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ФОРМИРОВАНИЕ ГРАДИЕНТНЫХ ПОВЕРХНОСТНЫХ СЛОЕВ НЕОДНОКРАТНЫМ ЛАЗЕРНЫМ ЛЕГИРОВАНИЕМ

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FORMATION OF GRADIENT SURFACE LAYERS BY MEANS OF MULTIFOLD LASER ALLOYING

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Исследовали возможность получения лазерно-легированных слоев с плавным градиентом свойств. Это достигалось проведением неоднократного легирования с последовательным уменьшением глубины зоны переплава. Полученный характер распределения структурных составляющих и градиента свойств по глубине, а также общая морфология упрочненного слоя заставляют ожидать высокого уровня его эксплуатационных свойств в условиях высоких контактных нагрузок.

Ключевые слова: многократная лазерная обработка, градиент свойств, микроструктура, распределение твердости.

Ил. 2. Табл. 3. Библиогр.: 4 назв.

The capability of deriving laser alloying layers with a smoothly varying gradient of properties was investigated. It was reached by conducting of repeated alloying with a series of lower depth of a melting zone. Obtained nature of allocation structural component and gradient of properties through the thickness, as well as general morphology of the hardened layer have proved a high level of its operation properties in conditions of high contact loading.

Keywords: multifold laser treatment, properties gradient, microstructure, hardness distribution.

Fig. 2. Tab. 3. Ref.: 4 titles.

Specific features of a layer structure formed at a laser alloying are: high degree of phases' metastability, a considerable supersaturating of solid solutions, high alloying of reinforcing phase, and also essential level of residual stresses [1–3]. Besides, there is a big gradient of physical-mechanical properties through the layer thickness that is connected with existence of sharp border between an alloying zone (melting bath) and the bulk material. However for a number of the details working in the conditions of big specific and/or sign-variable loadings, such structure character not always is optimum. Stable thermodynamic structures with a smooth gradient of properties through layer cross-section are more preferable. Considering that use of laser strengthening processing expediently for cases when traditional methods can't be used for constructive or technological reasons [4], is of interest studying influence of repeated heat treatment of the laser alloyed layers with laser radiation on a microstructure and properties of surface layers. It was the purpose of the present research.

Laser alloying was carried out using technological laser installation on the basis of the continuous laser "Comet 2" with power up to 1200 W.

In experiments on samples from steel 45 applied two alloying coatings: mix of equal volumes of boron and chrome carbides (B + Cr_7C_3, Cr_3C_2) and mix of equal volumes of boron and boron carbides (B + B_4C). Thickness of a plastering layer made 0.09–0.11 mm and was controlled by the MT-40NTs feeler gage.

Metallographic study of layer structure conducted by means of "Neophot-2" microscope. Phase structure studied on the X-ray diffractometer "DRON 3.0". For analysis of the X-ray diffraction results used specially developed package of programs.

Various technological parameters of an alloying (Tab. 1) were considered.

Table 1

Technological parameters of multifold laser alloying

№ of experiment	Type of treatment during processing			Beam velocity, mm/min		
	I	II	III	I	II	III
1	LL	–	–	200	–	–
2	LL	LQ	–	200	400	–
3	LL	LL	–	200	400	–
4	LL	LL	–	200	900	–
5	LL	LL	LL	200	400	900
Remarks: I, II, III – number of passes; LL – laser alloying; LQ – laser quenching.						

The structure of the strengthened layer after laser borating and boron-chroming coatings has classical character for the samples subjected to a laser alloying irrespective of irradiation frequency rate [1–3]. In a hardening zone it is possible to allocate the following areas: the alloyed surface layer, transitional zone of thermal influence and the bulk metal. However feature of structure after double laser processing is that the alloyed layer is divided into two zones formed under the influence of primary and secondary remelting (Fig. 1). Depth of the alloyed layer corresponding to the lower bound of primary remelting is equal 220–300 microns. The border of a secondary remelting zone settles down at a depth of 170–270 microns.

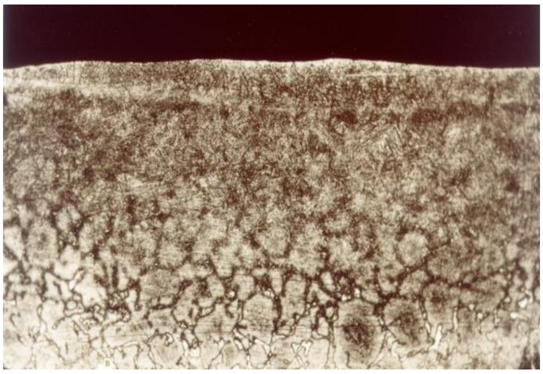

Fig. 1. Microstructure oflaser-alloyed layer after twofold laser treatment (coating B + B_4C), ×100

As show results of X-ray diffraction researches of the phase structure (Fig. 2) laser heat treatment of the coatings alloyed by the laser leads to change of their phase structure. Thus the amount of iron solid solution increases but the amount of a carbide component and non-reacted boron (at laser borating) decreases. In case of coatings with additives of chromium carbide the dissolution of a carbide component promotes increase of the content of residual austenite. The amount of oxides as the technology provides laser processing without use of the protective atmosphere increases.

