Optimization of Surface Roughness in Drilling of GFRP Composite Using Harmony Search Algorithm

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***Abstract*—Now-a-days the application of Glass Fiber reinforced polymer (GFRP) composite materials has increased a lot in the field of engineering. Afterward, the need for better surface finish of GFRP composite materials machining has increased greatly. In this paper a hybrid model of Harmony Search (HS) with Response Surface Methodology (RSM), has been developed for optimizing the surface roughness of three different GFRP composite materials during drilling operation. The machining parameters viz., cutting speed, feed rate, cutting tool point angle and lip clearance angle were optimized with the consideration surface roughness using HS algorithm. In addition, the optimized results using HS algorithm is compared with desirably analysis. Finally, the effect of different machining parameters on surface roughness are also studied.**

***Index Terms*—Glass Fiber Reinforced Polymer (GFRP), Harmony Search (HS), Response Surface Methodology (RSM), surface roughness, optimization**

I. Introduction

Drilling is one of the major complicated machining processes and is a frequently used process of machining in the latest developed industrial applications. This drilling process further becomes more complicated, when the work piece is a composite material. Surface quality of composite machined parts is often one of the most specified customer requirements and essential exploitation request where major significant indicator of surface quality is surface roughness. Numerous studies have been under taken on the details of drilling processes of various composite materials.

The Drilling of composites is different from the approach that adopted for conventional materials. Most of the researcher [1]-[3] found that the quality of machined surface of Fiber Reinforced Polymer (FRP) material by using conventional drilling machine tool is greatly depend upon the cutting parameters, tool geometry, tool material, work piece material, machining process, etc. An inappropriate selection of these parameters can lead to undesirable material deprivation, such as fiber pullout, matrix cratering, thermal damage and widespread delamination. Murthy *et al*. [4] optimized process parameters namely, cutting speed, feed, point angle and chisel edge width in drilling of Glass Fiber Reinforced Polymer (GFRP) composites. The experiments were carried out as per the Taguchi experimental design and an L9 orthogonal array was used to study the influence of various combinations of process parameters on hole quality. The results showed that the feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width and point angle; cutting speed is the most significant factor affecting the torque, speed and the circularity of the hole followed by feed, chisel edge width and point angle. The phenomenon of delamination during drilling was identified and analyzed by Hocheng and Tsao [5]. They developed a mathematical model to predict the critical thrust force using various drill bits. Khashaba *et al*. [6] studied the effect of machining parameters in the drilling of GFR/epoxy composites and they developed a model to predict the critical thrust force during drilling. Mohan *et al*. [7] outlined the Taguchi optimization methodology, which is applied to optimize cutting parameters in drilling of Glass Fiber Reinforced Composite (GFRC) material. Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. This study of response table indicates that the specimen thickness, and drill size are the significant parameters of torque. From the interaction among process parameters, thickness and drill size together is more dominant factor than any other combination for the torque characteristic. Kilickap [8] investigated the influence of the cutting parameters, such as cutting speed and feed rate, and point angle on delamination produced when drilling a GFRP composite. The damage generated associated with drilling GFRP composites were observed, both at the entrance and at the exit during the drilling. Finally, concluded that feed rate and cutting speed are the most influential factor on the delamination, respectively. Recently, Geem et al. [9] developed a New Harmony search (HS) meta-heuristic algorithm that was conceptualized using the musical process of searching for a perfect state of harmony. Compared to mathematical optimization algorithms, the HS algorithm imposes fewer mathematical requirements and does not require initial values for the decision variables. It can be concluded from the above study that most of the researcher worked on cutting speed, feed, depth of cut and point angle. However, the effect of lip

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cleanness angle of cutting tool on composite material has not been studied set. Moreover, major researcher used Taguchi based algorithm. For this reason, a hybrid Harmony search (HS) optimized algorithm is introduced in this study.

