EFFICIENT METHOD FOR UNSUPPORTED DRILLING OF COMPOSITES

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ABSTRACT

Drilling holes in laminated composites requires special tools and techniques. Their highly abrasive nature quickly dulls conventional steel and carbide tools, and their low interlaminar strength often results in splintering and delamination of the hole. There have been many innovative drill designs, but none have been able to produce clean repeatable holes without some kind of backside support or frequent sharpening. For applications where backside support or backing material is not cost effective, a new diamond coated drill has been developed. Even when operated at non-optimum speeds and feed rates, a hole free of delaminations is produced. These drills were evaluated for durability, variation, and hole quality over a six month period. The results and the operating requirements are presented.

KEY WORDS: Composites, Drilling, Machining

1. INTRODUCTION

For certain types of composites where the fabrication method precludes the ability to mold in the holes, drilling is the only acceptable method. But drilling holes in laminated composites is a challenge. Their highly abrasive nature quickly dulls steel and carbide tools, and their low interlaminar strength often results in splintering and delamination of the hole. Ho-Cheng and Dharan [1] presented a concise analysis of the problem of delaminations associated with drilling. This problem has prompted many innovative drill designs and fabrication techniques geared towards producing clean repeatable holes. Despite their general success, they all have their limitations. For example, carbide drills require frequent sharpening and poly-crystalline diamond (PCD) insert drills have to be run at speeds on the order of 6,000 rpm. Even under ideal conditions, these drills often require some kind of backside support. This backside operation to keep the composite from splintering or delaminating when the drill bit exits. Clearly, this backing tool has to have a precisely aligned matching hole to the drill or be made of a soft enough material to be drilled and discarded.

To aid in maintaining hole integrity, a backing material is sometimes employed. This material is typically a fine filament fiberglass fabric that is added to the laminate as either a localized patch or a complete layer. Its purpose is to support the outer plies of the laminate and not to splinter significantly when the drill enters or exits.

Neither of these techniques can be easily applied to long filament wound tubes with holes drilled in the center. The smallest tubes evaluated were 202.6 cm (79.75 in.) long and 10 cm (4 in.) square. These tubes have 12 holes in the ends and 13 holes in the center (see Figure 1). A backing tool would be very difficult to use and using a fabric layer would add unnecessary steps to the fabrication process. Basically, a drilling process was needed that could produce a clean hole in a laminated carbon composite without the aid of any backing support. A specialized drill bit was developed for this process. It has been evaluated for durability, variation, and hole quality over a six month period. The results and the operating requirements are presented.

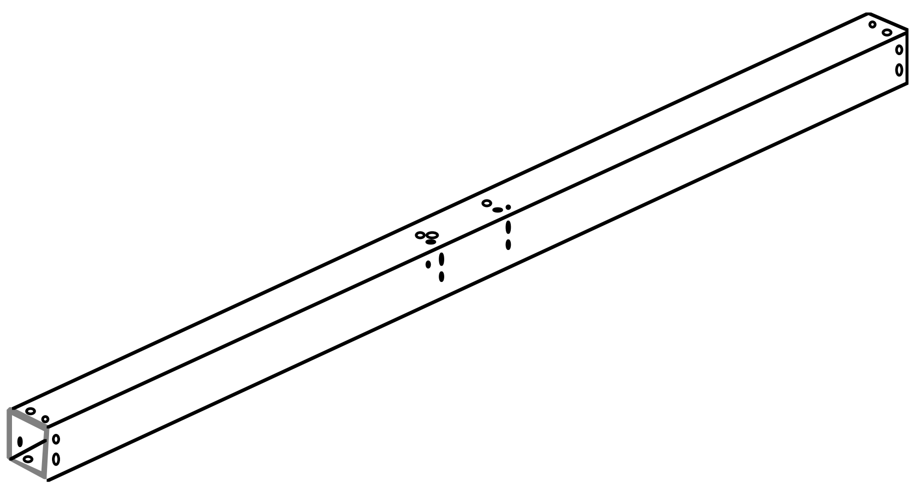

Figure 1. Filament Wound Composite Tube with Drilled Holes

2. DRILL DESIGN

This specialized drill bit is a diamond coated tapered spade bit that grinds a small hole and then proceeds to ream the hole to the proper size. Other than the initial punch through of the drill, most of the drilling loads are radial from the center of the drill bit. This eliminates the splintering that typically occurs when the drilling loads are in the direction of the drilling operation. The three basic parts of the drill as shown in Figure 2 are (1) the hole initiator, (2) the reamer, and (3) the venting flats. All three features are needed to produce a clean hole. This drill bit has been patented [2].

tapered, it slowly grinds the hole larger, removing all the initial splintering in the process. The taper transfers most of the grinding force radially from the drill centerline and minimizes forces normal to the laminate. Delaminations are eliminated because of this low normal force. A course diamond coating (40 grit) is used on the tip to remove most of the material from the hole. A steep taper angle is used to properly grind the hole larger and remove the splintering without causing any more splintering. A shallow angled tip is incorporated on larger drills to keep them from becoming too long.

