Minimization of Delamination Factor in Drilling Of Reinforced Carbon-Carbon (RCC) Composite Material by Applying Taguchi Method

K.V.Krishnasastry, V.Seshagirirao, Abhishek Kuravi

***Abstract:** Nowadays, The Reinforced Carbon-Carbon (RCC) Composite material is gaining significant place among the various engineering materials. The light weight and high strength composite is finding its way in recent advanced applications like Medical, Space, Defence and Bio related fields. The growing use of this composite in these advanced industries has created inquisitiveness among researchers and prompted them to study about developing technology for machining of these composites, especially with respect to the drilling operation. Drilling is the most frequently used material removal process and the production of a good quality hole will enhance the quality of the final product. The quality of hole of a composite depends on delamination mechanism and the increase in delamination factor reduces the quality of the product.This paper presents the application of Taguchi method to determine the suitable values of drilling parameters of RCC for the minimization of delamination factor.Taguchi technique emphasizes the importance of studying the response characteristic variation using S/N ratio, resulting minimization of variation in quality characteristic due to uncontrollable parameters. High Speed Steel tool is used for drilling the work piece material, i.e. RCC composite on a CNC machine.*

***Key Words:** Carbon-Carbon composites, RCC, CFRC, S/N ratio, Drilling operation, Orthogonal Array, Design of experiments.*

I. INTRODUCTION

Drilling is one of the major complicated forms of machining or material removal processes and it is also a frequently used process of machining in the latest advanced industrial applications. This drilling process further becomes more complicated, when the work piece is a composite material [1, 2].

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. Drilling is an operation that produces holes of desired diameter in the given material. But much attention was not given on the drilling process of the most advanced and promising engineering material called 'Reinforced carbon-carbon' composite material.

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II. RCC COMPOSITE MATERIAL

The ruler material of modern era, Reinforced Carbon-Carbon (RCC), is occupying a prominent position among the various advanced composite materials. These innovative materials are logical candidates for the construction of advanced structures. The properties of these materials are tailarable according to the requirements [3].RCC is a light weight and high strength composite, capable of withstandinghigh temperature environments. These composite materials, which consist of carbon fibers having various textile structures and a carbonaceous matrix based on coke, polymeric resins, pitch or prolificcarbon, occupy a special place. Hence these materials are also known as Carbon Fiber Reinforced Carbon (CFRC) composites or simply termed as carbon-carbon(C-C) or carbon/carbon(C/C) composites and they can be treated as an important subclass of ceramic matrix composites. These materials have lower density values, much lower than the metals and ceramics and hence make lower component weight [4]. This is an important consideration for selection of aerospace, defence and bio materials. It is so light and equally strong when compared to monolithic materials. For example, CVRDE has developed high performance carbon-carbon brake discs for the main brake assembly of MBT Arjun. The weight of brakes was compared with that of steel material, which is used generally to fabricate the brake discs and found a saving of weight by 75% [5].

The high thermal stability of the solid carbon is the basis for the high temperature applications of these carbon/carbon composite materials. Carbon or Graphite melts only under conditions of high pressure and temperature, i.e. in the order of 100 bars and 4000K.Most notable applications are heat shields for reentry vehicles, hot pressing dies, nozzles. Nose cones of ICBMs (Intercontinental Ballistic Missiles).These materials are also used as refractory materials for various industrial furnaces. Printed circuit heat exchangers are currently manufactured from theses carbon-carbon composites [6].

III.MACHININGOF RCC

Every day Scientists are developing new materials and for each new material, we require efficient and economical machining process. Very little literature is available onmachining processof RCC Composites. Since these composites are difficult to machine, a detailed study of their machinability features is essential. J.R.Ferreira et.al have carried out in rocket nozzle throats to study the performance of different tool materials. They also have carried out to observe the influence of cutting speed and feed rate on cemented carbide tool wear [7]. George et.al determined the setting of process parameters on EDM machine, while machining carbon-carbon composites using a Taguchi technique based on RSM and ANOVA [8]. To the author's knowledge, this little work is also on turning process and no literature is available on drilling process. Hence an experimental investigation is taken on drilling of this special material. The photograph of the work material used for experiment is shown figure.1.

