JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
43, 2, pp. 241-256, Warsaw 2005

CREEP ANALYSIS OF M1E COPPER AND PA6 ALUMINIUM ALLOY SUBJECTED TO PRIOR PLASTIC DEFORMATION[1]

Zbigniew L. Kowalewski

Institute of Fundamental Technological Research, Department for Strength of Materials, Warsaw
e-mail: zkowalew@ippt.gov.pl

The influence of prior plastic deformation on the creep process is studied for copper and an aluminium alloy. Variations of basic creep parameters due to differences in temperature of realized tests are also taken into account. Moreover, the paper reports the prestraining effects depending on the type of prior deformation. It is shown for both materials that, depending on the deformation history, the basic creep parameters may attain values which are more beneficial from the engineering point of view than those for the non-prestrained material determined. It is also shown that, in some cases, prior plastic deformation may lead to detrimental effects expressed, for example, by reduction of the lifetime.

Key words: creep, rupture, deformation history

1. Introduction

Since manufacturing and exploitation processes of most engineering structures or some their elements subjects them to deformation, it is important to know the influence of this deformation on such different material properties at high temperatures as minimum creep rate, ductility, lifetime, rupture and crack propagation. It has been found that plastic deformation prior to creep testing at both room and elevated temperatures has either beneficial or detrimental effects on the material properties (see References). Although the problem was previously studied experimentally for several materials, only limited amount of available data reflects the influence of plastic predeformation on the creep process up to rupture (Dyson and Rodgers, 1974; Dyson *et al.*,

---

[1] Paper presented at II Symposium on Failure Mechanics of Materials and Structures, Augustów, 4-7 June 2003.

1976; Kowalewski, 1995, 1996, 2003; Kowalewski *et al.*, 2003; Marlin *et al.*, 1980; Pandey *et al.*, 1984; Trąmpczyński, 1982). It is well known that the problem is particularly important during fabrication or assembly processes, where a number of materials used in critical elements of engineering structures may receive such cold work, which, as a consequence, may change significantly their lifetime. Up to now, the amount of experimental data is still insufficient to estimate exactly whether the increase or decrease of creep strengthening occurs up to a certain amount of prior deformation only, or whether this creep property is in some way proportional to the amount of predeformation. Thus, in order to achieve better understanding of this problem, further systematic investigations are required.

The main goal of this paper is to identify the influence of prior plastic deformation of pure copper and an aluminium alloy on the basic creep parameters under uniaxial tension.

2. Experimental procedure

Two engineering materials were subjected to creep investigations, i.e. M1E pure copper, and PA6 aluminium alloy (notation according to Polish Standards). Before creep testing, both materials were subjected to some standard tests in order to check their initial mechanical properties and microstructure.

2.1. Materials and their preliminary investigations

In order to find an appropriate stress level for creep tests, standard tension tests were carried out for both materials at three different temperatures, i.e. room temperature and elevated temperatures corresponding to those in the creep tests applied. In the case of aluminium alloy, they were 423 K and 473 K, whereas for copper – 523 K and 573 K, respectively. The material characteristics from these tests are presented in Fig. 1 for copper, and in Fig. 2 for aluminium alloy. The basic mechanical parameters determined from the standard tension tests for copper and aluminium alloy are listed in Tables 1 and 2, respectively. On the basis of data from tensile tests, stress levels for creep investigations of both materials were selected. All of them were lower than the appropriate conventional yield points. Hence, copper was subjected to creep at 70 MPa in 523 K and at 45 MPa in 573 K. Creep tests of the PA6 aluminium alloy were conducted at 300 MPa in 423 K and at 200 MPa in 473 K.

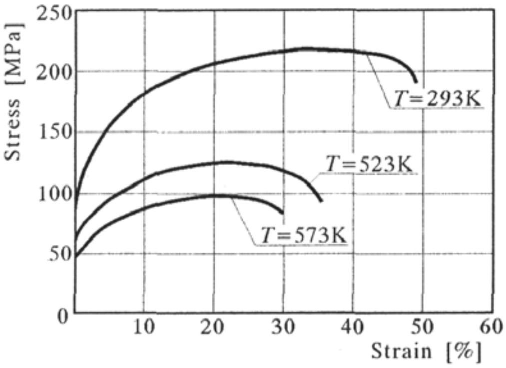

Fig. 1. Comparison of copper tensile characteristics at three different temperatures

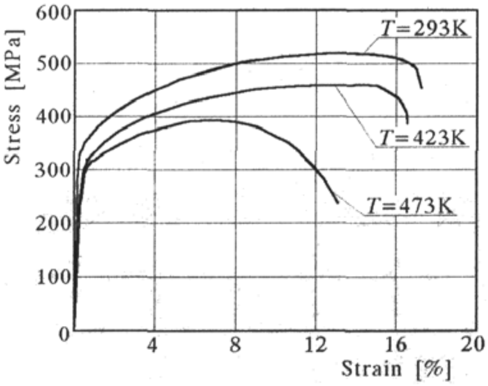

Fig. 2. Comparison of PA6 aluminium alloy tensile characteristics at three different temperatures

