MODIFICATION BY BORON OF DEPOSITED METAL OF WHITE CAST IRON TYPE

S.Yu. KRIVCHIKOV
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

The paper considers the effect of minor additions of boron on properties of hypoeutectic composition deposited metal of the white cast iron type provided by wide-layer hardfacing using flux-cored wire. It has been established that boron in an amount of 0.07–0.14 wt.% leads to a substantial improvement of crack resistance of metal of the deposited cast iron. It has been shown that growth of crack resistance is caused by modifying effect of boron on sizes and structural constituents of the deposited cast iron and strengthening of grain boundaries.

Keywords: *hardfacing, deposited cast iron, flux-cored wire, structure, boron modification and microalloying, crack resistance, hardness*

Formation of solidification and cold cracks in a deposited metal as well as in fusion zone is the main problem in hardfacing of parts manufactured from grey cast iron. Such defects can be a reason of fatigue failure in hardfacing of parts operating under cyclic and alternating loads (for example, crankshafts of car engines, compressors, diesel generators etc.).

Various methods of metallurgical and technological character, i.e. application of high-alloy surfacing materials of austenite class, pre-deposition of buffer sub-layer for reduction of carbon content in working deposited layer, preliminary and additional heating of deposited part and its delayed cooling after hardfacing etc. can be used for elimination of crack formation. However, such methods of crack elimination appear to be low-efficient or unacceptable for obtaining of thin layer of wear-resistant deposited metal over parts with relatively small (0.5–1.5 mm) wear-out which is characterized by a complex of difficult to combine properties (high hardness, wear and crack resistance).

Modification and microalloying by minor additions of surface-active elements (SAE) influencing the processes of structure formation of solidifying alloys [1] are one of the directions of improvement of physico-mechanical properties of iron-carbon alloys. Refining and strengthening effect of SAE on intergranular junctions (boundaries) which are a wide spread network penetrating the whole metal volume results in intergranular reinforcement of alloy matrix [2]. In turn the grain boundaries are energy barriers for crack propagation [3]. Thus, it can be assumed that SAE application can be an effective method for increase of crack resistance of alloys solidifying under non-equilibrium conditions of real welding process.

Boron refers to SAE and its peculiarity is a modimodifying capability, i.e. influence on grain size and condition of the grain boundaries [1, 2, 4, 5]. Boron alloying is also widely used in welding using flux-cored wires and strips for obtaining of abrasive-resistant deposited metal. In this situation it plays a role of a main alloying element taking part in formation of hard and wear-resistant carbides and carboborides of transition metals. Content of boron in such a type of deposited metal, as a rule, makes 1.5–3.5 wt.%. At the same time the information about the influence of relatively minor additions of boron on properties of low-alloyed cast iron deposited using flux-cored wire is not sufficient.

Aim of the present work was experimental study of effect of minor additions of boron on properties of deposited metal of the white cast iron type provided by wide-layer hardfacing using flux-cored wire of the parts manufactured from high strength cast iron with globular graphite. Composition of deposited metal developed at the E.O. Paton Electric Welding Institute and resistant under conditions of sliding friction at high contact loads [6], but solidifying at hardfacing with crack formation was taken as an object for investigation. Investigated deposited metal has the following chemical composition, wt.% : 2.4–2.6 C; 1.0–1.2 Si; 1.2–1.4 Mn; 0.5–0.6 Cr. Pilot flux-cored wires of 2 mm in diameter with different boron content were manufactured for obtaining and investigation of the samples of deposited metal with indicated chemical composition. Single wide-layer hardfacing of cylinder samples from cast iron with globular graphite was carried out at reversed polarity direct current using mode with 150–160 A current, 19–21 V voltage, 35 mm range of electrode oscillation, 5.5 m/h welding speed and 1.8–2.2 mm thickness of deposited layer.

Visual examination of the deposited samples showed that the macrocracks take place on the surface of deposited layer with no boron content and microcracks of various lengths and level of opening located in the deposited metal as well as in a fusion zone are present in the microsections. Nucleation of microcracks takes place, as a rule, in the fusion zone at the places of occurrence of graphite inclusions of the base metal and close to them areas of ledeburite colonies. Then they easily propagate in the whole volume of the deposited metal. At the same time, depos-

