INFLUENCE OF TOOL COATINGS AND DRILLING PARAMETERS ON THE QUALITY OF DRILLING IN NANO METAL MATRIX COMPOSITES

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ABSTRACT

In Assembly operations, drilling a machine component, made of nano metal matrix composite material, without any defect is a challenging task for Engineers. This work is focused on the effect of tool coatings and drilling parameters on the quality of holes made on Hybrid Aluminium nano-composite. In this work, stir cast hybrid nanocomposite is developed with the reinforcement of 2% of boron nitride and 4% of Aluminium oxide nano particles in the base matrix of Aluminium 7075. This composite is used in various load bearing applications due to their excellent wear resisting properties. Circularity error and poor surface finish of the drilled holes are the major problems encountered in the drilling process. To improve the quality of drilling, it is essential to study these responses under various drilling conditions by varying the drilling parameters and drill tool coatings. The primary aim is to optimise the drilling parameters involved to minimise the circularity error and to maximise the surface finish of the drilled holes. Drilling experiments are conducted in CNC vertical machining centre using three different drill tools (Uncoated carbide drill, TiAlN coated drill and High carbon coated drill) of 5mm diameter. The different drilling parameters considered in our study are drilling speed and feed rate. L27 orthogonal array is used to conduct the experiments followed by Taguchi analysis and ANOVA to find out optimum process parameters and their percentage contribution on the responses considered.

Keywords: hybrid nanocomposites, drilling, surface roughness, circularity error, ANOVA, taguchi technique.

INTRODUCTION

Hybrid metal matrix composites form a group of materials that have been attracted by a number of researchers because of their improved properties when compared with monolithic materials. Attempts have been made to fabricate mechanical components using these composite materials; however some measure of finishing should be done to complete the assembly process. In any case, for assembly and joining, additional machining process like drilling is required. Because of the reinforcements, drilling of hybrid composites became a challenging task in the production industries. Various factors affect the quality of drilled holes. Circularity error and surface roughness in drilling hybrid metal matrix composite materials have been observed to be affected by various parameters like spindle speed, point angle of the drill tool, feed rate and tool coating material.

Sarala Rubi *et al.* [1] studied the effect of process parameters, spindle speed, feed rate, drill tool and percentage of reinforcements on the surface roughness, thrust force and burr height in drilling of LM6 aluminium alloy reinforced with boron carbide and flyash and determined the optimal parameters by multi objective optimization technique using grey relational analysis. Similarly, Murthy *et al.* [2] conducted drilling experiments on GFRP using solid carbide drill tools and investigated the influence of various drilling parameters and thickness of materials on the surface finish of the drilled holes and predicted the relationship between drilling force and roughness using RSM and Taguchi techniques.

Rajesh kumar *et al.* [3] conducted drilling experiments on polymer nano composites using three different drilling tool and analysed the influence of process parameters on the roundness and roughness of the holes using ANOVA techniques. Venkateshwarlu *et al.* [4] conducted drilling experiments on titanium alloys as per L9 orthogonal array using different drilling tools and optimise the parameters to minimise the circularity error by statistical techniques.

Ramkumar *et al.* [5] focused on the parameters and the processes of drilling on titanium composites to optimize the parameters using Taguchi concept and found that the thrust force and roughness are mostly influenced by the feed rate. Raja.K *et al*, [6] focussed on characterization and optimization of drilling Al7075/BN composites using L27 Box - Behnken technique and revealed that the most significant factors affecting the thrust force and surface finish are the point angles of the drilling tool and the feed rate. In the work of Hari Singh *et al.* [7], an attempt has been made to prove that the combination of Taguchi Method and Grey Relational Analysis improves the Surface quality of drilled hole.

Juliyana *et al.* [8] fabricated LM5/ZrO2 composites and investigated the influence of drilling parameters, tool materials, reinforcement percentages by ANOVA technique and found that the drilling speed and feed rate are the major parameters influencing the thrust force developed during drilling. Eaben Rajkumar *et al.* [9] focused their studies on drilled hole surface and sub surfaces of Al/B4C/Mica hybrid composites and Al/ B4C MMCs and to minimise the issues related with surface integrity. In the same manner, Abbas, Ch Asad, *et al.* [10] analysed the influence of drilling speed and feed rate on the quality of holes made by high speed drilling on Al/SiC composites by diamond coated cemented carbide drill.

