OPTIMIZATION OF PROCESS PARAMETERS IN DRILLING OF AMMC USING SINE COSINE ALGORITHM

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Abstract: *Composite materials are important engineering materials due to their outstanding mechanical properties. Aluminium materials are widely used to take advantage of their low density, corrosion resistance and combination of strength and formability, especially in the automobile and aerospace industries for light weight applications. In the present work Al 6101 is reinforced with B_4C (8% wt) the AMMC have been prepared by using stir casting process. In this work we are studying how the helix angle of drill bit will Influence on the output responses of Drilling. Optimum levels of process parameters are identified by sine cosine algorithm (SCA).*

Index Terms: *AMMC, Drilling, Sine Cosine Algorithm.*

1. INTRODUCTION

A composite material is a heterogeneous solid consists of two or more different materials that are mechanically or metallurgical bonded together. Composite materials are difficult to machined and cost effective. To provide cost effective manufacturing and especially machining operations, there is a continuous need to reduce tooling costs. The most well-known methods used to reduce tooling costs are various applications of more resistant tool materials and tool geometry, heat treatments, cutting fluids, speed and feed rates and the development of the coated cutting tool. Drilling is a type of machining process where a multi-point cutting tool utilized to drill a hole in the workpiece. Twist drills are unique amongst all metal cutting tools, both in their geometry and their method of operation. The drill point geometry, drill and workpiece materials, drilling parameters like feed rate and spindle speed directly affects drill performance.

2. LITERATURE REVIEW

Zaima Shigeo et al. [1] investigated the Influence of helix angle of twist drill in drilling of wrought aluminium, in which the helix angle was varied within the range of l7°-45°. From the Experimental results the minimum time in drilling appeared in the range of 30-40° of the helix angle, in particular, at low cutting speed. M Balaji et al. [2] studied the effect of cutting parameters, namely cutting speed, feed rate and helix angle on the tool life. The drilling experiments were performed on AISI 304 steel with carbide drill bits. From the experimental results Optimum levels of cutting parameters for surface roughness are obtained at 25 degrees of helix angle, 12mm/min of feed rate and 800rpm spindle speed. K Narasimha et al. [3] investigated the torque thrust coupling effect in twist drills and the influence of helix angle on torsional and the cross coupling stiffness. From the Experimental results the stronger the torque-thrust interaction, the larger will be the increase in torsional stiffness due to thrust. Yingying wei et al. [4] investigated the effect of drilling parameters and tool geometry in drilling carbon fiber–reinforced plastic/titanium alloy stacks and how helix angle influence the cutting temperature and torque. From the experimental results thrust force and torque was affected by drilling parameters, especially the feed rate. Drilling forces increased with the elevation of feed rate, but had uncertain interactive relationships with cutting speed. Jolene S. Vas et al. [5] investigated the effect of drilling parameters (feed rate and spindle speed) on the twist drill bit temperature in the drilling of austenitic stainless steel material with and without the use of coolant. The experiments were conducted by using High Speed Steel (HSS) drills having 82°, 100° and 118° drill point angle. From the Experimental results temperature in drilling increases with increases in both cutting speed and feed rate. Gopal Krishna U B et al. [6] investigated to enhance the mechanical properties like tensile strength and hardness of AMMCs (Al 6061, B_4C). By stir Casting Technique, aluminium Metal Matrix was reinforced with 105 µm size boron carbide particulates of 6, 8, 10, 12 weight % respectively. From the experimental results the tensile strength of AMCCs was found to be maximum (176.37 MPa) for the wt % of 8. Seyedali Mirjalili [7] investigated the Sine Cosine Algorithm (SCA) algorithm obtains a smooth shape for the airfoil with a very low drag, which demonstrates that this algorithm can be highly effective in solving real problems with constrained and unknown search spaces.Yashavanth Kumar T et al. [8] studied the mechanical and tribological properties of Al-B_4C composite fabricated by powder metallurgy and stir casting techniques. From the experimental results, incorporation of B_4C particles in aluminium matrix improves Hardness, compressive strength and wear resistance. Nayan G Kaneriya and Gaurav Kumar Sharma [9] investigated the cutting temperature at drill tool-chip interface affects drill hole quality, lowers tool life, reduces hole finishing and blunt edges of drill tool this leads to decrease the productivity. The main objective is to reduce temperature in drill tool while dry drilling of AISI 304 austenitic stainless steel by optimizing drilling parameters and selecting suitable drill tool material. From the experimental results the feed rate has a greater influence on a twist drill bit temperature in dry drilling of AISI 304 austenitic stainless steel material. Topcua et al. [10] investigated on the mechanical properties of AMMCs of 5, 10, 15 and 20 % wt B_4C powder reinforcement. Increasing weight percent of B_4C and sintering temperature increased the hardness of the composite. B. Shivapragash et al. [11] investigated the Optimum cutting parameters (Speed, feed and depth of cut) in drilling to maximize the metal removal rate and minimize the surface roughness.

