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THE EFFECT OF CARBURIZING AND HEAT TREATMENT ON THE INCREASE MECHANICAL PROPERTIES OF COST-SAVING WEAR-RESISTANT Fe-Cr-Mn DEPOSITED METAL

Regularities and advantages of formation of metastable phase-structural modifications of deposited wear-resistant Fe-Cr-Mn steels in surface layers due to the use of carburizing and quenching from different temperatures are defined. After optimal quenching regimes, an increased level of wear resistance is achieved in different wear conditions.

Key words: *deposited metal, heat treatment, martensite, metastable austenite, martensite transformations, wear resistance.*

Introduction

Thermochemical treatment (TChT), especially carburizing and nitro-carburizing has found wide application for surface strengthening. Traditionally carburizing low-alloyed steels (with 0.1…0.3 mass.% C) undergo such treatment. By means of subsequent quenching and tempering martensite-carbide structure of carburized layers is usually obtained, ensuring the highest hardness HRC56…62 and retaining of retained austenite (A_{ret}) is avoided [1]. Meanwhile in some of investigations positive influence of different amount of A_{ret} in carburized and nitro-carburized layers upon improvement in wear-resistance, contact endurance and other services characteristics was mentioned, due to its metastability, the degree of which must depend on detailed conditions of service.

However, data on the features of the formation of complexes of phase-structural modifications of surface layers of deposited wear-resistant metal by TChT are very limited, which requires further researches to improve the operational properties.

The aim of this work is to investigate the possibility of further improving the wear resistance of the deposited Fe-Cr-Mn metal by using of carburizing and heat treatment to form metastable phase-structural modifications that realizing $\gamma \to \alpha'$ DIMTW with self-strengthening effect.

Literature review

Nevertheless, in a number of studies [2–8], the positive influence of A_{ret} in carburized and nitrocarburized layers on the increase wear resistance, contact endurance, and other operational properties of standard carburized steels is indicated due to their metastability, the degree of which should depend on the operating conditions [8].

Increasing the wear resistance of special steels after cementation and quenching from optimal temperatures due to the use of metastability of austenite, which is manifested in the realization of the deformation induced martensite $\gamma \to \alpha'$ transformation at wear (DIMTW) is shown in works [9–14].

As for deposited metal TChT application is so far limited [9, 10, 13, 14], still the results of contemporary investigations witness its good prospects. After hardfacing of low-carbon alloyed steels, their hardness is relatively low and they are quite well machined. By means of carburizing or nitro-carburizing wear-resistance and service properties of deposited metal can be drastically increased, especially with regard to formation of metastability of austenite component of the structure.

For additional surface strengthening of the majority of low and medium carbon DM the described types of TChT can be successfully applied, just like for ordinary carburized structural steels.

Still, as hardfacing is in most cases performed for restoration of parts, operating under difficult conditions of different wear types, it is necessary to presume development of ways and methods of subsequent heat treatment, ensuring obtaining some specified amounts and metastability of A_{ret} for such conditions. Then application of its $\gamma \to \alpha'$ DIMTW jointly with martensite-carbide structure will be mostly efficient for realization of the effect of self-strengthening and additional increase of wear-resistance.

Still, for medium and high alloyed deposited metal it is necessary to take into account the peculiarities of their alloying, so that it will be possible to design hetero-phase metastable modifications of the deposited layers for different objectives and diversified operating conditions of parts. Now, let us discuss the most promising ones.

Particularly, for low-carbon Fe-Mn deposited metal of 15 Mn (5…14)SiTi type investigations were carried out and it was recommended to apply carburizing and subsequent high-temperature tempering, which would allow obtaining at the depth of 1.2…1.5 mm high-carbon manganese containing (5…14 % Mn) austenite [10, 11]. The degree of metastability of austenite and the kinetics of its DIMTW are to be modified by the temperature and holding time.

