substance: boron compounds with group IV elements: boron carbide
property: further properties

(Review articles, see [65L, 79B2, 79T]. See also document **general papers on further properties of boron carbide**)

melting point

T_m	2490°C		For dependence on composition, see Fig. 1.	71K

specific heat capacity
(in J $g^{-1}K^{-1}$)

c_p	1.85(10)	T = 650...900 K	composition ~ $B_{4.3}C$ – B_9C	85W1
	$1.93 \cdot 10^{-5}$	T = 2.72 K	composition ~ $B_{4.3}C$ (denoted as	87F
	$1.90 \cdot 10^{-5}$	T = 2.79 K	B_4C in the original paper)	
	$1.97 \cdot 10^{-5}$	T = 2.87 K		
	$2.01 \cdot 10^{-5}$	T = 2.96 K		
	$2.00 \cdot 10^{-5}$	T = 3.06 K		
	$2.07 \cdot 10^{-5}$	T = 3.18 K		
	$2.13 \cdot 10^{-5}$	T = 3.35 K		
	$2.20 \cdot 10^{-5}$	T = 3.55 K		
	$2.27 \cdot 10^{-5}$	T = 3.82 K		
	$2.34 \cdot 10^{-5}$	T = 4.09 K		
	$2.57 \cdot 10^{-5}$	T = 4.48 K		
	$2.80 \cdot 10^{-5}$	T = 4.98 K		
	$3.18 \cdot 10^{-5}$	T = 5.59 K		
	$3.74 \cdot 10^{-5}$	T = 6.43 K		
	$4.97 \cdot 10^{-5}$	T = 7.77 K		
	$8.13 \cdot 10^{-5}$	T = 9.83 K		
	$1.04 \cdot 10^{-4}$	T = 10.95 K		
	$1.52 \cdot 10^{-4}$	T = 12.94 K		
	$2.38 \cdot 10^{-4}$	T = 15.39 K		
	$3.97 \cdot 10^{-4}$	T = 18.45 K		
	$6.67 \cdot 10^{-4}$	T = 21.95 K		
	$1.30 \cdot 10^{-3}$	T = 27.32 K		
	$2.05 \cdot 10^{-3}$	T = 31.62 K		
	$3.25 \cdot 10^{-3}$	T = 36.68 K		
	$4.81 \cdot 10^{-3}$	T = 41.60 K		
	$7.41 \cdot 10^{-3}$	T = 47.27 K		
	$1.24 \cdot 10^{-2}$	T = 54.98 K		
	$2.33 \cdot 10^{-2}$	T = 64.56 K		
	$3.28 \cdot 10^{-2}$	T = 70.80 K		
	$5.49 \cdot 10^{-2}$	T = 82.62 K		

Specific heat capacity of various boron carbides (B_9C) [86T3, 91D] ($B_{1-x}C_x$, x =0.1...0.2) [94M]; B_4C of different producers [87F, 41K] in Fig. 2.

Heat capacity of samples of different origin divided by T^3 in Fig. 3 [87F, 41K].

High temperature heat capacity of B_xC (x =3,4, 5) by direct heating pulse calorimetry [91M].

Heat capacity: see Fig. 4

thermal conductivity

κ	14.6 W m^{-1} K^{-1}	T = 100 K	depends on density	79B1
	26 W m^{-1} K^{-1}	T = 100 K		82S

11.7 W m^{-1} K^{-1}	T = 500 K	depends on density	79B1
19 W m^{-1} K^{-1}	T = 500 K		82S
9.3 W m^{-1} K^{-1}	T = 1000 K	depends on density	79B1
17 W m^{-1} K^{-1}	T = 1000 K		82S

For thermal conductivity of theoretically dense boron carbide, see [77M2].

Temperature dependence of the thermal conductivity of initial and neutron irradiated boron carbide with different chemical composition in Fig. 5 [85G, 94G].

Thermal conductivity of the boron-carbon system (C-doped boron and boron carbide) in Fig. 6 [94K3, 99W, 95W, 91G].

Temperature dependence of the thermal conductivity of boron carbides in Fig. 7 [79K, 87F, 85B, 85W2, 86W1, 86W2].

Thermal diffusivity of boron carbide with 11.6, 12.8, 16.3, 16.6, 20.0 at. % C [85B, 79G] and with 10.0, 13.3, 15.4, 16.0, 16.7, 18.2, 19.2, 20.0 at.% C [85W1, 90E, 91E, 94M, 95A] in Fig. 8.

Temperature dependence of the thermal conductivity in [89A].