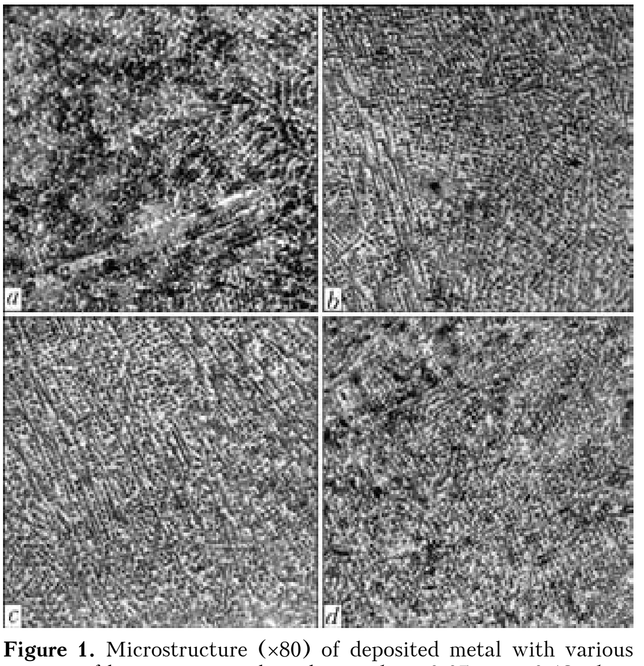

Figure 1. Microstructure (×80) of deposited metal with various content of boron: *a* — without boron; *b* — 0.07; *c* — 0.13; *d* — 0.21 wt.% B

ited metal with 0.05–0.07 wt.% B solidifies without formation of marcocracks and number of microcracks significantly decreases. Increase of boron content results in further reduction of amount of microcracks. Single microcracks take place at boron concentration 0.18–0.20 %. Boron microalloying of more than 0.2 wt.% makes not observable influence on crack resistance of the deposited metal. It was determined in a course of metallographic investigations that products of austenite decomposition (ferrite-pearlite mixture) and carbide-cementite phase are two main phase constituents of microstructure of the deposited metal. There are also areas of ledeburite eutectics located in the fusion zone and having honeycomb structure, that is character for low-alloyed cast iron of hypoeutectic composition. Carbide-cementite phase cannot be formed in all interaxial spaces of dendrites of solid solution in absence of boron, therefore, it looks like broken (non-solid) network in the section plane.

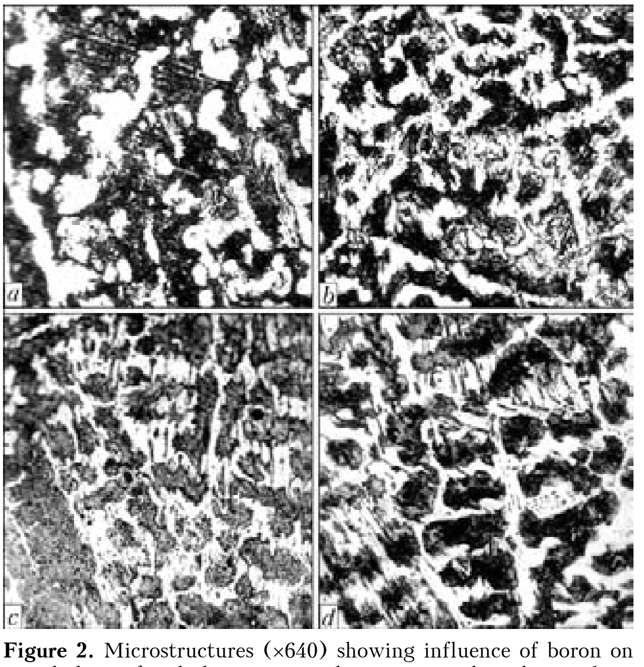

Figure 2. Microstructures (×640) showing influence of boron on morphology of carbide-cementite phase: *a* — without boron; *b* — 0.07; *c* — 0.13; *d* — 0.21 wt.% B

Boron microalloying makes significant influence on all structural constituents of the deposited cast iron. This influence becomes noticeable already at 0.03 wt.% B, and the most intensive changes take place in 0.07–0.15 wt.% interval of boron concentration. The structure of deposited cast iron changes insignificantly at boron content of more than 0.2 wt.%. Density of dendrite structure increases that is shown by decrease of size of solid solution grains from 100–112 (for deposited sample without boron) to 80–100, 64–80 and 32–48 μm for the samples containing 0.07; 0.13 and 0.21 wt.% B, respectively (Figure 1). Carbide-cementite phase, precipitating along the interaxial spaces of dendrites, also undergoes significant changes. It becomes less broken and solidifies in a form of solid network with thinned and widened areas (Figure 2). Width of areas of the carbide-cementite network in the deposited sample without boron makes 48–96 μm. Width of thinned areas equal 16–32, 8–16 and 3.2–2.4 μm and widened ones are 64–82, 48–64 and 32–40 μm at boron content of 0.07; 0.13 and 0.21 %, respectively.

Fusion zone in the investigated depositions has a structure of metal re-crystallized from solid-liquid state with presence of ledeburite colonies character for cast iron hardfacing. Ledeburite colonies in the section plane merge in a solid chill band at boron absence. Depth of regions of ledeburite areas achieves 600–800 μm in separate places of the fusion zone. Number of regions occupied by ledeburite reduces and character of their distribution becomes irregular with boron introduction. Maximum effect is achieved at 0.18–0.20 wt.% B. At that, sizes of ledeburite colonies in depth reduce up to 300 μm and level of their dispersion increase (Figure 3).

