# SUPERPLASTICITY OF SOME MATERIALS UNDER COMPRESSION

V. I. Kuneev, Ya. I. Rudaev,
A. G. Popov, and N. V. Zhdanov

UDC 539.374

The phenomenon of superplasticity has been studied in [1-3].

The fundamental phenomenological criteria for the presence of the superplasticity effect during tension can be formulated as the following statements [4]: 1) a uniform strain process; 2) extremely high relative elongation indices; 3) high responsiveness to the strain rate; 4) low values of the stress during strain; 5) low strain rate; 6) intensive growth of strain in definite temperature ranges.

The first attempt to formulate such criteria was in [5]. The formulation mentioned includes statements 2) and 6) and also the requirement of no local strain zones in the specimens. The absence of necks does not absolutely accompany the superplasticity effect [6]. Its origin can be explained by the appearance of a temperature gradient after the accumulation of sufficiently high strains.

The overwhelming majority of results has been obtained in a study of the effect of superplasticity on low-strength materials. A relatively small quantity of papers [7-9] has been devoted to the detection and study of superplasticity in steels. Until recently, physicists and metallographers investigated the behavior of materials under superplasticity conditions.

An attempt to apply the methods of the mechanics of continuous media to a theoretical description of the macroscopic behavior of materials during superplastic deformation was made in [2].

There is another attempt in [10], where the condition for the existence of a uniform tension strain during superplasticity is formulated analytically. Spoilage of the condition mentioned results in formation of a neck. The idea is expressed here of the need to study the superplasticity effect not only under tension, but also for other stress-state schemes (pure shear, biaxial tension, uniaxial compression).

Because the macroscopic nature of the behavior of materials under superplasticity conditions is known, the prospect for practical utilization of this phenomenon has appeared. It is considered that almost all metal materials are considered as potentially superplastic.

For a sufficient quantity of information about the mentioned phenomena under tension, the application of the superplasticity effect under compression is as yet potential in character. This is apparently associated both with the complexity of realizing uniaxial compression under superplasticity conditions and with the inadequate volume of information on the appearance of the superplasticity properties under compression.

Ordinary mechanical compression tests preceded tests on the steels U8A, 5KhNM, and 12KhNZA in the phase-transition temperature range. Specimens whose size and shape are shown in Fig. 1a were used in these tests.

A diagram of the dependence of the compressive force P on shortening of the specimen $\Delta h$ was recorded by using electronic apparatus developed on the basis of the MKe strain gauge.

Average $\sigma \sim \varepsilon$ ($\sigma = P/F$) diagrams, where F is the initial area of the specimen cross section, and $\varepsilon = \Delta h/h$, were constructed for each steel according to the test data. The diagrams are represented in Fig. 1b, where curve 1 corresponds to 5KhNM steel; 2, to U8A; and 3, to 12KhNZA. The magnitude of the stress at the intersection of two lines approximating the elastic section OA and the rectilinear segment of the diagram CK outside the elastic limit was taken as the yield point $\sigma_s$. The yield points $\sigma_s$ determined by the method mentioned and the Young's modulus E of the steels are given in Table 1.

---

Frunze. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 140-143, May-June, 1976. Original article submitted May 14, 1975.

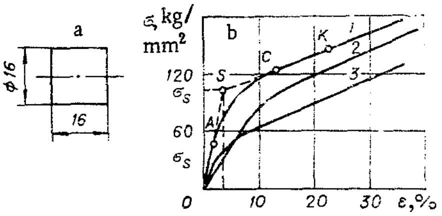

Fig. 1

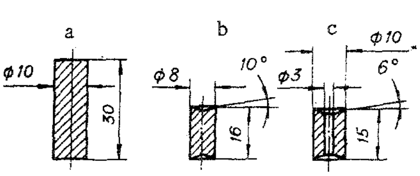

Fig. 2

TABLE 1

| Brand of steel | $\sigma_S$, kg/mm² | E, kg/mm² |
|---|---|---|
| U8A | 82 | $3.5 \cdot 10^3$ |
| 5KhNM | 119 | $2.9 \cdot 10^3$ |
| 12KhNZA | 34 | $2.8 \cdot 10^3$ |

