THE METALLOGRAPHIC ANALYSIS OF A PESTLE OBTAINED BY COLLAPSING OF A COPPER HEMISPHERICAL SHELL

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In this work, an experiment was performed and analyzed on the convergence of a shell made of M1 copper with a purity of 99.96%, having a shape close to hemispherical (Fig. 1). The shell (*1*) was surrounded by a layer of explosives having the shape of a cylinder (*2*). Under explosive loading, as a result of the interaction of a straight line and reflected by the shock waves, a spall occurred (shown by the dashed line in Fig. 1). The shell split into two parts during the spall. The part of the shell adjacent to the explosive layer has not been preserved. The remaining part converged; and a pestle was obtained, having the shape of a biconvex lens (Fig. 2). The diameter of the pestle is ~45 mm, the thickness is ~23 mm. A sharp-angled protrusion about 2 mm high has formed on the front surface of the pestle (Fig. 2 is the lower surface). A macro- and microstructural study of the transverse and longitudinal sections of the pestle showed the location, shape and size of the deflected pores, as well as the direction of flow (deformation) of the material during convergence [1].

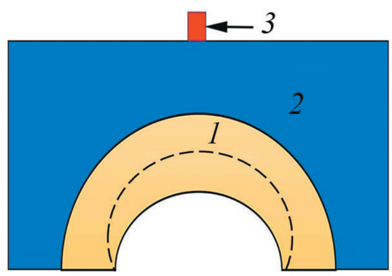
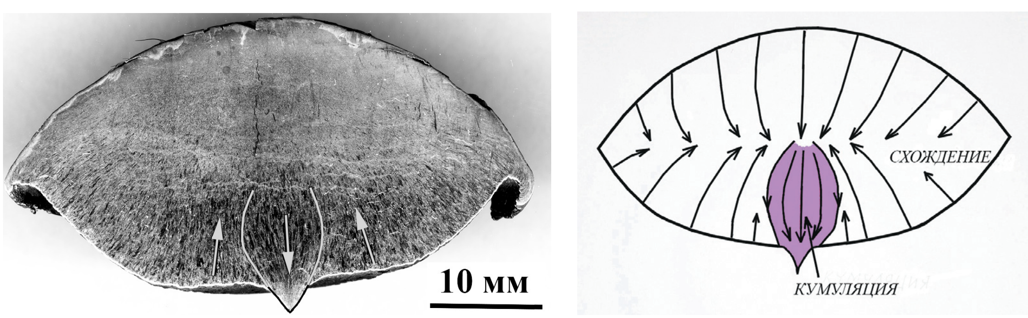


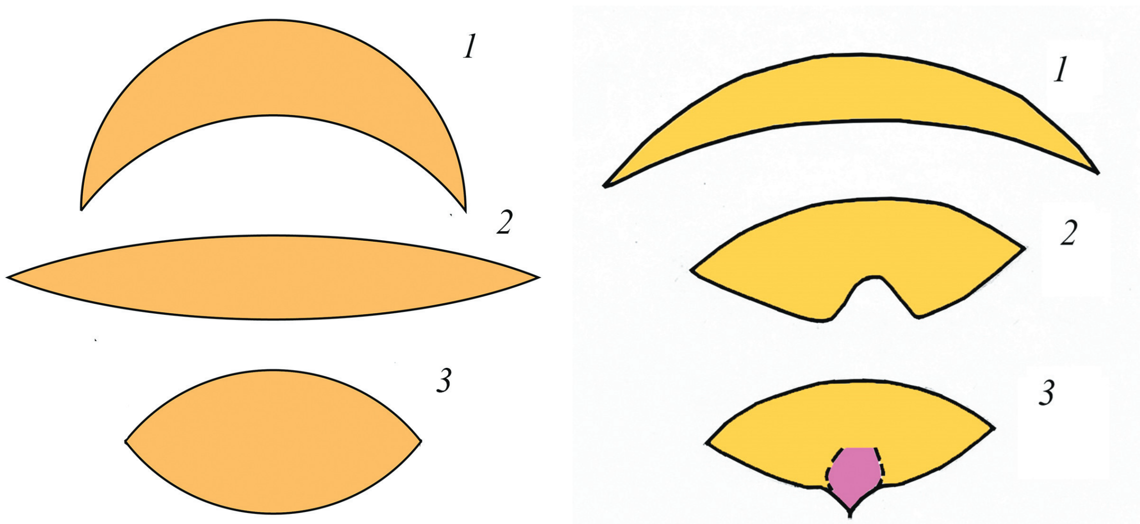
Fig. 1. Experimental scheme:
1 − shell, *2* − explosive, *3* − electric detonator



a *b*

Fig. 2. Macrostructure of the pestle in cross section (*a*) and the scheme of flow (*b*)

The transverse section of the pestle shows that the area of the deflected pores is located in the front half of the pestle (Fig. 2, *a* is the lower half). The pores have an elongated shape. The length of the pores reaches 400 microns, the thickness is about 50 microns. Fig. 2, *b* shows the scheme of flow, the arrows show the directions of the flows. When the shell collapses, the flow is directed inward towards the middle (horizontal) plane of the pestle (Fig. 2, *b*). This flow (deformation) transforms (compresses) the shell into a lenticular pestle. The flow in the center, in the front half of the pestle (Fig. 2 is the lower surface) is directed in the opposite direction, outward, and it creates a sharp-angled protrusion (highlighted in color). The protrusion is caused by high-speed deformation and release of material as it moves in the center of the shell. Obviously, the protrusion is a section that appeared at the initial stage of the formation of a cumulative jet. The study of the structure of the pestle allowed us to propose a scheme describing the convergence process. The complex deformation of the shell during convergence can be formally represented as two simpler deformations, shown in Fig. 3, *a*. The bending deformation straightens the initial shell (*1*), turning it into a thin disk (*2*). The second deformation compresses the shell in the plane of the disk, as a result, the diameter of the disk decreases and the thickness increases (*3*). This scheme helps to understand how the flow occurs during convergence, but does not explain the formation of a sharp-angled protrusion.



a *b*

Fig. 3. Formal (*a*) and real (*b*) shell convergence schemes

In a real experiment, bending and compression deformations occur simultaneously. Figure 3, *b* shows the convergence scheme, divided into stages. The initial shell (*1*) straightens out and transforms into a disk with a recess (*2*). The origin of the recess can be explained either by preserving part of the concave surface of the shell, or by the leakage of material from the periphery of the disk to the center under the action of compression stresses. With further compression, the recess turns into a cavity. The cavity closes, and the material is "ejected", forming a sharp-angled protrusion (*3*). However, in the general case, the formation of a recess on the surface of the disk is not necessary. The shell substance (copper) moves in the plane of the disk towards its axis with high speed. Near the axis, the flows of matter collide, and release occurs. The release represents the initial stage of the formation of a cumulative jet. Thus, a disk-shaped pestle with a sharp-angled protrusion is formed.

Thus, the experiment performed and the study of the macro- and microstructure of the resulting pestle for the first time showed a picture of deformation phenomena in the pestle (formation of deflected pores and flow directions) at the initial stage of the formation of a cumulative jet.

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References

1. **Zel'dovich, V. I.** The metallographic study of the structure of a pestle obtained by convergence of a hemispherical copper shell [Text] / V. I. Zel'dovich, I. V. Khomskaya, D. N. Abdullina, A. A. Degtyarev, A. V. Koval' // Phys. Met. Metallogr. – 2025. – Vol. 126.