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INFLUENCE OF MOLYBDENUM AND NICKEL ON PLASTIC PROPERTIES OF BORIDE LAYER

The influence of boride layer alloying with molybdenum and nickel on its plastic properties is investigated. Samples of steel 20, 45 and 38ChM were subjected to chemicothermal treatment at a temperature of 950 - 1090°C for 5 hours in a mixture of boron carbide, activators NaF, Na_2CO_3, KBF_4, and powders of Ni and Fe - Mo. Microprobe analysis shows that nickel and molybdenum are mainly concentrated at interphase boundaries with a high concentration of molybdenum (34.5%), which is conditioned by the segregation of molybdenum atoms at interphase boundaries and boride layer defects. The calculations of the total number of destruction ($\overline{Zp}$) and microbrittleness coefficient (K_{1C}) by known methods are correlated with each other and indicate an increase in boride layer plasticity on low-alloy steels 38ChM at the saturation in the boriding mixture containing molybdenum and nickel in the concentration of 3% and 7%, respectively. When comparing microbrittleness of boride layer alloyed with nickel and molybdenum or nickel and molybdenum separately, it is appeared that the co-alloying with molybdenum and nickel improves the boride layer thickness and plasticity.

Keywords: multicomponent saturation, boride layer, microbrittleness, total number of destruction, microhardness, plasticity, relief of wear.

Проведено дослідження впливу легування боридного шару молібденом та нікелем на його пластичні властивості. Зразки зі сталі 20, 45 і 38ХМ піддавали хіміко-термічній обробці при температурі 950 – 1090°С впродовж 5 годин у суміші карбіду бору, активаторів NaF, Na_2CO_3, KBF_4, порошків Ni та Fe - Mo. Результати мікрорентгеноспектрального аналізу показують, що нікель та молібден в основному концентруються на міжфазних границях із високою концентрацією молібдену (34,5%), яка обумовлена сегрегацією атомів молібдену на міжфазних границях і дефектах боридного шару. Результати розрахунку сумарного балу руйнування ($\overline{Zp}$) та коефіцієнту мікрокрихкості (K_{1C}) **за відомими методиками корелюють між собою й указують на підвищення пластичності покриття, утвореного на низьколегованих сталях при насиченні їх у суміші для борування, що містить молібден та нікель у концентрації 3 % і 7% відповідно. При порівнянні показників мікрокрихкості боридних покриттів, легованих молібденом і нікелем або окремо молібденом і нікелем, виявилося, що спільне легування боридного шару молібденом і нікелем сприяє підвищенню товщини та пластичності боридного шару.**

Ключові слова: багатокомпонентне насичення, боридний шар, мікрокрихкість, сумарний бал руйнування, мікротвердість, пластичність, рельєф зносу.

Проведено исследование влияния легирования боридного слоя молибденом и никелем на его пластические свойства. Образцы из стали 20, 45 и 38ХМ подвергали химико-термической обработке при температуре 950 – 1090°С в течение 5 часов в смеси карбида бора, активаторов NaF, Na_2CO_3, KBF_4, порошков Ni, Fe - Mo. Результаты микрорентгеноспектрального анализа показывают, что никель и молибден в основном концентрируются на межфазных границах с высокой концентрацией молибдена (34.5 %), которая обусловлена сегрегацией атомов молибдена на межфазных границах и дефектах боридного слоя. Результаты расчета суммарного балла разрушения ($\overline{Zp}$) и коэффициента микрохрупкости (K_{1C}) **по известным методикам коррелируют между собой и указывают на повышение пластичности покрытия на низколегированных сталях при насыщении их в смеси для борирования, содержащей молибден и никель в концентрации 3 % и 7% соответственно. При сравнении показателей микрохрупкостей боридных покрытий, легированных молибденом и никелем или отдельно молибденом и никелем, оказалось, что совместное легирование боридного слоя молибденом и никелем способствует повышению толщины и пластичности боридного слоя.**

Ключевые слова: многокомпонентное насыщение, боридный слой, микрохрупкость, суммарный балл разрушения, микротвердость, пластичность, рельеф износа.

