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Study and Analysis of Parametric Cutting Force & Torque in Drilling of Carbon Fiber Reinforced Composites

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***Abstract--* 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 and torque has been cited as main cause of delamination. In this paper the objective was to establish correlation between cutting parameters and thrust force, drilling torque and delamination. For the different value of point angle, speed and feed rate the Tsai-wu failure criterion index were to be find out for the lamina failure. Drilling tests were carried out on carbon epoxy composite material using HSS-Co twist drill. Analysis with the help of Ansys 15.0 software.**

***Index Terms*— Delamination, Thrust Force, Torque, Point angle.**

I. INTRODUCTION

Carbon Fiber Reinforced composite materials are finding increased applications in variety of engineering fields such as aeronautical, automotive, etc and subsequently, the need for accurate machining of composites has increased enormously. The mechanism behind the machining of carbon fiber reinforced composite is quite different from that of metals, and it brings about many undesirable results, such as rapid tool wear, rough surface finishes on finished components, and a defective sub-surface layer with cracks and delamination.

In order to drill holes efficiently with the least waste and defects, it is essential to understand the machining behavior. Traditional machining research has relied extensively on using experiments to understand machining behavior, but as materials get more complex obtaining results from experiments can become very cumbersome. Hence there is a need to turn to alternate methods of experimental techniques and this is where we find analytical and numerical modeling techniques useful. Let us first take a look at what FRP composites are and why such a modeling approach is preferred. Composites have a low co-efficient of thermal expansion, which can provide a greater dimensional stability when required. The machining of fiber reinforced composite materials is not the same as the machining of conventional metals. Hence, the spindle speed, drill diameter, feed rate of the machining operation should be selected carefully in the machining of fiber composite materials.

Composite materials are continuously replacing traditional materials due to their excellent properties. A single large part made of composites can replace many metal parts. They have high stiffness to density ratio thereby providing greater strength at lighter weights. The use of light-weight materials means an increase in the fuel efficiency of automobiles and airplanes. Also the endurance limit of some composites is higher than that of aluminum and steel. Most composites are made up of plastics or resins and hence provide a high level of resistance to corrosion, while aluminum and iron need special treatments like alloying to protect them from corrosion. Composites have a low co-efficient of thermal expansion, which can provide a greater dimensional stability when required. The machining of fiber reinforced composite materials is not the same as the machining of conventional metals. Hence, the spindle speed, drill diameter, feed rate of the machining operation should be selected carefully in the machining of fiber composite materials. Drilling of composite materials is analyzed by many researchers.

II. MATERIALS SELECTION

Carbon Fiber Reinforced Polymers (CFRP) are used for manufacturing: automotive marine and aerospace parts, sport goods , bicycle frames. Composite materials for drilling were fabricated from woven fabric carbon fibre/epoxy matrix. The stacking sequence of the laminates was 0°/90° and had a 55 % cured fibre volume fraction.

A. Properties of composites

Table 1: Properties of composites

Property	Carbon Fiber Reinforced Composite
Young's modulus E_1	155 GPa
Young's modulus E_2	15.2 GPa
Young's modulus E_3	15.2 GPa
Poisson's ratio ν_{23}	0.458
Poisson's ratio ν_{13}	0.248
Poisson's ratio ν_{12}	0.248
Shear modulus G_{23}	3.20 GPa
Shear modulus G_{13}	4.40GPa
Shear modulus G_{12}	4.40Gpa
Density	1600 kg/m^3

B. Parameters considered for analysis

Table 2: Parameters considered

Drilling Parameters	**Point Angle**	**Spindle Speed**	**Feed Rate**
Units	(^{o})	r.p.m	mm/min
Level 1	110	3000	100
Level 2	118	2000	300
Level 3	135	1000	500

III. FINITE ELEMENT ANALYSIS

Computer-aided engineering (CAE) is the application of computer software in engineering to evaluate components and assemblies. It encompasses simulation, validation, and optimization of products and manufacturing tools. The primary application of CAE, used in civil, mechanical, aerospace, and electronic engineering, takes the form of FEA alongside computer-aided design (CAD)

A.Element Definition

In this analysis work , SHELL 181 was used for composite modelling shell element with 6 degrees of freedom .

