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Optimization of process parameters in drilling of Al6061/CNT with carbide and nano coated drills by Taguchi Analysis

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Abstract - In general machining of composites is one of the critical aspect to make it useful. In machining in various forms loss of energy will takes place due to the utilization of ineffective combination of parameters. In this paper to machine the CNT reinforced Aluminium Metal Matrix Nano Composites (Al6061/CNT) of different CNT weight percentages of 0.3%, 0.6% and 0.9%, drilling experiments were conducted to identify the optimal combination of parameters to achieve lower temperatures which influences various mechanical aspects like surface roughness, tool wear, etc,. The considered input parameters for the present work were type of tool, speed, feed and type of coolant/cutting conditions. With respect to input parameters the output response (cutting temperature) was measured by performing the drilling experiments according to Taguchi design of experiments. Also Analysis of Variance (ANOVA) was conducted to determine the percentage influence of the input parameters on the cutting temperature. The optimal combination of process parameters was identified from Taguchi analysis and finally confirmation tests were conducted to achieve lower temperature.

Keywords: Drilling, optimization, Taguchi Analysis, ANOVA, S/N Ratio, CNT

I. INTRODUCTION

Due to their high strength, light weight and excellent corrosion resistance, Aluminium Metal Matrix Nano Composites (AMMNCs) are attractive materials for a variety of applications. A number of experiments have been conducted by various researchers worldwide in the last few decades. At first, they introduced the concept of obtaining the optimum speed for metal cutting operations relating various input parameters. A number of approaches have been proposed for minimizing / maximizing of machining parameters for better and economic performance [12].

The Taguchi Analysis developed by Dr. Genichi Taguchi, refers to Quality Engineering. Taguchi's parameter design reduces the production cost and also improves quality by reducing the experimental time interval. In this study, L_{18} mixed level experiments of orthogonal array is chosen based on its capability to verify the interactions among the input parameters and their range Table 2.1. Signal-to-noise ratios (S/N) of each and every experiment is calculated to find the effect of drilling parameters on the response characteristics. In this study, S/N ratio was chosen according to the criterion 'the smaller-the-better', in order to minimize the response [10].

The S/N ratio functioned as a measure of performance to develop the processes insensitive to noise factors. From the S/N ratio values, predicting the performance of a product or process can be made with the help of noise factors which are obtained from Taguchi Analysis [8]. For the obtained output response the smaller the S/N ratio, the better the result. Therefore, the desired "smaller-the-better" criterion implies that the lowest temperature would be the better result [3]. This is the method employed in this work to determine the optimal machining parameters [6].

In order to define the relationship between dependent variable and independent variables regression analysis can be used. In this work dependent variable is Temperature (T), whereas the independent variables were the type of the cutting tool, cutting speed, feed rate and coolant. Estimation equations for Temperature (T) was established using linear regression models [7]. Kuo et al. investigated the tool life, surface roughness and burr formation in high-speed drilling of stainless steel using TiN-coated carbide drill [9]. G. Tosun et al. were done experiments on drilling metal matrix composites of type A356/20% SiC-T6 by considering the objective to develop the correlations between input parameters and output responses using PCD drill [8].

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Davim. J P et al. performed high speed drilling to minimize the thrust forces during drilling which leads to high heat generation due to rubbing action between the work material and tool [1, 4]. In drilling operations, the high ductility of the work material leads to the formation of long continuous chips and to intensive sticking of the workpiece material to the cutting tool surface, which results in enhanced adhesive wear [2]. For various types of drilling operations combination of a high strength nano reinforcement in a soft metal matrix is the technological innovation in the field of composites, the designers can choose suitable materials for particular applications. The composites plays a major role in high various applications like automotive industries, aerospace applications, in medical appliances manufacturing, etc,. [11].

II METHODOLOGY

A. Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a statistical method for determining the existence of differences among several population means. The technique requires analysis of different forms of variance associated with the random samples under study, Hence the name Analysis of Variance. In this study, ANOVA is performed to investigate the statistical significance of the process parameters affecting the temperature. The objective is to analyze the influence of tool material, spindle speed, feed rate and type of coolant on the total variance of the results. This analysis was undertaken for a level of significance of 5.0%, i.e. for a level of confidence of 95.0%. The ANOVA table also consists of the F-values and the percentage contributions. By comparing the F-values with the tabulated ones, the significance of the factors can be understood. If the obtained F-value of a parameter is greater than the tabulated one, then that particular parameter has a significant influence over the response variable.

