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

Experimental Investigation on Drilling of Composite Materials

Jangam Eraiah Swamy
M Tech (Advanced Manufacturing Systems)
Department of Mechanical Engineering,
Bheema Institute of Technology & Science
Adoni Rd, Dhanapuram,
Andhra Pradesh 518302.

G Veeresh, M.Tech
Assistant Professor,
Department of Mechanical Engineering,
Bheema Institute of Technology & Science
Adoni Rd, Dhanapuram,
Andhra Pradesh 518302.

Abstract

For fastening purpose, drilling is the most widely carried out manufacturing process for composites. Problems like fiber-resin pull out, surface delamination, inadequate hole surface finish, inter-laminar cracks are quite common. These problems don't just affect the quality of the service of composite but are sometimes serious enough to thwart their intended use.

An approach to predict the damage in composite plates is brought forward in this project, which is based on Hashin's damage initiation criteria and energy based evolution criteria. The project utilizes the capability of a finite element model in ABAQUS 6.7-3 to simulate damage patterns in composite laminates subjected to drilling. A series of experiments were also conducted using radial drill machine to drill the composite laminate specimens at various cutting parameters and different drill geometries (like twist drill, parabolic drill and jo drill). The amount of delamination of the specimen was measured and analyzed using image processing software Image J 1.34, public domain software (National institute of health, USA). Numerical simulations were carried out, for the same dimensions and properties as of the specimen, with the help of ABAQUS 6.7-3 by giving different cutting parameters and drilling geometries as stated above. Numerical results thus found for the damage in laminate plates due to drilling are in good agreement with experimental observations and also helps to choose the best drill and cutting parameters for the drilling operation.

Introduction

Composite material, as the name suggests, is a combination of two or more materials which are combined on a macroscopic scale to form a useful material. The constituent materials have significantly different physical and chemical properties and remain separate in the final structure. These materials are ideal for structural applications where high strength-to-weight and stiffness-to-weight ratio are required.

The constituent materials are referred to as matrix and reinforcement. The matrix surrounds and supports the reinforcement material by maintaining their relative positions. The physical and mechanical properties of reinforcement synergize with the properties of matrix to produce composite material having superior properties than either matrix or reinforcement.

Because of their superior properties they are finding increasing applications in automobile, aerospace and petrochemical industry. The most visible applications pave our roadways in the form of either steel and aggregate reinforced portland cement or asphalt concrete. Those composites closest to our personal hygiene form our shower stalls and bath tubs made of

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

fiberglass. Solid surface, imitation granite and cultured marble sinks and countertops are widely used to enhance our living experiences.

Development of the Concept of FRP Composites

A generic FRP system use of fibers as high characteristics;

is based on three important

a) Polymer Matrix Composites (PMC's) - These are the most common and will the main area of discussion in this guide. Also known as FRP - Fiber Reinforced Polymers (or Plastics) - these materials use a polymer-based resin as the matrix, and a variety of fibers such as glass, carbon and aramid as the reinforcement.

b) Metal Matrix Composites (MMC's) - Increasingly found in the automotive industry, these materials use a metal such as aluminum as the matrix, and reinforce it with fibers such as silicon carbide.

c) Ceramic Matrix Composites (CMC's)- Used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibers, or whiskers such as those made from silicon carbide and boron nitride

Literature Review

The research in the field of machining of FRP composite materials has gained momentum in last few decades.

Abrao et al. [2] presented a review of the drilling of glass and carbon fiber reinforced plastics. The aspects such as tool materials and geometry, machining parameters and their influence on the thrust force and torque were investigated. Additionally, the quality of the holes produced is also assessed, with special attention paid to the delamination damage. Considerable efforts have been focused on the better understanding of the phenomena associated to the cutting mechanism. As far as the work material is concerned, glass and carbon fiber reinforced composites have been equally investigated; however, epoxy resin is preferred as the matrix material. Conventional high speed steel twist drills and cemented tungsten carbide drills have been used. The principal factors used to evaluate the performance of the process are damage caused at the drill entry or exit and the roughness on the wall of the hole produced. This damage is frequently measured in terms of delamination, techniques employed to measure the effect of the cutting parameters cutting speed (usually indicated as rotational speed) and feed rate. The measurement of the damage directly (using parameters such as damage width, delaminated area or delamination factor), and indirectly through thrust force, torque or power. How to get reduction of the damaged area without use of a backing material which makes the drilling operation longer and dearer.

Composite Fabrication

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 our case we would be using hand layup process 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.

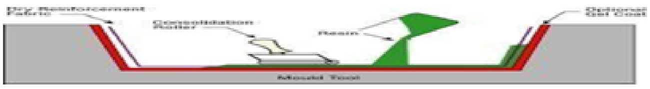

Fig 4.2 Schematic of Hand Lay up Process

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.

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

Laminates are left to cure under standard atmospheric conditions.