Materials, heat treatment, methods researches and experiments

Electric arc hardfacing was carried out by the aforementioned powder wire PP-Hp-20Cr12Mn10SiTiNV grade with a diameter of 4 mm at the A1401 welding machine with a VDU 1001 power supply with reverse polarity. To protect the weld metal, fluxes of AN-348 grades were used. The hardfacing modes are as follows: welding current 320...400 A, arc voltage 28...32 V, the deposition rate was V_{dep} = 22...32 m/h, the number of layers 3...4 [15]. From deposited metal samples for research and testing were made.

Carburizing of specimens (samples measuring 10×10×27 mm) of deposited metal of 20Cr12Mn9SiTiNV grade in a solid carburizer at 960…980 °C during 18 h. After carburizing varying the temperature of the subsequent quenching within 900…1100 °C (holding 20 min, cooling in oil) range gave the opportunity of modifying the phase structure of carburized deposited metal.

Analysis of the chemical composition was carried out using the “Spectrovac 1000” and “SpectroMAXx” vacuum quantometers using the spectral method. The microstructure was researched on metallographic microscopes MMR-2 and “Neophot-21” at enlargement from 50 to 500 times. The microhardness of the structural components was measured on a PMT-3 microhardness gauge by pressing a diamond tetrahedral pyramid under a load of 1.96 N, and the hardness of deposited metal on a Rockwell hardness gauge with a load of 1500 N (HRC) and 600 N (HRA). Dynamic bending tests were carried out on a pendulum copre IO5003 on samples with a measuring of 10×10×55 mm with a U-shaped notch.

Tests for wear were carried out under various friction and wear conditions. In the case of dry friction metal on metal, they were carried out on a MI-1M machine on samples measuring 10×10×27 mm in accordance with the scheme test sample – a roller (control body) rotating at a speed of 500 min^{-1} (linear speed in the friction zone – 1.31 m/s, the friction path is 1965 m). Wear time was: between two weightings – 5 minutes, the total – 25 minutes. Weighing was performed with an error of up to 0.0001 g. Relative wear resistance was determined by the formula:

$$\varepsilon = \frac{\Delta m_{st}}{\Delta m_{sample}}, \qquad (1)$$

where Δm_{st}, Δm_{sample} is the loss of mass, respectively, of the standard sample and the sample of the deposited metal for the same wear time. As a standard sample, steel 45 (contain 0.45 % carbon) was used with a hardness of HB180…190. Tests for impact abrasive wear were carried out on a facility described in [16] in a medium of cast iron shot (fractions 0.5...1.5 mm) at a samples rotation speed of 2800 min^{-1}. Tests for abrasive wear were carried out according to the Brinell-Howarth scheme in quartz sand. The relative impact-abrasive wear resistance (ε_{i-a}) and abrasive wear resistance (ε_a) was also determined by the formula (1).

Results of researches and its discussion

The microstructure of the surface layer of the deposited metal after carburizing (without heat treatment) is shown in Fig. 1. It consists of large austenite grains, inside and along the contour of which are carbides Cr_7C_3 and $Cr_{23}C_6$, closer to the transition layer the amount of carbides decreases, which causes coarsening of the austenite grain. Then, along carburized layer, martensite appears along with the austenite, its amount increases and the structure becomes martensitic-austenitic with a high microhardness $H_{0.98}$ = 6000...6500 MPa. Closer to the fusion zone with the base metal, due to an increase in the carbon content in the transition layer, an austenite structure with a small amount of carbides and crushed grain is observed. Next follows the pearlite structure of the parent metal along the grain boundaries, a carburized network was distinguished.