B. TAGUCHI METHOD

Essentially, traditional experimental design procedures are too complicated and uneasy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve such problems, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with less number of experiments. The greatest advantage of this method is the saving of effort in conducting experiments, saving experimental time, reducing the cost, and discovering significant factors quicker manner. Taguchi's robust design method is a powerful tool for the design of a high quality system. The Taguchi method uses S/N ratio to measure the variations of experimental design. The word signal says the desirable value and the word noise says the undesirable value. S/N ratios were calculated for surface roughness and amplitude of drill bit vibration using smaller is the best characteristic. In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on surface roughness values. In this way, the optimal levels of process parameters can be estimated. The steps involved in Taguchi optimization are:

Step 1: Quality characteristics selection

Step 2: Noise and control factors selection

Step 3: Taguchi orthogonal selection

Step 4: conduct experimentation and Temperature Measurement

Step 5: Analyse results (S/N ratio)

Step 6: prediction of optimum performance

Step 7: confirmation tests

C. Orthogonal Array

Taguchi employs design experiments using specially constructed table known as "Orthogonal Arrays (OA)". Orthogonal Arrays (OA) are a special set of latin squares, constructed by Taguchi to layout the design experiments. The Orthogonal Array considered for the experimentation is as shown in Table 2.1

Table 2.1 Orthogonal Array

S.no	Tool	Speed	Feed	Coolant
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

In this work for analysis 4 parameters A, B, C, D were considered i.e., A is with 2 levels, remaining B, C, D are each at three levels. This is called an L_{18} design. In this 18 indicates number of rows, configurations or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus L_{18} (Mixed Level Design) means that eighteen experiments are to be carried out to study variables. There are greater savings for larger arrays. Based on the S/N ratios the output responses were analyzed. For the present work the quality characteristic "smaller the better" is considered.

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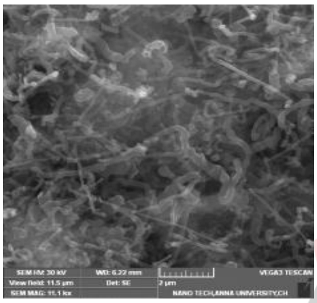
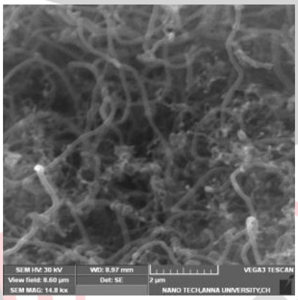
III. EXPERIMENTATION

A. Material

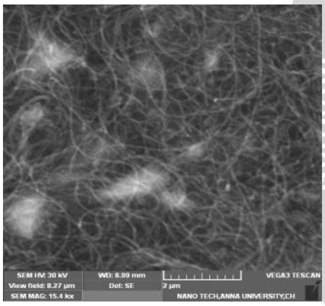
Aluminium alloy Al6061 is used as a base material to reinforce with powered Multi Walled Carbon Nano Tubes (MWCNT, OD: 4-6 nm, Length: <50nm). The various weight percentages of CNT used for reinforcement are 0.3%, 0.6% and 0.9% respectively. The Al6061 pieces are taken in a crucible and melted with the help of Electric Arc furnace, the melt is stirred with the help of ultrasonic method for uniform distribution of the reinforcements. The obtained castings were machined to proper tolerances and then the drilling experiments were carried out. The microstructure of the uniformly distributed CNT particles and its presence for various percentages are extracted through SEM tests at nano and micro scales and are shown in the Fig.3.1.



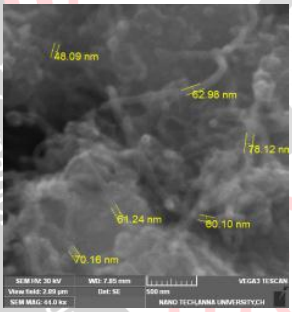
3.1 (a)



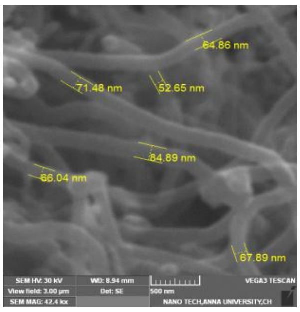
3.1 (b)