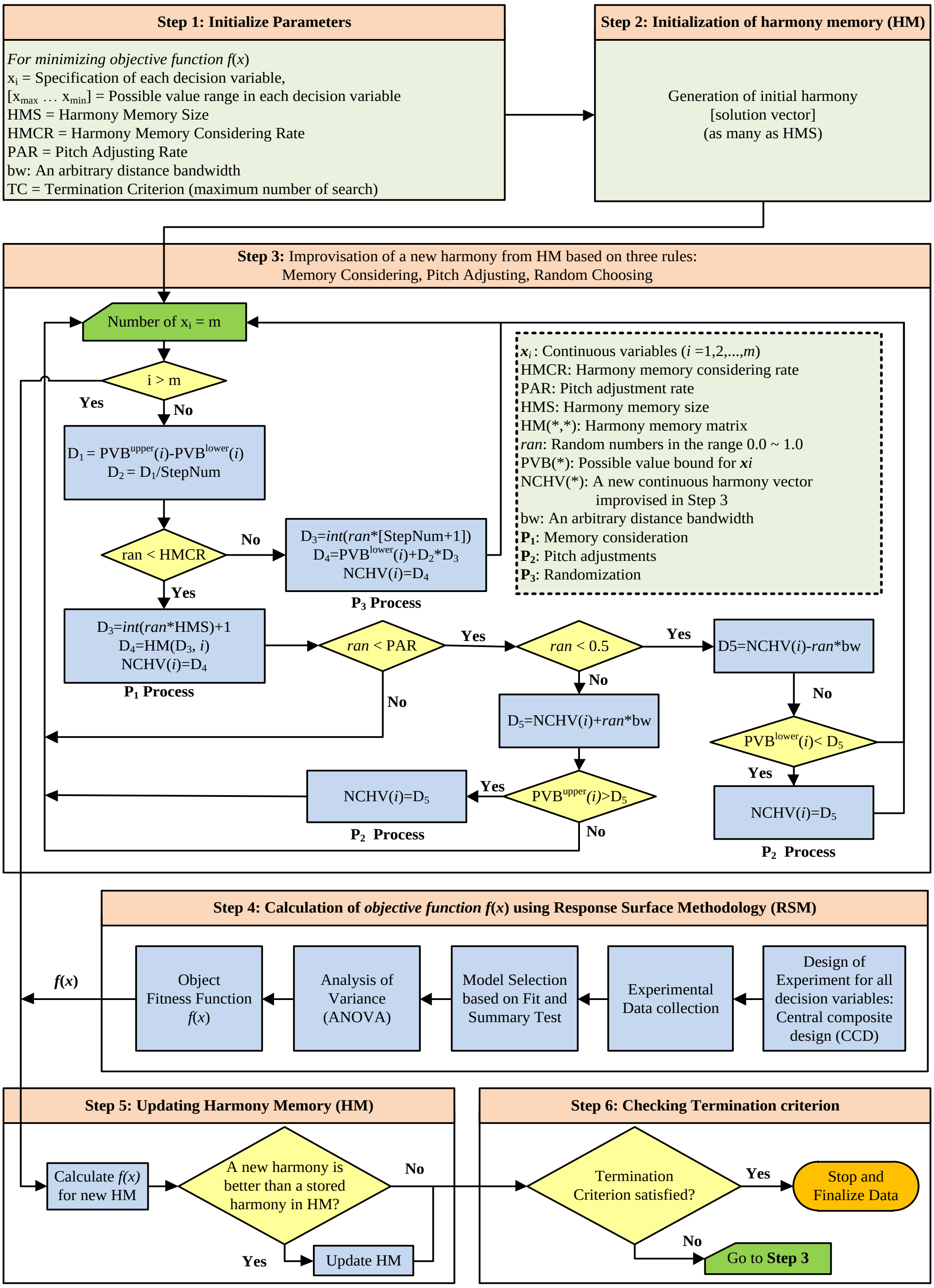

Figure 1. Flow chart of Hybrid HS algorithm with RSM

In the current work, a hybrid algorithm of Harmony Search algorithm [9] and Central Composite Design (CCD) for design of experiment is being introduced for optimization of drilling parameters for composite machining. The experimental details of using the HS method to determine and analyze the optimal cutting parameters range using RSM are described next. The machining parameters viz., cutting speed, feed rate, cutting tool point angle and lip clearance angle were used in the study. It has found that by optimizing the parameters smooth surface can be achievable. However, the surface roughness is proportional to the content of glass fiber. Next, the optimization results of HS are compared with desirability analysis and their effects are studied. Finally, the paper concludes with a summary of this study.