The final sizing of the hole is done by the cylindrical section called the reamer. Here a precision diameter hole can be obtained by using a fine diamond coating (100 grit) on a precision sized shank. Repeatable holes with tolerances of ±.05 mm (±.002 in.) have been achieved.

Two sides of the drill body are machined flat much like a spade drill. This allows for venting and the easy removal of the dust produced during the operation. Without them, the diamond coating loads up very quickly, rendering the drill bit inoperable.

Some additional features are the low cost shank material and the ability to be recoated. Because the diamonds are doing the grinding of the hole, the drill shank does not need to be constructed of specialty alloys. It can be mild steel. And when drill tip begins to wear or the hole quality begins to decrease, the drills can be recoated economically.

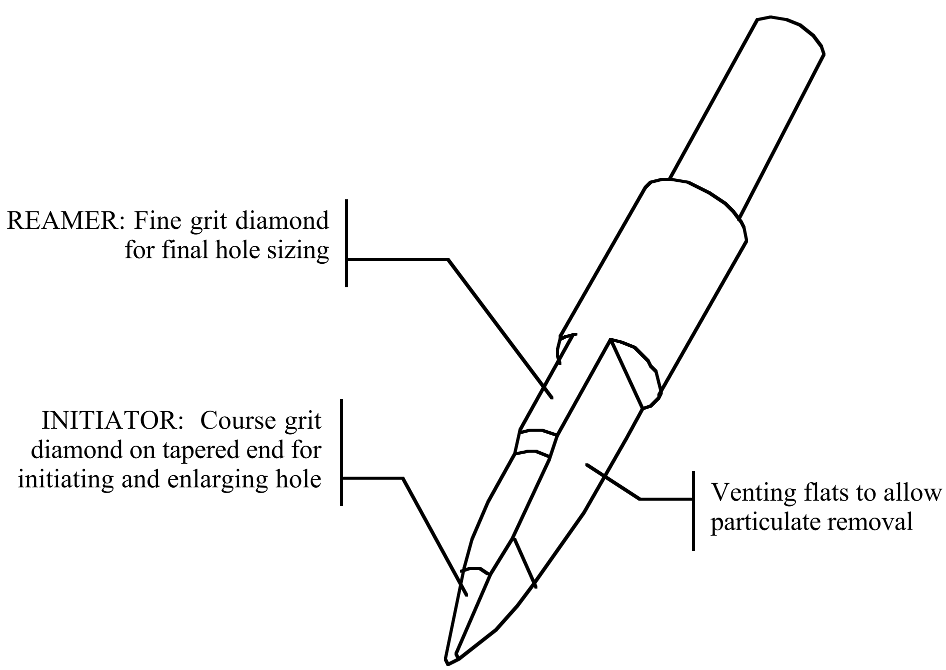

Figure 2. Major Components of the Diamond Coated Drill

3. OPERATING PARAMETERS

Only two operating parameters for this type of drill are important for creating a splinter free dimensionally correct hole; namely, a high rpm and a low feed rate. The correct combination allows the drill enough time to grind the composite away without causing splintering. Even with high rotational speeds, small diameter abrasive tools cannot achieve the high surface velocities recommended for composites. Therefore, the feed rate is kept low to permit complete grinding. If either of these two parameters are off, the splintering that occurs upon backside exit cannot be completely removed and the hole remains splintered.

With higher speeds, a higher feed rate can be used. For each application, the drill speed should be selected as high as possible and then the best feed rate can be determined experimentally. Typically, the drills operate at 3000 rpm and a feed rate of 25 mm (1 in.) per minute. For a 25 mm (1 in.) long drill, this equates to a minute of drill time. This limitation is acceptable when drilling time is not a factor in the overall process cycle time.

As with all spade type drills, rigid support is recommended to keep them from oscillating in the hole. The flats work well to keep the debris clear but does not help to keep the drill centered in the hole. Figure 3 shows a drill connected to the drive unit using a collet. The collet provides the necessary support to achieve consistent hole size and quality.

Figure 3. Drill Mounted in Collet

4. EVALUATION

Three quality characteristics were checked during the evaluation; namely, hole diameter, hole quality, and drill condition. The diameters of the holes were measured using pin gauges on every tenth part and the changes in diameter was tracked to evaluate the effect of drill use on hole size.

The holes were also check for the amount of fraying at the edges. A clean hole was defined as being without fraying. This fraying was not the same as splintering but was loose fibers that remained connected to the part. Fraying does not effect the performance of the holes but requires secondary cleaning. Excessive fraying is the precursor for splintering and delaminations.

Drill failure was established as either an inability to create a clean hole or the actual degradation of the drill where the diamond coating is missing and the shank is exposed.

For six months, the performance of these drill bits was evaluated on 950 filament wound composite tubes. The tubes were filament wound using a standard modulus carbon fiber and epoxy resin. The wall thickness was 2.8 mm (.110 in.) and the fiber volume was about 62%. Figure 1 shows the geometry of the tube and the location of the holes.