The scope of alternations of its structure along the cross-section of specimens from different temperatures quenching from 900 °C to 1100 °C with cooling in oil is pictured in Fig. 2. The surface layer consists of austenite grains, inside and along their contour lots of carbide particles of $(Cr,Fe)_7C_3$, $(Cr,Fe)_{23}C_6$, TiC and VC composition are placed. In the vicinity of the transitional layer the amount of carbides decreases and it causes some growth of austenite grains. Then, a little deeper, and the structure acquires martensitic-austenitic view, having high micro-hardness 6000…6500 MPa. Closer to the melting fusion zone with the base metal, due to the growth of carbon in the transitional layer austenite structure with small amount of carbides and fine grain is observed.

It should be noticed that the structure of the carburized layer of deposited steel contains a big amount of carbide phases and their content was determined according to Glagolev’s method [17], while the carbon content was estimated for zones 1…4 deposited steel (see Fig. 2) by means of the following formula:

$$C_{surface\ layer} = K \cdot C_{carb} + C_{s.s.}, \qquad (2)$$

where K – is the content of the carbide phase in the investigated segment;

C_{carb} – is carbide content in carbide phase, %;

$C_{s.s.}$ – is carbon content in solid solution, %.

Carbon content in $(Cr,Fe)_{23}C_6$ carbide is ~ 5.7…6.0 mass.% C, and in Cr_7C_3 ~7 mass.% C, in austenite (according to experimental data) is about 1.2 mass.% C.

