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Finite Element Analysis in Drilling GFRP Composites

Putti Venkata Siva Teja[1], S. Prakash[2*], B. Narasimha Prasad[2] and Gowra Elijah[2]

[1]Department of Mechanical Engineering, Gudlavalleru Engineering College, Krishna - 521356, Andhra Pradesh, India

[2]Department of Mechanical and Production Engineering, Sathyabama University, Chennai - 600119, Tamil Nadu, India; prakash_s1969@yahoo.com

Abstract

Glass Fiber Reinforced Plastic (GFRP) composites which are having various applications in the fields of mechanical and electrical engineering, due to its excellent properties such as lighter weight, higher specific strength and high stiffness. Machining is an important process in manufacturing operations and drilling of holes in GFRP leads to drilling induced damage which is one of the important research areas. In the present study finite element analysis of drilling behavior of GFRP has been carried out in LS-DYNA solver. The results are compared with experimental work and found that the thrust force and torque determined by finite element analysis showed good results when compared with the experimental results.

Keywords: Drilling, FEM Analysis, Glass Fiber Reinforced Plastic (GFRP), Thrust Force, Torque

1. Introduction

Machining of composites is a major concern in modern-day manufacturing industries due to non-homogeneity in their material properties. Making holes in GFRP is one of the main important applications as drilling of GFRP is quite significant in assembly operations in aviation industries, automobile industries and to print wiring on electronic circuits GFRP laminates. Normally drilling is a highly complex dynamic process involved in complicated geometrical interactions and friction. FRP played a vital role during post World War II in submarine parts and aircraft components, etc. Since the year 1990, the thrust force and cutting force in drilling of FRP composites were modeled and validated[1,2]. Dipaolo et al.[3] proposed that the properties of woven FRP composites make more challenging for numerical modeling, compared to its unidirectional counterpart of same number of material, and binding matrix. In 1996, the variation of thrust force and torque with change in fiber angles for unidirectional composites are reported after taking the video images through higher speed cameras at the onset of delamination. Rajamurugan et al.[4] studied the thrust force in drilling GFRP by multifaced drill bit. Palanikumar et al.[5] studied in detail the effect of cutting parameters on drilling GFRP such as spindle speed, feed and their interactions. Gopinath and Suresh[6] conducted static and dynamic analysis to predict thrust force and torque in drilling of FRP composites. Janarthanan and Nagarajan[7] conducted failure theories in GFRP and found that failure theory results are found in good agreement with the FEA results. Budan and Vijayarangan[8] conducted a Finite Element analysis of drilling process to predict the effects of the drilling parameters and fiber volume fraction on the surface finish, hole quality and delamination. The failure results gave a clear idea of the damage zone resulting due to the drilling operation. Durao et al[9] developed a cohesive model in order to simulate the thrust force and delamination during drilling of CFRP composites. The Finite Element model has been validated with the analytical model based on linear elastic fracture mechanics. Zitoune and Collomet[10] proposed a Numerical Finite Element method to calculate the thrust force responsible for the defect at the exit of the hole during drilling in Carbon Fiber composites. The numerical results provided the strong relationship with the experimental

* Author for correspondence

values. Rahme et al[11] developed the Finite Element model to determine the critical thrust force for delamination using a failure mechanics approach. The shape of the drill point geometry effects the delamination during drilling of FRP. Bhattacharyya and Horrigan[12] developed the Finite Element model to analyze the drilling behavior by using the LUSAS software. The Finite Element drilling was carried out using backing plate and without backing plate. In accordance with the experimental results, the Finite Element model predicts a lower value of the delamination load compared with that predicted by the model which ignores the shearing action. Durao et al.[13] studied the delamination during drilling of CFRP laminates using the Finite Element method with two different simplified drill point geometries i.e. Twist drill and C-shape drill. Singh et al.[14] developed a Finite Element model for predicting the drilling characteristics of UD-GFRP laminates. Rakesh et al.[15] conducted fem analysis using a standard FE package (ABAQUS) to investigate on the drill point geometry as an important parameter which governs the drilling induced damage

It is concluded that the thrust force and torque using Finite element analysis showed good results. In the present research work, a Finite Element model has been developed using a standard Ls-Dyna solver using Ansys 13.0 launcher. The investigation focuses mainly on comparison between experimental results and analytical results.

