SPALL FRACTURE AND COMPACTION IN NATURAL URANIUM UNDER SHOCK-WAVE LOADING

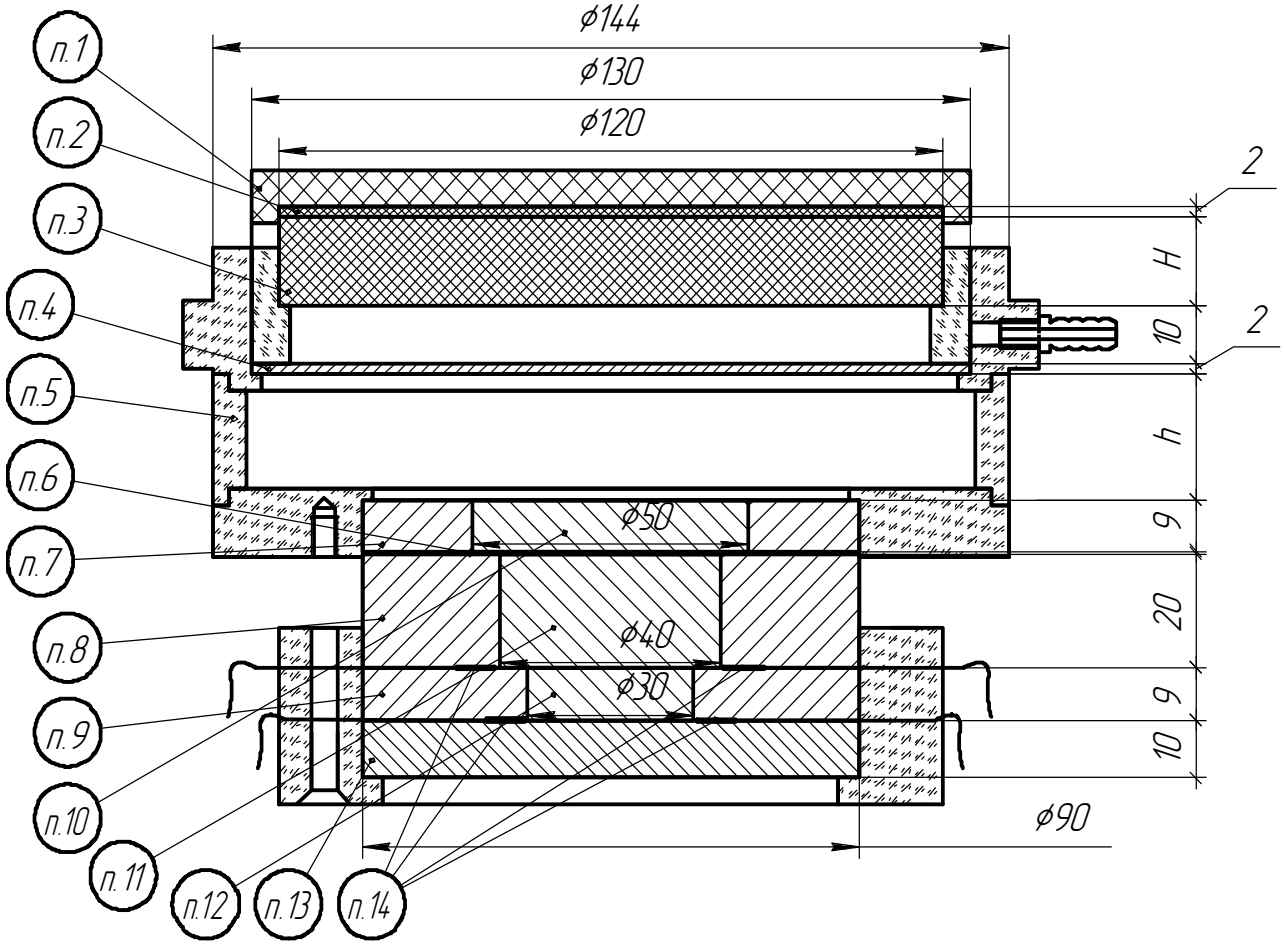
O.A. Tyupanova, S.S. Nadezhin, A.N. Malyshev,
O.N. Ignatova, V.I. Skokov, V.N. Knyazev,
V.A. Raevsky, N.A. Yukina

Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

Introduction

- Nucleation and growth of defects inside a solid under pulse tensile stresses signify a necessity to consider it as a damaged medium.
- A certain volume of experimental data, obtained in correct tests, which are sensitive to a characteristic under study, is necessary to develop a physically clear and theoretically substantiated model of such medium.
- Series of tests, presented in this work, consists of 4 experiments, which provides different level of damage, including that one variable along the sample diameter, and different amplitudes of compression waves, acting on the damage zone.
- The scope of experimental data allows specifying our understanding of nucleation, growth and compaction of damage in natural uranium, and verifying models of damage medium compaction.

Experimental set-up



1 – multipoint initiating system;
2 – supporting HE charge;

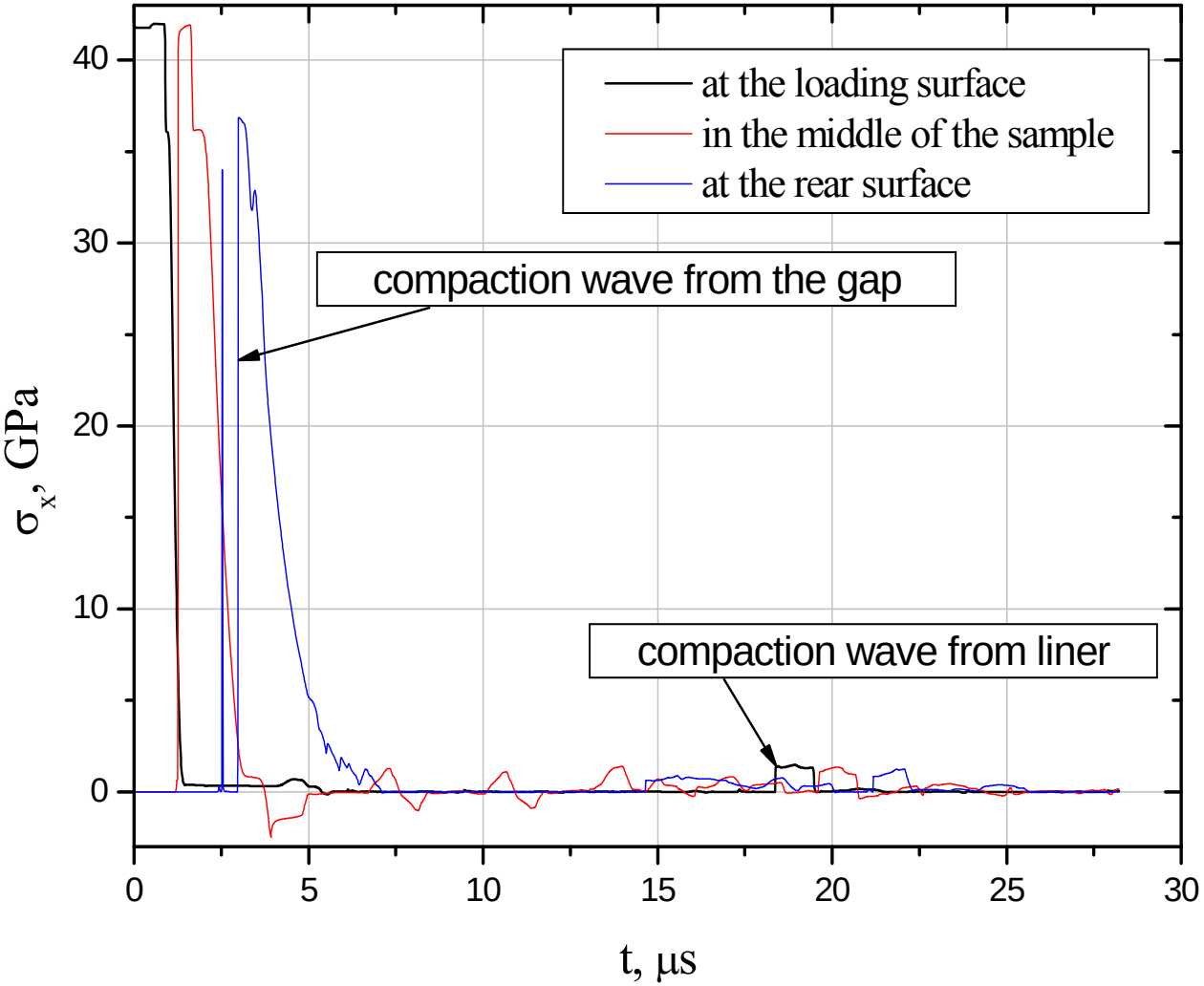
3 – main HE charge
(Δ_{HE} = 10 mm, h= 24 mm, Δ_{gap} = 360-705 μm – test #1;

