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THE EFFECT OF DOPING WITH BORON AND TITANIUM ON THE PHASE COMPOSITION AND PROPERTIES OF CHROMIUM DEPOSITED METAL

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Article deals with the improvement of wear resistance of machine components which may be achieved by an adequate selection of abrasion resistant materials. Iron-based alloys with chromium, manganese, titanium, in combination with boron and carbon have been selected as hardfacing alloys due to their high hardness and wear resistance. Research studies shown the following main results. Hardfacing macrocracks take place on the surface of deposited layer (metal with no boron) and microcracks of various lengths located in the deposited metal as well as in a fusion zone. Addition of boron to the deposited metal results reduction of amount of microcracks. Qualitatively the effect of increasing boron concentration on the phase composition of deposited metal both groups is identical, as for alloys without titanium, or with it. The proportion of boron-containing eutectic grows, and the martensitic-austenitic matrix decreases accordingly. Correlation between eutectic part and deposited metal hardness is shown.

Key words: hardfacing; alloying; boron; titanium; phase composition; cracks; fusion; zone; abrasive wear.

Петренко А. М. «Вплив легування бором та титаном на фазовий склад та властивості наплавленого металу».

У статті розглядаються питання підвищення зносостійкості деталей машин, яке може бути досягнуто шляхом адекватного підбору зносостійкого наплавленого металу. Сплави на основі заліза з хромом, марганцем, титаном, в поєднанні з бором і вуглецем були обрані для дослідження у зв'язку з їх високою твердістю і зносостійкістю. Дослідження показали наступні основні результати. Макротірщини в зносостійкому шарі розташовуються на поверхні. Мікротріщини – в наплавленому металі, а також у зоні сплавлення. Добавки бору знижують кількість мікротріщин. Якісно ефект збільшення концентрації бору на фазовий склад наплавленого металу однаковий для обох груп: як при легування титаном, так і без нього. Частка борвмісної евтектики зростає, а мартенситно-аустенітної матриці зменшується. Продемонстрована кореляція між часткою евтектики і твердістю наплавленого металу.

Ключові слова: зносостійке наплавлення; легування; бор; титан; фазовий склад; тріщини; зона сплавлення; абразивний знос.

Петренко А. Н. «Влияние легирования бором и титаном на фазовый состав и свойства хромистого наплавленного металла».

В статье рассматриваются вопросы повышения износостойкости деталей машин, которое может быть достигнуто путем адекватного подбора износостойкого наплавленного металла. Сплавы на основе железа с хромом, марганцем, титаном, в сочетании с бором и углеродом были выбраны для исследования в связи с их высокой твердостью и износостойкостью. Исследования показали следующие основные результаты. Макротерщины в износостойком слое располагаются на поверхности. Микротрещины - в наплавленном металле, а также в зоне сплавления. Добавки бора снижают количество микротрещин. Качественно эффект увеличения концентрации бора на фазовый состав наплавленного металла одинаков для обеих групп: как при легировании титаном, так и без него. Доля борсодержащей эвтектики растет, а мартенситно-аустенитной матрицы уменьшается. Продемонстрирована корреляция между долей эвтектики и твердостью наплавленного металла.

Ключевые слова: износостойкая наплавка; легирование; бор; титан; фазовый состав; трещины; зона сплавления; абразивный износ.

1. Introduction. Survey of prior research

Abrasive wear happens when a hard object is burdened against particles of a substance that contain identical or superior rigidity. Any material, even if the bulk of it is very soft, may cause abrasive wear if hard particles are in attendance [1]. Wear resistance of materials can be improved through bulk treatment and applying a wear resistant surface onto a cheaper core material [2-5]. While bulk treatment has been practiced for a long time, surface treatment is fairly recent and attains growing importance. Thus the use of coatings is an extremely attractive means of providing inexpensive, easy to fabricate metals with the special properties of materials that may be expensive, and often unworkable, at little increase in cost [2].

Improvement of the wear resistance of machine components may be achieved by an adequate selection of abrasion resistant materials for the deposition of hardfacing layers on the bulk parts. The addition of alloying elements and rapidly solidified fine crystalline microstructure containing finely distributed hard phases can exhibit an excellent combination of hardness and toughness of the hardfaced alloys [3-4]. Coarse hard phases and high hardness are important to achieve high abrasion resistance.

