

EFFECT OF CARBON CONTENT ON THE STRUCTURE, HARDNESS, AND THERMAL STABILITY OF BORON-CHROMIUM CAST STEELS

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Borides, which have high hardness, are used as a strengthening phase in alloys operating under intense abrasive wear conditions. The combined effect of boron and carbon on alloy properties has not been studied sufficiently.

The aim of this work is to study the effect of carbon content (within the limits 0.15-1.2% C) on the microstructure, hardness, and thermal stability of boron-containing steels (4.9-5.1% B; 2.85-3.10 Cr; 0.85-1.00% Si).

Steel melting temperature was determined by differential thermal analysis (DTA) in a VDTA-8 instrument for specimens 8 mm in diameter and 10 mm high. Specimen heating to 1400°C was carried out in an aluminum crucible at a rate of 80°C/min. Phase composition was determined by an x-ray method in a DRON-3 instrument in iron K_{α} -radiation, and microhardness was determined in a PMT-3 instrument. Steel microstructure was evaluated in an MIM-8 light microscope, and also in a Tesla-BS 500 electron microscope.

Melting of model steels (Table 1) was carried out in an induction 40-kg furnace. Boron was added in the form of 20% ferroboration FB-1. As a result of the ready oxidizability of ferroboration during storage in a moist atmosphere before use it was roasted at 800°C. Casting was carried out into a mold 20 mm in diameter.

Three basic structural components were revealed in the microstructure of cast alloys differing in morphological indicators (Fig. 1):

- a) finely lamellar eutectic forming dendrites with second order axes (Fig. 1a);
- b) columnar needle-shaped crystals of iron boride often with cracks filled by matrix alloy (Fig. 1b);
- c) three-dimensional skeletal dendrites having second and third order axes (Fig. 1d). The dendrites consist of tetragonal prisms with incomplete growth pyramids typical for crystallization from viscous solutions [1].

With an increase in carbon content in the steels the morphology of the eutectic component changed. Whereas in low-carbon steels (0.15% C) the eutectic is a lamellar skeletal formation apparently of boride and intermetallic phases having a second order axis, with an increase in carbon content the plates are thinned thus forming a branched structure (Fig. 2a).

The morphology of other elements of the steel microstructure also changes with an increase in carbon content. As a result of partial substitution of boron by carbon there is an increase in the total amount of boride phases, columnar crystals are thinned (see Fig. 1b), they take on a needle-like form (Fig. 1c), and they are placed almost parallel.

*Here and subsequently the weight fraction of elements is given.

TABLE 1

Steel	Content of elements, %			
	C	B	Cr	Si
1	0.15	5.0	2.9	0.95
2	0.39	5.0	3.9	0.85
3	0.82	5.1	3.0	0.90
4	1.20	4.9	2.9	1.00

Note. Apart from the elements listed the steels contained 0.33% Mn; 0.021% S; 0.010% P.

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TABLE 2

Alloy	Phase composition*	HRC	Microhardness of		
			strength- ening phase	eutec- tic	C-phase
Cast condition					
1	Fe ₂ B; Fe ₃ (Si, B)	45,5—47,5	1780	554	—
2	M ₂₃ (C, B) ₆ ; FeB; Fe ₂ B; M ₃ C	53,5—56,0	1780	464	—
3	M ₃ C; M ₂₃ (C, B) ₆ ; M ₂ B; Cr ₂ B ₄	63,0—65,0	1850	572	1890
4	M ₃ C; M ₂₃ (C, B) ₆ ; M ₂ B; CrB; Cr ₇ BC ₄	64,0—65,0	1850	642	1890
Oil quenching from 1100°C					
1	Fe ₂ B; CrB; Cr ₇ BC ₄	56,0—58,0	1590	824	—
2	Cr ₂₃ C ₆ ; M ₃ C; CrB; Fe ₂ B	66,0—67,0	1530	894	—
3		66,0—67,5	1780	1020	2010
4	M ₃ C; Cr ₂ B; CrB ₂ ; Cr ₃ B ₄	65,0—66,0	1680	762	2040

*Apart from the phases listed solid solution based on α - and γ -iron are observed in all steels.

