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STUDY OF WEAR OF THE BUILDING-UP ZONE OF MARTENSITE-AUSTENITIC AND SECONDARY HARDENING STEELS OF THE Cr-Mn-Ti SYSTEM

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The work deals with wear of the building-up zone of martensite-austenitic and secondary hardening steels of the Cr-Mn-Ti system (partially alloyed with Mo, B, and V). Additional alloying of the studied steels with titanium in the amount of 2…5% supported avoiding cleavages along the building-up zone. It was determined that there is a 7…15 µm wide parent metal zone next to the weld line. The influence of temperature on the weld toughness of the building-up zone was assessed according to the criterion of Malkin and Tetelman. The microhardness of the surface layers of built-up layers and the range of its dispersion are close to the results of laboratory tests, where T_{Cr} ~ 823 K. This approves the formation of structure of metal of contact volumes with the collective effect of heating, plastic deformation and diffusion. It was experimentally approved that the change of microhardness in the sub-surface layers at the wear stage is justified simultaneously with the processes of mutual diffusion of friction pair materials, selective oxidation and thermodiffusion redistribution of the hardening phase under the influence of temperatures and deformations. The diffusion coefficient in the deformed sub-surface layer, which is up to some dozen micrometers thick, is one of the values providing the kinetics of growing of nuclear cracks and development of destruction cracks. The received results provide an opportunity to use martensite-austenitic and secondary hardening steels of the Cr-Mn-Ti system with built-up surface for the hot forming tools.

INTRODUCTION

Quality of the surface layers of metal greatly determines its durability and wear resistance [1, 2]. For this purpose, various methods are used. For instance, such methods include detonation sputtering [3]; reinforcement of layers of steam turbine blades [4]; obtaining gas-plasma coatings [5, 6]; laser treatment [7]; modes of thermal treatment for the purpose of getting the required level of mechanical properties of details [8, 9]; nanomodification treatment [10], etc.

One of potentially productive approaches to improving the service characteristics of metal materials is depositing of their surface [11, 12]. In order to implement this process of depositing, observing the set technology parameters in the operating space is required. The operating space of the parameters of the technology of acquiring deposited surface is determined by many factors (material make, processing modes, etc.) that influence its durability.

One of the factors influencing the durability of the hot forming tools is temperature. The influence of temperature is related to the following events taking place in the surface and sub-surface layers:

– change of indicators of mechanical properties after temperature rising;

– tempering and structural transformation;

– manifestation of secondary deformations and stresses caused by the inequality of temperature distribution.

Therefore, the task of studying wear of the building-up zone is current. Research of wear of the building-up zone of martensite-austenitic and secondary hardening steels of the Cr-Mn-Ti system was performed in the work. At the same time, the diffusion coefficient in the deformed sub-surface layer, which supports the development of its destruction cracks, was considered.

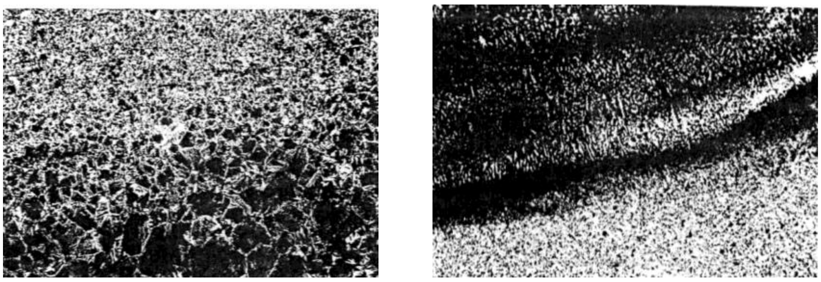
MATERIAL AND METHODS OF THE STUDY

For building-up of the studied materials, copper moulds were used. Cooling of the metastable steels of the Cr-Mn-Ti system (partially alloyed with Mo, B, and V) was performed forcefully according to the 30480-97 standard of product wear resistance.