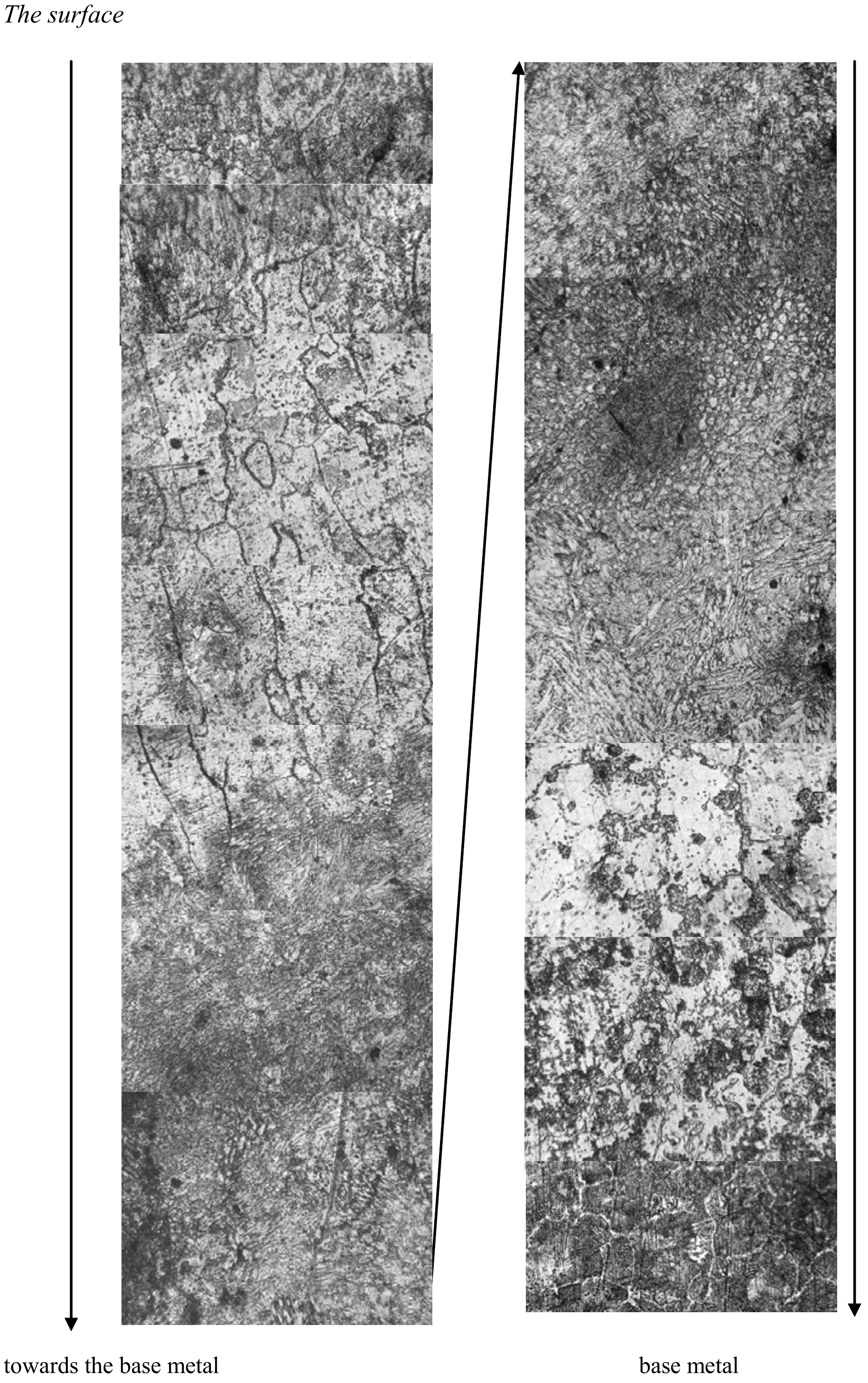

Fig. 1. The microstructure of the deposited steel grade 20Cr12Mn9SiTiNV after carburizing is 960...980 °C, 18 hours, ×400.

Estimated distribution of carbides (carbon-nitrides) and carbon along the depth of the carburized layer in deposited steel 20Cr12Mn9SiTiNV grade after quenching at 900 °C are shown in Fig. 3. At quenching from a relatively low temperature (900 °C), which is not sufficient enough for dissolving of special carbides, a large amount of carbide (carbon-nitride) phases of chromium, titanium and vanadium is retained, their aggregate share being about ~ 40 %, it corresponding to carbon content 2.85 mass.%. Gradually, the amount of carbide phases along the thickness of the carburized layer (h = 0,4…0,5 mm) is reduced to ~32 %, then micro-hardness within the area of fine-grain austenite drops from 6700 MPa near the surface to 5000 MPa at the distance of 1.1 mm, it corresponding to the amount of carbide phase equal to about 20 % in austenite matrix. Carbon concentration decreases when the distance from

