Holes manufacturing technology influence on the strength of fibrous composites

E Kh Akhmedshin¹, A N Polilov² and N A Tatus²

¹Moscow Polytechnic University
Bolshaya Semyonovskaya str., 38, Moscow, 107023, Russia
²Blagonravov Mechanical Engineering Research Institute of Russian Academy of Science
4 Maly Kharitonyevsky Pereulok, Moscow, 101990, Russia
fallenking74@gmail.com

Abstract. The hole effect on the unidirectional composite specimen bearing capacity describes in the article describes. A comparison of the finite element calculation of the plates with holes made in various ways with experimental data is carried out. Good convergence of the FEM calculation and experimental data is shown.

Introduction
The main reasons restraining the use of fiber reinforced plastics (FRP) are associated with the design and manufacture of junction. Indeed, over millions years of working with wood, mankind has come up with only nails, screws, adhesives, spikes, but all this is not effective enough for power connections. Composite panels are still connected with rivets through drilled holes that cut through the fibers. There are many attempts to reduce the diameters of rivets by replacing them with “nails”, “needles”, wire inserted into woven composites prior to resin impregnation and polymerization, not breaking, but spreading the fibers. So far this looks like the most promising direction, but unnecessarily laborious. Adhesive joints in laminated plates are ineffective due to low interlayer rigidity and strength. It looks like to try to break a book by sticking (strongly!) grips to the cover, but without gluing the pages. A completely different path is suggested by Nature (bio-inspired method) by the example of attaching a branch to the trunk. You can break a branch, but it is impossible to tear it from the trunk.

The purpose of this work is to study the hole effect on the bearing capacity of composite unidirectional specimens and comparing the results of the FEM calculation with the experimental data.

Finite element calculation statement
The plates were calculated in the ANSYS Workbench software, the plate properties and the direction of reinforcement were set using the ANSYS Composite PrepPost.

Composite plates, 135x20 mm, are tension under the influence of distributed load.

The first plate consists of 20 layers, unidirectional fiberglass with a thickness of 0.1 mm (Figure 1, a). Distributed load value \( q = 32090/20 = 1604.2 \) N/mm. The volume fraction of fibers is \( \mu = 0.66 \).

The second plate also consists of 20 layers, unidirectional fiberglass with a thickness of 0.1 mm (Figure 1, b). In the center of the plate drilled a hole with a diameter of 10 mm. Pressure value \( q = 8520/20 = 426 \) N/mm. The volume fraction of fibers is \( \mu = 0.66 \).
The second plate also consists of 20 layers, fiberglass with a thickness of 0.1 mm, with a reinforcement angle of 0° (Figure 1, b). In the center of the plate is a hole with a diameter of 10 mm. Distributed load value \( q = \frac{8520}{20} = 426 \text{ N/mm} \). The volume fraction of fibers is \( \mu = 0.66 \).

The third plate also consists of 20 layers, fiberglass with a thickness of 0.1 mm, the direction of reinforcement changes in the hole region (curved reinforcement imitating a punctured hole at the stage of molding the sample) (Figure 1, c). In the center of the plate punctured a hole with a diameter of 10 mm. Distributed load value \( q = \frac{25200}{20} = 1260 \text{ N/mm} \). The volume fraction of fibers is \( \mu = 0.68 \).

Figure 1. Direction of reinforcement: plain plate – Type 1 (a), a drilled plate – Type 2 (b), a curvilinear fiber plate – Type 3 (c).

Table 1. The properties of the material (fiberglass) used in the calculations.

| Characteristic | Value |
|---------------|-------|
| \( E_1 \), GPa | 50    |
| \( E_2 \), GPa | 8     |
| \( \nu_{12} \) | 0.3   |
| \( G_{12} \), GPa | 5     |

Curvilinear reinforcement was modeled by creating a new coordinate system that takes into account the change in geometry (Figure 2).
Border conditions
All plates from the left edge are fixed along all axes, displacements in the directions of the $Z$-axis are forbidden over the entire area of the plates, load is applied to the right edge (Figure 3).

Calculation results
In Figure 4, 5 and 6 show the results of finite element calculations.
Analysis of the calculation results
Based on the data obtained (Figure 4), critical loads for the plates were calculated.

| View                | Plate №. 1 | Plate №. 2 | Plate №. 3 |
|---------------------|------------|------------|------------|
| Deformation, mm     | 2.26       | 1.37       | 2.02       |
| Stresses, MPa       | 2.713      | 2.180      | 2.476      |
| Tsai-wu criterion   | 5.98       | 5.75       | 6.49       |
| Critical load, N    | 36 222     | 9 711      | 25 447     |

Experiment
For the experiment, specimens were made of 3 types: a plane plate, a drilled plate, with punctured holes (fibers are located around the hole). The geometric dimensions of the test specimens correspond to those shown in Figure 1. The test results are shown in Figure 3 and in Table 3.
Figure 7. The load-displacement diagram for flat samples of different types: a plane plate (1), a drilled plate (2), a plate with curvilinear fiber (3).

Table 3. Comparison of experimental and calculated data.

| Data/Specimens types | Type 1   | Type 2   | Type 3   |
|----------------------|----------|----------|----------|
| Tested maximum load, H | 32,090   | 8,520    | 25,200   |
| Type 1 to type 2 and type 3 tested load ratio in present | 100      | 27       | 79       |
| Calculated maximum load, H | 36,222   | 9,711    | 25,447   |
| Type 1 to type 2 and type 3 Calculated load ratio in present | 100      | 27       | 70       |

Conclusion
Using the standard methods of the ANSYS finite element program, it is possible to calculate the bearing capacity of samples with curvilinear laying of fibers with acceptable accuracy.

References
[1] Polilov A N, Tatus N A, Kamantsev I S, Kuznetsov A V, Akhmedshin E Kh, and Tian X Reducing the effect of holes on the bearing capacity of fiber-reinforced materials AIP Conference Proceedings 2176, 030010 (2019); https://doi.org/10.1063/1.5135134

Acknowledgments
This work was financially supported by the Russian Foundation for Basic Research, grant No. 18-08-00372 A