It is concluded from the literature survey that few studies have been carried out in the investigation of Helix angle of the drill bit in drilling performance.

3. MATERIALS AND TOOLS

Drilling experiments were performed on AMMC which has an Al 6101 as base material and B_4C as reinforcement in this project work. Al 6101 has a major composition of Magnesium, Iron and Silicon.

Table 3.1: The Chemical Composition of Al 6101

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	B	Zn
Weight %	97.6	0.03	0.1	0.5	0.35-0.8	0.03 Max	0.3-0.7	0.06	0.1

High Speed Steel (HSS) Drill bits of Diameter 9 mm with different Helix Angle (HA) is used in this work. High Helix Angle (>30°) drills used for high feed rate, low cutting speed, on soft non ferrous metals like Brass, Aluminium, Magnesium, Zinc and Plastics. Standard drills (=30°) have optimal chip ejection and strength of drill cross section and most widely used. Low Helix Angle (<30°) drills used with high spindle speeds on hard to drill materials because it has high cross section strength.

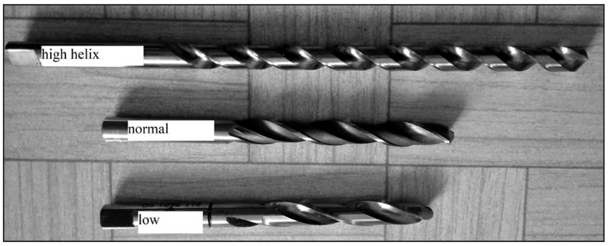


Fig 3.1 Types of Drill Bits Used

4. EXPERIMENTAL WORK

AMMC is prepared with Al 6101 as a base material and B_4C (8 % wt) as a reinforcement by stir casting technique. Properties like tensile strength, yield strength, Impact strength and Hardness of AMMC are tested. The drilling experiments are conducted on AMMC using Universal drilling machine with three different helix angle drill bits and Soluble oil (1:10) as a lubricant. In this work 27 experiments are conducted with different combinations of speed, feed and helix angle. Output responses such as power, torque and tool work interface temperature are measured by using Watt meter, Drill tool dynamometer and pyrometer respectively. After Drilling, Surface roughness and diameter of drilled hole measured by using talysurf and digital Vernier Caliper respectively. Actual diameter of hole is used for metal removal rate calculations.

4.1 Testing Mechanical Properties of AMMC

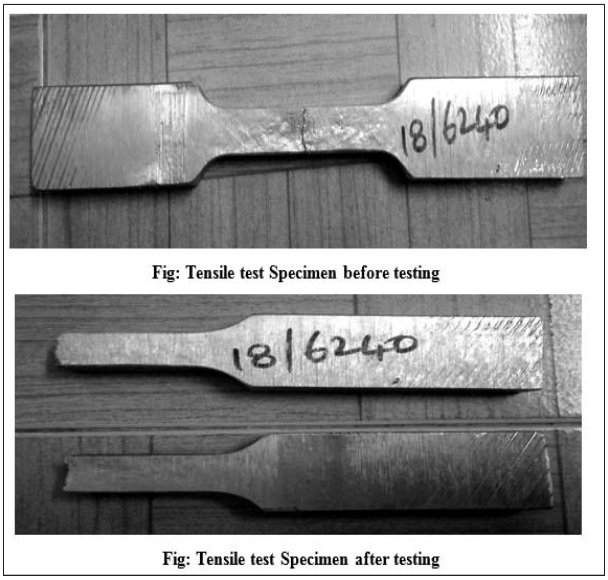


Fig 4.1 (a) Tensile Test Specimen Before Testing
(b) Tensile Test Specimen After Testing