At a twofold laser alloying the amount of oxides in case of plastering use with additives of boron carbides doesn't increase and oxides disappear in case of coatings with additives of chromium carbides. Like after laser quenching the amount of iron solid solution increases in last case. Specific feature for both mixtures is appearance of residual austenite that it is possible to explain with high degree of a solid solution alloying. It is the most probable that increase of degree of a solid solution alloying is connected with dissolution of the carbide phase which contents is compensated for the account of introduction of additional quantity of alloying components.

Change of phase structure at increase in speed of the second pass with a plastering on the basis of boron carbide consists in emergence of a small amount of residual austenite. In case of use of a coating with additives of chromium carbide increase of processing speed leads to reduction of a carbide component. It can be explained to that increase of beam velocity leads to higher cooling rate of melted bath and according to increase of formed structure's metastability degree. In the presence in melting bath of boron-containing components crystallization of a carbide component happens in the second turn after formation the boron phases.

Mentioned above is confirmed by results of the phase structure analysis of the layers obtained by a triple laser alloying in which the increase in laser beam velocity from pass to pass leads to receiving structure with even large amount of solid solution and the corresponding reduction of quantity of a reinforcing phase.

Results of estimates of alloying degree for different phases are given in Tab. 2.

It should be noted that the nature of a component alloying for this phase was estimated on compatibility of phases, in size of nuclear radiuses, by the form a crystal lattice and has probabilistic character.

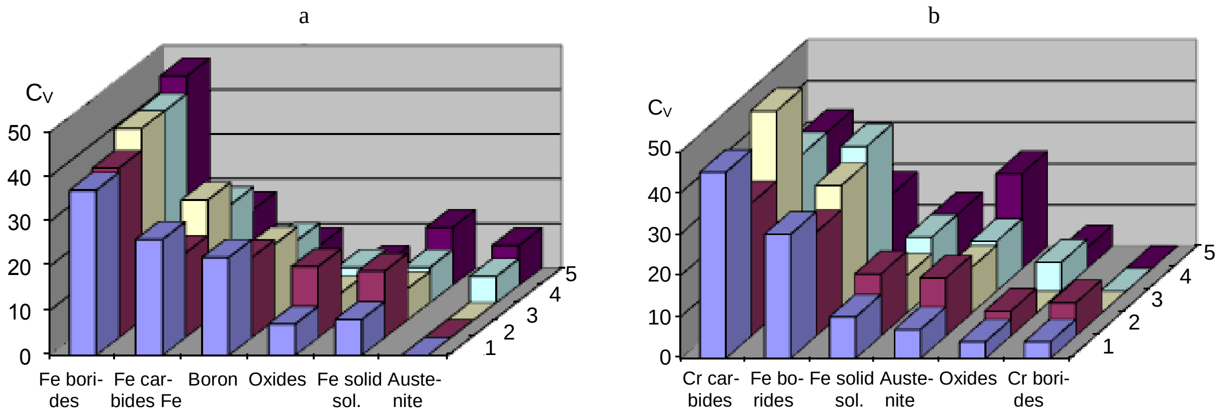

Fig. 2. Results of semi-quantitative analysis of phase composition after laser treatment of different coatings: a – $B_{ам} + B_4C$; b – $B_{ам} + Cr_7C_3$, Cr_3C_2

Table 2

Estimation of alloying degree for different phases

Phase	Probable nature and alloying degree depending on processing parameters, (% at.)				
	1	2	3	4	5
Amorphous boron + Boron carbide					
α-Fe	Carbon 0.03	Carbon 0.01	Non	Carbon 0.02	Carbon 0.03
γ-Fe	–	–	–	–	–
Fe_2B	Boron + 0.7	Non	Non	Non	Non
FeB	Non	Boron + 0.9	Boron + 0.5	Boron + 0.3	Boron + 0.25
Fe_3C	Non	C is replaced with B 5	C is replaced with B 6.3	C is replaced with B 2.7	C is replaced with B 2.3
Amorphous boron + Chromium carbide					
α-Fe	Chromium 0.8	Chromium 0.45	Non	Non	Non
γ-Fe	Carbon 0.8	Carbon 0.63	Non	Carbon 0.8	Carbon 1.0
Fe_2B	Chromium 0.9	Boron – 0.45	Boron – 0.6	Boron – 0.4	Boron – 0.3
FeB	Chromium 7	Chromium 7.5	Chromium 6	Chromium 3.5	Chromium 2
Cr_3C_2	Carbon + 1.5	Carbon + 0.8	Carbon + 0.65	Carbon + 0.85	Carbon + 1.0
Cr_7C_3	Carbon + 1.8	Carbon + 0.8	Carbon + 0.1	Carbon + 0.1	Carbon + 0.1
Fe_2C	Boron + 1.4	Boron + 1.15	Boron + 1.5	Boron + 1.2	Boron + 1.35

