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# Porous metal screens against man-made space debris

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The impact of an elongated striker with the speed higher than 8 km/s on a barrier after passing a porous screen has been investigated. A region of effective striker-screen interaction has been established; it coincides with that of anomalous behavior of the adiabat of shock compression of the screen porous metal. The paper discusses the striker thermal disturbance by a high temperature of the shock-compressed porous material of the screen and features of subsequent penetration into the barrier.

**Keywords:** impact, porous screen, compaction, plasma, temperature.

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In this work we studied the consequences of the elongated metal striker disturbance after passing through porous metal screens; the striker shape and speeds were characteristic of fragments of man-made debris in the near-Earth space. Review [1] presents an analysis of numerous options of the screen design. The review has revealed distinctive features of the screen containing porous copper in view of the effect of the destroyed compact striker residues on the barrier. Papers [2,3] demonstrate the influence of the prevention of phase transitions (melting, evaporation) in the interacting screen and striker materials at speeds above 8 km/s on the parameters of impact on the barrier. Rapid phase transitions proceeding with increasing specific volume promoted the striker disturbance in passing through the screens and reduction of its impact on the barrier.

Porous metals subjected to shock compression at the pressures exceeding those ensuring melting and partial evaporation of the matrix medium are known to allow reaching temperatures higher than those in the case of shock compression of solid materials [4,5]. In the case of isentropic unloading of a shock-compressed porous metal to pressures below the matrix-medium critical point, the final state exists in the form of a mixture of two phases (liquid−gas) or in the form of plasma [6,7].

The goal of this study was to reveal whether porosity can improve the screen efficiencies [8,9] via reducing the impact on the barrier from elongated high-speed striker (EHSS) with a speed higher than 8 km/s under the conditions of conically diverging shock compression of a low-strength condensed material of the screen.

The experiments were performed in a vacuum chamber at pressures below 1 kPa. Fig. 1, *a* presents the experiment schematic diagram. EHSS was formed as a copper jet by exploding device *1* containing high-energy (5 kJ/g) organic matter 40 g in mass (the device was equipped with copper funnel *2*). The obtained EHSS passed through porous screens *3* with initial speed $V_{j0} = 8.26$ km/s and, being extended at the distance of 6 cm, got embedded into barrier *4*. The striker was 0.08 cm in average diameter and 9.8 cm in length. The low-porosity screens were produced by pressing copper powder PMS-1 (GOST 4960−75) 10−100 $\mu$m in dispersion onto a brass mesh. What was used in bulk was copper powder PMF-40 kept in sealed glass ampoules in the form of spherical particles 40−70 $\mu$m in size. Using a package of brass meshes (GOST 6613−86) No 16 and 18, we obtained screens of a higher porousity. The screen plates $4 \times 4$ cm in size had a thickness meeting the condition of constancy of the unit area mass of 0.89 g/cm$^2$, which was equivalent to a solid copper screen 0.1 cm thick. Barrier *4* was fabricated from the AMg6 alloy sheets 1 cm thick; between the sheets, contact sensors *5* were mounted.

The experimental results are presented in the Table and Fig. 1, *b*. They show that the depth of the cavity in the barrier becomes divided into two ranges under the impact of copper EHSS after its passing through two copper porous screens (see the Table, lines 1−4 and 5−8). Penetration through the barrier becomes weaker at the screen density $R_s$ lower than 5 g/cm$^3$. The barrier's cavity volume varies insignificantly within the main density variation range (except for solid screens).

Study [11] has experimentally demonstrated the advantage of using copper screens which cause an increase in the EHSS disturbance at $V_{j0} > 8$ km/s due to partial evaporation of copper. At the same time, destabilization of EHSS was observed, which manifested itself in a slowdown in the penetration trajectory and decrease in the depth of penetration into the barrier. The measured EHSS trajectories of penetration into the barrier after passing through porous screens show that penetration slows down more and more with the density decreasing to 4.1 g/cm$^3$; however, experimental penetration depths do not change.