II. Harmony Search Algorithm and Methodology

Harmony Search (HS) algorithm is created on natural musical performance processes that arise when a musician searches for a better state of harmony. The engineers pursue for a global solution as determined by an objective function, just as the musicians seek to find musically pleasing harmony as determined by an artistic. HS algorithm includes a number of optimization operators, such as the Harmony Memory (HM), the Harmony Memory Size (HMS, number of solution vectors in harmony memory), the harmony memory considering rate (HMCR), and the Pitch Adjusting Rate (PAR). In the HS algorithm, the Harmony Memory (HM) stores the feasible vectors, which are all in the feasible space. The harmony memory size determines how many vectors it stores. A new vector is generated by selecting the components of different vectors randomly in the harmony memory. And if the New Harmony is better than existing worst harmony in the HM, the New Harmony is included in the HM and the worst harmony is excluded from the HM. This procedure is repeated until fantastic harmony is found. When each decision variable chooses one value in the HS algorithm, it follows any one of three rules: (1) choosing any one value from HS memory (defined as memory considerations), (2) choosing an adjacent value of one value from the HS memory (defined as pitch adjustments), and (3) choosing totally random value from the possible value range (defined as randomization). The three rules in HS algorithm are effectively directed using two parameters, i.e., Harmony Memory Considering Rate (HMCR) and Pitch Adjusting Rate (PAR). In the algorithm for calculating the object function *f(x)* Central Composite Design (CCD) algorithm of Response Surface Methodology (RSM) has been implemented. The steps in the procedure of harmony search are as follows [9], [10]:

Step 1. Initialize the optimization problem and algorithm parameters.

Step 2. Initialize the Harmony Memory (HM).

Step 3. Improvise a new harmony from the HM.

Step 4. Calculation of object function f(x) using Response Surface Methodology (RSM)

Step 5. Update the HM.

Step 6. Repeat Steps 3 and 4 until the termination criterion is satisfied.

For better understanding, the flow diagram of HS algorithm with RSM is shown in Fig. 1.

III. Design of Experiment and Experimental Setup

A. Design of Experiment

Experimental design is widely used for controlling the effects of parameters in many processes. Its usage decreases number of experiments, using time and material resources. In these study, total four parameters are studied, they are cutting speed, feed, cutting tool point angle and lip clearance angle. For all parameters, five levels of data using CCD is used (Table I). Total thirty experiments are conducted, where, 24 of them are non-center points and 6 of them are center points.

TABLE I. Process Parameters with their Values at Different Levels

		Level				
	Parameters (Unit)	**-2**	**-1**	**0**	**+1**	**+2**
A:	Cutting speed, *v* (m/min)	8	12	16	20	24
B:	Feed, *f* (mm/rev)	0.04	0.06	0.08	0.1	0.12
C:	Point angle, θ (^{0})	118	122	126	130	134
D:	Lip clearance angle, ψ (^{0})	8	9	10	11	12

B. Experimental Setup

For the drilling process, Z K 2512-3 CNC drilling machine (Fig. 2) was utilized. Its maximum drilling capacity was 25mm and X, Y and Z axis travel length were 250mm, 180mm and 150mm respectively. The advantage of this machine is that it has a built in computer terminal and software. Thus, the outputs of the model can be programmed using this software and input into the machine. The surface roughness value was measured by Mitutoyo Surftest SJ-210 portable surface roughness tester (Fig. 3). Fig. 4 shows the HSS cutting tool of 12 mm diameter used in the study.

