QUANTIFING DEFECTS IN DRILLING UD-GFRP

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Rezumat. *Compozitele cu matrice polimerică au devenit de la materiale exotice folosite doar în aplicații de nişă după cel de-al doilea război mondial, la materiale comune folosite în diverse aplicații. În prezent există o tendință accentuată de înlocuire a materialelor metalice cu materiale compozite, în special cu compozite polimerice, datorită proprietăților superioare ale acestora, proprietăți ce pot fi proiectate şi perfecționate pentru a răspunde unor cerințe specifice. Deşi aceste materiale sunt realizate la forma necesară, deseori este nevoie şi o prelucrare a acestora în vederea asamblării. Găurirea este cel mai des întâlnit procedeu de prelucrare a materialelor compozite cu matrice polimerică. Un defect des întâlnit la acest tip de prelucrare îl constituie defectele muchiilor ce include şi fibrele netăiate. Acest raport abordează probleme legate de proprietățile mecanice ale acestui tip de materiale cu fibre continui lungi ranforsat cu fibră de sticlă şi comportarea lui la găurire.*

Abstract. *Fibre reinforced polymer (FRP) composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications. Currently there is a strong tendency to replace metals with composite materials, particulary polymer composites, because of their superior properties, properties that can be designed and built to meet specific requirements. Though these composites are manufactured in near-net shape, machining is often necessary for integration and assembly. Drilling is the most frequently employed operation of secondary machining for fiber-reinforced materials owing to the need for structure joining. A commonly observed defect in drilling is edge defects which include incomplete fiber cutting. This report approaches issues related to mechanical properties of polymer matrix composites with continous long fibers, fiberglass reinforced, and aspects of the drilling process of these types of materials for assembling of different components.*

Keywords: composites, twist drill, defects, UD-GFRP, drilling.

1. Introduction

Fibre reinforced polymer (FRP) composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications.Currently

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there is a strong tendency to replace metals with composite materials, particulary polymer composites, because of their superior properties, properties that can be designed and built to meet specific requirements. The incresead used of polymer composites can be justified due to improving manufacturing technologies of composite materials and technologies for obtaining reinforcing elements, and benefits of full cycle manufacturing simulation. Composites are now used in aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure, and there is the potential for common use in medical prothesis and microelectronic devices.[9]

Drilling of FRP composite materials presents a plethora of questions to the engineers and scientists due to their anisotropic properties and the nature of the constituents that make difficult to predict the behavior of the materials. A number of research endeavors have been made in the recent past to fully characterize the drilling process for FRP composite materials.

Though most of the composite products are made to a near-net shape using any of the primary manufacturing processes, such as hand-lay up, compression molding, pultrusion, and filament winding, secondary manufacturing in terms of machining and drilling sometimes becomes unavoidable. Hole making thus becomes an integral part of the product development cycle. A number of techniques have been used to make holes in composite laminates, but conventional drilling by far is the most widely accepted hole generation method. In most cases a composite part needs to be assembled to other parts, either in composite or in a differet material (steel, aluminium alloys, wood, etc). Since composite materials cannot be welded, and glueing is quite complex (and cannot be disassembled), mechanical joining (rods, pins, fasteners, rivets, etc) is the solution commonly adopted to assemble a composite part to other parts. [3]

Drilling is one of the most commonly used machining processes. A typical drill has several design parameters such as tip angle, chisel edge lenght, cutting lip lenght and helix angle. Each one of these parameters affectting the cutting forces and drilled hole qualities in various ways. [7]. In order to achieve the necessary knowledges for better understanding and optimization of the phenomena that takes place in drilling of composite materials reinforced with glass fiber we need to model and simulate the process. This modeling will help us to control the process parameters so we can obtaine the most accurate surfaces to meet the requirements imposed.

2. Theoretical background and research gap

There has been considerable work in the past decade studying the machining of FRP materials. Komanduri et al [6] studied the orthogonal machining of FRP and concluded that fiber orientation is the major influencer of the machining behavior.

Gordon and Hillery [2] presented a detailed review of work in the machining of composite materials, though they do not focus much on drilling and delamination.

Hocheng and Dharan [3] presented the first model that attempted to predict the occurrence of delamination during drilling of fiber reinforced composites. Two modes of delamination failure were identified, push-out during drill exit and peel-up during drill entry. During push-out delamination, the uncut-thickness decreases as the drill is fed through the material and at a critical point the drilling thrust force exceeds the inter-laminar bond strength resulting in delamination. Peel-up delamination occurs in the same mechanism, with the cutting action introducing a peeling force upwards forcing the layers to delaminate.

Jain and Yang [4] revisited the work of Hocheng and Dharan and took into account anisotropy effects to determine the critical thrust force. Lachaud et al [7] also used a similar fracture energy approach as the previous work, but modeled the drilling forces as a distributed load and took into account material anisotropy. Zhang et al [10] presented a detailed study where the nature of delamination and improper fiber cutting during drilling were discussed.

