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EXPERIMENTAL STUDY OF THE INFLUENCE OF THE TYPE OF STRESS-STRAIN STATE ON THE DYNAMIC COMPRESSIBILITY OF SPHEROPLASTIC

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Abstract. By using a set-up that implements the Kolsky method, dynamic tests were carried out at compression under conditions of uniaxial stress state and uniaxial strain of the spheroplastics in the initial state and aged. Dynamic diagrams were obtained for these modes. In the uniaxial stress state, the strength of the material was determined. In the uniaxial deformation, the lateral expansion ratio and shear strength were determined.

Keywords: high-speed deformation, experiments, the Kolsky method, spheroplastic, dynamic diagrams

1. Introduction

It is known that objects of rocket and space technology can be subjected to intense dynamic loading of explosive, shock and other nature in operation. In modern constructions, various composite materials are widely used, both as load-bearing structural elements and as damping materials such as metal honeycombs, porous compounds, polymeric foams, etc. [1-10]. Many aspects of the behaviour of cellular solids are summarized well in the book by Gibson and Ashby [11].To prevent damage of the structures under the impact of shock wave loads, the rocket engine body is covered with a protective layer - a spheroplastic, which reduces the action of shock-wave loads by introduction of damping caused by the work required to compress the porosity.

Spheroplastics are polymeric materials reinforced with microspheres, usually of glass, ceramic or polymer. Due to the use of microspheres, the spheroplastics possess a number of important technical characteristics: reduced density with simultaneously increased stiffness, reduced thermal conductivity, and increased radio engineering characteristics. Spheroplastics are actively used to create heat-shielding materials for rocket engines. To create composites with predetermined properties that provide resistance to impact loads, data on the properties of constituent composite materials obtained at high strain rates are needed.

The purpose of the research is experimental confirmation of the protective characteristics of the spheroplastic under conditions of dynamic shock-wave loading. For this purpose the dynamic characteristics of spheroplastic (including aged ones) under high-speed loading were determined experimentally.

2. Experimental methods and specimens

Compression tests of spheroplastic were performed using the traditional Kolsky technique and its original modification. The traditional version of the Kolsky technique allows one to investigate the dynamic properties of materials at compression under uniaxial stress and

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volumetric strain [12]. In this case, on the basis of the strain pulses in the measuring bars, the parametric dependences of the axial (longitudinal) components of stress $\sigma_x(t)$, strain $\varepsilon_x(t)$ and strain rate $\acute{\varepsilon}_x(t)$ tensors in the specimen are determined. After synchronization of those it is possible to construct the stress-strain curve $\sigma_x \sim \varepsilon_x$, with the dependence $\acute{\varepsilon}_x \sim \varepsilon_x$ and determine the parameters: conditional yield stress, hardening modulus, ultimate strength.

To investigate the compressibility of the material under conditions of volumetric stress state and uniaxial deformation, an original modification of the Kolsky technique [13] is used: the tested specimen is placed in a rigid jacket, equipped with the strain gauges, from whose impulses it is possible to determine the radial stress component in the sample $\sigma_r(t)$. The combination of the longitudinal and radial stress components in the specimen makes it possible to determine the tangential stress $\tau(t)$, the pressure $P(t)$, the lateral thrust coefficient $\xi(t)$ and then to construct the curves $\tau \sim P$ and $\xi \sim P$.

For compression tests, specimens were used in the form of tablets with a height of ~10 mm and a diameter of ~20 mm. Such dimensions (the ratio $L/D \approx 0.5$) correspond to the minimum error in the stress measurement caused by inertia forces. Specimens were made of material in two states: as received (initial state) and artificially aged.

In the compression tests the end faces of the specimen were smeared with a thin layer of graphite grease immediately before installation into the working position. That was made to ensure acoustic contact between the ends of the bars and the specimen, and to reduce the effect of frictional forces during radial expansion. The same lubricant was used to fill the gap between the lateral surface of the sample and the inner surface of the confining jacket.

3. Results of dynamic tests at different types of stress-strain state

Some of the tests were carried out using steel measuring bars (and confining jacket), which made it possible to achieve high stress level in the specimen and, correspondingly, high strain rates. To obtain properties at low strain rates, when the amplitude of the detected signal from the transmitting bar has a small value, we used pressure bars (and jacket) made of aluminum alloy. At the lowest levels of the transmitted pulse, the polymeric (vinyl-plastic) bar was used as the transmitting one.