Materials Options

Resins: epoxy, polyester, vinylester, phenolic.
Fibers: carbon fiber or glass fiber.

Materials used

- Dr Beck's Epoxy (Dobeckot 520F).
- Glass Fibers (woven bidirectional).
- Dr Beck's Hardener No. 758. (Mixing Ratio of Epoxy and Hardener is 10:1 by volume).
- Arrow Mold Release Spray (Silica Based).

Fabrication Steps

Various steps involved in the fabrication process are:

Spraying 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.

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.

Chemicals and equipments used

Epoxy resin
Release spray
Measuring vessel
Brush
Wooden roller
Glass fiber

Fig. 4.3 Chemicals and Equipments used

Experimental setup

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

Fig. 5.1 Radial Drill Machine.

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

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

Radial Drill machine
Machine power

8hP and working at 230V and 5A current.

Table 5.1 Spindle speed and feed rate

Lower speed (rpm)	Higher speed (rpm)	Feed rate (mm/rev)
90	450	0.03
140	710	0.05
224	1120	0.08
355	1800	0.12
560	2800	0.19
900	4500	0.30

Three types of drill bits have been used:

4-facet
Jo-drill
Parabolic

4 – Facet

Jo-drill

Parabolic

Fig. 5.2 Various types of drill bits

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 (3^4) orthogonal array

Taguchi Hand book [11] was employed. To perform ANOVA(Analysis of Variance) software **Design Expert 1.7.6** was used.

Methodology used to obtain the damage area

In the present work, the digital image of the damaged area was used to quantify the delamination at the drill entrance. Before taking the image, **nondestructive dye penetrant** test was performed. The image processing produces satisfactory results, allowing the observation and analysis of details from the digitalized image. Using a discrete process, the image is positioned under a rectangular grid, which pixels (cells) are identified by the coordinated pair with origin at the upper left corner of the image.

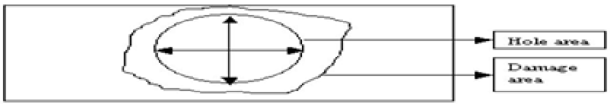

Fig. 5.3 Schematic layout of Damage Area (Amax) and Hole Area (Ahole)

The damage area is obtained through the image digitalization and processing. The picture was treated using **Image J 1.34**, public domain software (National Institute of Health, USA). In order to obtain an image with acceptable quality, a series of parameters must be appropriately selected, such as brightness intensity, noise suppression (despeckle), image enhancement and edge detection. By drawing an edge boundary of the damaged region represented after die penetrant test gives A_{max}, after that drawing a circle touching the inner diametric periphery of the hole gives hole area.

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.

8mm

Delamination using dye penetrant Delamination

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

Fig. 5.4 Delamination of FRP composite

Numerical Analysis

FEM implementation in ABAQUS 6.7-3

The constitutive model described above is applied to determine the damage in the fibre-reinforced composite specimen by taking different drill tool geometries (as shown in Fig.

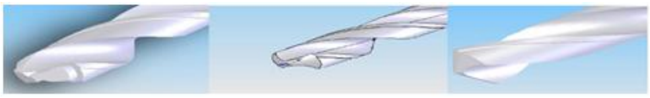

Fig 6.1: Jo-drill
4-Facet drill
Parabolic drill (not to scale)

Fig 6.2: Meshed Jo, 4-Facet and Parabolic drills (not to scale)

The geometry of the specimen is shown in Fig. 6.3. The plate is of 20×20cm^2 dimensions and the hole to be drilled is of 8mm dimension. The thickness of the plate is of 2mm as shown in fig.

Fig 6.3: Geometry of fibre-reinforced composite specimen (not to scale)

The specimen consists of two layered UD-GFRP specimens of 2 mm thickness. The specimen is a square plate of 20cm length and is divided into two zones (as shown in Fig. 6.3). Hashin‘s damage model is applied to the inner damage zone of the plate and the outside zone is assumed to be showing linear-elastic behaviour throughout the drilling process. The plate is meshed(as shown in Fig. 6.4) using S4R quad-dominated elements(plane stress element) and total no. of elements are 580.The three different drills with point angle of 118°are made in ProE and then imported into ABAQUS 6.7-3. The drills are assumed to be discrete rigid and meshed with R3D4 (a 4node bilinear rigid quadrilateral element) elements. Then the assembly is made combining the plate and drills. The assembly consisting of drill and the composite plate is shown in Fig. 6.5.

