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EFFECT OF EXIT SUPPRESSED POSITION ON DELAMINATION IN DRILLING COMPOSITE MATERIALS USING CORE DRILL

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ABSTRACT

Composites face a serious challenge for tool geometries in machining process due to its poor machined defects. This is why many researches and manufacturers now pay attention to the tool life, machining efficiency, and surface quality. Core drilling, which has the annular distributed load at the drill periphery, is an important process in hole generating for structural components of composites. Reducing thrust force at the drill exit in workpiece was suggested to avoid delamination. Active backup force was developed for the reduction of delamination during drilling of composites. The core drill with suppressed position offer higher critical thrust force than the core drill without suppressed position. The critical thrust force for core drill with outer suppressed position is lower than that of core drill with inner suppressed position. The proposed models explain the inner suppressed position is more advantageous than the outer suppressed position to avoid induced-delamination in drilling composites under the same condition.

KEYWORDS

Composites, Suppressed Position, Delamination, Thrust Force, Core Drill.

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INTRODUCTION

In the past decade, composites have grown rapidly in the structure components of aerospace, defense and transportation applications due to its superior mechanical properties, such as higher strength-to-weight ratio, higher fracture toughness and excellent corrosion resistance properties. In fact, composite components still require hole-generating owing to the need for fastening these mechanical structures by screw or rivet during assembly operations. Inherency of composites, however, is neither homogeneous nor isotropic. The most drilled defects and damages of the exit edge of the hole because their anisotropic, inhomogeneous and abrasive nature. Many previous studies of drilling composites reported the defects and damages correlated the drill material, drill geometry and selected drilling parameters [1-7].

Hocheng and Dharan [8] first formulated the analytical model of the critical thrust force, which relates the drilling induced-delamination of composite laminates, for the twist drill by linear elastic fracture mechanics (LEFM) method. A series analytical model of special drills correlating the thrust force with the onset of delamination was developed by [9-10]. They show the merit of core drill at the onset of delamination for correlating the drilling-induced thrust with distributed circular load. Bhattacharyya and Horrigan [11] shown through finite element analysis that a major surface delamination is unlikely to happen when a back support is used. Tsao and Hocheng [12] simplified the support load of exit back-up as a single concentrated central load on delamination in drilling composite materials using a saw drill and a core drill. However, the effects of core drill and its various support positions were rarely discussed in analytical fashion. Therefore, the theoretical analysis of support load of exit back-up for core drill can give wealth information about drilling-induced delamination of composite materials.

DELAMINATION ANALYSIS

Physical Model

Figure 1 depicts the model of drilling in composite materials. At the propagation of delamination, the drill movement of distance dX is associated with the work done by the thrust force F, which is used to deflect the plate as well as to propagate the interlaminar crack.

The energy balance equation gives:

$$G_{IC}dA = FdX - dU \tag{1}$$

where dU is the infinitesimal strain energy, dA is the increase in the area of the delamination crack, and G_{IC} is the critical crack propagation energy per unit area in mode I.

Mathematical Analysis

Core drill with inner (positive) suppressed position

Figure 2 depicts the schematics of a core drill with inner suppressed load and the induced delamination. F_R is the thrust force, X is the displacement, H is the workpiece thickness, h is the uncut depth under tool, and a is the radius of delamination. The outer and inner deflection of a circular plate is clamped and subjected to annular distributed load over a round area of radius c. c^* and c are the inner and outer radius of core drill, respectively. t is the thickness of core drill, and β_S is the ratio between thickness and radius of core drill (namely, $\beta_S = t / c$). In Figure 2, F_{RI} is the inner suppressed load by an inner suppressed mechanism, and c_{RI} is the radius of inner suppressed load. The isotropic bahavior and pure bending of the laminate are assumed in the model. The deflection of the circular plate by a core drill with inner suppressed load is given by Ref. [13] as:

$$X = \frac{F_{RI}}{8\pi M}[2c_{RI}^{\ 2}\ln\frac{c_{RI}}{a} + \frac{1}{2}(1 - \frac{c_{RI}^{\ 2}}{a^2})(a^2 + c_{RI}^{\ 2})] \tag{2}$$

Differentiation of Eq. (2) with respect to a yields:

$$\frac{dX}{da} = \frac{F_{RI}}{8\pi M}(a - \frac{2c_{RI}^{\ 2}}{a} + \frac{c_{RI}^{\ 4}}{a^3}) \tag{3}$$

