Research Article

Effect of High Velocity Deformation on Strength of ArmoredComposite Materials

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Abstract: This paper considers the problem of determining the strength of carbon fiber reinforced plastic with straight and curved fibers under high-speed loading. High-speed tests of unidirectional CFRP specimens with rectilinear and wavy structure have been carried out. The influence of the structure and high-speed loading on the ultimate strength and ultimate deformation of the material is investigated. For the first time, a detailed study of the effect of fiber curvature on the properties of CFRP under high-speed deformation has been carried out. As a result of dynamic tests, it was shown that the ultimate strength in unidirectional laying is higher than in wavy laying. The effect of increasing the ultimate deformations of specimens with bent fibers was established, which was noted earlier for the case of tensile tests.

Keywords: Strength, high-speed loading, tensile strength, dynamic tests.

1 Introduction

During loading, a material subjected to high-rate deformation may change its mechanical properties, in comparison with the properties found as a result of static tests[1-8]. To calculate the structures under consideration, it is necessary to assess the effect of the strain rate on the properties of the materials used[9-16]. Therefore, the high-speed properties of CFRP were investigated, from which the master device of the product can be made.

The order of the realized rates of deformations in the problems under consideration can be estimated from simple ratios: in a time of 0,001 – 0,005 sec, deformations close to the limiting ones can develop in the product, that is, no more than 1-2% for a standard material such as epoxy carbon fiber. Thus, the strain rate is about 20 s^{-1}.

However, well-known studies were carried out mainly for the case of quasi-static loading of materials[17-25]. The effects of strain rate influence on the strength of composites with curved fibers have been studied to a much lesser extent, although they have also been considered.

2 Investigation of the strength of composite materials under high-speed loading

Samples of the composite material were made on the basis of ED-20 epoxy resin with Torey T800 reinforcing fibers. The volumetric content of fibers was 60%, the diameter of the fibers was 5 µm. Samples of three types were considered: 1) a quasi-homogeneous layered composite with a unidirectional reinforcement scheme, 2) a unidirectional composite with a wavelike layered structure, and 3) a pure matrix[26-37].

The samples had cylindrical shapes with a diameter of 15 mm for wavy packing and matrix, and a diameter of 10 mm for straight packing with a height of each sample equal to 10 mm.

The Kolsky method is implemented on an experimental stand (Fig. 1), which consists of a system of two identical long cylindrical rods, between which a sample is placed, which is a cylinder. The principle of operation of the Hopkinson bar is to determine the dynamic stresses, deformations or displacements at the ends of the bars, obtained in the middle of the bars used. The impulse is transmitted through the striker 1 to the rod 2, similar in properties and geometry, but smaller in length. Under the assumption that the wavelengths in the loading pulse are much larger than the diameter of the rods used, the perturbation will propagate along the rods without dispersion (retaining the shape) at the velocity of the longitudinal wave.

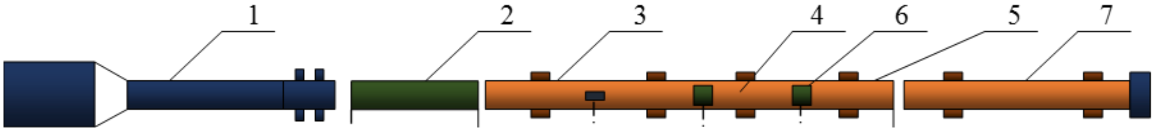

Figure: 1. Scheme of the Kolsky method (1 - gas gun, 2 - striker, 3 - transmitting rod, 4 - sample, 5 - support rod, 6 - strain gauges, 7 - damping rod).

Upon reaching sample 4, the incident wave splits due to differences in the cross-sectional areas and acoustic stiffnesses of the rods and the sample: part of it is reflected back by the wave, and part of it passes by the wave through sample 4 into the second rod 5. The sample undergoes elastoplastic deformation, while the rods are elastically deformed. Dependences of the deformations of the reflected and transmitted shock deformation of the rods are recorded by strain gauges 3 and 6.

To determine the stress-strain state in the sample and construct dynamic loading diagrams according to the readings of strain gauges and the following hypotheses of the Kolsky method are accepted:

- rods remain linearly elastic, of all stress and strain components, only longitudinal components are considered nonzero, stress and strain distribution in cross sections is assumed to be uniform;
- there is no dispersion when waves propagate in measuring rods;

- the main hypothesis of the method: neglecting inertial effects and friction, the stress-strain state in the sample is assumed to be homogeneous and uniaxial.

