Laws of the creep of metallic materials at high temperatures

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Abstract. The uniaxial tension with various strain rates for the alloy V95ochT1 at the room temperature and at the temperature of aging 165ºC is investigated experimentally for finding of the rational modes of deformation. The range of deformation rates, close to strain rate at superplasticity, at the temperature of aging was found when the value of deformation at destruction is maximum. Increasing or decreasing of the deformation rate leads to decrease of the strain value at which the material is destroyed. Increasing the preheat period leads to a decrease in the strain value at fracture at temperature of aging. The elastoplastic characteristics are reduced in the alloy in the cold state after the full aging at 165ºC without load.

1. Introduction

The processing of materials pressure in the quasi-static mode with deformation rates of the order of several percent per second is the most widespread method in industry. The treatment of new high-strength structural materials in this mode leads often to appearing of serious defects in the material and the product practically exhausts all resource already at the manufacturing stage before exploitation. The slow shaping modes due to irreversible creep strain and modes close to superplasticity are alternative to a fast shaping modes due to 'instant' plastic deformations [1-4].

The use of slow modes with the stress not exceeding the elastic limit with the strain rate about or less than $10^{-3}\,\mathrm{s}^{-1}$ due to increasing temperature and increase the duration of force action leads to reduced [5-9]:

- level of stresses;
- damage of material at the manufacturing stage of a detail;
- level of residual stresses after removal of the load since the internal stresses relax to small values in the process of slow temperature-force action on the material.

2. Experiments and discussion

The treatment of the material in slow modes allows one to expand the range of a temperature and force loading regimes, including nonstationary modes of deformation, to combine the process of forming with the processes of heat treatment of the material. This significantly increases the ability of the material to deformation that leads to the preservation of residual service life (survivability) of details at the manufacturing stage [10-13]. For instance, bending plates of aluminum alloy ABT-102 with a thickness of 24 mm at the room temperature (in the foreground) and the hardening temperature of 470ºC (in the background) are shown in figure 1.

Figure 1. Bending plates of aluminum alloy ABT-102 with a thickness of 24 mm at the room temperature (in the foreground) and the hardening temperature of 470ºC (in the background).

Experimental studies in uniaxial tension for alloys based on aluminum V95ochT1 (very pure alloy V95 treated in mode T1) were carried out for the purpose of definition of rational modes of loading. The experiments were performed on testing machine Zwick/Roell Z100. The diameter of tested round specimens is 8 mm, working length L has value from 36 to 41 mm. Specimens were cut from the plate of thick 15 mm. The rate of the traverse displacement (one of the specimen end) has constant value during the experiment. The logarithmic strain is determined based on the traverse displacement. Since the strains obtained by measurements of the traverse displacement in the linear elastic stage have overestimated values, the strains are corrected based on measurements of the additional strain sensor in the elastic stage. The stresses are determined in view of the incompressibility. Since the cross-sectional area of the sample changes in the process of loading, the strain rate isn't constant value at a constant rate of the traverse displacement [14, 15]. For small deformations the strain rate can be assumed to be constant and equal to the rate at the initial stage of deformation with correction of the elastic component.

2.1. Elastic-plastic and creep properties of aluminum alloy V95ochT1 in tension at room temperature and the temperature of aging

The curves in figure 2 are diagrams 'stress σ - logarithmic strain ε' of uniaxial tension up to fracture at room temperature $T = 19$ºC (curves 1-4) and at aging temperature $T = 165$ºC (curves 5-6) with different strain rates. The strain rate at the initial stage of deformation, conditions of deformation and the fracture time t^* of specimens corresponding to the curves in figure 2 are given in table 1. The uniaxial tension 'σ-ε' diagrams at room temperature $T = 19$ºC after pre-deformation of 3% at $T = 165$ºC (curve 2) and after preheating for 18 h without any deformation at $T = 165$ºC (curve 4) are given for comparison. The preheating time at temperature $T = 165$ºC for curves 5 and 6 is 1.5 h.

Table 1. Modes of deformation corresponding to the curves in figure 2.

	$\dot{\varepsilon}$ (1/s)	T (°C)	Pretreatment at $T = 165$°C	t^* (h)
1	0.0004	19	—	0.11
2	0.0004	19	Pre-deformation of 3% during 0.4 h	0.09
3	0.000004	19	—	6.4
4	0.0004	19	Preheating 18 h without load	0.106
5	0.0004	165	Preheating 1.5 h without load	0.2
6	0.04	165	Preheating 1.5 h without load	0.003