2. Experimental Procedure

In present study, woven glass fiber laminate specimens with 56 percent fiber volume ratio with 0°/90° were prepared with E-glass fiber using epoxy resin by hand lay-up process. To check the process parameters and their effects on drilling GFRP to find thrust force and torque, experimental studies were carried out on drilling machine with variable feed drive with a piezoelectric dynamometer of Kistler 9257B and charge amplifier of Kistler 5070A where used to capture and save outputs. The woven glass fiber plate of 100×50×2 mm has been used to drill with High speed steel of 5 mm diameter as shown in Figure 1 and Figure 2 shows the drilling process which is carried out at speed of 300 rpm and feed rate of 0.09 mm/rev was chosen to do finite element analysis and to compare with experimental results.

Figure 1. HSS drill bit.

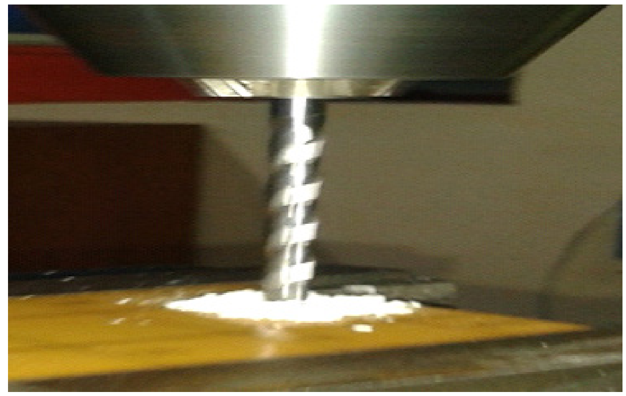

Figure 2. Drilling process.

3. Finite Element Approach

The experimental approaches were established a number of facts and theories regarding drilling of GFRP but still a lot research remain to be done. The estimation of thrust force and torque largely depends on modeling of drill bit tool and work material. There is no specific model or knowledge base which is used to analyze and understand the drill behavior of GFRP. The effect of drill with three different drill bits has been investigated. The model has been designed using CREO 1.0 software as shown in Figure 3 with the following assumptions.

- The drill is considered to be rigid.
- For fem study, a 20 mm square plate was considered with all the outer boundary planes are to be constrained in all the directions including rotations.
- The actual drill bit has a length of 75 mm but for computational model as per time perspective 5 mm has been chosen.
- The maximum thrust force and torque was taken as the reactions obtained at the boundary nodes in X and Z directions over steady zone.

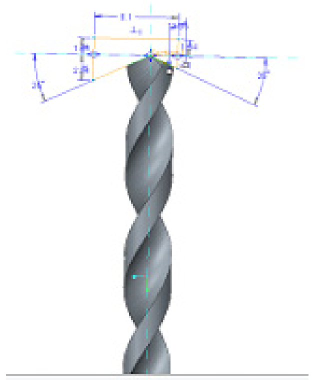

Figure 3. Design of drill bit.

3.1 Meshing of Drill Bit

The tool geometry model was imported from CAD design package in IGES format to HYPRMESH 11.0 for meshing. The tool has been meshed with ten-nodded tetrahedral element with an average element size of 0.59 mm. A fine mesh was done only at the chisel edge of average dimension 0.032 mm as shown in Figure 4.

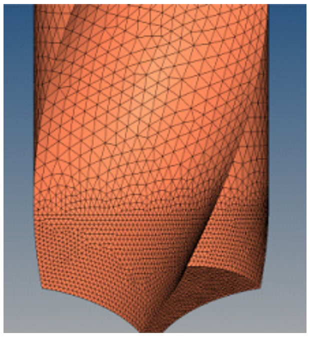

Figure 4. Meshed drill bit.