Compression tests were carried out on a high-speed system "Strain Master High-Speed 3D DIC" (La Vision) with visualization of deformation by the method of correction of digital images with registration of fast deformation processes of materials by the Kolsky method. The impact was carried out using a striker with a diameter of 20 mm and a length of 300 mm made of high-strength martensitic steel. The tests were carried out at a striker speed of 10-18 m/s. The striker speed was chosen from the results of static tests and experience of similar high-speed tests. The strain rate was ~ 600 s^{-1}.

Diagrams of incident, reflected and transmitted pulses depending on the strain rate, as well as the corresponding stress-strain diagrams are given in Figure 2. The elastic moduli determined in dynamic tests can be considered unreliable.

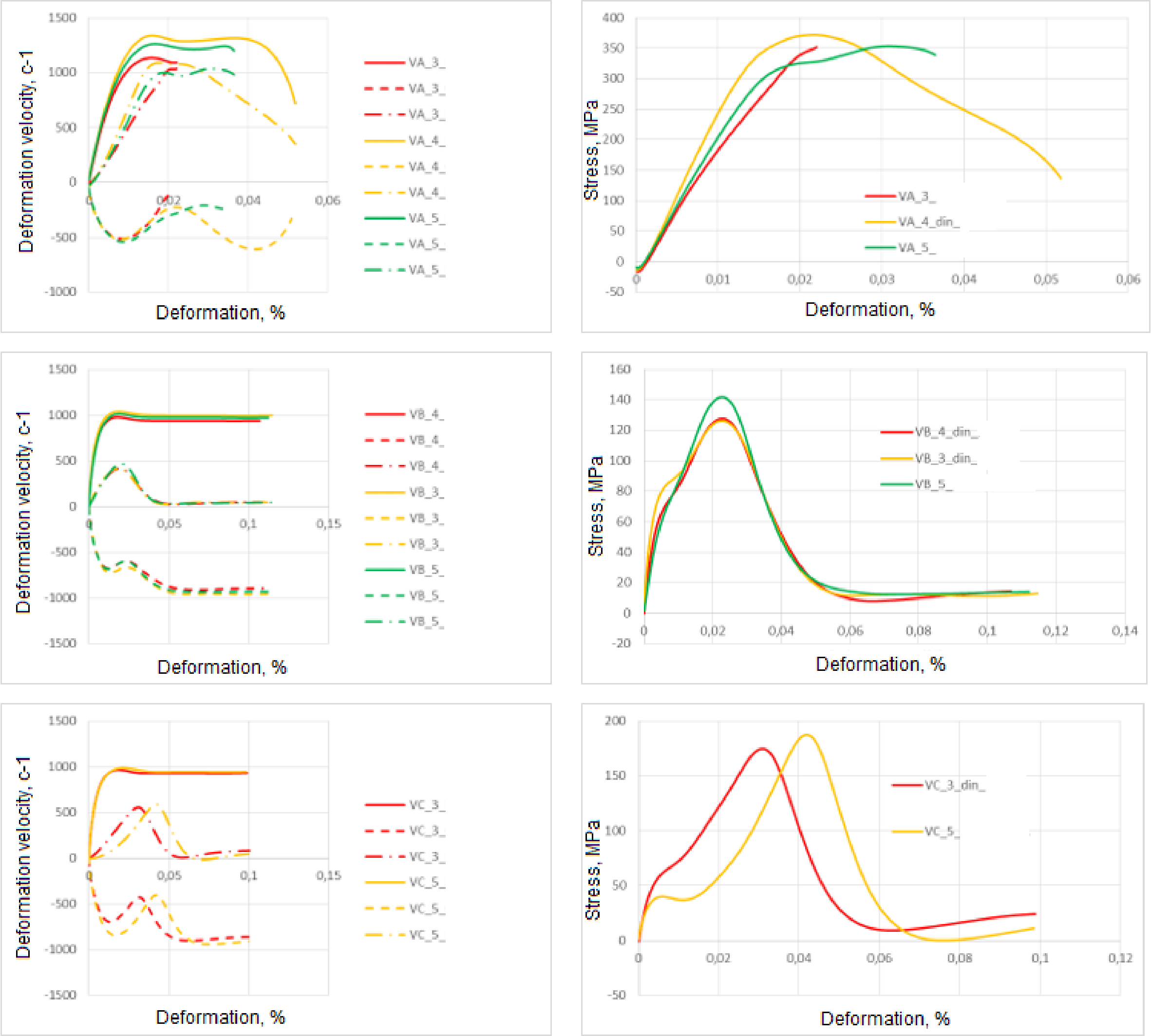

Figure: 2. Diagrams of impulses versus strain rate and stress-strain diagrams obtained during dynamic compression test of specimens with wavy packing.

