ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

An Experimental Analysis of Delamination Factor of a GFRP Composite Material on Radial Drilling Machine

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ABSTRACT:
In recent years, the use of composite materials has been increased substantially in many engineering applications due to excellent properties (light weight, high specific strength and stiffness) compared to other conventional materials. GFRP (Glass fiber reinforcement plastics) is widely used composite which is available in the form of sheets (copped strand mat) or woven fabric. The applications include Aerospace, Automobile, shipping, storage tanks, piping and construction industries. Drilling is one of the commonly used machining operation for fastening of composite structures. However, there are some common problems while carrying out this operation like, surface delamination, fiber resin pull - out, poor finishing of a hole, cracks in internal layers, burning and powder formation etc. These defects not only have greater influence on quality but also on overall life of the products. The objective of this study is to analyze different process parameters such as, spindle speed, feed rate and tool geometry by experimenting with L9 orthogonal array of Taguchi method where the delamination factor is considerably minimum.

Keywords:
GFRP, Delamination factor, Radial Drilling Machine, Speed, Tool geometry, Feed Rate, Taguchi method.

1) Introduction:
Delamination is one of the common defects being noticed during GFRP composite drilling operation. Delamination is a failure of composite material which leads to separation of layers/plies.

Possible delamination modes are

a) Pull -out delamination:
Initially, the cutting edge of the drill bit will first abrade the laminate and by applying force, tends to pull the abraded material away along the flute. The material coils up before it is machined completely. This action introduces a peeling force upwards to separate the upper laminas from the uncut portion held by the downward acting thrust force.

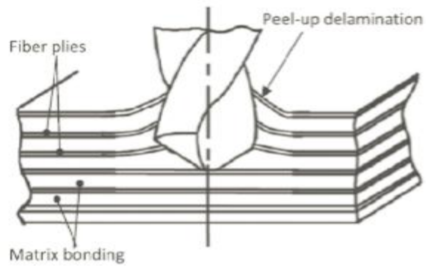

Fig 1.1 Pull -out delamination

b) Push-out lamination:
During drilling, a compressive force will be applied on the laminate This force will weaken the inter-laminar bond around the hole. As the drill approaches the end, the uncut thickness becomes smaller and the resistance to deformation decreases. At some point, the loading exceeds the inter-laminar bond strength and delamination occurs.

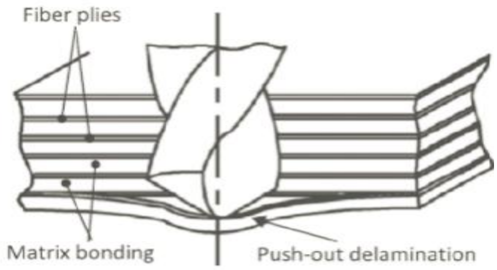

Fig 1.2 Push -out delamination

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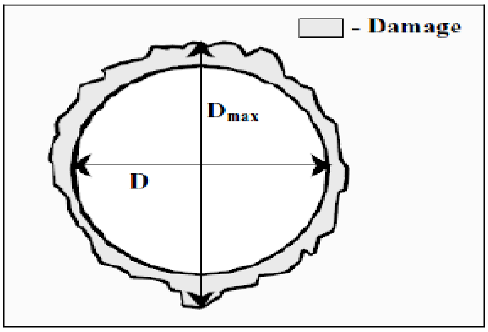
c) Delamination Factor (Fd):

Delamination factor (Fd) is the ratio between D_{max} to D, a factor used to determine the extent of delamination. Fd =Dmax/D



D max is the maximum diameter created due to delamination around the hole and D is the hole or drill diameter. At a critical thickness, the bending stress becomes greater than the inter-laminar strength between the plies and an inter-laminar crack is initiated around the hole. Further pushing down by the drill point causes the crack to propagate and the flexural rigidity of the supporting plies becomes weaker. This leads to fracturing the material below the drill point as the chisel edge proceeds to exit the laminate. The damage at exit plies is shown as spalling that extends beyond the diameter of the hole.