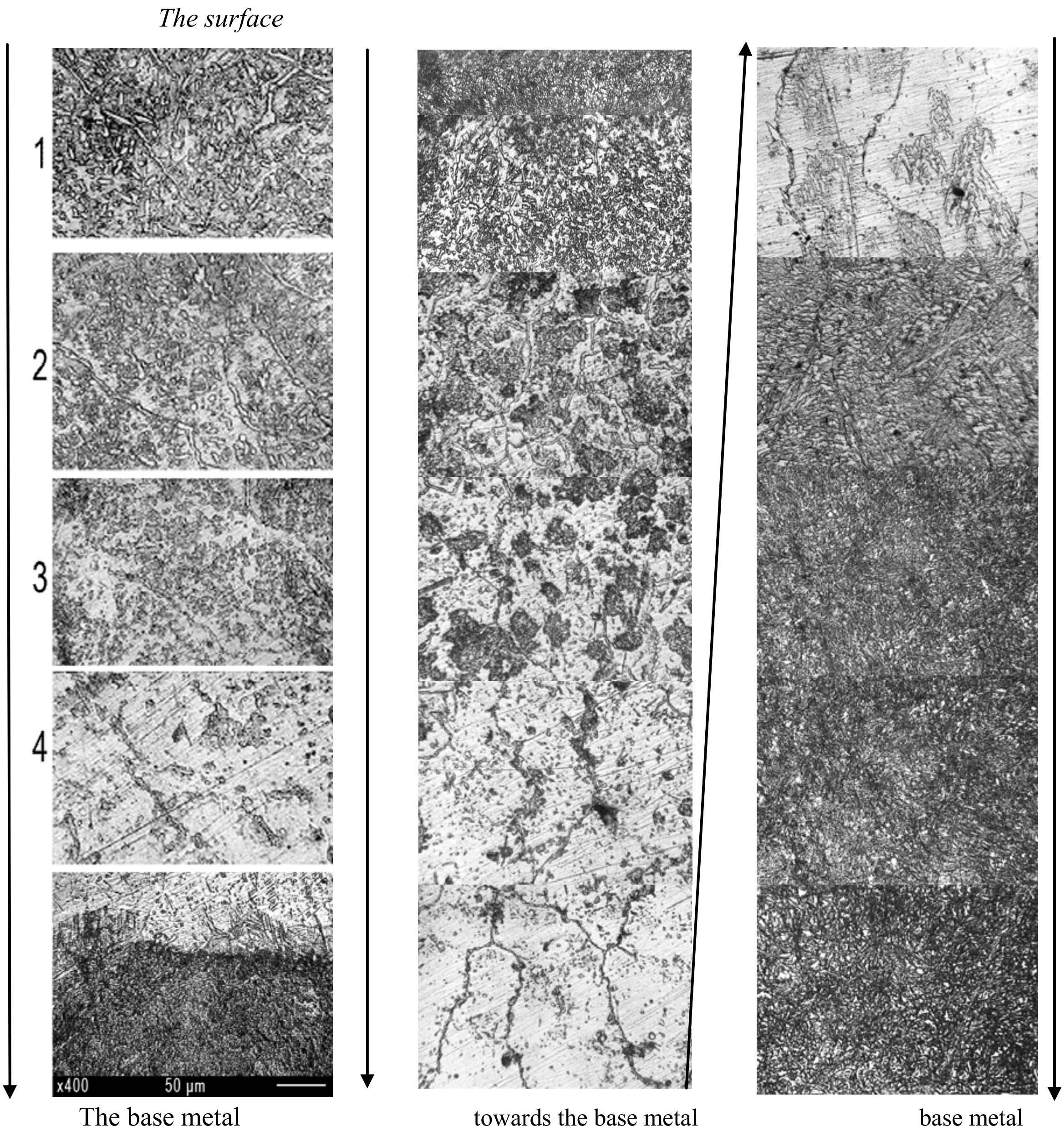

Fig. 2. The microstructure of the deposited steel of 20Cr12Mn9SiTiNV grade after carburizing at 960…980 єC, for 18 hours and quenching at 900 єC (*a*) and 1100 °C (*b*)

the surface is raised, it leading to a drop in micro-hardness to 2500…3000 MPa.

The reason of such substantial growth in carbide and carbon content in the carburized surface layer – exceeding the equilibrium level in Fe-Cr-Mn deposited steel (with chromium content exceeding 8 %) is the presence of the mechanism of internal carburizing, due to high degree of affinity of chromium and carbon, leading to reactive diffusion of carbon and chromium.

To study the distribution of alloying elements according to the depth of the carburized layer of the deposited metal, spectral analysis on quantimeter was carried out (with sequential grinding every 0.2 mm). The curves of changing in the concentration of alloying elements along the depth of the carburized layer are shown in Fig. 4. It is interesting that in a thin surface layer the chromium content of 10.76 mass.% is a bit lower than at some depth ~ 0.4...0.6 mm – 11.84 mass.% Cr (Fig. 4), which is due to the effect of reverse diffusion of chromium in the process the formation of special carbides $Cr_{23}C_6$ and Cr_7C_3 [18]. The content of manganese, on the contrary, is above the equilibrium surface in the thin surface layer and is 9.72...10.04 mass.%, although at a small distance of 0.4...0.6 mm its content is reduced to 9.11...9.30 mass.%, and at a distance ~ 0.2 mm from the surface only 8.83 % Mn contains in the layer (see Fig. 4). This can be explained by the diffusion redistribution of manganese in connection with the formation of carbide phases and austenite structure. It is