Thermal conductivity depending on the density in [91G].

Effect of isotope concentration of boron on the speed of sound in [94K1].

Isotopic effect of boron carbide thermal conductivity [94K4].

Thermal conductivity (isotope effect, correction for porosity), temperature dependence in [87M].

Tunneling model prediction for the low temperature thermal conductivity of crystalline B_9C (amorphous boron and YB_{63}) compared with the thermal conductivity of B_9C calculated from internal friction in [98M].

Theoretical discussion on the composition-dependent change of the thermal conductivity in boron carbides [87E]. It is assumed that CBB chains are significantly softer than CBC chains in contrast to the results of phonon spectroscopy.

Theoretical approach to the thermal conductivity of boron carbides based on the assumption of carrier phonons, whose frequency is modulated by lower-frequency phonons which "dress" the carrier phonons through strong interaction. Fig. 9 shows the comparison between theory and experiment for the case that the fit parameters are specifically adapted to each composition. The fit is not satisfactory, if the parameters for "B_4C" are used for B_9C (see ref.) [87K].

plastic wave velocities
(in 10^5 cm/s)

v	9.4	T = 300 K	0 % porosity	91B
	7.9		2.5 % porosity	
	7.7		4.8 % porosity	
	7.1		10 % porosity	
	6.17		16.3 % porosity	

Hugoniot elastic limit of porous boron carbide in Fig. 10 [91B].

magnetic susceptibility

Magnetic susceptibility of B_4C, $B_{6.5}C$, $B_{7.5}C$ and B_9C vs. magnetic field and vs. $1/T$ in Fig. 11 [85A, 86A].

Magnetic susceptibility compared with ESR results in Figs. 12 and 13 [96C].

Grüneisen parameter
(calculated on the basis of averaged macroscopic properties taken from literature)

γ_G	0.81	94K2

densities
(in g cm^{-3})

d	2.52	T = 300 K	B_4C	91G
	2.49		B_9C	86G
	2.51	T = 300 K	B_4C hot-pressed	81S
	2.44		B_4C (1 wt.% C) sintered	
	2.46		B_4C (3 wt.% C) sintered	
	2.51	T = 300 K		91L
	2.52		calculated	71G
	2.456	T = 300 K	experimental	75Y
	2.47...2.51	T = 300 K	exp., dependent on composition (B_7C–B_4C)	53A
	2.465...2.52	T = 300 K	exp., dependent on composition (8.8...20.0 at% C)	81B

linear thermal expansion coefficients
(in 10^{-6} K^{-1})

α	5.73			86T2
	2.6...4.5	T = 25...800 °C		86T1
	4.6	T = 25...800 °C	average	85S
	5.0			91L
	5.65(5)	T = 0...1000 °C	carbon-rich boron carbide	73Y
	5.87(4)	T = 0...1000 °C	boron-rich boron carbide	73Y
	$3.016\cdot10^{-6} + 4.30\cdot10^{-9}\,T - 9.18\cdot10^{-13}T^2$ (T in °C)			77M2
	$2.6...4.5\cdot10^{-6}$ K^{-1}	T = 25... 800°C	polycrystals	77M1, 79B1

For temperature dependence, see literature.

strength

310 MPa	T = 300 K	three-point bending	86G
230 MPa		four-point bending	

Strength and creep in boron carbide (B_4C) and aluminum dodecaboride (AlB_{12}) [99A].

critical stress intensity factor

3.27 MPa $m^{1/2}$	T = 300 K	86G

microhardnesses

H_K	36.6(60) GPa	T = 300 K		86G
	~3000 kg mm^{-2}	T = 300 K	load 0.98 N	85S
H	45.0 GPa	T = 300 K	type not specified	88B
H_K or H_V	30...38 GPa	T = 300 K		91L
H_K	2970(150) kg mm^{-2}	T = 300 K	B_4C, 1 N load, Knoop hardness	75L, 82S
	3200(150) kg mm^{-2}	T = 300 K	B_4C, 1 N load, Vickers hardness	75L, 82S

Note on the temperature dependence of the hardness of boron carbide; decrease up to 1300 °C [83D].

For dependence on composition, see [75L] and [79B3]; for dependence on temperature, see [79B1].

For metallography of boron carbide, see [76C].

For properties of irradiated boron carbide, see [77M2].