The material behavior of composite plate is assumed to be Lamina type with fail strain data, and it is modeled using the elastic and hashin damage model available in ABAQUS 6.7-3. The material properties for composite are listed in Appendix. The orthotropic elastic constants and the strength properties for Hashin‘s damage initiation criteria are listed in (Appendix: Tables 5 and 6) respectively and these are taken from Mallick [21] and fracture energies Gic of glass fibre-reinforced epoxy are available in open literature and are given in (Appendix: Table 7)

Fig 6.4: Meshed composite plate (not to scale)

Fig 6.5: Assembly of drill and plate

A uniformly distributed pressure load of 600 N was used as the boundary condition (shown in Fig. 6.6) .The load is applied on the reference point of the drill (midpoint of chisel edge) and is taken from Redouane Zitoune, Francis Collombet [26]. The composite plate is constrained from four sides. The interaction between drill and plate is taken as general. The appropriate combination of feed rate (mm/rev) and speed (rpm) is given to the reference point of the drill only in the direction of –ve z axis and is constrained to move any other directions. The model is simulated for nine combinations as shown in the Table 5.2 and 5.3.

Fig. 6.6: Pressure load on drill (not to scale)

Then the model is solved in Abaqus-explicit in which future or next time step is only dependent upon the previous time step. Small time step is taken in order to avoid divergence.

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

The rules of mixtures lead to the elasticity moduli and strength parameters of the undamaged UD-lamina, calculated from the properties of fiber and resin data together with the volume ratios of fibers and matrix.

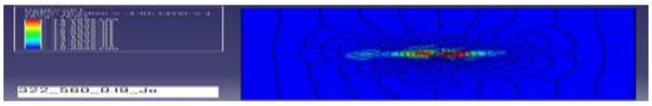

Fig 6.9 Hashin Damage 133_355rpm_0.3mm/rev_Parabolic

Fig 6.10 Hashin Damage 212_450rpm_0.12mm/rev_Jo

Fig 6.11 Hashin Damage 223_450rpm_0.19mm/rev_Parabolic

Fig 6.12 Hashin Damage 231_450rpm_0.3mm/rev_4 Facet

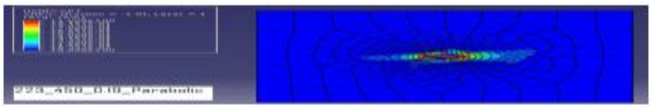

Fig 6.13 Hashin Damage 322_560rpm_0.19mm/rev_Jo

Fig 6.14 Hashin Damage 331_560rpm_0.3mm/rev_4 Facet

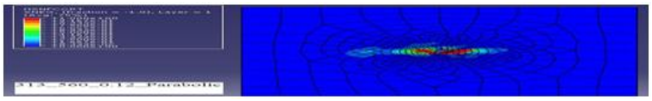

Fig. 6.15 Hashin Damage 313_560rpm_0.12mm/rev_Parabolic

Results for both experimental and numerical analysis are compared in the table 6.1 shown on next page. Graphs are also plotted to compare them in Fig. 6.16-6.17. Similar trend was observed for delamination factor of both experimental and FEM results. A multiplicative factor of 1.5 was suggested so as to make FEM results in congruence with the experimental results. This factor takes into account complexities which are difficult to model

Conclusions

Drilling of composite materials has been realized as a potential area to put in research efforts. The research endeavors in the field have identified the problem areas and scientists and engineers have tried to attack the problem from all possible perspectives. Damage studies have been an area of paramount importance. A number of such efforts have been reported that proposed different damage mechanisms while drilling composite laminates. Fiber pull-out, fuzzing, matrix cracking, delamination are all possible modes of damage. Push-down at exit and peel-up at entrance are the possible modes of delamination. An elliptical damage zone has been reported and this has been attributed to the angular positioning created by the drill cutting edge and the fiber orientation. The hole produced has a circularity defect due to this. Plate bulge, crack opening and fiber tearing and twisting are also the prominent mechanisms of material damage.

References

1 Mohr J. G.Rowe, W. P., ―Glass Fibers An Insight‖, John Wiley Publication, 1978.

2 A.M. Abrao, P.E. Faria, J.C. Campos Rubio, P. Reiz, J. Paulo Davim, ―Drilling of fiber reinforced plastics : A review‖ , Journal of materials processing Technology 186 (2007) 1-7.

3 J.P. Davim, Pedro Reis, ―Drilling of carbon fiber reinforced plastics manufactured by autoclave experimental and statistical study‖, Material & Design 24 (2003) 315-324.

4 Davim J.P.; Reis P.; Antonio C.C., ―Experimental Study of Drilling Glass Fiber Reinforced Plastics (GFRP) Manufactured by Hand Lay-up‖ , Composites Science and Technology. 2004, 64, 289-297.

5 El-Sonbaty I.; Khashaba U.A.; Machaly T., ―Factors Affecting the Machinability of GFR/epoxy Composites‖, Composite Structures 2004, 63, 329-338.

6 Singh , N. Bhatnagar , P. Viswanath, ―Drilling of

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

uni-directional glass fiber reinforced plastics: Experimental and finite element study‖, Material & Design (2007)

7 Marta Fernandes, Chris Cook, ―Drilling of carbon composites using a one shot drill bit PartII: empirical modeling of maximum thrust force‖, International journal of Machine tool & Manufacture 46 (2006) 76-79.