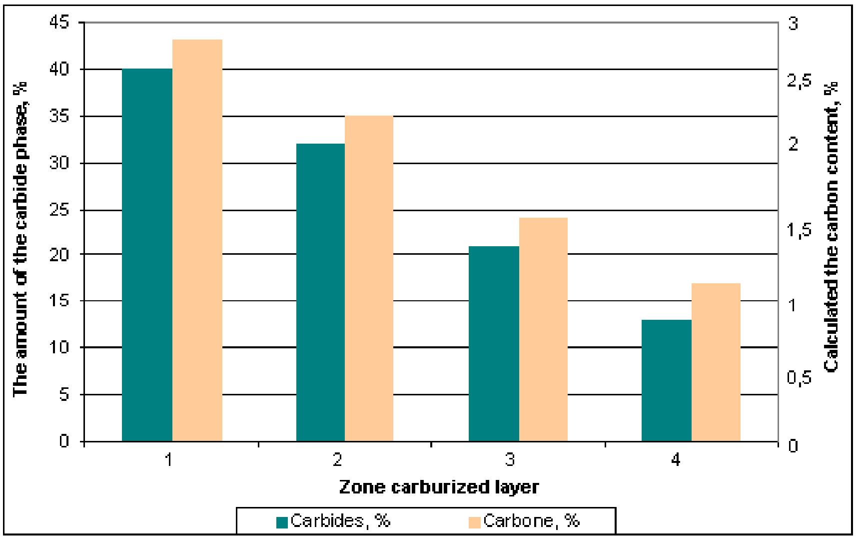

Fig. 3. Distribution of the amount of carbide phase and estimated carbon convent along the depth of the carbonized layer in deposited metal 20Cr12Mn9SiTiNV grade, after quenching at 900 °C (see Fig. 2 *a*)

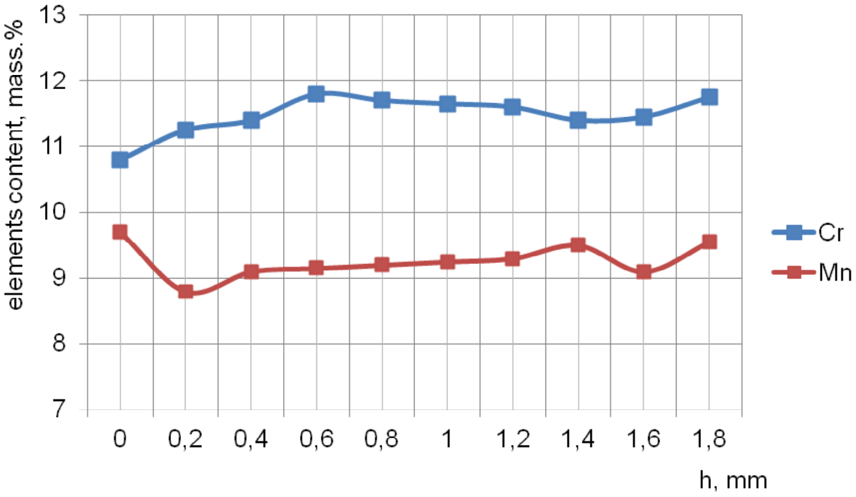

Fig. 4. Distribute concentration of alloying elements for depth carburized layer of deposited metal 20Cr12Mn9SiNV

interesting to slightly increase the silicon content in a thin surface layer (1.38...4 mass.%), although at a depth of 0.4...0.6 mm its content was only 1.18...1.24 mass.%. This is probably also due to the reverse diffusion of silicon, which displaces carbon from the solid solution when it is bound to carbides [19].

