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Drilling simulation of Fibrous Composites: Technical Note

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ABSTRACT:

Drilling of composite material is more complex than conventional drilling, as material removal of isotropic material is uniform than composite material. The cutting edge of drill bit will damage the composite material and removes the fibre in indefinite manner. Improper holes in composite material will cause improper assembly and even can cause premature failure of components made with composite material such as CFRP, Carbon fibre, glass epoxy. By estimating optimal machining parameter such as Feed rate and cutting speed, machining of improper holes in composite material can be eliminated. Optimal machining parameter can be estimated by simulation of composite material. Simulation is performed with help of Abaqus/Explicit software from Simulia.

KEYWORDS:

Abaqus; Composite; Lamina; Laminate; Ply; Failure; Fibre; Braid; Delamination; VUMAT

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1. Introduction

As material sciences have improved over past decades, many materials can be designed and manufactured to meet the application demand. Such us composite materials tailored to have high tensile strength rather than a compressive strength and shear strength. As Nano carbon tubes composites are exploited to have high young's modulus such as single walled carbon nanotube-borosilicate glass composite [1, 2]. Tailored materials can't be implemented directly into application without destructive and non-destructive test. Rapid acceleration of application is done with usages of simulation. Simulation alone is sufficed when material properties are known to full extent. As of now, there is no unified solution on material science to predict material damage for different kinds of material like anisotropic, isotropic, metal matrix composite and fibrous composite. So, constant experimental analysis and numerical analysis are required to validate simulation analysis [3].

Simulation of metal matrix composite is same as isotropic material simulation when material is defined accordingly to structure in metal matrix. Fibrous composite on other hand composes of different fibres with different material in different fibre orientation [4-5]. Each ply is composition of fibres. Most common ply orientation is 0 °, 45 ° and 90 °. Material properties for a fibrous material are defined on basis of mechanical properties of individual fibre material. Fibres can be braided [6] and twisted to form a new complex single strand composed of different fibres. As materials are tailored by individual fibre, machinability of tailored material can be challenging and complex to simulate. Existing isotropic material will not be sufficient enough to describe damage under gone by a fibrous composite material. On different orientation in fibrous material have different mechanical properties. One fibre orientation can compensate other mechanical property on other orientation. Fibrous composite material is a mix bag of different material fibres. Failure of composite fibre is mostly explained by Hashin unidirectional fibre failure [7]. Hashin unidirectional fibre failure is not sufficient to fit into experimental analysis. Therefore modified Hashin failure criteria are followed [8]. Modified Hashin failure is called as Hashin-puck composite failure criteria.

2. Modelling & simulation

Modified Hashin-Puck composite failure is implemented [8] in Abaqus/Explicit via user-subroutine called as VUMAT. Material property of Fibrous composite is passed to VUMAT through User-Defined Materials in material module in Abaqus/Explicit. Ply is modelled as a cuboid with thickness less than 2 mm. Ply thickness can be obtained from manufacturer's specification sheet. A twist drill bit modelled in CAD software and imported into Part module in Abaqus. Lamina or ply is stacked up each other in assembly module till desired laminate thickness. Material property is assigned to ply as normal as isotropic material. All stacked up ply have same material property as defined in part property of single ply. More different material properties can be assigned to ply and can be mix-matched in laminate with different material orientation in ply. For different orientation of ply, separate ply has to be modelled to get different material orientation. Back plate can be defined, if fibrous composite deform under its own weight.

Interactions have to be defined between laminates and drill bit. Surface to node interaction is defined with penalty contact with friction factor. Friction factor varies from material to material combination of laminates to drill bit. Appropriate friction factor have to be estimated. A global interaction is defined between ply to ply, as friction between ply-ply have larger impact in simulation. An approximate ply-ply friction is estimated as 0.6 for inner lamina interaction. Experimental boundary conditions are implemented in simulation, by restriction on freedom of motion in respective part in assembly. Drill bit is freely allowed to translate and rotate along Y-Axis and all four outer faces of laminate are arrested with clamped boundary conditions. Feed rate and cutting speed are defined in accordance with experimental analysis. Drill bit and laminate is meshed with three dimensional stresses with desired mesh element. Smaller mesh size will have higher accuracy and details but will take longer computation time. The meshes of drill bit, composite and back plate assembly are shown in Fig. 1 to Fig. 3.