The stored strain energy is as follows:

$$\begin{aligned} U &= \pi\int_0^{c_S} M(\frac{d^2X}{dr^2} + \frac{1}{r}\frac{dX}{dr})^2 rdr \\ &= \frac{F_{RI}^{\ 2}}{32\pi M}[a^2 + 4c_{RI}^{\ 2}\ln\frac{c_{RI}}{a} + \frac{c_{RI}^{\ 4}}{a^2}] \end{aligned} \tag{4}$$

Differentiation of Eq. (4) with respect to a yields:

$$\frac{dU}{da}=\frac{F_{RI}{}^{2}}{16\pi M}\left(a-\frac{2c_{RI}{}^{2}}{a}+\frac{c_{RI}{}^{4}}{a^{3}}\right) \tag{5}$$

Let $\eta = F_{RI} / F_R$ and $\xi = \delta_I / c = c - c_{RI}$ is the deviation between the radius of core drill (c) and radius of inner suppressed load (c_{RI}), the critical thrust force with inner suppressed position (F_{RI}) by a core drill at the onset of crack propagation can be calculated by:

$$F_{RI} = \pi\sqrt{\frac{32\,G_{IC}M}{(1-\eta^2)-s^2[K_1-2\eta^2(1-\xi)^2]+s^4[K_2-\eta^2(1-\xi)^4]}} \tag{6}$$

where

$$K_1=(2-2\beta_S+\frac{3\beta_S{}^{2}}{2})+\frac{4(1-\beta_S)^2}{\beta_S(2-\beta_S)}\ln(1-\beta_S)$$

and

$$K_2=\frac{(2-4\beta_S+5\beta_S{}^{2}-3\beta_S{}^{3}+\beta_S{}^{4})}{2}+\frac{2(1-\beta_S)^2(2-2\beta_S+\beta_S{}^{2})}{\beta_S(2-\beta_S)}\ln(1-\beta_S)$$

Core drill with outer (negative) suppressed position

Figure 3 depicts the schematics of a core drill with outer suppressed load and the induced delamination. In Figure 3, F_{RO} is the outer suppressed load by an outer suppressed mechanism, and c_O is the radius of outer suppressed load. The deflection of the circular plate by a core drill with outer suppressed load is given by Ref. [13] as:

$$X=\frac{F_{RO}}{8\pi M}[2c_O{}^{2}\ln\frac{c_O}{a}+\frac{1}{2}(1-\frac{c_O{}^{2}}{a^2})(a^2+c_O{}^{2})] \tag{7}$$

Differentiation of Eq. (7) with respect to *a* yields:

$$\frac{dX}{da}=\frac{F_{RO}}{8\pi M}\left(a-\frac{2c_O{}^{2}}{a}+\frac{c_O{}^{4}}{a^{3}}\right) \tag{8}$$

The stored strain energy is as follows:

$$U = \pi \int_0^{c_S} M\left(\frac{d^2X}{dr^2} + \frac{1}{r}\frac{dX}{dr}\right)^2 r dr = \frac{F_{RO}{}^2}{32\pi M}\left[a^2 + 4c_O{}^2 \ln\frac{c_O}{a} + \frac{c_O{}^4}{a^2}\right] \tag{9}$$

Differentiation of Eq. (9) with respect to *a* yields:

$$\frac{dU}{da} = \frac{F_{RO}}{16\pi M}\left(a - \frac{2c_O{}^2}{a} + \frac{c_O{}^4}{a^3}\right) \tag{10}$$

Let $\eta = F_{RO} / F_R$ and $\xi = -\delta_O / c = c_{RO} - c$ is the deviation between the radius of core drill (c) and radius of outer suppressed load (c_{RO}), the critical thrust force with outer suppressed position (F_{RO}) by a core drill at the onset of crack propagation can be calculated by:

$$F_{RO} = \pi \sqrt{\frac{32 G_{IC} M}{(1-\eta^2) - s^2[K_1 - 2\eta^2(1+\xi)^2] + s^4[K_2 - \eta^2(1+\xi)^4]}} \tag{11}$$

RESULTS AND DISCUSSION

According to the push-out model, the critical thrust force without suppressed position for core drill is [10]:

$$F_R = \pi \sqrt{\frac{32 G_{IC} M}{1 - K_1 s^2 + K_2 s^4}} \tag{12}$$

where $M = Eh^3 / 12(1 - v^2)$ is the flexural rigidity of the fiber reinforced material, E is Young's Modulus and ν is Poisson's ratio for the material.