In considering the case of the striker operation (see Fig. 2, *a, b* taken from [12]) one can see that the porous medium does not collapse after embedding, unlike strong solids [13]. The striker is embedded into the shock-compressed compacted part of the porous medium with the density lower than that of the continuous medium but with higher temperature and specific energy [4.5];

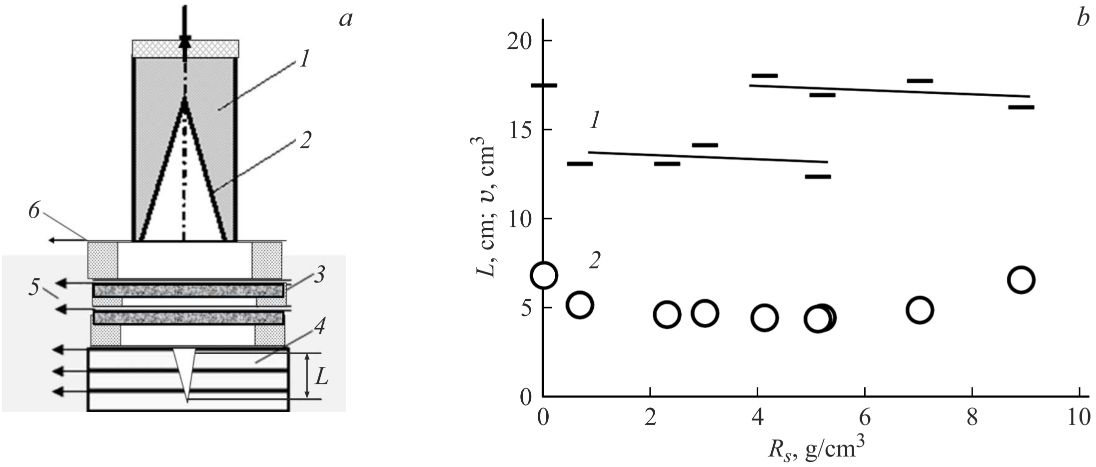


**Figure 1.** *a* — schematic diagram of the experiment. *1* — a cylinder 2.5 cm in diameter made from high-energy organic matter 40 g in mass; *2* — a copper funnel with the base diameter of 2 cm, thickness of 0.08 cm, and apex angle of 30°; *3* — porous copper screens; *4* — a barrier made from the AMg6 alloy sheets with the cavity formed after the EHSS impact; *5* — contact sensors for measuring the penetration time; *6* — aluminum foil 40 $\mu$m thick. *b* — parameters of the cavity formed in the AMg6 barrier by the impact from EHSS that has passed through porous copper screens $R_s$ in density: *1* — depth $L$, *2* — volume $v$.

Results of experimental study of the EHSS embedding ($R_j = 8.9\,\text{g/cm}^3$, $V_{j0} = 8.26$ km/sat are the copper striker density and initial speed, respectively) into the AMg6-alloy barrier after passing through porous copper screens $R_s$ in density

| Item No. | Screens | | | | | Barrier | |
|---|---|---|---|---|---|---|---|
| | Density $R_s$, g/cm$^3$ | Screen thickness $t_s$, cm | Penetration parameters | | | Cavity parameters | |
| | | | Speed $U^*$, km/s | Time $2t_s/U$, $\mu$s | Pressure $P^*$, GPa | Depth $L$, cm | Volume $v$, cm$^3$ |
| 1 | 8.9 | 0.1 | 4.1 | 0.48 | 76 | 16.1 | 6.5 |
| 2 | 7.0 | 0.12 | 4.4 | 0.51 | 67 | 17.6 | 4.8 |
| 3 | 5.2 | 0.2 | 4.7 | 0.79 | 57 | 16.8 | 4.4 |
| 4 | 4.1 | 0.2 | 4.9 | 0.74 | 50 | 17.8 | 4.4 |
| 5 | 3.0 | 0.3 | 5.2 | 1.03 | 41 | 14.0 | 4.7 |
| 6 | 2.3 | 0.4 | 5.5 | 1.24 | 34 | 12.9 | 4.6 |
| 7 | 5.1 | 0.2 | 4.7 | 0.78 | 56 | 12.2 | 4.4 |
| 8 | 0.66 | 0.9 | 6.5 | 1.4** | 14 | 12.9 | 4.9 |
| 9 | w/o screens | | | | | 17.8 | 6.9 |

* Speed $U$ of penetration into screens and initial pressure $P$ in the region of the striker–screen interaction are determined based on the one-dimensional approximation of the jet flow via the compressibility-free Bernoulli equation [10] for the initial speed of the striker.
** Single screen.

the compaction pressure increases with decreasing density of the initial porous medium [14]. Under the EHSS embedment, the compacted part of the porous medium covers the cavity surface (Fig. 2, *a*, *b*).

The use of porous screens is accompanied by an increase in temperature and fraction of evaporated copper thermal energy in the products of local screen-EHSS interaction. Variation in the effect of screen density lower than 5 g/cm$^3$ evidence that a new mechanism determining the EHSS penetration into porous media comes into action, in contrast to previously studied materials [3,11–13].

