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THE EFFECT OF CUTTINGTOOL GEOMETRY ON THRUST FORCE AND DELAMINATION WHEN DRILLING CARBON FIBRE REINFORCED COMPOSITE MATERIALS

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ABSTRACT
Among the several machining processes, drilling is one of the most frequently used for the hole production for screws, rivets and bolts. Drilling of composite materials causes several damage modes, such as: delamination, fiber-pull out, edge chipping, spalling, uncut fibers, surface roughness and dimensional errors, and others.
Delamination is a major problem associated with drilling fiber reinforced composite materials. It causes poor assembly tolerance, reduces structural integrity of material and the potential for long term performance deterioration. The thrust force has been cited as main cause of delamination.
In this paper the objective was to establish correlation between cutting tool geometry, cutting velocity and feed rate with delamination during drilling carbon fibre reinforced composite materials. Drilling test were carried out on carbon epoxy composites using different twist drills.
Keywords: drilling, carbon fibre reinforced composite materials, delamination

1. INTRODUCTION

Composite materials are more and more used in demanding constructions, due to their hardness to weight and stiffness to weight ratios. Parts made out of composite materials are joined and connected by joining elements into complex construction sections and subsections. In this purpose, it is necessary to drill numerous holes with different dimensions. Having in mind the structure of composite materials that consist of fibres and a matrix that usually has low melting point (epoxy resins melt at about 160°C), the process can be considered complex. During the drilling process, created dust, beside the abrasive effect has a harmful influence on human health, so its expansion must be stopped, and it should be removed simultaneously with its' creation. Due to low melting point of the resin, melted resin sticks to the cutting tool together with dust particles, changing tool's cutting geometry, affecting its' life span and surface working quality. These features result in some specific problems which may lead to occurrence of characteristic material damage shapes [1-6]. Local dynamic load, especially bending load, may result in delamination of carbon fibres, due to different rigidity of fibres and the matrix. Delamination represents separation of surface layer during tool entrance in and exit from the

CONTENTS

material. Characteristic shapes of damage in composites reinforced with carbon fibres are delamination, edge chipping, fibre pull-out, spalling and uncut fibres.

2. EXPERIMENTAL WORK AND RESULTS OF THE INVESTIGATION

A machining center “SPINNER VC560” with 13 kW spindle power and a maximum spindle speed of 12000 rpm was used to perform the experiments. The thrust force was measured using a KISTLER piezoelectric dynamometer model 9271A. The Dynamometers signal were then processed to make them suitable for computer. This was achieved via charge amplifiers and an analog to digital (A/C) converter and than to computer. The damage around holes was measured with a microscope OLYMPUS S7X9, with 12,5x magnification and 1 μm resolution and software Olympus DP Soft.
Carbon fibre reinforced epoxy resin laminates used as work material. Laminates were made up of epoxy matrix reinforced with 55 % weight of woven carbon fibre with an orientation of 0/90°. Dimension of experimental laminates were 80 x 150 mm, thick 4 mm.

Three drills different geometry were tested as indicated in table 1.

Table 1. Tool material and geometry used in experimental work

Drill	Description
HSS-Co 	Twist drill bit made of alloyed high speed steel, 6 mm diameter, cobalt content 5 %, point angle 135°, two cutting edge, manufactured by BOSH
HSS-R 	High speed steel twist drill, 6 mm diameter, point angle 135° and two cutting edge, manufactured by BOSH
Multiconstruction HMCT 	Multiple diamond ground tungsten carbide drill manufactured by BOSH, 6 mm diameter, reduction of main cutting edge for accurate centring

Figure 1. Experimental setup

CONTENTS

The orthogonal array for two factors at three levels was used for elaboration of the plan of experiments. Table 2 indicates factors to be studied and the assignment of the corresponding levels. The array L_9 (2^4) shown in Table 3 was selected which has nine rows corresponding to the number of tests with two columns at three levels. The plan of experiments is made of nine tests where the first column was assigned to the cutting velocity and second column to the feed and remaining were assigned to the iterations. The outputs to be studied are thrust force and delamination factor (K_d). The delamination factor is determined by ratio of maximum diameter of delamination zone to the hole diameter. The experimental results were treated based on the analysis average and analysis of variance.