For mechanical properties of hot-pressed B – B_4C materials, see [79C].

flexural strength

	480 MPa	T = 300 K	4-point bend	85S

transverse rupture strength

	300...500 MPa	T = 300 K		91L

activation energy of internal friction
(in eV)

E_A	2.05	T = 780K	before annealing	91A
	2.0	T = 780K	after annealing (1h, 950K) in hydrogen	
	1.15	T = 470 K	before annealing	
	0.90	T = 470 K	after annealing (1h, 950K) in hydrogen	

relaxation times of internal friction

τ	$1 \cdot 10^{-14}$ s	780 K	no influence of annealing	91A
	$8 \cdot 10^{-12}$ s	470 K	decrease after annealing	

Low temperature internal friction of B_4C, $B_{13}C_2$ and B_9C in Fig. 14 [98M].

Temperature dependence of the internal friction of arc melted H-enriched boron carbide for higher temperatures in Fig. 15; comparison with hot-pressed boron carbide in [91A].

Longitudinal and shear acoustic velocity depending on carbon content of boron carbide compared with the C-B-B force constant in [94K3].

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Fig. 1.

B–C system. Melting point vs. C content (open, full circles: different experimental arrangements) [71K]. Data from [61Fl] and [56S] for comparison.

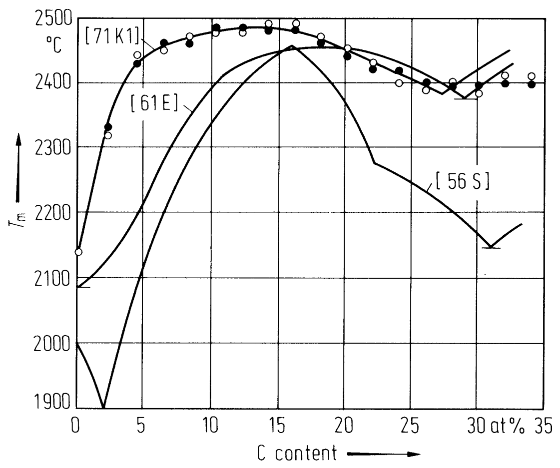

Fig. 2.

Boron carbide. Specific heat capacity vs. temperature. Pluses: B_9C, triangles down: $B_{6.5}C$ [91D]; full circles: B_9C [86T3]; triangles up $B_{1-x}C_x$, x = 0.1...0.2) [94M]; open circles: B_4C, General Atomic, squares: B_4C, Elektroschmelzwerk Kempten [87F], crosses: B_4C [41K].

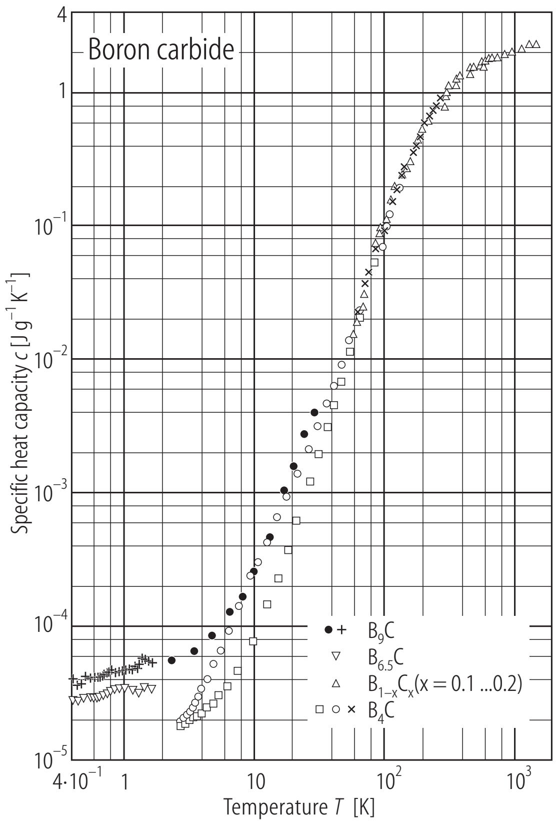

Fig. 3.

Boron carbide. Heat capacity of B_4C samples [87F]; open circles: B_4C, General Atomic, full circles: B_4C, Elektroschmelzwerk Kempten [87F], open triangles: B_4C [41K].