Δ_{HE} = 13 mm, h= 14mm , Δ_{gap} = 500 μm – test #2;

Δ_{HE} = 14mm, h= 10mm , Δ_{gap} = 500 μm – test #3);

4 – liner;
5 – frame (PMMA);
6 – gap;
7-9 – saving rings;
10-12 – samples;
13 – support;
14 – manganin gauges (D1-D4).

Stress history in upper sample



Typical calculated history of stresses in upper sample

The idea of the experiments:

The post-shot state of upper samples in each test is the result of consecutive effect of :

-- *the intensive shock wave* (~40 GPa),

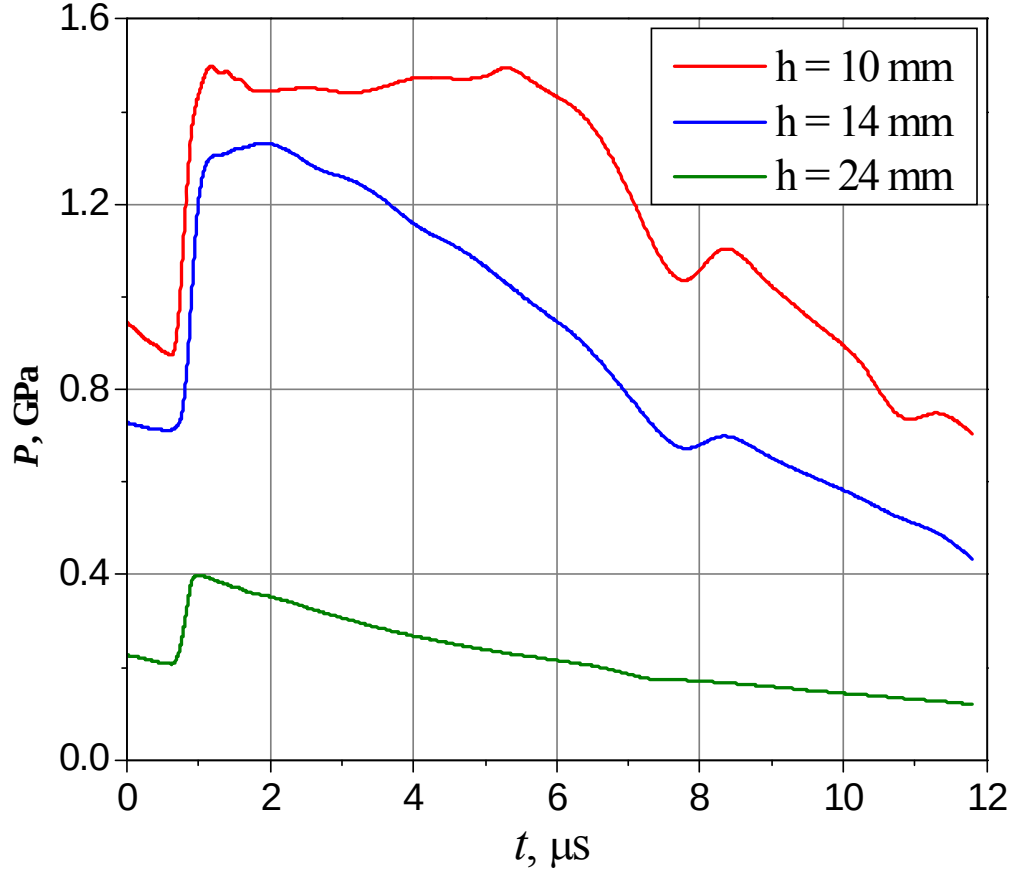
-- *the tensile stresses*, which are enough for damage nucleation and growth up to ω~0.9,

