The Material for Physical Simulation of Metal-Forming Processes in Super-Plastic State

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Abstract. In the article it was suggested to simulate the process of super-plastic deformation on optically transparent materials, created on diene and vinyl-aromatic carbohydrates, polar softener and achromatic stabilizer. It was shown that the index of rate hardening of such materials could change from 0.2 to 1.0 within the rate intervals of super-plastic deformation. The authors are convinced that prior to this article the alloy Sn-38%Pb was the best material for simulation of the processes of super-plastic deformation. Advantages and disadvantages of tin-lead alloy for simulation of super-plastic deformation were mentioned in the article. The article contains examples of chemical composition of new materials: the foundation (component content – 100 weight parts) – butadienesterene, isoprenesterene, butadiene-α-metylsterene; stabilizer (component content – 0.5 weight parts) – 2,6-ditretbutyl-4-metylphenol; polar softener (component content – 5-40 weight parts) – dibutylphtalate, dibutylebacate. It was shown that introduction of polar softener reduces the effort of material flow. An unsufficient alternation of softeners content allowed modifying either behaviour of an alloy with different super-plastic structure or various temperature conditions of deforming.

1. Introduction

The phenomenon of super plasticity of metals (hereinafter SPM) was first observed by G.D. Bengough back in 1912, when he managed to reach elongation of a locally heated bronze sample by 160 % in a series of experiments, aimed at its slow elongation. Up to the present time such results are still taken into account and quoted in various works [1–3]. Elongation and deformation with local heating of the blank part are applied for manufacturing shaped and elongated parts of different materials [4–13]. Two decades later SPM ceased to be an object of exotic investigations and became an efficient foundation for creating new materials and technologies of their plastic forming, ensuring unique properties of manufactured parts and high engineering and economic efficiency of production processes [1, 14, 15].

Developing new technologies of super-plastic deformation presumes their simulation by application of the following ways: 1) by manufacturing industrial pilot batches [16–18]; 2) by computer simulation [19–21]; 3) by simulation of the processes with application of special materials [22–24]. The first variant produces the most precise results; however it requires substantial labour consumption that sometimes can’t be justified. The second variant does not imply material expenses (except for purchasing expensive licensed computer software and training of personnel),
however it largely depends upon the peculiarities of software, where a set of some or other materials models, methods of evaluation and formulae are used [25–27]. The third variant is a simplified variant of the first variant and presumes substantial reduction of labour consumption, due to selection of special materials for simulation, that are either relatively cheap, or they can simplify the process of simulation and raise its efficiency.

At present the second variant prevails, though computer simulation methods of deformation processes are often criticized [28]. That is why the search of new modelling materials, as an alternative to the first two variants of SPM processes simulation seems to be quite vital. These materials possess the following peculiarities: according to the firm opinion of many researchers [1, 29, 30] eutectic alloy Sn-38%Pb, this is the best material for simulating of super-plastic deformation processes. Selection of an alloy depends upon the following factors:

– the simplicity of forming an ultra-fine grained super-plastic structure in the alloy (an intensive deformation after advisable quick recrystallization of the melt);

– high sensitivity of the flow effort to deformation rate, usually determined by the value of the index of rate hardening

\[
\frac{d(\ln \sigma)}{d(\ln \xi)}
\]

(where \(\sigma\) – is flow effort, \(\xi\) – is deformation rate);

– low flow rates and high ultimate degrees of alloy’s deformation;

– the range of optimal temperatures of super-plasticity of Sn-38%Pb eutectics includes the room temperature, thus eliminating the problems with samples heating.

However, practical application of Sn-38%Pb alloy is connected with a series of difficulties that are not discussed very often. In [31] the fact that after intense deformation of a blank part, manufactured of Sn-38%Pb alloy it should be kept in a freezer, in order to avoid grain growth, occurring at the room temperature, was mentioned quite superficially (detailed explanation was missing there). Alloy deformation in optically transparent object (like, for instance, a transparent matrix at super-plastic forming) allows observing the dynamics of transformation of deformed state of the blank). Still it is true only for the surface of the blank, if it is covered with a coordinate grid. Deformation of the inner layers of the alloy can be investigated only after the process of deformation has been completed and subsequent mechanical separation of the sample.

A perspective of application of optically transparent polymeric materials that undergo loading (deforming) with subsequent investigation of the deformed state has but lately been found. Such materials were used in experimental process, described in [32, 33] and in the facilities elements in [34–36]. However, for selecting a group of materials, suitable for simulation of SPM processes it is necessary to investigate their composition and mechanical properties; it has not been performed up to now. The objective of the paper is to determine an opportunity and a degree of efficiency of application of optically transparent materials, similar to synthetic rubber for simulation of super-plastic deformation.

2. The Methods of Investigation

For reaching the desired goal a material is required, having beside the advantages of Sn-38%Pb eutectics possesses physical and chemical properties, stable in time and at room temperature, allowing to observe deformation of both surface and internal layers of the blank, i.e. it should be optically transparent.

