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Influence of structural features of spatially reinforced and laminated fiber carbon plastics on the nature of deformation and fracture

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ABSTRACT

The work is devoted to the experimental study of polymer composite materials samples with different types of reinforcement to assess the breaking force during tests for uniaxial tension and tension of samples with an open hole. The paper presents an analysis of the mechanical behavior of CFRP specimens with a round concentrator and solid specimens without a concentrator, obtained using special technologies, based on a number of different spatial reinforcing frames. An assessment of the sensitivity of a particular reinforcement scheme to the presence of a hole has been carried out.

1. Material, equipment and study methods

A spatially reinforced carbon fiber composite based on **T26 epoxy resin and AKSA A-49 carbon fiber** is considered as the material under study. Tensile tests on solid specimens without a hole in accordance with **ASTM D 3039** and specimens with an open hole in accordance with **ASTM D 5766** were carried out using the universal electromechanical testing system **Instron 5989 (± 600 kN)** with a grip displacement speed of **2 mm / min.**

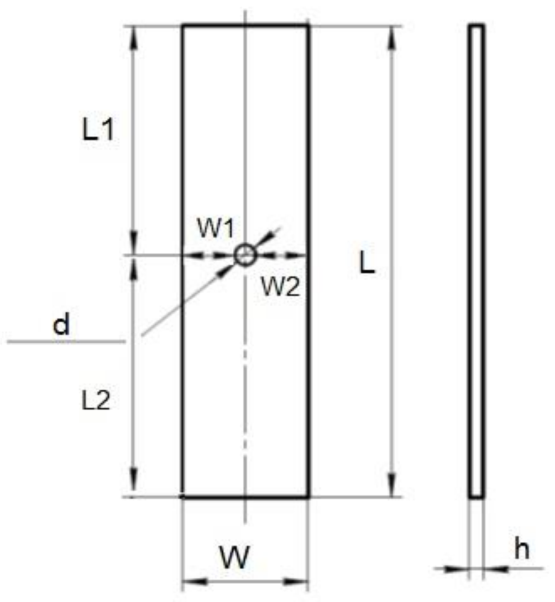

Fig. 1. Sketches of specimens with open-hole

According to the tensile testing results of specimens with an open hole and without a hole, the corresponding mechanical characteristics were determined. The comparison was carried out according to the values of the maximum stresses.

A series of mechanical tests for uniaxial tension of composite specimens with a circular concentrator in the form of a hole along the axis of symmetry of the specimen was carried out (in accordance with the sketch of the specimen in Fig. 1 a **W1 = W2 = 15mm and L1 = L2 = 147mm).**

Specimen strip preforms are made using 3D weaving technology in various weaving methods (types 1-4), as well as **layered preforms (type 5).** Four weaving patterns of 3D-woven preforms are considered: **orthogonal (type 1); orthogonal combined (type 2); with pairwise interlayer reinforcement (type 3); with pairwise interlayer reinforcement and longitudinal layer (type 4).**

The central part of rectangular specimens measuring 300x36x4 mm (LxWxh) (according to ASTM D 5766) contains a concentrator in the form of a single open hole with a diameter of 6 mm (d), specimens without a concentrator measuring 250x25x4 mm (LxWxh) (ASTM D 3039).
A total of 10 specimens were tested in each group.

2. Test results and discussion

For all series of CFRP specimens, tensile tested according to ASTM D 3039, deformation and loading diagrams were obtained (Fig. 2), mechanical characteristics were determined, and statistical processing was carried out (Table 1) for 10 specimens.