Thus, we may conclude that the increased carbon content ~ 2.85…1.61 mass% in the carburized layer of deposited steel (much higher than the equilibrium level) is caused by a big amount of carbide (carbon-nitride) phases (see Fig. 3) and it corresponds to the composition of white alloyed wear-resistant cast irons. Along the depth of the carburized layer the content of chromium carbides and accordingly carbon is reduced from 2.85 to 1.1 mass.% and even less. By means of hardfacing of chromium-manganese metastable steel, its carburizing with subsequent quenching it is possible to obtain a natural bi-metal corresponding in the carburized layer to white chromium-manganese cast iron with gradient content of carbide (carbon-nitride) phases along the layer's cross-section. It should be mentioned that carburized deposited steel layers (just like similar cast steels) possess pseudo-eutectic structure (A + Cr_7C_3 + $Cr_{23}C_6$) (see Fig. 2), similar to eutectic structure of cast irons, mentioned above.

When the temperature of heating of the carburized 20Cr12Mn9SiTiNV deposited steel for quenching varies from 900 °C to 1100 °C, the character of micro-structure's alternation along the thickness of the carburized layer is similar to the one discussed above. The difference is in the smaller number of carbide phases, due to their partial dissolving in austenite, thus lowering martensite points (M_s, M_f) and being the reason of raise in austenite stability and, consequently, its content within all typical areas of the carburized zone.

Alternation of the chemical composition and the structure of the carburized layer at carburizing and subsequent quenching exert sufficient influence upon mechanical and service properties of deposited steel (Table 1).

Table 1 – Effect of carburizing and quenching temperature upon mechanical properties of deposited steel of 20Cr12Mn9SiTiNV grade (tempering at 200 °C)

Heat treatment modes	HRC	Relative wear-resistance at condition:		
		Sliding friction (ε)	Abrasive (ε_a)	Impact-abrasive (ε_{i-a})
In deposited state	33	2.53	1.74	1.5
Carburizing (C.) without quenching	30	3.41	1.9	1.79
C. + quenching 900 °C	40	4.53	2.1	2.66
C. + quenching 1000 °C	38	4.36	2.1	2.4
C. + quenching 1100 °C	37	4.26	2.9	3.32

The hardness deposited steel HRC40...41 after quenching from 900 °C corresponds to austenite-martensite-carbide structure. As the quenching temperature grows from 900 °C to 1100 °C its hardness drops substantially to HRC31...32, and it is explained by a decrease in carbides amount and growth of austenite amount.

Wear resistance of deposited steel is determined by the content of special carbide particles ((Cr,Fe)$_7$C$_3$, (Cr, Fe)$_{23}$C$_6$, VC, TiC) having high hardness and the structure of the metal matrix, primarily by quenching martensite and metastable austenite, capable of DIMTW. Relative wear resistance of deposited steel under conditions of sliding friction, after carburizing is increased from ε = 2.53 (in deposited state) to ε = 3.41 (see Table 1). The highest wear resistance of carburized deposited steel 20Cr12Mn9SiTiNV grade (ε = 4.53) is observed after quenching at 900 °C, and with an increase of its temperature up to 1000 °C and 1100 °C it is slightly dropped to 4.36 and 4.26 respectively (see Table 1). This is due to solution of a part of carbides (Cr, Fe)$_{23}$C$_6$ in austenite.

Another character of changes in wear-resistance, depending upon the temperature of quenching is revealed at testing under conditions of abrasive and impact-abrasive wear. Relative abrasive wear resistance (ε_a = 1.9) is the smallest after carburizing without heat treatment. With increase of the quenching temperature after carburizing from 900 to 1100 °C, wear resistance grows from 2.1 to 2.9. Impact-abrasive wear-resistance changes in quite a similar way: the smallest value ε_{i-a} = 1.5 corresponds to the state without carburizing, while after carburizing – with an increase in the quenching from 900 °C to 1100 °C it increases to = 3.32 (see Table 1).

Such ambiguous influence of the phase content and microstructure upon wear-wear resistance, observed for different testing conditions is explained by the difference in inclination of metastable austenite to cold hardening, DIMTW and absorption of the energy of external impact, depending upon deformation-stress-wear conditions. That is why for particular service conditions it is required to determine an optimal phase content and the degree of austenite metastability experimentally.