Table 1. Parameters of tensile tests for copper

Temperature	$T = 293\,\mathrm{K}$	$T = 523\,\mathrm{K}$	$T = 573\,\mathrm{K}$
Young's modulus E [MPa]	107000	92000	88000
Conventional yield limit $R_{0.2}$ [MPa]	107	76	50
Ultimate strength R_m [MPa]	220	120	98

Table 2. Parameters of tensile tests for the aluminium alloy

Temperature	$T = 293\,\mathrm{K}$	$T = 423\,\mathrm{K}$	$T = 473\,\mathrm{K}$
Young's modulus E [MPa]	71589	69452	68500
Conventional yield limit $R_{0.2}$ [MPa]	350	324	316
Ultimate strength R_m [MPa]	516.5	454	389

The initial microstructures of both materials are shown in Fig. 3 for copper, and in Fig. 4 – for aluminium alloy. Their chemical compositions were also assessed, and the results are presented in Tables 3 and 4.

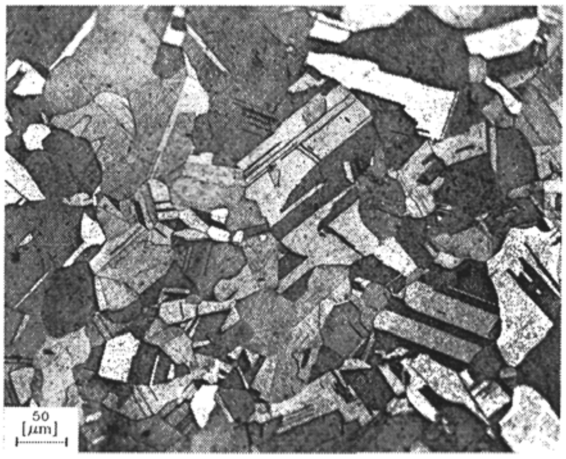

Fig. 3. Microscopic structure of M1E copper (magnification 200×)

Table 3. Chemical composition of M1E

Notation	Cu	Others
M1E	99.9	Rest

Table 4. Chemical composition of PA6

Notation		Si	Fe	Cu	Mn	Mg
EN AW-2017A	PA6	0.42	0.21	4.5	0.82	0.73
Notation		Ni	Zn	Ti	Aluminium	
EN AW-2017A	PA6	< 0.02	< 0.05	< 0.05	Rest	

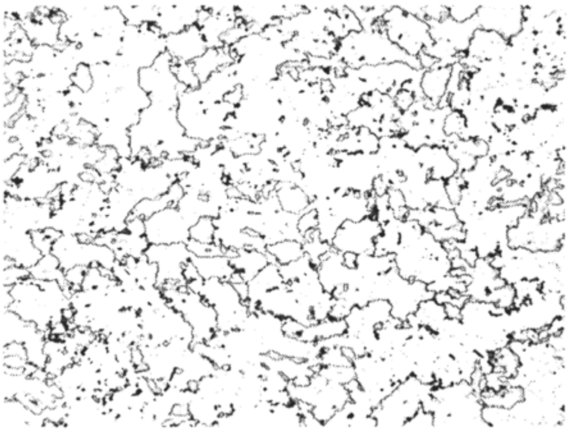

Fig. 4. Microscopic structure of PA6 aluminium alloy (magnification 100×)

2.2. Details of creep investigations

Thin-walled tubular specimens were used in all creep tests. As mentioned above, for both materials the experimental programme comprised creep tests under uniaxial tension carried out at two different temperatures (523 K and 573 K in the case of pure copper, 423 K and 473 K for aluminium alloy). Creep tests were performed using a computer controlled creep testing machine for materials in an as-received state and for the same materials plastically prestrained at the room temperature. In the case of copper, the prestrain values of 2.5%, 5.0%, 7.5% and 10.0% were selected in tests at 523 K, whereas tests at 573 K were carried out for testpieces prestrained up to 5.0% and 10.0%. The aluminium alloy specimens were prestrained up to 1.0%, 2.0%, 6.0% and 8.0% for both creep test temperatures taken into account.

Investigations of the effect of plastic predeformation on the subsequent creep process were carried out according to the following procedure. First of all, each thin-walled tubular specimen was proportionally deformed up to a selected value of plastic prestrain by uniaxial tension at the room temperature using an Instron testing machine, and then unloaded. Subsequently, each specimen was mounted at the standard creep testing machine, heated uniformly at a chosen test temperature for 24 h prior to creep testing, and then subjected to a constant stress level depending on the creep testing temperature. Both creep stress levels selected for the tested materials were below the yield point of each material at the considered temperatures. A diagram of the experimental procedure is schematically presented in Fig. 5.