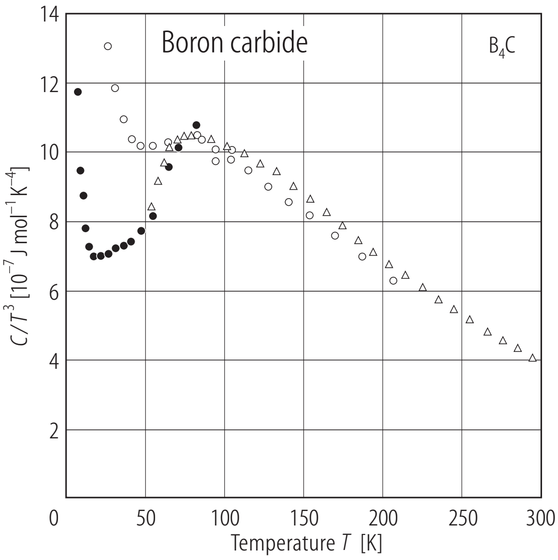

Fig. 4.

Boron carbide. Specific heat capacity vs. temperature [72V]. Dashed line [60K].

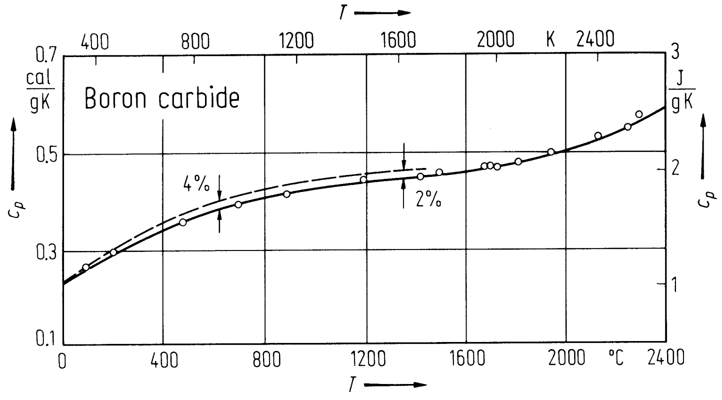

Fig. 5.

Boron carbide (B_4C, B_9C). Thermal conductivity of initial and neutron irradiated boron carbide vs. *T*. Carboth. B_4C, (— ■ —) initial, (·····) irradiated; magnes. B_4C, (— □ —) initial, (———) irradiated; B_9C, (— ◆ —) initial, (–··–··–) irradiated [94G]; B_4C (— ◊ —) initial, (------) irradiated [85G].

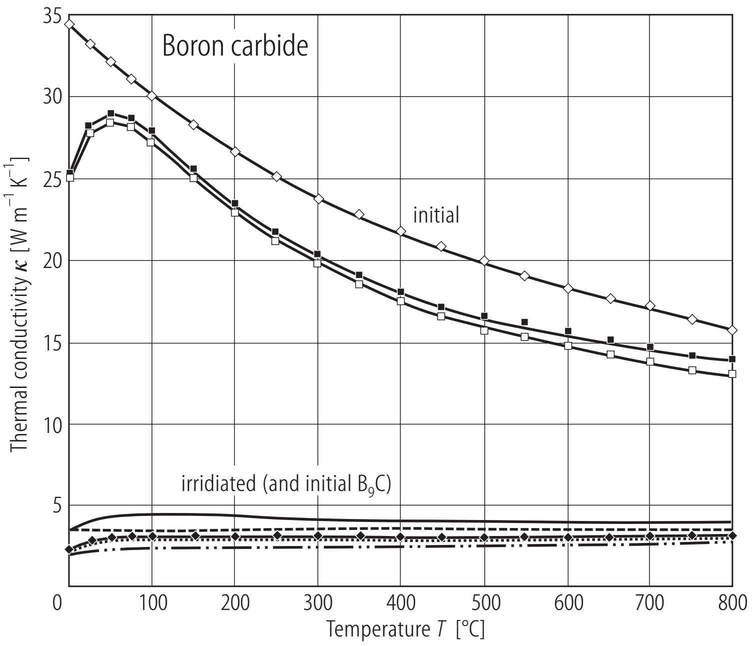

Fig. 6.

Boron-carbon system. Thermal conductivity of the boron-carbon system from pure boron to boron carbide with excess carbon vs. carbon content. Open symbols [91G], full symbols [94K3, 95W, 99W].

