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Dynamic Testing of Reinforced Glass Fibre–Epoxy Composite at Elevated Temperatures

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Динамические испытания армированного стекловолокном эпоксидного композита при повышенных температурах

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Представлен экспериментальный анализ деформирования, прочности и разрушения трубчатых образцов, изготовленных из армированного стекловолокном эпоксидного композита. Образцы подвергались одноосному растяжению при средних скоростях деформации от 10^{-5} до 20 c^{-1}. Испытания проводились при комнатной температуре, а также при трех повышенных температурах до момента фазового превращения матрицы.

Ключевые слова: эпоксидный армированный композит, трубчатый образец, одноосное динамическое испытание на растяжение.

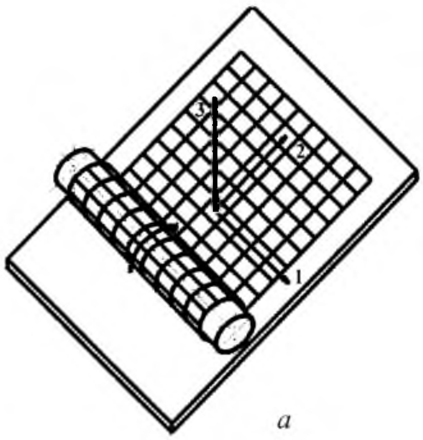
Introduction. Due to the rapidly expanding applications of composites in the manufacturing industries, the mechanical behavior of composites subjected to strain rate loading have been extensively studied as fundamental research field in the last two decades [1, 2]. In investigations on mechanical properties of composites, the main problem is to develop testing methods under conditions of general stressed state for various strain rates and temperatures. This is related to the necessity of testing properties of new materials under conditions similar to the operational ones of a construction designed. Up to now, no unification or standardization of testing methods, particularly dynamic, of composites has been achieved. Insofar as different experimental stands and specimens are used, generally, it becomes quite difficult to compare the results obtained by different authors and to verify their hypotheses.

Polymer composites are thermoviscoelastic solids and, consequently, they are particularly sensitive to the loading variation time, and even to small changes in temperature. At high strain rates, an adiabatic process develops and a local heating of specimen occurs, thus exerting a substantial influence on mechanical properties.

In the framework of our study, two types of tubular specimens were used for the static and dynamic tests. In the specimens of the first type, orientation of the crossing glass fibres to the longitudinal axis of specimens was parallel/perpendicular, while fibres in specimens of the second type were inclined at the angle of 45° to this axis.

For static tests, a standard tensile test machine was utilized. For dynamic experiments, apparatuses were designed in which impact loading conditions were obtained by burning of an explosive or by a drop-weight scheme of a mass. At these impact conditions, properties and failure of the composite were considerably different from those in the static ones. Additional changes were caused by ambient temperatures and location of fibres in specimens. This paper describes the above phenomena and presents the following relationships: the elastic and tensile strength versus strain rates for various temperatures, for two orientations of fibre glass textile used in the specimens.

Experimental. The subject of the experimental investigations was the laminar polymer composite in form of plates and tubes, made of an epoxy resin and a glass fibre textile. This material is critical for the aircraft, automotive and naval industries. The average weight content of glass was 0.5 in this composite. Figure 1 illustrates the preparation procedure of this composite in a tubular form. There are two orientations of glass fibres.



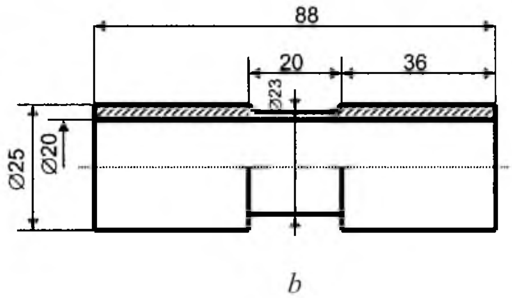


Fig. 1. Preparation procedure of composite specimen in tubular form.

In the first one, the crossing fibres were oriented parallelly and perpendicularly to the longitudinal axis of specimens. In the second one, the fibres were at an angle of 45° to this axis. The cuboid specimens were cut out from the plate composite by way of milling. Their overall dimensions were the following: length – 140 mm, width and thickness – 20 mm. They were used for determining the selected static mechanical properties depending on the angle between the principal axis of ortothropy and the direction of loading. Measurements of elastic constants: elastic modulus and Poisson's ratio were evaluated within the stress range of $(0.02–0.2)\sigma_f$, where σ_f denotes the tensile strength. Extreme values of these constants and the tensile strength were obtained for various angles (0°, 90°, and 45°) between the textile fibre direction and that of tensile loading For the composite under study, relations for two thermal properties (linear expansion α and conductivity λ) versus temperature T were determined for the principal axes of orthotropy. The glassy temperature T_g of this composite is about 345 K. The corresponding values of the composite components: the epoxy resin and the glass fibre are: $E^r = 2270$ MPa, $E^g = 64660$ MPa,

$\nu^r = 0.3$, $\nu^g = 0.25$, $\sigma_f^r = 42$ MPa, $\sigma_f^g = 1032$ MPa, $\alpha^r = 1.3 \cdot 10^{-5}$ K^{-1}, $\alpha^g = 0.8 \cdot 10^{-5}$ K^{-1}, $\lambda^r = 0.04$ W(m$\cdot$K)$^{-1}$, $\lambda^g = 0.74$ W(m$\cdot$K)$^{-1}$, respectively. The curves of the linear expansions are temperature-dependent, but the conductivity is constant in the temperature range of 293–360 K.