Data from paper [15] devoted to determining the adiabats and isotherms of copper with different porosities under the plane shock-wave compression demonstrate that at the density below 4 g/cm$^3$ and pressure of up to 200 GPa the shock adiabat behaves anomalously, namely, an increase in the shock compression pressure causes an increase in the porous medium specific volume and temperature.

When EHSS is being embedded into the screen, the newly supplied striker material gets instantly heated by thermal radiation from the the cavity wall (Fig. 2, *a*, *b*). Thus, the EHSS disturbance after passing through the screens less than 4.5 g/cm$^3$ in density occurs without the delay typical of the radial kinetic (mechanical) impact of the cavity walls [13] and is determined by heating due to radiation from the shock-compressed porous screen material. The consequences of thermal disturbance in the form of the expected ablation of a part of EHSS manifest themselves in a decrease in the cavity depth in the barrier.

Based on the data graphical representation [15], the temperature in the region of the striker–porous screen interaction was estimated for the pressures listed in the Table.

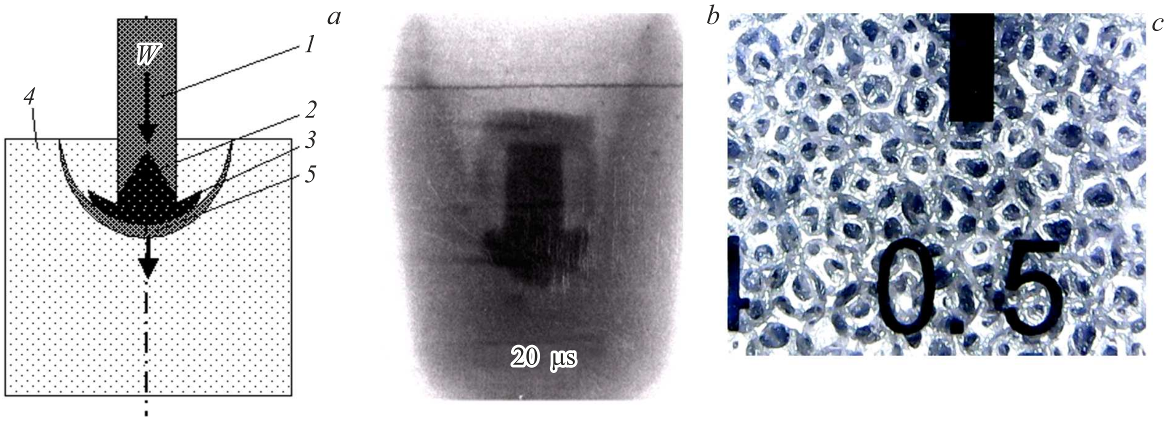


**Figure 2.** *a* — schematic diagram of penetration. *1* — steel striker; *2*, *3* — zones of the compressed and plastically deformed striker; *4* — corundum powder; *5* — zone of shock-compressed powder. *b* — pulsed radiograph of the process of the 0.6 cm-dia steel striker penetration with speed $W = 1006$ m/s into corundum 2.0 g/cm$^3$ dense. *c* — structure of the nickel-based porous composite (the reference line thickness is 0.5 mm).

It appeared to be $(9-10) \cdot 10^3$ K, which was an order of magnitude higher than the EHSS initial temperature in the process of its formation from cumulative funnel *2* (Fig. 1).

The question of the nature of disturbance of the next flying EHSS elements (heating, ablation, evaporation, transformation into plasma, destruction, dispersion) remains open.

Potentials of porous metal screens are evident from the results given in the Table (lines 5–8). For instance, the effect of the porosity character (closed or open) manifests itself in the case of packages made from the mesh and porous nickel [16]. The use of copper powder consisting of spherical particles $50-100\,\mu$m in size from a sealed ampoule and porous nickel composite (Fig. 2, *c*) have demonstrated the influence of the metal particles' surface condition (the absence of oxide film). To clarify the influence of the porous metal screen structure, more research is necessary.

The results of comparing the experimental results with data of [15] prove that the region of effective EHSS disturbance under the interaction with a metal screen coincides with that of anomalous behavior of the adiabat of the porous metal shock compression.

Kinetics of the EHSS front part penetration into the barrier reflects the trajectory slowdown with increasing metal screen porosity.

The temperature of interaction between the copper striker (head speed above 8 km/s) with the porous (more than 50 %) copper screen is $(9-10) \cdot 10^3$ K and determines the thermal disturbance of a part of the striker.

We have shown that, despite the conically diverging shock-wave compression produced by the elongated striker with the speed higher than 8 km/s with the porous (more than 50 %) copper screen, a decrease in the depth of penetration into the AMg6 barrier takes place.

### Conflict of interests

The authors declare that they have no conflict of interests.

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