In the case of aluminium alloy, the tensile creep tests were also carried out for specimens prestrained due to pure torsion. The amounts of prior plastic

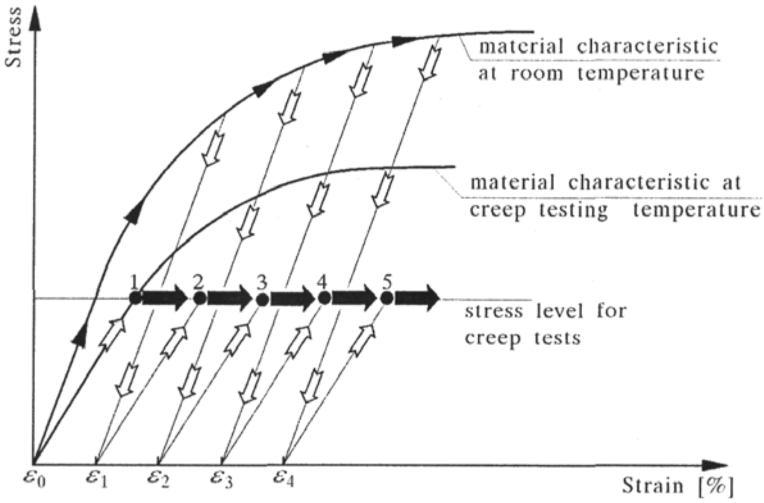

Fig. 5. Scheme of the experimental programme (copper tested under 70 MPa at 523 K – $\varepsilon_0 = 0\%$, $\varepsilon_1 = 2.5\%$, $\varepsilon_2 = 5.0\%$, $\varepsilon_3 = 7.5\%$, $\varepsilon_4 = 10.0\%$; copper tested under 45 MPa at 573 K – $\varepsilon_0 = 0\%$, $\varepsilon_2 = 5.0\%$, $\varepsilon_4 = 10.0\%$; aluminium alloy tested under 300 MPa at 423 K, and under 200 MPa at 473 K – $\varepsilon_0 = 0\%$, $\varepsilon_1 = 1.0\%$, $\varepsilon_2 = 2.0\%$, $\varepsilon_3 = 6.0\%$, $\varepsilon_4 = 8.0\%$)

deformation induced by pure torsion were the same as those at uniaxial tension achieved, i.e. the equivalent plastic prestrain defined as

$$\varepsilon^{(p)} = \sqrt{\varepsilon_a^2 + \frac{4}{3}\varepsilon_s^2} \tag{2.1}$$

where ε_a, ε_s are the axial and shear strains, respectively, was equal to 1%, 2%, 6% and 8%. Such a selection enabled evaluation of the influence of plastic prestrain orientation on basic creep parameters.

3. Experimental results

3.1. Study of the prestraining effects depending on the temperature

The experimental results for copper and aluminium alloy prestrained during tensile tests at room temperature are presented in Fig. 6 and Fig. 7, respectively. As it is clearly seen, the creep process under a constant stress is generally affected by prior plastic strain at the room temperature. The identification of this problem will be given on the basis of variation of creep parameters expressed in a dimensionless form. The creep parameters determined from creep tests of non-prestrained materials will be selected as the reference values, Table 5 and Table 6.

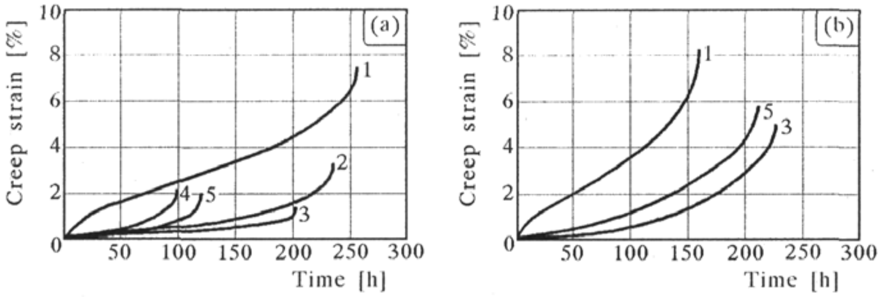

Fig. 6. Creep curves of copper at: (a) $\sigma = 70\,\mathrm{MPa}$, $T = 523\,\mathrm{K}$; (b) $\sigma = 45\,\mathrm{MPa}$, $T = 573\,\mathrm{K}$; 1 – material in the as-received state; 2, 3, 4, 5 – material prestrained up to 2.5%, 5.0%, 7.5%, 10.0%, respectively

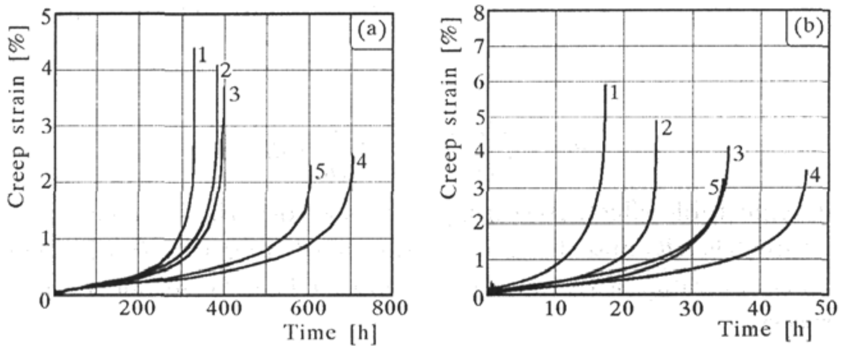

Fig. 7. Creep curves of the PA6 aluminium alloy at: (a) $\sigma = 300\,\mathrm{MPa}$, $T = 423\,\mathrm{K}$; (b) $\sigma = 200\,\mathrm{MPa}$, $T = 473\,\mathrm{K}$; 1 – material in the as-received state; 2, 3, 4, 5 – material prestrained up to 1.0%, 2.0%, 6.0%, 8.0%, respectively

