Journal of Solid State Chemistry **154,** 191–193 (2000)
doi:10.1006/jssc.2000.8834, available online at http://www.idealibrary.com on IDEAL®

Strength and Creep in Boron Carbide (B_4C) and Aluminum Dodecaboride (α-AlB_{12})

T. G. Abzianidze, A. M. Eristavi, and S. O. Shalamberidze[1]

The Institute of Stable Isotopes 21, Kavtaradze str., Tbilisi, 380086, Georgia

Received September 9, 1999; in revised form February 10, 2000; accepted February 15, 2000

Some thermomechanical properties of boron carbide and aluminum dodecaboride are presented. The dependence of the bending strength on the temperature of B_4C and AlB_{12} in the ductile rupture region was studied. It was detected that the ductile rupture of B_4C starts at temperatures above 1500°C while that of AlB_{12} begins at 1400°C. Total deformation, however, did not exceed 2% even at 1800°C. The investigation of the creep of B_4C and AlB_{12} showed that the rate $d\varepsilon/dt$ of steady creep depends on the applied stress and the temperature: $d\varepsilon/dt = A\sigma^n \exp(-E/RT)$. Besides, creep in boron carbide at stress values lower than 90 MPa occurred by the vacancy-diffusive mechanism, for which $n = 1$. At stress values over 90 MPa, $n = 3$ and the creep mechanism changes to dislocation creep. A similar phenomenon is observed in the case of aluminum dodecaboride; however, the replacement of the vacancy-diffusive mechanism by dislocation creep takes place at stress values of 80 MPa. © 2000 Academic Press

Key Words: **boron carbide; aluminum dodecaboride; mechanical properties; bending strength; creep rate.**

INTRODUCTION

Refractory boron-rich compounds of boron carbide and aluminum dodecaboride are widely used at high temperatures (1000–2000°C) in various advanced technical fields (1) and the investigation of the thermomechanical properties of these materials at high temperatures ($T > 0.5T_{\mathrm{melt}}$) is of interest.

This paper contains the results of the investigation of strength and creep in boron carbide and aluminum dodecaboride at temperatures above 1000°C. To our knowledge, this is the first investigation of this kind.

EXPERIMENTAL

Strength tests were carried out by a three-point bending technique with a deformation rate of 0.2 mm/min. The size of the samples was $2 \times 2 \times 20$ mm.

Creep was studied on prismatic samples ($3 \times 3 \times 12$ mm) under compression and the 1246P-2/2500 (USSR) device was used in the experiments. The temperature was measured and controlled with an optical pyrometer and tungsten–rhenium thermocouples. Deformation was measured with the cathetometer. A detailed description of the experimental technique is reported in (2, 3).

The samples of boron carbide (B_4C) and aluminum dodecaboride (α-AlB_{12}) were produced by hot pressing (4, 5) and their characteristics are reported in Table 1.

RESULTS AND DISCUSSION

Figure 1 presents the temperature dependence of bending strength in boron carbide and aluminum dodecaboride samples. The behavior with three regions has a "classical" shape specific to ceramic materials. At temperatures below 1000°C, the temperature increase does not lead to a considerable change of the fracture strength. In this region the fracture is brittle, owing to expansion of pre-existing defects (cracks, pores). Above 1000°C, with the development of microductility the strength increases and reaches a maximum at the temperature of brittle–ductile transition as a result of thermally activated relaxation of the local peak stresses near the structural defects. Further temperature increase causes progression of macroductility and a monotonic decrease of yield stress and strength (6, 7).

The results of creep in boron carbide and aluminum dodecaboride are respectively presented in Figs. 2 and 3. The boron carbide creep is characterized by a short (10 minutes) transitional creep and low values (up to 0.3%) of instantaneous deformation.

The aluminum dodecaboride creep also has a short (30 minutes) transitional creep and a prolonged steady-state section. The samples were tested up to 7% of deformation, since deviations from linearity in the steady-state creep region were observed owing to an increase in the sample cross section. The main contribution to the total deformation is made by steady creep; however, instantaneous deformation and deformation at transition creep markedly

---

[1] To whom correspondence should be addressed. Fax: (99532)325990. E-mail: kalandadze@sun20.hepi.edu.ge.

