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INFLUENCE OF VARIOUS PARAMETERS ON THE HOLE QUALITY IN DRILLING OF ALUMINIUM BASED HYBRID COMPOSITES

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ABSTRACT

Nowadays composites are finding wide application in all fields of Engineering as a result of their desirable properties and qualities. Drilling is the most widely recognized machining operation performed on composites and the nature of drilled hole has a vital bearing. The tools used for drilling play a major role in increasing the profitability of a cutting process. Although the price of such tools are moderately low, the wastages caused by tool failures are relatively higher. Therefore, from the perspective of expense and efficiency, optimization of drilling processes are of much importance for the assembling and manufacturing industries. The poor expulsion of chips in deep and fine drilling of small diameter holes is often the cause of breakage of tools as well as the low quality surface. The effect of different drilling parameters on quality of drilled holes in drilling Aluminium based hybrid composites has been discussed in detail. The experiments were conducted on a Vertical machining centre using Solid Carbide twist drill and step drills of diameter 5mm, 7.5mm and 10mm. Response surface model is developed to correlate the quality of drilled holes namely surface roughness and circularity error with respect to different drilling parameters. The machining parameters considered for the experiments are spindle speed, feed rate, diameter and type of drills. The results proved that the developed model can be effectively used for the prediction of drilled hole quality of the hybrid composites.

Keywords: surface roughness, circularity error, drilling, hybrid metal matrix composites, twist drills, step drills.

1. INTRODUCTION

Considerable research work in the field of material science has been progressed towards the development of new light weight, high performance engineering materials like composites. Metal matrix hybrid composites are one among them. Metal matrix composites have become the necessary materials in various engineering applications like aerospace, automobile and marine engineering, because of their light-weight, high strength, stiffness and resistance to high temperature. Most industries are usually looking for replacement of ferrous components with lighter and high strength alloys like Al metal matrix composites. Aluminum matrix composites (AMCs) refer to a class of light weight and high performance aluminium centric material systems. High specific strength, Low density, high strength to weight ratio, Good corrosion resistance and higher elevated temperature strength are the major advantages of Aluminum Matrix Composites (AMCs) over ferrous and non – ferrous materials [1].

The reinforcement in AMCs could be in the form of continuous/discontinuous fibers, whisker or particulates, Properties of AMCs can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route [2].

When at least three materials are present, it is called hybrid composite. [3]. Al / Sic / Gr is one of the important hybrid composite, which have silicon carbide and graphite particles reinforced with aluminium metal matrix. Graphite particles provide high resistance to wear in the hybrid composite. This hybrid composites found applications in automobile industries for the manufacturing of cylinder block and piston which operates at elevated temperatures around 300 ºC. The machining / drilling characteristics of the composite materials are inferior and so the drilling of these materials are treated as a tough task for production engineers [4].

In view of the growing usage of hybrid composites, the parameters used for drilling must be enhanced and optimized to achieve better drilled hole quality [5].

The matrix material chosen for our investigation is Al 6061, and its chemical composition is given in Table I. The reinforcement materials for the first specimen are 10% of Silicon carbide of particle size 40µm and 5% of Graphite powder and that for the second specimen being 10% of silicon carbide of particle size 40 µm and 5% of mica powder. The specimens are prepared by stir casting method since it is the simplest and cheapest method for manufacturing the metal matrix composites [6].

Drilling is one of the conventional machining process basically used for the production of variety of hybrid composite products. Achievement of desired quality of these products is depending on the surface quality of the drilled hole and its accuracy. Drilled hole quality is influenced by the configuration of the drilling tool and drilling parameters like speed and feed rate. [7]. Poor selection of the cutting tool configuration and drilling parameters result in overheating , excessive wear of the tool and heavy thrust force, which steer to inferior quality of holes and hole surfaces [8].

The objective of our study is to examine the effect of various drills and drilling parameters on the quality of drill hole during drilling of Al/Sic/Gr and Al/Sic/Mica hybrid composites.

2. EXPERIMENTATION

Preparation of specimen

Stir casting method is used to prepare the specimen for our investigations. It is a liquid state method for composite preparation, in which the melting was carried out in a graphite crucible. Scraps of aluminium alloy (Al 6061) were preheated at 450 °C for 3 hours Then the furnace temperature was raised above the liquidus to melt the alloy scraps completely and then preheated reinforce materials (silicon carbide particles and graphite powder / Mica powder) are added and mixed thoroughly with a molten matrix metal [9].

