Channel Angular Pressing of the Annular Billets from Copper M4

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Abstract. The article presents a new method of channel angular pressing (CAP) of annular metal billets developed on the basis of the invention patented in the Russian Federation. The diagram, general view and details of the device produced on the basis of the invention are presented. An example of cold CAP of an annular billet from technical copper M4 is given. Annular billets from copper M4 with 13.9 mm outer diameter, 1.9 mm wall thickness and 4.1 mm height were subjected to CAP at room temperature with a device with the outlet and inlet channels diameters ratio D / d ≅ 1.14. The annular billet was loaded with a tubular punch by a hydraulic press. The diagram of the loading of an annular billet from copper M4 is presented. The CAP resulted in the hardening of the billet material. The results on the mechanical properties under axial compression of annular samples from commercial copper M4 in the initial state and after CAP are presented. Mechanical tests for axial compression of annular samples with 16 mm outer diameter, 1.45 mm wall thickness and 3.35 mm height were carried out with Instron-1195 testing machine at a constant loading rate of $\approx 0.83*10^{-5}$ ms^{-1}. An increase in strength of copper M4 as a result of CAP at room temperature was found.

1 Introduction

To obtain the final products, machine and unit parts, items for various purposes from metallic materials, it is required to complete a number of production processes, from metallurgical to final finishing. The required operational and functional properties of materials and parts are provided from the first stage of a material creation (chemical composition, structure, phase, etc.) to the last additional processing and refinement. At this, the production pattern, creation and processing technologies may vary. In the technological process, such concepts as technique optimization, production efficiency, shorter the production path, material saving, etc. are of no minor importance. In this issue, a topical point is the combination of the deformation processing that strengthens the material with the production of a semi-finished product or the part as such.

In the field of pressure metal treatment, methods of severe plastic deformation (SPD) have been developed in recent decades, making it possible to increase the strength of metals and their alloys by several times [1-12]. The main SPD methods are high pressure torsion

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[13], equal-channel angular pressing [1] and its modifications [14], all-round forging [15], "upset – extrusion – upset" ("hourglass") cycle dependent stress [16], screw extrusion [17] and others.

These methods are largely aimed at strengthening the metal material without changing the billet shape. They do not solve the problem of obtaining semi-finished products or the parts and products as such during the SPD process. In solving this topical issue, an approach seems promising based on the development of new and modification of known SPD methods, as well as combined SPD methods. Technical solutions for such methods should be aimed at strengthening the material and obtaining parts of complex shapes. Preliminary data on obtaining a hardened billet in the form of a profile from a thin copper plate are presented in [18]. The extrusion and the method of extrusion combined with screw pressing (ESP) viewed in [19] provide for the production of prismatic and screw metal profiles. Commercial copper M4 subjected to ESP is shown to have a higher energy/output ratio due to increased ductility.

The purpose of the present study was to strengthen and obtain an annular billet from technical copper M4 by channel angular pressing (CAP) and to determine the strength properties.

2 Channel angular pressing

In the present study, the CAP scheme according to the patented invention [20] was used: by "dD" pattern, an annular metal billet *6* is inserted into the inlet channel *3* of the matrix *1* and pushed through the tubular punch *2* into the intermediate *4* and consequently into the outlet *5* channels of the device (Fig. 1). The CAP by the "dD" pattern means an increase in the original outer diameter d of the annular billet to D value. The ratio of the diameters of the outlet and inlet channels $D / d \cong 1.14$. At the channels *3* and *4*, *4* and *5* intersection, the metal material undergoes shear deformation.

3 Test material and methods

The test material was technical copper M4 in the state of delivery with the following chemical composition (%): 99.1 Cu, 0.427 Zn, 0.132 Pb, <0.01 Sn, <0.005 P, 0.0028 Mn, 0.0054 Fe, 0.126 Ni, 0.0587 Si, <0.005 Mg, 0.0063 Cr, 0.0013 Al, 0.0077 S, <0.001 As, <0.01 Be, 0.0011 Ag, 0.0238 Co, 0.0235 Bi, <0.002 Cd and 0.0062 Zr. Chemical analysis was made with Foundry-Master atomic emission spectrometer (Worldwide Analytical Systems AG, Germany).

