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Models of Anisotropic Creep in Integral Wing Panel Forming Processes

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Abstract. For a sufficiently wide range of stresses the titanic and aluminummagnesium alloys, as a rule, strained differently in the process of creep under tension and compression along a fixed direction. There are suggested constitutive relations for the description of the steady-state creep of transversely isotropic materials with different tension and compression characteristics. Experimental justification is given to the proposed constitutive equations. Modeling of forming of wing panels of the aircraft are considered.

1. Introduction.

Large integral panels are widely used to extend the operating life of the airframe. The stress-strain state resulting from panel forming determines the quality, the geometrical, physical, and mechanical performance of the panel, as well as the geometry of dies and blanks. One of the key salient features of high-strength light alloys is a large difference in (heterogeneous) resistances to tension, compression, and torsion. The alloys have limited ductility; that is why the panels considered often are inappropriately classified in terms of conventional forming technologies using “instant” plastic deformations. In forming under plasticity conditions, the material life does not extend beyond the panel manufacturing stage, causing the panel to suffer intolerable damage and cracks, which results in rejection of the entire panel. Slow forming under creep, where stresses are restricted by the elastic limit vicinity, while the shape is generated by gradually accumulating creep strains, seems promising for extending the material life, minimizing damage and residual stresses, and providing high quality of panel manufacturing.

The paper deals with computations of process performance of viscoplastic forming, blank, and die tooling for large integral wing structures. The constitutive relations between the steady creep strain rates and stresses describe steady, transversely isotropic creep with different characteristics under tension and compression. Computer modeling of these forming processes involves the use of the finite element method for consecutive solutions of three-dimensional quasi-static problems of elastoplastic straining, relaxation, and springback with allowance for large displacements and turning angles, anisotropy, and different resistances of the material.

2. Constitutive Potential Model of Steady Creep of Incompressible Transverse Isotropy Materials with Different Properties under Tension and Compression.

Test data argued that the material is transversely isotropic under the steady-state creep with the isotropy plane - rolling plane. For instance, the 180°C temperature creep curves of aluminum alloy B95T2 are essentially divergent for samples in direction in the plate rolling plane, and in the direction of the normal to this rolling plane [1]. Meanwhile, the creep degree is the same for every direction, but creep coefficients are considerably different.

Let be a Cartesian rectangular system of coordinates. The strain rate of the steady-state creep depends on the current values of stresses and the temperature. If the form of this dependence does not change under the coordinate system rotation on arbitrary angle around the x_3 axis then the material is transversely isotropic (initially transverse isotropy) under the steady-state creep with the isotropy plane x_1, x_2.

We propose the following creep equations of incompressible transversely isotropic, which follow from [2],

$$\dot{\varepsilon}_{ij}^{c} = \frac{\partial \Phi}{\partial \sigma_{ij}}, \; \Phi = \frac{f_1(\xi,\eta)}{n_1+1}\sigma_{et1}^{n_1+1} + \frac{f_2(\xi,\eta)}{n_2+1}\sigma_{et2}^{n_2+1}, \tag{1}$$

where

$$\sigma_{etm} = \sqrt{3/2\, T_m}, \; T_m = a_m J_1^2 + b_m J_2 + c_m J_3, \; (a_m > 0, \; b_m > 0, \; c_m > 0; \; m = 1,2), \tag{2}$$

$$\xi = \frac{J_1}{\sqrt{J}}, \; \eta = \frac{J_4^{1/3}}{\sqrt{J}}, \tag{3}$$

where

$$J_1 = \sigma_{33} - \frac{1}{2}(\sigma_{11} + \sigma_{22}), \; J_2 = (\sigma_{11} - \sigma_{22})^2 + 4\sigma_{12}{}^2, \; J_3 = \sigma_{13}{}^2 + \sigma_{23}{}^2, \tag{4}$$

$$J_4 = 4\sigma_{12}\sigma_{13}\sigma_{23} + (\sigma_{22} - \sigma_{11})(\sigma_{23}^2 - \sigma_{13}^2), \; \left(J = J_1^2 + J_2 + J_3\right) \tag{5}$$

The simplest (tensor-linear) theory follows from (1) if in these relations we do not take into account the dependence of the functions f_1 and f_2 on the parameter η and assume that the type of the stress state is adequately characterized by the following parameters ξ .

The creep curves calculated by Eqs. (1) for different constant values of tensile and compressive stresses for the same directions of the plate as those in the steady creep experiments are in reasonable agreement with the experimental curves. For comparison, we give the numerical and experimental data [1], which differ from the results obtained in the steady creep experiments. Figure 1 shows the calculated and experimental creep curves for pure torsion of a thin-walled sample tube whose centerline coincides with the transverse isotropy axis of the AK4-1T alloy in the plate at a temperature of 200°C. The following geometric parameters of the tube are used in the calculations: length 10 mm; inner and outer diameters 1.84 and 2 mm, respectively; one of the tube ends is rigidly fixed, while the other end is subjected to shear forces below the yield stress. The forces are applied rather rapidly, as compared with the time during which stress relaxation occurs and creep strains are developed, but rather slowly, as compared with the time of pulsed application where accelerative effects should be taken into account. Therefore, the configuration at the initial time (t = 0) with zero creep strains in the numerical solution is the deformed configuration of the tube made from this elastic material under the action of constant shear forces. The behavior of the sample material at the stage of force application is isotropically elastic and is described by Hooke's law; the creep of this material is transversely isotropic with different characteristics under tension and compression and is described by the flow law (1). It follows from Fig. 1 that the results calculated by Eqs. (1) ensure reasonable agreement with experimental data under pure torsion, especially under moderate stresses when the steady creep phase is realized.