The wear resistance of the material was determined using the 2070 CT-1 installation, using the board-disc methodic. At the same time, the disc was rotating at the speed of 0.5 m/s, the load on the sample being 25 and 50 N. The board was made of the 45X steel, the HRC of which is within the range of 47–49 units.

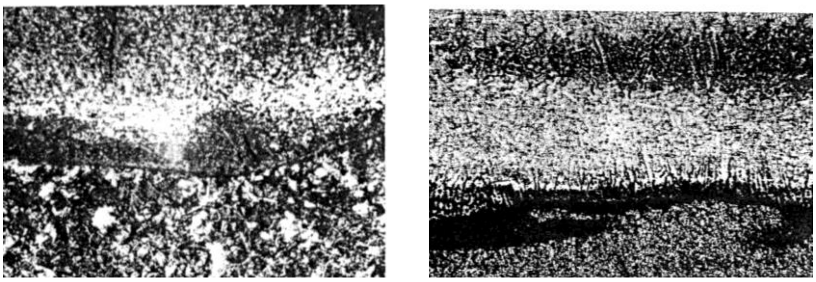
Measurement of the temperature of samples and rods was also performed during back-and-forth movement, using the chromel-alumel thermocouple of 0.1 mm radius. The speed of the temperature change recording ribbon was 2.160 mm/min.

The study of the primary structure of metallographic specimens of built-up steels showed the presence of white interfacial layers that are hardly pickled, and their width is insignificantly different (Figs. 1 and 2).



20Х3Г9М5Т2С *40Х4Г9Т2С*

Fig. 1. Structure of the alloying zone. Transverse template, ×100



20Х3Г9М5Т2С *40Х4Г9Т2С*

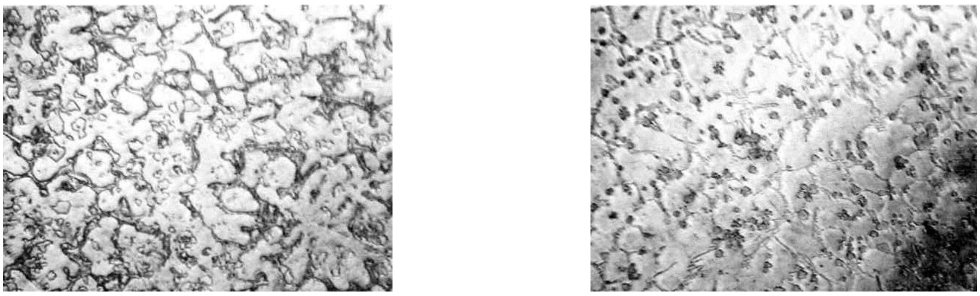
Fig. 2. Structure of the alloy zone. Transverse template, ×100

The metallographic analysis of the interfacial layers showed that in most cases their location copies the front of crystallization of the built-up metal.

RESULTS AND DISCUSSION

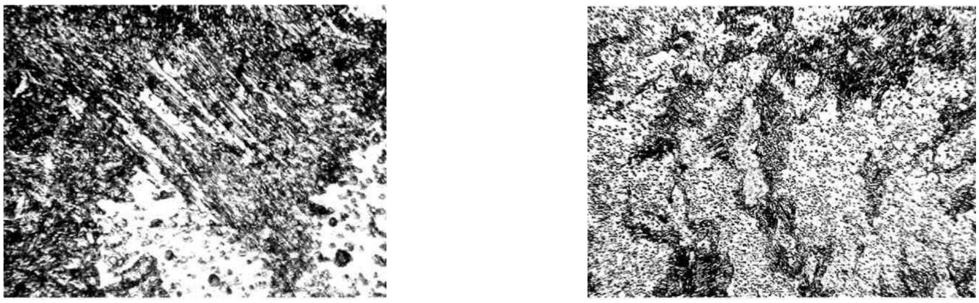
Additional alloying of these steels with titanium in the amount of 2…5% supported avoiding cleavages along the building-up zone. There is a parent metal zone, which is 7…15 μm wide, next to the weld line, the microhardness of which is slightly lower than the microhardness of the parent metal, which provides evidence of diffuse processes [12]. The microstructure of built-up chrome-manganese metal with up to 4% of titanium is shown on Fig. 3.