Table 5. Creep parameters determined from tensile creep tests on copper prestrained due to uniaxial tension

	$\sigma = 70\,\mathrm{MPa}$, $T = 523\,\mathrm{K}$					$\sigma = 45\,\mathrm{MPa}$, $T = 573\,\mathrm{K}$		
ε [%]	0	2.5	5.0	7.5	10.0	0	5	10
$\dot{\varepsilon} \cdot 10^{-5}$ [1/h]	18.4	4.8	3.0	6.5	3.0	28.0	3.0	6.2
t_I [h]	45	5	2	3	3	25	2	2
t_{II} [h]	170	100	90	25	15	75	45	35
t_R [h]	254	234	200	97	121	160	227	212

Table 6. Creep parameters determined from tensile creep tests on the PA6 aluminium alloy prestrained due to uniaxial tension

	$\sigma = 300\,\text{MPa},\ T = 423\,\text{K}$					$\sigma = 200\,\text{MPa},\ T = 473\,\text{K}$				
ε [%]	0	1.0	2.0	6.0	8.0	0	1.0	2.0	6.0	8.0
$\dot{\varepsilon} \cdot 10^{-5}$ [1/h]	1.4	1.3	1.2	0.7	0.9	5.5	3.0	2.3	1.8	2.9
t_I [h]	70	60	50	50	40	1	2	2	4	3
t_{II} [h]	160	180	200	260	250	6	9	12.5	17	12
t_R [h]	330	384	399	705	601	17.3	24.8	35.3	46.6	34.6

Notation in Tables: ε – prior plastic deformation, $\dot{\varepsilon}$ – minimum creep rate at uniaxial tension, t_I – duration of primary creep, t_{II} – time to third creep period, t_R – time to rupture.

Cold work preceding the creep, either for copper or aluminium alloy, induced a hardening effect expressed by significant decrease of the minimum creep rate, Fig. 8. A similar effect was earlier observed by Trąmpczyński (1982, 1985), Waniewski (1984), and Kowalewski (1991a,b) who also tested copper, but at different conditions than those applied here. Taking into account the recovery creep theory based on Orowan's equation in the following form

$$d\sigma = \left(\frac{\partial\sigma}{\partial\varepsilon}\right) d\varepsilon + \left(\frac{\partial\sigma}{\partial t}\right) dt \tag{3.1}$$

this is an expectable effect. According to this theory, the balance between the recovery rate $(\partial\sigma/\partial t)$ and the rate of strain hardening $(\partial\sigma/\partial\varepsilon)$ is responsible for the constant value of the strain rate observed in the second period of the creep process.

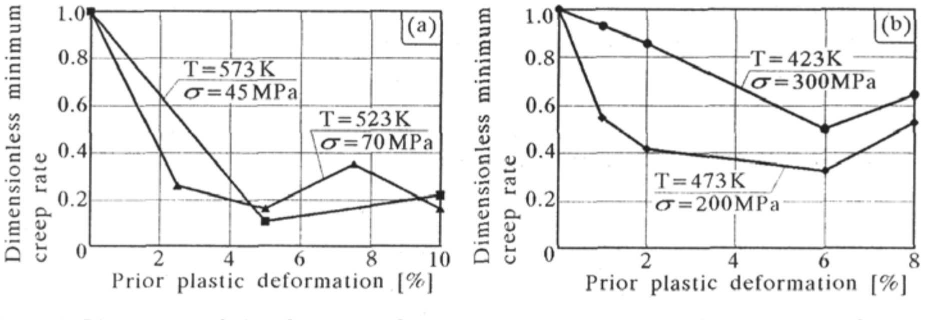

Fig. 8. Variation of the dimensionless minimum creep rate due to prior plastic deformation for: (a) copper, (b) PA6 aluminium alloy. (Minimum creep rates achieved during creep of nonprestrained materials are used as the reference values)