Based on the results (curves 1-4), it is noted that after the full no-load aging (curve 4) the elastoplastic characteristics are reduced in the alloy in the cold state. The resulting elastic limit for the

curve 6 is $\sigma_e = 446$ MPa. 'The resource plasticity' in the slow deforming at creep mode with strain rate $\dot{\varepsilon} = 0.0004$ 1/s at $T = 165$ºC (curve 5 corresponding to elastic-creep deformations with stress not exceeding the elastic limit) is significantly higher than when cold forming (curve 4) and when quick elastic-plastic deformation (curve 6) at $T = 165$ºC.
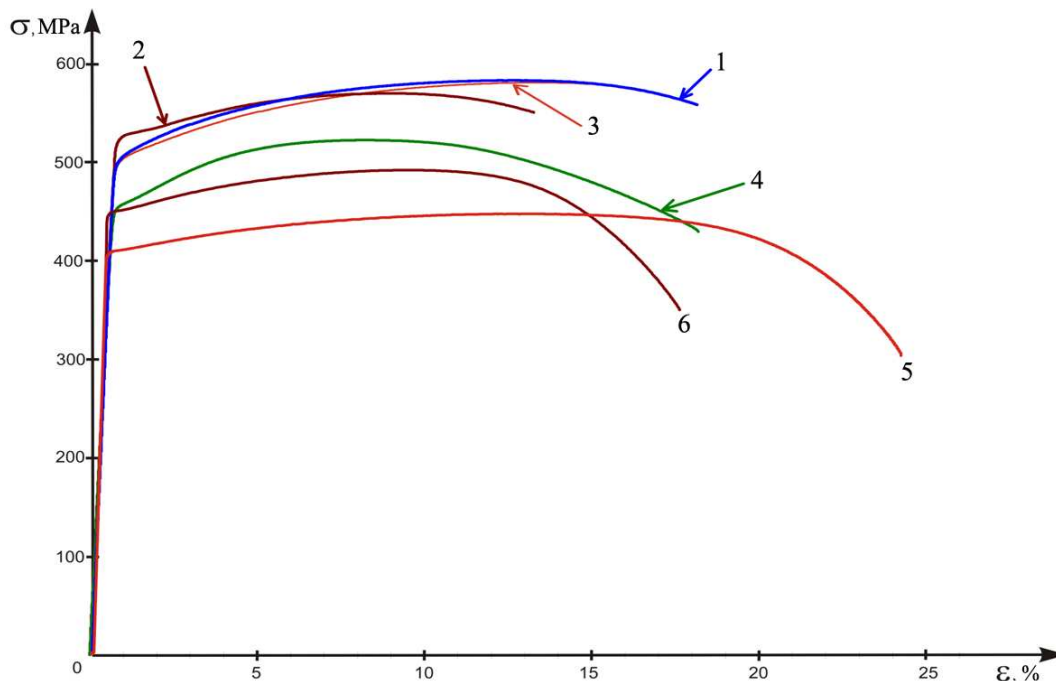

Figure 2. The diagrams 'σ-ε' of uniaxial tension at the room and at the aging temperatures.

2.2. Rational modes at creep of aluminum alloy V95ochT1 at the aging temperature
Curves 1-8 in figure 3 are experimental results in uniaxial tension with constant rate of the traverse displacement on machine Zwick/Roell Z100 for aluminum alloy V95ochT1 in creep modes with a short and long period of preheating at a temperature of aging $T = 165$ºC. The rate, conditions of deformation and the fracture time t^* are indicated in the table 2. The heating time at the temperature $T = 165$ºC before loading for curves 1, 3, 5, 6, 8 is 1.5 h. The long preheating time without loading for curve 2 is 10 h and for curve 4 is 20 h.

Table 2. Modes of deformation corresponding to the curves in figure 3.

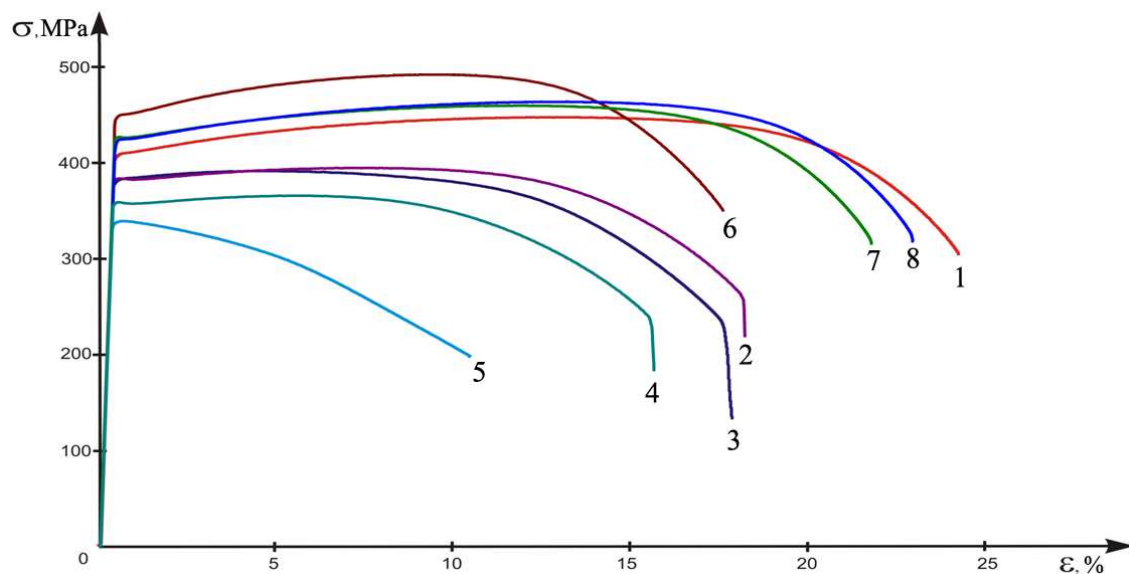|	$\dot{\varepsilon}$ (1/s)	Preheating time (h)	t^* (h)
1	0.0004	1.5	0.2
2	0.0004	10.0	0.15
3	0.00004	1.5	1.49
4	0.0004	20.0	0.14
5	0.000004	1.5	9.1
6	0.04	1.5	0.003
7	0.002	2.5	0.04
8	0.002	1.5	0.04