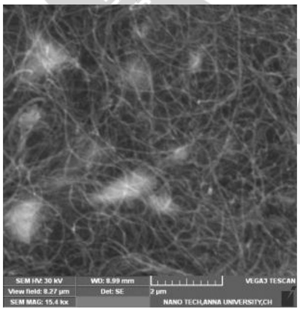
3.1 (c)



3.1 (d)



3.1 (e)



3.1 (f)

Fig. 3.1(a) SEM image of Al6061 + 0.3% CNT composite (b) Al6061 + 0.6% CNT (c) Al6061 + 0.9% CNT at micro level (2 µm)
Fig. 3.1(d) SEM image of Al6061 + 0.3% CNT composite (e) Al6061 + 0.6% CNT (f) Al6061 + 0.9% CNT at micro level (500 nm)

B. Process parameters

In this paper, 4 factors are considered as input parameters namely type of the tool, Spindle speed (rpm), Feed (mm/rev) and coolant. To incorporate these parameters in an orthogonal array mixed level experiments design is considered with Levels 2,3,3,3 respectively as shown in Table 3.1. With these levels of input parameters the Design of Experiments leads to L_{18}. Where 18 indicates number of experimental runs [10]. The same is shown in Table 3.2.

Table 3.1 Process parameters and their levels

Factor	Level-1	Level-2	Level-3
Tool material (A)	Carbide	Nano Coated - Hyperlox	-
Spindle Speed in rpm (B)	500	560	630
Feed in mm/rev (C)	0.2	0.3	0.36
Coolant(D)	Dry	Vegetable oil	Soluble oil

Table 3.2 Typical Orthogonal Array (L18)

SNO	Type of the Tool	Spindle Speed (rpm)	Feed (mm/rev)	Coolant
1	Carbide	500	0.2	Dry
2	Carbide	500	0.3	Veg oil
3	Carbide	500	0.36	Soluble oil
4	Carbide	560	0.2	Dry
5	Carbide	560	0.3	Veg oil
6	Carbide	560	0.36	Soluble oil
7	Carbide	630	0.2	Veg oil
8	Carbide	630	0.3	Soluble oil
9	Carbide	630	0.36	Dry
10	Hyperlox	500	0.2	Soluble oil
11	Hyperlox	500	0.3	Dry
12	Hyperlox	500	0.36	Veg oil
13	Hyperlox	560	0.2	Veg oil
14	Hyperlox	560	0.3	Soluble oil
15	Hyperlox	560	0.36	Dry
16	Hyperlox	630	0.2	Soluble oil
17	Hyperlox	630	0.3	Dry
18	Hyperlox	630	0.36	Veg oil

C. Experimental Setup and procedure

Drilling tests were conducted on the Radial Drilling Machine (ACCU MAX), with the carbide drill bit and nano coated (Hyperlox) drill bit of 8mm in diameter. The machining samples were prepared in size of 100mmX100mmX10mm blocks. The experiments were carried out with twist drill bits of 8mm diameter made of carbide and Hyperlox coated HSS twist drill as shown in Fig. 3.2 and the information regarding coating material is mentioned in the Table 3.3.

Table: 3.3 Information of coating material

Coating class	2^{nd} gen, Super Nitride	**Micro hardness [$HV_{0.05}$] up to**	3.7
Coating material	Hyperlox	**Coating Thickness in µm**	$3^{\pm1}$
Colour	Black Anthracite		

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Coating composition	AlTiN	

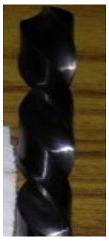

Fig. 3.2(a)

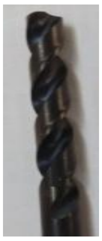

Fig. 3.2 (b)

Fig. 3.2. (a)Carbide and (b) Hyperlox coated HSS twist drill

During drilling with the specified tools according to the DOE, the output response Temperature is measured with infrared gun at the tool-work interface and is recorded in Table 3.4.