1. Introduction

Diffusion saturation of the metal surface with one element in some cases can not satisfy the practical requirements because does not provide a product with a complex of the necessary operational properties. Therefore more often diffusion saturation of the surface of metals and their alloys is carried out simultaneously by multiple elements. For example, the saturation of steel with boron and transition metals - tungsten and molybdenum - contributes to a greater increase in wear resistance than borating. At saturation of the steel surface with one element, such as boron, a boride layer having a high hardness and brittleness is formed. Due to different surface stresses on the phases boundary FeB and Fe_2B a cleavage can be formed on the surface. Boride layer alloying (in small quantities) allows to remove signs a critical difference of residual stresses therein [1] and to improve the surface quality.

The aim of this work is to study the influence of boride layer alloying with molybdenum and nickel on its plastic properties.

2. Experimental procedure

Experimental samples of steel 20, 45 and 38ChM were subjected to chemicothermal treatment at a temperature of 950 - 1090°C for 5 hours in a mixture of boron carbide, activators NaF, Na_2CO_3, KBF_4, and powders Ni and Fe - Mo. Metallographic analysis of the samples was carried out using a microscope NEOPHOT 21 and microdurometer PMT-3. To investigate the surface relief of samples and to determine the borated layer composition the scanning electron microanalyzer REMMA - 102-02 was used. Calculations of I mode deformations critical stress intensity factor (K_{1C}) and the total destruction number ($\overline{Zp}$) were performed according to the methods [2] and [3], respectively.

3. Results and discussion

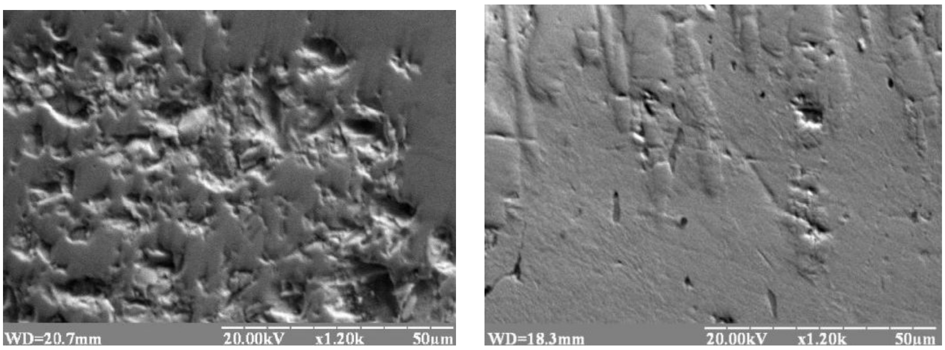
The results of the diffusion layer investigation are shown in Table 1, and Fig. 1, 2, 3.

Table 1

The results of micro brittleness calculation by methods [2, 3]

№	Grade of steel	Amount of alloying elements in the boriding mixture, wt%		Phase	Z_{200}	K_{1c}
		Fe-Mo	Ni			
1	38ChM	3.9	6.6	FeB	117	
				Fe_2B	75	5.1 - 5.2
2	45	10	-	FeB	117	
				Fe_2B	72	4.1 - 4.2
3	38ChM	3	7	FeB	102	
				Fe_2B	57	4.7 - 4.8
4	20	-	6	FeB	-	-
				Fe_2B	100	2.8 – 3.0
5	45	-	-	FeB	-	1.4
				Fe_2B	110	2.9 - 3.2

Fig. 1 shows the relief of boride phases wear alloyed with molybdenum and nickel on steels 45, 38ChM. Carbon steel has fewer defects (Fig. 1, b) and wear is carried out over the cells, but the layer destruction is due to brittle fragments. At the saturation of surface steel with boron and nickel a continuous borides layer thickness and relative content of high boron phase increased, but boride layer plasticity reduced.



(a) **(b)**

Fig. 1. Microstructure of boride phases wear in secondary electrons: (a) – steel 38ChM (№1, table 1), (b) – steel 45 (№ 2, table 1).