Figure 4 depicts the critical thrust force for core drill without and with outer and inner suppressed position at $\xi = 0.05$, and various β_S and η. From Figure 4, it is found that the values of critical thrust force for core drill without and with outer and inner suppressed position increase fast with increasing β_S, η and s. The critical thrust forces of core drill with outer and immer suppressed position are larger than that of core drill without suppressed position. However, the increasing amount of s was limited due to the suppressed position, which act on the exit of workpiece. From Figure 4, It is also found that the increasing β_S for $\eta = 0.5$ has a different effect on the reduction of critical thrust force when s is above 0.5. However, no difference exists for s below 0.5. Lower β_S causes an increased thrust force to avoid induced-delamination in drilling composite materials. Increasing the η increases the thrust force at the onset of delamination.

Figure 5 depicts the critical thrust force for core drill without and with outer and inner suppressed position at $\beta_S = 0.3$, $\eta = 0.3$ and various ξ. It can be seen that the values of critical thrust force for core drill with suppressed position at $\beta_S = 0.3$ and $\eta = 0.3$ increase fast with increasing ξ and s. As reported by DiPaolo et al. [14], the delamination of size less than drill is not of concern because it is drilled out afterwards anyway. When the delamination grows beyond the drill radius, the core drill with suppressed position can sustain much larger thrust force than the core drill without suppressed position, as shown in Figure 5. Hence, the core drill with suppressed position can offer higher feed rate to drill the composite materials without causing delamination. In addition, the values of critical thrust force for core drill with outer suppressed position are lower than with inner suppressed position. It also implies that positive ξ can offer higher critical thrust force than negative ξ. This suppressed mechanism allows the elimination of a delamination, which increases the critical thrust force at the exit to avoid the interlaminar bonding yields. It also reduces the risk of chip clogging for traditional core drilling. However, the value of positive ξ was limited due to the size of suppressed position (or drilled hole).

CONCLUSION

The effect of exit suppressed position on delamination for drilling composite material in use of core drill is developed in this study. The results are obtained based on the elasticity, linear elastic fracture mechanics (LEFM) and energy conservation. The core drill with outer and inner suppressed position offer higher critical thrust force than the core drill without suppressed position. The results agree with those obtained by industrial experience. The critical thrust force for core drill with outer suppressed position is lower than that of core drill with inner suppressed position. The proposed models explain the inner suppressed position is more advantageous than the outer suppressed position to avoid induced-delamination in drilling composite materials under the same condition, as shown in the case of core drill.

ACKNOWLEDGEMENT

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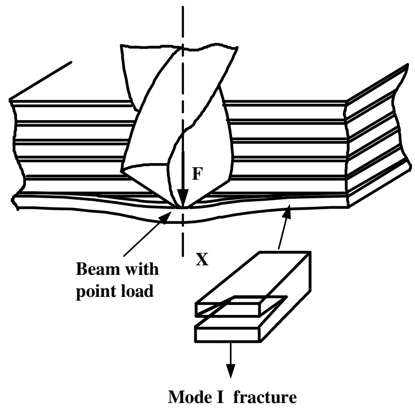

Fig. 1. Schematics of drilling in composite materials.

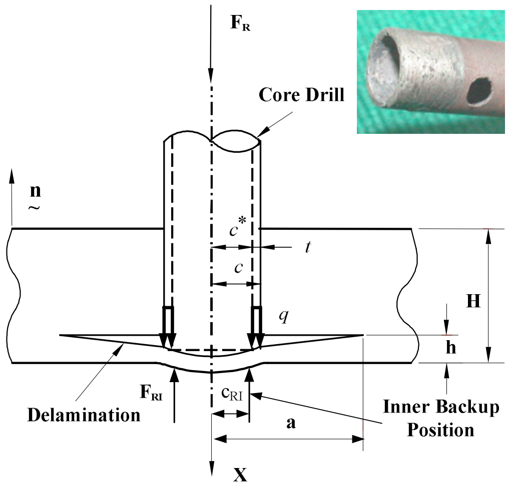

Fig. 2. Circular plate model for delamination analysis (core drill with inner suppressed position).