Since the acoustic impedance ρC of the spheroplastic is much lower than the acoustic impedance of the measuring bars, the specimen undergoes loading by a large number of cycles with gradually decreasing amplitude during single test [14]. The low speed of elastic waves in the vinyl-plastic bar allowed undistorted registration of several loading cycles of the specimen in a single experiment (Fig. 1). It can be seen that only after the sixth loading cycle the amplitude of the transmitted pulse begins to decrease.

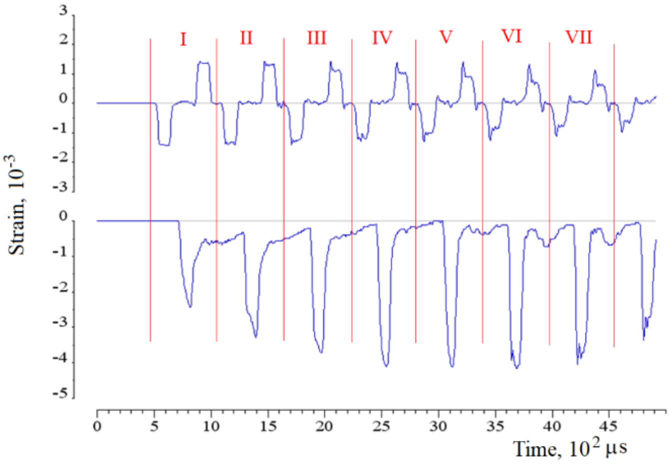

Fig. 1. Loading cycles for the spheroplastic with the use of the polymeric transmitting bar

In the condition of a uniaxial stress state, strain-strain curves were obtained for the spheroplastic in the initial state and aged. In Fig. 2 shows only 3-4 loading cycles, since the subsequent cycles do not produce significant changes in the levels of achieved stress and strain. As one can see, the structural strength of the spheroplastic is very low - about 5 MPa. Spheroplastic in an aged state showed a greater dispersion of strength properties, however, this may be a consequence of poor-quality end surfaces of the tested specimens.

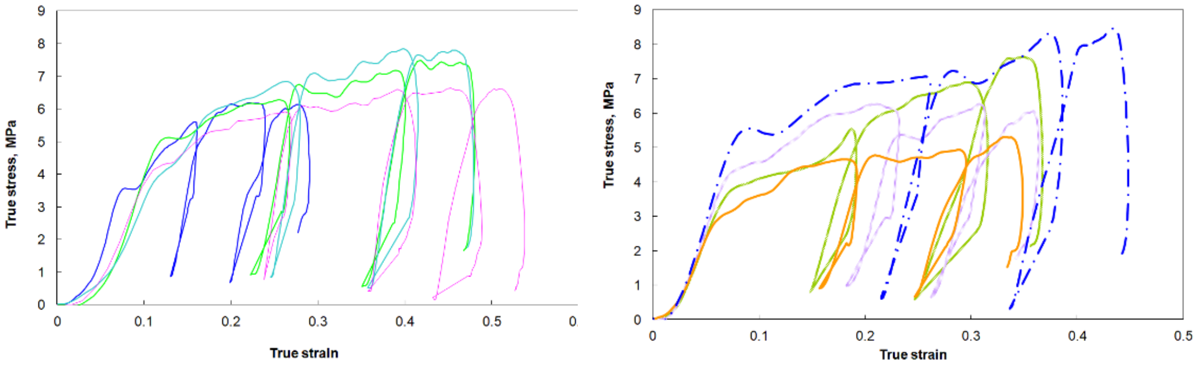

Fig. 2. Stress-strain curves of spheroplastic in the initial state (left) and aged (right)

Due to the high viscosity of the polymer binder the material demonstrates a very slow recovery of the initial shape after each loading cycle, as is clearly shown in Fig. 1 (lower beam). It is not possible to obtain a complete specimen unloading for several tens of microseconds (pause between cycles). Therefore, the sections of the diagram between the load cycles are rather hypothetical.

