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EFFECT OF SHEAR STRENGTH ON THE DEVELOPMENT OF INSTABILITY DURING THE DECELERATION OF IMPLODING CASINGS

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Ivanov et al. [1] examined problems involved in the development of determinate perturbations in cylindrical casings filled with air and accelerated by explosion products. They established that the shear strength of the material of the casing had a marked effect on the shape and amplitude of the perturbations at the stage of acceleration of the casing toward the axis of symmetry. Of interest is the case of a compressed casing cavity filled partially or, as, for example, in [2], fully by a medium more dense than air. In this case there is the possibility of studying deceleration processes and the subsequent disintegration of the casings, when the conditions for Rayleigh–Taylor (RT) gravitational instability of the interface between the casing and the compressed medium may arise.

1. During accelerated motion of the interface between two mediums with different densities (in the presence of initial perturbation) they can be unstable, if the acceleration is directed from the light medium to the heavy one, and stable, if the acceleration is in the other direction. During the approach stage of motion of the casing toward the axis of symmetry, the acceleration is directed toward the axis and the conditions for RT instability can be realized only at the outer interface of the casing accelerated by the explosion products. The inner casing interface (ICB) will be stable. During deceleration of the casing at the disintegration stage of its motion, conditions for RT instability of the ICB can be realized with variation in the direction of acceleration.

While investigation of RT instability in liquid and gases has been the subject of a large number of articles, the number of publications dealing with instability in solid mediums is limited. As a result of experimental [4-6] and computational–theoretical investigations in the framework of an ideally elastic [7], an ideally plastic [8], and an elastoplastic [9, 10] model of a medium it has been possible to establish that the rheological characteristics of a medium (strength and viscosity) have a significant stabilizing effect on RT instability. As a function of the model of the medium used, the criteria defining the transition of the surface from the region of stability to the unstable region are taken to be: the critical wavelength λ_* [7, 9], the critical initial perturbation amplitude a_* [8], or their combination [10]†:

$$\lambda \geqslant \lambda_* = \frac{4\pi G}{\rho g}; \tag{1.1}$$

$$a_0 \geqslant a_* = \frac{\sigma_s}{\rho g}; \tag{1.2}$$

$$a_0 \geqslant a_* = \frac{\sigma_s}{\rho g}\left(1 - \frac{\lambda}{\lambda_*}\right). \tag{1.3}$$

Here g is the acceleration; G is the shear modulus; and σ_s is the dynamic yield point.

Three stages in the development of RT instability are usually distinguished. In the first stage, perturbation at the unstable interface grows exponentially and at the second its growth slows with the transition to the exponential law. The final

†Expression (1.3) is a simplified variant of formula (31) from [10].

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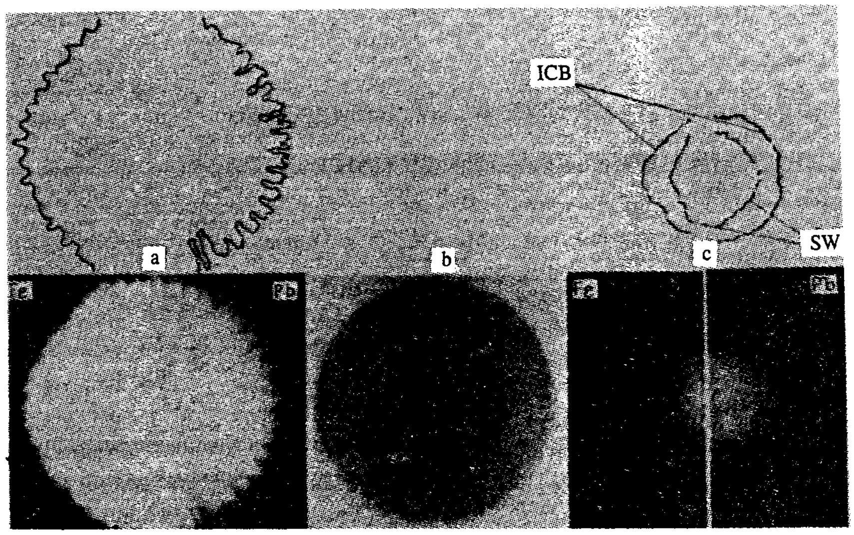