Table 3.4 Experimental data

S.NO	Input Parameters				Output Responses			S/N Ratios for Temperature		
	Tool	Speed (rpm)	Feed (mm/rev)	Coolant	0.3% CNT Temperature (^{0}C)	0.6% CNT Temperature (^{0}C)	0.9% CNT Temperature (^{0}C)	0.3% CNT	0.6% CNT	0.9% CNT
1	Carbide	500	0.2	Dry	36.8	31.4	37	-31.32	-29.94	-31.36
2	Carbide	500	0.3	Veg oil	36.3	31.9	31	-31.20	-30.08	-29.83
3	Carbide	500	0.36	Soluble oil	32.3	39.7	32.4	-30.18	-31.98	-30.21
4	Carbide	560	0.2	Dry	35.5	32.3	36.9	-31.00	-30.18	-31.34
5	Carbide	560	0.3	Veg oil	33.9	31.5	30.9	-30.60	-29.97	-29.80
6	Carbide	560	0.36	Soluble oil	30.6	32	38.5	-29.71	-30.10	-31.71
7	Carbide	630	0.2	Veg oil	33.9	32.2	33.3	-30.60	-30.16	-30.45
8	Carbide	630	0.3	Soluble oil	33.9	32.9	37.7	-30.60	-30.34	-31.53
9	Carbide	630	0.36	Dry	33.6	34.5	38.6	-30.53	-30.76	-31.73
10	Hyperlox	500	0.2	Soluble oil	31.7	32.9	31.9	-30.02	-30.34	-30.08
11	Hyperlox	500	0.3	Dry	32.8	34.3	34.2	-30.32	-30.71	-30.68
12	Hyperlox	500	0.36	Veg oil	30.7	31.7	32.2	-29.74	-30.02	-30.16
13	Hyperlox	560	0.2	Veg oil	32	32.4	34.7	-30.10	-30.21	-30.81
14	Hyperlox	560	0.3	Soluble oil	31.9	34.4	33.7	-30.08	-30.73	-30.55
15	Hyperlox	560	0.36	Dry	41.2	32.2	32.7	-32.30	-30.16	-30.29
16	Hyperlox	630	0.2	Soluble oil	34.8	37.7	41.2	-30.83	-31.53	-32.30
17	Hyperlox	630	0.3	Dry	32.8	34	31.9	-30.32	-30.63	-30.08
18	Hyperlox	630	0.36	Veg oil	30.9	30.3	33.2	-29.80	-29.63	-30.42

IV. RESULTS AND DISCUSSIONS

A. ANOVA Analysis

The output parameters were analyzed in view of minimization of cutting temperature through Analysis of Variance (ANOVA). The results of ANOVA are shown in Table 4.1, 4.2 and 4.3

Table 4.1 ANOVA results for Al6061/ 0.3%CNT

Source	DOF	SS	Adj MS	F	P	% Contribution
Tool	1	3.556	3.556	0.45	0.517	3.03%
Speed	2	2.654	1.327	0.17	0.847	2.26%
Feed	2	2.448	1.224	0.16	0.858	2.08%
Coolant	2	29.861	14.931	1.9	0.201	25.45%
Error	10	78.786	7.879			
Total	17	117.304				

Table 4.2 ANOVA results for Al6061/ 0.6%CNT

Source	DF	SS	Adj MS	F	P	% Contribution
Tool	1	0.125	0.125	0.02	0.881	0.13%
Speed	2	5.374	2.687	0.51	0.618	5.90%
Feed	2	0.234	0.117	0.02	0.978	0.25%
Coolant	2	32.148	16.074	3.03	0.094	35.33%
Error	10	53.121	5.312			
Total	17	91.003				

Table 4.3 ANOVA results for Al6061/ 0.9%CNT

Source	DF	SS	Adj MS	F	P	% contribution
Tool	1	6.242	6.242	0.94	0.356	4.01
Speed	2	24.654	12.327	1.85	0.207	15.85
Feed	2	20.298	10.149	1.52	0.265	13.05
Coolant	2	37.601	18.801	2.82	0.107	24.18
Error	10	66.669	6.667			
Total	17	155.46				

Taguchi Analysis was performed to verify the ANOVA results and to identify the major influencing parameters, its results and relevant graphs are shown below.

B. Taguchi Analysis

S/N ratio is one of the critical parameter which decides the optimum response , therefore the S/N ratios were calculated for every run considering the criteria smaller is the better.

$$S/N = -10\log\frac{1}{n}\left(\sum_{i=1}^{n} y_i^2\right) \text{ ------- } (1)$$

where, n is the number of repetitions of the experiment and y_i is the average measured value of experimental data

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'i'. The obtained results Temperature versus Type of tool, Speed, Feed and Coolant for different reinforcements are shown in Table 4.4, 4.5 and 4.6.