-- *and two waves of compression* (compaction).

Amplitude of first compression wave is adjusted by the gap thickness (Δ_{gap}),

of second one – by the distance between liner and upper sample at initial position (h).

Action of explosion products onto the liner



Calculated pressures on the liners' surface contacting with explosion products (time is counting from impact moment)

Numerical simulation

Materials were considered as elastic-viscous-plastic media.

Spherical component – Mie-Gruneisen EOS
with variable Gruneisen coefficient Γ_p

Deviator component – phenomenological model of relaxational medium (RING)

Damage growth kinetics – two-stage kinetic model of NAG type

Numerical simulation

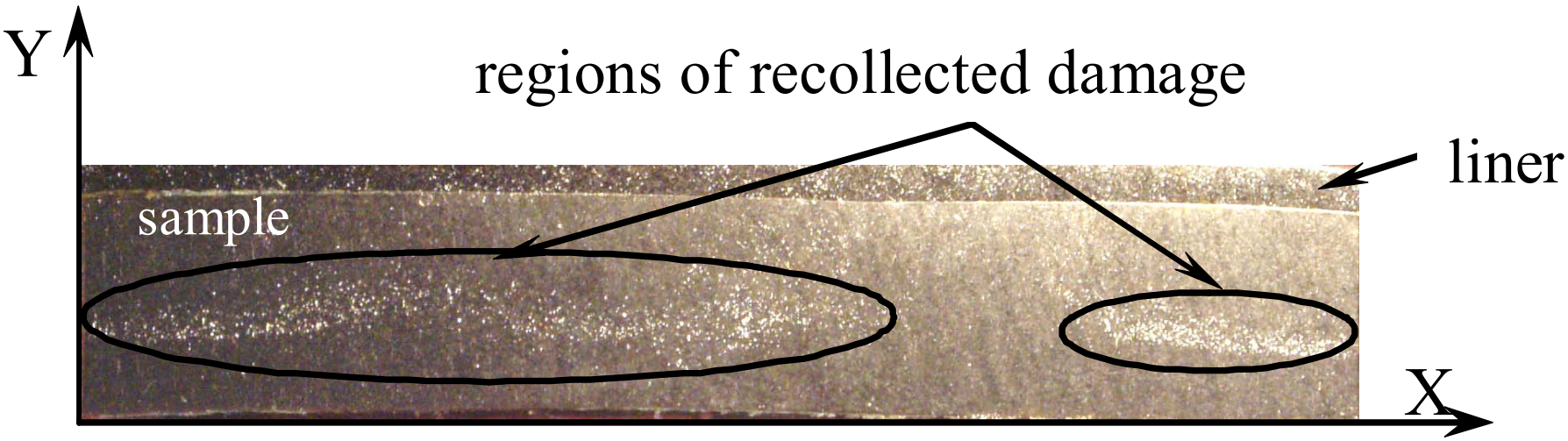
Model of damaged matter compaction [*]

$$\begin{cases} P = 0 \quad if \qquad \omega > \omega_0, \\ P = P_{comp}\left(1 - \left(\dfrac{\omega}{\omega_0}\right)^{1/2}\right) \\ \omega = 0 \quad if \qquad P > P_{comp}, \end{cases} \qquad or \qquad \omega = \omega_0 \cdot \left(1 - \frac{P}{P_{comp}}\right)^2 \quad if \qquad P < P_{comp} \; and \; \omega < \omega_0$$

where P_{comp} – is the pressure of full compaction, ω_0 – is the limit of damage, below which the damaged material begins to demonstrate strength for compression. It means that a cell is compressing without any resistance while the damage in it is over the value ω_0.