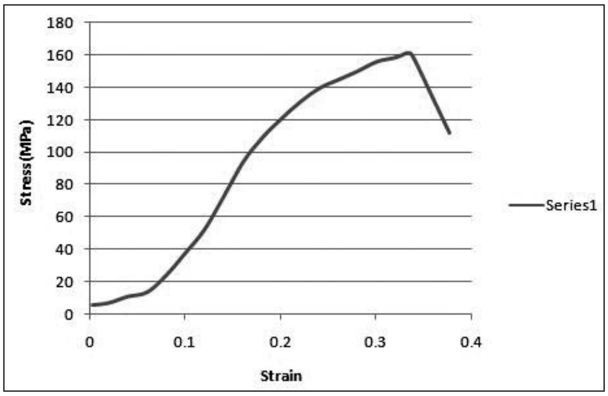


Fig 4.2 Stress vs Strain Graph

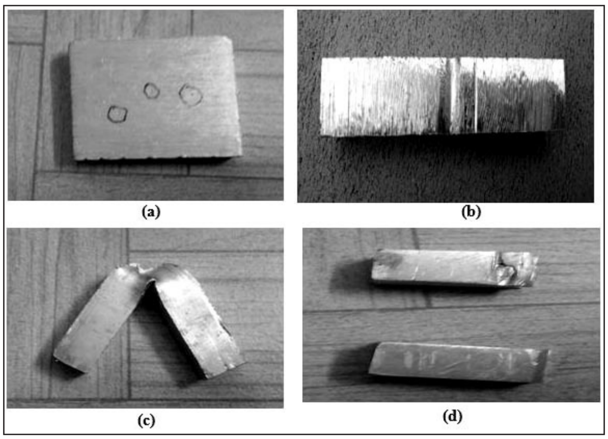


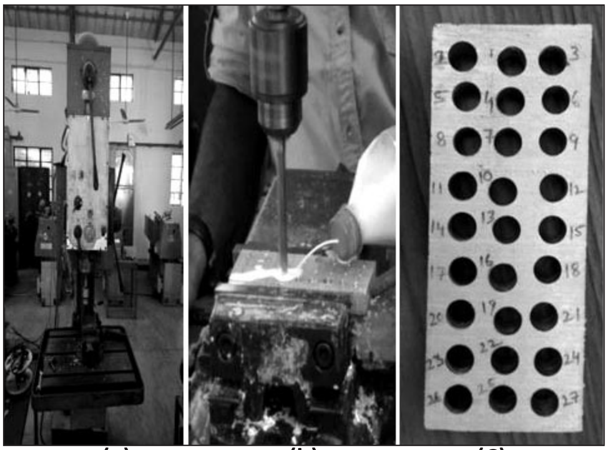
Fig 4.3 (a) Hardness test Specimen
(b) Impact test Specimen
(c) Al 6101 Specimen after Impact test
(d) AMMC Specimen after Impact test

This AMMC is tested for Mechanical Properties like Tensile strength, Hardness and Impact strength.

4.2 Design of Experiments

Table 4.1: Process Parameters and Their Levels

Process Parameter	Level 1	Level 2	Level 3
Helix Angle (deg)	20	30	40
Speed (rpm)	450	500	560
Feed (mm/rev)	0.15	0.2	0.3



(a) (b) (C)

Fig 4.4 (a) Universal Drilling Machine
(b) Drilling on Specimen (c) Specimen after Drilling

4.3 Output Responses

Output responses such as Power, Torque, Temperature, Surface Roughness and Diameter of hole are measured by the following measuring instruments.

Fig 4.5 Drill Tool Dynamo Meter

Fig 4.6 Watt Meter

Fig 4.7 Pyrometer

Surface roughness is one of the most important responses in the Drilling Machining process. SR is usually expressed in µm. Surface Roughness affect several functional attributes of parts, such as friction, wear and tear, light reflection, heat transmission, ability of distributing and holding a lubricant, coating etc.

Fig 4.8 Talysurf

Diameter of Hole is an important output parameter in Drilling operation. To produce a nearly accurate hole in manufacturing industries is a very important aspect. The digital Vernier Caliper is used to measure the diameter of drilled holes.