B.Workpiece

After selecting SHELL 181 element the tabulated values of properties are applied the Workpiece of dimension 10*10 cm with thickness of 5 mm was modelled.

C. Meshing

Initially constructing the finite element workpiece model the solid elements were used to meshthe workpiece with uniform mesh density all over the workpiece. They had a disadvantageofincreasing the computational time. The original mesh of workpiece as shown

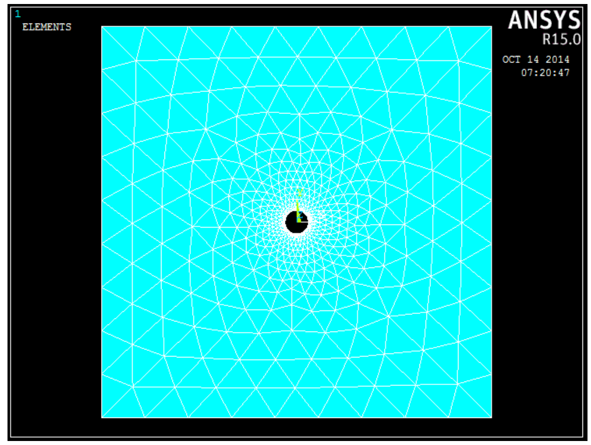


Fig.1.Meshing of workpiece

D. Boundary Conditions

Boundary conditions were simulated according to experimental set-up. The base and top face of the workpiece are constrained in all degree of freedom. The material property of workpiece was given as that of carbon fiber reinforced polymer..

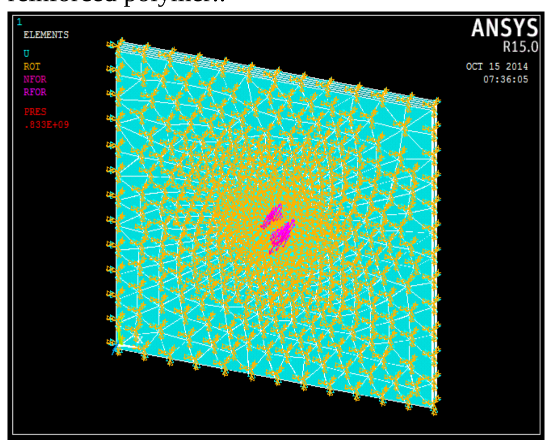


Fig.2 Applying boundary conditions

E. Element solution

Below shown is element solution of the specimen after which failure criteria to be define. Tsai-wu failure criterion was chosen as for composite material.

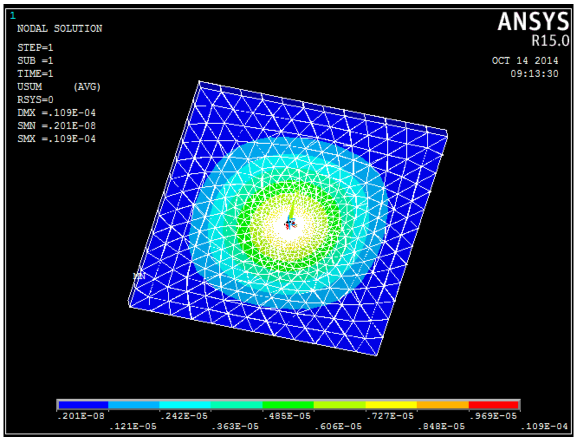


Fig.3 Element solution

IV. FAILURE ANALYSIS

A. Calculation of thrust force & pressure

Thrust force during drilling can be defined as "the force acting along the axis of the drill during the cutting process." Cutting forces help monitor tool wear, since forces increase with tool wear. Thrust force is also used to monitor tool wear and, in turn, monitor tool life. Tool failure can occur if tool wear is not monitored. Other than being an important factor in the monitoring of tool wear, thrust force is considered to be the major contributor of de lamination during drilling. Considerable research has been done to prove that there is a "critical thrust force" that causes de lamination, and thrust force below that will constrain or

eliminate de lamination during drilling. Vibratory drilling has been known as one of the methods to reduce thrust force during drilling of steel and during drilling of composites. Machining of de lamination free composites using conventional methods would lower the cutting quantities. If the "critical thrust force" is known, then the machining efficiency can be increased and higher quantities can be machined. This thesis deals with the prediction of thrust force at which de lamination will occur during drilling of composites.