The comparison of calculated and experimental values of wear intensity showed that the calculated values of wear intensity may be used for rough estimate of wear resistance of alloys of various chemical composition, but of similar structural classes. According to the fatigue wear theory, the destruction of surface layers during external friction is due to alternating load [13]. In some cases, during normal stress corresponding to elastic deformations, plastic deformation along the surface layers is caused by shear stress. In case of plastic contact load leading to plastic flow, it significantly depends on the molecular component of the friction coefficient.



1.07% C, ×600 1.31% C, ×600

a



×200 ×600

b

Fig. 3. Microstructure of built-up chrome-managanese metal with up to 4% content of titanium:
a – Cr: 9.51; Mn: 8.86; Si: 1.87%; b – Cr: 8.20; Mn: 7.54; Si: 1.87%

A characteristic feature of all the studied alloys is graduate reduction of spread of microhardness values regarding the depth of the friction zone.

The change of microhardness in the sub-surface layers at the wear stage is due to simultaneous processes of mutual diffusion of materials of friction pairs, selective oxidation and thermodiffuse re-distribution of the hardening phase under the influence of temperature and deformations. The listed changes have various influences on the intensity of wear of the studied materials.

The microhardness of the surface layers of built-up layers and the range of its dispersion are close to the results of laboratory tests, where $T_{Ст} \sim 823$ K (Fig. 4), which means that the formation of structure of metal of contact volumes takes place due to collective effect of heating, plastic deformation and diffusion.

The diffusion coefficient in the deformed sub-surface layer, which is up to some dozen micron thick, is one of the values providing the kinetics of growing of nuclear cracks and development of destruction cracks.

Indeed, the critical length of the nuclear crack on the background of influence of its normal stress area is determined by the (1) equation:

$$l_л \approx \frac{2E\gamma_e}{\pi(1-\mu^2)\sigma^2},\ l_к \approx (D_П \cdot \tau)^{0.5}, \quad (1)$$

where $\gamma_e=\gamma_0+\gamma_p$ is the effective surface energy.

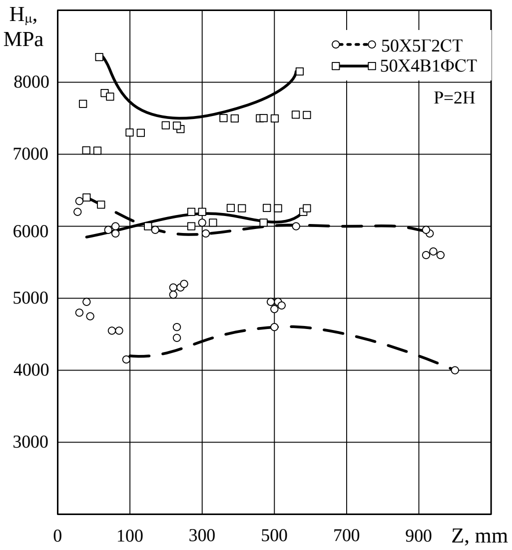


Fig. 4. Microhardness of surface layers of the built-up rolls after operation

The minimum thickness of the wear layers (h (2)) and the minimum distance between the cracks (S_{min} (3)) are correspondingly determined as follows:

$$h = \frac{G_в}{4\pi(1-\mu)\sigma_f}, \quad (2)$$

$$S_{min} = 2\rho \cdot в \cdot \frac{c^2 \cdot l_f^2}{V_r^2}, \quad (3)$$

where G and b are the shear modulus and the Burgers vector of the destroyed metal; σ_f is the dislocation friction stress; ρ is the dislocation density; C is the speed of distribution of elastic transverse waves in the material; l_f is the length of the Frank-Read source; V_r is the speed of crack growth; and μ is the Poisson ratio.