Annular billets from copper M4 of 13.9 mm outer diameter, 1.9 mm wall thickness and 4.1 mm height were subjected to CAP by "dD" pattern on the developed device prototype tooling. The general view (a) and the disassembled composite matrix (b) of the device are shown in Fig. 2. In the engineering form of the device, the stop *6* is screwed onto the threaded rod *8*. Above the stop *6*, the matrix cover *3* is installed in the annular groove *7*. The assembled unit is fixed with a nut *4*. The inner surface of the cover *3* and the outer surface of the stop *6* form channels *3*, *4* and *5* in the matrix (Fig. 1). The extruded billet goes into the groove *9*. The billet is removed from the matrix after disassembling the composite matrix. The billets were made from a copper rod of 14 mm diameter. The annular billet was loaded with a tubular punch on a PSU 125 ZIM hydraulic press with a force of 1,250 kN To reduce the friction of the surface of the annular billet against the walls of the matrix channels, the ROSOIL-ANGELINA technological grease with additions of flake graphite was used. Tests on deformation processing of billets were made at room temperature.

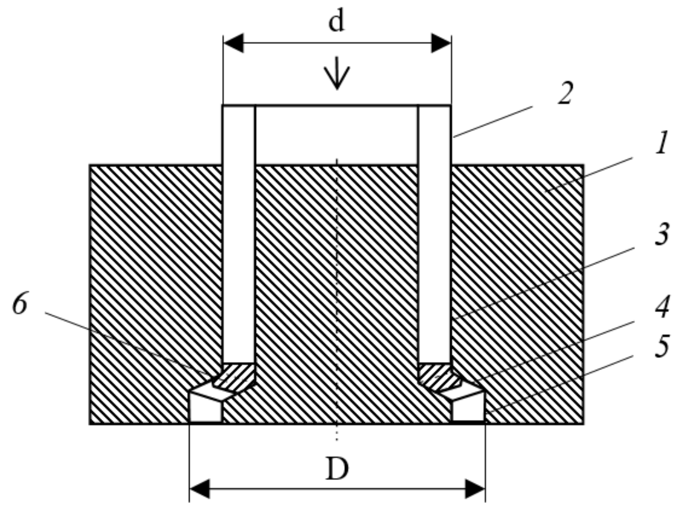

Fig. 1. Device diagram for “dD” CAP [20]:
1 – matrix, *2* – tubular punch, *3*, *4*, *5* – inlet, intermediate and outlet channels, respectively, *6* – annular billet.

The mechanical properties of copper M4 were determined from axial compression tests of annular samples (with working dimensions of 16 mm outer diameter, 1.45 mm wall thickness, 3.35 mm height) on Instron-1195 testing machine at a constant loading rate of $\approx 0.83*10^{-5}$ ms^{-1}.

4 Results

As an example, Fig. 3 shows samples from copper M4 in the initial state before (a) and after (b) axial compression.

The CAP diagram of an annular billet from copper M4 is shown in Fig. 4. The discontinuity of the deformation curve is associated with the processes of shear deformation at the intersection of the channels when the annular billets pass through the matrix channels.

Annular samples of 16 mm outer diameter, 1.45 mm wall thickness and 3.35 mm height were made from pressed-off blanks. Examples of deformation diagrams for annular billets from copper M4 in the initial state (curve *1*) and after “dD” CAP (curve *2*) under axial compression are shown in Fig. 5. The shape of the curve features the deformation of the plastic material. As seen, the section of elastic deformation for the treated copper increases in comparison with the initial state. The upset at axial compression results in the barrel shape of the annular sample.

The stresses at axial compression tests of annular samples were calculated by the known equation. The mechanical properties of copper M4 in various states are presented in Table 1.

