DISTRIBUTION OF ALLOYING ELEMENTS, BORON, AND CARBON IN THE BORIDED CASE OF MEDIUM-CARBON STEELS

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The following variants of steel 40 were prepared: 40Kh (0.81% Cr), 40Kh2 (2.0% Cr), 40Kh3 (3.10% Cr), 40Kh5 (4.94% Cr), 40M (0.63% Mo and 1.14% Mo), 40M2 (1.72% Mo), 40T (0.23% Ti and 0.65% Ti). The ingots were diffusion annealed 10 h at 980°C, forged into bars, and annealed 4 h at 880°C.

Samples 20 × 20 × 50 mm, prepared from the bars, were borided in molten borax in a semicommercial apparatus for 4 h at 950°C, with a current density 0.2 A/cm^2, and cooled in air.

The distribution of alloying elements in the case and the transition zone was determined by spectral analysis with the use of the IG-3 high-voltage spark generator.

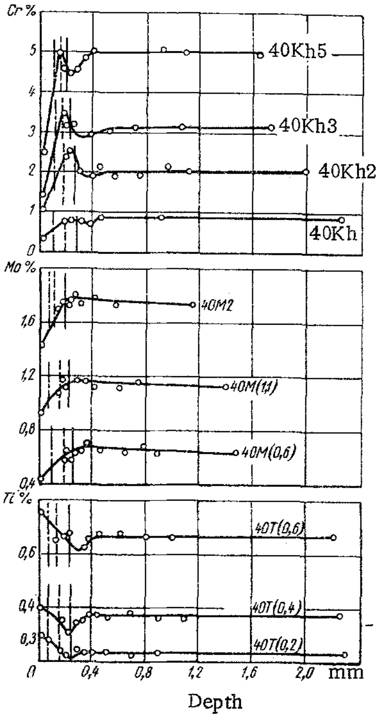

Fig. 1. Distribution of chromium, molybdenum, and titanium in the case and transition zone. ———) Total depth of case (to the end of boride needles); - - - -) depth of FeB (end of needles); -·-·-·) depth of continuous FeB layer.

The distribution of chromium, molybdenum, and titanium in the case and transition zone is shown in Fig. 1.

In the chromium steels the concentration of chromium in the surface zone of the boride case (FeB) is approximately one-half the original concentration. The chromium concentration is highest in the Fe_2B. The transition zone beneath the case is impoverished in chromium, which points to the redistribution of chromium between the boride phases and also between the base metal and the boride case during boriding (Fig. 1).

In the molybdenum steels the molybdenum concentration in the surface (FeB) is lower than the original concentration in the steel but is approximately equal to the original concentration in the Fe_2B boride. The transition zone is enriched in molybdenum: during boriding the molybdenum is forced from the boride zone into the base metal (Fig. 1).

Titanium is concentrated mainly in Fe_2B. The highest amount of titanium was found in the surface of the boride case. The titanium concentration in FeB matches the original concentration in the steel. The impoverishment of the transition zone in titanium points to the migration of titanium from the base metal to the boride zone during boriding (Fig. 1).

This behavior of the alloying elements in the process of boriding can be explained by the possibility of the formation of solid solutions in the system of iron boride — alloying element boride.

The conditions for the formation of a continuous series of solid solutions between intermetallic compounds were described in [1]. The requirements for the formation of continuous solid solutions between interstitial phases are as follows [2]: 1) isomorphous compounds; 2) the same type of chemical bond; 3) the formation of continuous solid solutions between the metals entering into the compound.

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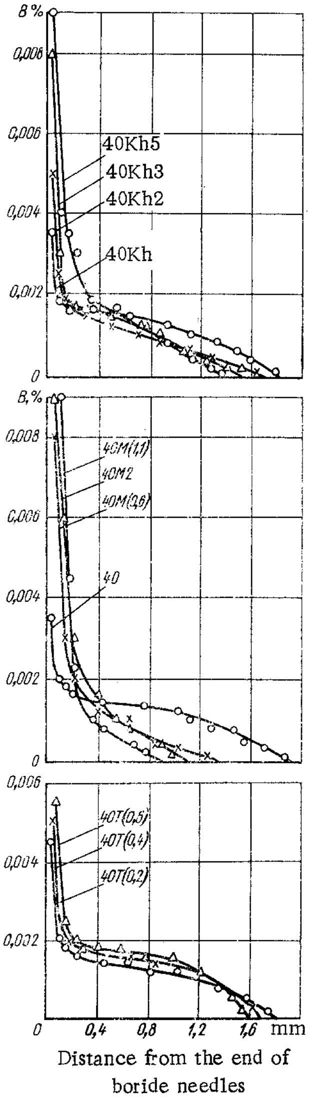

Fig. 2. Distribution of boron in the transition zone in steels with chromium, molybdenum, and titanium.

Borides of transition metals are compounds intermediate between beryllides and interstitial phases, and therefore the conditions given above are applicable to boride systems.

Two iron borides were found — FeB (orthorhombic lattice, a = 4.061 Å, b = 5.506 Å, c = 2.952 Å [3]) and Fe_2B (tetragonal body-centered lattice, a = 5.109 Å, c = 4.249 Å, c/a = 0.832). Iron borides have covalent — metallic bonds with a predominance of metallic, particularly in the case of Fe_2B, in which the bond is almost metallic.

Of the chromium borides only Cr_2B is isomorphous with Fe_2B. The type of bond in Cr_2B is the same as in Fe_2B. The lattice constants of these borides are fairly close (a = 5.180 Å and c = 4.316Å for Cr_2B). The difference in the atomic diameters of iron and chromium is 1.5%; the solubility is unlimited. All of this leads to the conclusion that Fe_2B and Cr_2B must be mutually soluble to a considerable extent.

Comparison of chromium borides with FeB leads to the conclusion that their mutual solubility is low.

Of all the molybdenum borides, only Mo_2B is isomorphous and has lattice constants matching those of Fe_2B. The difference in the atomic diameters of iron and molybdenum is 10%; the maximum solubility of molybdenum in iron is 5% at room temperature and 34% at the melting point. One would expect limited solubility of iron and molybdenum borides and the highest solubility in the Fe_2B — Mo_2B system.

The structure and parameters of the titanium boride lattices, the difference in atomic diameters of iron and titanium (15%), and the low solubility of titanium in iron indicate that titanium borides must have a limited solubility in iron borides. The highest solubility would be expected in the FeB — TiB system.

This analysis leads to the conclusion that chromium and molybdenum should have a high solubility in Fe_2B, and titanium in FeB, which is confirmed by the data on the distribution of alloying elements in the boride case. Figure 2 shows the distribution of boron in the transition zone. All the elements investigated (chromium, molybdenum, titanium) raise the boron concentration in the transition zone and lower it in the base metal, i.e., reduce the depth of the transition zone and, consequently, the diffusion rate of boron in austenite.

In the process of boriding steel 40 the carbon in the zone of borides is forced into the transition zone. The alloying elements have almost no effect on the highest carbon concentration in the transition zone but reduce the depth of the zone enriched in carbon.

CONCLUSIONS

1. Alloyed borides of the type (Fe, alloy. el.)B and (Fe, alloy. el.)$_2$B are formed in electrolytic boriding, the chromium and molybdenum concentrating in Fe_2B and the titanium in FeB.

2. Chromium, molybdenum, and titanium increase the boron concentration in the transition zone and reduce the boron concentration in the base metal but do not change the maximum carbon concentration in the transition zone.

LITERATURE CITED

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