The hardness of the hard phases and/or the hardness of the matrix should be higher than the hardness of the abrasive [4]. Iron-based alloys with chromium, manganese, titanium, in combination with boron and carbon have been selected as hardfacing alloys due to their high hardness and wear resistance gained by the precipitation of different abrasion resistant hard phases. The high chromium irons are widely used for hardfacing of industrial components in mining, cement plants, thermal power plants and iron and steel industries due to their higher hardness and excellent abrasive resistance which attributed to the formation of chromium carbides [2,6,7]. The wear properties are affected by the microstructures and weight fraction of eutectic or primary carbides. So the wear resistance of a hardfacing alloy depends on many factors such as the type, shape and distribution of hard phases, as well as the toughness and strain hardening behavior of the matrix [2]. For this reason, the concordance between the carbide eutectic and matrix should be investigated too.

2. Experimental study

Boron alloying is also widely used in welding using fluxcored wires and strips for obtaining of abrasive-resistant deposited metal [7]. 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 1.5-3.5 wt.%.

Investigated in the present work hardfasing steels can be divided into two groups: "R" - the variation of boron concentration in the deposited metal and "RT" - with a boron and titanium variations (Table 1).

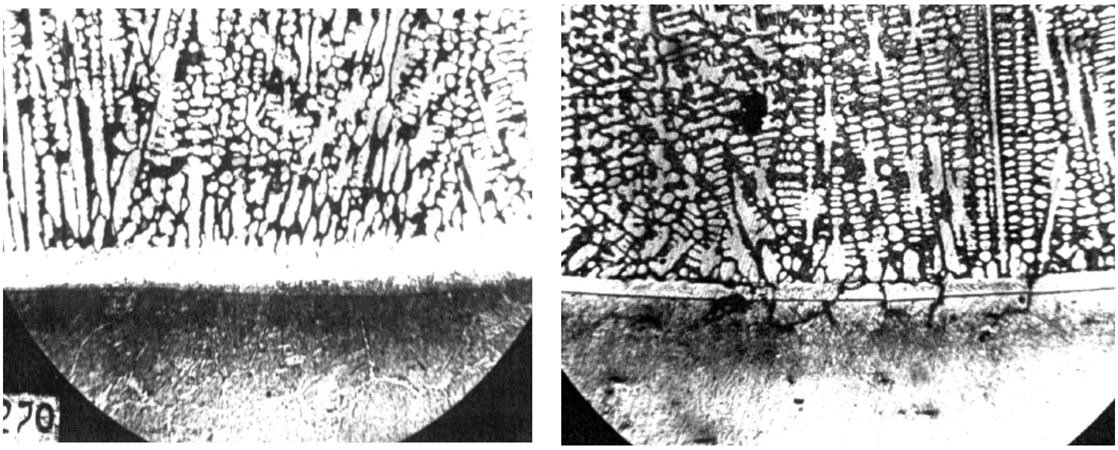
Table 1 – Deposited metal chemical compositions

№ prototype	Elements concentration, %					
	C	Mn	Si	Cr	B	Ti
1	2,0	2,20	0,46	8,7	-	-
2	2,38	3,0	0,48	9,0	-	-
3 (R)	2,66	2,70	0,43	8,8	0,05	-
4 (R)	1,86	2,90	0,57	7,0	0,11	-
5 (R)	1,80	2,57	0,54	6,8	0,25	-
6 (RT)	1,67	1,21	0,44	-	0,23	1,52
7 (RT)	1,80	1,23	0,47	-	0,3	1,52
8 (RT)	2,08	1,32	0,76	-	0,68	2,80
9 (RT)	1,77	1,40	0,76	-	1,10	3,00
10 (RT)	1,86	1,38	0,90	-	0,35	2,89
11 (RT)	1,64	1,41	0,88	-	0,45	3,02

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 samples 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.

3. Results and discussions

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 close to the areas of ledeburite colonies (Fig. 1b). Then they easily propagate in the whole volume of the deposited metal.



a. b.