Fig.1.RCC composite material

IV. COMPOSITION OFRCCC (WORK MATERIAL)

The Composition of the Reinforced Carbon-Carbon Composite material is constituted by 99.2% of Carbon material. This is clearly evident from the EDAX given in figures 2 and 3.

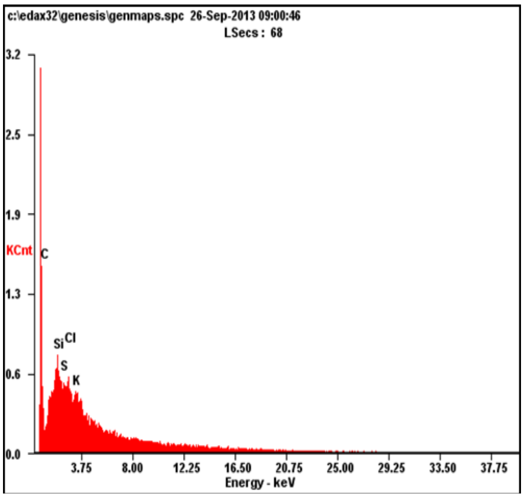

Fig.2 EDAX graph

Element	Wt.%	At%
CK	98.15	99.2
SiK	1.85	0.8
Matrix	Correction	ZAF

Fig.3. EDAX TABLE

IV.EXPERIMENTAL METHODOLOGY

Based on Taguchi quality design concept [9], a L27 mixed orthogonal array table was chosen for the experiments as shown in Figure 4.Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments is easy to adapt and apply for users with limited knowledge of statistics, hence gained popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce with low development and manufacturing costs. Taguchi method improves the quality of manufactured goods, and engineering development of designs for studying variation. Taguchi technique emphasizes the importance of studying the response characteristic variation using S/N ratio, resulting minimization of variation in quality characteristic due to uncontrollable parameters. Orthogonal array and S/N ratios are the two major important tools of a robust design of experiment [10].

In drilling, speed and motion of the multipoint cutting tool is specified by many parameters. They depend upon the selection of work material, tool material, tool geometry etc. In this experiment, Drill bit point Angle, Spindle speed and feed rate were chosen as the three controlling factors and each parameter was designed to have three levels, denoted by 1, 2, and 3 as shown in Table 1.

1. Drill bit point angle: The twist angle of the tip of the drill bit tool and is measured in degrees (0).
2. Spindle Speed: The rotational speed of the spindle holding multipoint cutting tool in revolutions per minute (rpm).
3. Feed rate: The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. It is measured in millimeter/minute (mm/min).

Experiment	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Fig.4, ORTHOGONALARRAY (L27)

TABLE I Control Factors and levels for the experimentation

Drilling Parameters	Symbol	Unit	Level 1	Level 2	Level 3
Point Angle	θ	degree	135	100	118
Spindle Speed	N	r.p.m	1000	2000	3000
Feed Rate	f	mm/rev	100	300	500

VI.EXPERIMENTAL SETUP

The Drilling experiments were carried out on a computer numerical control Vertical Machining centre (VMC100), which is manufactured by ARIX CNC MACHINE Co.Ltd., Taiwan. The experimental setup is shown in Figure.5. High Speed Steel (HSS) drilling tool is used to drill the holes on the work piece. Three tools with different point angles mentioned in table.1 are used for drilling. The drilling process performance is evaluated by two characteristics i.e., Delamination Factor at entry side of the hole and Delamination Factor at exit side of the hole.