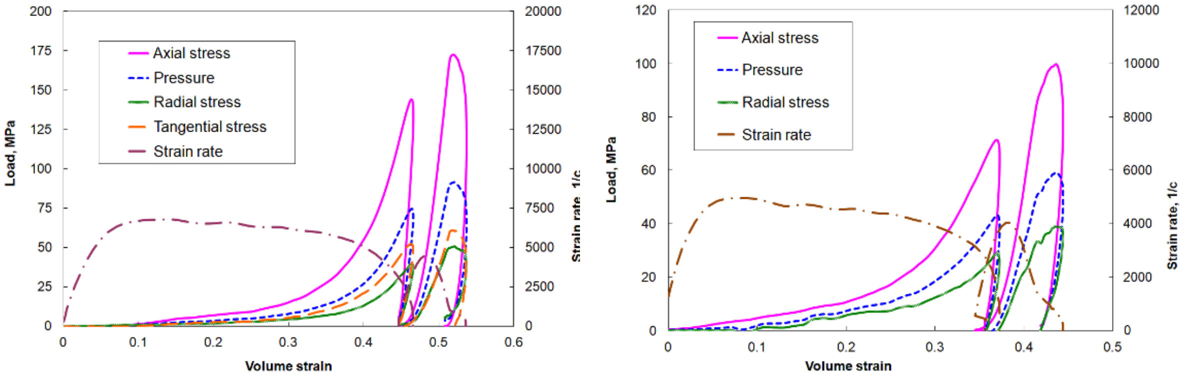

Fig. 3. Stress-strain curves for spheroplastic in the initial (left) and aged (right) states under uniaxial strain condition

When the specimen is placed in a rigid jacket the uniaxial deformation process is realized. The stress-strain curves of spheroplastic obtained in this case for both initial and aged states for two loading cycles are shown in Fig. 3. The parameters of shear strength (the dependences $\tau \sim P$ and $\xi \sim P$) are shown in Fig. 4.

The dynamic properties of spheroplastic in two states (initial and aged) are compared. Next, characteristic diagrams of spheroplastic specimens are shown in tests without a jacket (Fig. 5) and in a jacket (Fig. 6). It is possible to note somewhat less deformability of the spheroplastic in the artificially aged state.

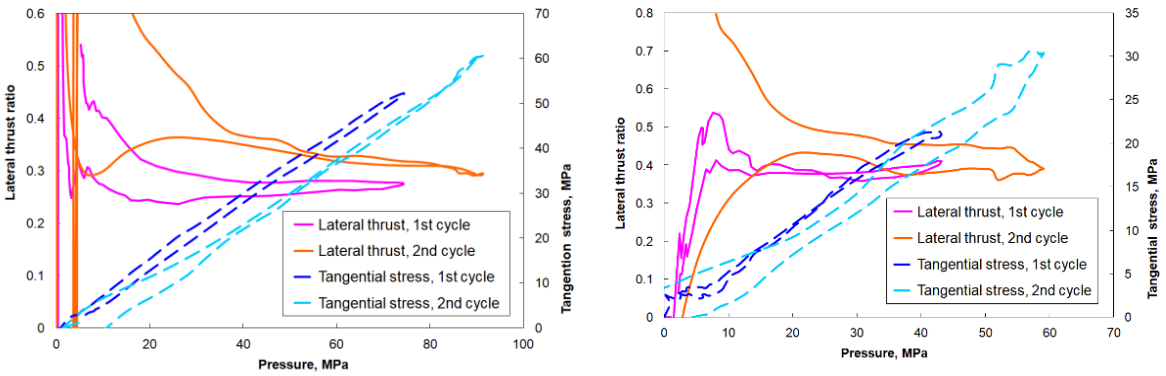

Fig. 4. Shear strength parameters for spheroplastic in the initial (left) and aged (right) states under uniaxial strain condition