Fig. 1

stage is associated with the formation of a zone of turbulent agitation (ZTA). If we stop at the first stage of RT instability, since it will in the final analysis define the maximum possible quantity of the material of the casing involved in the ZTA, then at this stage the perturbation at the ICB close to the sinusoidal form increases in accordance with the law $a(t) = a_0 \exp \beta t$ [2], where $\beta = [(\rho_1 - \rho_2 / \rho_1 + \rho_2)_g (2\pi/\lambda)]^{1/2}$ is the increment of increase in the perturbation and ρ_1, ρ_2 are the densities of the material of the casing and of the medium. As is evident from this function, the amplitude of the perturbation increases proportionally to the initial level of asymmetry at the ICB and the faster, the shorter the wavelength of the perturbation. Since, as follows from [1], a dense steel casing has a perturbation amplitude 1.5 times less than a casing made of lead, we may conclude that the shear strength of the material of the casing during its deceleration will have a stabilizing effect on the increase in the perturbation, which means that the quantity of casing material involved in the ZTA will be limited.

2. In order to test this prognosis experimentally, experiments with casings made of steel and lead and differing in the magnitude of their shear densities by more than an order of magnitude were carried out.

A cut-away diagram of the experimental device is given in [1]. As in [1], the determinant perturbation was generated by multiple-point initiation of an explosive charge. In contrast to the experiments described in [1], in our experiments the effect of the presence in the cavity of the casings of a solid cylinder of penoplast with an initial strength $\rho_0 = 0.312$ g/cm^3 on the process of the implosion and disintegration of the ICB was investigated. This cylinder was placed coaxially with the charge casings and had a radius of $0.2R_+$ ($R_+ = 150$ mm is the external radius of the explosive charge). Pulse x-raying of the shape of the ICB was performed at the approach and disintegration stages of the motion of the casings toward the axis of symmetry.

Figure 1 shows x-ray photographs of the experiments at the approach stage of motion of the steel and lead casings (*a* is the shape of the ICB during their approach to the radius $\sim 0.2R_+$, corresponding to the time interval from the beginning of the ICB's motion until the moment of x-raying t = 23.08 μsec for steel and 23.18 μsec for lead; *b* is the penoplast cylinder with an external radius of $0.2R_+$; *c* is the shape of the ICB during implosion on the penoplast to a radius of $\sim 0.1R_+$, corresponding to a time interval of t = 27.5 μsec for steel and 27.2 μsec for lead).

Figure 2 shows x-ray photographs of experiments at the disintegration stage of motion of a steel ICB (*a*: t = 33.27 μsec; *b*: t = 35.25 μsec) and a lead ICB (*c*: t = 35.30 μsec). Figure 2 also shows ICB contours obtained from the mathematical processing of the images with the aid of a computer. Figure 3 shows the computed R−t diagrams of motion of the ICB. The numerical one-dimensional calculations were performed under the hydrodynamic approximation. The experimental points from [1] are plotted here. Since at the disintegration stage of motion the position of the ICB is more difficult to demonstrate, two extreme evaluations are given. The first is done as in [1], along the maximum radius, while the second is done along the effective radius of the area of the contour yielded by mathematical processing of the image.