Figure 2. Photograph of the CNC drilling machine

Figure 3. Mitutoyo surface roughness tester

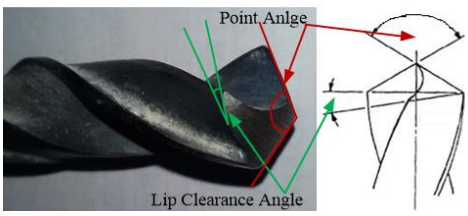

Figure 4. HSS drilling tool used in the study

The composition of different material of three composites are shown in table II. The compositions are mainly resin, glass fiber, methyl ethyl ketone peroxide (MEKP) and colors. The colors (yellow, grey and blue) are added mainly given for easy visual distinction. Fig. 5 shows the three different composites with color variation. The thickness of all plates are 15 mm. All the experiments are repeated five times to get an average roughness. The average roughness values for thirty conditions are given in Table III.

TABLE II. COMPOSITION OF DIFFERENT COMPOSITE MATERIALS

	Yellow Composite	Grey Composite	Blue Composite
Resin (%)	77.14	73.93	66.33
Glass Fiber (%)	19.17	22.57	30.27
MEKP (%)	1.59	1.48	1.33
Color (%)	2.11	2.02	2.07

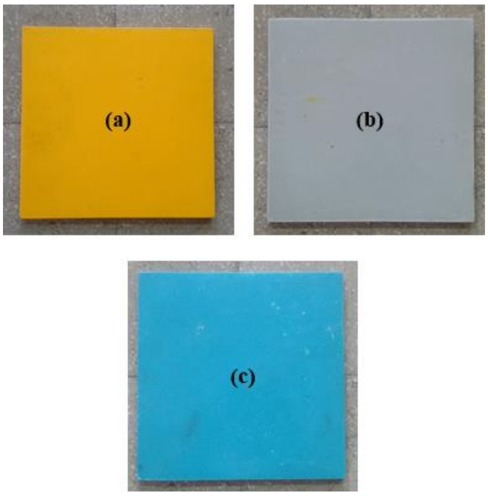

Figure 5. (a) Yellow composite (b) Grey composite (c) Blue composite

TABLE III. SURFACE ROUGHNESS VALUES FOR DIFFERENT EXPERIMENTAL CONDITIONS

	A: Cutting speed v (m/min)	B: Feed f (mm/rev)	C: Point angle θ (^{0})	D: Lip Clear. angle ψ (^{0})	Composite Surface Roughness (µm)		
					Yellow	Grey	Blue
1	12	0.06	122	9	2.568	3.091	3.890
2	20	0.06	122	9	3.455	4.157	5.232
3	12	0.1	122	9	3.280	3.946	4.967
4	20	0.1	122	9	4.080	4.910	6.180
5	12	0.06	130	9	2.621	3.154	3.970
6	20	0.06	130	9	3.359	4.043	5.088
7	12	0.1	130	9	3.658	4.402	5.540
8	20	0.1	130	9	4.615	5.554	6.990
9	12	0.06	122	11	3.607	4.340	5.463
10	20	0.06	122	11	3.915	4.712	5.930
11	12	0.1	122	11	3.678	4.425	5.570
12	20	0.1	122	11	4.277	5.146	6.477
13	12	0.06	130	11	3.777	4.545	5.720
14	20	0.06	130	11	4.133	4.974	6.260
15	12	0.1	130	11	3.647	4.388	5.523
16	20	0.1	130	11	4.619	5.558	6.996
17	8	0.08	126	10	3.063	3.686	4.640
18	24	0.08	126	10	2.707	3.258	4.100
19	16	0.04	126	10	3.235	3.893	4.900
20	16	0.12	126	10	3.499	4.211	5.300
21	16	0.08	118	10	3.259	3.922	4.937
22	16	0.08	134	10	3.876	4.664	5.870
23	16	0.08	126	8	4.370	5.258	6.618
24	16	0.08	126	12	4.232	5.092	6.409
25	16	0.08	126	10	4.386	5.278	6.643
26	16	0.08	126	10	4.386	5.278	6.643
27	16	0.08	126	10	4.386	5.278	6.643
28	16	0.08	126	10	4.386	5.278	6.643
29	16	0.08	126	10	4.386	5.278	6.643
30	16	0.08	126	10	4.386	5.278	6.643

