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INVESTIGATION OF STRENGTH AND TIME PROPERTIES OF LIME-SAND BRICK UNDER DYNAMIC LOADING

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Abstract. The results of experimental study of mechanical properties of samples of sand-lime brick under dynamic loading are presented. The tests were carried out using the traditional Kolsky method and its modification - dynamic splitting (the so-called «Brazilian test»). The laws of change in strength and time properties of the investigated material are determined in the strain rate range of $3\cdot10^2$-$2.5\cdot10^3$ s^{-1} under compression and in the stress rate range of $2\cdot10^1$-$3\cdot10^2$ GPa/s under tension.
Keywords: sand-lime brick, dynamic loading, high-speed deformation, experiments, identification of model parameters

1. Introduction

Investigation of the mechanical properties of building materials subjected to dynamically applied loads is relevant in up-to-date engineering science due to increase in number of various types of emergencies (natural disasters, technological accidents, terrorist acts, etc.). Such tragedies are accompanied by intense impacts and explosions, which are characterized by continuous variation of parameters, high intensity and short duration. In recent years, the design and construction of industrial facilities have been developed actively. When in service, the structures of the facilities are exposed to a variety of dynamic effects. Multipurpose programs of finite element analysis such as ANSYS, NASTRAN, LS-DYNA, ABAQUS and others are widely used in modern design and calculation of building structures. In this case it is necessary to carry out calculation based on the mechanical characteristics of the material which will determine the behavior of the simulated structure subjected to loading. Experimentally obtained mechanical properties of materials for various types of stress-strain state are also necessary for constructing ultimate surfaces (yield surface, fracture surface, etc.) in order to develop new hypotheses of dynamic strength and to test the existing ones. Therefore, studying the behavior of modern building materials under dynamic loading is becoming topical.

An experimental study of the dynamic behavior of sand-lime brick grade 150 was carried out. The experiments were performed at facilities using the classical Kolsky method for compression tests under uniaxial stress state conditions at high strain rates. In addition, a modification of this technique – dynamic splitting (the so-called «Brazilian test») was employed to determine the properties of the material under tension. As a result of these experiments the deformation diagrams were constructed at different dynamic impact regimes; strength and time characteristics were obtained as well as their dependence on strain rate or stress rate. The influence of strain rate and stress rate on the properties of the tested material is noted.

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2. Making samples

Samples were made in the form of cylinders with a diameter of 20 mm and a length of 10 mm for compression tests and a length of 20 mm for tensile tests (splitting tests). At first, the plates of 10 mm and 20 mm thick were cut off from bricks on a stone-cutting machine with a diamond disc and then for experiments, cylindrical samples were drilled from these plates on a drilling machine with a diamond-coated crown.

3. Dynamic test methods and experimental setup

Among the known methods of dynamic testing of materials the Kolsky method with the split Hopkinson pressure bar (SHPB) [1] was most widely used due to its good theoretical validity and simplicity of implementation. Numerous modifications of this technique have been developed by now, [for example 2-5], which allow to determine the various mechanical properties of materials at high strain rates. In this paper the classical Kolsky method was used to determine the strength of samples of sand- lime brick under uniaxial compression and its modification the «Brazilian test» (splitting test) [6], which is an analogue of the tensile testing scheme (Fig. 1).

