FAILURE OF WATER-FILLED CYLINDRICAL GLASS-REINFORCED EPOXY SHELLS UNDER INTERNAL IMPULSIVE LOADING


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The study of the behavior of polymeric and composite materials under dynamic loading has recently been attracting considerable interest [1]. This is because of their widespread use in engineering applications and, in particular, because of the use of glass-reinforced epoxies for fabricating various kinds of pressure vessels [2]. In this connection, it is especially important to know whether the results of testing small models can legitimately be applied to the full-scale structure. This is particularly relevant to the simulation of emergency situations involving the failure of structures under impulsive loads, since, for example, the explosive failure of steel shells is associated with a pronounced scale effect (SE) [3-6]. In impulsive failure the SE is energetic in nature. This has been convincingly demonstrated both for brittle fracture [7] and for failure at large plastic strains [8].

We selected for investigation spirally wound circular cylindrical shells made from T1 glass fabric preimpregnated with a composition based on IF-ÉD-6KT epoxy resin. The width of the fabric was 900 mm and its thickness was 0.4 mm. The warp was directed along the generator of the shell.

The results of mechanical tests on flat specimens cut from the shells and of hydraulic testing of the shells showed that under static loading (strain rate $\dot{\varepsilon} \approx 10^{-3}$ sec$^{-1}$) in the circumferential direction the strength of the glass-reinforced epoxy was $\sigma_u = 5000 \pm 1000$ kgf/cm$^2$, Young's modulus $E = (2.35 \pm 0.2) \times 10^5$ kgf/cm$^2$, and Poisson's ratio $\nu = 0.15$. The density of the material was $\rho = 1.75 \pm 0.05$ g/cm$^3$. The values of $E$ and $\rho$ are given with the maximum error.

Young's modulus of the glass-reinforced epoxy under high-rate deformation was determined from the radial vibration frequencies of rings cut from a shell with outside radius $R_0 = 103.8$ mm and $\delta/R_0 = 3.7\%$ ($\delta$ is the thickness of the shell). The thickness of the rings was 5 mm. The natural vibration of the rings was obtained by brief internal impact, using the method described in [9]. The results of these tests showed that on the strain rate range $\dot{\varepsilon} = (0.5-1.5) \times 10^3$ sec$^{-1}$ the radial vibration frequency was equal to $5.6 \pm 0.2$ kHz and did not depend on $\dot{\varepsilon}$. Consequently, within the limits of experimental accuracy, on this strain rate range Young's modulus is constant and given by $E = (2.4 \pm 0.3) \times 10^5$ kgf/cm$^2$.

The experimental setup is shown schematically in Fig. 1. Impulsive loading of the shell was produced by exploding at its center an explosive charge (EC) in the form of a ball of TNT/RDX (50/50 wt. %). Detona-

* SE consists in a decrease in strength and an increase in the tendency to brittle fracture with a similar increase in the dimensions of the specimen or structure.
Fig. 1. Experimental setup for applying an internal impulsive load to a glass-reinforced epoxy (GRE) shell: 1) GRE shell; 2) steel tie rod; 3) steel top and bottom; 4) steel damper; 5) steel rod; 6) explosive charge; 7) water; 8) ring wire strain gauge; 9) manganin pressure sensor.

Fig. 2. Typical $\varepsilon$ versus $t$ diagrams for impulse-loaded glass-reinforced epoxy shells: 1) experiment 2 (see Table 1); 2) series 2, loading 2 (see Table 2); 3) experiment 9 (see Table 1); 4) experiment 11 (see Table 1); 5) experiment 3 (see Table 1); 0 the moment of failure.

Fig. 3. Oscillogram of the pressure pulse in experiment 1 (see Table 1). Pulse amplitude, 5000 kgf/cm$^2$; period of sinusoid, 10 $\mu$sec.

Fig. 4. External appearance of shell after explosive loading in experiment 9 (see Table 1).

The detonation was initiated at the center of the charge. The detonation of 1 g of this explosive releases 1.14 kcal. The energy release time is $r/D$, where $r$ is the radius of the charge and $D = 7.65 \cdot 10^5$ cm/sec is the detonation velocity. This time varied from 1.2 to 6.2 $\mu$sec.

We investigated the failure of geometrically similar shells with $\delta/R_0 = 3.7\%$ and $R_0 = 103.8$, 155.8, and 457 mm and of shells with a constant inside radius of 100 mm and $\delta/R_0 = 3.7\%$, 9.1\%, 16.7\%, and 21.3\%.

By means of high-speed motion-picture photography [10, 11] and strain gauge techniques [12, 13] we recorded the $R$ versus $t$ and $\varepsilon$ versus $t$ diagrams in the central cross section ($R$ is the variable outside radius of the shell, $t$ is time counting from the moment at which the shell first begins to move, and $\varepsilon = R/R_0 - 1$ is the circumferential deformation of the shell). From these diagrams we determined the following parameters of the deforming shells: maximum rate of radial expansion of the shell $W_0$, maximum strain rate $\dot{\varepsilon}_0 = W_0/R_0$, period of the natural radial vibrations of the shell, and the maximum circumferential strain before failure $\varepsilon_{\text{max}}$, which was determined with a relative error of not more than 10\%.