parameters corresponding rank one experiment is
Drill bit –CYC
Thickness-6mm
Feed-0.1 mm/rev,
Spindle speed-1000 rpm.

3.2 ANOVA analysis for grey relational grade

Table 9: ANOVA analysis for grey relational grade

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
T	1	0.220838	31.17%	0.220838	0.220838	118.13	0.001
F	1	0.071044	10.03%	0.035245	0.035245	18.85	0.002
S	1	0.006683	0.94%	0.014294	0.014294	7.65	0.014
HT	3	0.258875	36.54%	0.258875	0.086292	46.16	0.001
T*T	1	0.015703	2.22%	0.015703	0.015703	8.4	0.011
F*F	1	0.011472	1.62%	0.008701	0.008701	4.65	0.048
S*S	1	0.012553	1.77%	0.002848	0.002848	1.52	0.236
T*F	1	0.01029	1.45%	0.007626	0.007626	4.08	0.062
T*S	1	0.000001	0.00%	0.000001	0.000001	0	0.981
T*HT	3	0.028917	4.08%	0.028917	0.009639	5.16	0.012
F*HT	3	0.01693	2.39%	0.01693	0.005643	3.02	0.063
S*HT	3	0.027102	3.83%	0.027102	0.009034	4.83	0.015
Error	15	0.028041	3.96%	0.028041	0.001869		
Total	35	0.708449	100.00%				

R-square 96.04%, R-square (adj) 90.76%

- From the ANOVA analysis the following observations The determination coefficient (R^2) indicates the goodness of fit for the model. In this case, the value of the determination coefficient (R^2 =0.9604) indicates that 96.04 per cent of the total variability is explained by the model after considering the significant factors.
- As the p-values less than 0.05, the responses are significantly different at the p value= 0.05 level and responses are significant predictor.
- The value of adjusted determination coefficient (adjusted R^2 =0.9076) is also high, which indicates a high significance of the mode

3.3 Mathematical models developed for GRG from RSM

Using response surface methodology, the following mathematical models developed for grey relational grade (GRG)

Table 10: Mathematical models for GRG

Type of drill bit	*Equation*
Coated drill bit	GRG = 1.025 - 0.0564 T + 0.287 F - 0.000304 S + 0.002769 T*T + 3.81 F*F - 0.0891 T*F
Cryogenically Treated drill bit	GRG = 1.076 - 0.0614 T + 0.032 F - 0.000282 S + 0.002769 T*T + 3.81 F*F - 0.0891 T*F
Cryogenically treated And coated drill	GRG = 1.660 - 0.0751 T - 0.317 F - 0.000444 S + 0.002769 T*T + 3.81 F*F - 0.0891 T*F
Normal heat treated Drill bit	GRG = 0.958 - 0.0520 T - 0.362 F - 0.000283 S + 0.002769 T*T + 3.81 F*F - 0.0891 T*F

3.4 Results of Grey Relational Analysis

From grey relational analysis the grey grades for various factors are calculated and the effect of various input parameters on grey relational grade is discussed below.

3.4.1 Effect of drill bit on grey relational grade (GRG)

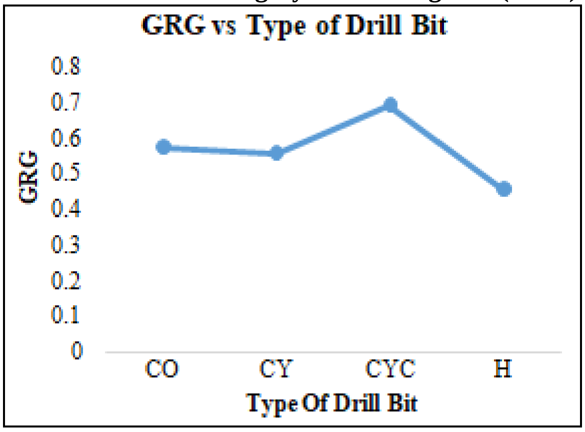

Figure 5: Effect of drill bit on grey relational grade.

From the above graph it is clear that cryogenically treated+coated drill bit gives better performance compared to the other bits. This shows that by coating AlTiN on cryogenically treated drill bit increases the wear resistance of drill bit and the cryogenic treatment helps to from carbides uniformly andcryo-tempering converts retained austenite to martensite.