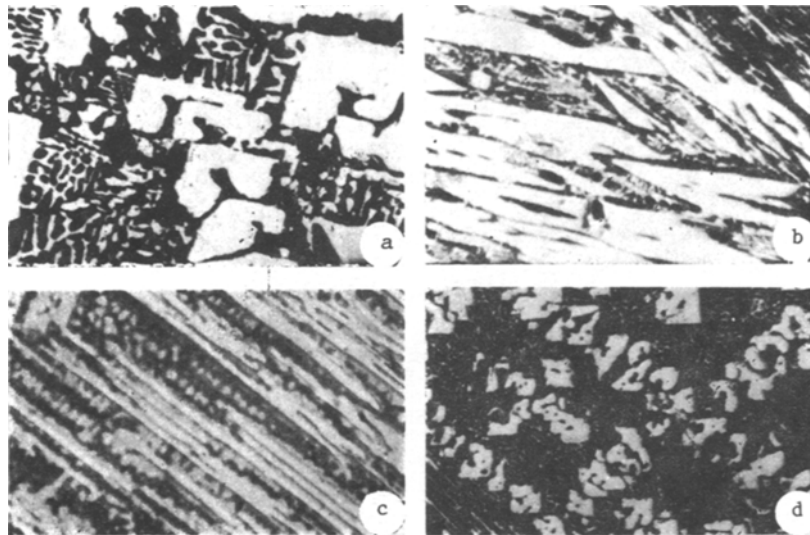


Fig. 1. Microstructure of test steels in the cast condition with different carbon contents ($\times 300$): a) 0.15% C; b) 0.39% C; c) 0.82% C; d) 1.20% C.

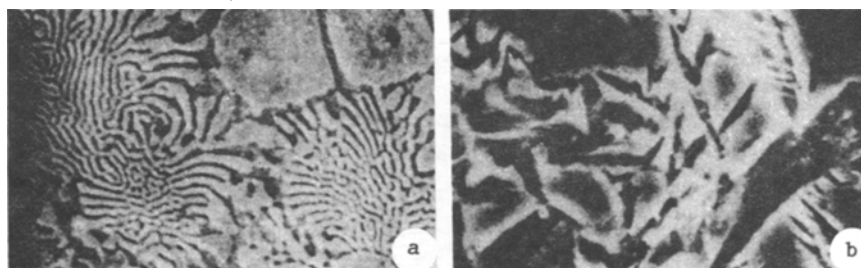


Fig. 2. Microstructure of cast (a) and quenched (b) steel with 1.20% C oil quenching from 1100°C): a) $\times 1000$, photographic angle $\alpha = 30^\circ$; b) $\times 3000$, $\alpha = 0^\circ$.

With a further increase in carbon content to 1.2% the main phase becomes a cementite type (Fig. 1d) alloyed with boron. Development of this phase is observed in an alloy containing 0.82% C. Carbide phase has a needle-like shape and it crystallizes together with the boride phase only differing in color. A similar phase was detected in studying Fe-B-C alloys in [2].

TABLE 3

% C	Hardness HRC after quenching from T, °C				
	cast cond.	900	1000	1100	1170
0,15	46—48	52—54	58—61	56—58	59—60
0,39	54—57	59—61	61—62	66—67	65—66
0,82	63—65	64—65	66—67	66—68	65—66
1,20	64—65	64—65	66—67	65—66	65—66

TABLE 4

% C	t_{te}	T_m	A_{r1}	T_s
	°C			
0,15	1145	1230—1360	645	1262—1100
0,39	1127	1212—1350	710	1247—1092
0,82	1095	1185—1330	680	1240—1042
1,20	1075	1170—1365	610	1260—1040

Notation. t_{te} , T_m , and T_s are temperatures for the start of recording a thermal effect, melting, and solidification respectively.