2) Materials Used:

GFRP Composite Fabrication:

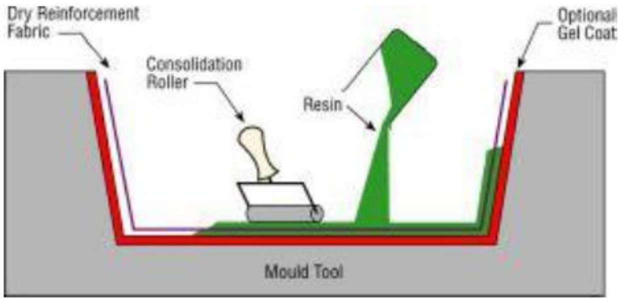
There are various industrial and commercial processes are being extensively used at industry and academic level. The different methods use different ways of impregnating and curing.

The curing temperature and period vary for different processes yielding a wide range of mechanical properties.

Hand layup process:

In present study, hand layup process is used because of following reasons

1. Simple principles to carry out.
2. Lower cost, if room-temperature cure resins are used.
3. Wide choice of suppliers and material types.
4. Higher fiber contents can be easily controlled.
5. Longer fibers than with spray lay-up.



Description:

Resins are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, which is used to force resin into the fabrics by means of rotating rollers. Laminates are left to cure under standard atmospheric conditions.

Fabrication Steps:

Various steps involved in the fabrication process are:

Application of release gel on mold:

The silica gel spray is applied uniformly on the die surface to prevent sticking of fabricated laminates on the surface.

Laying the polyester sheet:

A single layered polyester sheet is laid between the topmost and the lowermost layer of the laminate and die surface to enhance releasing ability of laminates.

Laying Glass Fibers:

The glass fibers are cut into required dimension and laid carefully on the die surface.

Wetting The Glass Fibers With Epoxy:

The epoxy and hardener solution is applied on the glass fiber layer. Generous application of solution ensures proper impregnation of epoxy between the pores of glass fiber

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Subsequent Application Of Alternate Glass Fiber And Epoxy:
Alternatively glass fiber layers and epoxy solution is applied and the process is continued to get the laminate of requisite layer.

Laying The Final Polyester Layer:
Final polyester layer is laid on the top surface to prevent sticking

Applying The Roller To Squeeze Out The Extra Epoxy:
Roller is applied with mild pressure to squeeze out extra epoxy and to increase the volume fraction of fiber in the laminate.

Closing And Bolting Of Mold:
The die is closed and the bolts are tightened properly to ensure enough pressure acts on the laminate.

Curing for 24 Hrs. under normal room temp condition:
The setup is left for curing under normal room temperature and pressure for 24 hours.

Releasing the cured samples of FRP:
The cured laminate is taken out of the die.

Cutting the sample sheet into required dimension:
The laminate is cut in required dimension using a hand shearing machine.

Materials and Equipment used:

a) Epoxy resin (Dr Beck 's Epoxy (Dobeckot 520F).
b) Glass Fibers (Woven bidirectional).
c) Hardener Dr Beck's Hardener No. 758. (Mixing Ratio of Epoxy and Hardener is 10:1 by volume)
d) Mold Release Spray (Arrow - Silica Based).
e) Measuring vessel
f) Brush
g) Wooden roller

A 4 layered GFRP (woven bidirectional) specimens of 2 mm thickness were prepared using the hand lay-up process.

3) Experiment Set up

Radial Drilling machine - Machine power **(**8hP and working at 230V and 5A current.

Fig. 2.1 Radial Drilling Machine

Drilling tests were conducted on Radial drill machine using backup plate of wood.