3.4.2 Effect of thickness on Grey relational grade

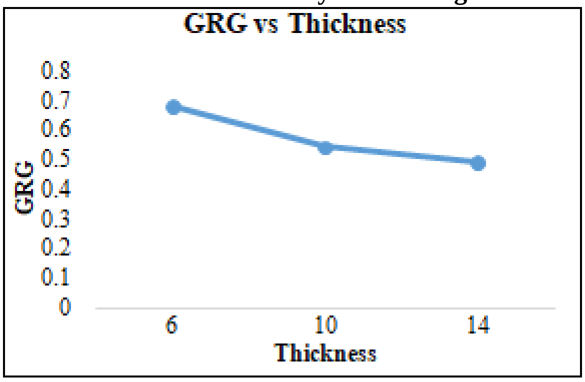

Figure 8: Effect of thickness on Grey relational grade

From the above graph shows that drilling of low thickness plate gives best results. This is because asthickness of plate increases the amount metal to be removed increases this may cause the tool wear and as the drill travels from top to bottom the tool temperature increases continuously, this causes softening of drill bit, also for coated drill the pealing of coated material occurs as it moves. These conditions lead drilling of low thickness plates gives good hole quality (diametrical error and surface roughness).

3.4.3 Effect of feed on grey relational grade

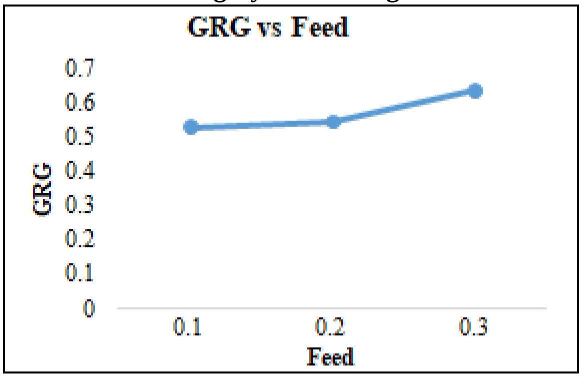

Figure 7: Effect of Feed on Grey Relational Grade

As feed increases the machining performance decreases due to the increase of vibrations but increase of flank wear. Above graph shows as feed increases the machining performance increases this shows that the drill bits are able to minimise the flank wear and increases the drilling performance as the feed increases**.**

3.4.4 Effect of spindle speed on grey relational grade

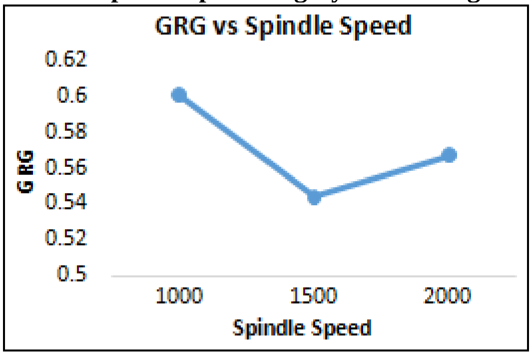

Figure 9: Effect of spindle speed on grey relational grade

Above graph shows that at low spindle speed the machining performance is better. This is due to increase in spindle speed increases the thermal loads on the tool which leads the increase in tool wear.

3.5 Optimal parameters combinations

From the above graphs good hole quality is achieved with low thickness, high feed, low speed and with cryogenically treated + coated drill bit.

Table 11: Optimal parameters combination

Thickness	Feed	Speed	Drill bit type
6	0.3	1000	CYC

3.6 Confirmation test results

Table 12: Confirmation test results

	Optimal parameters combination		Percentage of Error
	Predicted	Experimental	
Grey relational grade	0.952	0.981	3.04%

For the optimal parameters combination an experiment is conducted, diametrical error and surface roughness values are measured. From RSM an equation is developed for GRG, from that GRG value is predicted. An error of 3.04% is occurred between predicted and experimental value. The error obtained is within the acceptable limits.

4. Conclusions

From the experimental study of drilling on AA7075 plates with coated and cryogenically heattreated drill bits the following conclusions are drawn

1) From ANOVA analysis it is observed that the model is significant
2) Among all the input parameters Type of drill bit (36.54%) and thickness of plate (31.17%) are the most influential parameters on hole quality
3) Among all the drill bits 'Cryogenically heat treated + coated' drill bit gives the best hole quality.
4) Cryogenically heat treated+ coated drill bit gives 52.58% better hole quality than normal drill bit,20.68% better performance than the coated drill bit and 24.15% better performance than the cryogenically heat treated drill bit.
5) Low thickness (6mm), high feed (0.3mm/rev) and low spindle speed (1000rpm) are the optimal parameters combinations to achieve good hole quality.
6) There is an error of 3.04% occurred between predicted and experimental values, which is within the acceptable limits.

5. Future Scope

- This work can be extended by coating different type of materials to the cryogenically heat treated drill bit, the performance of drill bit can be evaluated.
- We can extend this work by varying soaking time in cryogenic liquid and using different coating material on the drills, the performance of drill bits can be evaluated.

6. Acknowledgement

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