3. Experimental Research

The machined material is a UD-GFRP made by pultrusion provided by Fiberline with a thickness of 10 mm. The mechanical properties of this material valid in the temperature range of -20^{0}C to 60^{0}C are presented in the tables below:

Table 1. Material properties

Typical stiffness figures and transverse contraction (dry condition)			
		[MPa]	[--]
Modulus of elasticity	E_0	23000/28000	
Modulus of elasticity	E_{90}	8500	
Modulus in shear	G	3000	
Poisson's ratio	$\upsilon_{0,90}$		0.23
Poisson's ratio	$\upsilon_{90,0}$		0.09

Drilling experiments were performed on a high speed machining center MIKRON HSM 600U. It is a 5 axis CNC machining with a ITNC 530 control with the following specifications:

Table 2. MIKRON HSM 600U specifications

Rotation speed	Feed rate	Nominal power (Sl)	Nominal torque
36000rpm	40m/min	32kW	16Nm

The tool used is an uncoated carbide drill made by Guhring with a 110^0 point angle with a diameter of 6.35mm. During the experiments, two different ways of monitoring the cutting forces were used. The first one is based on the scope function directly on the controller Heidenhain ITNC530 that allows to save numerous information (spindle current, feed current, electrical and mechanical power consumption etc...) directly from the machine controller. The second methodology used for the monitoring is based on 6 component dynamometer (cutting forces and moments).

To evaluate the defects that apears in drilling we used a digital microscope Dino-Lite Pro AM413T that has a high resolution of 1,3 megapixel and an adjustable magnification of appr. 10 to 70 times as well as 200x. This model also provides the possibility to calibrate the microscope for measurements. Most used model in the industrial field.

4. Experimental Results

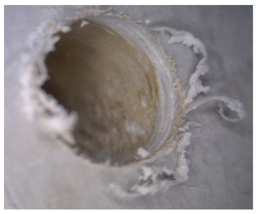
In order to see how the defects evolves, we have made two series of testes. The first regarding the influence of the cutting speed and feed, and the second the influence of the tool wear. For the first series of tests were chosen three values for the cutting speed and three values for the feed as following:

- v_c= 50m/min, v_c= 100m/min, v_c= 150m/min
- f = 0.05mm/rot, f= 0.10mm/rot, f= 0.15mm/rot.

v_c=100m/min
f=0,1mm/rot

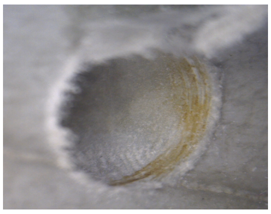
v_c=100m/min
f=0,15mm/rot

v_c=150m/min
f=0,1mm/rot



v_c=50m/min
f=0,1mm/rot

The cutting conditions used for evaluating the tool wear are cutting speed of 100m/min (N=5000rpm) and a feed speed of 250mm/min. During the cutting process no coolant was used.



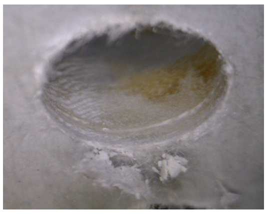


Fig. 1 Burning in drilling UD-GFRP

a. Hole nr. 1; **b.** Hole nr. 30.

Conclusions

Measuring the defects around a hole edge during FRP machining is challenging due to several reasons, including the out-of-plane nature of the defects and the brittle fibers breaking during measurement. Also, sometimes the defects themselves may not be of concern, but the debris they cause during assembly may be an issue. It is again instructive to draw comparisons between FRP drilling and metal drilling to better understand techniques for quantitative characterization as metrology and process control methods for metal machining are more advanced.

Non-contact optical techniques have been successfully demonstrated to measure edge defects formed during micro-drilling. Since these methods do not rely on the properties of the material being machined, they are ideal for application in the case of FRPs. Koand Park (2004) demonstrated that the Conoscopic Holography method is best suited as it can capture very small features, which is very important in the case of FRPs as the fibers can be only a few-hundred microns in diameter. It is also possible to use the Conoscopic method to obtain 3D profiles of the burr. This information, along with the mechanical properties of the fibers can be used to estimate the behavior of the edge defects during assembly.

Ultimately, a standardized method to formally characterize the tolerable defect around an edge is needed for optimal manufacturing with minimal waste of effort from over-precision. Several characterization methods have been used for metal burrs [1,5] and these can be adapted and extended to include FRP machining as well.

Although empirical methods may be currently better suited to predict defects, analytical models that take into account material properties are useful in material design. More sophisticated models can also take into account cutting dynamics; however, given the complexity of the drill geometry and the different phases in the workpiece, these models will need numerical approaches to arrive at practical solutions to this complex problem.

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R E F E R E N C E S

[1] Gillespie, L. K., "Burr and edge standards: A compilation of standards", Woldwide Burr Technology Comitee, (1996);

[2] Gordon, S., Hillery, M.T., "A review of the cutting of composite materials", Proceeding of Institution of Mechanical Engineers, Vol.217(1), pp. 35-45, (2002);

[3] Hocheng, H., Dharan,C.K.H. "Delamination during drilling in composite laminates", Journal of Engineering for Industry, Vol.112, pp.236-239, (1990);

[4] Jain, S., Yang, D.C.H., "Delamination-free drilling of composite laminates", Journal of Engineering for Industry, Vol.116, pp.475-481, (1994);

[5] Kato, K., "The standardized classification for the edge quality of the precise machining products", Proc. of the 5th International Conference on Deburring and Surface Finishing;

[6] Komanduri, R., "Machining fiber-reinforced composites", Mechanical Engineering, vol.115,pp.58-64, (1993);

[7] Lachaud, F., Piquet, R., Collombet, F., Surcin, L., "Drilling of composite structures", Composite Structures, Vol.52, pp.511-516, (2001);

[8] Singh I, Nayak D, Saxena R, Bhatnagar N - Drilling Induced Damage in FRP Composite Laminates;

[9] Tong L., Mouritz A.P. and. Bannister M.K - 3D Fibre Reinforced Polymer Composites, Elsevier, ISBN 0-08-043938-1;

[10] Zhang, L., Zhang, H., Xiang, M. W., A force Prediction Model for cutting unidirectional fibre-reinforced plastics, Machining Science and Technology, 5 (3), pp. 293-305, 2001.