Specimen 1: Aluminum 6061-T6 alloy reinforced with 10% SiC particulates of size 40μm and 5% of Graphite powder

Specimen 2: Aluminum 6061-T6 alloy reinforced with 10% SiC particulates of size 40μm and 5% of Mica powder

Specimen Size: 100mm x 100mm x 10mm.

Drilling experiments

In our study, the drilling experiments were conducted on a Vertical CNC machining centre using Solid carbide twist drill and Step drills of diameter 5mm, 7.5mm and 10mm under different spindle speeds of 1000, 2000 and 3000 rpm and for different feed rates of 0.05, 0.10, 0.15 mm/rev. Drilling parameters and their levels are given in Table II. To improve the effectiveness, the experiments were conducted as per the L27 orthogonal array. The Signal – to – Noise (S/N) ratio, analysis of variance (ANOVA) and regression analysis are employed to analyze the effect of the type of drill and drilling parameters on the drill hole quality. Solid carbide Twist Drills used in these experiments had a helix angle of 30º and point angle of 118º. The step drills also made of solid carbide with two steps.

3. MODELING

The basic purposed of our study is, to plan and formulate a model and investigate the impact of various parameters on the drill quality like surface roughness and circularity of the drilled holes. The study inspects and estimate the impact of Solid Carbide twist drill and step drill on responses of interest for two different hybrid composites [10]. Specimen materials and tools are listed in Table-3.

Table-1. Composition of aluminium 6061.

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sn	Cr	Pb	Al
Wt %	0.8	0.1	0.4	0.15	1.2	0.25	0.15	0.01	0.02	0.02	96.9

Table-2. Process parameters and their levels.

Process Parameters	Level 1	Level 2	Level 3
Drill diameter mm	5	7.5	10
Feed rate mm/rev	0.05	0.10	0.15
Spindle speed rpm	1000	2000	3000

Table-3. Specimen and tools.

	Specimen	Tool
1	Al/Sic/Gr	Solid carbide twist drill
2	Al/Sic/Mica	Solid carbide step drill

Experimental procedure

The stir cast hybrid composite specimens are machined to the required size of 100mm x 100mm x 10mm slab. Drilling tests are performed on each specimen using ARIX-CNC vertical machining center by solid carbide plain twist drill and Solid carbide step drill of diameter 5, 7.5 and 10mm under different spindle speeds 1000, 2000 and 3000 rpm and for different feed rates 0.05, 0.10, 0.15 mm/rev.

Drilling experiments were carried out on both the composite specimens using L27 orthogonal array. To investigate the influence of the drilling parameters on the response of interest, three factors, spindle speed, feed rate and drill diameter, each at three levels are taken into account as shown in Table II. [11]

The surface roughness of the drilled hole was measured by using Kosaka - Surfcoder SE700, a surface roughness measuring instrument. The surface roughness was measured parallel to each hole axis [12] from various points and the average values of the measurements were evaluated and considered for analysis.

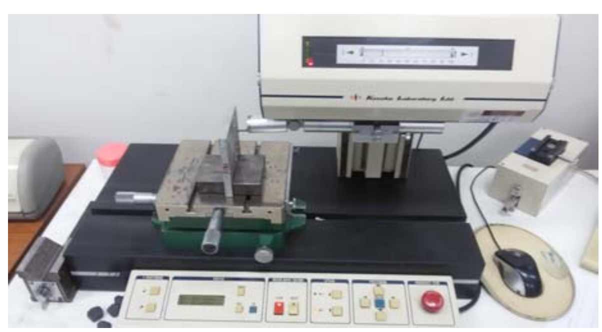

Figure-1. Kosaka surfcoder SE700.

Coordinate Measuring Machines are able to perform the measurement of error in roundness of the drilled holes. Deviation from circularity of the holes is generally the result of vibration, wear and deflection [13].

Diameter of the drilled holes and the error in roundness are measured using CMM.

In our experiments we have been used TESA MICRO-HITE 3D Direct Computer Control (DCC) coordinate measuring machine with an accuracy of 1micron, shown in Figure-2.

The measurements are taken randomly at 6 points in each hole and the values are evaluated by taking the average of the measured values.

Figure-2. Coordinate measuring machine.

4. RESULTS AND DISCUSSION

Table-3 shows the L27 orthogonal array with experimental results of the surface roughness of the drilled holes when using solid carbide twist drills and step drills respectively on Al/Sic/Gr hybrid composites. Similarly Table-4 shows similar results on Al/Sic/Mica hybrid composites.