Figure 3. The diagrams 'σ-ε' of uniaxial tension in creep modes with a short and long period of preheating at the aging temperature $T = 165$ºC.

From the presented results (curves 1, 3, 5, 6, 8), it follows that there is a range of strain rates (close to superplasticity, curve 1), when the value of deformation at fracture is the maximum. A comparative analysis of diagrams 1, 2 and 4 shows that increasing the preheating period and succeeding deformation at the strain rate $\dot{\varepsilon} = 0.0004$ 1/s also leads to lower value of deformation at fracture. Increased preheat period from 1.5 to 2.5 h without loading (the curves 8 and 7) does not lead to significant strain values reduction at which the specimen collapses.

3. Conclusion

From the analysis of experimental diagrams obtained at the room and at the aging temperature 165ºC, it follows that a rational modes of deformation of the V95ochT1 alloy are the creep modes at the aging temperature 165ºC with stresses that do not exceed the limit elasticity $\sigma_e = 446$ MPa at a rate of the order from 10^{-3} to 10^{-4} s^{-1}, which close to the superplasticity rate. Increasing or decreasing the rate of deformation leads to a decrease in the strain value at which the material is destroyed and to a reduction the residual service life.

The elastoplastic characteristics are reduced in the alloy in the cold state after the full aging at 165ºC without load. The increase of the preheating period at the temperature of 165ºC also leads to a decrease in the strain value at fracture. Thus the rational mode of deformation from the point of view of preservation of the residual service life is the mode of loading at creep with a rate of the order from 10^{-3} to 10^{-4} s^{-1} immediately after the workpiece preheating period from 1.5 to 2.5 h.

Acknowledgments

References

[1]   Padmanabhan K A, Vasin R A and Enikeev F U 2001 *Superplastic Flow: Phenomenology and Mechanics* (Berlin Heidelberg: Springer-Verlag) p 363
[2]   Watanabe H and Fukusumi M 2014 *Journal of Materials Engineering and Performance* **23** 3551–7

[3]   Gorev B V, Zakharova T E and Klopotov I D 2002 *Physical Mesomechanics* **5**(2) 17–22

[4]   Enikeev F U 2008 *Russian Journal of Non-Ferrous Metals* **49**(1) 34–41

[5]   Zolochevsky A A, Sklepus A N and Sklepus S N 2001 *Nonlinear Solid Mechanics* (Kharkov: Business Investor Group) p 720

[6]   Banshchikova I A, Gorev B V and Tsvelodub I Yu 2007 *J. Appl. Mech. Tech. Phys.* **48** 751–54

[7]   Banshchikova I A, Gorev B V and Sukhorukov I V 2002 *J. Appl. Mech. Tech. Phys.* **43** 448–56

[8]   Banshchikova I A, Muraveva A E and Tsvelodub I Yu 2014 *Obrabotka Metallov — Metal Working and Material Science* (in Russian) **4**(65) 68–77

[9]   Banshchikova I A and Tsvelodub I Yu 1996 *J. Appl. Mech. Tech. Phys.* **37** 876–83

[10]   Gorev B V and Banshchikova I A 2008 *Vestn. Samar. Gos. Tekhn. Univ. Ser. Fiz.-Mat. Nauki* (in Russian) **2**(17) 110–7

[11]   Klopotov I D, Ljubashevskaja I V, Raevskaja G A, Rublevskij L L and Sosnin O V 2002 Shaping apparatues *Patent RU 2251464*

[12]   Pekarsh A I, Sarykov S E, Krupskij R F, Fizulakov R A, Stankevich A V, Olejnikov A I, Bojko V M and Krivenok A A 2001 Method of forming *Patent RU 2475322*

[13]   Senatorova O G, Tkachenko E A, Sidelnikov V V, Antipov V V, Blinova N E, Shestov V V, Krasova E V and Girsh R I 2008 Procedure for production of item out of high-strength aluminium alloy *Patent RU 2396367*

[14]   Panamaryov V A, Peretyat'ko V N, Gorev B V, Remorov V E and Bazaykin V I 2012 *Izvestiya Visshikh Uchebnykh Zavedenii. Chernaya Metallurgiya – Izvestiya. Ferrous Metallurgy* (in Russian) **55**(4) 24–6

[15]   Panamarev V A, Karpov E V, Larichkin A Yu and Zhuravleva M I 2013 *Modern Science: Actual Problems of Theory and Practice. Series Natural and Technical Sciences* (in Russian) **5-6** 52–4