Drilling was done on an automated production drilling station equipped with 21 drill bits mounted to 11 drill heads. These 21 drill bits were used to make 25 holes in the part. The hole diameters ranged from 4.0 mm (.157 in.) to 14.3 mm (.562 in.). Figure 4 shows a schematic of the machine. During the process, several drill units with multiple spindles were engaged in a specific sequence depending on the orientation of the tube. The tube was rotated during the process to produce holes on all sides. Each drill was used only once except for the double drill units on each end which were used twice on every tube. All drilling was done without any air or liquid coolant and was cycled at a rate of one tube every 15 minutes.

Figure 4. Schematic of Automated Drilling Station

6. RESULTS

After 950 tubes, all but one out of the 21 drill bits were still producing clean holes. This one drill bit (#2) was one of the four that drills twice on each tube (see Figure 5). After 1650 holes (825 tubes), the tip had wore down and the edges of the holes displayed unacceptable fraying. Even though the fraying cleaned up easily, the drill was replaced.

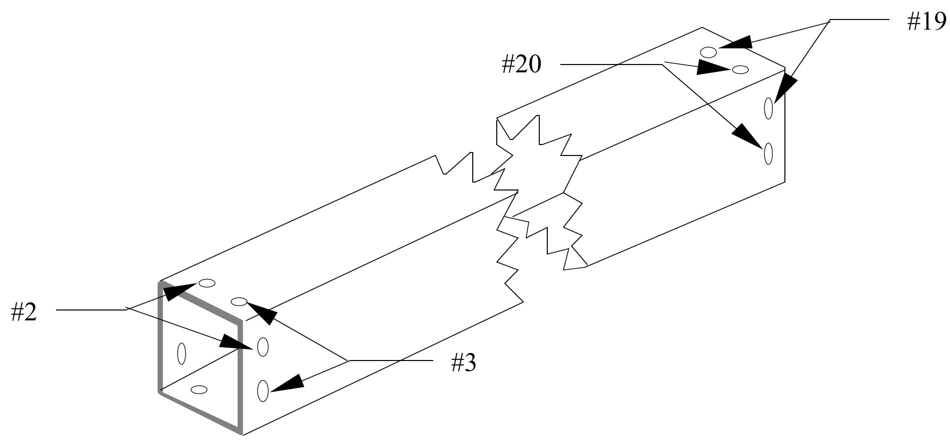

Figure 5. Location of Holes Drilled with Double Cycle Drill Bits

The diameter variation for the four double drilled end holes are graphed in Figure 6. The diameter change for the remaining 17 holes followed the same trend but only for 950 holes. All the hole diameters dropped about .05 mm (.002 in.) in the first 200 drilling operations but then stabilized to a gradual decrease over the life of the drill. The maximum change was .10 mm (.004 in.).

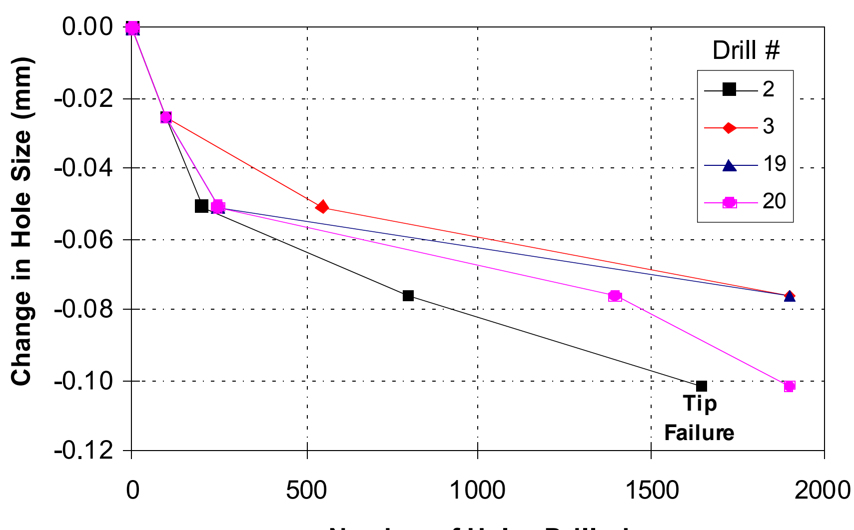

Figure 6. Hole Size Variation Versus Number of Holes Drilled

6. CONCLUSIONS

This drill design is capable of drilling at least 1500 holes in carbon laminated composites. Some of the performance results are:

- Does not require backing support
- Works without coolant
- Easily determined drill wear, i.e., the tip wears down
- Drill tip wear occurs before hole quality is affected
- Precise size can be achieved and maintained within .10 mm (.004 in.)

7. REFERENCES

1) Ho-Cheng, H., and Dharan, C.K.H., "Delamination During Drilling in Composite Laminates", ASME Machining Composites, 1988, pp.39-47

2) U.S. Patent #5,354,155, October 11, 1994