TABLE 2

| Specimen No. | Load on the specimen in fractions of $P_S$ |
|---|---|
| 1 | 0.4 |
| 2 | 0.3 |
| 3 | 0.2 |
| 4 | 0.09 |
| 5 | 0.08 |
| 6 | 0.07 |
| 7 | 0.06 |
| 8 | 0.05 |

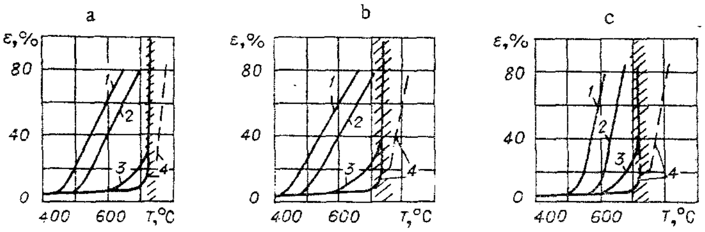

Fig. 3

To study changes in the shape and microstructure of the specimens during deformation, the specimens were subjected to a different degree of pressing from $\varepsilon = 5\%$ to $\varepsilon = 40\text{-}50\%$.

The specimens took the shape of a barrel because of friction between the slabs of the TsD-40 press and the specimen end faces.

Let us examine the singularity of uniaxial compression at elevated temperatures. To study the superplasticity of steels under compression, ZST-2/3 creep machines were equipped with special reverse clips which convert the tensile force into compressive force. Deformation of the specimens occurred in the reverse clips with a negligible temperature gradient (±2°C).

Specimens of different size and shape, shown in Fig. 2, were tested at elevated temperatures. Forces whose values are taken from Table 2, where $P_S = \sigma_S F$, were applied to the specimens according to the condition of the first program. The specimens were heated after having been loaded. Compression of the specimens ceased when they achieved a relative elongation of $\varepsilon = 65\text{-}70\%$.

If the specimen hence fell into the phase-transformation domain, then its temperature would change cyclically with overlapping of the domain boundaries. Constancy of the compressive stresses in this case was assured by additional loading of the specimens at the lower boundary of each cycle, starting with the second.

The results of executing the first program of experiments are shown in Fig. 3a-c, where curves of the dependence of the shortening ε on the temperature T are given, respectively, for the steels U8A, 5KhNM, and 12KhNZA for different values of the stress σ [curve 1 corresponds to $\sigma = 0.4\sigma_S$; 2) $\sigma = 0.3\sigma_S$; 3) $\sigma = 0.09\sigma_S$; 4) $\sigma = 0.07\text{-}0.08\sigma_S$].

Specimens from the materials listed were subjected to compression ($\sigma = 0.07\sigma_S$) with a cyclic temperature change beyond the upper boundary of the phase transformations in a number of tests.

The specimens received the strains $\varepsilon_1 = 15\%$, $\varepsilon_2 = 30\%$, $\varepsilon_3 = 45\%$, $\varepsilon_4 = 60\%$, $\varepsilon_5 = 75\%$ for the stresses $\sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 = \sigma_S = 0.08\sigma_S$ in the phase-transition temperature range in the second program of experiments. The structures of the specimens were investigated after deformation on an MIM-9 microscope.

As the experiments performed showed, the growth of plastic strains ceased at the second cycle because of an increase in the cross-sectional area of the specimens. In the interest of assuring the shortening $\varepsilon$, an additional load $\Delta P$ was applied to the specimens at the lower limit of the cycles, starting with the second. The value of $\Delta P$ was computed from the condition of constant stress.

