Correct FRP tensile specimen

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Abstract. The article depicts a problem of creating a correct composite tensile specimen. Loading of the sample was carried out by shear stresses applied on the gripping part of its lateral surface. The calculation of the stress state of the object of study was carried out with the use of ANSYS software. The results obtained were compared with a standard flat sample.

The most common structural composite materials - fiber-reinforced plastics - are widely used in various industries (mainly in the aircraft industry and in space engineering) due to a number of their unique advantages. At the same time, traditional design methods and production technologies in most cases do not fully realize the potential of fiber composites. The optimization of composite structures consists in "customization" the composite structural element to the stress fields by changing the direction of the fibers to better realize their strength characteristics. Using "smart" reinforcement allows for to solve the problem of connection nodes, namely, to exclude drilling holes in composite plates for rivets or bolts. But also there is the problem of correctly tensile testing unidirectional composite samples. And with help curvilinear reinforcement we can make to produce a specimen in the strip form for the correct tensile testing of a uni-directional sample.

Composite tensile specimens are standardized in the form of rectangular strips. The load from the grippers is transmitted either through glued pads, or the tests are carried out in special grippers with constant across force [1]. However, such an experiment technique is rather laborious and does not allow to correctly determine the strength along the direction of reinforcement.

The technologies make it possible to create strip specimens with an arbitrary change in the width $w(x)$ and thickness $t(x)$ (1), but with the constant of area (2), i.e. with a constant number of fibers along the length $L$ [2, 3] (Figure 1).

\[ w(x) = w(0)(1 - x \cdot L^{-1})^\alpha, \quad t(x) = t(0)(1 - x \cdot L^{-1})^\beta \]

\[ S(x) = S(0) \]

(1) (2)

The article considers the design of the shape of the specimen to more accurately determine the strength of one-directional composites during tensile. The new specimen shape exclude the possibility of fiber cutting, as, for example, in the case of specimens made using pads [4].

As a starting point for the study, we took constarea beam profile with a constant cross-sectional area - as the best option for the shape of an equal-strength composite beam.
As you know, the geometry of the constarea beam depends on the root section and the length of the profiling section. To determine these parameters, it is worth setting the conditional initial dimensions, for example, taking a standard composite specimen without overlays (10mm X 3mm X 300mm).

Considering that the length of the gripping zone and the working zone of the specimen should approximately be equal to 50 mm, we can obtain the total length of the profiling sections, which is equal to 150 mm. Taking into account the initial selected data and the dependence on the power coefficients $\alpha$ and $\beta$ (1), it is possible to construct curves corresponding to the profiling section, i.e. the contours of the constarea beam, which are shown in Figure 1.

![Figure 1](image.png)

**Figure 1.** Changing the beam width of a constant cross-sectional area (constarea) at various exponents.

Based on numerous experimental and theoretical data, it is considering that in the region of sharp changes in the shape of the body, an increase in stress concentration. In this case, the most appropriate is to accept a change in the width of the constarea beam with the parameter $\alpha = -1$ (red curve).

By analyzing the “red curve” corresponding to $\alpha = -1$, it is possible to derive the dependence of the change in the misorientation angle of the fibers along the contour of the specimen along the length of the profiling section. A numerical solution gives an angle of about 5 degree with a length of the profiling section equal to 75 mm.

A general view of a flat specimen to determine the ability to increase the realization of strength using curved paths of fibers is shown in Figure 2, the dimensions of the specimen are presented in table 1.
Figure 2. General view of a strip specimen and an enlarged view of the fiber trajectories.

Table 1. Specimen dimensions for a more accurate determination of strength realization.

| Parameter | w  | h  | lw | ln | lg | l  | W  | α   |
|-----------|----|----|----|----|----|----|----|-----|
| Value, mm | 10 | 3  | 50 | 75 | 50 | 300| 17,5| -1  |

1) Dimensionless parameter

Schematizing external loads so that their distribution is most consistent with real, it is worth considering the influence of the tests machine grips on the specimen, however, this task is very time-consuming. The specimen is strain by applying a load directly to the specimen itself, i.e. non-linear contact interaction is excluded.

The composite specimen loading scheme for plane strain state problem is presented in Figure 3.

Figure 3. FEM specimen model a with curvilinear reinforcement (plane case). Red shows the applied tensile load.

This task does not describe the stress-strain state in the contact interaction of the grips of the testing machine with the test specimen. However, the adopted degree of approximation of the design scheme allows us to make a qualitative assessment of the influence of curvilinear reinforcement on the realization of the strength of the specimen.

In the working and gripping part of specimen, the fibers are located along the longitudinal axis of the specimen. The gripping part is wider than in the working part, which reduces the shear stresses and the concentration of tensile stresses in the gripping area.

The initial geometry was divided into 10 planes, the reinforcement direction of which was determined by the internal bounding contour of the corresponding plane. When changing the direction of reinforcement, the characteristics of the material in each finite element of the mathematical model also changed. The initial design geometry is shown in Figure 4.

Figure 4. Initial design geometry.
The finite element method has been used to calculate a number of plane tasks. An iterative approach and analysis of the results allowed us to develop the best option for reinforcement. The initial and final types of reinforcement are shown in Figures 5 and 6.

**Figure 5.** Unidirectional specimen.

**Figure 6.** Curved fiber specimen.

Figures 7-10 show the calculation results corresponding to the reinforcement schemes. The stress distribution patterns make it possible to evaluate the effect of the specimen reinforcement structure on the stress concentration of the gripping areas and in the zones where the reinforcement path changes.

**Figure 7.** Normal stress distribution in a unidirectional specimen.

**Figure 8.** Tangent stress distribution in a unidirectional specimen.

**Figure 9.** Normal stress distribution in a curved reinforced specimen.
Figure 10. Tangent stress distribution in a curved reinforced specimen.

A specimen with curvilinear reinforcement destroyed under a load of 42.89% higher than the breaking load of the specimen reinforced along the longitudinal axis. That curved reinforcement made it possible to more evenly distribute the load across the specimen.

The FEM assessment of the stress concentration of a specimen with curvilinear reinforcement shows that the use of weakly misoriented curvilinear reinforcement makes it possible to more effectively use the bearing capacity of composite structures, reduce the effective stress concentration and increase the strength realization of a unidirectional composite.

References
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