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Drilling analysis of chopped composites

U.A. Khashaba [a,*], M.A. Seif [b], M.A. Elhamid [a]

[a] Mechanical Design and Production Engineering Department, Faculty of Engineering, Zagazig University, P.O. Box 44519 Zagazig, Egypt
[b] Mechanical Engineering Department, Alabama A&M University, Normal, AL 35762, USA

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Abstract

This work investigates the effects of the drilling parameters, speed, and feed, on the required cutting forces and torques in drilling chopped composites with different fiber volume fractions. Three speeds, five feeds, and five fiber volume fractures are used in this study. The results show that feeds and fiber volumes have direct effects on thrust forces and torques. On the other hand, increasing the cutting speed reduces the associated thrust force and torque, especially at high feed values. Using multivariable linear regression analysis, empirical formulas that correlate favorably with the obtained results have been developed. These formulas would be useful in drilling chopped composites. The influence of cutting parameters on peel-up and push-out delaminations that occurs at drill entrance and drill exit respectively the specimen surfaces have been investigated. No clear effect of the cutting speed on the delamination size is observed, while the delamination size decreases with decreasing the feed. Delamination-free in drilling chopped composites with high fiber volume fraction remains as a problem to be further investigated.

Keywords: A. Laminates; B. Fracture; B. Mechanical properties; E. Machining

1. Introduction

The variation of the geometrical parameters along the cutting edge of the twist drill makes drilling a complex machining process. The chisel edge of the drill and the edge of the margins have unfavorable geometrical parameters [1,2]. The rake angles on the chisel edge have large negative values. This makes cutting process difficult and sharply increases the feeding force required for drilling holes. The relief angles at the edge of the margins are equal to zero. This leads to intensive friction and wear. The variation of the rake angle along the whole length of the lip is an essential shortcoming of twist drills, since it leads to complex conditions of chip formation. The actual value of the relief angle during the drill operation differs from that obtained in sharpening and measured in the static state. This is explained by the fact that the drill not only rotates, but also travels axially during operation. The path of the motion of a point on the lip will not be a circle (as assumed in measuring the relief angle), but a helix of a lead equal to the feed of the drill in millimeters per revolution. Thus, the surface of the cut formed by the whole cutting edge will be a helical surface. The maximum cutting speed is, of course, on the periphery of the drill at the outer corner of the cutting lip. This is one of the principal reasons for intensive wear of this zone, and this limits drill life.

The use of fiber-reinforced composite materials in automobile and aerospace industries has grown considerably in recent years because of their unique properties such as high specific stiffness and strength, high damping, good corrosive resistance, and low thermal expansion. Drilling is usually the final operation during the assembly of the structures in these applications. Any defects that lead to the rejection of the parts represent an expensive loss. For example, in the aircraft industry, drilling-associated delamination accounts for 60% of all part rejections during final assembly of an aircraft [3]. The economic impact of this is significant considering the value associated with the part when it reaches the assembly stage. The quality of the

* Corresponding author. Tel.: +20 10 336 4264; fax: +20 55 230 4987.
E-mail address: khashabu@hotmail.com (U.A. Khashaba).

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drilled holes such as waviness/roughness of its wall surface, axial straightness, and roundness of the hole cross-section can cause high stresses on the rivet, which will lead to its failure. Stress concentration, delamination, and micro-cracking associated with machined holes significantly reduce the composites performance [4–6].

Several hole production processes, including conventional drilling, ultrasonic drilling, laser-beam drilling, water jet drilling, etc., have been proposed for a variety of economic and quality reasons. Conventional drilling is still the most widely used technique in industry today [7]. A major concern that has received considerable attention in drilling holes in FRCM is the delamination, especially at the bottom surface of the workpiece (drill exit). The thrust force developed during the drilling process affects the width of the delamination zone. It is believed that there is a "critical thrust force" below which no damage occurs [3,6,8–11].

Tsao and Hocheng [12] have established a correlation that relates feed rate, spindle speed, and drill diameter to the induced delamination in a CFRP laminate. The correlation is obtained by using a multivariable linear regression analysis. Davim and Reis [13,14] used the same technique to construct the correlations between cutting parameters (cutting velocity, feed rate) and cutting power, specific cutting pressure and delamination factor in CFRP composite laminate. The obtained models demonstrate a feasible and an effective way for the evaluation of the drilling-induced delamination factor. Dharan and Won [15] investigated the effect of feeds in high-rate drilling of woven carbon fiber/epoxy laminates on thrust force and torque using carbide-tipped twist drills. The experimental data was well-described empirically by power law expressions relating the thrust force and torque to the feed and tool diameter.

The main objective of the present study is to investigate the effects of the cutting variables, speed and feed, on the thrust force, torque, and delamination in drilling chopped composites with different fiber volume fractions. Based on the results from this investigation, empirical formulas are developed. Such formulas would be very useful in selecting the drilling conditions in chopped composites.

2. Experimental work

2.1. Specimen preparation

"The drilling processes are carried out on chopped glass fiber-reinforced polyester (GFRP) composites with various values of fiber volume fractions (V_f = 10.2%, 16%, 23.2%, and 27.7%) and compared with pure matrix. The variation in fiber volume fractions was achieved through the variation in the number of fiber layers. Therefore the thickness of the laminates with different fiber volume fraction was in the range 4.14 ± 0.3 mm. Whereas the variation in the laminate thickness, with certain fiber volume fraction, was in the range ± 0.05 mm. This variation approximately has insignificant effect on fiber volume fractions. Details about the manufacturing technique are illustrated elsewhere [16]. The chopped composites are investigated to characterize their mechanical properties as affected by the fiber volume fraction [16–18]. Such investigations include uniaxial tension and bending properties [16], notched and pin bearing behavior [17], and environmental effects on compressive strength of notched and unnotched specimens [18]. The constituent materials of the composite laminate are illustrated in Table 1.

2.2. Drilling operations

Drilling processes are conducted on chopped glass fiber reinforced epoxy GFRP composites using a radial drilling machine with standard HSS twist drills. To ignore the effect of drill wear each hole was implemented using new drill. The influence of the cutting variables (speed and feed) on the thrust force, torque, and delamination has been investigated experimentally. The drilling variables are

- feed, *f*, with the values of 0.03, 0.08, 0.15, 0.23, and 0.3 mm/rev,
- cutting speed, *N*, with the values 455, 875 and 1850 rpm.

Many investigators [13,19,20] show that the hole surface quality (surface roughness and dimensional precision) is strongly dependent on cutting parameters, tool geometry, and cutting forces (thrust and torque). In the present work, the drilling process is carried out using commercial HSS twist drills with constant geometry, Table 2.

2.3. Measurements of the thrust force and torque

In the present work, two-component drill dynamometer, Fig. 1, has been used to measure the thrust force (F_t) and

Table 1
Composition of GFRP composite laminates

Material	Type
Matrix	Orthophthalic polyester (RESIPOL 9024 ST)
Hardener	Methylethyl ketone peroxide (0.8% of matrix volume)
Reinforcement	E-glass, chopped strand mat (450 g/m^2)

Table 2
Specifications of HSS twist drill

Drill diameter (mm)	Point angle (degree)	Helix angle (degree)	Rake angle (degree)	Clearance angle (degree)	Cutting edge length (mm)	Chisel edge length (mm)	Chisel edge angle (degree)	Land of margin (mm)
8	118	30	30[a]	12[a]	3.75	2.2	51	0.8

[a] Measured at the outer diameter.