Tables-5 and 6 show the experimental results of the circularity error in the drilled holes when using solid carbide twist drills and solid carbide step drills respectively on Al/Sic/Gr and Al/Sic/Mica hybrid composites.

For analysis, Response surface methodology is used, which is a gathering of test procedures, factual and numerical systems that are helpful for the investigation of issues in which the response of interest is impacted by different parameters and the goal is quality improvement and to minimize the response parameter [14]. In response surface methodology, the quantitative relationship between the response of interest and the independent process variables is represented as follows

RI = f (A,B,C)

Where RI is the response of interest, f is the response function, A is drill tool diameter in mm, B is feed rate in mm/rev and C is the spindle speed in rpm [15].

Table-4. L27 Orthogonal array and experimental results – AL / SIC / GR.

Test No	Drilling Parameters			Response – Surface Roughness (μm)	
	Drill dia (mm)	Feed rate (mm/rev)	Speed (rpm)	Plain Twist drill	Step drill
1	1	1	1	3.97	1.19
2	1	1	2	3.58	1.11
3	1	1	3	2.79	1.01
4	1	2	1	4.53	1.48
5	1	2	2	4.04	1.29
6	1	2	3	3.68	1.21
7	1	3	1	5.02	2.12
8	1	3	2	4.64	1.94
9	1	3	3	4.08	1.77
10	2	1	1	3.97	1.23
11	2	1	2	3.38	1.14
12	2	1	3	2.97	1.07
13	2	2	1	4.58	1.89
14	2	2	2	3.98	1.77
15	2	2	3	3.93	1.62
16	2	3	1	4.8	2.14
17	2	3	2	4.17	2.08
18	2	3	3	4.01	1.92
19	3	1	1	4.15	1.32
20	3	1	2	4.2	1.26
21	3	1	3	3.64	1.15
22	3	2	1	4.57	1.54
23	3	2	2	4.4	1.46
24	3	2	3	4.06	1.38
25	3	3	1	5.07	1.76
26	3	3	2	4.43	1.59
27	3	3	3	4.38	1.47

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Table-5. L27 Orthogonal array and experimental results – AL / SIC / MICA.

Test No	Drilling Parameters			Response – Surface Roughness (µm)	
	Drill dia (mm)	Feed rate (mm/rev)	Speed (rpm)	Plain Twist drill	Step drill
1	1	1	1	4.77	1.76
2	1	1	2	3.35	1.23
3	1	1	3	2.3	0.85
4	1	2	1	6.32	2.33
5	1	2	2	5.29	1.95
6	1	2	3	2.86	1.05
7	1	3	1	6.98	2.57
8	1	3	2	6.13	2.26
9	1	3	3	5.32	1.96
10	2	1	1	4.04	1.49
11	2	1	2	3.72	1.37
12	2	1	3	2.15	0.79
13	2	2	1	4.87	1.79
14	2	2	2	3.92	1.44
15	2	2	3	3.3	1.21
16	2	3	1	6.25	2.30
17	2	3	2	5.82	2.14
18	2	3	3	5.7	2.10
19	3	1	1	4.93	1.81
20	3	1	2	4.11	1.51
21	3	1	3	3.91	1.44
22	3	2	1	5.81	2.14
23	3	2	2	5.72	2.11
24	3	2	3	5.56	2.05
25	3	3	1	6.55	2.41
26	3	3	2	6.03	2.22
27	3	3	3	5.87	2.16

Table-6. L27 Orthogonal array and experimental results – AL / SIC / GR.

Test No	Drilling Parameters			Response – Circularity error (mm)	
	Drill dia (mm)	Feed rate (mm/rev)	Speed (rpm)	Plain Twist drill	Step drill
1	1	1	1	0.012	0.008
2	1	1	2	0.047	0.014
3	1	1	3	0.056	0.022
4	1	2	1	0.036	0.018
5	1	2	2	0.053	0.023
6	1	2	3	0.063	0.030
7	1	3	1	0.043	0.020
8	1	3	2	0.061	0.026
9	1	3	3	0.065	0.031
10	2	1	1	0.091	0.019
11	2	1	2	0.102	0.025
12	2	1	3	0.1123	0.031
13	2	2	1	0.0723	0.028
14	2	2	2	0.0851	0.035
15	2	2	3	0.0991	0.040
16	2	3	1	0.0631	0.032
17	2	3	2	0.0641	0.042
18	2	3	3	0.0712	0.049
19	3	1	1	0.0601	0.031
20	3	1	2	0.0662	0.036
21	3	1	3	0.0901	0.045
22	3	2	1	0.0911	0.042
23	3	2	2	0.0907	0.054
24	3	2	3	0.106	0.072
25	3	3	1	0.0812	0.045
26	3	3	2	0.0726	0.061
27	3	3	3	0.0991	0.079

Table-7. L27 Orthogonal array and experimental results – AL / SIC / MICA.