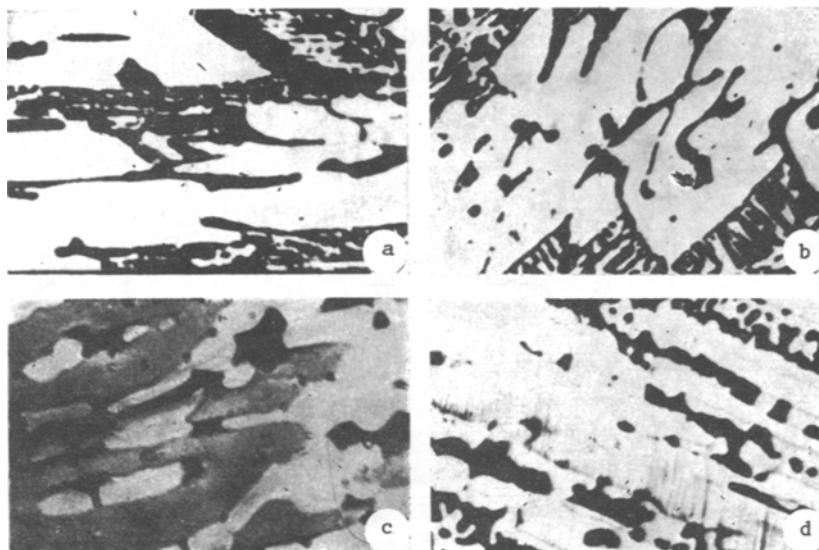


Fig. 3. Microstructure of the test steels after oil quenching from 1100°C ($\times 300$): a) 0.15% C; b) 0.39% C; c) 0.82% C; d) 1.20% C.

With an increase in carbon to 0.39% crystals comprising skeletal dendrites become more dense thus forming areas of joint growth with first and second order axes, but with a concentration of 0.82% C development of these crystals is suppressed, they are located in narrow spaces between the boride and carbide phase needles having first order axes (Fig. 1c). Crystals of circular shape predominate. With an increase in carbon content to 1.2% dendrites are morphologically identical to dendrites in alloy with 0.39% C although in shape they are identical to carboboride primary crystals (Fig. 1d). The comparatively smaller number of phases (in area) in this steel leads to formation of skeletal dendrites similar to alloys with 0.39% C. This explains the greater density of cementite phases which leads to a reduction in their total volume.

With an increase in carbon content in cast steels there is displacement of boron by carbon in iron boride. This leads to reaction of the boron liberated with chromium and to formation of new chromium-containing boride and carboboride phases. It can be seen from data in Table 2 that chromium-containing boride and carboborite phases form in cast steel with a content of 0.82-1.20% C.

With exposure of cast steel in a salt bath (100% $BaCl_2$) at temperatures of 900, 1000, 1100 and 1170°C for oil hardening there are intense processes connected with diffusion redistribution of carbon, which substitutes for boron in phases of the cast structure. This leads to a change in microstructure, microhardness, and phase composition of the steels, to an increase in the proportion of chromium-containing phases, and to development of new chromium-containing and carbide phases (Table 2). The greatest microhardness in the cast and quenched conditions is exhibited by a light-brown component, conditionally called "C-phase" revealed by etching in 4% ethanolic HNO_3 solution.

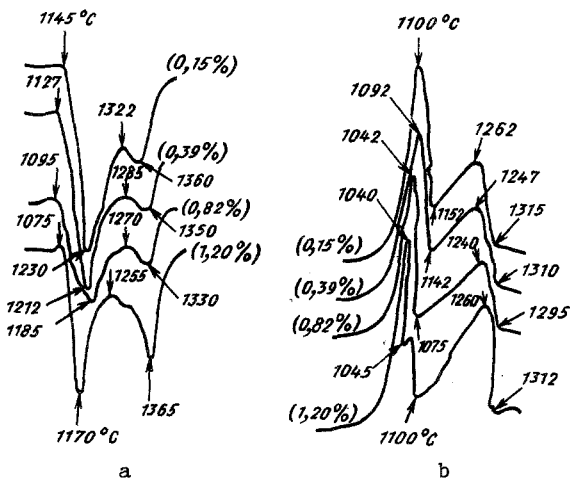


Fig. 4. Thermal curves for test steels with a different carbon content (indicated on the curves in brackets) with heating (a) and cooling (b).