For each batch of samples, the resulting diagram was obtained as a result of averaging the experimental data for three samples of the same type (Figure 3). During the tests, the tensile strength and ultimate deformations were determined for each sample.

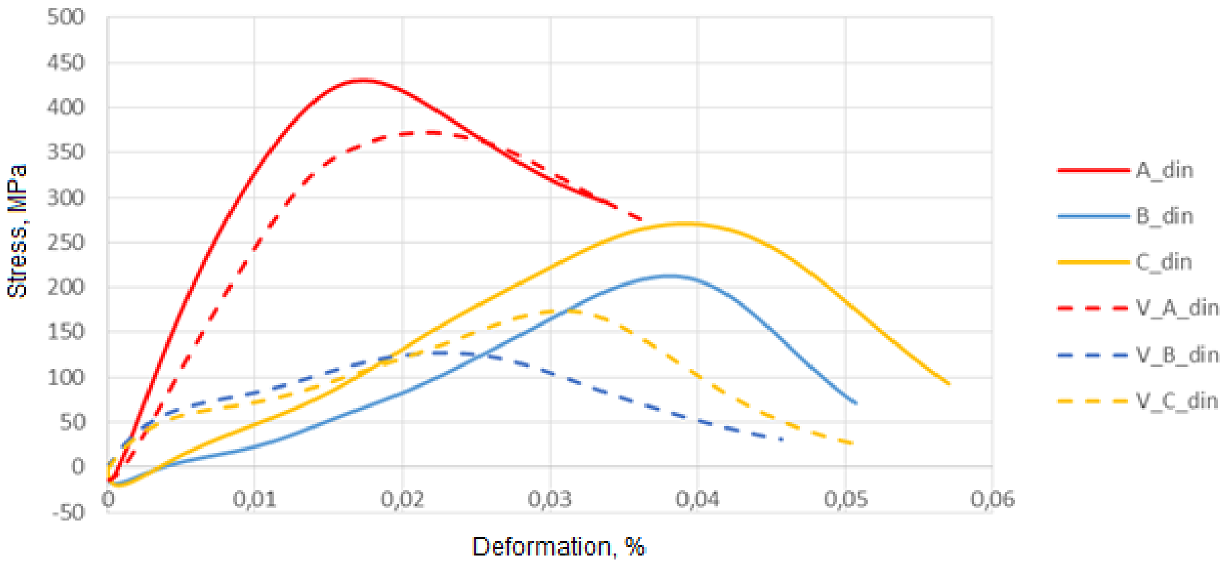

Figure: 3. The resulting stress-strain diagram obtained during dynamic compression tests of specimens with straight (solid lines) and wavy packing (dashed lines).

In high-speed tests, the tensile strength, in unidirectional laying is higher than in wavy laying, however, if during static tests this difference was not so significant (in the A-5% direction, in the B-32% direction, in the C-23% direction), then during the high-speed test, the difference increased significantly in comparison with the static test (in the A-15% direction, in the B-38% direction, in the C-37% direction). The ultimate deformations during high-speed testing in direction A, for unidirectional installation are lower than for wavy installation by 25%, and for unidirectional installation it is higher than for wavy installation in direction B (45%) and C (5,2%).

From dynamic tests it was found that the ultimate strength in direction A for unidirectional laying (424 MPa) is higher than for wavy (359 MPa), in direction B for unidirectional laying (212 MPa) it is higher than for wavy (132 MPa), in direction C for unidirectional laying (287 MPa) higher than for corrugated (181 MPa).

Dynamic tests also show that the ultimate deformations in direction A for unidirectional laying (2%) are lower than for wavy (2,5%), in direction B for unidirectional laying (4,2%) higher than for wavy (2,3%), in direction C for unidirectional styling (3,8%) is higher than for wavy (3,6%).

3 Conclusions

For the first time, experimental studies of the effect of fiber curvature on high-speed strength and ultimate deformations of epoxy-carbon-fiber plastic samples under high-speed loading have been carried out. Based on the experimental studies carried out, the static and high-speed characteristics of the composite laminate material, which are promising for use in the considered structures, have been determined. Based on the test results, it was demonstrated that in the design calculations for the products under consideration, it is possible to use static characteristics, since an increase in the deformation rate of the material leads to an increase in strength and, therefore, the calculation results will provide an additional margin of safety.

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