Taskesen *et al.* [11] analysed the drilling of hybrid composites using TiAlN coated carbide drills and concluded that the drill tool material was the more influential parameter than the drilling parameters like feed rate and spindle speed. They also suggested that the TiAlN coated drill showed the best performance among the various drill tool materials.

Our choice of Aluminium alloy as matrix material is Al7075 which is highly versatile and can be used for many structural and automobile components due to its excellent mechanical properties. Inclusion of Boron nitride as Ceramic reinforcement with Al7075 improve the lubrication property of the material. It also increases the hardness drastically. To improve the mechanical properties of the composite, different proportion of Aluminiom oxide is also added to make the composite a hybrid nano composite. This hybrid nano composites possess a good combination of improved elastic property, specific strength, high thermal stability and excellent wear resistance [12].

A restricted research work has been done on Aluminium hybrid nano composites reinforced with Boron nitride because of higher material cost and poor wetting property. It is a vigorous material having brilliant chemical and thermal properties and high hardness.

MATERIALS AND METHODS

AA7075, an aluminium alloy with zinc as the main alloying element is the base material for our experiment. The composition of AA7075 is shown in Table-1.

Table-1. Composition of AA7075.

Zn	Mg	Cu	Fe	Cr	Si	Mn	Al
5.6	2.5	1.5	0.35	0.2	0.09	0.06	balance

A stir cast nano hybrid composite was prepared by reinforcing 2% of hexagonal boron nitride of average particle size of 70nm and 4% of alumina (Alpha) of average particle size 20 - 30nm in a graphite crucible. Stir Casting is a liquid state technique for the preparation of hybrid nano composites, in which the reinforcement materials are blended together with the liquid aluminium (AA7075) matrix by mechanical stirring. The AA7075 bar was cut into small pieces and in a graphite crucible they are softened. The reinforcement materials are separately preheated and added continuously with a consistent motion with the help of a ceramic stirrer along with a motor running at a normal speed of 300rpm for 30 minutes to set up the slurry. The liquid slurry is then poured into the mould cavity of size 100mm x 100mm x 10mm and cast by conventional casting methods to prepare the specimen for our investigations [13].

The SEM image shows that the specimen is homogenous. Boron nitride inclusion in the base AA7075 made the surface, fine and the aluminium fragments protruded as fine particles on the surface. Lodged particles of aluminium oxide can be seen on the matrix as grey spots on the track surfaces, which is shown in Figure-1.

Our work is to investigate and analyse the influence of drilling parameters and tool materials on the quality of holes like circularity error and roughness of the drilled hole surface. The drilling tests are performed by making use of vertical machining centre which is shown in Figure-2. The surface roughness of the drilled hole is measured using Kosaka - Surfcoder SE700. Circularity error is measured for all the holes using coordinate measuring machine. The tool materials and drilling parameters used are given in Table-2.

Table-2. Various parameters and their levels.

Level	Tool Material	Spindle speed (rpm)	Feed rate (mm/min)
1	Uncoated carbide (A)	1200	40
2	TiAlN coated (B)	2400	80
3	Hard carbon coated (C)	3600	120

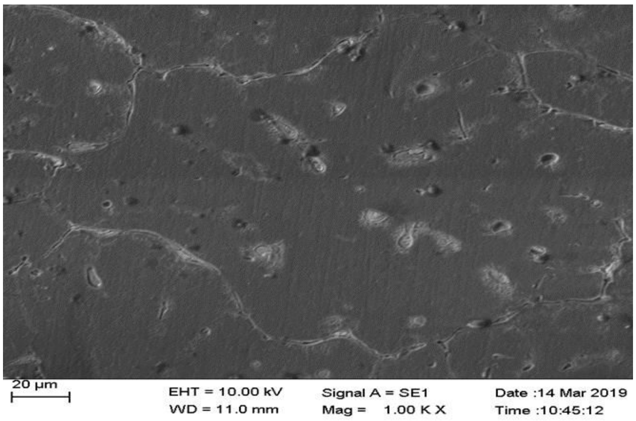

Figure-1. SEM image of the specimen.