Three types of drill bits have been used:

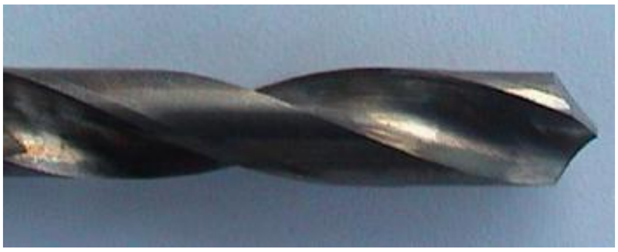

Fig 2.2 4- facet drill bit

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Fig 2.3 Jo-drill bit

Fig 2.4 Parabolic drill bit

Drilling parameters used:

Paremeter	1	2	3
Speed(rpm)	355	450	560
Feed(mm/rev)	0.12	0.19	0.3
Tool geometry	4-Facet	Jo-drill	Parabolic

Damage area of the composite being inspected by "Dye Penetrant Test"

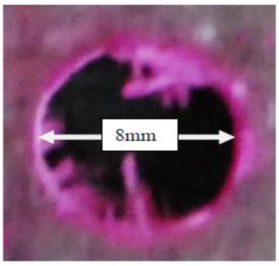
Dye Penetrant Test:

Dye penetrant test, also called liquid penetrant test, is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials.

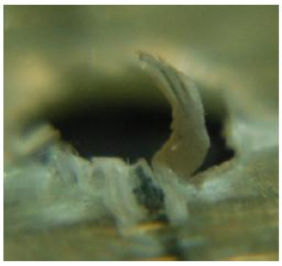
Following are the different steps of the test.

a) Pre-cleaning
b) Application of Penetrant
c) Excess Penetrant Removal
d) Application of Developer
e) Inspection:

The test surface is the analyzed carefully for the damaged area which can now be easily noticed by as the dye remaining inside the crack appears as purple color



Dye penetrant Test



Delamination.

4) Taguchi method :

Taguchi methods which combine the experiment design theory and the quality loss function concept have been applied to the robust design of products and process and have solved some confusing problems in manufacturing. In order to observe the influence degree of control factors (feed rate, spindle speed and drill point geometry) in drilling, three factors, each at three levels, are considered. Namely, a L9 (34) orthogonal array was employed.

Data of Experiment # 1

L_9 (3^4)	Spindle Speed	Feed	Tool Geometry	Delamination factor (F_d)
1	1	1	1	1.407
2	1	2	2	2.356
3	1	3	3	2.329
4	2	1	2	1.530
5	2	2	3	1.034
6	2	3	1	1.507
7	3	1	3	2.689
8	3	2	2	2.474
9	3	3	1	2.307

Data of Experiment # 2

L_9 (3^4)	Spindle Speed	Feed	Tool Geometry	Delamination factor (F_d)
1	1	1	1	1.407
2	1	2	2	2.214
3	1	3	3	2.140
4	2	1	2	1.006
5	2	2	3	1.034
6	2	3	1	1.352
7	3	1	3	2.322
8	3	2	2	1.892
9	3	3	1	2.058

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Delamination Factor Fd (Amax/Ahole)

$L_9(3^4)$	Spindle Speed	Feed	Tool Geometry	Delamination factor (F_d)		Average_Value (experiments)
				Experiment # 1	Experiment # 2	
1	1	1	1	1.407	1.407	1.407
2	1	2	2	2.356	2.214	2.285
3	1	3	3	2.329	2.140	2.235
4	2	1	2	1.530	1.006	1.268
5	2	2	3	1.034	1.034	1.034
6	2	3	1	1.507	1.352	1.430
7	3	1	3	2.689	2.322	2.506
8	3	2	2	2.474	1.892	2.183
9	3	3	1	2.307	2.058	2.183

5) Conclusions:

- It was observed that the drill point geometries, the feed rate and the rotation speed of drill bit significantly influence the damage.

- It was noticed that minimum damage occurred for the combination of speed (450 rpm), feed (0.19mm/rev) and Parabolic tool geometry with **delamination factor '1.034'**

In present investigation, only three drill geometries – 4-facet, Jo and parabolic twist drill and three different feed rate and rotation speed values, but if this work would be extended for further different geometries and process parameters, this work has the capability to give a better combination of drill type and process parameters to minimize the damage. The next step in the research efforts in this direction can be the 3D simulation of drilling process which can give more accurate results.

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