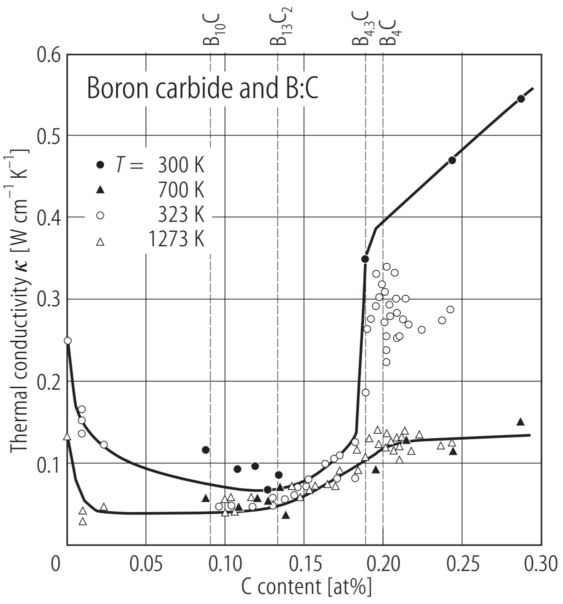

Fig. 7.

Boron carbide. Thermal conductivity of several compositions vs. temperature. **(a)** log-log plot (amorphous boron and YB_{66} for comparison) [87F, 85B, 85W2, 86W2]; **(b)** thermal conductivity at higher temperatures [86W2].

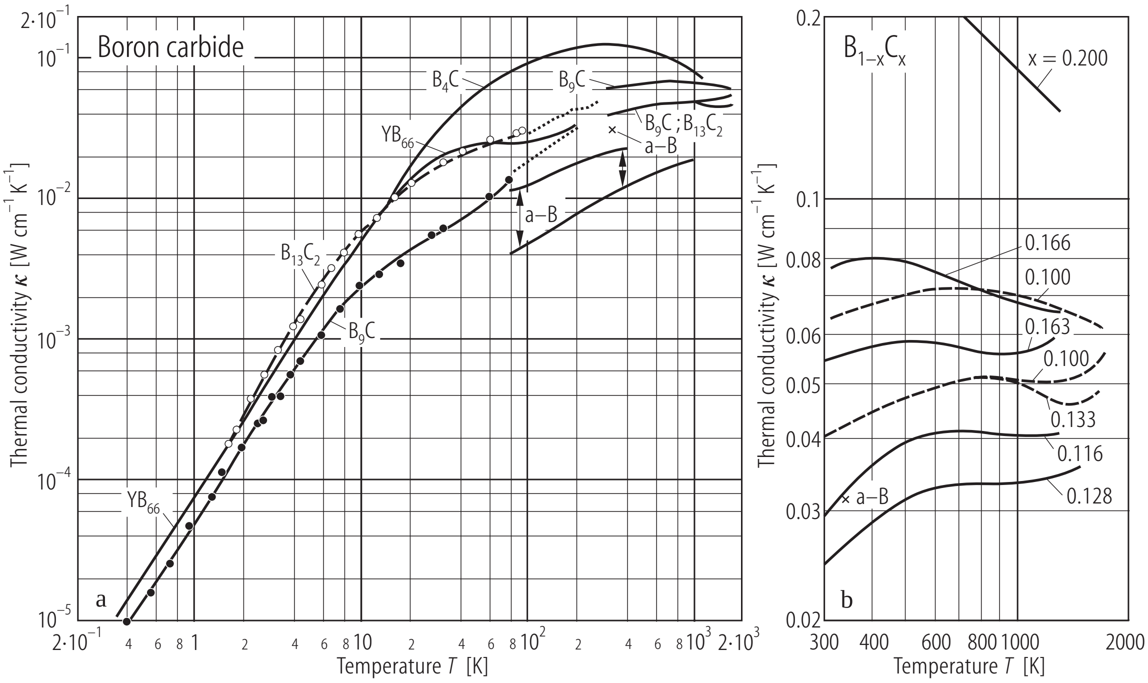

Fig. 8.

Boron carbide. Thermal diffusivity vs. temperature. Solid symbols [85B, 79G]; open symbols and crosses [85W1, 90E, 91E, 94M, 95A].