Apparently from the provided data, at a single laser alloying rather high degree of structural components' alloying which remains at the subsequent laser quenching though its level and decreases for all phases is observed. The repeated laser alloying at beam velocity 400 mm/min leads to equilibrium iron component – the effect of "laser annealing" of strengthened layer is reached. At the same time at velocity 900 mm/min as in case of double and triple processing degree of a structural components' alloying increases. It should be noted non-equilibrium state of reinforcing phase for all laser processing options, thus cementite is enriched with boron and represents boron-cementite.

Estimation of residual stresses' level in layers' phases, i.e. stress of the second type, was carried out by comparison of parameters of a lattice of the alloyed layers with those of a lattice of the shaving received at turning of the alloyed layer and prosowing through a sieve with a cell 0.3 mm. The described technique itself assumes rather high error (about ±50 MPa). However it is possible to estimate both a sign of stresses, and their value at qualitative level (high or low). Results of stresses estimates in the solid solution phases are given in Tab. 3.

The analysis of the data provided shows that in α-phase the squeezing stresses, and in residual austenite – the stretching stresses are formed.

Researches of microhardness of twofold alloyed layers showed that the general nature of distribution through cross-section remained, that is curves have three characteristic hardness areas: alloying zones, thermal influence zone, bulk material.

Table 3

Character and level of residual stresses in solid solutions phases

Phase	Residual stresses, MPa for different processing			
	1	2	3	4
Amorphous boron + Chromium carbide				
α-phase	–295	–202	+12	–26
Austenite	+126	+16	+801	–658
Amorphous boron + Boron carbide				
α-phase	–44	–196	–105	–213

However repeated laser processing provides smoother gradient of microhardness through layer thickness. When borating the microhardness value can reach about 9000 MPa at a single alloying and about 8000 MPa at repeated processing that can speak more uniform distribution of reinforcing boride components and also diffusion of alloying elements in layer depth at secondary laser influence. At single processing higher gradient of hardness change takes place. With increase in repetition rate of processing and velocity during repeated passes the hardness gradient in a remelted zone decreases. Values of hardness in thermal influence zone decrease from 4500 MPa at single processing to 3500 MPa at double fold treatment (v_2 = 900 mm/min.). Its depth at all modes of processing remains to a constant and makes from 200 to 350 microns and is defined by heat amount’s input in metal at the first pass by a laser beam.

Nature of hardness distribution in the boron-chroming layers has a number of essential differences. Almost on all areas their hardness is higher. The maximum values of hardness on a surface reach 11000 MPa at single processing. With additional passes they make 10000 MPa at double fold and 8000 MPa at a triple alloying. Hardness increase in comparison with borating is connected with a alloying of chromium solid solution and also emergence of bigger quantity reinforcing phases to what results of the X-ray diffraction analysis testify.

Distribution of hardness values in remelting zone at a boron-chroming unevenly: there are pronounced maxima on a surface and at a depth of 150–200 microns, and at a depth of 100 microns hardness falling is observed. The specified excess of curves can be explained to that at repeated remelting of the laser alloyed zone the maximum crystallization rate takes place in its lower part on border with a bulk material. As a result in this area metastable structure of solid solution is fixed and the smaller quantity of a strengthening phase manages to crystallize that leads to hardness fall compare to surface hardness.

CONCLUSION

1. It is established that at a laser alloying the phase structure of remelting zone includes a metal matrix (α-and γ-Fe) and reinforcing phases: borides FeB and Fe_2B, cementite, as well as chromium carbides and boride in case of a laser boron-chroming. Repeated laser processing doesn't cause high-quality changes of phase structure but only leads to increase of a reinforcing phase.
2. Depending on the velocity of the second pass at a laser alloying receiving both equilibrium structure without distortion of a crystal lattice of a metal matrix (laser annealing) and more non-equilibrium structure in comparison with a single alloying (laser quenching) is possible. The repeated laser alloying at a velocity of the laser beam movement on the second pass of v_2 = 400 mm/min provides a minimum level of residual stresses in the α-Fe.
3. Repeated laser processing provides possibility of receiving the alloyed layers with a smooth properties’ gradient through layer thickness.

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