Plastic predeformation of a material generates dislocations the density of which depends on the prestrain amount. A greater number of dislocations increases probability of some slide directions to be blocked during creep, and in consequence, it leads to decrease of the creep strain rate. Therefore, the plastically prestrained material should creep at a lower rate during the second period of the process than the nonprestrained one. Taking into account the results of tests carried out at 523 K for copper, Fig. 8a, it is easy to note that the strain hardening effect observed exhibits gradual increase with the plastic predeformation increase only up to the prior plastic deformation close to 5%. Over this value, the hardening effect expressed by decrease of the secondary creep rate was also remarkable, but its amount was not proportional to the magnitude of prestraining. In the tests carried out for copper at 573 K, a similar tendency can be observed. Conformation of the phenomena observed for pure copper was achieved during creep examinations of the PA6 aluminium alloy, Fig. 8b. Again, the reduction of the minimum creep rate was associated with the increase of prior plastic deformation, and moreover, such an effect exhibits a proportional character solely up to a certain limit value of prestraining. In the case of aluminium alloy, the value of this limit was slightly higher than that for copper determined. It was equal approximately to 6%. (It is stated only approximately, since this value comes from experiments carried out in this research. More exact values could be known if more tests would be carried out with the amount of prior plastic deformation close to the value of 6%.) Further increase of plastic deformation led to the increase of the minimum creep rate. On the basis of the results achieved for copper and aluminium alloy, it may be concluded that the tensile plastic prestrains decrease the secondary creep rate, but the magnitude of this decrease is not proportional to the amount of tensile plastic prestrain. Such behaviour cannot be predicted by the recovery creep theory.

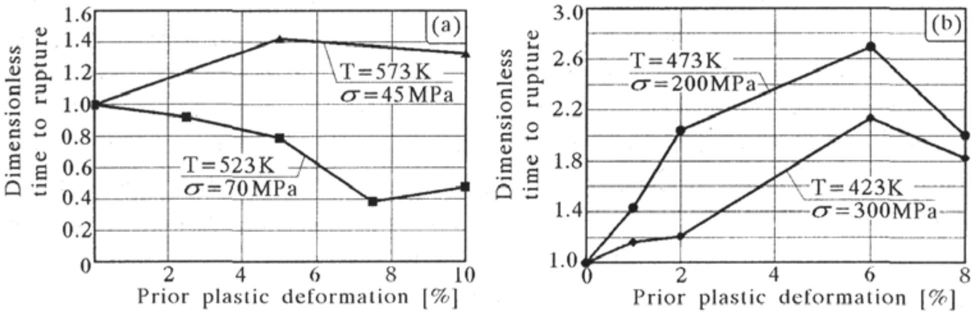

Fig. 9. Variation of the dimensionless time to rupture due to prior plastic deformation for: (a) copper, (b) PA6 aluminium alloy. (Times to rupture achieved during creep of nonprestrained materials are used as the reference values)

The results for copper tested at 523 K also show that the time to rupture, Fig. 9a, and ductility, Fig. 6, were reduced due to plastic prestraining. As it is shown, such behaviour has a character of a proportional relation up to the prior deformation equal to 5%. Further variation of these parameters connected with further increasing of the prior plastic deformation has a rather accidental character (see the creep curves 4 and 5 in Fig. 6). The decrease of time to rupture is relatively not significant for tests with the prestraining magnitude up to 5%, whereas for prior deformations greater than 5% the change of this parameter is essential, Fig. 9a.

Contrary to the creep tests of prestrained copper carried out at 523 K, the lifetimes obtained during tests at 573 K were longer than the lifetime achieved for the material in the as-received state at the same temperature equal to 573 K. One of the possible reasons for such a difference is presumably connected with the influence of grain size variation on the creep process. The process of grain size growing during creep of copper at 573 K was much more advanced than that at 523 K observed, since the higher creep testing temperature was significantly closer to the recrystallization temperature of copper. It has been found from previous creep investigations that in comparison to fine-grained copper the coarse-grained one exhibits lower values of the minimum creep rate and longer lifetimes at the same stress level (Kowalewski, 1992). Hence, it may be supposed that this is one of the key reasons for the opposite behaviour concerning time-to-rupture variation obtained in both temperatures, namely, the reduction of the creep lifetime at lower temperatures, and extension of the lifetime at higher ones.

Such type of behaviour was not observed for the aluminium alloy, Fig. 9b. In this case, the same tendency of lifetime variation was demonstrated for both temperatures under the question. For relatively small values of prior plastic deformation (up to 6%), the material exhibited lifetime extension, and moreover, the mutual relation between the lifetime and the amount of prior plastic deformation was almost proportional. For higher values of plastic prestraining, the lifetime extension can be also observed in comparison to the lifetime achieved for the nonprestrained material, however, in these cases the mutual relation between the lifetime and the amount of prior plastic deformation was not proportional. It means that for higher magnitudes of plastic prestrainning ($> 6\%$), the creep lifetime becomes smaller, and for a sufficiently high magnitude it may reach a lower value than that obtained for the material tested in the as-received state.