Block-copolymer raisins, on the basis of diene a vinyl-aroma carbons satisfy nearly all these conditions. For simulation of pressing composite in diameter cross-section samples Ø 20x30 mm in dimensions were prepared of non-linearly viscous material of polybutadien – 25 % polystyrene composition. On the division plane a rectangular coordinate grid was marked with Indian ink, after that the blank was placed into an optically transparent stamping facilities and a deforming load was applied.

The character of the material flow and distortion of the coordinate grid during the process of deformation was registered by a video camera during the entire process of deforming. Unlike simulation on Sn-38%Pb alloy, in our case, beside the data, received by means of the coordinate grid, it was possible to build kinematic pictures of the pressing process along the flow lines, i.e. to increase the volume and the quality of the obtained data.
Simulation of other processes of plastic forming of other materials showed that it was advisable to add some quantity of polar softener and achromatic stabilizer into the block-copolymer raisin. For that purpose, a number of compositions of non-linearly viscous polymeric materials were developed for simulation of super-plastic deformation. Block-copolymer raisins, with achromatic stabilizers were rolled at 70–75 °C for 2 minutes until an elastic band was formed, then a polar softener (dibutylphthalate or dibutylcebacate). Then the mixture was mixed in rolls by its partial cutting off from the rolls. The samples for testing were pressed in hydraulic press at the die temperature 150 °C and pressure 7.5 MPa, after that they were cooled under pressure up to 30 °C.

Physical and mechanical tests of the samples were conducted in accordance with GOST 269, 270 for rubber materials, index \( m \) was determined by the method of strains relaxation [1, 30], on the samples Ø 20x30 mm in dimensions.

### 3. The Results of the Investigation and Their Discussion

The results of the tests are summarized in table 1.

As can be seen in table 1 sensitivity of flow effort to deformation rate of the materials proposed for simulation can vary within wide limits, mostly, because of some small additions of softeners. Introduction and alternation of the softeners content causes changes of strength condition of the compound, when it undergoes elongation (simplification of simulation conditions), as compared to the materials without softeners, also changed are deformation characteristics of compounds, however relative elongation value until tear remains constantly high.

Besides, changes in \( m \) parameter can be reached by selecting one or another block-copolymer. However, the softener content should not exceed 40 % of the entire mass share of the block-copolymer, because: first, practically, there are no super-plastic metals and alloys with index \( m = 1 \), and second, the material softens and poorly preserves its shape.

The compounds, registered in table 1 were used for manufacturing blanks and further simulation of the process of metal setting in the state of super-plasticity. A composite blank part was cast into matrix, in parts, then a rectangular coordinate grid was marked with Indian ink along the cutoff plane. At simulation of the process of setting the prepared blanks together with the tool were placed into transparent rectangular bath, filled with water, for elimination of optical distortions, occurring as a result of changing of curvature of the surfaces of the blanks.

| Composition variant |
|---------------------|
| 1 2 3 4 5 6 7 8 9 10 11 12 13 14 |
| Specific strenth at elongation, MPa | 6.5 2.9 1.12 0.45 0.31 0.14 1.82 0.84 0.38 0.20 0.1 0.19 0.42 |
| Relative elongation until tear, % | 615 502 463 268 214 145 635 560 490 312 215 167 392 309 |
| Relative residual deformation after tear, % | 18 24 52 37 26 18 22 29 56 47 32 21 41 27 |
| Plasticity acc. to Carrer | 0.29 0.51 0.59 0.64 0.72 0.90 0.34 0.54 0.63 0.70 0.77 0.92 0.68 0.60 |
| Coefficient of rate sensitivity \( m \) at deformation rates \( 10^{-3} \ldots 10^{-4} \text{ sec}^{-1} \) | 0.29 0.37 0.42 0.51 0.56 1.0 0.26 0.39 0.52 0.72 1.0 1.0 0.49 0.61 |

The conducted experiments made it also possible to build the \( \sigma = f(\xi) \) diagrams in logarithmic coordinates and determine \( m \) index by the tangent of inclination angle of the graphs to \( \xi \) axis (see figure 1).
Figure 1. Dependence of rate hardening index from strain rate for optically transparent block-copolymers: (1) Butadienesterene block-copolymer; (2) Isoprenesterene block-copolymer; (3) Butadiene-α-metylsterene block-copolymer; (4) 2,6-di-tret-butyl-4-metylphenol; (5) Dibutylphtalate; (6) Dibutylsebacate.

The analysis of the results, summarized in figure 1 proves that just like for super-plastic metals and alloys, deformation of samples, made of block-copolymers is characterized with high rate sensitivity of the flow effort, index of rate hardening $m$ has its maximum value within the same range of deformation rates with metallic materials. Slight changes of the softener content allow to modify either alloy’s behavior with one or another super-plastic structure, or some or other temperature conditions of deforming.

4. Conclusions

The simulation of the processes of super-plastic deformation with the help of optically transparent non-linear viscous block-copolymers, on the basis of diene and vinyl-aromatic carbohydrates of polar softener and achromatic stabilizer makes it possible to observe physically the process of deformation along the entire process of samples deforming. In prospects, by means of a coordinate grid, placed upon the diametric plane of such samples and video recording of the process it is possible to analyze quantitative and qualitative changes along the entire volume at any time span.

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