Deterministic Perturbations Developing on Steel Shells under Quasispherical Explosive Loading. Investigation Results using Laser Interferometry and Ultrasmall-Direction Gamma-Tomography

E. A. Kozlov[*], S. A. Brichikov[*], N. S. Zhilyaeva[*], L. P. Brezgina[*], V. N. Povyshev [*], A. V. Dobromyslov[†], and N. I. Taluts[†]

[*]Russian Federal Nuclear Center – Zababakhin All-Russia Research Institute of Technical Physics, P.O. Box 245, Snezhinsk, Chelyabinsk region, 456770, Russia

[†]Institute of Metal Physics, RAS Ural Branch, Ekaterinburg

Author Contact: e.a.kozlov@vniitf.ru

Introduction

The purpose of this project is to obtain systematic experimental data how the deterministic perturbations development depends on the rheological properties of the shell material in order to verify modern kinetic strength models and 3D-software complexes.

Subjects of research – spherical shells of the 12Kh18N10T steel and the hardened 30KhGSA steel (HRC 35…40) with the 30-mm external radius and initial thickness h_0 = 1, 2, 3, 4, and 5 mm.

Explosive loading mode for shells – HE spherical layer with the external radius R_{HE} = 40 mm and thickness h_{HE} = 10 mm are synchronously initiated by 96 detonation initiators.

Recording techniques

During explosive loading, the shells convergence was investigated via:

- multi-channel laser-interferometry [1],
- ultrasmall-direction gamma-tomography [2],
- recovery method with the follow-on study of the "softly stopped" converging shells.
- After explosive loading, the recovered shells were studied via:
- integral small-direction gamma-tomography,
- optical and electron (scanning and transmission) microscopy,
- X-ray diffraction analysis,
- investigation into distributions of microhardness $H_n(r,q,j)$ and hardness $H_n(r,q,j)$ over r,q,j .

Results and their discussion

Results are reported in terms of time-resolved streak-camera interferometric records (Figure 1a,b) and the time-dependent velocity profile $W_{ij}(t)$ [1] determined based on these records and/or numerical calculations (Figure 1c). The value of the first subscript i = 1 corresponds to the movement of the shell's internal boundary under the initiators and i = 2 – under the projections of quadruple collisions between waves from adjacent initiators. The value of the second subscript j = 1, 2, 3, 4, and 5 corresponds to the nominal initial thickness of the test shell.

30KhGSA HRC 35…40 12Kh18N10T

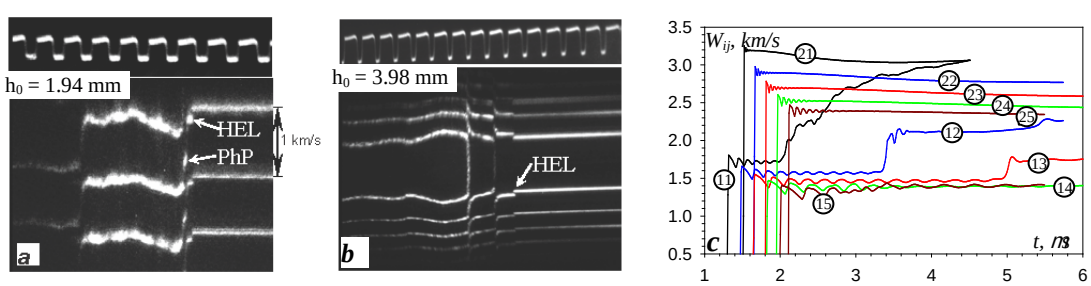

Figure 1. Typical streak-camera interferometric records (a,b) of the hardened 30KhGSA steel shells having different initial thickness h_0 = 1.94 and 3.98 mm, as well as calculated time-dependent velocities for the internal boundary of steel shells having initial thickness h_0 = 1, 2, 3, 4, and 5 mm (c).

Deterministic perturbations developing at the internal boundary of shells were judged by the results of integrating the difference between experimental velocity profiles $h_j(t) \propto \int_0^t (W_{2j} - W_{1j})dt$ and the data of the ultrasmall-direction gamma-tomography (Figure 2).