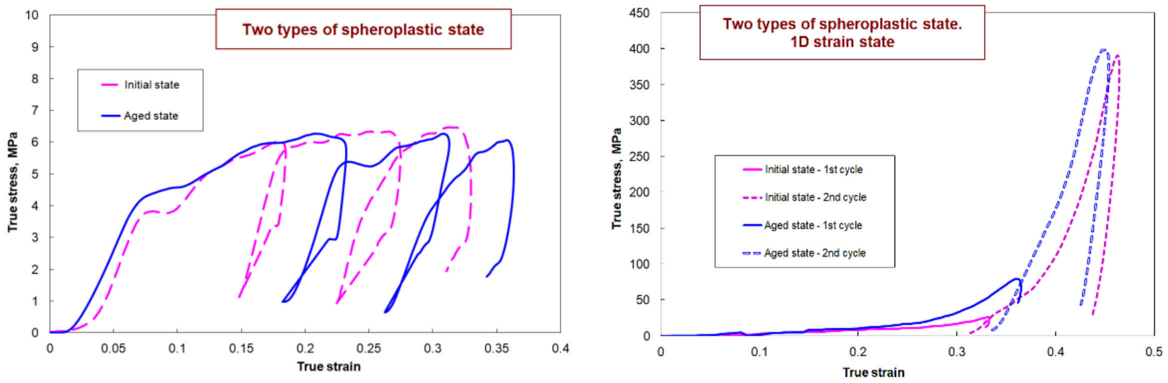

Fig. 5. Comparison of stress-strain curves for spheroplastic in the uniaxial stress state (left) and uniaxial strain state (right)

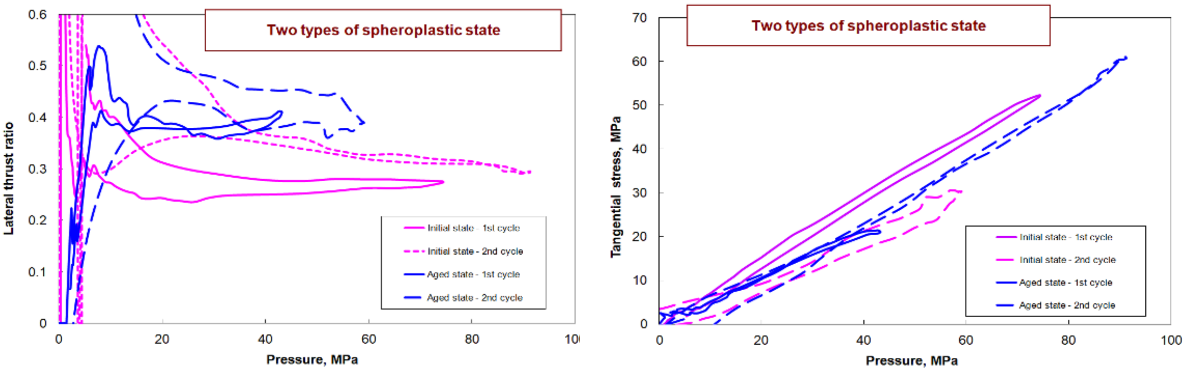

Fig. 6. Comparison of the parameters of shear strength of spheroplastic in two states under uniaxial deformation

Comparison of the shear strength parameters (the dependences $\xi \sim P$ and $\tau \sim P$) is shown in Fig. 6. The coefficient of lateral thrust of the material in the aged state is somewhat greater than in the initial one. The curve $\tau \sim P$ can be approximated by a linear dependence.

The appearance of the specimens after deformation with different load levels under uniaxial stress conditions is presented in Fig. 7.Analysis of the nature of the material destruction as a result of testing under uniaxial stress condition (without a confining jacket) revealed the following. At low loading pulse energy the specimen retains apparent integrity, but its actual residual strain is much less than that obtained from the curves in Fig. 2.

Apparently, the polymeric binder of the spheroplastic has a large coefficient of shape recovery, but because of high viscosity of the binder the registration of specimen's unloading after the loading pulse end seems to be impossible.

Fig. 7. The appearance of spheroplastic specimens in the initial (a) and aged (b) states after loading without a confining jacket

The destruction of samples is fragile and occurs closer to the outer peripheral surface, while the central zone remains intact. This may be due to the presence of friction on the end surfaces of the samples, leading to triaxiality of its stress state.

4. Conclusion

The structural strength of spheroplastic at compression under uniaxial stress condition was found to be about 5 MPa for both specimens in the state of delivery and artificially aged. For the condition of uniaxial strain, the coefficient of lateral thrust was determined. The average value of the lateral thrust ratio was found to be 0.35 for the spheroplastic in the initial state, and 0.45 for the aged state.

In the aged state the spheroplastic showed somewhat less deformability for both types of stress-strain states. The shear strength $\tau \sim P$ of the aged spheroplastic is less than that in the initial state.

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