0022-4596/00 $35.00

TABLE 1
Characteristics of the Samples Used in the Investigations

Material	Density, g/cm^3	Porosity, %	Grain size, µm
Boron carbide (B_4C)	2.34	7	5
Aluminum dodecaboride (α-AlB_{12})	2.37	7	10
Aluminum dodecaboride (α-AlB_{12})	2.22	13	10
Aluminum dodecaboride (α-AlB_{12})	1.99	22	10

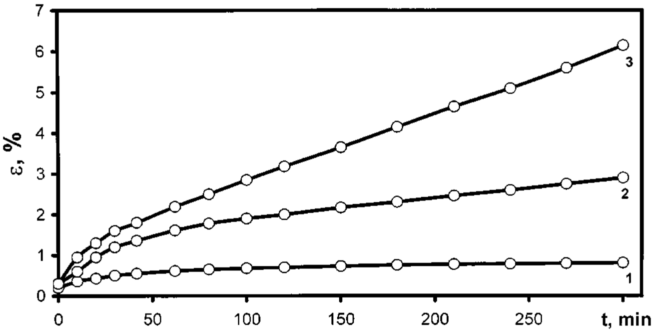

FIG. 2. Boron carbide creep under 100 MPa; (1) 1500°C, (2) 1650°C, (3) 1800°C.

increase when the sample density decreases (up to 1% and 2.5% respectively at a density of 1.99 g/cm^3).

Figures 4 and 5 illustrate the steady creep rate versus applied stress and temperature. The steady creep rate ($d\varepsilon/dt$) in both boron carbide and aluminum dodecaboride is described as

$$d\varepsilon/dt = A\sigma^n\text{-}\exp(-E/RT), \qquad [1]$$

where A is a constant, σ the applied stress, E the creep activation energy, R the gas constant, and T the temperature.

An analysis of the results (Figs. 4 and 5) shows that boron carbide creep occurs by the vacancy-diffusive mechanism with an exponent of $n = 1$ at stress values below 90 MPa. At stresses above 90 MPa the creep mechanism changes and dislocation creep with an exponent of $n = 3$ is dominant (Fig. 4). The creep activation energy in both cases is the same and equal to 385 kJ/mole (Fig. 5).

A similar phenomenon is observed in aluminum dodecaboride; however, the replacement of the vacancy-diffusive mechanism by dislocation creep takes place at stress values of 80 MPa (Fig. 4). The creep activation energy in aluminum dodecaboride also does not depend on applied stress and is equal to 460 kJ/mole (Fig. 5).

As previously mentioned (8, 9), the materials in the dislocation creep region are subdivided into two classes: for one, exponent $n = 3$ in Eq. (1), for the other, $n = 5$. In Ref. (10), it is supposed that here the difference in the types of interatomic bonds is predominant, and compounds with covalent bonds (both boron carbide and aluminum dodecaboride belong to this class) have exponent $n = 3$.

The creep rate versus temperature for applied stress values of 50 and 100 MPa give parallel lines (Fig. 5), which indicate that both creep mechanisms (the vacancy-diffusive and dislocation mechanisms) have the same nature. The creep in ceramic materials is controlled by the diffusion of the slowest atom (2). In the case of boron carbide, carbon atoms are the slowest ones, because the diffusion rate of boron into carbon was higher than the diffusion rate of carbon into boron (11). A good agreement of the creep