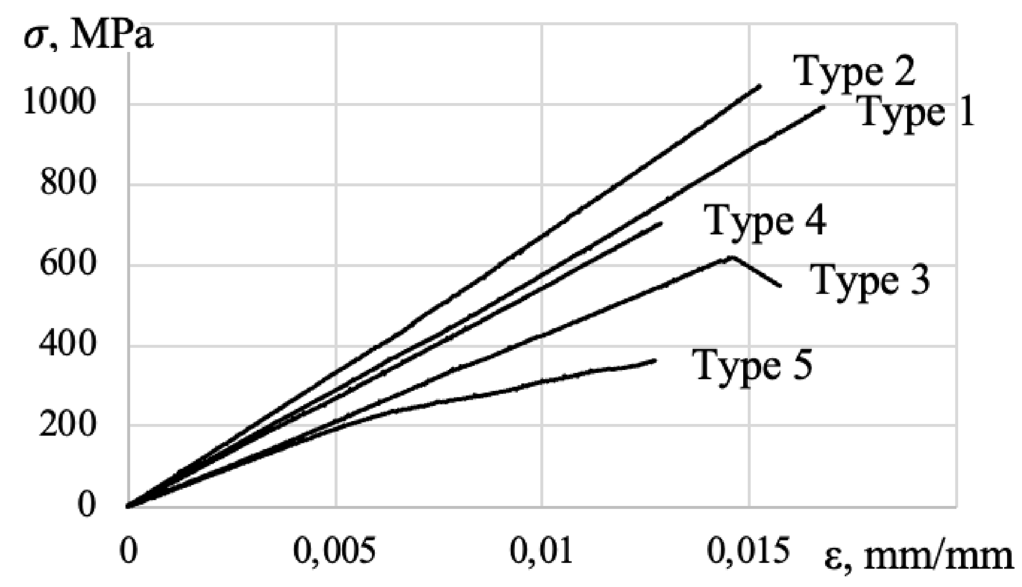

Fig. 2. Typical deformation diagrams of CFRP specimens of various reinforcement schemes during uniaxial tensile testing (according to ASTM D 3039)

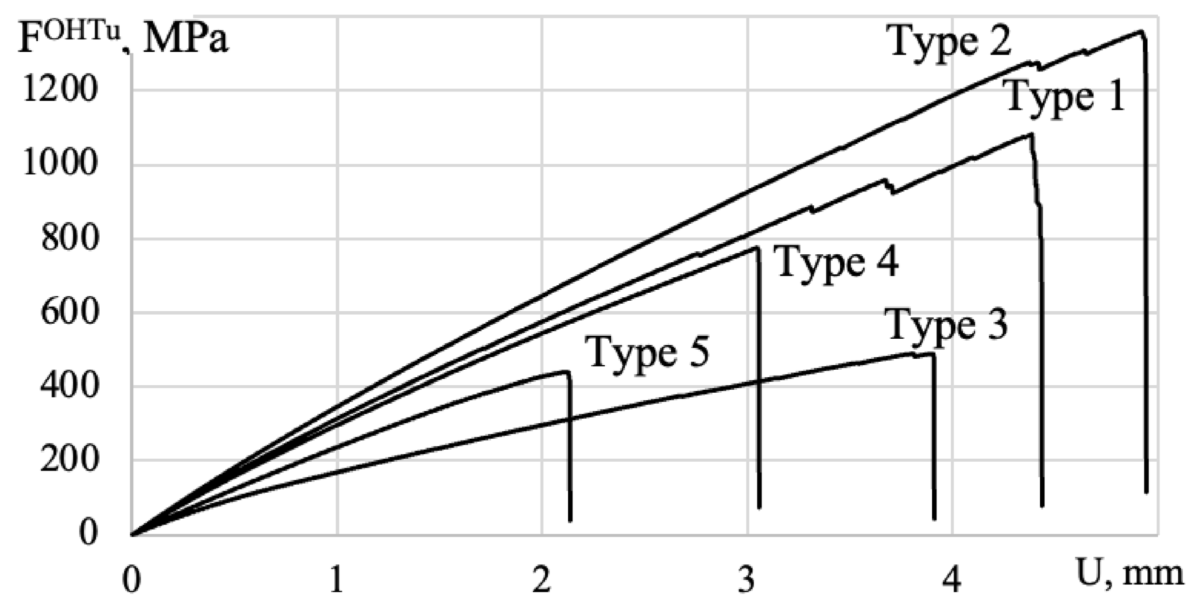

Fig. 3. Loading diagrams of CFRP specimens with an open hole in tension (according to ASTM D 5766) with different reinforcement schemes

Table 1. Mean ultimate strength (ASTM D 3039) and ultimate stresses (ASTM D 5766) for carbon fibre specimens of the studied reinforcement types

Reinforcement types	$\sigma_в$, MPa	F^{OHTu}, MPa	K_e	Reinforcement types
Type 1	940±65	929±50	0.99	940±65
Type 2	922±119	1129±51	1.22	922±119
Type 3	599±39	419±22	0.70	599±39
Type 4	758±60	649±38	0.86	758±60
Type 5	317±54	358±11	1.13	317±54

Fig. 3 presents loading diagrams for specimens with an open hole tested under ASTM D 5766**, which are characteristic of each reinforcement type. Tensile and specimen tests, with an open hole, show that polymeric composite specimens, with orthogonal (type 1) and orthogonal-combined (type 2) interweaving schemes, have a high ultimate load as compared with specimens with inter-layer reinforcement (type 3, type 4) and layered specimens (type 5).**
For all carbon fiber specimens with different reinforcement types, loading diagrams show breaks related with structural failure.
Fig. 4 shows photographs of destroyed specimens of all reinforcement schemes with characteristic damage in the area of the hole. In general, almost all curves in the loading diagram (Fig. 3) are linear. But in some cases, **at a later stage of loading, the curves show obvious failures caused by permanent local damage and a decrease in the bearing capacity of the structure (types 1, 2, 3).**