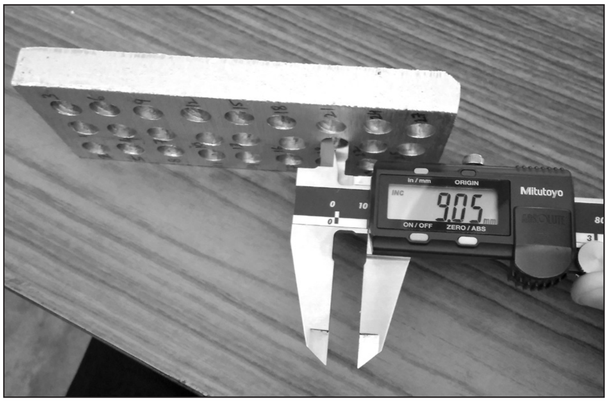


Fig 4.9 Digital Vernier Caliper

Metal Removal Rate is calculated by using following formula

$$\text{MRR} = \frac{\pi}{4} \times D^2 \times S \times f$$

Where

MRR = Metal Removal rate (mm^3/min)

S = Speed (rpm)

f = feed (mm/rev)

D = Diameter of hole (mm)

(Refer Table. 4.2 Output Response Value)

5. SINE COSINE ALGORITHM (SCA)

SCA is a population based optimization technique, found the optimization process with a set of random solution. These random solutions are repeatedly calculated over the course of iterations by an objective function. The probability of finding global optima is increased, with the sufficient number of random solutions.

The position updating equations in this Algorithm are:

$$X_i^{t+1} = X_i^t + r_1 \times \sin(r_2) \times \left| r_3 p_i^t - X_i^t \right| \quad \dots 5.1$$

$$X_i^{t+1} = X_i^t + r_1 \times \cos(r_2) \times \left| r_3 p_i^t - X_i^t \right| \quad \dots 5.2$$

Where X_i^t is the position of current solution in i-th dimension at t-th iteration, $r_1/r_2/r_3$ are the random numbers, Pi is the position of the destination point in the i-th dimension.

Table 4.2: Output Response Values

Ex. No.	Helix angle (deg)	Speed (rpm)	Feed (mm/rev)	Power (Watts)	Temperature (°C)	Surface Roughness (µm)	Torque (N-m)	MRR (mm^3/min)
1	20	450	0.15	900	29.5	0.426	1.961	4393.0
2	30	450	0.15	1050	29.3	0.567	1.863	4541.9
3	40	450	0.15	800	28.3	0.263	1.765	4419.1
4	20	450	0.20	900	29.4	0.540	2.942	5874.1
5	30	450	0.20	1000	29.0	0.660	1.961	5883.1
6	40	450	0.20	850	28.7	0.390	1.863	5861.2
7	20	450	0.30	950	29.2	0.806	3.923	8714.8
8	30	450	0.30	1000	29.6	0.953	2.942	8747.5
9	40	450	0.30	850	28.9	0.463	1.961	8714.8
10	20	500	0.15	1050	29.0	0.416	1.961	4910.1
11	30	500	0.15	1000	29.2	0.480	1.863	5054.2
12	40	500	0.15	900	28.7	0.203	1.765	4910.1
13	20	500	0.20	1100	29.3	0.426	2.942	6489.9
14	30	500	0.20	1050	29.3	0.643	1.961	6651.9
15	40	500	0.20	1000	28.9	0.273	1.863	6432.6
16	20	500	0.30	1050	30.0	0.656	2.942	9854.7
17	30	500	0.30	1000	29.7	0.853	2.452	9934.6
18	40	500	0.30	950	28.8	0.326	1.961	9648.9
19	20	560	0.15	1050	30.2	0.380	1.961	5466.9
20	30	560	0.15	1100	29.6	0.470	1.863	5660.7
21	40	560	0.15	1050	29.0	0.193	1.765	5463.3
22	20	560	0.20	1050	31.7	0.430	2.942	7225.2
23	30	560	0.20	1100	29.7	0.510	1.961	7252.4
24	40	560	0.20	1050	29.8	0.256	1.863	7204.5
25	20	560	0.30	1100	33.9	0.530	3.923	10916.9
26	30	560	0.30	1150	31.9	0.560	2.942	11022.8
27	40	560	0.30	1100	29.8	0.256	2.452	10749.5