3.2 Material Constitutive Model

The material model used for work piece was orthotropic elastic. The data used for orthotropic model follows in Table 1. The work piece has been meshed with eight-nodded hexa element with an average element size of 5.8 mm. A fine mesh was done only at the center of average dimension 0.074 mm as shown in Figure 5.

Table 1. Specifications

Elastic modulus (GPa)		Shear modulus (GPa)		Poisson's ratios	
Notations	Values	Notations	Values	Notations	Values
E_{11}	21	G_{12}	1.52	υ_{12}	0.26
E_{22}	21	G_{23}	1.52	υ_{23}	0.26
E_{33}	7	G_{13}	2.65	υ_{13}	0.3

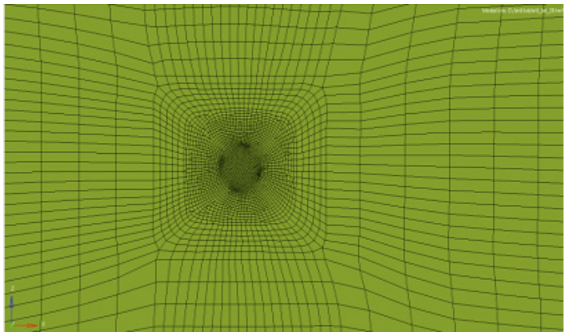

Figure 5. Meshed work piece.

3.3 Solver Methodology

The present work was carried out in LS-DYNA solver using ANSYS 13.0 launcher as the contact type for drill bit and laminated plate is surface to surface eroding (ESTS) and the loading options which were taken on all axis to calculate thrust force and torque. Figure 6 shows the displacement at initial entry of drilling and Figure 7 shows the displacement at middle of drilling and Figure 8 shows the displacement at the exit of drilling at speed of 300 rpm and feed rate of 0.09 mm/rev.

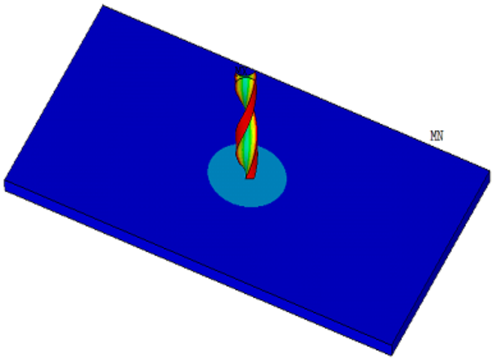

Figure 6. Displacement at entry.

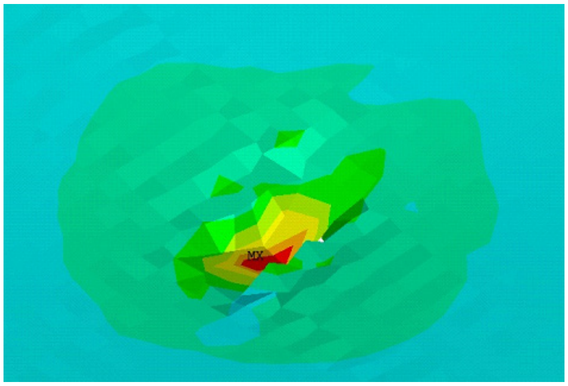

Figure 7. Displacement at middle of drilling.

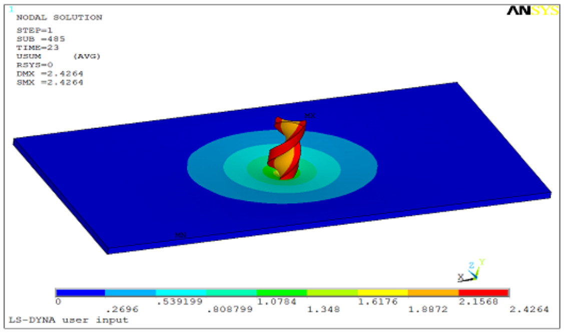

Figure 8. Displacement at exit.