Thrust Force for uni-directional composite plate

F =1.4365ρ+402.8315f-98.031………….(1)

Where

ρ=point angle of drill bit.

f= feed of drill pit (mm/rev).

Thrust pressure for uni-directional composite plate

(q)=F/A …………(2)

A = 3.14*d2

Where,

F= Thrust Force

A= Area of drilled hole

D = drilled hole.

Because the thrust force applied is very difficult. Reason is to apply thrust force is each node of the drilled hole. It's complicated one. So the thrust pressure is used to apply input into finite element software.

Table.3 calculation of thrust force and pressure

Point angle	**Feed**	**Thrust force**	**Circumferential Pressure**
(^{o})	mm/s	N	Gpa
110	0.1	706.75	25
118	0.3	765	27
135	0.5	848	30

B Drill Point Angle 110^O

After applying different element conditions and meshing steps the below shown results are shown for tungsten HSS drilll. After applying Tsai-wu failure criterion we get the result shown below.

Here we can observe that when there is change in point angle there is also increase or decrease in damage around the hole. In this case also point angle of 110 make.

Table 4 Tsai-Wu failure criterion with point angle 110^o

	X	Y	Z
strain in tension	0.01164	0.00155	0.00155
strain in compression	-0.01132	-0.02182	-0.02182
	XY	YZ	XZ
strain in shear	0.01218	0.0013	0.01367
	X N/m^2	Y N/m^2	Z N/m^2
stress in tension	1260.12x10^3	3949.56x10^3	575.12x10^3
stress in compression	-223.78x10^3	1534.16x10^3	7.91.4x10^3
	S_{XY}	S_{YZ}	S_{XZ}
stress in shear	-17.12x10^3	27.34x10^3	-41.16x10^3

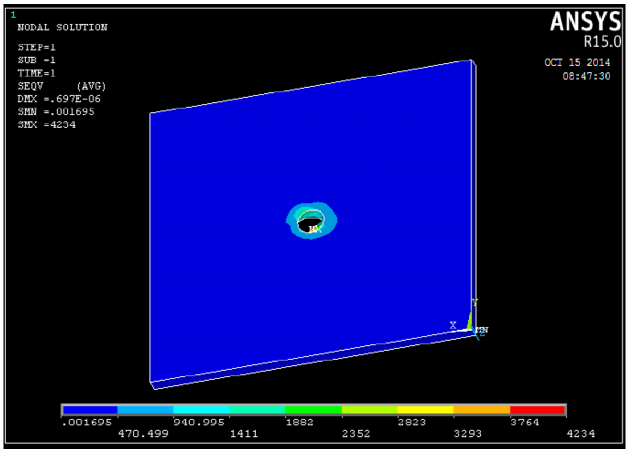


Figure 4. Drilled hole with 110° point angle HSS drill

C. Drill Point Angle 118°

After applying different element conditions and meshing steps the below shown results are shown for tungsten HSS drilll. In this case value of pressure applied for the point angle of 118°.

Table 5 Tsai-Wu failure criterion with point angle 118°

	X	Y	Z
strain in tension	0.026423	0.004512	0.004512
strain in compression	-0.023167	-0.02615	-0.02614
	XY	YZ	XZ
strain in shear	0.031801	0.011302	0.01267
	X	Y	Z
stress in tension	$2146.21x10^3$	$3210.16x10^3$	$575.21x10^3$
stress in compression	$-213.06x10^3$	$1532.57x10^3$	$703.3x10^3$
	S_{XY}	S_{YZ}	S_{XZ}
stress in shear	$-51.67X10^3$	$31.07X10^3$	$-43.6X10^3$

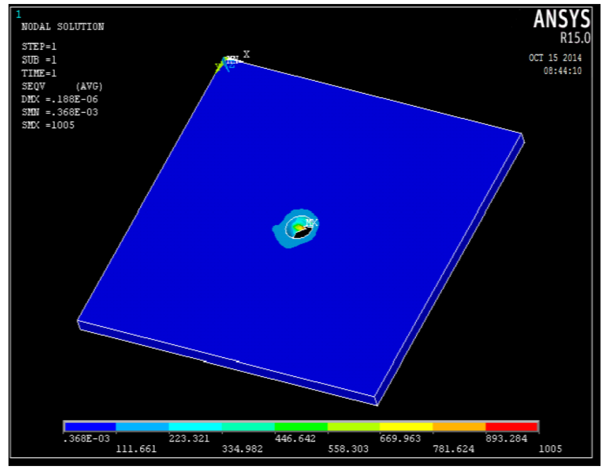


Figure 5. Drilled hole with 118° point angle HSS drill

D Drill Point Angle 135°

After applying different element conditions and meshing steps the below shown results are shown for tungsten HSS drilll. In this case value of pressure applied for the point angle of 135°