[*] S.V. Mikhailov, A. A. Sadovoy, et al.
Kinetic model of plastic fracture subject to dissipative processes (in Russian)
// Chemical Physics. ***21*** *[9] 104-109 (2002).*

Results and Discussion



Macrostructure of cross-section for test #3 sample
(loading was from upwards, magnification ×2.5)

Results and Discussion

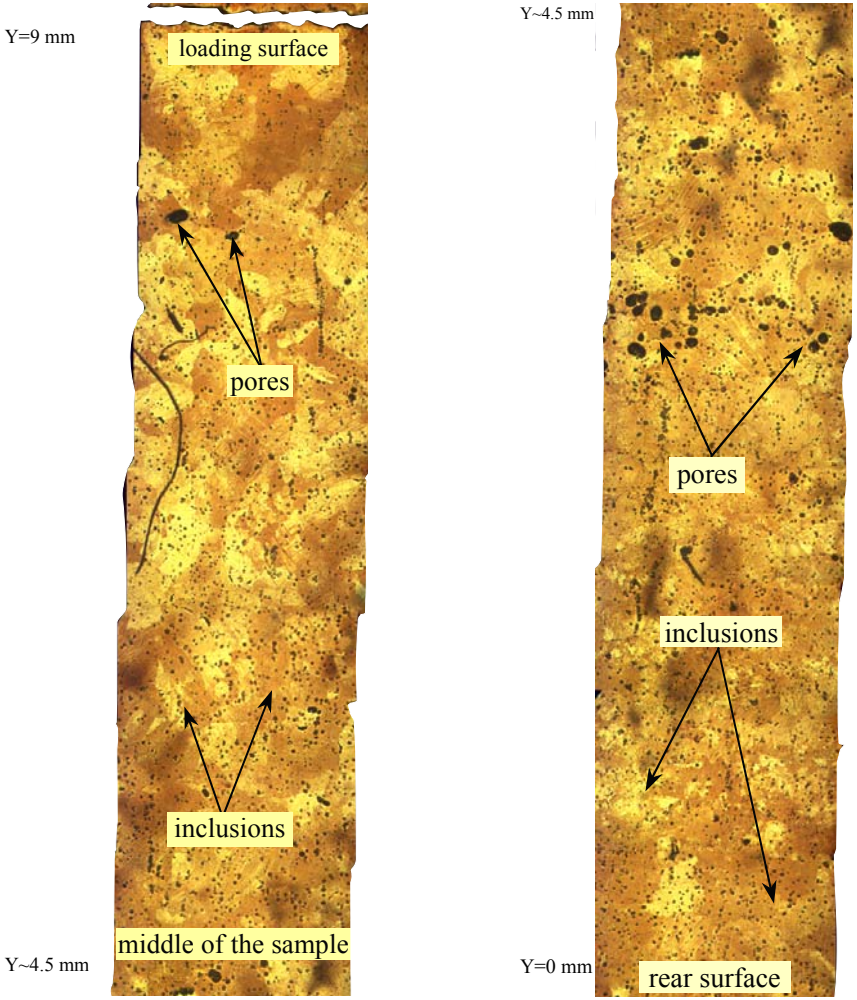
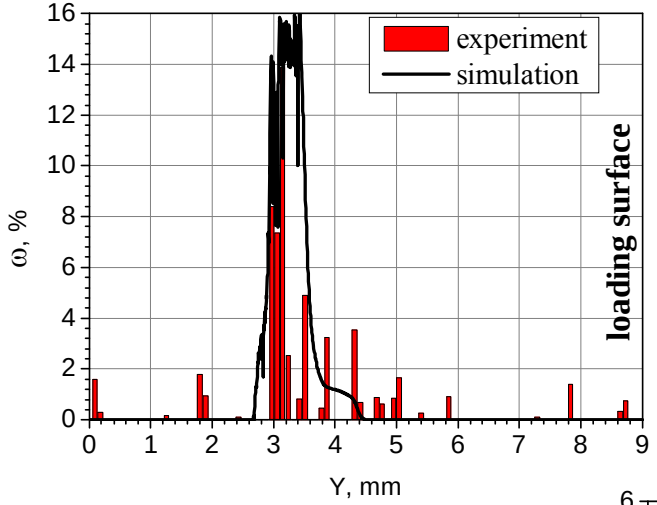