Test No	Drilling Parameters			Response – Circularity error (mm)	
	Drill dia (mm)	Feed rate (mm/rev)	Speed (rpm)	Plain Twist drill	Step drill
1	1	1	1	0.0231	0.0104
2	1	1	2	0.0405	0.0182
3	1	1	3	0.0636	0.0286
4	1	2	1	0.0520	0.0234
5	1	2	2	0.0665	0.0299
6	1	2	3	0.0925	0.0416
7	1	3	1	0.0578	0.026
8	1	3	2	0.0809	0.0364
9	1	3	3	0.0896	0.0403
10	2	1	1	0.0549	0.0247
11	2	1	2	0.0723	0.0325
12	2	1	3	0.0896	0.0403
13	2	2	1	0.0809	0.0364
14	2	2	2	0.1012	0.0455
15	2	2	3	0.1185	0.0533
16	2	3	1	0.0925	0.0416
17	2	3	2	0.1358	0.0611
18	2	3	3	0.1561	0.0702
19	3	1	1	0.0896	0.0403
20	3	1	2	0.1040	0.0468
21	3	1	3	0.1301	0.0585
22	3	2	1	0.1214	0.0546
23	3	2	2	0.1561	0.0702
24	3	2	3	0.2081	0.0936
25	3	3	1	0.1301	0.0585
26	3	3	2	0.1763	0.0793
27	3	3	3	0.2283	0.1027

Design expert is used to fit the experimental data to the second order polynomial. Taguchi method is used for statistical analysis of the roughness and circularity error [16] in the holes drilled on two different specimens using two different tools.

The final regression equations for the response factor roughness are given below.

For Specimen1 and tool1, Roughness = $4.04 + 0.14\,A + 0.44\,B - 0.4C - 0.13\,AB + 0.11AC + 0.023\,BC + 0.20\,A^2 - 0.13B^2 + 0.031C^2$ (1)

Figure-3 shows the graph between predicted and actual values of roughness while drilling specimen1 using tool1 and it proved that the model provides reliable prediction.

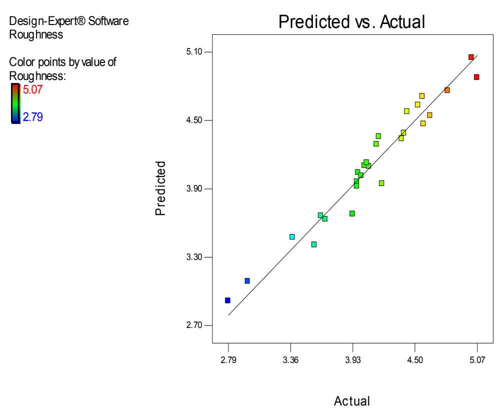

Figure-3. Predicted vs actual values of roughness specimen-1 Tool-1.

For specimen1 and tool2, Roughness = $1.65 - 0.011A + 0.35\,B - 0.12C - 0.12AB + 0.015AC - 0.029BC - 0.20A^2 - 5.556 \times 10^{-4}\,B^2 - 5.556 \times 10^{-4}\,C^2$ (2)

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Predicted vs actual roughness values for specimen 1 with tool2 are plotted in Figure-4.

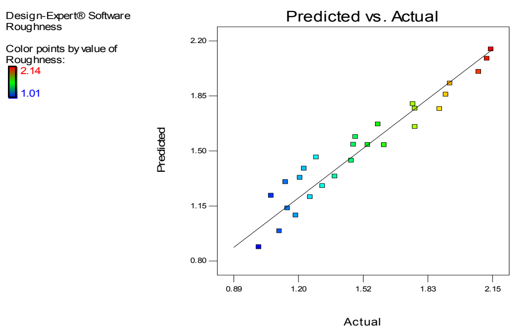

Figure-4. Predicted vs actual values of roughness specimen-1 Tool-2.

