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Development of computer simulation of industrial superplastic sheet forming

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ABSTRACT

A new technique estimating progressive shape changes for three-dimensional shells based on the generalized cross-sections method is introduced. The formulation of mathematical simulation of technological conditions of forming of three-dimensional shells in conditions of superplasticity is reviewed. An original algorithm of a solution finite element method with usage of orthogonal sections results. The veracity of a receivable solution is analyzed. Experimental tests are realized and a procedure to correlate the idealized forecasts with experimental data is constructed. The results and designed algorithms allow essentially to increase performance and operationability at mining new and retrofit of existing manufacturing processes of gaseous forming in conditions of superplasticity.

1. Introduction

Production of titanium shells is widely used presently when manufacturing aerospace purpose structures. In comparison with aluminum, titanium has higher specific strength, better fatigue properties, higher thermal stability; it does not corrode in typical for aircraft conditions and has higher resistance to propagation of cracks. Due to these characteristics, titanium is used to manufacture elements of planes with high in-flight qualities [1]. The elements manufactured of titanium make from 10% to 30% of such plane gross weight.

Increase of aircraft speed has led to temperature rise of the covering. So aluminum alloys have ceased meeting the requirements demanded by supersonic aircraft. The covering temperature in this case increases up to 240–315 °C (Fig. 1). The most acceptable materials for these conditions appeared to be titanic alloys.

Nevertheless, designers constantly try to minimize use of titanium, only applying it where it is absolutely necessary for temperature or other reasons. The cause of it is high cost of titanium and its difficult working. In recent years, many studies have been carried out in order to develop less expensive manufacturing methods of titanium structures. A process combining superplastic forming (SPF) and diffusion welding (DW) opens basically new possibilities in the technology of titanium processing when developing structures of aircraft. Application of the SPF/DW process can save funds and material by 50–70%, reduction of the structure mass by 30–50% and increase metal recovery up to 0.0–1.0 in comparison with the traditional methods used when manufacturing titanium structures.

The success reached in the mathematical simulation and forecasting of titanium alloy properties when forming in superplasticity conditions [2–4], allowed essential lowering of operation temperatures of SPF of sheet workpieces. For the first time, based on the research, it has become possible that one can decrease the temperature of titanium alloy industrial forming by almost 100 K. As an example, Fig. 2 shows results of comparison of theoretical forecasts and experimental forming performed at various deformation modes (different temperatures and speeds).

While developing the technological processes for isothermal gas forming of the complicated shape shells, it is very important to monitor the progression of the shape changes, and to be able to predict thinning of a shell and filling of die cavities. These problems are solved using computer simulation.

Creating a complex three-dimensional mathematical model for this simulation is not always justified as it leads to a significant labor cost resulting from both data preparation and subsequent calculations. In order to obtain the essential estimates for the above-mentioned technological processes and for the optimization of pressure and temperature parameters, it is more practical to use simplified 2.5-dimensional (3D) models. This allows analyzing significantly larger number of feasible parameter sets in search for the optimal solution. It turns out that in many cases these estimates are

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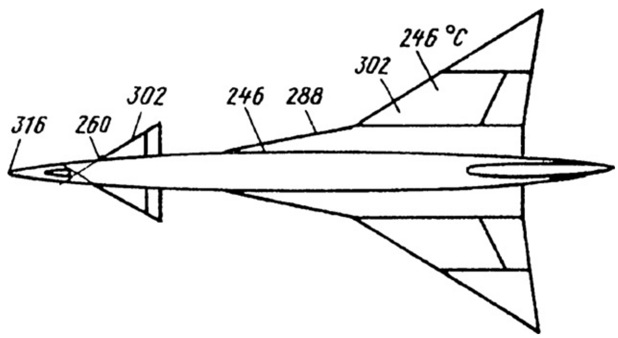

Fig. 1. Temperature distribution on the housing of the jet flying at 20 km altitude with a speed three times exceeding sound speed.

practically acceptable except for extremely complex die patterns. For the most critical parts, after getting an initial estimate solution, one can carry out additional calculations utilizing a full 3D model. This approach reduces to a minimum the number of prototypes of forming trials.

2. Solution algorithm

When analyzing spatial form changing by means of the deformed item plain sections, it is supposed that the characteristic dimension in the direction orthogonal to the section, considerably exceeds the characteristic dimension of the section itself.