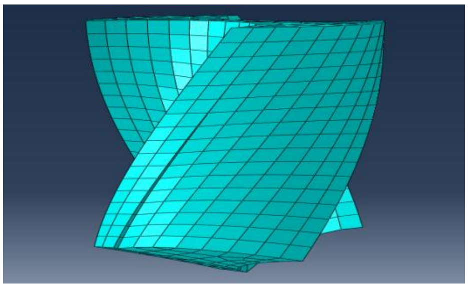

Fig. 1: Drill bit mesh

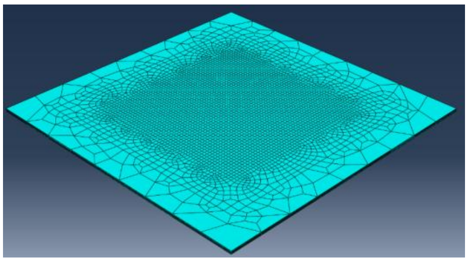

Fig. 2: Ply mesh with ply thickness less than 1 mm

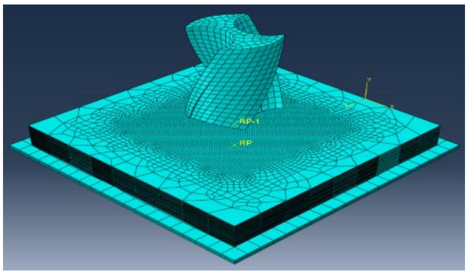

Fig. 3: Assembly of laminate and drill bit with back plate in mesh

3. Results and discussion

The results of the simulations are presented in Fig. 4 to Fig. 6. Fig. 7 shows the delaminations post drilling. Reaction force is estimated at tip of the drill bit. As drill tip experience maximum reactive force throughout drilling operation. The reaction force vs. time is plotted in Fig. 8. The simulation is run for 3 seconds. Further analysis is required for validity of the model. For some random feed rate, reaction force is not in the expected range. As reaction force vs. feed rate follows a linear trend, reaction force can be estimated by linear regression and accuracy of results yielded through simulation can be estimated. Simulation parameters are given in Table 1. Reaction force vs. time graph depicts the reactive force acting against the drill bit over various layers in composite. A maximum peak is observed in graph, when the drill bit experience maximum resistance to penetration on laminate. Maximum peak observed will vary from feed rate to feed rate. Negative dip in graph is observed because of least reaction force offered from laminate. Drilling operation is completed at 1.8 s. Reaction force after completion of drilling operation is neglected.

Table 1: Simulation parameters

Parameter	Details
Material type:	CFRP
Drill type:	Twist drill
Laminate size:	(18 x 18 x 0.22) mm
Drill diameter:	6 mm
Spindle speed:	1326.29 rpm
Feed rate:	2.21 mm/s

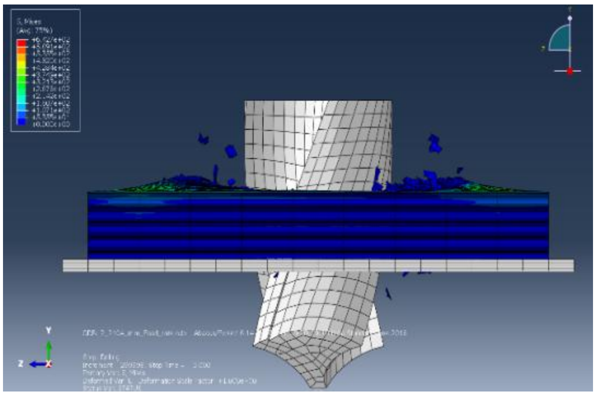

Fig. 4: Von-Mises stress with chips at side-view

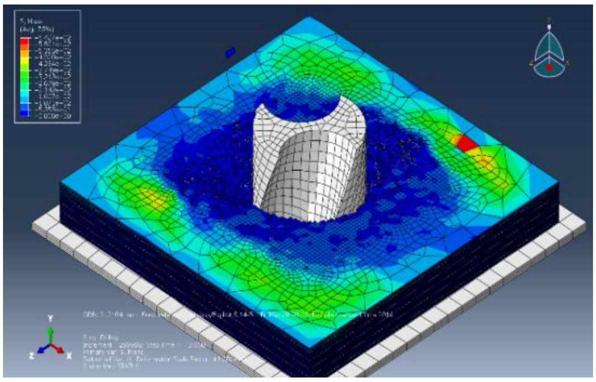

Fig. 5: Von-Mises stress at isometric view

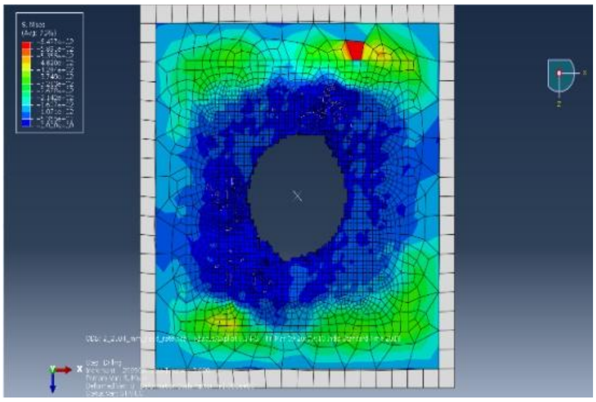

Fig. 6: Improper hole due to non-optimal machining parameter

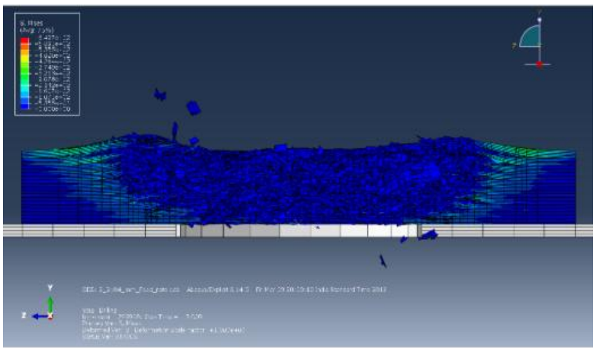

Fig. 7: Delamination of laminates

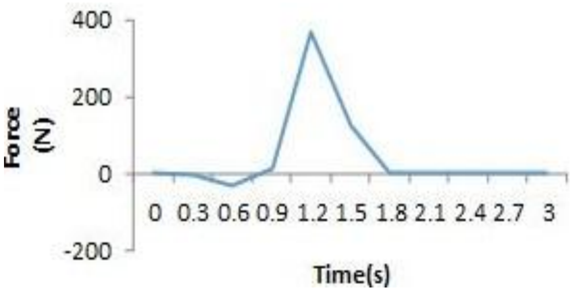

Fig. 8: Reaction force vs. time

4. Conclusion

Simulation of drilling of fibrous composite is in close agreement with the expected behaviour. Visual inspection states that behaviour of composite material can be predicted with modified Hashin failure criteria [7]. Due to computational limit, mesh size is moderate. By further analysis at fine mesh, even refined results can be obtained. Highly accurate results are only important when composite material is intended to be used in a mission critical application. For any different composite material, modified Hashin failure criteria can be used.

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