For specimen2 and tool1, Roughness = $4.42 + 0.29A + 1.19B - 0.75C - 0.21AB + 0.47AC + 0.21BC + 0.68A^2 + 0.035B^2 - 0.038C^2$ (3)

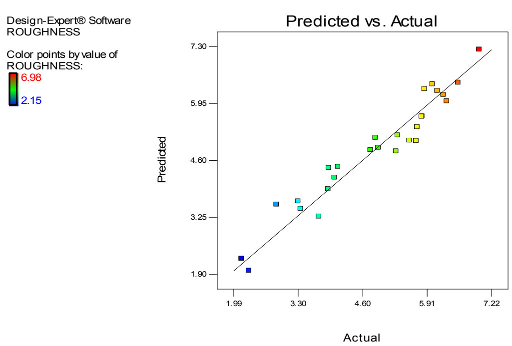

Figure-5. Predicted vs actual values of roughness specimen-2 Tool-1.

For specimen2 and tool2, Roughness = $1.63 + 0.11A + 0.44B - 0.28C - 0.077AB + 0.17AC + 0.076BC + 0.25A2 + 0.013B^2 - 0.014C^2$ (4)

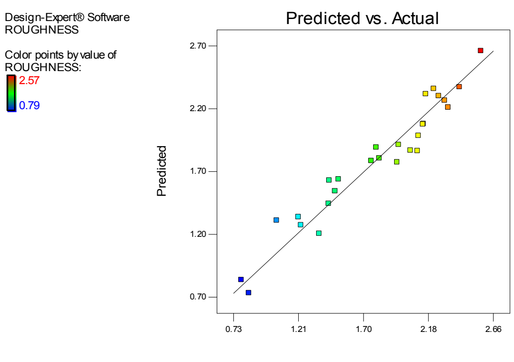

Figure-6. Predicted vs actual values of roughness specimen-2 Tool-2.

Predicted vs actual roughness values for specimen 2 are plotted in Figure-5 and Figure-6 for tools 1 and 2 respectively.

The final regression equations for the response factor circularity error are given below.

For Specimen1 and tool1, Circularity error = $0.088 + 0.018A - 9.111\times10^{-4} B + 0.012C - 1.458\times10^{-3} AB - 2.517\times10^{-3} AC - 3.942\times10^{-3} BC - 0.018A^2 - 7.533\times10^{-3} B2 + 1.567\times10^{-3} C^2$ (5)

For specimen1 and tool2, Circularity error = $0.036 + 0.015A + 8.556\times10^{-3}B + 8.667\times10^{-3}C + 3.333\times10^{-3}AB + 3.417\times10\text{-}3AC + 1.883\times10^{-3}BC + 3.056\times10^{-3}A^2 - 3.778\times10^{-3}B^2 + 5.556\times10^{-4}C^2$ (6)

For specimen2 and tool1, Circularity error = $0.11 + 0.043A + 0.027B + 0.026C + 9.152\times10^{-3}AB + 9.393\times10^{-3}AC + 6.503\times10^{-3}BC + 5.941\times10^{-3}A^2 - 9.955\times10^{-3}B^2 + 6.423\times10^{-4}C^2$ (7)

For specimen2 and tool2, Circularity error = $0.048 + 0.019A + 0.012B + 0.012C + 4.117\times10^{-3}AB + 4.225\times10^{-3}AC + 2.925\times10^{-3}BC + 2.672\times10^{-3}A^2 - 4.478\times10^{-3}B^2 + 2.889\times10^{-4}C^2$ (8)

All the above models provide reliable prediction. For a sample, the predicted vs actual values of circularity error in the specimen2 when using tool2 is plotted in Figure-7

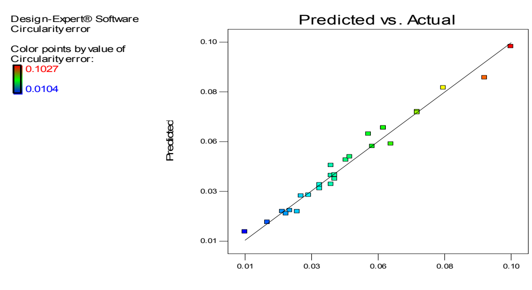

Figure-7. Predicted vs actual values of circularity error specimen-2 tool-2.

Table-8. Response table for S/N ratios smaller is better (specimen1, tool1, roughness).