Prior plastic deformation also can change duration of typical creep stages of both materials tested, Fig. 10 and Fig. 11. The duration of the primary cre-

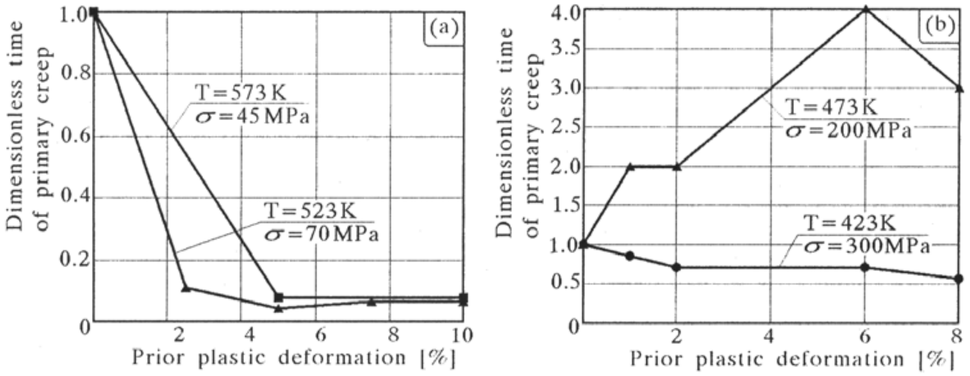

Fig. 10. Variation of the dimensionless time of primary creep due to prior plastic deformation for: (a) copper, (b) PA6 aluminium alloy. (Times of primary creep achieved during creep of nonprestrained materials are used as the reference values)

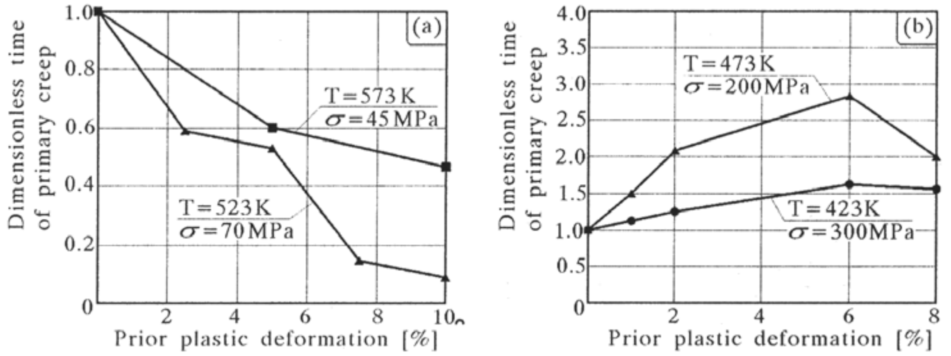

Fig. 11. Variation of the dimensionless time to tertiary creep due to prior plastic deformation for: (a) copper, (b) PA6 aluminium alloy. (Times to tertiary creep achieved during creep of nonprestrained materials are used as the reference values)

ep period for copper was reduced, in practice, independently of the amount of prior plastic deformation, Fig. 10a. For the aluminium alloy however, this parameter depends on the amount of prior plastic deformation. Depending on temperature, the time of primary creep can be extended (higher temperature) or shortened (lower creep temperature), Fig. 10b. In the case of pure copper, the sum of primary and secondary creep periods was decreased with the increase of the plastic prestrain magnitude, Fig. 11a. The opposite behaviour was observed during creep of prestrained aluminium alloy specimens, Fig. 11b.

The ductility during creep was also strongly affected by the prior plastic deformation at room temperature. For both materials, the same tendency of this parameter variation was demonstrated for all temperatures considered, i.e. essential reduction of the total creep strain at rupture.

3.2. Study of the prestraining effects depending on the type of prior deformation

As it has been already shown, deformation history may change the basic creep parameters. From a practical point of view it is also important to know whether, and up to which degree the orientation of plastic deformation plays a role in modifications of the creep parameters. In order to achieve an answer to this question, additional tensile creep tests were carried out for the PA6 aluminium subjected to prior plastic deformation realised by means of pure torsion. In comparison to tests carried out on the material prestrained due to tension, the same magnitudes of prestraining were applied. The creep curves representing these conditions are shown in Fig. 12. As it is clearly seen, also prior deformation due to pure torsion significantly changes the creep process of the aluminium alloy. Evolution of variation of the basic creep parameters expressed in a dimensionless form are demonstrated in Fig. 13. The creep parameters determined from the creep test of the non-prestrained material were selected as the reference values, Tables 6 and 7.

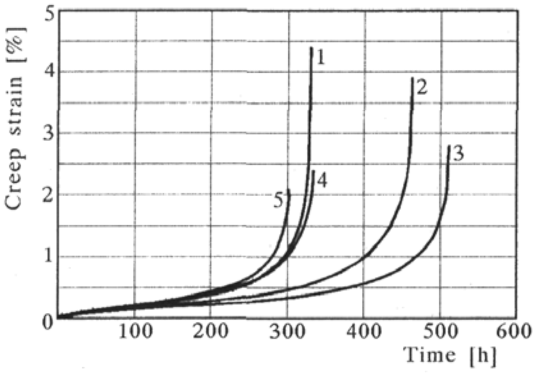

Fig. 12. Creep curves of the PA6 aluminium alloy at $\sigma = 300\,\mathrm{MPa}$, $T = 423\,\mathrm{K}$; 1 – material in the as-received state; 2, 3, 4, 5 – material prestrained due to pure torsion up to 1.0%, 2.0%, 6.0%, 8.0%, respectively

Table 7. Creep parameters determined from tensile creep tests on the PA6 aluminium alloy prestrained due to pure torsion

