Damaged zone thickness estimation method for machined FRP composite specimens

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Abstract. The results of the experimental study of machining effect on the fiberglass specimens' tensile strength realization are presented. According to the data obtained, the size of the damaged zone, which does not carry applied loads and reduces the actual net cross-section of the specimen, has been estimated.

1. Introduction
Fibrous composite materials have a heterogeneous structure where strong and brittle fibers, which are easily damaged during machining, play a major bearing role. The damage may not be visible, but if for metals machining process leads to local hardening and microplastic deformations that have little effect on strength, then for glass and carbon plastics machining damage can have a significant negative effect [1]. Due to this fact machining on the thickness of composite plates is not allowed, and the technology and cutting modes of linear specimens have been carefully worked out.

The need to cut composite materials along curved trajectories required the acquisition and adjustment of a modern, imported CNC 6040Z milling machine, which allows you to direct the cutting tool along any trajectory, and not only straight.

2. Setting the task
When working out cutting modes, several questions arise: How does cutting technology affect the damage of material near the cutting line? How can we estimate the thickness of damaged layer of material that actually goes out of bearing part of specimen?

To answer these questions, at the first stage it was decided to do a tensile test of rectangular specimens with different width that have been cut out with the single technology. This made it possible to assess the size of damaged zone - the "edge," which is formally the part of the cross section of the specimen, but does not bear any load. It is considered that in a rectangular specimen cut from the plate with a width of \( b \) and a length of \( L \) the width of damaged area \( \delta \) (figure 1) remains constant.

It should be noted that the width of the "edge" must be constant for a given size and type of cutting tool, as well as at fixed cutting modes (rotation and feed speed). Therefore, with an increase of the size of the structure (sample width), the relative width of the damaged edge and its effect on strength should be reduced.
3. Specimen fabrication and testing
The fiberglass plate with the thickness of $h = 2$ mm has been made with the vacuum infusion technology. The plate has been molded from 6 layers of glass fabric with a weave type of "web" and laying $[0/90]$.

Specimens with a length of 250 mm with different widths have been cut from a plate on the CNC milling machine using a corn cutter tool (figure 2) with a diameter of 1.5 mm. Horizontal feed rate: 250 mm·min$^{-1}$, inverter current frequency: 160 Hz. The cutting mode for all specimens has not changed.

![Corn type cutter tool](image)

**Figure 2.** Corn type cutter tool.

For the test implementation 7 series of three specimens with different widths have been made: 2.5; 3; 4; 5; 7.5; 10 and 30 mm. Series number $i = 1, 2, ..., 7$.

The specimens have been tensile tested on an INSTRON machine in self-tightening grips. All specimens have collapsed in the working area, which indicates the correctness of the test results.

4. Test results
According to the obtained experimental data, the dependence of strength of the specimen on its width was built. Figure 3 shows that when the width of the specimen increases to 10 mm, the conditional critical stresses increase sharply, and then they go to the "plateau" with a value of about 400 MPa. This behavior of the diagram shows a strong effect of the damaged zone on the conditional strength of small-width specimens and a much smaller effect for wider ones.

To estimate the width of the damaged zone, we use simple formulas for conditional and real ("true") strength.

Conditional strength (critical load to full cross section):

$$\sigma_{i}^{\text{eff}} = \frac{F_i}{b_i \cdot h}$$

Real strength from test (load to unknown net cross section):
\[ \sigma_{r} = \frac{F_i}{b_i \cdot h} \]  

(2)

where \( b_i' = b_i - 2\delta \) is the effective (actually resisting applied force) width.

For approximate calculations, the maximum value of the conditional strength of this material can be used as the real ("true") strength. On the basis of the diagram (figure 3), the "true" strength has been taken as the value of the conditional strength obtained on specimens with the width of 30 mm since at this width the damaged zone no longer has a significant impact on the implementation of the strength.

![Specimens` strength](image)

**Figure 3.** Conditional strength on width dependence.

Changing \( \sigma_{r} = \sigma = \sigma_{eff} = 402\text{MPa} \) in (2) (index «7» means the width of specimen \( b_7 = 30 \text{ mm} \)) we estimate from the experimental values of the critical load \( F_i \) the width of the damage zone \( \delta \), which turns out to be slightly different for specimens of different widths:

\[ \sigma^* = \frac{F_i}{b_i' \cdot h} \]

(3)

\[ \delta = \frac{1}{2} \left( b_i - \frac{F_i}{\sigma^* \cdot h} \right) \]

(4)

The results of the evaluation according to the formula (4) of the size of the "edge" for specimens of different widths (i = 1-5), taking into account the spread, are given in figure 4. It was assumed at first that the width of the damaged zone should not depend on the width of the specimens: its average value according to the data given in figure 4 is 0.24 mm. However, in reality, the calculation according to the formula (4) gives different values, and the linear dependence on the width of the samples obtained using the least squares method is built on figure 4. What is the reason for this dependence is still difficult to explain, but it is important that the width of the damaged area for a given tool and the selected cutting mode is within the range of 0.2-0.3 mm, at least not more than 0.3 mm, which can be used to practically evaluate the effect of machining.
Results

1. The showed method can become the basis for estimating the effective width of the damaged zone when cutting composite parts. For the given data, $\delta \approx 0.24$ mm, which is about a sixth part of the diameter of the cutting tool.

2. The value of $\delta \leq 0.3$ mm corresponds only to the tool size and type used in the experiments at the selected horizontal feed rate and rotation speed. When changing the tool type and cutting modes, the effective width of the damage zone may be different.

3. The nominal size of the damaged zone is small and can be ignored for big parts, but making small parts from fibrous composites, the effect of damaged zone should be taken into account.

References

[1] Savitskiy R S and Veshkin E A 2017 Effect of mechanical processing of samples at cutting on composites testing Izvestia of Samara Scientific Center of the Russian Academy of Sciences vol 19 4-2 p 214-19