Therefore, the compressive stress referred to the initial specimen cross-sectional area increased from 0.07 to $0.15\sigma_S$ during the test; however, the true stresses remained constant and equal to $0.07-0.08\sigma_S$. If the accumulation of anomalous strains during tension is compared with an analogous process during compression, it can then be noted that a cyclic change in temperature within the phase-transition limits contributes to a continuous growth of strains in the stretched specimens from cycle to cycle in contrast to the compression.

The appearance of maximum strains under the effect of stresses called optimal [11], was noted in specimens subjected to tension.

By analogy, we call the magnitudes of the least stresses which cause specimen strain at a rate of 0.5 mm/min optimal under compression. The range of optimal compression stresses is shown by the hatched portion of Fig. 3a-c. The range has the boundaries $0.07\sigma_S \leq \sigma_0 \leq 0.08\sigma_S$ ($\sigma_0$ is the optimal stress), while the optimal stresses under tension were within the limits $0.05\sigma_S \leq \sigma_0 \leq 0.07\sigma_S$.

Therefore, superplasticity of compressed specimens is observed under the effect of higher stresses than under tension. A diminution in the strain rate of the specimens as compared with the strain rate in the phase-transition domain was detected in special tests outside the upper limits of phase transformations.

The circumstance mentioned is shown by the dashed line in Fig. 3a-c.

Accumulation of anomalous strains is accompanied by changes in specimen shape and structure. The specimens took on the shape of a double barrel, which then went over into a single barrel, with the increase in the strain to $\varepsilon = 15-20\%$.

The microstructure grains of the material, which diminished negligibly in size, were oriented along the specimen axis with the growth in the anomalous deformations. Let us note that the structure grains were arranged along the barrels being formed in ordinary tests.

## LITERATURE CITED

1. A. A. Bochvar and Z. A. Sviderskaya, "Superplasticity of some steels during compression," Izv. Akad. Nauk SSSR, Otd. Tekh. Nauk, No. 9, 241 (1945).
2. A. R. Ragab and G. L. Duncan, "Superplasticity; governing equations and molding problems," in: Mekhanika [Periodic Collection of Translations of Foreign Articles] (1969).
3. O. E. Pearson, J. Metals, No. 54 (1974).
4. V. I. Kuneev, Ya. I. Rudaev, and A. G. Popov, "On supercreep of steels during phase transformations," Tr. FPI. Rasch. Prochn., No. 65 (1974).
5. G. V. Starikov, "Investigation of the superplasticity phenomenon in metal alloys," Abstract of Candidate's Dissertation, Institute of Metallurgy and Additives, Academy of Science of the Kazakh SSR, Alma-Ata (1963).
6. V. I. Kuneev, Ya. I. Rudaev, and A. G. Popov, Anomalous Creep of Some Steels at Elevated Temperatures [in Russian], Izd. Akad. Nauk KirgSSR (1974).
7. A. S. Tikhonov, Elements of the Physicochemical Theory of Deformability of Alloys [in Russian], Nauka (1973).
8. Ya. M. Okhrimenko, O. M. Smirnov, and L. V. Surmach, "On the possibility of a quantitative estimate of the superplasticity state," Fiz. Khim. Obrab. Mater., No. 6 (1971).
9. Ya. M. Okhrimenko and O. M. Smirnov, "Method of joint investigation of deformation and phase-transformation processes of steel and alloys," Fiz. Khim. Obrab. Mater., No. 3 (1967).
10. M. Kh. Shorshorov, A. S. Tikhonov, et al., Superplasticity of Metallic Materials [in Russian], Nauka, Moscow (1973).
11. V. I. Kuneev, Ya. I. Rudaev, and A. G. Popov, Investigation of Superplasticity of U8A, 5KhNM, 12KhNZA Steels under Tension in the $\alpha \rightleftharpoons \gamma$ Transition Temperature Range [in Russian]. Report on Kh/Theme 52/72, VINITI, Frunze (1974).