BEHAVIOR OF BODIES OF REVOLUTION IN DYNAMIC CONTACT WITH A RIGID WALL

A. N. Bogomolov, V. A. Gorel'skii,
S. A. Zelepugin, and I. E. Khorev

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The study of the dynamic interaction of deformable bodies with rigid walls began with the basic paper of Taylor [1] in which a relationship was established between the dynamic yield stress and the residual length of the cylindrical body of revolution considered.

In the present paper we examine, both experimentally and theoretically, the deformation and fracture of cylinders in their interaction with rigid walls over a wide range of initial conditions.

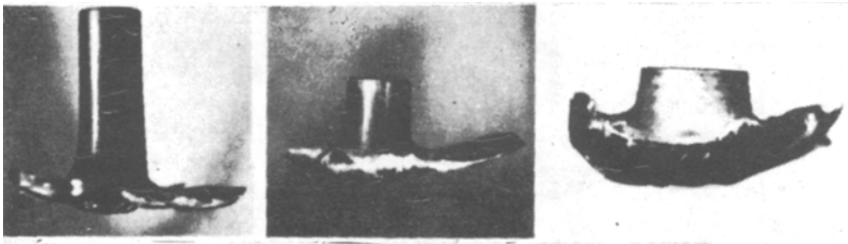
1. In our experiments projection of the cylindrs was accomplished with the aid of a smooth-bore powder gun. Specimens of deformable cylinders of ShchKh-15 steel, subsequent to their interaction with a rigid wall, are shown in Fig. 1.

The residual lengths of the specimens, obtained through experiment, and the characteristic dependences formulated on the basis of these data, are shown in Fig. 2, where the points labeled 1, 2, 3, and 4 correspond to specimens of copper, steel 3, steel 40, and steel ShchKh-15, respectively. To estimate the effect of the pliability of the rigid wall (a high-strength thick plate of hardened steel with HRC hardness index ∿54-57) on the final results, we carried out experiments on the coaxial impact of two identical cylinders. In the case of coaxial impact the conditions for the interaction of a deformable body with an ideal nondeformable wall are realized; in Fig. 2 points corresponding to this case are labelled 5 (for copper) and 6 (for steel 3). The experimental data involving the rigid wall and the coaxial impact data yield results which are very close to one another (within 3-5%) for the impact speeds considered. However, the rigid wall impact case, by virtue of its easy realization in experiments, is more favorable for the investigation of plastic materials, including various steels. In Fig. 2, for comparison, we give the results of the rigid wall experiments described in [2] for copper and 1090 steel (points 7 and 8).

Values of the dynamic yield stress for various materials, calculated from our experimental data, are shown in Fig. 3. In our calculations we employed the following empirical relation from [2]:

$$L^f_{\mathrm{exp}}/L_0 = 0{,}88\exp\left(-\rho_0 V_0^2/2\sigma_s^D\right) + 0{,}12,$$

where L_0 is the initial length of the cylinder; ρ_0 is its density; V_0 is the impact speed; L^f_{exp} is the experimentally determined residual length of the cylinder; σ_s^D is the unknown dynamic yield stress. The curves in Fig. 3, which show how the dynamic yield stresses obtained through our experiments depend on the impact speed, are continued by means of dashes extending to the experimentally determined values of the static yield stresses on the axis of ordinates. It follows from Fig. 3 that for collison speeds greater than 200 m/sec the



V_0 = 630 m/sec L^f_{exp} = 35 mm

V_0 = 773 m/sec L^f_{exp} = 18.2 mm

V_0 = 918 m/sec L^f_{exp} = 12 mm

Fig. 1

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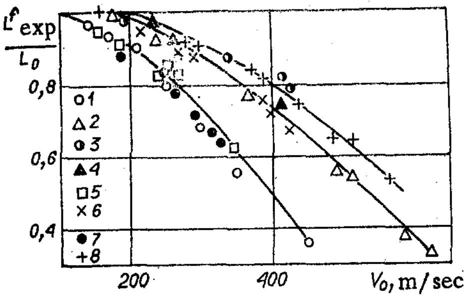

Fig. 2

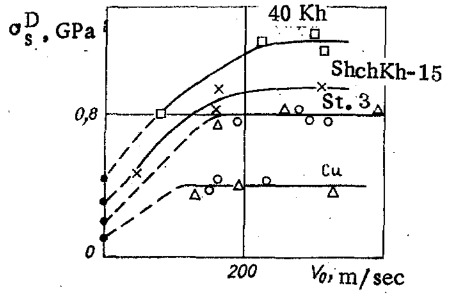

Fig. 3

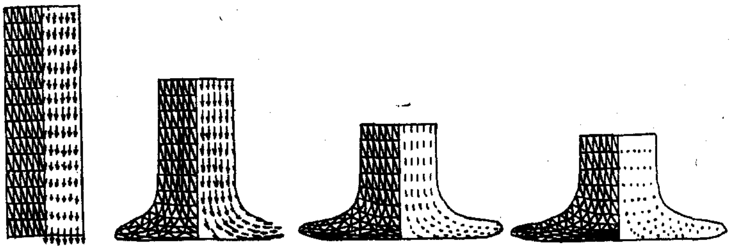

Fig. 4

dynamic yield stress, determined in accordance with the procedure described, is a constant of the material. For speeds larger than 500 m/sec there begins to appear a tendency for the dynamic yield stress values to decrease; this is associated with an increase in the influence of thermal effects at high impact speeds; however, the influence of a variation in strength properties at high impact speeds is unimportant. The stage of the process, characterized by the largest change in the dynamic yield stress and corresponding to encounter speeds up to 200 m/sec (see Fig. 3), has only a weak influence on the resulting parameters of the interacting bodies, which, taking into account what we said above, allows us in our computations to use a constant value for the dynamic yield stress over a wide range of impact speeds.