The drilling was performed on the specimen with twist drills made with different coatings [14] and of point angle 118^0 each (Uncoated carbide drill, TiAlN coated carbide drill and Hard carbon coated carbide drill) of each 5mm diameter.

Figure-2. Vertical machining centre.

Our design of experiment was planned to find out the drill tool materials and drilling parameters influencing the drilling operations to accomplish least circularity error and surface roughness. The examinations were set up based on L27 orthogonal array to relate the impact of drill tool material, spindle speed and feed rate [15]. Three factors at three levels each are utilized in this investigation, so 33, 27 examinations were needed for full factorial plan based on Taguchi's Design of Experiments. Parameters are picked based on the relevant literatures and Table-2 shows the parameters and their levels.

The experimental results are analysed using Taguchi's technique, which is one of the statistical approaches used for optimization [16]. In this method the optimization of process parameters can be done by minimizing the variances. In Taguchi's approach, SNR values (signal to noise ratio) measure the deviation of the response values from the target values.

Based on the goal of our experiments, there are three types of SNR, Larger is better, nominal is best and smaller is better when the goal is to maximize or optimize or minimize the responses respectively. In our investigations, the responses, surface roughness and circularity error both are to be minimised (SNR-smaller is better).

For Smaller is better, the formula used for Signal to Noise ratio is

$$SNR = -10 \log10 (\Sigma(Y^2)/n)$$

where Y is the responses taken for a particular combination of input factors and n is the number of output responses for the same combination of input factors.

Table-3. Experimental results.

Expt. No	Tool Material	Speed (rpm)	Feed rate (mm/min)	Surface Roughness (µm)	Circularity Error (mm)	SNR1 A	SNR2 B	Combined objective function (A*0.5+B*0.5)
1	A	1200	40	1.635	0.016	-4.270	35.918	15.824
2	A	1200	80	1.758	0.018	-4.902	34.740	14.919
3	A	1200	120	2.578	0.020	-8.225	34.036	12.905
4	A	2400	40	1.622	0.021	-4.202	33.489	14.644
5	A	2400	80	1.726	0.022	-4.743	33.075	14.166
6	A	2400	120	2.148	0.024	-6.640	32.490	12.925
7	A	3600	40	1.590	0.023	-4.029	32.585	14.278
8	A	3600	80	1.643	0.026	-4.315	31.853	13.769
9	A	3600	120	1.933	0.027	-5.724	31.259	12.768
10	B	1200	40	1.272	0.068	-2.090	23.295	10.602
11	B	1200	80	1.441	0.078	-3.173	22.117	9.472
12	B	1200	120	2.583	0.085	-8.242	21.413	6.585
13	B	2400	40	1.255	0.091	-1.971	20.866	9.448
14	B	2400	80	1.399	0.095	-2.916	20.452	8.768
15	B	2400	120	1.985	0.102	-5.955	19.867	6.956
16	B	3600	40	1.210	0.100	-1.658	19.962	9.152
17	B	3600	80	1.284	0.109	-2.171	19.230	8.529
18	B	3600	120	1.687	0.117	-4.542	18.636	7.047
19	C	1200	40	0.768	0.155	2.293	16.216	9.254
20	C	1200	80	0.826	0.177	1.660	15.039	8.350
21	C	1200	120	1.211	0.192	-1.663	14.334	6.336
22	C	2400	40	0.762	0.204	2.361	13.788	8.074
23	C	2400	80	0.811	0.314	1.820	10.061	5.940
24	C	2400	120	1.009	0.229	-0.078	12.788	6.355
25	C	3600	40	0.747	0.227	2.534	12.883	7.708
26	C	3600	80	0.772	0.247	2.248	12.151	7.199
27	C	3600	120	0.908	0.264	0.838	11.558	6.198

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RESULTS AND DISCUSSIONS

The three input parameters involved in our drilling experimental investigations and the corresponding response values measured are tabulated as per L27 orthogonal array and are shown in Table-3. SN ratios for surface roughness and circularity error are calculated separately for all the 27 experimental values and are tabulated in the columns named SNR1 and SNR2 in Table-3. The unit for surface roughness is micron (µm) and that for circularity error is mm. But the SNR values of both responses are in a common unit, decibels (dB).