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times \sin(r_2) \times |r_3 p_i^t - X_i^t|, & r_4 < 0.5 \\ X_i^t + r_1 \times \cos(r_2) \times |r_3 p_i^t - X_i^t|, & r_4 \geq 0.5 \end{cases} \quad \text{... 5.3}$$

Where r_4 is a random number in [0, 1]

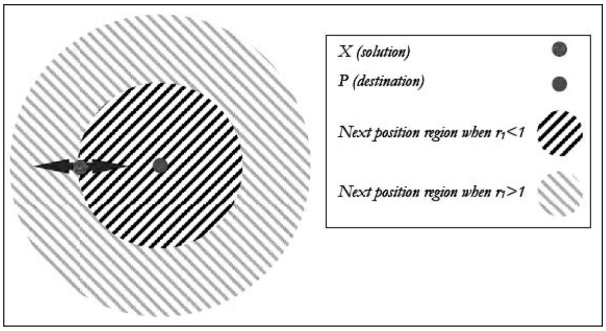


Fig 5.1 Effects of Sine and Cosine in Equations 1 and 2 on the Next Position

In the above equations, there are four main parameters r_1, r_2, r_3 and r_4. The parameters r_1 states that the next position region between solution and destination or outside it. Parameter r_2 tells how far the movement should be towards or outwards the destination. The parameter r_3 brings the random weight for destination in order to stochastically force ($r_3 > 1$) or deemphasize ($r_3 < 1$) the effect of destination in defining the distance. And parameter r_4 equally switches between sine and cosine component in eqn. (5.3) Fig. 5.1 shows that in the search space how the proposed equations define space between the two solutions. The cyclic pattern of sine and cosine function describes the position of solution around another solution. Also, this can give guarantee exploitation of the space between two solutions. We can explore the search space by changing the range of sine and cosine function.

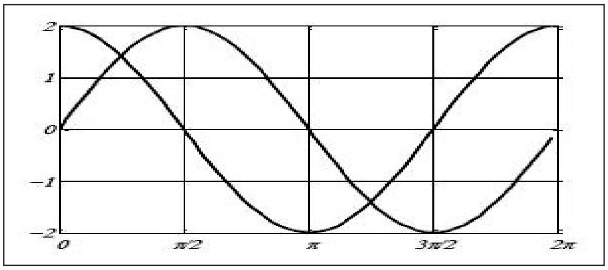


Fig 5.2 Sine and Cosine with Range of [-2,2]

The Sine Cosine function [-2,2] operation is illustrated by the conceptual model as shown in the fig. 3. By changing the ranges of Sine Cosine function we can find the promising region in the search space. Also, it ensures the exploration and exploitation of search space. To make a balance between exploration and exploitation, the range of sine and cosine in eqn. (5.1) to (5.3) is changed adaptively using the below equation:

$$r_1 = a - t\frac{a}{T}$$

Where t is current iteration, T is the maximum number of iterations and a is constant. SCA explores the search space when ranges of sine and cosine function are in [-2,-1] and (1,2] and exploits the search space when ranges are in [-1,1]. Sine cosine with the range [-2,2] allowing a solution to go around (inside the space between them) or beyond (outside the space between them) the destination shown in the below figure.

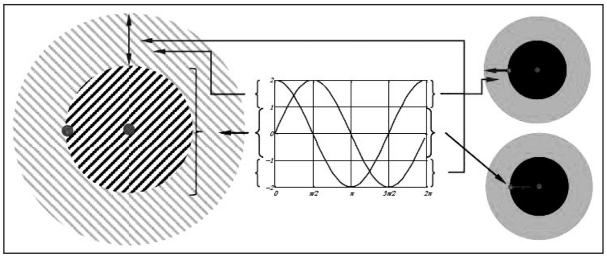


Fig 5.3 Sine Cosine with the Range [-2,2] Allowing a Solution to go Around or Beyond the Destination

General steps of the SCA Algorithm:

Initialize a set of search agents (solutions) (X)

Do

Evaluate each of the search agents by the objective function

Update the best solution obtained so far (P=X*)

Update r_1, r_2, r_3, and r_4

Update the position of search agents using Eq. (5.3)

While (t < maximum number of iterations)

Return the best solution obtained so far as the global optimum.

5.1 Regression Analysis

In statistical modeling, regression analysis is a set of statistical processes for estimating the relationships among variables. In Regression Analysis the equations for output Responses are developed. These Regression equations are used in the optimization technique (Table 5.1).

