

## Use of the superplasticity effect of materials in engineering technology

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**Annotation.** Technological aspects of using the effect of superplasticity in the manufacture of many mechanical engineering products by pressure treatment methods are considered. Superplasticity, which manifests itself under special conditions, allows the formation of complex forms of specific materials with heat and deformation resistance, hardness and brittleness, and atypical physical and technical properties at low costs.

The conditions and factors of the manifestation of superplasticity effect for traditional and innovative materials, such as metallic glass and nanoceramics, are revealed.

New mold forming technologies that do not require press equipment are considered, and the areas of optimal use of the capabilities of the superplastic state of materials are specified.

The leading processes in the manufacture of many parts are punching materials by pressure (PMP). However, traditional PMP is often resource-intensive; it requires special measures to combat hardening to reduce friction in the deformation zone [1]. In addition, critical parts are made of materials and alloys with special properties. These materials, as a rule, are low-ductile and deformation resistant, which forces technologists to use alternative, but high-cost foundry technologies.

The effect of superplasticity of materials is the resource of increasing the applicability of PMP technology in engineering. The present work is devoted to the analysis of main aspects of this problem.

By superplasticity we mean nonlinear viscous behavior of a number of materials possessing a hyperfine grain microstructure [3].

The state of superplasticity can be determined by a combination of characteristics:

- 1) Increased sensitivity of the yield stress of materials to the change in the rate of deformation;
- 2) Extremely low value of strain hardening;
- 3) Very high resource of deformation ability;
- 4) The yield stress of material in superplasticity state is several times less than the yield point, which characterizes the plastic state of a particular material.

The effect of superplasticity in the case of PMP manifests itself under certain conditions, such as the structural state of the deformable metal, metal temperature, and the rate of deformation. Most often, superplasticity manifests itself at the temperature  $(0.4-0.8) T$  melting. The rate of deformation is between  $10^{-5} - 10^{-3} \text{ sec}^{-1}$ .

The effect of superplasticity has two varieties: structural and phase. The use of phase superplasticity is under study. Structural superplasticity has been studied quite well for practical use.



To realize the structural superplasticity, the treated metal must be given a special equiaxial fine-grained structure. The grain size does not exceed 10 microns in diameter. In the process of heating to the PMP temperature, the grains must be resistant to growth.

Alloys can be converted into superplastic state by preliminary thermal or thermo-mechanical treatment.

The temperature of the manifestation of superplasticity effect must be maintained constant over the volume of the deformable metal during the entire processing period to ensure even flow of the material.

The advantages of using the effect of superplasticity in engineering technology are the following:

1) PMP of low-plastic and deformation resistant alloys based on Ni, Ti, Al, Fe, Mg becomes possible. It is possible to process the part in one technological transition.

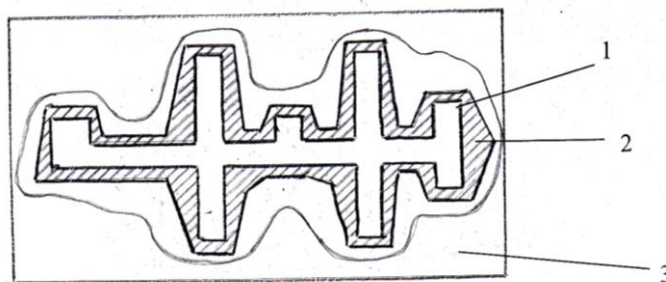
2) It is possible to forge details of particularly complex shape (thin-walled parts, details with ribs, details with relief texture, etc.).

3) The forging force and the power of the equipment used are reduced.

4) The quality of the finished product is improved due to the better filling of the stamping die, the dimension accuracy is improved, the surface defects are reduced, and the microgeometry of the surfaces of the processed parts is improved.

5) The cost of manufacturing products with the use of superplasticity effect is reduced by 30-40% compared to punching metal in ordinary state.