Three different drilling tool materials, Uncoated carbide, TiAlN coated and Hard carbon coated tools are proposed. The remarkable effects of tool materials, drilling speed and feed rate on the surface roughness and circularity error are investigated by Taguchi's approach. Using the Minitab19 software, the SN ratios of both responses and their response tables are obtained. In Taguchi analysis, SNR values are used to predict the optimum process parameters and their influences on the responses to be analysed.

The response table contains the mean value of SN ratios for each parameter for each level. The delta values are the difference between maximum and minimum mean SNR values for each parameter. The parameter having maximum delta value is ranked number 1 and minimum is ranked 3. The process parameter ranked 1 is the most influencing parameter for the particular response. Table-4 is the response table obtained for surface roughness. From the table it is clear that the tool material is the most influencing parameter for surface roughness of the drilled holes followed by feed rate and spindle speed.

Table-4. Response table for surface roughness.

LEVEL	TOOL	SPEED	FEED
1	-5.228	-3.179	-1.226
2	-3.635	-2.481	-1.883
3	1.335	-1.869	-4.470
DELTA	6.563	1.310	3.245
RANK	1	3	2

Based on the SN ratios, the main effect plots for surface roughness are obtained from Minitab19 software and is shown in Figure-3. It is the graphical representation of the response table. The range of mean SN ratios for the parameter, Tool, is high (From -5.228 to 1.335) when compared with speed and feed and so we can conclude that the tool material is the most influencing parameter for surface roughness, followed by feed and speed. The optimum parameters are found to be High carbon coated tool with spindle speed of 3600rpm and feed rate of 40mm/min.

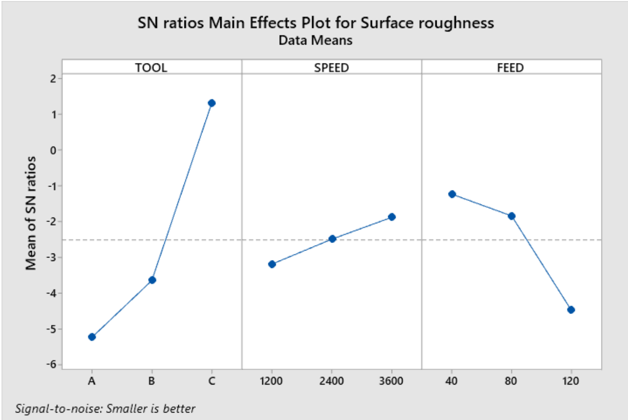

Figure-3. Main effects plot for surface roughness.

The interaction plots for surface roughness are shown in Figure-4. These plots show the relationship between one categorial factor and the response (surface roughness) depends on the value of another categorial factor. The interaction effect is negligibleas most of the plots are parallel. We can see some interaction between speed and feed as the three lines for different speed meet at a point for the feed of 40mm/min.

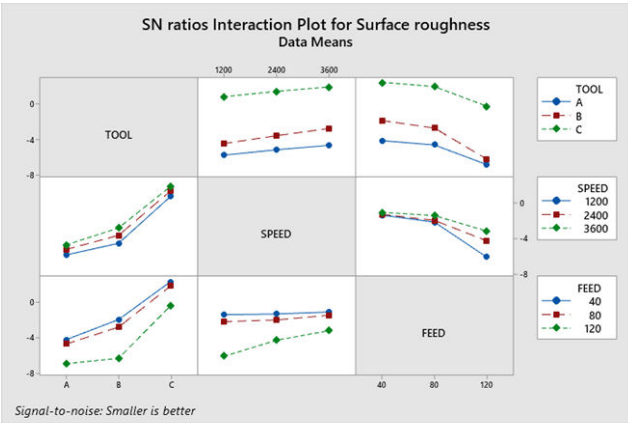

Figure-4. Interaction plots for surface roughness.