4. Results and Discussion

In the present work, experimental as well as finite element simulation of drilling process has been carried out as the effect of HSS drill bit at 300 rpm speed and 0.09 mm/rev feed rate on thrust force and torque was studied. Figure 9 shows the maximum thrust force obtained through experiment, Figure 10 shows the maximum torque obtained through experiment, Figure 11 shows the maximum thrust force obtained through fem analysis and Figure 12 shows the maximum torque obtained through fem analysis. All the output results from experimental and analytical results were shown in Table 2.

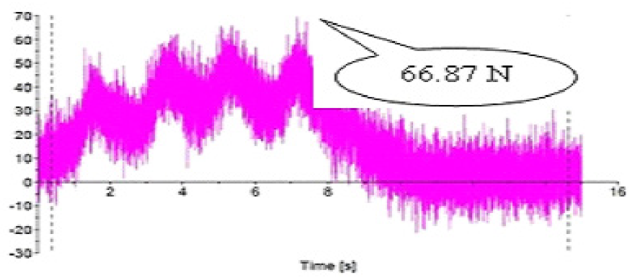

Figure 9. Thrust force through experiment.

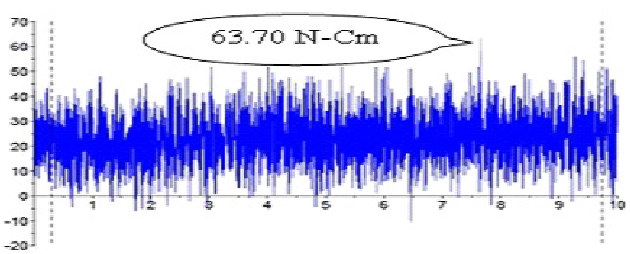

Figure 10. Torque through experiment.

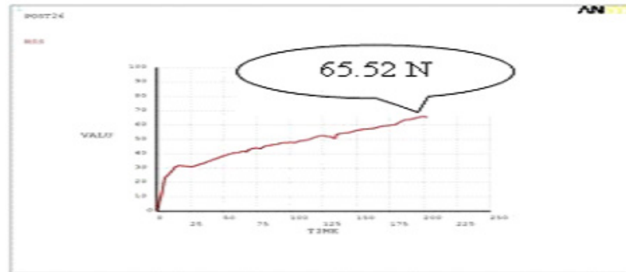

Figure 11. Thrust force through analysis.

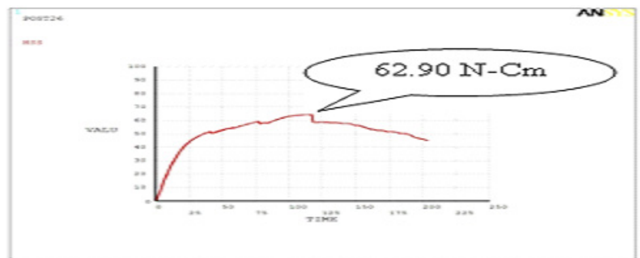

Figure 12. Torque through analysis.

Table 2. Output results

Description	Speed (rpm)	Feed (mm/rev)	Thrust Force (N)	Torque (N-Cm)
Experimental value	600	0.09	66.87	63.70
Analytical value	600	0.09	65.52	62.90

5. Conclusion

The main objective of the present research is to develop a FE model in order to investigate the drill behavior of GFRP composites. The following conclusions were drawn on the basis of the present investigation:

- Experimental work results are compared with Finite element results and found that the thrust force and torque determined by finite element analysis showed good results when compared with the experimental results.
- Utilization of this type will improve the quality of drilled area, if online monitoring introduced. This system will reduce the tedious model making, time and computational cost.
- Further improvement of process can be possible, by introducing different variables and wider range of cutting conditions.

6. References

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