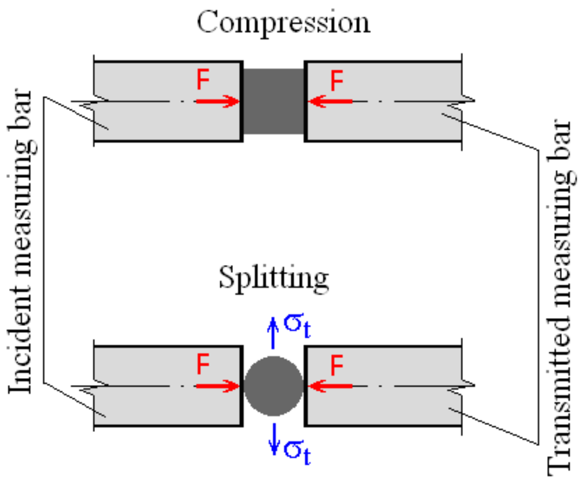


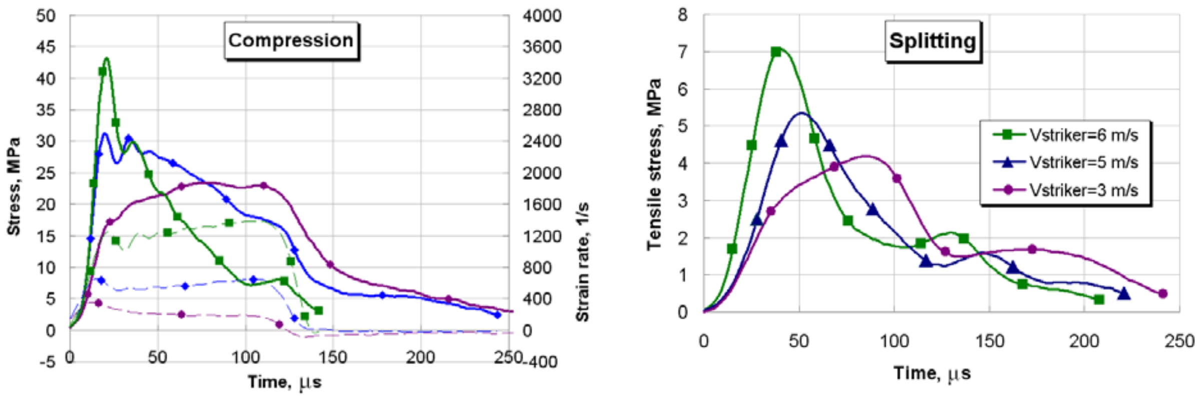
Fig. 1. Techniques used in dynamic testing of sand-lime brick

The setup for dynamic tests consisted of a pneumatic loading device (gas gun) with a control system, a set of measuring and registering equipment and a replacement set of measuring bars with a diameter of 20 mm. Registration of initial experimental data was carried out using strain gauges glued on the lateral surface of measuring bars, signals from which were transferred to a digital storage oscilloscope through dynamic tensometry schemes. Then the oscillograms were saved digitally and processed using the original software.

4. Results of dynamic tests on uniaxial compression

Dynamic compression tests under conditions of a one-dimensional stress state were carried out on cylindrical samples with a diameter of 20 mm and a length of 10 mm. Cylindrical bars with a diameter of 20 mm and a length of 300 mm were used as strikers. The change in the amplitude of the loading wave was achieved by the alteration of the velocity of the striker. Herewith, such loading regimes were achieved that the sample was destroyed completely into pieces and even «into dust».

In dynamic tests the sample is exposed to an intense pulsed short-term loading which can cause a non-homogeneous stress state of the sample as a result of the stress waves propagation in it and considerable inertial forces acting on the sample. The results of the investigations and some of the recommendations for brittle material described in [7-9] were taken into account in order to fulfill the basic prerequisites of the Kolsky method is the realization of a uniaxial stress state with a uniform distribution of stresses and strains along its length. Thus, the ratio of the length to the diameter of the samples was within the recommended limits of 0.3-1.0. A thin layer of grease was applied to the ends of the measuring bars before testing in order to reduce the influence of frictional forces during the radial expansion of the sample. Time history analysis of the synchronized strain pulses in measuring bars has shown that the forces are practically equal at the ends of the sample and the state of equilibrium deformation in the sample is achieved.



a b

Fig. 2. Deformation diagrams of samples of sand-lime brick at compression (a) and tension (b)