Table 6 Tsai-Wu failure criterion with point angle 135°

	X	Y	Z
strain in tension	0.03624	0.005245	0.005225
strain in compression	-0.03332	-0.05382	-0.05282
	XY	YZ	XZ
strain in shear	0.02318	0.2113	0.23367
	X	Y	Z
stress in tension	$3460.04x10^3$	$4449.78x10^3$	$1275.07x10^3$
stress in compression	$-321.97x10^3$	$204.12x10^3$	$-359.15x10^3$
	S_{XY}	S_{YZ}	S_{XZ}
stress in shear	$-34.21x10^3$	$27.34x10^3$	$-41.16x10^3$

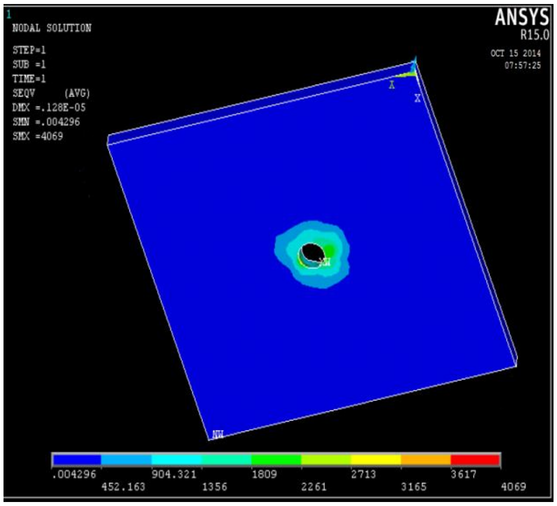


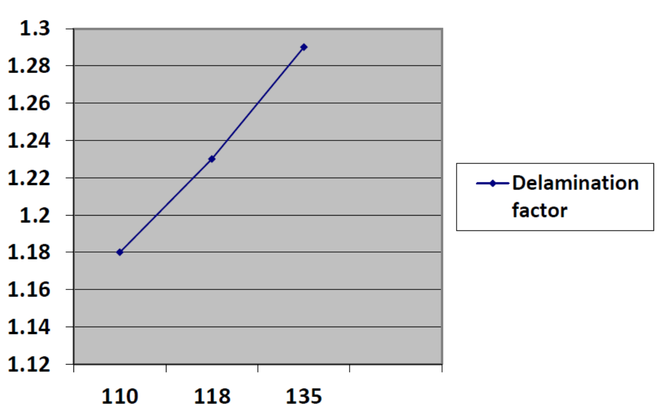
Figure 7 Drilled hole with 135° point angle HSS drill

V. RESULTS AND DISCUSSIONS

Trial and error method is used to find critical thrust pressure with constant drill bit size. The pressure increased with point angle of 135°, Tsai-Wu failure index reached higher value is called critical thrust pressure. From this, it can be observed that the critical thrust pressure is about 30MPa will increases the delamination factor. The above conclusion arrived from Tsai-Wu failure criteria is further validated from other theoretical failure criteria viz. Delamination factor values of drilling Carbon Fiber Reinforced composite using FEM of HSS twist drill are shown bellow.

Table 7 Tsai-Wu failure index

Drilling point angle	110°	118°	135°
Delamination factor	1.18	1.23	1.29
Tsai-Wu failure index	0.88	1.16	1.2



Graph.1:Point angle Vs Delamination factor

VI. CONCLUSION

In this paper we predict delamination level generated in composite when drilling due to the drilling thrust and torque. The finite element simulations were carried out on carbon fiber sheet after doing holes to study the effect of cutting forces and torque value. Predictions of cutting forces help designers to design tools without having to conduct experiments. This cut down the time and money involved in product development life cycle. The cutting forces exerted by the cutting tool on the work piece during a machining have been identified in order to control the delamination..

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