Let the section be chosen in plane (x,y) at z = constant. Implementation of plainly-deformed state means that

$$\dot{\varepsilon}_{33} = 0, \qquad \dot{\varepsilon}_{13} = \dot{\varepsilon}_{23} = 0, \qquad \sigma_{13} = \sigma_{23} = 0, \qquad \sigma_{33} \neq 0, \tag{1}$$

and displacement speeds look like

$$u_1 = q_1(x, y), \qquad u_2 = q_2(x, y), \qquad u_3 = 0. \tag{2}$$

Thus formed solution does not take into consideration strains probably arising in the direction along axis O_z when form changing a real item.

Let us form some model allowing to specify the solution obtained in the assumption of plainly-deformed state implementation in a being studied object.

Let for each fixed value z = constant taken in a deformation zone along axis Z, two groups of equalities simultaneously take place,

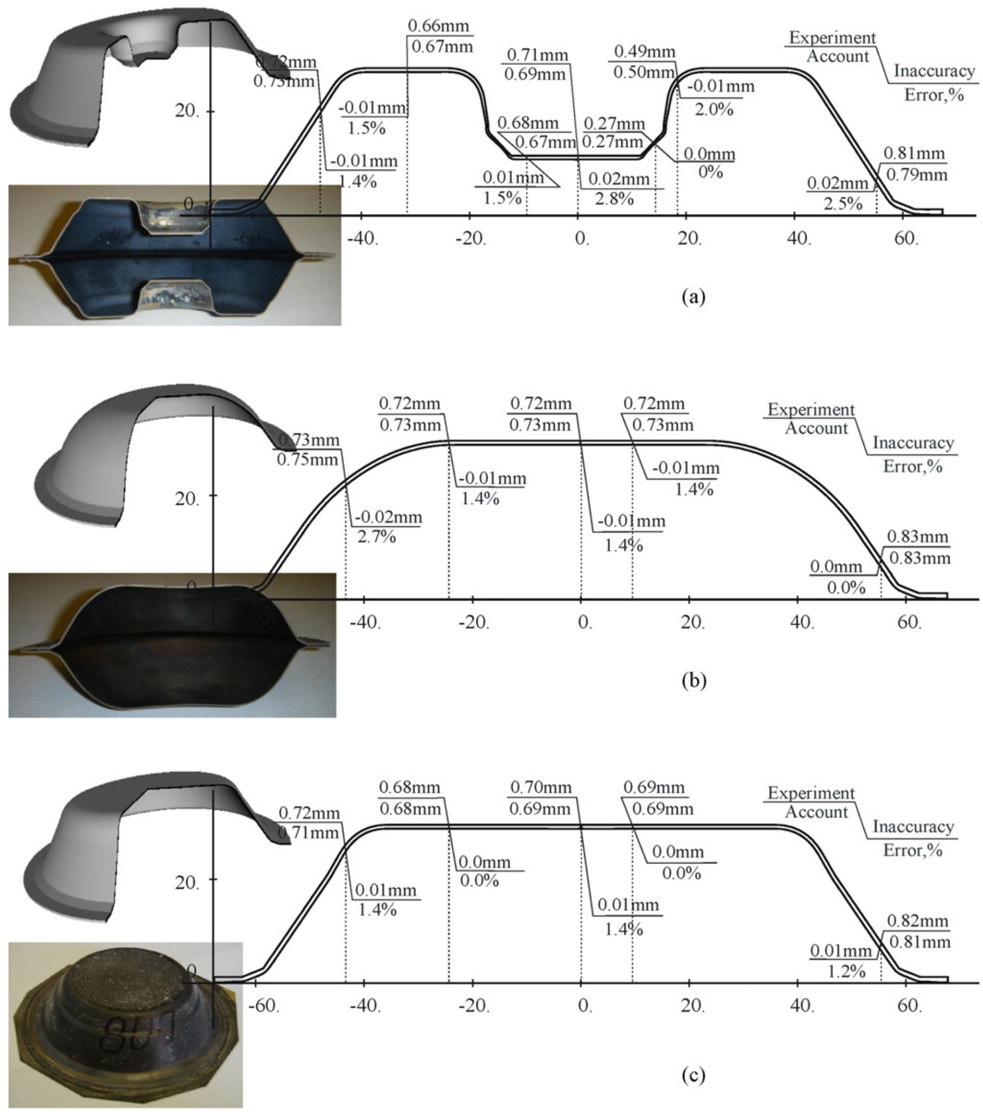

Fig. 2. Estimation of the forecasts accuracy for shell form changing at created SPF optimum modes: (a) T = 900 °C, (b) T = 775 °C and (c) T = 800 °C.