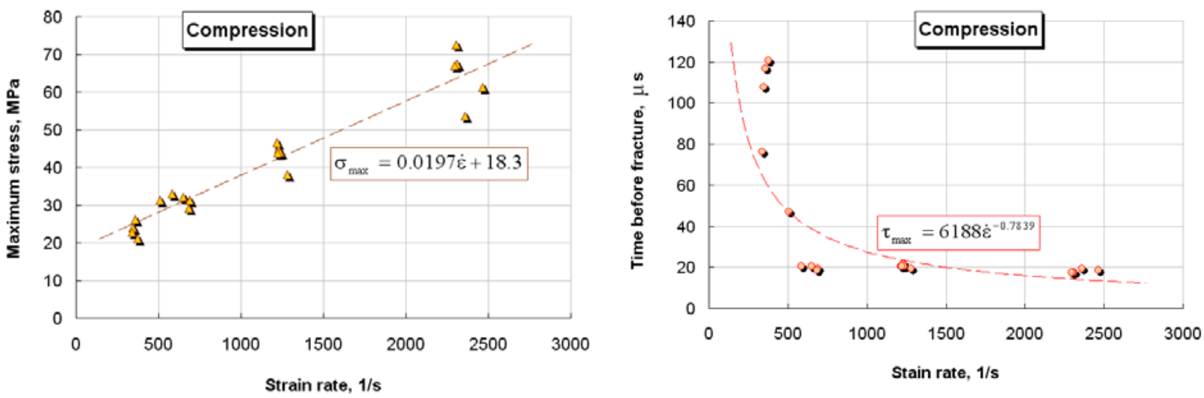


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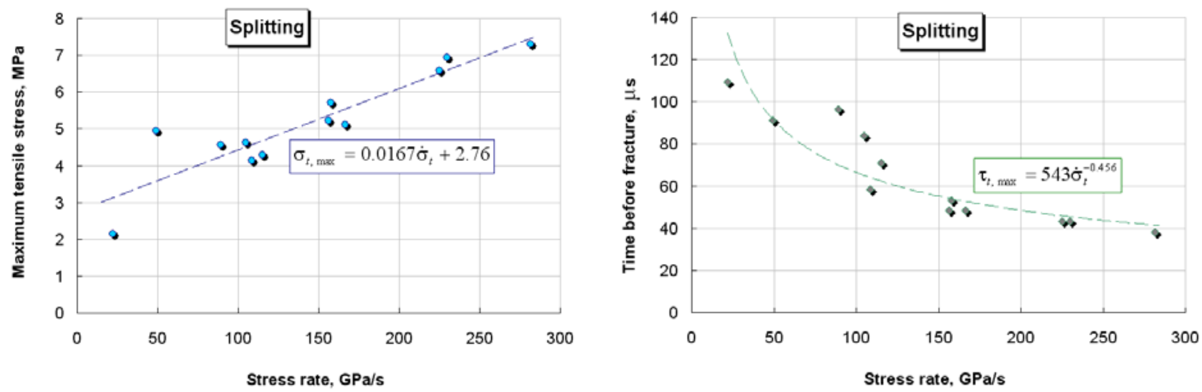
Fig. 3. Dependencies of maximum stress (a) and time before the beginning of fracture (b) on the strain rate under compression

Compression tests were carried out in order to study the influence of the strain rate on the deformation diagram, strength and time before the fracture of sand-lime brick. Figure 2a shows the average deformation diagrams with the strain rate history obtained for some regimes of dynamic loading of the samples. The solid lines show the stress dependences $\sigma \sim t$ versus time (the left vertical axis is stress) and the dotted curves correspond to the strain rate dependence $\dot{\varepsilon} \sim t$ versus time (the right vertical axis is the strain rate). Herein, the curves with the same markers (solid lines and dashed lines) correspond to a certain loading regime. According to the deformation diagrams the values of the mechanical characteristics of the material were determined: the maximum stress and the time prior to fracture which corresponds to the maximum stress at different strain rates. As a result of the experiments, the strain rate dependencies of the mechanical characteristics were constructed. Herewith, taking into account that the strain rate changes during the deformation, the maximum value of the strain rate prior to the beginning of fracture in each test was taken to plot the empirical relationships. The plotted dependencies indicated that with increasing strain rate the maximum stresses increase (Fig. 3a) and the time prior fracture decreases (Fig. 3b). This tendency was observed in the testing other brittle materials [for example 10-13].

5. Results of dynamic tensile (splitting) tests

Dynamic tensile (splitting) tests (or the so-called «Brazilian test») were carried out on cylindrical samples with a diameter of 20 mm and a length of 20 mm. The amplitude of the loading wave in experiments was changed by varying the velocity of a cylindrical striker 20 mm in diameter and 300 mm in length. The analysis of the of this technique was carried out in [6] where it is noted that the «Brazilian test» can be used to determine the tensile strength of brittle materials when the elastic behavior of the material and the state of equilibrium deformation of the sample are observed and its fracture occurs along the diametrical plane direction. To assess the implementation of these conditions, time history of the synchronized impulses of strain of the measuring bars were examined, which showed the practical equality of forces acting on the lateral surfaces of the sample leading to the state of equilibrium deformation. The ends of the measuring bars were covered with a thin layer of grease before the test to reduce the effect of frictional forces on the process of deformation of the sample. In addition, the crack formation or complete fracture of the samples into two halves occurred along a diametrical plane direction.



a b

Fig. 4. Dependencies of maximum tensile stress (a) and time before the beginning of fracture (b) on the stress rate under splitting

The average dependences of the tensile stress versus time obtained for different loading regimes based on the variation of striker's speed are shown in Fig. 2b. In addition the values of the mechanical properties of the material: the maximum stress and the time before the beginning of fracture corresponding to the maximum stress at different stress rates were determined on the basis of the time history of the tensile stress in each test. The plotted dependences of these mechanical characteristics on the values of the stress rate showed that strength of material increase (Fig. 4a) and the time before the beginning of fracture decrease (Fig. 4b) with the stress rate increasing which was also characteristic of compression tests.

6. Conclusions

Uniaxial compression and tensile (splitting) tests with the use of the Kolsky method and its modification were carried out for samples from sand-lime brick grade 150. The obtained experimental results are characterized by a temperate scatter and show the influence of the strain rate and the stress rate on the strength and time properties of the tested material. Herewith, a significant increase in strength and a decrease in time before the beginning of fracture are observed under the dynamic loading conditions.

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