Influence of additional vibration loads on the processes of deformation and fracture of composite tubular samples

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Abstract. The work is devoted to an experimental study of the influence of additional vibration torsional effects on the deformation and fracture of composite tubular specimens under quasistatic tensile stress. A series of tests with various parameters of torsional vibration load for thin-walled CFRP tubular samples were performed according to the developed method. As part of the work, the methodological aspects of testing tubular specimens are considered. As a result, experimental data were obtained that reflect the effect of vibration effects on the behaviour of composite specimens during quasi-static tension. Additional vibrations contributed to the implementation of the deformation resources of the composite structural elements.

1. Introduction
During operation, structures made of composite materials, in addition to cyclic, low-speed impacts longitudinal and transverse loads, are subjected to vibration effects. The additional vibrational torsional influences have a stabilizing effect of the postcritical deformation process under tension conditions of solid cylindrical samples of structural steels [1, 2]. Based on this, it can be assumed that additional vibration effects, in addition to changing the residual strength, can also affect the processes of damage accumulation and destruction of composites.

The number of works devoted to the study of the processes of deformation and fracture of tubular specimens [3-6] is growing. The development of technologies for the production of composite materials and the improvement of test systems that make it possible to implement complex modes of mechanical loading, such as (in) proportional quasi-static and cyclic tension with torsion, all-round tension and hydrostatic compression, including internal pressure, etc. [7-9].

The main aim of this research was to study the regularities of the mechanical behavior of polymer composite tubular specimens under conditions of quasi-static tension with additional vibration loads.

2. Materials and equipment
The method of experimental study of the processes of deformation and fracture of polymer tubular composite specimens under additional torsional cyclic actions at different stages of quasi-static tension is schematically shown in figure 1, where:

P - maximum value of the tensile stress; u – maximum value of the displacement of the loading system of the specimen-traverse of the testing machine under tensile stress; P' – maximum value of the load under tensile with torsion; u' – maximum value of the displacement of the loading system.
(specimen-traverse of the testing machine) under tensile with additional torsional vibrations; $\varphi_a$ – amplitude of the twist angle during torsional vibrations; $\gamma$ – frequency of vibrational torsional loading.

Figure 1. The research methodology of tensile tests with additional torsional vibration loads.

The technique includes the following tests: 1 – carrying out uniaxial tensile tests with the determination of the value of the maximum tensile forces at destruction $P$; 2 – tensile tests with additional torsional vibration loads with low amplitude and high frequency.

In order to study the influence of possible effects of additional vibration effects on the processes of deformation and destruction of carbon fiber reinforced polymer (CFRP) composite materials, a series of experiments were carried out on carbon-fiber (T700SC-12000-50C with Etal-Inject SL / M binder) tubular specimens with an outer diameter of 26 mm, wall thickness of 0.5 mm and concentrator 5 mm in diameter (figure 2).

Figure 2. CFRP tubular specimen.

Vibration load mean cyclic loading with a small amplitude of the twist angle $\varphi_a$ and a high frequency $\gamma$.

To implement such a complex loading, it is necessary to take into account the rigidity of the loading test system. The Instron 8802 universal biaxial testing system is the most rigid and allows the implementation of complex loading conditions. The main advantage of biaxial test systems is associated with their design feature, which allows simultaneous application of axial load and torque to the specimen: $\pm 100$ kN, $\pm 1000$ N·m, 30 Hz (figure 3).

Figure 3. The Instron 8850 testing system.
Methodological aspects of testing tubular composite specimens under complex stress state conditions are reflected in [10]. In order to prevent crushing of the tubular specimen in the grips of the test system, cylindrical metal rods were pressed into the ends of the specimen by the length of the collet (figure 4).

![Figure 4. Photo of a metallic rod.](image)

3. Results

The study included experiments on quasi-static tension (figure 5) and tension with vibration torsional actions.

![Figure 5. Loading diagrams of GFRP tubular specimens under quasi-static tension (a) and torsion (b).](image)

Based on the results of quasi-static tests, the following parameters of the vibration torsional action were selected: \( \phi_a = 1^\circ, \nu = 20 \text{ Hz}; \phi_a = 0.5^\circ, \nu = 25 \text{ Hz}; \phi_a = 0.25^\circ, \nu = 30 \text{ Hz} \).

As a result of the imposition of additional actions on the stress loading diagrams under tension, there appeared areas of stage failure and zones of equilibrium deformation (figure 6). For the convenience of analyzing the results, the diagrams are plotted in relative coordinates \( P'; u' \).

\[
P' = P \cdot \frac{P_{\text{max}}}{N}
\]

Where:
- \( P \) – value of the compressive load, N;
- \( P_{\text{max}} \) – value of the compressive load at destruction, N.

\[
u' = u \cdot \frac{u_{\text{max}}}{m}
\]

Where:
- \( u \) - sample displacement, mm;
- \( u_{\text{max}} \) - displacement of the sample during destruction, mm.
Additional vibration loads reduce the value of the maximum load $P_{\text{max}}$ during specimen failure, but contribute to the realization of equilibrium loading sections. The obtained experimental dependencies can be used to create databases of materials, which are subject to increased requirements from the point of view of the safety of destruction and catastrophe. Photos destroyed specimens are shown in figure 7.

**Figure 6.** Loading diagrams of CFRP tubular specimens.

**Figure 7.** Photographs of fractured CFRP specimens after tests for tensile (a), torsion (b), tension with additional vibration effects $\phi = 0.25^\circ$, $\nu = 30$ Hz (c).

### 4. Conclusions

Within the framework of the study, a technique was developed for studying the processes of damage accumulation and destruction of composite tubular specimens under conditions of a plane stress state under joint tension with vibrational torsion using a two-axis servo-hydraulic testing machine. The study of the effect of additional vibration torsional vibrations on deformation and fracture of CFRP tubular specimens has been carried out. It was revealed that additional vibration loads contribute to the implementation of the deformation resources of the samples under study.

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