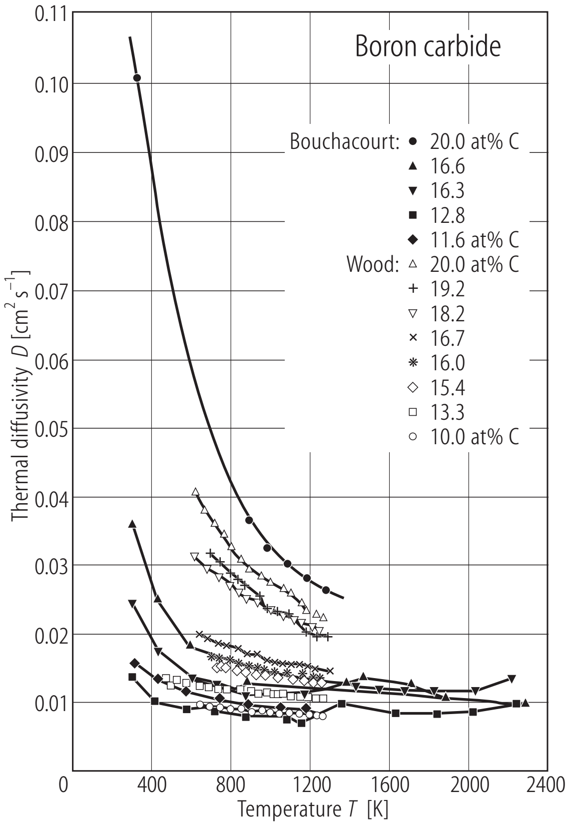

Fig. 9.

Boron carbide (B_9C, B_4C). Theoretical fit to the thermal conductivity based on assumption of carrier phonons whose frequency is modulated by lower-frequency phonons, which „dress“ the carrier phonons through strong interaction [87K].

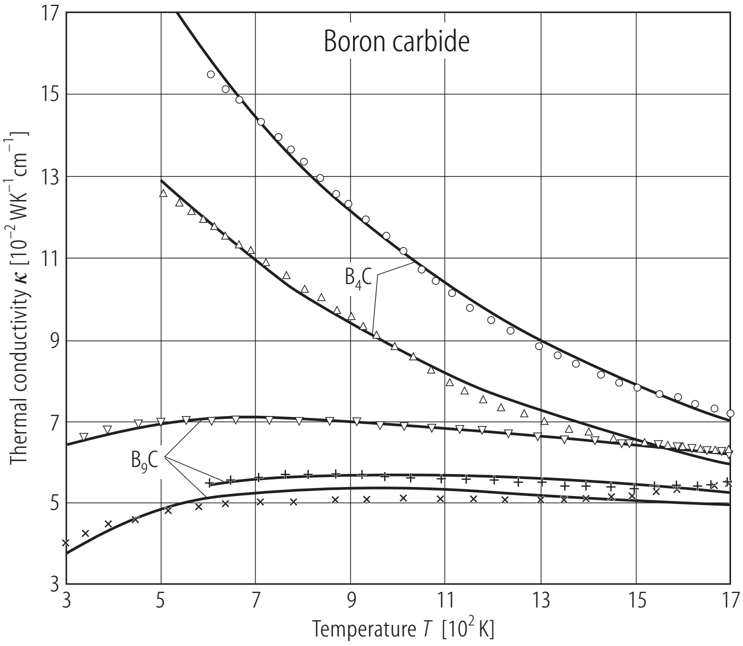

Fig. 10.

Boron carbide (porous). Hugoniot elastic limit (HEL) vs. porosity; circles: measured, triangles: calculated applying Steinberg's model [91B].

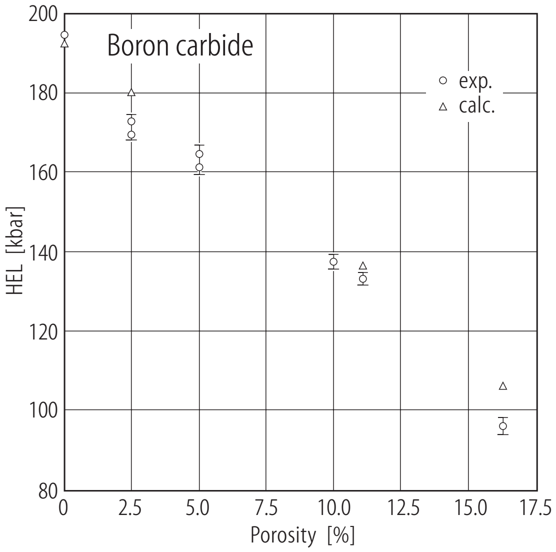

Fig. 11.

Boron carbide. Magnetic susceptibility measured at 5 kOe vs. reciprocal temperature for B_4C, $B_{6.5}C$, $B_{7.5}C$, B_9C [86A]. χ_m in CGS-emu.