IV. RESULTS AND DISCUSSION

A. Optimization Process

For HS optimization process, first the fitness function for the surface roughness is calculated. To find out the fitness function the natural log transformation is selected and quadratic type equation is used for this case. By using these conditions, the ANOVA for response surface quadratic model shows significant behavior and for lack of fit is shows non-significant behavior. This proves that, the fitness equation is working with in the reasonable range. The quadratic model (Eq. 1, 2 and 3) as suggested for three different composites by the fit and summary tests is shown below:

$$R_{Yellow} = \exp\left(\begin{array}{l} -57.30+0.17A+33.92B+0.83C+0.59D+0.095AB+ \\ 0.00023AC-0.0068AD+0.163BC-2.74BD-0.00087CD \\ -0.0036A^2-163.98B^2-0.0033C^2-0.005D \end{array}\right) \quad (1)$$

$$R_{Grey} = \exp\left(\begin{array}{l} -57.11+0.17A+33.92B+0.83C+0.59D+0.095AB \\ +0.00023AC-0.0068AD+0.163BC-2.74BD \\ -0.00087CD-0.0036A^2-163.98B^2-0.0033C^2-0.005D^2 \end{array}\right) \quad (2)$$

$$R_{Blue} = \exp\left(\begin{array}{l} -48.64+0.24A+31.66B+0.70C+0.43D+0.095AB \\ +0.00023AC-0.0068AD+0.163BC-2.74BD-0.00088CD \\ -0.0061A^2-145.83B^2-0.0028C^2-0.003D^2 \end{array}\right) \quad (3)$$

By using the fitness equation and algorithm of HS which has discussed earlier, the optimization process is conducted the using developed code. In the program code the upper and lower bound of each parameter is given the +2 and -2 level. The optimized results have found by this process is tabled in Table IV. In order to verify the optimized results achieved from HS method, desirability analysis using design expert 7.0 software is used. The optimized result found in desirability analysis is found the same as HS method. Results shows that using this cutting conditions yellow composite show lower roughness than other two because of less content of glass fiber. It show a proportional ratio of the roughness and glass fiber content. Fig. 6 shows the machined holes for the three composites.

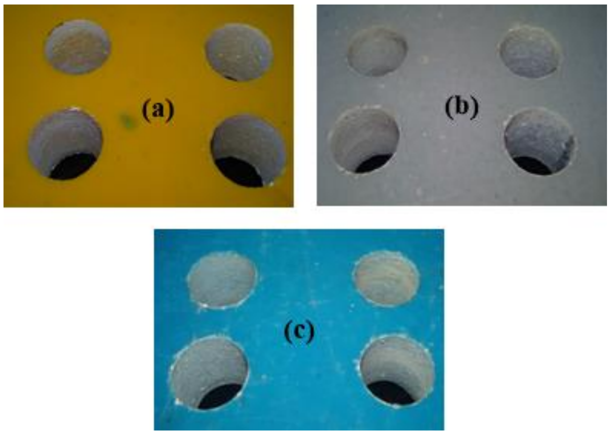

Figure 6. Machined hole on (a) Yellow composite (b) Grey composite (c) Blue composite

TABLE IV. OPTIMIZED PROCESS PARAMETERS AND THEIR CORRESPONDING ROUGHNESS VALUES

Optimized process parameters				Minimum roughness values for composites		
A: Cutting speed v (m/min)	B: Feed f (mm/rev)	C: Point angle θ (^{0})	D: Lip Clearance angle ψ (^{0})	Yellow	Grey	Blue
8	0.04	118	8	1.094	1.316	1.611

B. Effect of Parameters on Surface Roughness

Fig. 7, Fig. 8, Fig. 9 and Fig. 10 show the effects of cutting speed, feed rate, point angle and lip clearance angle on surface roughness. In order to visualize the effect of a particular parameter, the values varies within the design range while other parameters are kept constant in the optimum conditions. In all the conditions it is found that, the yellow compositeent of glass fiber plays a significant role in this phe gives better surface roughness than other two. The cont nomenon. It is clear from all the diagrams that the surface roughness value is proportionally depends on the glass fiber content. With the increase of cutting speed, feed rate and point angle the surface roughness increases. However, the effect is not that significant as compared to lip clearance angle. In case of slight variation of lip clearance angle the surface roughness varies significantly (Fig. 10).