2. In the studies that have been carried out, numerical modeling of the interaction of bodies of revolution with a rigid wall was accomplished by the method of finite elements [3-5]. As for the material in our model, we employed a compressible durable medium whose behavior under shock loading is characterized by a shear modulus, a dynamic yield stress, and a viscosity [5, 6]. A sequence of chronograms of the projectile deformation process, for an initial projectile speed of 500 m/sec, with calculations made every 10 μsec through graphical construction, is shown in Fig. 4. The projectile had a diameter of 12.5 mm and height 37.5 mm. In our model of the behavior of the tempered steel ShchKh-15, we calculated the value of the dynamic yield stress to be 0.8 GPa. The results of this and similar calculations are shown in Fig. 5 (o for ShchKh-15 steel and Δ for 1090 steel). It is evident that the values of the calculated residual lengths for the two cylinders of differing materials, with dynamic yield stresses of 0.8 GPa and 1.2 GPa, lie on the corresponding experimental curves 2 and 1, respectively, to within 5%. What the calculated results tell us is the following. For impact speeds less than 300 m/sec, the calculated values lie below the experimental curve, but for higher speeds the residual relative length of the specimens exceeds the experimental value. The calculations also show that for the materials considered the greatest dependence of the residual length on the dynamic yield stress is observed in the range from 200 m/sec to 500 m/sec. In these calculations we used a model involving a material with a lower bound on the domain of admissible negative pressures equal in absolute value to one-third of the dynamic yield stress. The shortcomings of this model for the material are the impossibility of determining the extent to which damages have occurred during incomplete fracture, and, consequently, the inability to take into account continuous changes in the mechanical properties of the materials in the interaction process. Of interest here, therefore, are the results obtained in [7, 8] in describing the behavior of projectiles through the application of a kinetic energy model for the development of damages in which, as a continuous measure of the damage, use is made of the specific volume v_T of cracks (crack volume per 1 g of material). Here the common specific volume of the medium is given as the sum of the volume of the cracks and the volume v_c of the continuous material; the value of the pressure acting in the element is determined from the value of v_c. The fracture rate, i.e., the rate of change of the specific volume of the cracks, is, according to [8], determined as a function of the acting

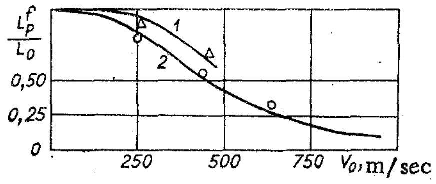

Fig. 5

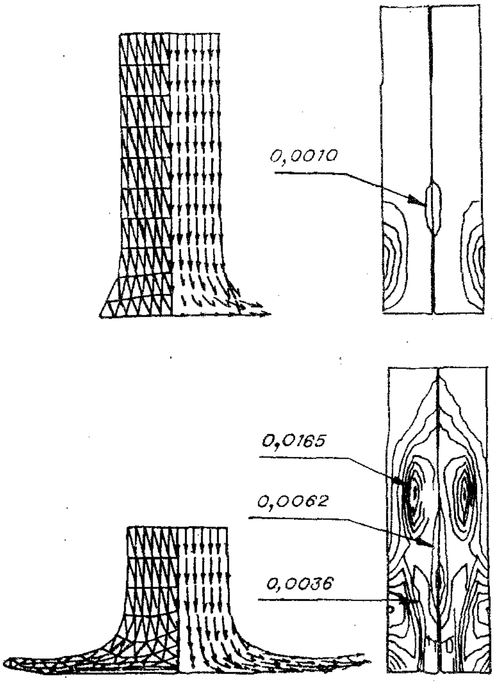

Fig. 6

stress and the crack volume attained. In the computational process the shear modulus and the dynamic yield stress were varied as a measure of the material damage. Figure 6 displays calculated configurations of the projectile and isolines of the specific volume of cracks in the projectile at one and seven microseconds, respectively, following the start of the interaction. The steel projectile, of diameter 8 mm and height 24 mm, impacts onto a rigid wall with speed 1800 m/sec. The calculations show that already by one microsecond two fracture nuclei have formed: one on the axis of the projectile, where the crack volume at a distance of 6 mm from the wall surface has attained a value of 0.0018 cm^3/g, and the other close to the lateral free surface where, at a distance of 3 mm, the crack volume amounts to 0.011 cm^3/g. Initially, fracture formation close to the surface is due to the interaction of unloading waves, subsequent to which damage occurs as the lower part of the projectile spreads out along the surface of the wall. After this, yet another fracture zone forms on the axis, where the maximum specific crack volume amounts to 0.088 cm^3/g; then at seven microseconds, the specific crack volume is equal to 0.0125 cm^3/g, approximately what it was at one microsecond. The distance between these fracture zones is 4.36 mm, the lower being located 0.52 mm from the wall surface. Thus, the calculations show that the deformation of the projectile during its dynamic interaction with the wall is accompanied by a collapse which is systematic in nature. For encounter speeds up to 800 m/sec this collapse, and the change in the mechanical characteristics of the material associated with it, are unimportant, thereby making it possible to use this range of impact speeds for estimating the dynamic yield stress of materials.

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