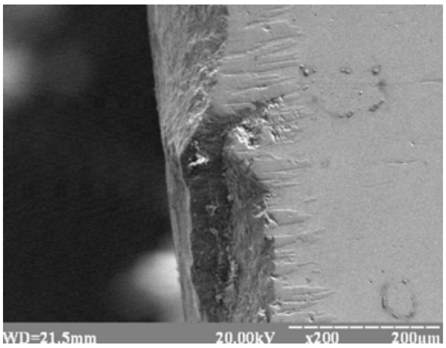


Fig. 2. The relief of boride phases wear in secondary electrons for steel 20 (№4, table 1)

Fig. 2 shows the relief of boride phase wears with cleavage of the boride layer alloyed by nickel. According to X-ray spectral analysis, nickel in small amounts (0.5%) is present in the composition Fe_2B only at the saturation temperature of 1000 ° C and above. At temperatures of 900 - 1000°C Ni is allocated on the boride phases boundaries.

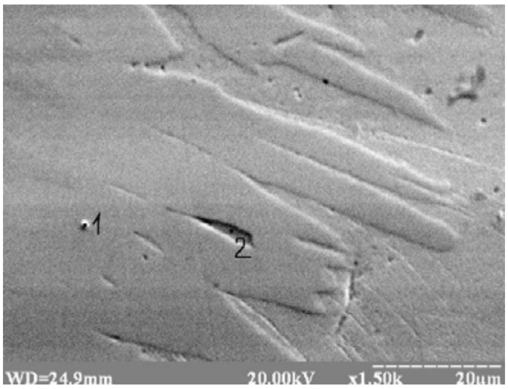


Fig. 3. The microstructure of borides (x1200, in secondary electrons) on steel 45 with points for electron microprobe analysis (1 - 0.5% Mo, 2 – 34.28 %Mo).

At the saturation of surface with boron and molybdenum a total thickness of continuous boride layer decreased (130 microns or less), but a monoborid iron microhardness and micro brittleness increased [4]. It indicates that the molybdenum effect on Fe_2B microbrittleness is much weaker. Microcrystalline carboboride inclusions of $(Fe,Mo)_3(C,B)$ appeared in a sublayer under the needle.

At the surface saturation with boron, nickel, and molybdenum, the continuous borides layer with thickness of 150-170 microns, microhardness H_μ = 13-15GPa and microinclusions with increased microhardness (H_μ = 24-25GPa) in diboride layer and with the lowest total number of destruction (Z_{200}) was obtained (Table 1). The micro X-ray spectral analysis shows that the nickel and molybdenum are mainly concentrated at interphase boundaries. Fig. 3 shows zones with a low content of molybdenum (point 1) and the zone (point 2) where there is an accumulation of molybdenum (high percentages). Low concentration of molybdenum in the Fe_2B phase is due to weak boride forming ability of molybdenum. Molybdenum presence in this phase is caused by the ability to dissolve molybdenum in iron on the replacement mechanism [4]. The high concentration of molybdenum (34.5%) in point 2 (fig. 3) is due to segregation of molybdenum atoms at interphase boundaries and boride layer defects.

There are only traces of nickel on the boride phase boundary, but nevertheless its modifying effect influences the boride layer thickness, promoting the growth of layer. When comparing micro brittleness of the boride layer alloyed with nickel and molybdenum or nickel and molybdenum separately, it appeared that co-alloying with molybdenum and nickel improves the boride layer thickness and plasticity (Table 1).

5. Conclusions

Thus, co-alloying of boride layer with molybdenum and nickel promotes the formation a complex coating with elements of different microhardness and increased resistance to brittle fracture, while preserving its thickness and microhardness. The calculations of the total number of destruction ($\overline{Z}p$) and micro brittleness coefficient (K_{1C}) by known methods are correlated with each other and indicate an increase in boride layer plasticity on low-alloy steels 38ChM at the saturation in the boriding mixture with containing 3% and 7% of molybdenum and nickel, respectively.

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