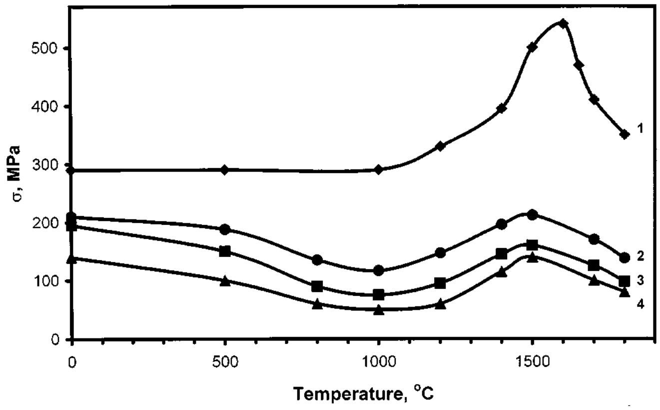

FIG. 1. High-temperature bending stress: (1) boron carbide (B_4C); (2) aluminum dodecaboride (α-AlB_{12}), density 2.37 g/cm^3; (3) aluminum dodecaboride (α-AlB_{12}), density 2.22 g/cm^3; (4) aluminum dodecaboride (α-AlB_{12}), density 1.99 g/cm^3.

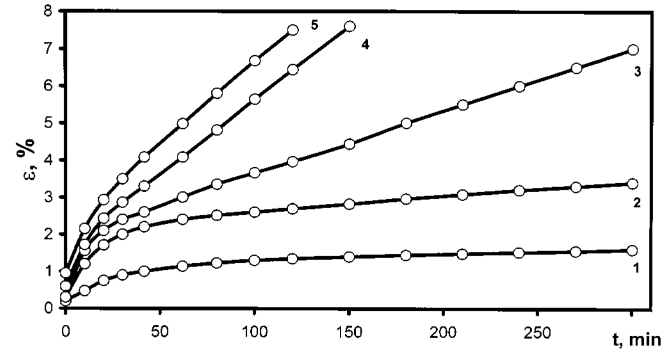

FIG. 3. Aluminum dodecaboride creep: (1) 50 MPa, 1500°C, density 2.37 g/cm^3; (2) 100 MPa, 1500°C, density 2.37 g/cm^3; (3) 100 MPa, 1650°C, density 2.37 g/cm^3; (4) 50 MPa, 1500°C, density 2.22 g/cm^3; (5) 50 MPa, density 1.99 g/cm^3.

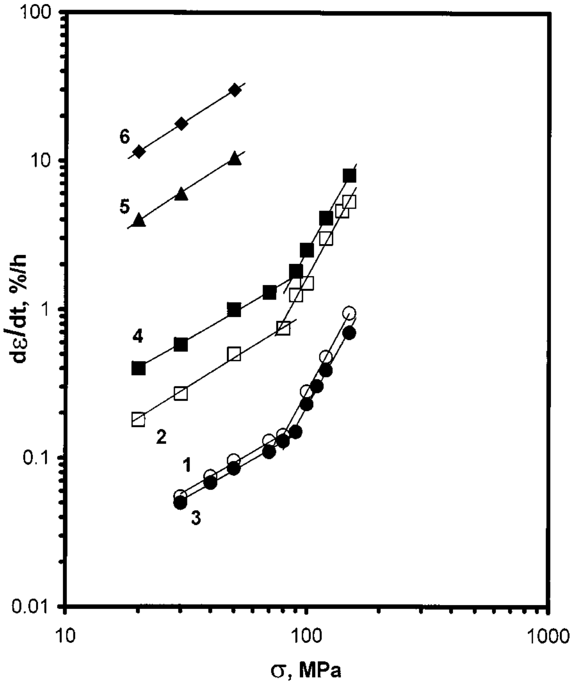

FIG. 4. Steady creep rate versus a stress: (1) boron carbide, at 1650°C; (2) boron carbide, at 1800°C; (3) Aluminum dodecaboride, density 2.37 g/cm^3, at 1500°C; (4) aluminum dodecaboride, density 2.37 g/cm^3, at 1650°C; (5) aluminum dodecaboride, density 2.22 g/cm^3, at 1650°C; (5) aluminum dodecaboride, density 1.99 g/cm^3, at 1650°C.

activation energy (385 kJ/mole) in boron carbide with the activation energy of carbon self-diffusion, −382 kJ/mole (12), supports this statement. In the case of aluminum dodecaboride, we can presume the steady creep rate to be controlled by the boron atom diffusion.