Level	Dia	Feed	Speed
1	-12.01	-11.11	-13.07
2	-11.91	-12.43	-12.20
3	-12.68	-13.06	-11.34
Delta	0.77	1.94	1.72
Rank	3	1	2

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From Table-8, observation can be made such that the feed rate have greater influence on surface roughness of the holes in the specimen1 (Al/Sic/Gr) when using tool1 (Solid carbide twist drill). The next influencing factor is spindle speed and then the drill tool diameter.

We observed similar effect on the specimen2 (Al/Sic/Mica) when using the same tool as shown in Table-9.

Table-9. Response table for S/N ratios smaller is better (specimen2, tool1, roughness).

Level	Dia	Feed	Speed
1	-13.12	-11.05	-14.86
2	-12.50	-13.44	-13.59
3	-14.51	-15.64	-11.68
Delta	2.01	4.59	3.18
Rank	3	1	2

The main effect plots for drilled hole surface roughness in the specimen 1 and 2 when using solid carbide twist drill are shown below in Figure-8 & 9.

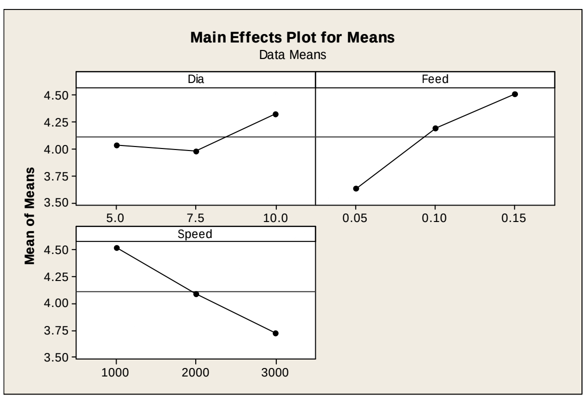

Figure-8. Main effect plots – roughness (specimen1 & drill tool1).

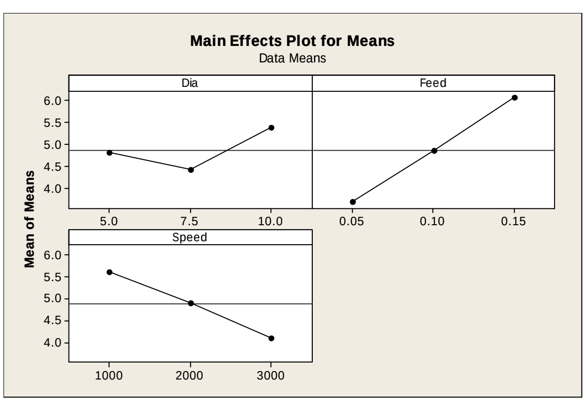

Figure-9. Main effect plots – roughness (specimen2 & drill tool1).

Similarly from the response Tables-10 and 11, we can made observations such that the most influencing factor affecting the error in the circularity of the drilled holes is drill tool diameter. The next influencing factors are feed rate and spindle speed respectively.

Table-10. Response table for S/N ratios smaller is better (specimen1, tool2, circularity error).

Level	Dia	Feed	Speed
1	31.60	30.48	30.04
2	27.32	26.75	27.40
3	23.83	25.53	25.31
Delta	7.77	4.94	4.72
Rank	1	2	3

Sample response tables for the specimen Al/Sic/Gr and Al/Sic/Mica when using solid carbide step drills are shown in Tables-10 and 11.

Table-11. Response table for S/N ratios smaller is better (specimen2, tool2, circularity error).

Level	Dia	Feed	Speed
1	34.02	32.75	32.31
2	29.82	29.11	29.86
3	26.11	28.08	27.77
Delta	7.90	4.67	4.54
Rank	1	2	3

The main effect plots of drill diameter, feed and speed for means of circularity error in the specimen1 when using step drills are shown in Figure-10.

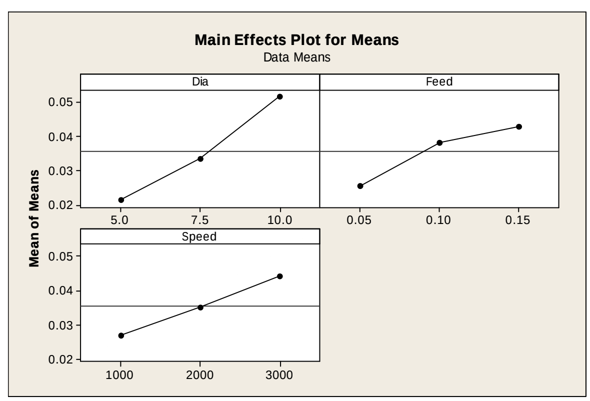

Figure-10. Main effect plots – circularity error (specimen1 & drill tool2).