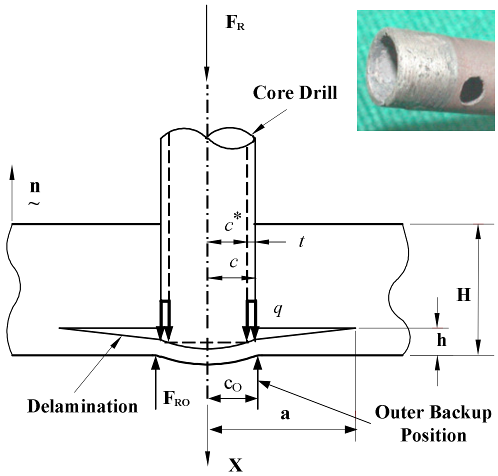

Fig. 3. Circular plate model for delamination analysis (core drill with outer suppressed position)

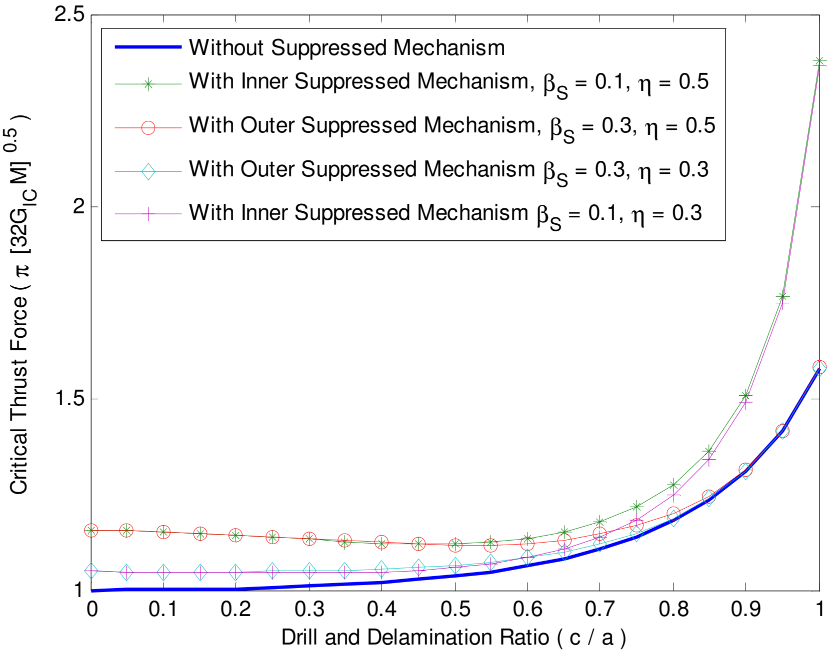

Fig. 4. Critical thrust force for core drill without and with outer and inner suppressed position at $\xi = 0.05$, and various β_s and η.

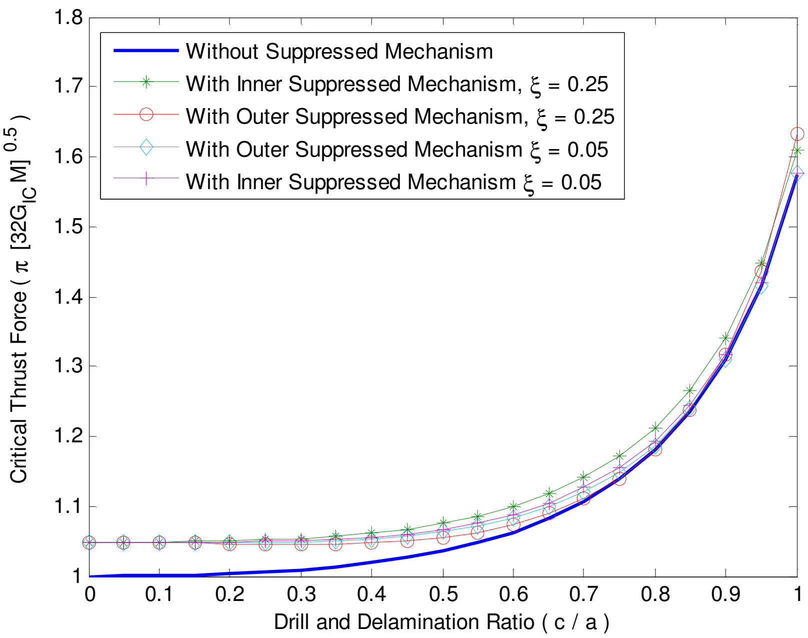

Fig. 5. Critical thrust force for core drill without and with outer and inner suppressed position at $\beta_S = 0.3$, $\eta = 0.3$ and various ξ