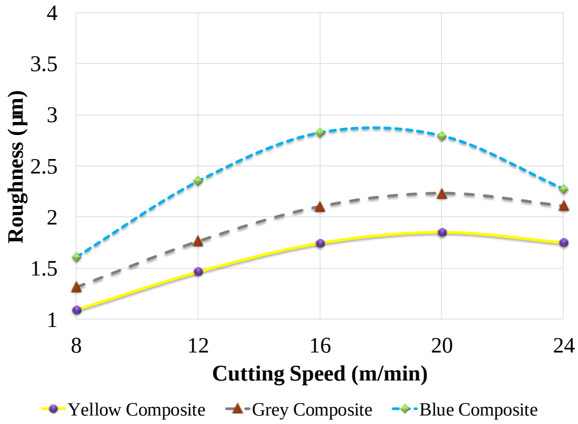

Figure 7. Effect of cutting speed on surface roughness

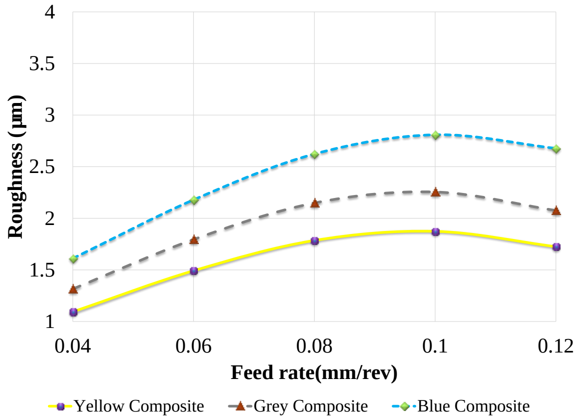

Figure 8. Effect of feed on surface roughness

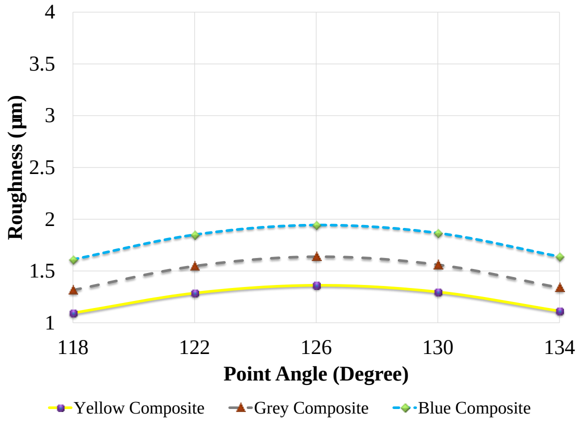

Figure 9. Effect of point angle on surface roughness

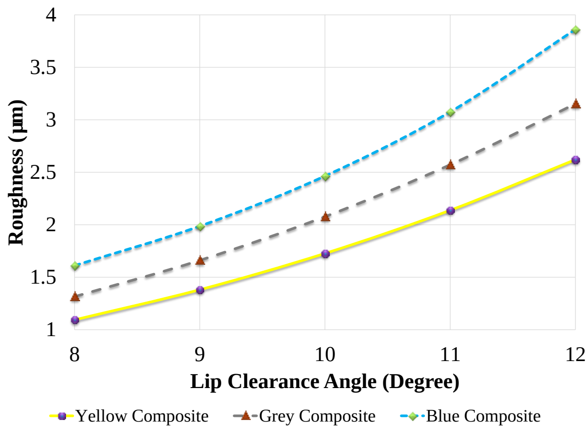

Figure 10. Effect of lip clearance angle on surface roughness

V. CONCLUSIONS

In this study, in order to get better surface roughness for GFRP composite material, Hybrid HS with RSM optimization algorithm is used. It is shown that by using this algorithm it is possible to optimize the surface roughness with in less number of experiments. Additionally, the HS optimized results are verified with desirability analysis and it has shown the same results. Moreover, the amount of glass fiber plays a significant role on the surface roughness. It has also found that the lip clearance angle has a major role on surface roughness for composite material.

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