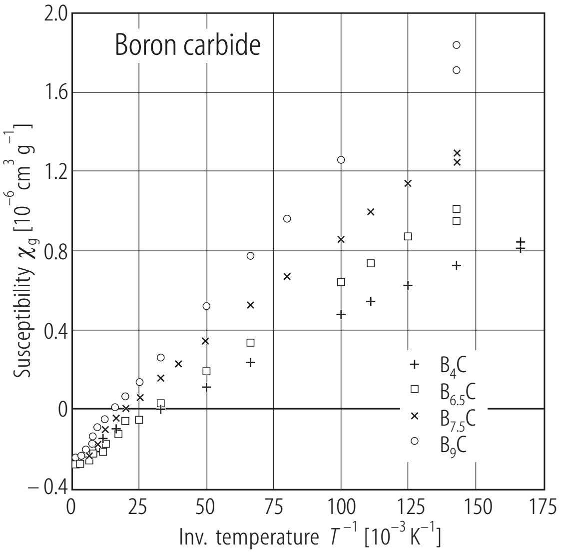

Fig. 12.

Boron carbide. ESR results. **(a)** Spin density/cell, **(b)** susceptibility (in CGS-emu), **(c)** *g*-factor, **(d)** linewidth of boron carbide with high carbon concentration (> 19 at.%) vs. *T* [96C].

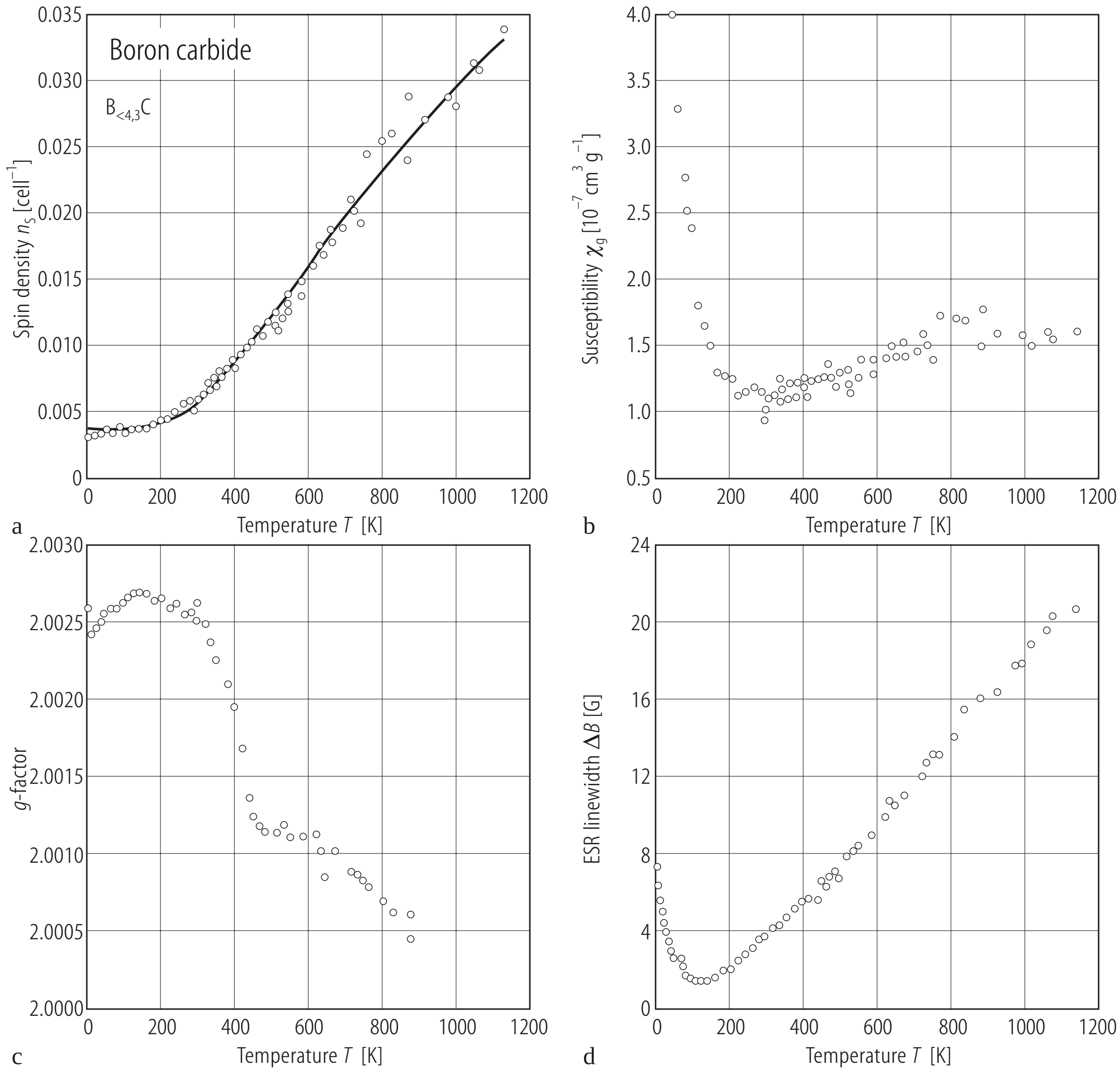

Fig. 13.