Fig. 1 – Microstructure Fe-C-Cr-Mn weld metal B and Ti alloyed and fusion zone (compositions No. 6, 8) [8]

Partially melted zone (PMZ) has the “light lamellar zone” close to fusion boundary. It is quite clearly divided into two sections (Fig.1):

- Bright structureless zone, located mainly in its upper part,
- Needle structure zone adjacent to the base metal.

The microhardness of structureless part of “light lamellar zone” approximately equal to the hardness of austenite deposition. Hardness of needle-like structure is characteristic to bainite or bainite-martensite structure. Assuming, this case the initiation of cracking or lamellar tearing is the shear stresses occurring in the light lamellar zone [8].

Increase of boron content results reduction amount of microcracks. Single microcracks take place at boron concentration 0.18-0.20 % more. Boron microalloying more than 0.2 wt.% makes not observable influence on crack resistance of the deposited metal. It was determined by metallographic examinations 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 that have “honeycomb” structure, that is character for low-alloyed cast iron of hypoeutectic composition.

Qualitatively the effect of increasing boron concentration on the phase composition of deposited metal both groups is identical, as in the alloys without titanium, and the alloying of this element. The proportion of boron-containing eutectic grows, and the martensitic-austenitic matrix decreases accordingly.

Evolving carbides (TiC) reduce matrix carbon concentration, microhardness of eutectic and integral hardness for surfacing with minimal (0,3...0,35 %) boron concentration (Fig. 2.).

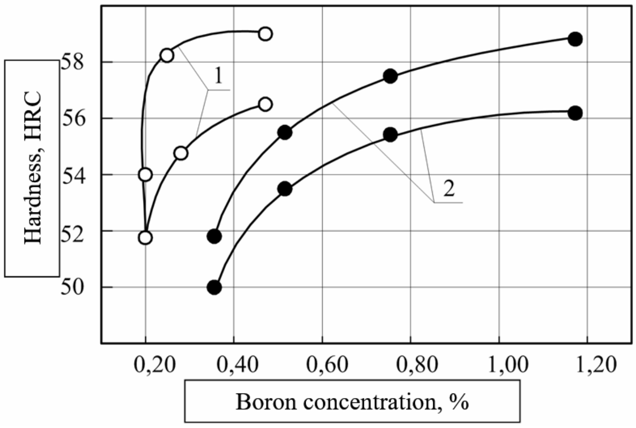


Fig. 2 – Hardness of he deposited metal variable boron and titanium concentration:
1 – 1,7% C; 1,55% Ti; 0,45% Si; 1,2% Mn;
2 – 1,75% C; 2,9% Ti; 0,8% Si; 1,4% Mn

Increasing boron concentration to 0.60...0.70 percent determines the hardness of the alloys with titanium, and microhardness of the eutectic increases less intensively than in the group "R" (Fig. 1) that can be associated with the substance of carbides TiC. The possibility of evolving of appreciable amounts of nitrides of titanium is low, as the nitrogen concentration for single-layer and double-layer hardfasing are respectively 0,008…0,022 % and 0,033…0,038 %.

The influence of thermal conditions on the phase composition shown on Fig. 3, Fig. 4. Decreasing of hardness due to a change in the structure of the products of decomposition solid solution, and some reduction in the fraction of eutectic.

Deposited metal with higher level of boron and titanium has less structure changes and hardness after welding with preheating. Eutectic fraction, which significantly affected mechanical properties and wear resistance deposited metal is calculated as:

$$S_E = \frac{C - C_E}{C - C_C}$$

where: C, C_c, C_e – carbon concentration in the deposited metal, eutectic, and austenite, %.

$$C_C = 4{,}26 - 0{,}3(Si + P) - 0{,}4S + 0{,}03Mn - 0{,}07Ni - 0{,}07Cr, \quad \%$$

$$C_E = 2{,}01 - 0{,}15Si - 0{,}3P + 0{,}04(Mn - 1{,}7S) - 0{,}09Ni - 0{,}07Cr, \quad \%$$