	$\sigma = 300\,\mathrm{MPa}$, $T = 423\,\mathrm{K}$				
ε [%]	0	1.0	2.0	6.0	8.0
$\dot{\varepsilon} \cdot 10^{-5}$ [1/h]	1.4	0.9	0.7	1.6	1.7
t_I [h]	70	90	100	40	40
t_{II} [h]	160	210	250	140	130
t_R [h]	330	463	512	334	303

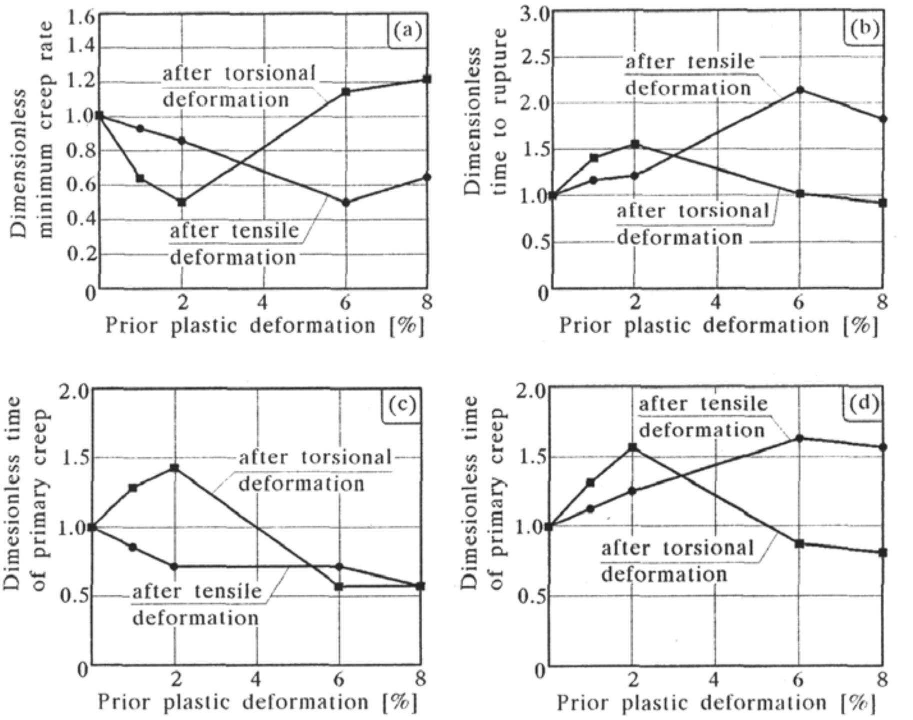

Fig. 13. Variation of creep parameters of the PA6 aluminium alloy due to prior plastic deformation: (a) dimensionless minimum creep rate, (b) dimensionless time to rupture, (c) dimensionless time of primary creep, (d) dimensionless time to tertiary creep. (Tensile creep tests were carried out for stress equal to 300 MPa and temperature – 423 K)

Observing variations of the minimum creep rate (Fig. 13a), time to rupture (Fig. 13b), time of primary creep (Fig. 13c), and time to tertiary creep (Fig. 13d) versus the magnitude of plastic predeformation it can be concluded that the values of these parameters depend on the way along which prior plastic deformation is realized. Moreover, it is easy to notice that the maximum hardening effect observed for the aluminium alloy due to prestraining by pure torsion takes place for the test with prior deformation equal to 2%. In the case of creep tests after prestraining due to uniaxial tension, such a maximum was significantly greater (6%).

4. Conclusions

- Prior plastic deformation significantly changes values of typical creep parameters. Depending of the magnitude of prestrainning, some of these parameters can be improved, other however become weaker than those for the nonprestrained material achieved.

- The tensile creep resistance measured as the value of a steady creep rate was generally enhanced by plastic prestrain, which was expressed by significant decrease of the steady creep rate. It was observed for both materials tested. The effect has a proportional character up to a certain limit value of plastic deformation only.

- In comparison to nonprestrained copper, small increase of the time to rupture with increase of plastic predeformation has been observed for prestrained specimens tested at a higher temperature (573 K). In the case of a lower temperature (523 K), the lifetime decreased significantly with the increase of plastic predeformation. The creep data for the aluminium alloy exhibit the same tendency of lifetime variation due to prestraining in both temperatures under the question, namely, extension of the lifetime proportional to the magnitude of plastic prestrain. It has to be noted, however, that tensile plastic prestrain magnitudes greater than 6% led to the opposite effect, i.e. lifetime reduction.

- The amount of creep deformation for both temperatures considered was markedly reduced by prior tensile plastic strain, yielding very low levels. Elongation of the testpieces was proportionally decreased when the magnitude of plastic prestrain was increased.

- A type of prior plastic deformation played an important role in the subsequent creep of the PA6 aluminium alloy. More beneficial creep parameters were achieved in the case of plastic prestraining realised by means of uniaxial tension.

- It has been found that good agreement between experimental data and predictions of the recovery creep theory can be achieved only for a sufficiently low level of predeformation, lower than 5% in the case of copper and lower than 6% for the aluminium alloy.

Acknowledgement

The support from the Polish State Committee for Scientific Research under grant 7T07A 00218 is gratefully acknowledged.