On the whole carburizing and subsequent quenching of deposited steel made it possible to improve drastically (by 1.5...2) times its wear-resistance. At that the character of changes in ε_a and ε_{i-a} of the carburized deposited steel of 20Cr12Mn9SiTiNV grade from the quenching temperature is basically opposite to alternations in hardness. In most cases lowering of hardness corresponds to a substantial increase in wear-resistance. This contradiction is explained by metastability of the deposited steel structure, which undergoes in its thin surface layer $\gamma \rightarrow \alpha'$ DIMTW as well as intense deformation dynamic ageing, it causing intense self-strengthening of the surface layer and simultaneous relaxation of micro-stresses during wear tests [20, 21]. The developed technology of additional surface strengthening by means of carburizing possess a series of advantages as it retains after hardfacing an ability of being machined, quite normally by cutting, it allows subsequent raise in wear-resistance of deposited steel, owing to carburizing and quenching from optimal temperatures. This raises tremendously functionality and manufacturability of deposited steel. Of course, this can be applied for certain technological possibilities of renovation of actual parts.

So, the process of restoration of many machine parts by means of hardfacing, especially, with metastable metal and the described methods of formation of surface metastable phase-structural modifications by means of high-energy, chemical or deformation action may be considered as promising and efficient technologies of additional surface strengthening for practical applications.

Conclusions

1. The use of carburizing of deposited Fe-Cr-Mn steels and subsequent quenching from different temperatures makes it possible to regulate the phase composition and microstructure over a wide range, create various metastable phase-structural modifications of surface layers, and effectively manage their properties.

2. In a thin surface layer of carburized deposited Fe-Cr-Mn metal, an increased carbon content of 2.85 mass.% (significantly higher than equilibrium) is found and an

austenitic-martensitic-carbide microstructure is formed corresponding to the structure of white alloyed cast iron with increased wear resistance. In fact, a natural bimetal with a metastable austenite is formed: white alloyed cast iron on the surface, and wear-resistant steel in the core.

3. For each of the adopted wear conditions, there is a certain optimal phase-structural and metastable state ensuring maximum wear resistance of the carburized deposited metal: for metal-to-metal dry-friction conditions, it is formed during quenching from 900 ° C, for abrasive and impact abrasive wear – is at quenched - from 1100 ° C.

4. Carburizing of deposited metal is a promising technological operation, which allows additionally, and quite significantly, to strengthen the parts and, simultaneously, to improve processability, improving machinability (before carburizing).

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Чейлях Я.О., Чейлях О.П. Вплив цементації та термічної обробки на підвищення механічних властивостей економнолегованого зносостійкого Fe-Cr-Mn наплавленого металу

Установлено закономірності та переваги формування в поверхневих шарах метастабільних фазово-структурних модифікацій наплавлених зносостійких Fe-Cr-Mn сталей завдяки застосуванню цементації та гартування з різних температур. Після оптимальних режимів гартування досягнуто підвищеного рівня зносостійкості в різних умовах зносу.

Ключові слова: *наплавлений метал, термічна обробка, мартенсит, метастабільний аустеніт, мартенситні перетворення, зносостійкість.*

Чейлях Я.А., Чейлях А.П. Влияние цементации и термической обработки на повышение механических свойств экономнолегированного износостойкого Fe-Cr-Mn наплавленного металла

Установлены закономерности и преимущества формирования в поверхностных слоях метастабильных фазово-структурных модификаций наплавленных износостойких Fe-Cr-Mn сталей благодаря применению цементации и закалки с разных температур. После оптимальных режимов закалки достигается повышенный уровень износостойкости в различных условиях изнашивания.

Ключевые слова: *наплавленный металл, термическая обработка, мартенсит, метастабильний аустенит, мартенситные превращения, износостойкость.*