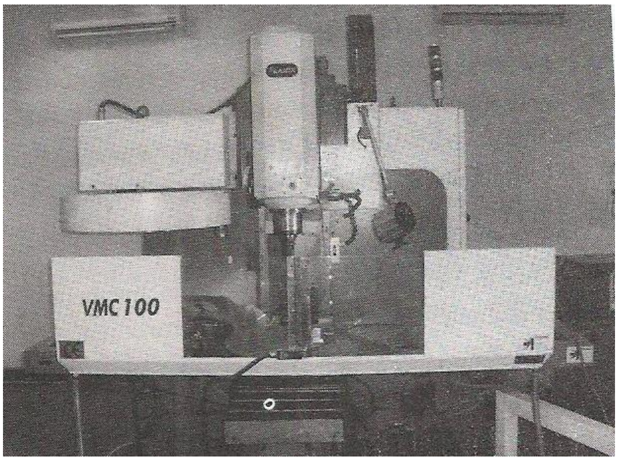

Fig.5 CNC VERTICAL MACHINING CENTRE

Drilling of Carbon Fibre Reinforced Carbon composites may generate several kinds of damage, which can lead to the degradation of quality of holes. Expensive loss may occur due to the drilling defects, as the process is done during the assembly of the structure. For example, in the aircraft industry, drilling associated delamination accounts for 60% of all part rejections during the final assembly of aircraft [11, 12]. Hence care should be taken in selecting the parameters of drilling process. The delamination phenomenon of the drilled hole observed through Scanning Electron Microscope (SEM), is shown in figure.6

Delamination Factor {D_f}. It is the degree of Delamination and Delamination is a mode of failure in composite materials. It is the separation of layers in a laminate. The most important phases during drilling composite laminates are close to the entry and exit where extensive damage in terms of delamination occur due to peel-up and push-out effects respectively[13].The degree of delamination or the delamination factor is defined as the ratio between the diameter D_{max} and D. The parameter D represents the nominal diameter of the hole drilled and parameter D_{max} is the greatest diameter identified between the centre of drilling and a point located on the maximum extent of the delamination defect [14].

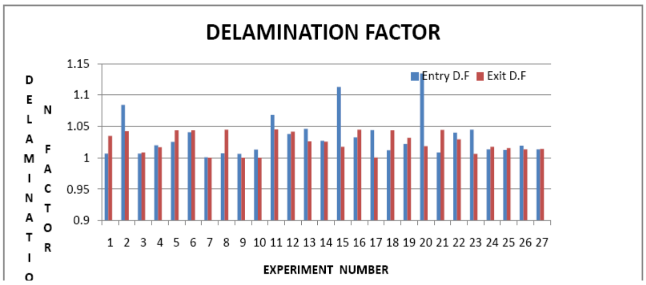

Figure.8 Graph presenting the details of delamination factors

Measurement of Delamination factors: These Factors are measured by an inexpensive technique, known as imaging technique. The drilled holes are photographed by using a digital camera and it is measured with the help of image software *Corel DRAW X5*. The values of diameters of drilled holes are magnified and the diameter values are calculated by using Corel Draw software. The procedure is shown in the figure.7. After the measurement of diameters from the picture, the delamination factor is calculated by using diameter ratio i.e. D_{max}/D.The values are calculated for 27 holes on both sides and entered in to the table.2.The Graph presenting the details of delamination factor values is also shown in figure.8