References

1. DYSON B.F., RODGERS M.J., 1974, Prestrain, cavitation and creep ductility, *Metal Science*, **8**, 261-266

2. DYSON B.F., LOVEDAY M.S., RODGERS M.J., 1976, Grain boundary cavitation under various states of applied stress, *Proc. R. Soc. Lond. A*, **349**, 245-259

3. KAWAI M., 1989, Creep and plasticity of austenitic stainless steel under multiaxial non-proportional loadings at elevated temperatures, *Visco-Plastic Behavior of New Materials*, PVP-vol. 184, Edit. D. Hui, and T.J. Kozik, Book No. H00576, 85-93

4. KOWALEWSKI Z.L., 1991, Creep behavior of copper under plane stress state, *International Journal of Plasticity*, **7**, 387-404

5. KOWALEWSKI Z., 1991, The influence of deformation history on creep of pure copper, *Proc. of IUTAM Symp. "Creep in Structures"*, Edit. M. Życzkowski, Springer-Verlag Berlin Heidelberg, 115-122

6. KOWALEWSKI Z.L., 1995, Effect of plastic prestrain magnitude on uniaxial tension creep of copper at elevated temperatures, *J. Theor. Appl. Mech.*, **33**, 3, 507-517

7. KOWALEWSKI Z.L., 1996, Analysis of creep process and its effect on mechanical behaviour of metals under uniaxial and complex stress (in Polish), *IFTR Reports*, **7**

8. KOWALEWSKI Z.L., 2003, Creep analysis of PA6 aluminium alloy subjected to prior deformation history, *Proc. of the II Symposium on Damage Mechanics of Materials and Structures*, Augustów (in Polish)

9. KOWALEWSKI Z.L. ET AL., 2003, KBN Report of Grant No 7 T07A 00 218, "Macro and micro effects induced by creep in aluminium alloy under complex stress states" (in Polish)

10. KOWALEWSKI Z.L., 1992, The role of grain size on creep of copper under uniaxial tension, *Archives of Metallurgy*, **37**, 66-76

11. MARLIN R.T., COSANDEY F., TIEN J.K., 1980, The effect of predeformation on the creep and stress rupture of an oxide dispersion strengthened mechanical alloy, *Metallurgical Transactions A*, **11A**, 1771-1775

12. MURAKAMI S., KAWAI M., YAMADA Y., 1990, Creep after cyclic-plasticity under multiaxial conditions for type 316 stainless steel at elevated temperature, *Journal of Engineering Materials and Technology*, **112**, 346-352

13. OHASHI Y., KAWAI M., MOMOSE T., 1986, Effects of prior plasticity on subsequent creep of type 316 stainless steel at elevated temperature, *Journal of Engineering Materials and Technology*, **108**, 68-74

14. PANDEY M.C., MUKHERJEE A.K., TAPLIN D.M.R., 1984, Prior deformation effects on creep and fracture in inconel alloy X-750, *Metallurgical Transactions A*, **15A**, 1437-1441
15. REES D.W.A., 1981, Effects of plastic prestrain on the creep of aluminium under biaxial stress, *Creep and Fracture of Engineering Materials and Structures*, Edit. B. Wilshire, D.W.J. Owen, Pineridge Press, 559-572
16. TRĄMPCZYŃSKI W.A., 1982, The influence of cold work on the creep of copper under biaxial states of stress, *Acta Metallurgica*, **30**, 1035-1041
17. TRĄMPCZYŃSKI W.A., 1985, Investigation of the influence of deformation history on creep of metals under complex stress states, *IFTR Reports*, **36**
18. WANIEWSKI M., 1984, The influence of direction and value of plastic prestrain on steady- state creep rate using the combined isotropic-kinematic hardening rule, *Engineering Transactions*, **32**, 523-535
19. WILSON R.N., 1973, The influence of 3% prestrain on the creep strength of Al-2.5%Cu-1.2%Mg alloys at 150C, *Journal of the Institute of Metals*, **101**, 188-196
20. XIA Z., ELLYIN F., 1993, An experimental study on the effect of prior plastic straining on creep behavior of 304 stainless steel, *Journal of Engineering Materials and Technology*, **115**, 200-203

Analiza pełzania miedzi M1E i stopu aluminium PA6 po wstępnej deformacji plastycznej

Streszczenie

W pracy przedstawiono badania dotyczące wpływu wstępnej deformacji plastycznej na proces pełzania miedzi i stopu aluminium. W doświadczeniach uwzględniono wpływ zmian temperatury na podstawowe parametry pełzania. Omawiane są również efekty zależne od rodzaju wstępnej deformacji. Dla obu badanych materiałów pokazano, że zależnie od historii deformacji podstawowe parametry pełzania mogą ulegać poprawie w stosunku do parametrów otrzymanych dla takich samych materiałów testowanych w stanie dostawy. Przedstawiono również warunki, przy których wspomniane parametry ulegają istotnemu pogorszeniu (np. obniżenie żywotności).

Manuscript received February 12, 2004; accepted for print November 30, 2004