Photo of microstructure of test #1 sample from loading to rear surface (X=25 mm, Y=9÷0 mm)
(without etching, the photo is sliced into two parts)

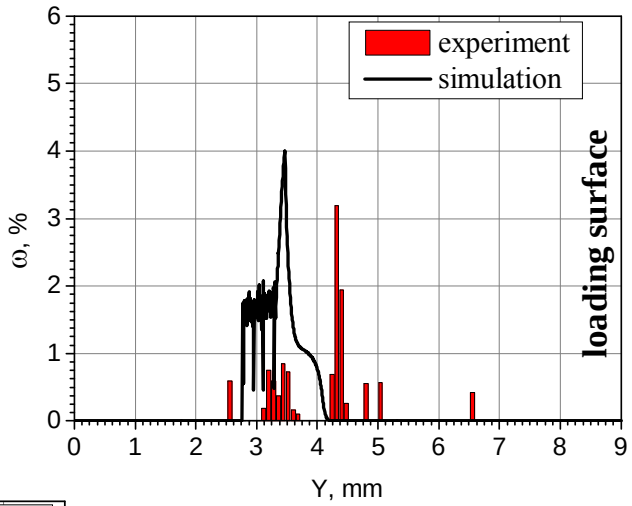
Results and Discussion



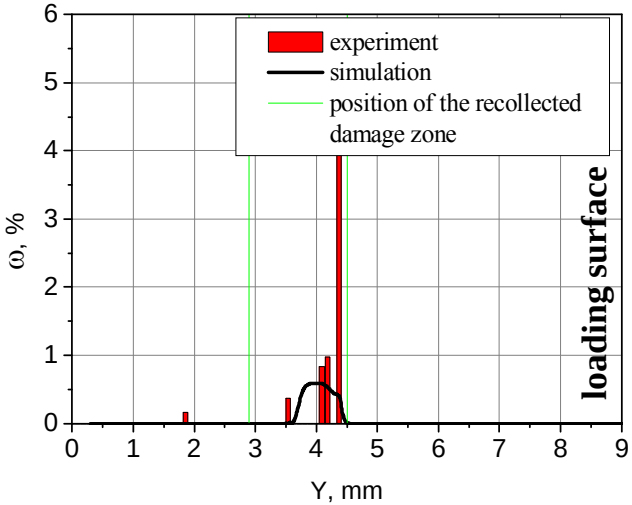
test #1 (h=24 mm)

P_{comp} = 3.0 GPa,

ω_0 = 0.256.



test #2 (h=14 mm);



test #3 (h=10 mm);

Comparison of calculated and experimental distributions of damage ω along the sample thickness in central section (X=25 mm)

Conclusion

- A method to study nucleation and compaction of damage in solids is proposed, where damage level during growth and compaction are simply varied.
- Natural uranium has demonstrated a complicated character of damage nucleation and compaction under shock-wave loading.
- There is still a question what are the reasons of arising of non-monotonic damage distribution along the sample's radius in the test with variable gap between samples.
- Verification of parameters for natural uranium compaction model became the result of experimental and theoretical researches done.

Thank you for attention!!!

Tyupanova Olga
root@gdd.vniief.ru