It follows from Figs. 1 and 3 that at the approach stage of motion of the casings the presence of penoplast leads to a certain symmetrization of the ICB and has virtually no effect on their dynamics (at least in the section of motion from a radius

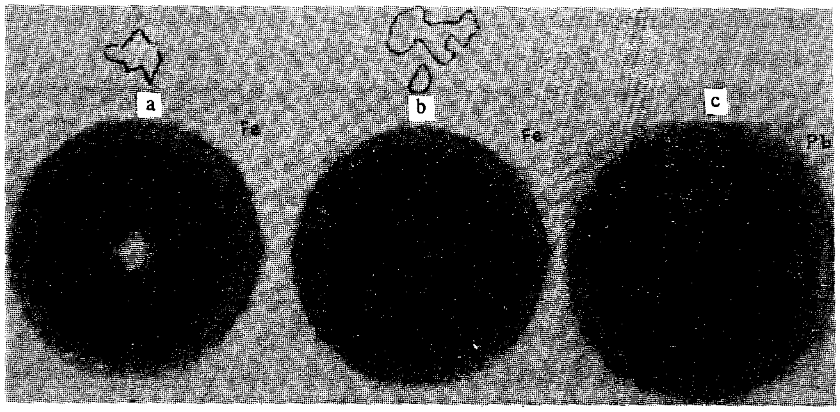

Fig. 2

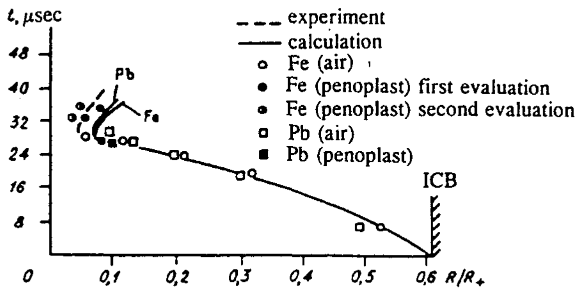

Fig. 3

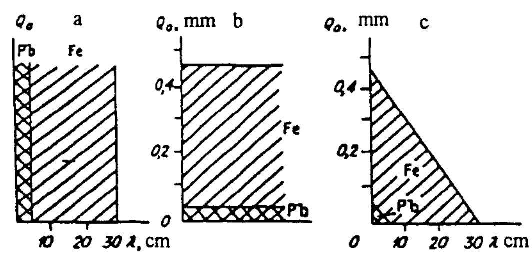

Fig. 4

$0.2R_+$ to $0.09R_+$). In front of the casings the zone of the penoplast is compressed by the shock wave (SW). At the disintegration stage of motion of the steel casing (Fig. 2a, b) at first the symmetrical shape of the ICB loses stability and the material of the casing mixes with the penoplast. For the lead casing the behavior is evidently the same, but due to the lower shear strength a more intense mixing occurs, and for the interval $t = 35.30$ μsec it is practically impossible to distinguish the contour of the ICB (Fig. 2c).

3. It is of interest to trace the regions of perturbation stability in the steel and lead casings using criteria (1.1-1.3). As evaluations of the criterion magnitudes, the shears for steel and lead were taken to be 77 and 7 GPa and the dynamic yield points were taken to be 1.4 and 0.09 GPa respectively, taking into account its dependence on deformation speed [11-13]. We note that the experimental points as a whole fit consistently onto the calculated diagram of motion of the casings (Fig. 3). This justifies using in the evaluations the values of the ICB accelerations at the disintegration stage of motion taken from the calculations. For steel and lead, for example, they are identical ($g = 4 \cdot 10^{10}$ cm/sec^2). Taking this into account, Fig. 4 is a graphic representation of the results of the evaluations, in which the regions of stability for the steel and lead casings are shown by the dotted lines and correspond to formulas (1.1-1.3) (a-c). It is clear from Fig. 4 that the regions of stability for perturbation in casings made of the weaker lead are significantly narrower, which indicates the stabilizing effect of the shear strength on the development of gravitation instability and does not contradict the experimental data (see Fig. 2). It follows from the experiments using steel casings that $\lambda < \lambda_*$, but $a_0 > a_*$ ($a_0 \geq 1$ mm) and the perturbed boundaries are found qualitatively in the unstable region in accordance with [8, 10].

Thus it has been shown that in the deceleration of casings with determinate perturbation, they can lose stability. The significant quantity here is the amplitude of the perturbation, which initially depends on the shear strength of the material of which the casing is made. This also confirms that the shear strength of the casing material inhibits loss of stability.

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