Reducing of holes effect on composite elements strength

E Kh Akhmedshin¹, A N Polilov² and N A Tatus²,³

¹Moscow Polytechnic University, 38, Bolshaya Semyonovskaya str., Moscow, 107023, Russia
²Blagonravov Mechanical Engineering Research Institute of Russian Academy of Science, 4, Maly Kharitonyevsky Pereulok, Moscow, 101000, Russia
³Moscow State University of Civil Engineering (MGSU), 26, Yaroslavskoye Shosse, Moscow, Russia
fallenking74@gmail.com

Abstract. Reducing the effect of holes on the attachment points of composite elements is one of the key tasks from the time the composites appeared to the present. Since the composite material and the structure are inseparable, it is necessary to design the joints at the stage of manufacturing the structural element. The work is devoted to the experimental assessment of the effect of holes made by various technologies on the strength of composite specimen. A significant increase in the bearing capacity of composite flat specimen, holes in which are made by the separation of the fibers during the manufacturing. For fiberglass, the bearing capacity of a specimen with a drilled hole decreased by 4 times, and the specimen with fibers "flowing around" the hole by only 25% compared to a solid flat specimen.

Introduction

The manufacturing technology of composite elements is of primary importance. The composite does not exist outside the construction element. Subsequent machining carries a serious reduction in bearing capacity, so it should be avoided. Holes - a structural element, without which it is difficult to imagine the connection of parts. Cut fibers in composites are unacceptable, since it is the fibers carries the load. Making holes in composites by drilling breaks the integrity of the element and reduces the bearing capacity of not only a single composite element, but also the entire structure. Nature creates wood structures with many branches, but without cut fibers. (Figure 1). Moreover, the branch-trunk junction is so strong that when the ultimate loads are reached, the branch breaks, not the branch-trunk connection. A person has been working with wood materials throughout his existence, so it is intuitively clear that for fiber materials in the manufacture of holes it is better to expand the space between the fibers than to drill a hole. Why is this not done? - This is a question for technologists.

Any, even the most insignificant change in technology leads to a partial or complete shutdown of production and is associated with serious costs - this may be the main problem.

An analysis of the literature shows that the authors are not alone in their research, they are engaged in similar work at the MSTU named after N.E.Bauman. Colleagues studied [1] the stresses in terms of fiber in the holes area, the coefficient of stress intensity near the hole was determined. Study was carried out with cross reinforcement ring specimens. An increase in bearing capacity specimens with a puncture hole compared to specimens in which holes were drilled by 44% is shown. Studies were also carried out [2] of the effect of various types holes on the bearing capacity of specimens with orthogonal reinforcement. When tensed, specimens with a puncture hole a showed a 12% increase in breaking strength compared to drilled.
Problem statement and experiment
That is, the decrease in the effect of holes made without breaking the fibers on the bearing capacity of specimens with cross reinforcement has been experimentally and theoretically proved [3]. The aim of this work is to investigate the effect of holes on the strength of unidirectional composites. It is clear that the effect of the holes on the bearing capacity of unidirectional specimens is higher than on the bearing capacity of specimens with cross reinforcement. The purpose of the work is to evaluate this effect. To achieve this goal, it was required to create an installation and work out the technology for manufacturing specimens with holes of various types. It was carrying out a series of experiments.

The installation for manufacturing composite specimens created at IMASH RAS (Figure 2) is a winding machine with a rotating mandrel for laying fibers. After winding a predetermined number of layers, the mandrel is placed in a vacuum bag for impregnation with binder. Glass fibers were wound with an elastic modulus of about 60 GPa, a tensile strength of about 2 GPa, and Etal-200M epoxy resin with Etal-1472 hardener acted as a binder.

Figure 2. The scheme of manufacturing specimens: 1. - a coil with fiberglass thread, 2 mandrel.
Figure 3. Types of specimens: 1) type 1, 2) type 2, 3) type 3.

After winding a predetermined number of layers, the mandrel is placed in a vacuum bag, where the specimen is impregnated with a binder, followed by curing at a temperature of 80° C. Specimens of
three types were made: 1 - continuous (Figure 3, 1), 2 - with a hole drilled after curing (Figure 3, 2), 3 - with fibers “flowing around” the hole (Figure 3, 3).

Tensile tests of the specimens were carried out in self-tightening grippers. The specimen was brought to complete failure. The maximum load (bearing capacity) was measured. The data are presented in figure 4 and in table 1.

![Figure 4](image-url)

Figure 4. The load-displacement diagram for flat specimens of different types: 1 - type 1, 2 - type 2, 3 - type 3.

| Types of Flat Specimens | Type 1 | Type 2 | Type 3 |
|-------------------------|--------|--------|--------|
| Maximum load, N         | 32 090 | 8 520  | 25 200 |
| Maximum load as a percentage of ultimate load for smooth specimens, % | 100    | 27     | 79     |

The discussion of the results

Type 1 specimens, on which the manufacturing and testing technology was tested, showed variation in the maximum tensile load. The first few specimens broke at very low loads until the manufacturing technology was developed, which confirms the significant dependence of composites mechanical characteristics on the manufacturing technology. The bearing capacity of the specimens in the process of testing the technology increased from 8 to 32 kN.

Specimens of types 2 and 3 were made according to the technology developed in the manufacture of a specimen of type 1. The manufacturing quality of the specimens is quite high, despite the fact that they were manufactured not in production, but in laboratory conditions.
The destruction of type 2 specimens occurred according to the standard scheme for composites - the cut fibers practically do not carry loads and the specimen is destroyed by shear stresses, figure 4. The bearing capacity of such specimens decrease by 4 times compared with continuous type 1.

Type 3 specimens showed a decrease in bearing capacity of less than a quarter of the standard, which confirms the theory of the low impact on the bearing capacity of the holes around which the fibers are laid and explains the strength of the tree-trunk joints.

**Conclusion**
The results obtained are very encouraging and are in good agreement with theory. The production of holes by the puncture method significantly increases the bearing capacity of the structural element with the hole.

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

**References**
[1] Komkov M A and Kolganov A V Modeling the process of forming holes in composite structures by piercing an uncured polymer fiber material *Bulletin of MSTU N E Bauman Ser. "Engineering"* 2007 No 3 p 33-47 (in Russian)

[2] Komkov M A, Bolotin Yu Z and Vasilyeva T V Determination of hole forming parameters in an uncured fabric composite by a piercing method with a pointed indenter. *Engineering Journal: Science and Innovation* 2017 No 9 (69) p 11 Doi 10.18698/2308-6033-2017-9-1678 (in Russian)

[3] Polilov A N and Tatus N A Biomechanics of the strength of fiber composites *Moscow: FIZMATLIT* 2018 328 p ISBN 978-5-9221-1760-9 (in Russian)