Table 2. Assignment of the levels to the factors

Level	Cutting velocity V (m/min)	Feed rate f (rpm)
1	16	0,05
2	24	0,10
3	32	0,20

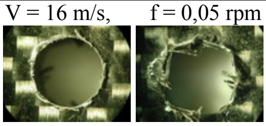
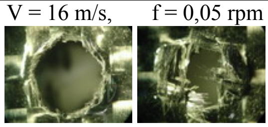
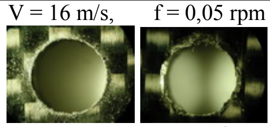
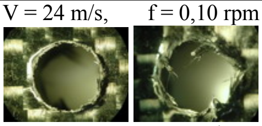
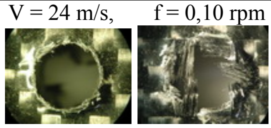
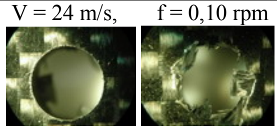
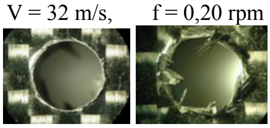
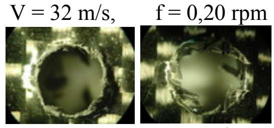
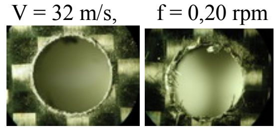
Table 3. Ortogonal array L_9 (2^4) of Taguchy

L_9 (2^4) Test	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4. Values of thrust force (F) and delamination factor (K_d) as function of cutting parameters

Test	Cutting velocity V (m/min)	Feed rate f (rpm)	HSS-Co		HSS-R		Multiconstruction	
			F (N)	K_d	F (N)	K_d	F (N)	K_d
1	16	0,05	102,40	1,123	117,39	1,154	115,09	1,208
2	16	0,10	148,41	1,128	161,31	1,192	158,01	1,176
3	16	0,20	209,65	1,149	239,72	1,194	229,44	1,318
4	24	0,05	138,21	1,259	150,99	1,268	112,09	1,191
5	24	0,10	186,62	1,143	214,21	1,247	142,70	1,163
6	24	0,20	278,46	1,103	300,95	1,215	207,03	1,233
7	32	0,05	153,01	1,143	176,09	1,173	101,99	1,222
8	32	0,10	209,10	1,151	258,13	1,207	130,50	1,182
9	32	0,20	319,77	1,225	392,89	1,211	219,34	1,197

Table 5. View of entrance and exit side of drilled holes for different cutting parameters and drills

HSS-Co drill	HSS-R drill	Multiconstruction drill
V = 16 m/s, f = 0,05 rpm  Entrance Exit	V = 16 m/s, f = 0,05 rpm  Entrance Exit	V = 16 m/s, f = 0,05 rpm  Entrance Exit
V = 24 m/s, f = 0,10 rpm  Entrance Exit	V = 24 m/s, f = 0,10 rpm  Entrance Exit	V = 24 m/s, f = 0,10 rpm  Entrance Exit
V = 32 m/s, f = 0,20 rpm  Entrance Exit	V = 32 m/s, f = 0,20 rpm  Entrance Exit	V = 32 m/s, f = 0,20 rpm  Entrance Exit

CONTENTS

The correlation between thrust force and cutting parameters in drilling carbon fibre reinforced composite materials was obtained. The equation can be express as follows:
HSS-Co drill:

$$F = 106{,}167 v^{0{,}565} f^{0{,}553}, \qquad R^2 = 0{,}992 \qquad ...(1)$$

HSS-R drill:

$$F = 112{,}237 v^{0{,}545} f^{0{,}477}, \qquad R^2 = 0{,}990 \qquad ...(2)$$

Multiconstruction drill:

$$F = 787{,}705 v^{-0{,}145} f^{0{,}521}, \qquad R^2 = 0{,}972 \qquad ...(3)$$

3. CONCLUSION

Based on above experimental results presented, the following conclusions can be draw:

- Thrust force and delamination depend on the cutting velocity, feed rate, tool geometry and tool wear.
- Chisel edge has a significant impact on the increase thrust force. Reducing chisel edge length, thrust force may be considerably reduced.
- The damage delamination increases with both cutting parameters, which means that damage is bigger for higher cutting velocity and for higher feed rate.
- Multiconstruction and HSS-Co drills produced less damage than the HSS-R drill.
- HSS-R drill produced hole with more uncut fibers and bigger delamination then other drills.
- Aiming to obtain efficient manufacture of composite material parts, it is essential to continue research of machining process and optimise it choosing means and machining regimes. Special consideration must be taken in choosing material and tool geometry.

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