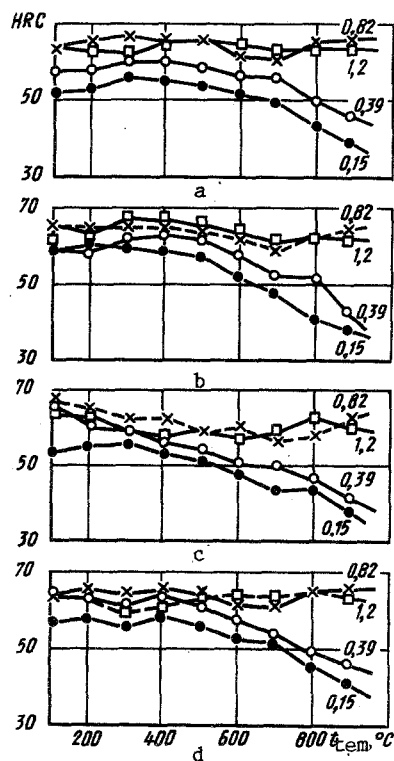


Fig. 5. Dependence of the hardness of quenched steels with different carbon content (shown on the curves in %) on tempering temperature: a) quenching from 900°C; a) from 1000°C; b) from 1100°C; c) from 1170°C.

In the steel microstructure needle-shaped crystals gradually merge with crystals forming dendrite branches (Fig. 3). In [2] these crystals were identified as $Fe_3(C, B)$. The change in microhardness of structural elements points to intense occurrence of diffusion processes. A martensitic structure is observed in the matrix of quenched steel (see Fig. 2b).

The hardness of quenched steels depends on carbon content and heating temperature for hardening (Table 3). It can be seen from Table 3 that the optimum hardening temperature is 1000-1100°C for all steels.

With heating to higher temperatures diffusion processes start to develop very intensely, and there is alloy melting. Presented in Table 4 are the results of thermal analysis tests for the steels*. It can be seen that the start† of melting and the melting temperature depend on carbon content. Characteristic temperatures decrease as the carbon content in steel increases.

Melting occurred in two steels (Fig. 4). Apparently the second peak is connected with combined melting of austenite and high-temperature phases in the steel. The peak temperature is almost independent of carbon content in the steels, which points to the identical nature of phase ratios in this temperature range. With steel cooling marked thermal hysteresis of 100-140°C is observed, i.e., the steels are inclined towards overcooling.

An increase in the hardness of quenched steels is connected not only with martensitic transformation during quenching, but also probably with strengthening as a result of precipitation of new boron-containing phases and additional alloying of austenite.

Steel thermal stability was determined in the range 200-700°C after each 100°C. Specimens were held at each test temperature for 1 h, air cooled, and their hardness measured. It was established (Fig. 5) that the thermal stability of cast steels also depends on carbon content. In hypoeutectoid steels hardness decreases with an increase in tempering tempera-

*Thermal analysis was carried out with participation of V. G. Ivanchenko,

†Differential thermal analysis (DTA) data were checked by microscopic monitoring of alloy microsections heated in the temperature range corresponding to the start and end of melting.

ture. In hypereutectoid steels hardness is maintained up to 730-750°C, then some increase in hardness is observed connected apparently with an increase in solubility not only of carbide, but also of boride phases in austenite (Fig. 5). For all the steels there is an increase in hardness in different temperature ranges connected with dispersion hardening. These effects are most developed in hypereutectoid steels where an increase in chromium boride line intensity is observed with x-ray analysis.

CONCLUSIONS

1. An increase in carbon content from 0.8 to 1.2% in cast steels causes formation of chromium-containing boride and carboboride phases.
2. With an increase in carbon content in steels the microhardness of structural components changes a little.
3. The maximum hardness is exhibited by steel oil quenched from 1000-1100°C.
4. Steels with 0.82-1.20% C has the greatest thermal stability (up to 900°C). In steels with 0.15-0.39% C with heating up to 900°C a marked reduction in hardness is observed.

LITERATURE CITED

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