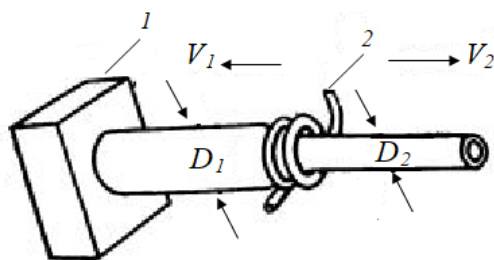
Figure 1 shows a comparative analysis of the effectiveness of various types of processing in the manufacture of parts of complex shapes [4]. In the example considered, the stamping slopes are  $1^\circ$ . The coefficient of metal use is 0.8, whereas for stamping under normal conditions it is 0.2-0.5.



**Figure 1.** Comparative analysis of the efficiency of the superplasticity process: 1-component; 2 – PMP under superplasticity conditions; 3 - casting.

Along with the above mentioned advantages, innovative technologies that do not require press equipment are implemented together with the effect of superplasticity. Such technologies include free-flow drawing, gas-static molding from sheet material, thermoelastic stamping.

Free-flow drawing based on superplastic behavior of the material combines loading only with tensile forces with localized heating. The tubular blank (Figure 2) is clamped from one end, and the other end is pulled at a controlled speed  $V_2$ .



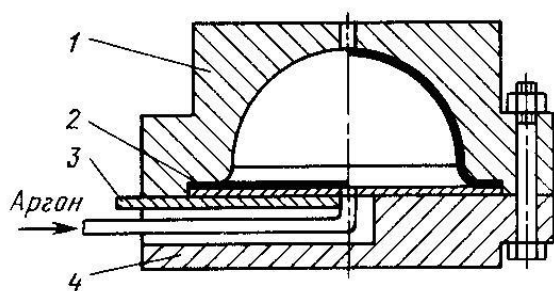
**Figure 2.** Scheme of the free-flow drawing: 1 - fixture; 2 - inductor

The inductor heats the localized section of the pipe to the superplastic state and moves with velocity  $V_1$ . The resulting reduction is determined according to the formula:

$$(D_1 / D_2)^2 = (V_2 / V_1) - 1$$

In one pass, a reduction of up to 50% was achieved. Multiple passes allow to obtain large total reductions. This scheme is promising for cases when it is necessary to preserve the axial symmetry in the reduction of blanks [4]. Similarly, sheets or plates of any given size can be rolled with high precision, while for local heating during deformation the contact resistance in the deformation zone can be used.

The scheme of gasostatic molding of hollow products from sheet material is shown in Figure 3.



**Figure 3.** Scheme of superplastic pneumatic shaping of hemispheres: 1 - matrix; 2 - blank; 3 - valve; 4- Clamping cover

Forming of the sheet blank is carried out under the influence of the difference in pressure created on both sides of the workpiece. The sheet blank 2 of the superplastic material is rigidly clamped between the clamping cover 4 and the matrix 1 and heated together with the die to the desired temperature. Then, gas (argon, carbon dioxide, compressed air) is fed into the cavity of the lid 4 at a pressure of 0.1-0.5 MPa. Under this pressure, the blank is expelled into the cavity of matrix 1 and then fills the whole space.

The innovative complex technology of isothermal punching of high-precision products from super heat-resistant alloys is described in [6]. Unorthodox technique for forming the alloy structure by high-gradient directional crystallization is proposed. When developing such complex technologies, it is necessary to use the construction of analytical models [7].

An example of complex optimization of the modes of superplastic forming of shells from titanium alloy VT6 is given in [8].

A significant number of parts and elements of precision instrumentation is made of ceramic materials, amorphous alloys, composites on a ceramic matrix. Superplastic ceramic materials with a stable submicron grain are of particular interest. The material exhibits superplasticity under certain temperature-velocity strain conditions during technically acceptable time.

There are two types of superplastic ceramics: single-phase ceramics and composites. The principal difference between the superplastic deformation of metals and ceramics is the required size of the structural constituents of the material. For ceramics, the grain size should be 0.1 - 1.0  $\mu\text{m}$ , i.e. an order of magnitude less than for most superplastic metals. The preparation of ceramic blanks for subsequent superplastic deformation is carried out from nanocrystalline powders by high-temperature consolidation.