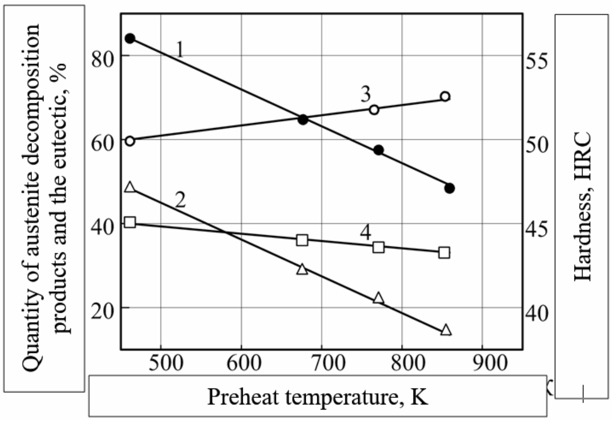


Fig. 3 – Phase composition and hardness of deposited metal is 1.7%; a 1.55% Ti, 0.45% of Si; 1.2% of Mn:
1, 2 – initial hardness and after tempering (853 K).
3, 4 – quantity of austenite decomposition products and the eutectic, respectively

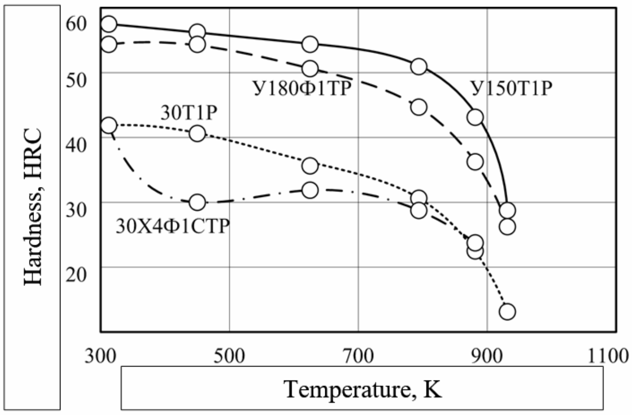


Fig. 4 – The influence of four-time temper (t = 84 h) on the hardness of the deposited metal

Our experiments confirmed a satisfactory convergence fraction of eutectic calculated by the equations and the method of quantitative metallography. Relatively thin (12 mm thick) plates of medium-alloyed cast irons system C-Cr-Mn-Si-Ti was studied. Casting was carried out using copper massive forms, which provided a cooling speed close to the typical values during arc welding. Curves metal hardness eutectic quality for each of the three groups creating total function HRC=f(e) (Fig. 5).

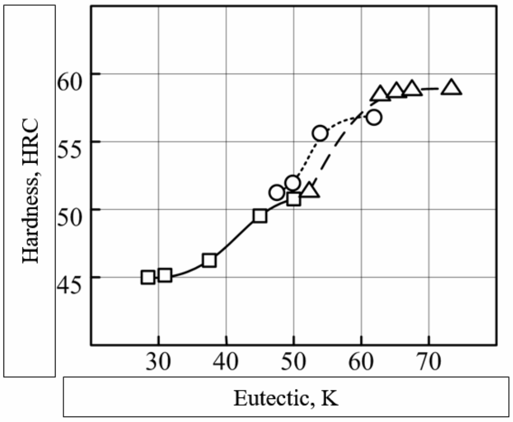


Fig. 5 – Relationship between integral hardness and eutectic fraction

Possibility of using predicted expressions for approximate calculation amount of eutectic in the deposited metal, is indirectly confirmed by the similarity of structure: finely branched structure of dendrites and dispersion of cementite. The structure of deposited metal is martensite or bainite, residual austenite and carbides.

Experimental studies confirm satisfactory convergence predicted values for the fraction of eutectic, calculated by formulas and the method of quantitative metallography.

Summary and conclusion

1. Boron addition to the deposited metal results reduction amount of microcracks. Single microcracks take place at boron concentration 0.18-0.20 % more.

2. Qualitatively the effect of increasing the boron concentration on the phase composition of deposited metal of both groups is identical, as in the alloys without titanium, and the alloying of this element. The proportion of boron-containing eutectic grows, and the martensitic-austenitic matrix decreases accordingly.

3. The influence of welding conditions on the eutectic fraction, and the abrasion resistance of a weld metal has allowed to construct a dependence of the phase composition and hardness.

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