Boron carbide. Magnetic susceptibility **(a)** and ESR linewidth **(b)** of boron carbide with 18, 16, 13 and 10 at.% C vs. *T* [96C]. "Single crystal" with a composition close to the carbon-rich homogeneity limit, precipitated from a metallic copper solvent by slowing cooling from 2000 to 1300 K.

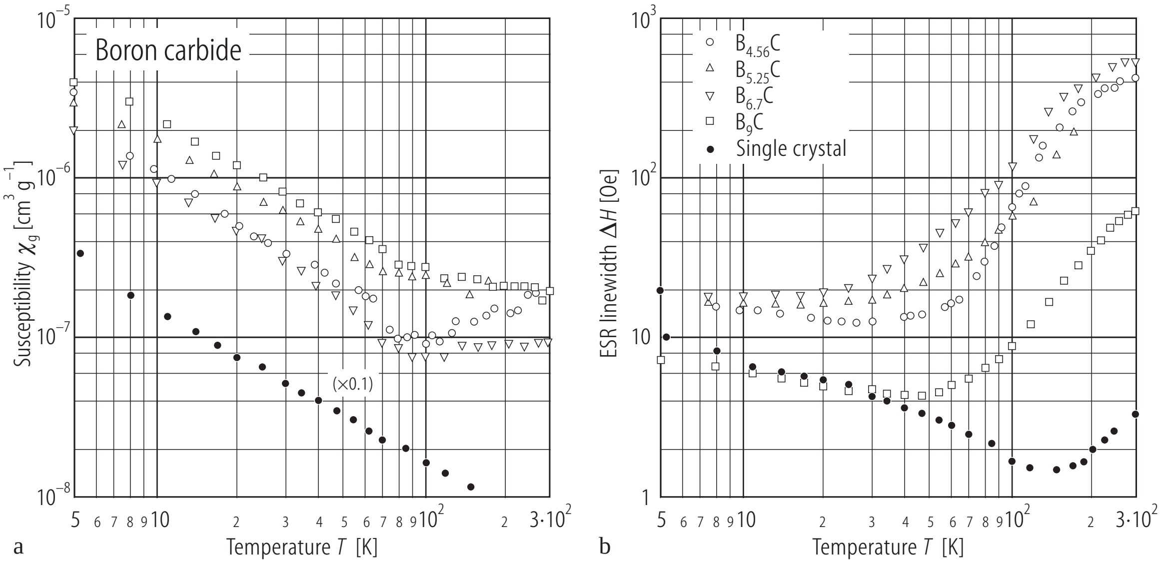

Fig. 14.

Boron carbide. Low temperature internal friction vs. temperature for crystalline B_4C, $B_{13}C_2$ and B_9C [98M]. β-rhombohedral boron for comparison.

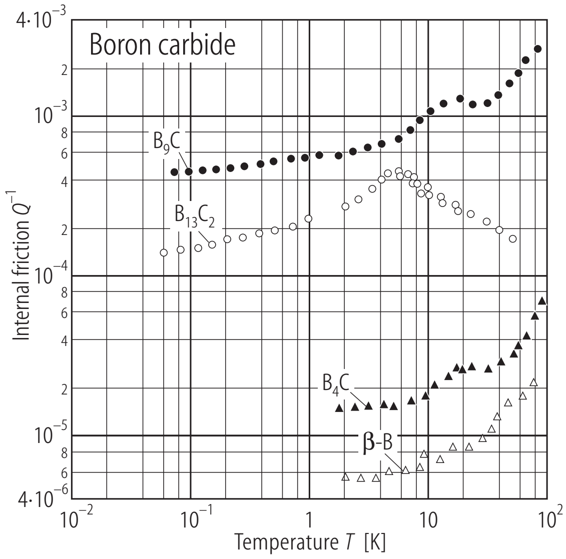

Fig. 15.

Boron carbide. (arc melted; composition not specified, probably approximately $B_{4.3}C$). High-temperature internal friction (*1*, *2*) and shear modulus (*1'*, *2'*). *(1)* initial arc melted specimen; *(2)* specimen after 1h annealing at 950 K in hydrogen atmosphere [91A].