Tubular specimens were used in static and dynamic tests at room and elevated temperatures. The longitudinal section and overall dimensions of test specimens are shown in Fig. 1b. A standard tensile tester was used in static tests with the average strain rates $\dot{\varepsilon}$ of about 10^{-5} s^{-1}. Impact tests were performed using either a drop weight machine at $\dot{\varepsilon}$ about 10^{-1} s^{-1} or a specially designed apparatus in which an impact loading was obtained by confined explosion. In the last case, the average strain rates were within the range from 1.0 to 20 s^{-1}.

Figure 2 shows the block diagram of the apparatus designed for the impact testing. Specimen loading is produced by a pulse pressure. This pulse pressure is generated by burning of an explosive. Combustion products indirectly exert the dynamic action on the specimen tested. Detonation of blowing charges or burning of powder makes it possible to obtain high dynamic values of pulse loads. The loading system design allows one to control values, shapes and duration times of impact loading over a wide range by selecting the type and amount of a propellant charge, the volume of burning and expansion chambers and by controlling the inflow and outflow parameters of the gas combustion products.

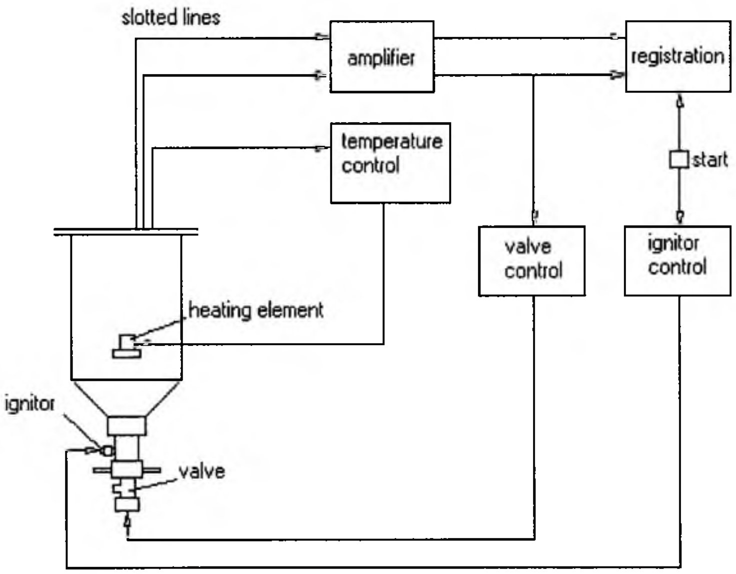
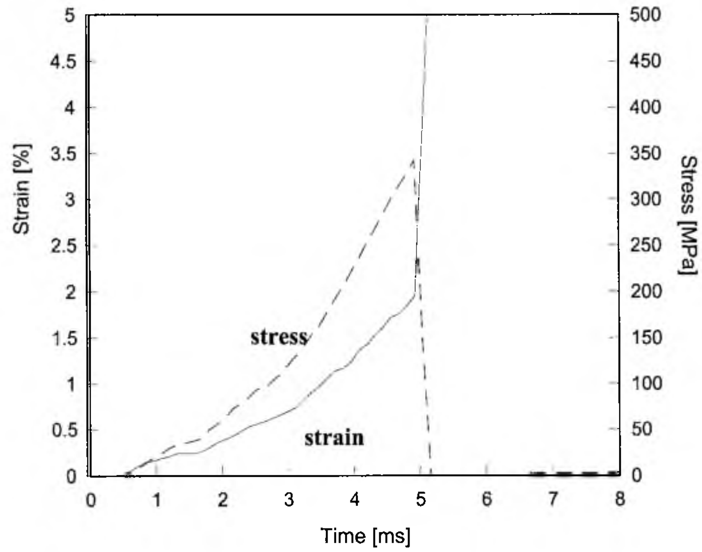
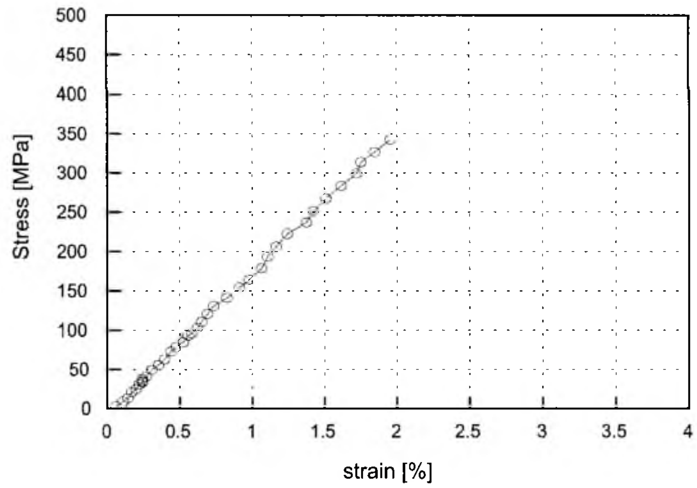


Fig. 2. Block diagram of the dynamic testing set-up.