6. RESULTS

The Mechanical Properties of AMMC after testing are shown in the Table 6.1.

Table 5.1: Regression Equations

Regression equations
Power = 337 - 3.33 **HA** + 1.456 **Speed** +167 **Feed**
Temperature = 22.96 - 0.0628 **HA**+ 0.01416 **Speed** + 6.67 **Feed**
Surface roughness = 1.241 - 0.01104 **HA** - 0.001491 **Speed** +1.475 **Feed**
Torque = 2.009 - 0.04577 **HA** + 0.00060 **Speed** + 6.37 **Feed**
MRR = - 6818 - 2.45 **HA** + 13.924 **Speed** + 32281 **Feed**

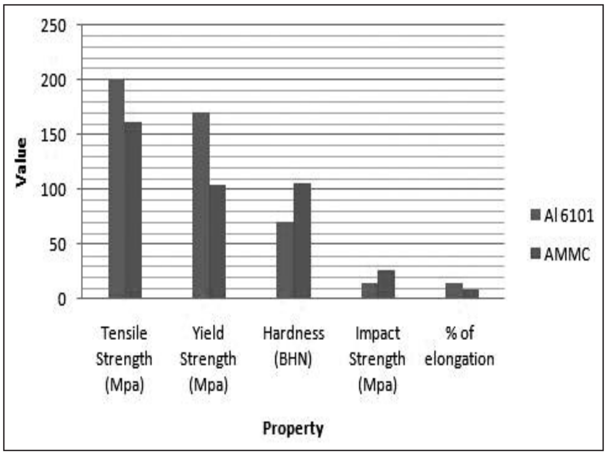


Fig 6.1 Property Variations in Al6101 and AMMC

Table 6.1: Properties of Al 6101 and AMMC

S. No	**Property**	**Al 6101**	**Al 6101 + Wt 8 % B_4C**	**% of change**
1	Tensile strength (MPa)	200	162	19
2	Yield strength (MPa)	170	105	38.24
3	Hardness (BHN)	71	105.882	49.13
4	Impact strength (MPa)	14.4	26.18	81.8
5	% of elongation (e)	15	9	40

Table 6.3 Confirmation Test Results

Output Response	**Input parameters (HA, Speed, Feed)**	**Optimized value**	**Conformation test value**	**% deviation**
Power (watts)	40, 450, 0.15	884.05	850	4
Torque (N-m)	40, 450, 0.15	1.4037	1.52	7.65
MRR (mm^3/min)	20, 560, 0.3	10614.74	10916.92	2.77
Surface roughness (µm)	40, 560, 0.15	0.18569	0.19	2.27
Temperature (^oC)	40, 450, 0.15	27.8205	28.2	1.35

Table 6.2 SCA Optimized Values

Output Response	**Input parameters (HA, Speed, Feed)**	**Optimized value**
Power (watts)	40, 450, 0.15	884.05
Torque (N-m)	40, 450, 0.15	1.4037
MRR (mm^3/min)	20, 560, 0.3	10614.74
Surface roughness (µm)	40, 560, 0.15	0.18569
Temperature (^oC)	40, 450, 0.15	27.8205

Optimized Process parameters and Output responses in Drilling by Sine Cosine Algorithm (SCA) are shown in the Table 6.2.

Confirmation Test Results of Drilling of AMMC is shown in the table 6.3.

The Sine Cosine Algorithm is used for optimization of process parameters shows minimum deviation 1.35 % in Temperature and maximum deviation 7.65 % in Torque with the Experimental conformation test values.

7. CONCLUSIONS

The following Conclusions are drawn from the above Experimental work.

1. In the present paper, parameters of Drilling have been optimized for obtaining higher MRR and lower Torque, Power, tool work interface Temperature and Surface Roughness values.
2. Addition of boron carbide reinforcement to AA 6101 it increases the hardness and Impact strength of AMMC.
3. With the Increase of Helix Angle Surface finish is improved.
4. With the Increasing of Helix Angle Power, Torque and tool work interface temperature are decreased.
5. The Sine Cosine Algorithm used for optimization of process parameters produced good prediction. The maximum deviation produced was 7.84 % with the Experimental conformation test value, which is satisfactory.

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