To determine the influence of various parameters on surface roughness, the analysis of variance (ANOVA) was carried out and is shown in Table-5. For 95% confidence level, the probability value less than 5% that is 0.05 shows the remarkable drilling parameters that are affecting surface roughness. From the % contribution values, it is clear that the most influencing parameter is the type of drilling tool followed by the feed rate.

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Table-5. ANOVA table for surface roughness.

Parameter	DOF	Sum of Squares	Mean Squares	Probability	% Contribution
Tool	2	210.919	105.46	0.000	74.82
Speed	2	7.737	3.869	0.000	2.74
Feed	2	53.558	26.779	0.000	19.00
Tool * Speed	4	0.362	0.091	0.055	0.13
Tool * Feed	4	2.986	0.747	0.000	1.06
Speed * Feed	4	6.153	1.538	0.000	2.18
Residual Error	8	0.197	0.025		0.07
Total	26	281.913			100.00

Table-6 is the response table obtained for circularity error in the drilled holes. Based on the rank, we can conclude that the tool material is the most influencing parameter for circularity error followed by the speed and feed rate.

Table-6. Response table for circularity error.

LEVEL	TOOL	SPEED	FEED
1	33.27	24.12	23.22
2	20.65	21.88	22.08
3	13.2	21.12	21.82
DELTA	20.07	3.0	1.4
RANK	1	2	3

The main effect plots for circularity error are obtained from Minitab19 software and is shown in Figure-5.

From these plots we can infer that the optimum parameters to minimize the circularity error are uncoated carbide tool with drilling speed of 1200rpm and feed rate of 40mm/min.

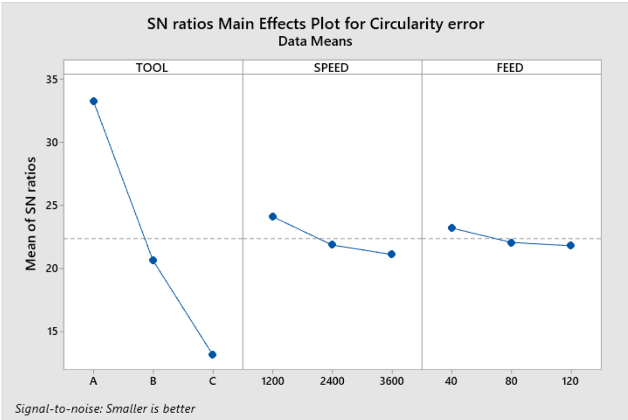

Figure-5. Main effects plots for circularity error.

Table-7. ANOVA table for circularity error.

Parameter	DOF	Sum of Squares	Mean Squares	Probability	% Contribution
Tool	2	1852.76	926.379	0.000	96.764
Speed	2	43.83	21.916	0.000	2.289
Feed	2	10.02	5.008	0.004	0.523
Tool * Speed	4	1.63	0.406	0.461	0.085
Tool * Feed	4	1.63	0.406	0.461	0.085
Speed * Feed	4	1.62	0.406	0.461	0.085
Residual Error	8	3.25	0.406		0.170
Total	26	1914.73			100.00

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Table-7 shows the ANOVA results for circularity error. The % contribution for the type of coating on the tool is very high (96.76%) followed by speed and feed.

The interaction plots for circularity error are shown in Figure-6. Here also the interaction effect is negligible as most of the plots are being parallel

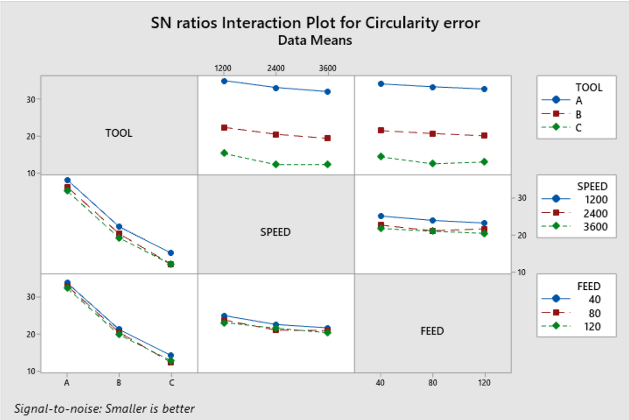

Figure-6. Interaction plots for circularity error.