Likewise, the tubular specimen was fixed in a loading system of a drop apparatus and of a standard tester. The selected experimental result obtained from the impact test for $\dot{\varepsilon} = 4.1$ s^{-1} (where nitrocellulose powder was used as the propellant charge) is presented in Fig. 3, whereas $\dot{\varepsilon}$ is the average slope of the curve $\varepsilon(t)$.



a



b

Fig. 3. (a) Strain and stress versus time from impact test; propellant charge consisted of the nitrocellulose powder. (b) Stress–strain curve corresponding to this test ($\dot{\varepsilon} = 4.1$ s^{-1}, $\varphi = 0°$, $T = 293$ K).

Results. Experimental static and dynamic strain-stress curves obtained from testing of 4–6 individual specimens for the given strain rate, four levels of temperatures and two direction angles of tension were averaged. On the basis of the averaging results, the graphs of the elastic modulus E and the tensile strength σ_f versus strain rate, in logarithmic scale, are obtained for temperature levels and two orientations of woven used in the specimens (see Fig. 4). The increase in the strain rates causes the elastic modulus and the ultimate strength to increase within the considered range of the strain rate, while the increase in the ambient temperature produces inverse effects. When the orthotropy axis coincides with the loading direction, corresponding values of the elastic modulus and tensile strength are larger than those obtained for the case where the fibres are at the angle of 45° to this direction. For values of fracture strains, this effect was inverse. Static tests on cuboid specimens confirmed these relationships to be valid for the tubular ones. For the specimens with the direction angle of 45°, at temperatures close to the glassy temperature T_g the epoxy resin provided less reinforcement contribution than at lower temperatures. For temperatures higher than T_g, the strain rate had no influence on the elastic modulus. This is attributed to the phase change in the matrix.

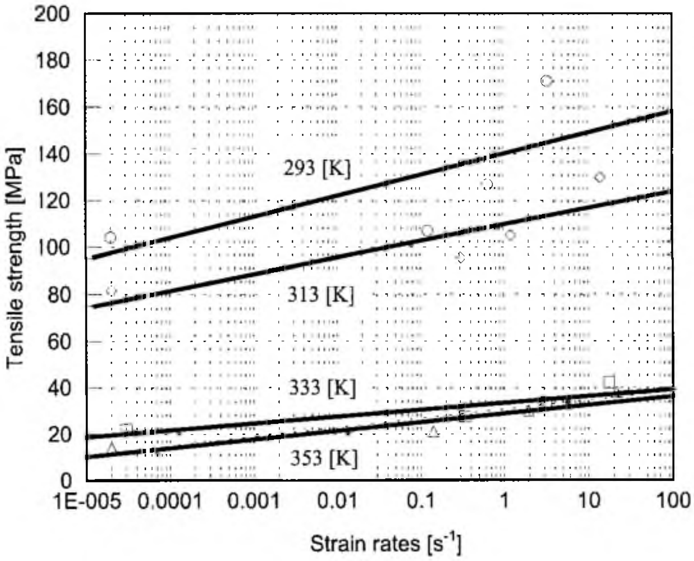


Fig. 4. Tensile strength vs strain rate for various temperatures and the angle $\varphi = 45°$.

Conclusions. The new designed apparatus, in which an impact loading was obtained by burning of an explosive or by dropping of a mass, was used for tests, which permitted us to obtain the strain-rate behavior at elevated temperatures of the tested composite subjected to dynamic tension. These experimental results describe the thermomechanical properties of composites at elevated temperatures, up to the glassy one and those observed at static loading and medium strain rates. Thermal and strain rates affect the characteristics of the strain–stress curve. For the range of strain rates applied in these tests, a percentage increase in the elastic modulus at a room temperature is almost twice as high for $\varphi = 0°$ as compared to $\varphi = 45°$. The increase in the tensile strength for these two types of the composite is similar: 41% and 65%, respectively. The temperature change within a range from the room to the maximum elevated one at $\dot{\varepsilon} = 0.1\ \mathrm{s}^{-1}$ causes a reduction of the elastic modulus equal to 55% for the composite with $\varphi = 0°$, and 94% for the composite with $\varphi = 45°$. This change deteriorates the tensile strength by 45% for first type of the composite and by 81% for the second one.

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Р е з ю м е

Проведено експериментальний аналіз деформування, міцності і руйнування трубчастих зразків, виготовлених із армованого скловолокном епоксидного композита. Зразки випробовували на одновісний розтяг при середній швидкості деформації від 10^{-5} до 20 $с^{-1}$. Випробування проводили за кімнатної температури, а також за трьох підвищених до моменту фазового перетворення матриці.

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