In objects with a hole, there is an obvious decrease in the strength (bearing capacity) of the composite in comparison with the same objects without a hole. According to ASTM D 5766, the calculation of the value of the ultimate stress of a specimen with a concentrator is carried out without considering the hole, on the assumption that a hole with a diameter of d = 6 mm with a total sample width of 36 mm does not affect the bearing capacity. To assess the sensitivity of a particular reinforcement scheme to the presence of a hole, the coefficient of change in strength Ke (formula 2) was introduced in the work, which is defined as the ratio of the ultimate stress values of specimens with a concentrator (open hole) to the value of the ultimate strength of a solid specimen ($\sigma_в$).

$$F^{OHTи} = \frac{P_{max}}{h w_{вк}} \qquad (1)$$

$$K_e = \frac{F^{OHTи}}{\sigma_в} \qquad (2)$$

where P_{max} - maximum load (N);
h – specimen thickness (mm);
$w_{вк}$ – specimen width, without taking into account a hole (36 mm).

Analyzing the diagrams in Fig. 4, it can be noted that types of reinforcement 1 and 5 are not sensitive to the presence of a concentrator, which is associated with the structure of the material and the redistribution of stresses arising in the specimen. According to the average values for type 5, an increase in ultimate stress by 13% is observed, however, it can be seen from the diagram that this increase falls within the statistical dispersion. For reinforcement types 3 and 4, there is a decrease in ultimate stresses by 30% and 14%, respectively. **Type 2 shows the opposite result i.e. Ultimate stresses in specimen with an open hole are 22% higher than that of standard specimens. This can be explained by the complex scheme of 3D reinforcement, as well as the influence of the scale factor, since the width of the specimens according to ASTM standards differs by about 30%.**

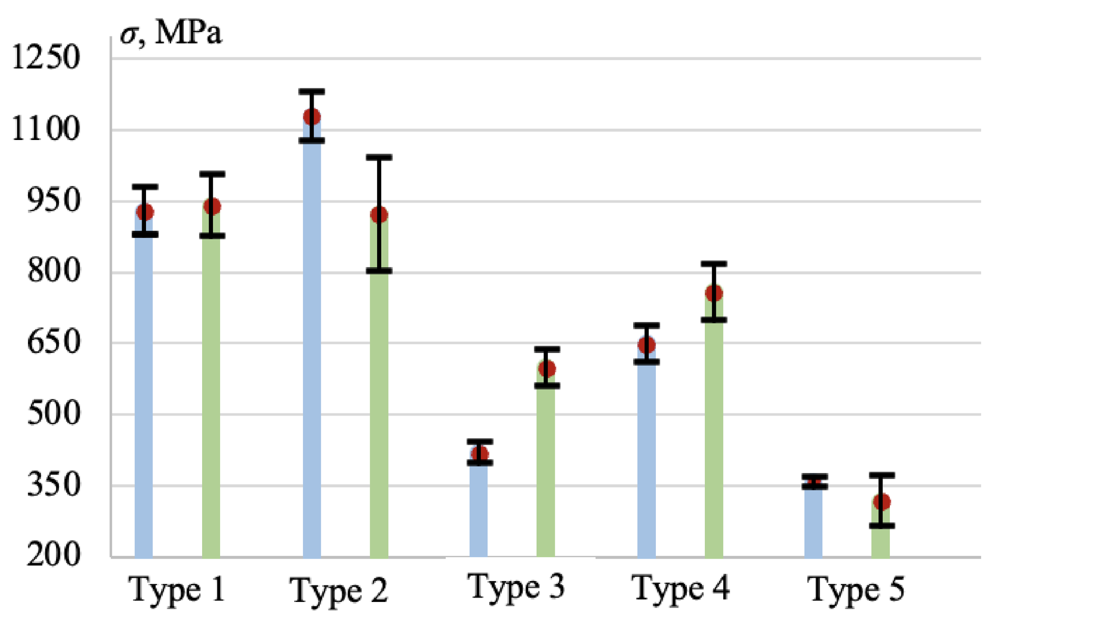

Fig. 4. Dependence of ultimate strength characteristics on the type of reinforcement of composite specimens: stress limit value according to ASTM (F^{OHTu}) – blue line; solid specimen tensile strength ($\sigma_в$) – green line

3. Conclusion

Thus, in the course of the research, a series of experimental studies of the CFRP specimens' strength with various reinforcement schemes were carried out during tensile and tensile with open hole tests. The analysis of the results obtained and the assessment of the effect of concentrators on the mechanical behavior of CFRP samples based on a number of different spatial reinforcing frames is carried out. A coefficient of strength variant has been proposed, which clearly shows the effect of strength variant depending on a particular structure in the presence of a stress concentrator. The least of open hole (concentrator) sensitive reinforcement schemes were identified.