In our investigations, the combined objective function is formulated by giving equal weightage to the responses surface roughness and circularity error (50% each) and the SN ratios for combined objective function is calculated and tabulated in the last column of Table-3. Main effect plots for the combined objective function are attained using Minitab19 software and is shown in Figure-7.

The response values are also obtained and are given in Table-8. From the main effect plots and response table, we can say that the most influencing factors for the combined objective function is the type of coating in the tool followed by the feed rate and spindle speed of the drilling process.

Table-8. Response table for combined objective function.

LEVEL	TOOL	SPEED	FEED
1	14.0219	10.4719	10.9982
2	8.5065	9.6973	10.1236
3	7.2683	9.6275	8.6748
DELTA	6.7536	0.8444	2.3234
RANK	1	3	2

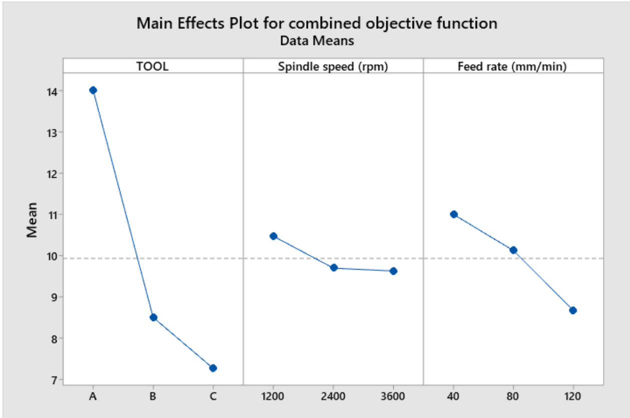

Figure-7. Main effects plots for combined objective function.

The ANOVA results for the combined objective function is shown in the Table-9. Considering 95% confidence level, the most influencing parameter is found to be the type of coating on the tool (% contribution of 82.73) followed by feed (11.6%) and speed (1.52%) of drilling. The optimum parameters for the combined objective function (To minimize both surface roughness and circularity error) are high carbon coated drilling tool with 3600rpm speed and 120mm/min feed.

Table-9. ANOVA table - combined objective function.

Parameter	DOF	Sum of Squares	Mean Squares	Probability	% Contribution
Tool	2	164.485	82.243	0.000	82.73
Speed	2	3.02	1.51	0.012	1.52
Feed	2	23.066	11.533	0.000	11.60
Tool * Speed	4	0.977	0.244	0.345	0.49
Tool * Feed	4	3.243	0.811	0.037	1.63
Speed * Feed	4	2.527	0.632	0.067	1.27
Residual Error	8	1.496	0.187		0.75
Total	26	198.814			100.00

CONCLUSIONS

Aluminium nano composites (AA7075/BN/Al2O3) were effectively prepared using stir casting techniques and drilling experiments were carried out as per L27 orthogonal array with Taguchi's experimental design to optimize the process parameters of drilling. The conclusions inferred from the investigations are given below:

From the results of investigations, it is observed that, better surface finish of drilled holes can be obtained at the drilling speed of 3600rpm and feed rate of 40mm/min with high carbon coated drill tool.

The observations also revealed that, the circularity error can be minimised at the drilling speed of 1200rpm, feed rate of 40mm/min with uncoated carbide drills.

Optimization of combined objective function to minimise both surface roughness and circularity error was carried out and we conclude that the optimum parameters are high carbon coated drill tool with high speed and high feed.

The percentage contribution of the process parameters on surface roughness and circularity error are also computed using ANOVA technique.

High carbon coated drill tool gives better quality holes than uncoated and TiAlN coated tools.

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