CONCLUSION

The ductile rupture of B_4C starts at temperatures above 1500°C while that of AlB_{12} begins at 1400°C. Total deformation, however, did not exceed 2% even at 1800°C. The steady creep rate $d\varepsilon/dt$ depends on the applied stress and the temperature. Creep in boron carbide at stress values lower than 90 MPa occurred by the vacancy-diffusive mechanism. At stress values over 90 MPa the creep mechanism changes to dislocation creep. A similar phenomenon is observed in the case of aluminum dodecaboride; however, the replacement of the vacancy-diffusive mechanism by dislocation creep takes place at stress values of 80 MPa.

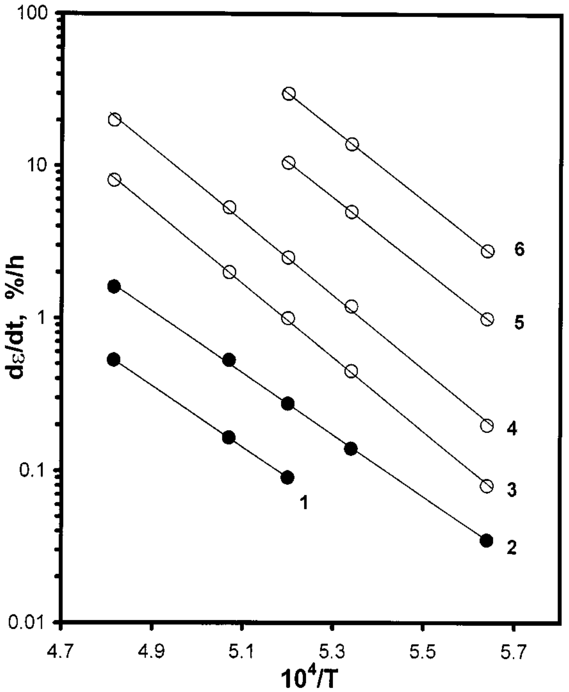

FIG. 5. Steady creep rate versus a temperature: (1) boron carbide, under 50 MPa; (2) boron carbide, under 100 MPa; (3) aluminum dodecaboride, density 2.37 g/cm^3, under 50 MPa; (4) aluminum dodecaboride, density 2.37 g/cm^3, under 100 MPa; (5) aluminum dodecaboride, density 2.22 g/cm^3, under 50 MPa; (6) aluminum dodecaboride, density 1.99 g/cm^3, under 50 MPa.

REFERENCES

1. "Ogneupori dlya kosmosa" (In Russian), Handbook. Metallurgiya, Moscow, 1967.
2. P. V. Zubarev, "High-temperature strength of the interstitial phases." Mettallurgiya, Moscow, 1985.
3. R. A. Andrievski and I. I. Spivak, "Strength of refractory compounds and materials on their base." Mettallurgiya, Cheliabinsk, 1989.
4. A. M. Eristavi, *et al.*, *Bull. Acad. Sci. Georgian SSR* **137**(3), 565 (1990).
5. I. A. Bairamashvili, A. M. Eristavi, and G. I. Kalandadze, *Bull. Acad. Sci. Georgian SSR* **100**(2), 389 (1980).
6. B. Wiltshire, *J. Strain Anal.* **13**(1), 67 (1978).
7. A. G. Lanin, *in* "Materials Science of Carbides, Nitrides, and Borides" (Y. G. Gogosti and R. A. Andrievski, Eds.), NATO Science series, p. 305. Kluwer, Dordrecht, 1999.
8. W. R. Cannon and T. G. Langdon, *J. Mater. Sci.* **18**(1), 1 (1983).
9. Z. Horita and T. G. Langdon, *Sci. Metallurgica* **17**(5), 665 (1982).
10. S. H. Kirby and C. B. Raleigh, *Technophysics* **19**(2), 165 (1973).
11. V. S. Dergunova, Y. V. Levinskii, A. N. Shurshakov, and G. A. Kravetskii, "Interaction of carbon with refractory metals." Metallurgiya, Moscow, 1974.
12. G. B. Fedorov and E. A. Smirnov, "Diffusion in reactor materials." Atomizdat, Moscow, 1978.