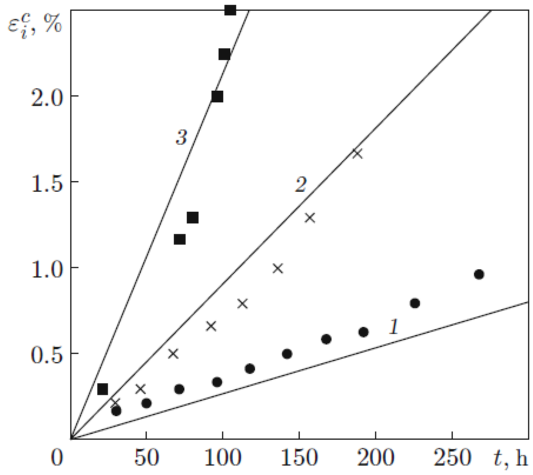

Figure 1. Calculated data (curves) and experimental data (points) on creep of the AK4-1T alloy at a temperature of 200°C under conditions of torsion of a thin-walled cylindrical sample whose centerline coincides with the transverse isotropy axis ($\sigma_i = \sqrt{3/2 s_{ij} s_{ij}}$, $\varepsilon_i^c = \sqrt{2/3 \varepsilon_{ij}^c \varepsilon_{ij}^c}$): 1) $\sigma_i = 144.4$ MPa; 2) $\sigma_i = 153$ MPa; 3) $\sigma_i = 170$ MPa.

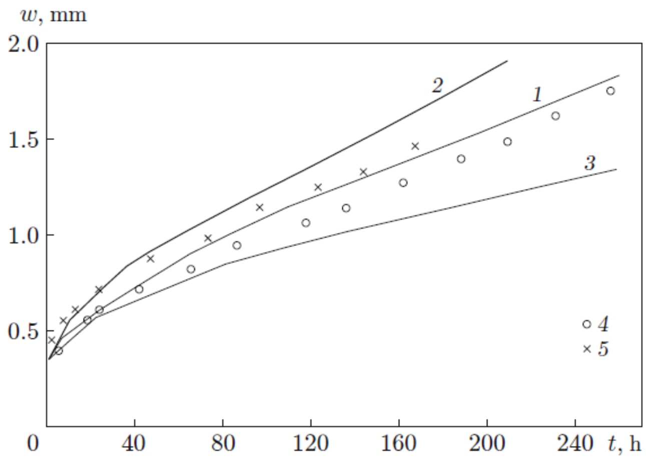

Figure 2. Deflection at the point of the plate versus time during the creep process under bending by the moments of torsion: curves are the results calculated with the use of constants (1) corresponding to tensile and compressive loading, respectively (curve 1), corresponding to tensile loading (curve 2), and corresponding to compressive loading (curve 3); points are the experimental data from experiment No. 1 and No. 2.

For the same material, we also compare the calculated and experimental curves of deflection of a square thick-walled plate with the creep process (the transverse isotropy plane of the material is parallel to the midsurface) under the action of four vertical concentrated forces P = 1850 kgf applied at the centers of the corner areas. The applied forces simulate pure bending of the plate by the moments of torsion with intensity P/2 uniformly distributed over the edges [3]. The points in Fig. 2 show the deflections obtained in the experiments with two identical plates [4]. Figure 2 also shows the time evolution of the deflection, which was calculated on a uniform grid consisting of three-dimensional eight-node hexagonal elements with the rib length of 10 mm. The following geometric parameters of the plate are specified in the calculations: length 180 mm, thickness 20 mm, and corner area size 20 × 20 mm. It follows from Fig. 3 that the results calculated by Eqs. (1), which take into account the difference in material characteristics under tension and compression are in reasonable agreement with the results of experiments on pure bending of the plate by the moments of torsion. At the same time, it is obvious that significant errors are obtained if this difference is ignored: the calculated plate deflection is overpredicted (as compared with the experimental data) if the characteristics under tension are used in all directions and underpredicted if the characteristics under compression are used. This type of plate bending can be accurately described by the constitutive relations derived in this paper for transversely isotropic materials with different characteristics under tension and compression.

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2.1. *Problem of Wing Panel Forming.* In this type of forming, the blank is also subjected to bending. In contrast to the direct problems discussed above, however, the values of the surface forces and boundary displacements are unknown in the general case and have to be determined alongside with the fields of stresses, strains, and displacements. For this purpose, it is possible to use the residual boundary displacements, for instance, the displacements over the normal to the frontal face of the blank, which can be easily calculated from the specified geometric parameters of the panel.

Let us consider a case with the problem of forming at the stage of active loading being solved in the kinematic formulation. We find the sought elements of the boundary displacements. The distributions of these components at the 8th iteration are shown in Fig. 3. Using these displacements, we modeled all stages of the forming process [5].

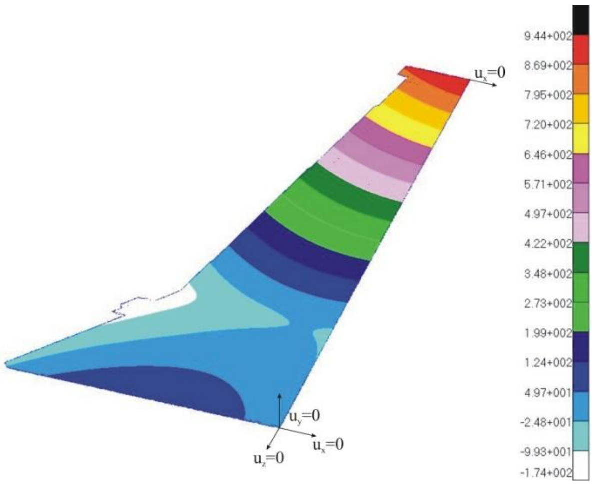

Figure 3. Distributions of the boundary displacements calculated at the 8th iteration.

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