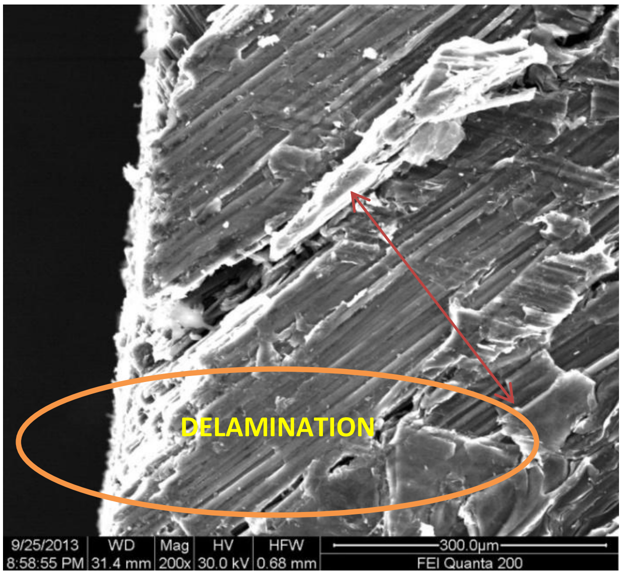

Fig. 6 SEM image of delamination

TABLE.2 DELAMINATION FACTOR VALUES

Expt. No.	Point Angle	Spindle Speed	Feed rate	Entry Delamination factor	Exit Delamination Factor
1.	100	1000	100	1.00654	1.03475
2.	100	1000	300	1.08430	1.04234
3.	100	1000	500	1.00644	1.00840
4.	100	2000	100	1.01970	1.01665
5.	100	2000	300	1.02514	1.04382
6.	100	2000	500	1.04061	1.04382
7.	100	3000	100	1.00054	1.00000

8.	100	3000	300	1.00685	1.04461
9.	100	3000	500	1.00632	1.00000
10.	118	1000	100	1.01290	1.00000
11.	118	1000	300	1.06834	1.04501
12.	118	1000	500	1.03780	1.04156
13.	118	2000	100	1.04607	1.02584
14.	118	2000	300	1.02701	1.02562
15.	118	2000	500	1.11280	1.01738
16.	118	3000	100	1.03232	1.04461
17.	118	3000	300	1.04404	1.00038
18.	118	3000	500	1.01210	1.04382
19.	135	1000	100	1.02187	1.03182
20.	135	1000	300	1.13427	1.01850
21.	135	1000	500	1.00803	1.04421
22.	135	2000	100	1.03980	1.02939
23.	135	2000	300	1.04489	1.00623
24.	135	2000	500	1.01316	1.01753
25.	135	3000	100	1.01244	1.01522
26.	135	3000	300	1.01923	1.01323
27.	135	3000	500	1.01324	1.01398

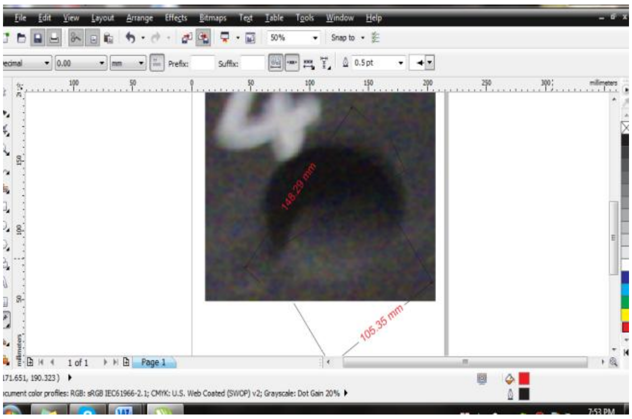

Fig.7 measurement of diameters by using Corel Draw software

V. TAGUCHI METHOD OF DESIGN OF EXPERIMENTS

Once the values of delamination factors, i.e. both at entry and exit of hole are calculated by using the Corel Draw image software, then he values of delamination factors are entered in the table 2. The Signal to Noise(S/N) ratio and Mean values are calculated by using Minitab 16 software. Taguchi method emphasizes the importance of S/N ratio to minimize the variation in quality characteristic due to uncontrollable parameters. The S/N ratio for delamination factor to be considered as 'smaller-the-better', as delamination factor variation is to be minimized. The formula for S/N ratio for a smaller-the-better characteristic is Signal-to-Noise Ratio for smaller -the -better,

$$\frac{S}{N} = -10\log_{10}\left[\sum {Y_{ij}}^2/n\right] \quad (1)$$

The Mean and S/N ratio values calculated by using the Minitab software are entered in the table.3. The response graphs for both Mean and S/N ratio effects on parameters are also given in figures 9&10. The response tables 4&5 for Means and S/N ratios, which are obtained by using Minitab software is also given below.