Table 4.4. Results of Taguchi Analysis for Al6061/ 0.3%CNT

Level	Tool	Spindle Speed	Feed	Coolant
1	-30.64	-30.46	-30.65	-30.96
2	-30.39	-30.63	-30.52	-30.34
3	-	-30.45	-30.38	-30.24
Delta	0.25	0.19	0.27	0.73
Rank	3	4	2	1

Table 4.5. Results of Taguchi Analysis for Al6061/ 0.6%CNT

Level	Tool	Spindle Speed	Feed	Coolant
1	-30.39	-30.51	-30.39	-30.4
2	-30.44	-30.23	-30.41	-30.01
3	-	-30.51	-30.44	-30.84
Delta	0.05	0.28	0.05	0.83
Rank	3	2	4	1

Table 4.6. Results of Taguchi Analysis for Al6061/ 0.9%CNT

Level	Tool	Spindle Speed	Feed	Coolant
1	-30.88	-30.39	-31.06	-30.91
2	-30.6	-30.75	-30.41	-30.24
3	-	-31.08	-30.75	-31.06
Delta	0.29	0.7	0.65	0.82
Rank	4	2	3	1

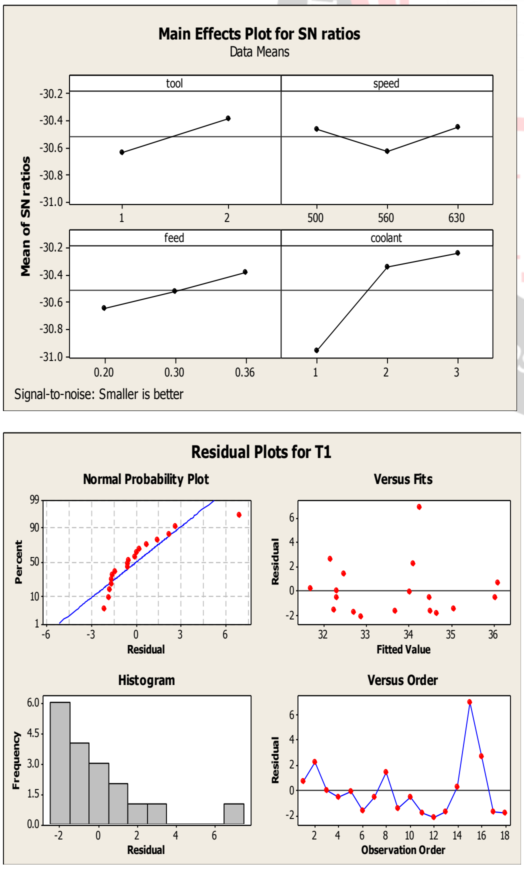

Fig.4.1Effects of process parameters on Temperature and Normal probability plots – Al6061/ 0.3% CNT

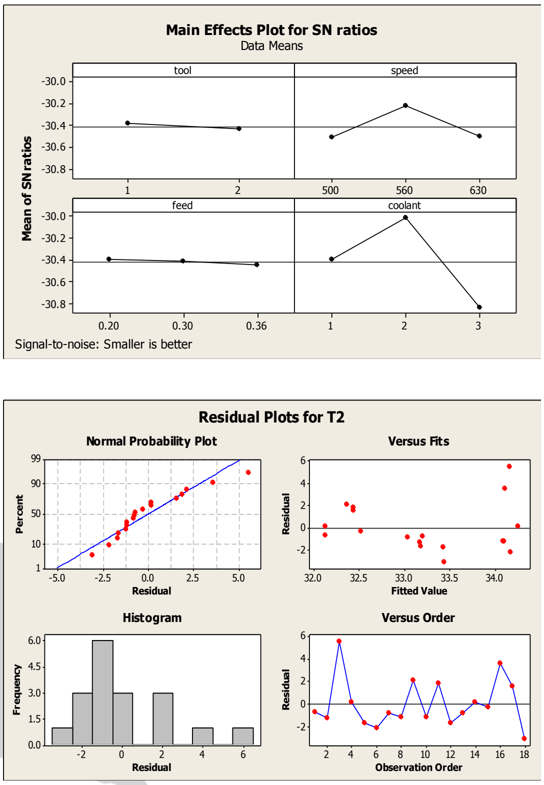

Fig.4.2Effects of process parameters on Temperature and Normal probability plots – Al6061/ 0.6% CNT