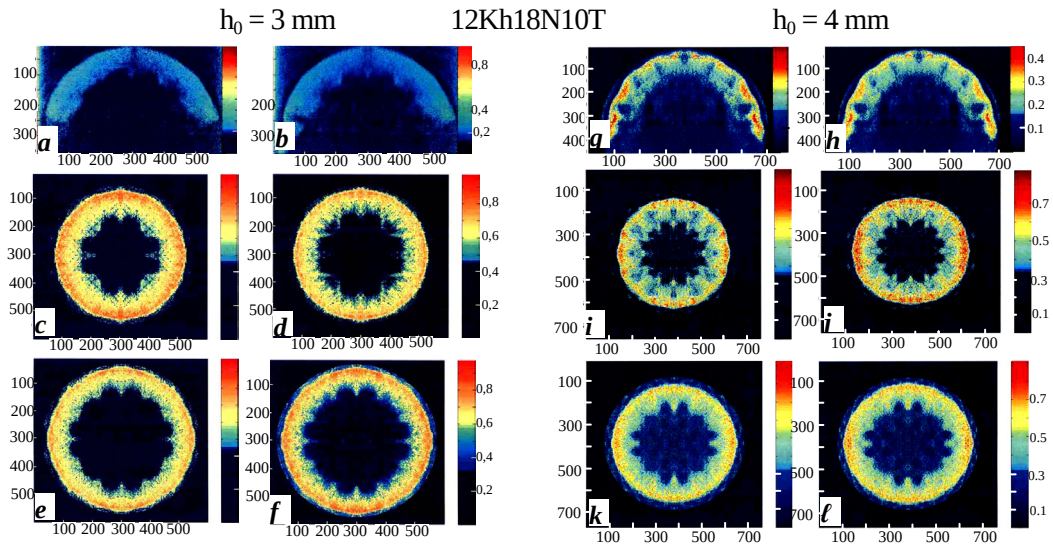

Figure 2. Integral small-direction gamma-tomographic images of the 12Kh18N10T steel shells having initial thickness h_0. Distributions of the reduced radiation attenuation factor $\mu(r,\theta,\varphi)/\mu_{max}$ over r,θ in the meridional microsection of the shells at φ = 0° (a,g – front view) and at φ = 90° (b,h – side view). Distributions of the reduced radiation attenuation factor $\mu(r,\theta,\varphi)/\mu_{max}$ over r,φ in the coaxial microsections being from the domical part of the shells at distances z = 11.5 mm (c,i – microsection 170), z = 12.27 mm (d,j – microsection 181), z = 15,33 mm (e,k – microsection 225), z = 16,10 mm (f,ℓ – microsection 236).

In these or other special recovery experiments, many steel shells (Figure 3) were "softly stopped" and then investigated via scanning electron microscopy (Figure 4) and other methods.

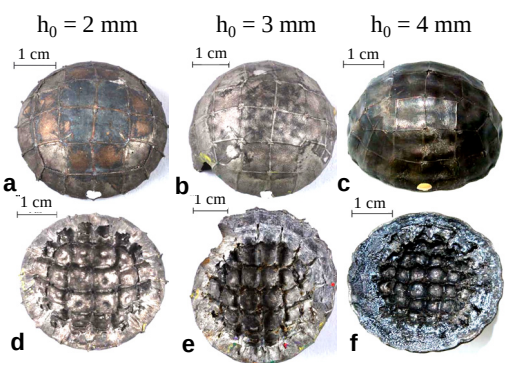

Figure3. Photos of external (a, b, c) and internal (d, e, f) surfaces of the austenitic 12Kh18N10T steel shells having different initial thickness.

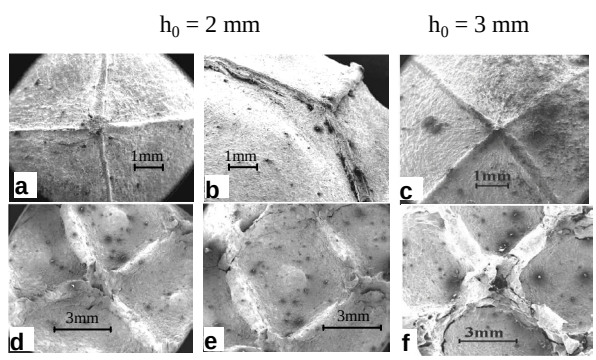

Figure 4. Perturbations on the external (a, b, c) and internal (d, e, f) boundaries of the 12Kh18N10T steel shell having

Conclusions

The obtained comparative experimental data allowed understanding how development of deterministic perturbations depends on the shell material properties, namely shear and spall strength. Systematic experimental results proved to be useful for verification of models and numerical codes.

E. A. Kozlov, S. A. Brichikov, D. S. Boyarnikov et al., "Special features in convergence dynamics of steel shells under explosive loading according to results of laser- interferometric measurements," *Russ. J. The Physics of Metals & Metallography* **112** [4] (2011).

L. P. Brezgina, E. A. Kozlov, V. N. Povyshev, "Ultrasmall-direction and integral small-direction gamma-tomographies: comparison of their potentialities as for diagnostics of spall and shear fracturing in iron and steel shells under explosive loading," *Russ. J. Nondestructing Testing*, **46** [12] 3-22 (2010).