Copper M4 elastic limit and conditional yield stress resulting from “dD” CAP are seen to increase by ~1.3-1.4 times compared to the initial state.

Fig. 2. Device for “dD” CAP (a) and tooling for “dD” CAP (b):
1 – punch holder; *2* – tubular punch; *3* – matrix cover; *4* – nut; *5* – matrix base; *6* – matrix stop; *7* – annular groove; *8* – threaded rod; *9* – groove.

a b

Fig. 3. Annular sample from copper M4 in the initial state: a) before and b) after axial tension.

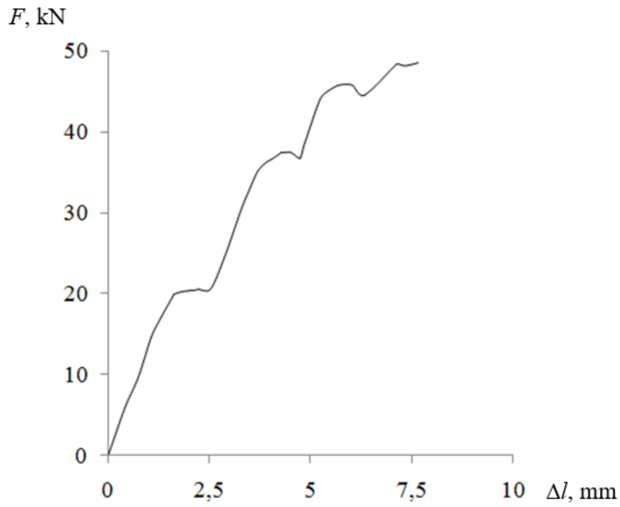

Fig. 4. "dD" CAP curve for annular sample from copper M4.

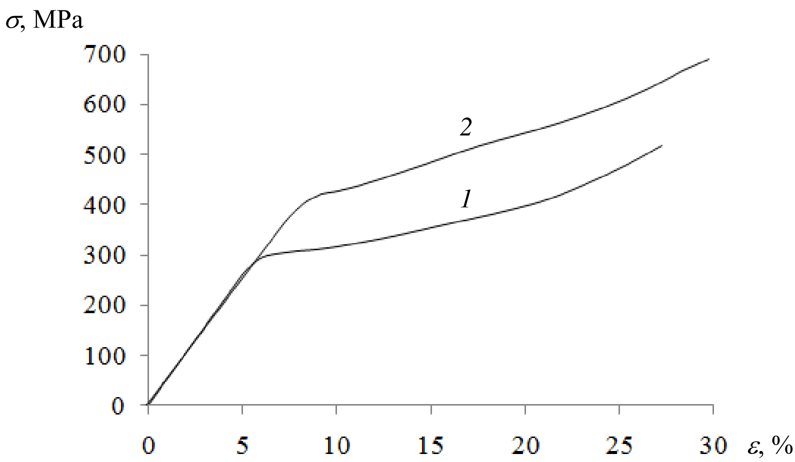

Fig. 5. Deformation curves for annular samples from copper M4 at axial tension:
1 – in the initial state; *2* – after "dD" CAP.

Table 1. Mechanical properties of copper M4

Material state	Elastic limit σ_e	Conditional yield stress $\sigma_{0,2}$
	MPa	
Initial	296	304
After "dD" CAP	385	422

5 Conclusion

It is shown that with the device developed according to the patented invention, the hardening of technical copper M4 with an increase in the annular billet diameter was achieved. For copper M4, the elastic limit and conditional yield stress after "dD" CAP increased by ~1.3-1.4 times. Hardening resulted in the expanded region of elastic deformation of copper M4.

The proposed method of channel angular pressing and the obtained results can be helpful in the development of techniques for strengthening annular billets and sleeves made of metals and alloys. Further development of this method demands the implementation of a multi-pass CAP with a variation in the heating temperature of the billet and improvement of the CAP pattern. During the CAP process, it is also possible to affect the billets with other physical agents, e.g. electric current, ultrasound or other types of processing.

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