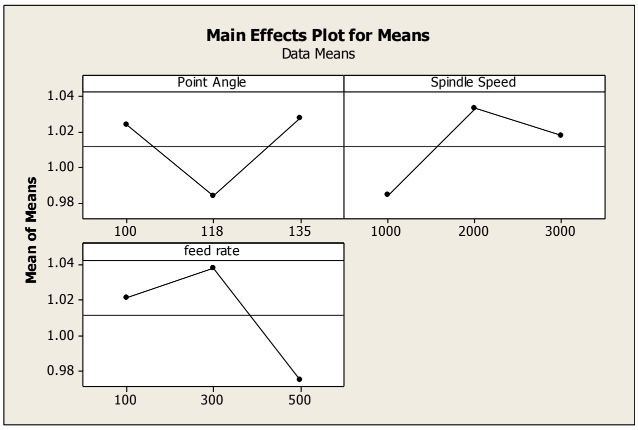

Fig.10 response graph for means

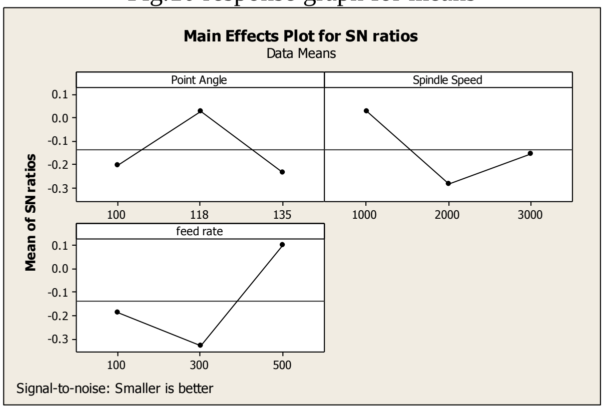

Fig.9 response graph for s/n ratios

Table.4Response Table for Signal to Noise Ratios

Smaller is better

Level	Point Angle	Spindle Speed	Feed rate
1	-0.20443	-0.02374	-0.18593
2	- 0.02756	-0.28313	-0.32912
3	-0.23694	-0.15442	- 0.10124
Delta	0.26451	0.30687	0.43036
Rank	3	2	1

Table. 5 Response Table for Means

Level	Point Angle	Spindle Speed	Feed rate
1	1.0239	1.0008	1.0217
2	1.0002	1.0331	1.0385
3	1.0276	1.0179	1.00003
Delta	0.0237	0.0323	0.03822
Rank	3	2	1

Table.3 S/N ratios and Mean values

Expt.No.	S/N Ratio	Mean Value
1	-0.17835	1.02065
2	-0.53497	1.06332
3	-0.06421	1.00742
4	-0.15647	1.01818
5	-0.2948	1.03448
6	-0.35915	1.04221
7	-0.00234	1.00027
8	-0.22211	1.02573
9	-0.02744	1.00316
10	-0.05603	1.00645
11	-0.47933	1.05667
12	-0.3265	1.03973
13	-0.30721	1.03595
14	-0.2256	1.02631
15	-0.55641	1.06509
16	-0.32796	1.03846
17	-0.19278	1.02221
18	-0.24057	1.02796
19	-0.23019	1.02684
20	-0.65189	1.07638
21	-0.22532	1.02612
22	-0.29549	1.03459
23	-0.22073	1.02556
24	-0.13227	1.01534
25	-0.11933	1.01383
26	-0.13987	1.01623
27	-0.11741	1.01361

VI. RESULTS, ANALYSIS AND CONCLUSION

It is clearly evident from the response graphs, the effect of point angle on delamination factor is decreasing and then increasing and the optimum value is $118^{0,}$ the effect of spindle speed is increasing and then decreasing and the optimum spindle value is 2000 rpm and the other parameter feed rate's effect on the response characteristic is increasing and then decreasing and the optimum feed rate value is 500 mm/minute.

From the response tables 4&5, we can clearly understand the feed rate plays more important role in effecting the quality of hole, when compared to that of spindle speed and point angle.

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