The physical-and-technical properties of products made from superplastic ceramics are greatly influenced by the process of evaporation which occurs during plastic deformation.

In superplastic deformation in ceramics, powder formation is most pronounced at higher strain rates, and in metals, on the contrary, at the lowest rates.

Amorphous alloys are among modern and very promising materials. A large group of amorphous alloys characterized by a low rate of amorphization form a special kind of glass-forming systems called metal glass. These materials have excellent mechanical, magnetic and anti-corrosion properties, but are extremely fragile. At the same time, they behave like superplastic materials in a super cooled liquid state.

Some of these materials can be obtained in the form of dimensional amorphous blanks. In supercooled liquid state they are characterized by very low viscosity and high deformability which can be used for punching products of complex shape using conventional PMP technologies.

When evaluating the ability of amorphous alloys for superplastic deformation, two features must be taken into account, namely: glass formation ability and the stability of the amorphous state. Glass-forming ability is characterized, mainly, by the critical cooling rate of the melt and the relative glass-transition temperature.

Metallic glass is in a supercooled liquid state at a temperature above the glass transition temperature. This state is internally equilibrium and metastable regarding the crystallization process. In this state, they exhibit a linearly viscous flow over a wide range of deformation rates. This leads to a very high deformation capacity of the materials. Experimental samples achieved elongation of about 20,000% at 200<sup>0</sup> C and deformation rate of  $5 \times 10^5 \text{ sec}^{-1}$  [8].

The field of application of metallic glass is still limited by the fact that they can be obtained by rapid cooling from the liquid state only in the form of thin ribbons below 60  $\mu\text{m}$  thick and not more than 200 mm wide or a wire with a diameter of 0.5-20  $\mu\text{m}$ . However, there are broad prospects for the development of materials of this group. Soft magnetic amorphous alloys are already widely used in various industries.

## Conclusions

The effect of superplasticity of many materials widely used in engineering and instrument making can be fundamental for resource-saving technologies based on plastic deformation.

## References

- [1] Berdichevskij E 2011 *Trenie i smazka pri plasticheskoy obrabotke metallov (Friction and lubrication in the plastic processing of metals: monograph)* (Velikij Novgorod)
- [2] Saprykina N A, Saprykin A A and Matrunchik M S 2014 Formation of Surface Layer of Cobalt Chrome Molybdenum Powder Products with Differentiation of Laser Sintering Modes *Applied Mechanics and Materials* **682** pp 294-298
- [3] Tihonov A S 1978 *Effekt sverhplastichnosti metallov i splavov (Superplasticity of metals and alloys)* (Moskva: Nauka)
- [4] Kokorin V, Titov Y, Tamoverov V and Fedorov L V 2006 *Special'nye sposoby obrabotki metallov davleniem (Special methods of metal forming by pressure: textbook)* (Ul'yanovsk: ULGTU)
- [5] Kablov E, Osvennikova O and Lombert B 2012 Kompleksnaya innovacionnaya tekhnologiya izotermicheskoy shtampovki na vozduhe v rezhime sverhplastichnosti diskov iz superzharoprochnykh splavov (Integrated innovative technology of isothermal stamping of disks made from super-high-temperature alloys in superplasticity mode) *80 let. Aviacionnye materialy i tekhnologii* (Moskva: VIAM) pp 3-23
- [6] Chumachenko E, Portnoj V K and Logashina I 2014 Mekhanicheskie ispytaniya i postroenie analiticheskikh modelej povedeniya materialov v usloviyah sverhplastichnosti (*Mechanical tests and construction of analytical models of materials behavior under superplasticity conditions*) **1** (Moskva: Metallurg) pp 68-71
- [7] Zung N and Pol'kin V 2014 Optimizaciya rezhimov sverhplasticheskoy formovki obolochek iz titanovogo splava (Optimization of regimes of superplastic forming of shells made of titanium alloy) *VT6 Tekhnologiya legkih splavov* **1** pp 91-96
- [8] *Metallicheskie stekla* (Metallic glass) Perevod s angl 1984 (Moskva: Mir)