Similar main effect plots for means of circularity error in the specimen Al/Sic/Mica when using step drills are shown in Figure-11.

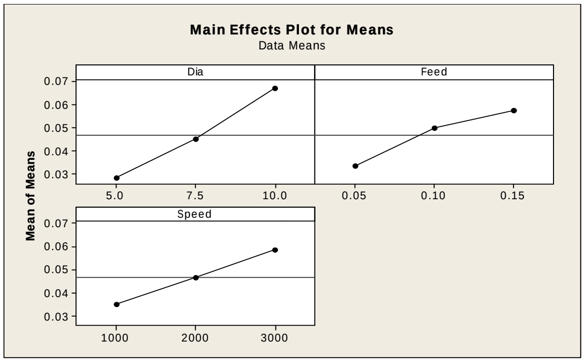

Figure-11. Main effect plots – circularity error (specimen2 & drill tool2).

The drilled hole surface roughness of the specimen Al/Sic/Gr when using Solid carbide twist drill and Solid carbide two stepped drill are compared and the values are plotted as shown in Figure-12.

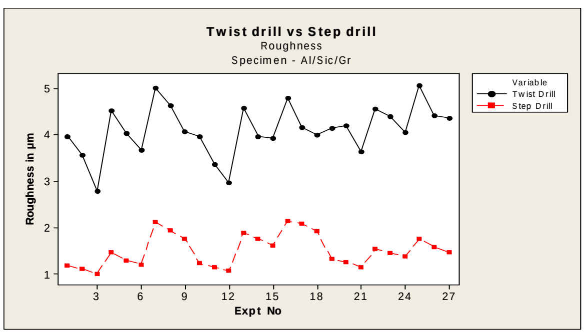

Figure-12. Comparison of roughness when using twist drill and step drill.

The Circularity error in the drilled holes in the specimen Al/Sic/Mica when using Solid carbide twist drill and Solid carbide two stepped drill are compared and the values are plotted as shown in Figure-13.

It is observed form the Figures-12 & 13, that the stepped drills provide smoother drilled hole surface with less circularity error when compared with Solid carbide twist drills.

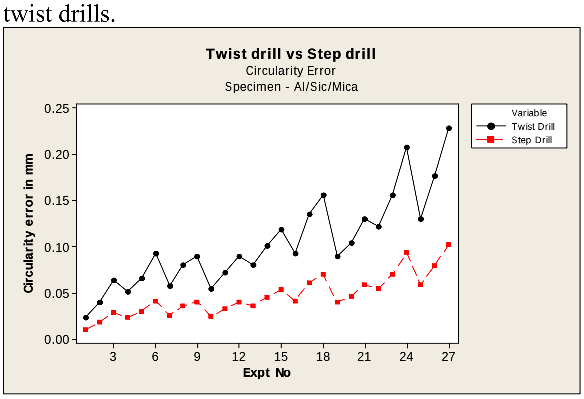

Figure-13. Comparison of circularity error when using twist drill and Step drill.

5. CONCLUSIONS

The investigations on the drilling performance of Al / SiC / Gr and Al / SiC / Mica hybrid metal matrix composites using solid carbide twist drills and solid carbide two stepped drills have been done and the following points were concluded.

- The regression equations for the responses of drilled hole roughness and circularity error in terms of various drilling parameters were formulated and the plots show that the predicted values are very close to actual values and so they are considered as acceptable models.
- Feed rate of the drilling tool is found to have significant influence on the roughness of the drilled holes. Next to feed rate, spindle speed influencing the roughness.
- Drilling tool diameter is the most influencing parameter on the circularity error in the drilled holes. Feed rate is the drilling parameter that influencing the circularity error next to drill diameter.
- For the given hybrid composites, the surface roughness increases directly with feed rate and inversely with spindle speed. Drill diameter is not having significant influence on roughness.
- The error in circularity of the drilled holes increases directly with speed, feed and drill diameter.
- Finally, it is concluded that the solid carbide stepped drills provide better quality of drilled holes when compared to solid carbide twist drills.

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