It should be noted that areas of structure of the deposited metal attached directly to the zone of complete melting have more differential structure than central areas of the deposited layer. Dendrites of solid solution solidify in this areas and have axles of the third order, interaxial distances of which have the following dependence on boron content (average values), i.e. without boron — 80 μm, 0.07 % B — 64; 0.13 % B — 48; 0.21 % B — 32 μm.

Modification by boron, except for structural changes, influences the hardness of deposited metal HV^A and microhardness of grains of solid solution HV^K, while microhardness of carbide phase HV remains virtually without changes (Figure 4). Increase of density and spreading of the grain boundaries strengthened by boron is probably connected with the rise of hardness of the deposited metal at insignificant

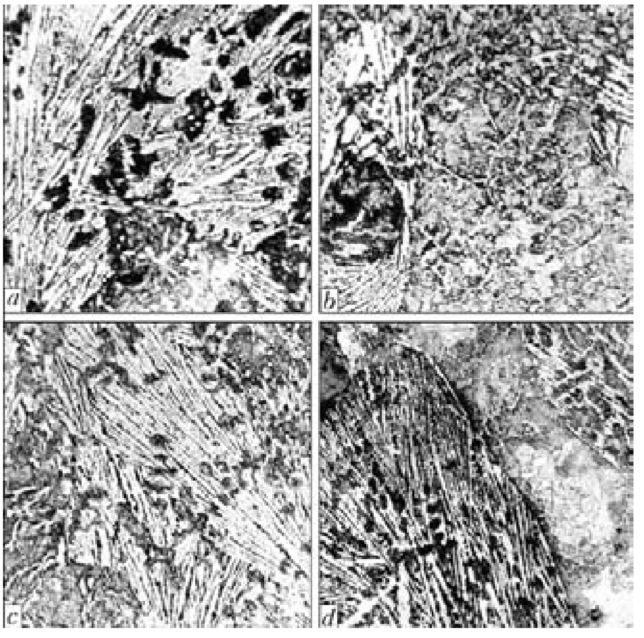

Figure 3. Microstructures (×200) of deposited metal with various dispersion of ledeburite colonies and boron content: *a* — without boron; *b* — 0.07; *c* — 0.13; *d* — 0.21 wt.% B

reduction of hardness of products of austenite decay, that does not contradict the theory of modification of cast iron using SAE [2, 4]. Anisotrophy of hardness values Δ (difference between the largest and the smallest hardness values) is also reduced. ΔHV and ΔHV^{A} values reduce from 640 and 700 (in deposit without boron) to 140 and 210 MPa (in deposit containing 0.21 % B), respectively. At the same time, ΔHV^{K} remains virtually on one level and makes 140–158 MPa independent on boron content. Microhardness of ledeburite colonies in the fusion zone increases with the rise of boron content from 6600–7300 (without boron) to 8500–9300 MPa (0.21 % B), that is caused by its influence on the level of ledeburite dispersion.

Thus, obtained data indicate that the minor additions of boron have significant modifying effect on all structural constituents of the deposited cast iron and homogeneity of values of their hardness.

Dual character of influence of boron on the processes of initial solidification can explain its determined significant effect on increase of crack resistance of the deposited cast iron. Presence of boron, from one side,

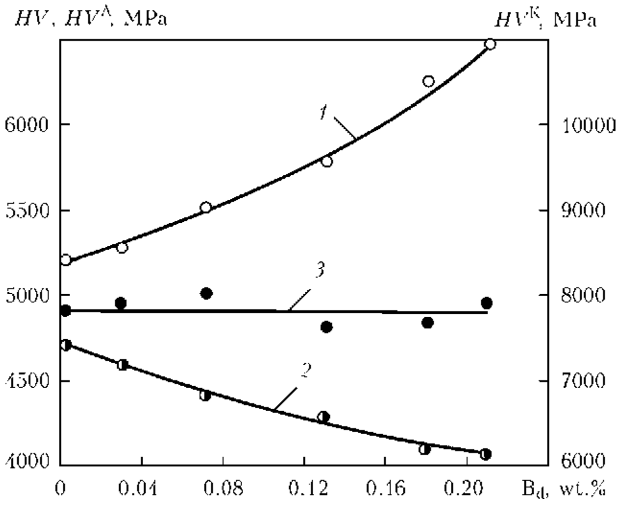

Figure 4. Influence of boron content on macrohardness of deposited metal HV (*1*), of grains of solid solution HV^{A} (*2*) and carbide-cementite network HV^{K} (*3*)

results to significant reduction of grain sizes, increase of density, homogeneity and spread of solidified dendrites of solid-solution and carbide-cementite phase, i.e. formation of fine differential structure with developed network of grain boundaries reinforcing alloy with high strength closed frame. From the other side, the minor additions of SAE, in particular boron, adsorb on the boundaries or sections of crystallites, where concentration of vacancies and lattice distortions [2–4 et al.] is the highest one. At that, further growth of microcracks stops after their rise from the fusion zone in adjacent regions of the deposited metal with fine grain, differential structure and grain boundaries reinforced with boron.

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