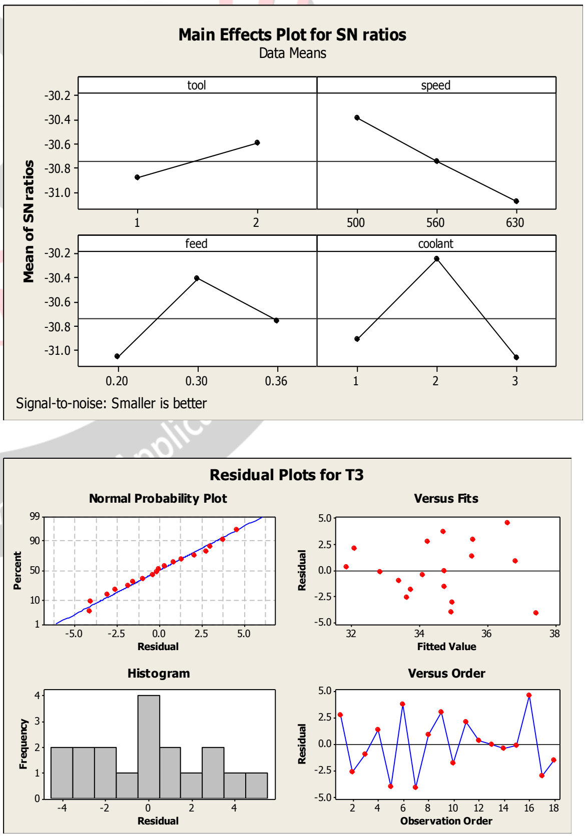

Fig.4.3 Effects of process parameters on Temperature and Normal probability plots – Al6061/0.9% CNT

Estimation equations for cutting temperature (T) were established for linear regression models and are given from Equations (2-4). The term 'R^2' is known as coefficient of determination of the equations obtained

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from the linear regression model for Temperature (T), these were calculated for all the three reinforcement percentages of CNT added to Al6061. The adj (R^2) for 0.3%, 0.6%, 0.9% CNT values are 93.29%, 94.17%, and 95.71% respectively. R^2 is the statistical measure of how well the regression line approximates the real data points and generally its value should be between 0.8 and 1 [7]. Fig. 3.1, 3.2 and 3.3 represents normal probability plots of the residuals and this reveals that almost all the residuals follow a straight line pattern which confirms that the regression model obtained from the response cutting temperature (T) for drilling of fabricated AMMNCs matches very well with the experimental data (R^2 > 0.8). Thus, the linear regression model can be applied for all the reinforcements for estimation of Temperature. Present work could be useful for various industrial applications, for the selection of process parameters in the drilling of AMMNCs and it would be helpful for manufacturing engineers in prediction the of machining output responses.

The regression equations for

$T_{0.3\%CNT}$ = 40.2 - 0.89 tool - 0.0012 spindle speed - 5.58 feed - 1.46 coolant -----------(2)

$T_{0.6\%CNT}$ = 30.7 + 0.17 tool + 0.0001 spindle speed + 1.42 feed + 0.908 coolant -----------(3)

$T_{0.9\%CNT}$ = 26.0 - 1.18 tool + 0.0220 spindle speed - 9.6 feed + 0.342 coolant -----------(4)

From the Taguchi analyses, the following combinations are obtained and the experiments were conducted for these combinations for confirmation and results are shown in Table 4.7.

Table 4.7 Confirmation test Results

S.No	Combination	Temperature (^{0}C)
1	A1B2C1D1	32.3
2	A2B3C3D3	30
3	A1B3C1D3	31

V. CONCLUSIONS

In this paper drilling experiments were conducted on the fabricated AMMNCs successfully and the following conclusions are drawn from the results.

i. As per Scanning Electron Microscope (SEM) results revels the reinforcement is uniform distribution of reinforcement particles in Al6061 alloy providing good strength and mechanical properties.

ii. From ANOVA, the most influencing parameter among all the input parameters is coolant utilization for all the considered percentages of CNT. The next influencing parameter is tool type i.e., Hyperlox coated tool in case of 0.3% CNT and speed for the remaining percentage of CNT (0.6 % and 0.9%).

iii. The optimum parameter combinations obtained for 0.3%CNT, 0.6%CNT & 0.9%CNT were A1B2C1D1, A2B3C3D3 & A1B3C1D3 respectively. Among these combinations, the better combination for obtaining the minimum temperature is A2B3C3D3 i.e., 30^{0}c.

iv. The normal distribution plot of the residuals shows a linear trend for the response of cutting temperature (T), that indicates the drilling of fabricated AMMNCs matches very well with the experimental data (R^2 > 0.8).

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