Considering for low sliding speeds (4):

$$V_r = 2Cl_f\sqrt{\frac{2\pi(1-\mu)\sigma_f\rho}{G}}. \quad (4)$$

From (1); time of crack formation (5):

$$\tau \approx \frac{4E^2\gamma_1^2}{\pi^2(1-\mu^2)^2\sigma^4 D_П}. \quad (5)$$

The h value was determined, considering assessment calculations, and the crack is formed as a result of cyclic deformation in case of combination of shear and tear, which are the conditions different from those considered by the (1) equation.

The wear intensity I ~ f(A, E, √ρ), where A, E, and ρ are correspondingly the friction effort, the elastic module and the dislocation density. The friction effort may be considered as a value depending on the change of dislocation density on the friction surfaces, on an assumption of its correspondence to the internal work of change of the dislocation structure. Upon the mentioned precognition, the friction force may be expressed using the following formula (6):

$$F_{Tp} \approx P\frac{\sigma_T}{G} \cdot \sqrt{\frac{\rho_1}{\rho_0}}, \quad (6)$$

where ρ_0 and ρ_1 are the initial dislocation density and that which appeared due to friction; and P is the normal load.

Friction is accompanied with a complex aggregate of physical and chemical processes; energy dissipation may not be narrowed down to dislocation processes even approximately, but their role in the metal destruction is approved by many studies of national and foreign scientists.

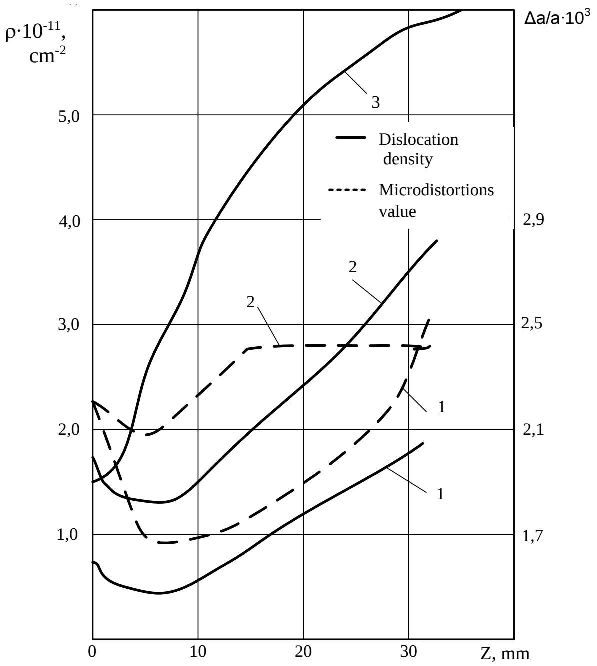


Fig. 5. Dislocation density (ρ) and microdistortions (Δa/a) of the built-up metals with carbide and intermetallidic strengthening after the wear test (τ=1 h, P = 20 MPA, VВ.П.П.=18.8 cm/s, ТСМ ~ 923 К).
1 – 0Х3М5В8К10Ф; 2 – 0Х3М5В8К15Ф;
3 – 70Х4М3ВФ

The type of ρ = f(Z) dependences is close to all the alloys mentioned on Fig. 5; therefore, one of the reasons of formation of the zone with reduced dislocation density is backstock. Recrystallization is made more difficult with the dispersion particles slowing down the strengthening phases and relatively low temperature.

The influence of temperature on the weld toughness was assessed according to the criterion of J. Malkin and A.S. Tetelman [14]. As far as for the conditions of molecular and mechanical wear the wear resistance coefficient K_I~KC [14], the KC increase shall change the correlation (7):

$$K_I \approx j^2 \cdot (1 - \sigma_1 \sigma_B)^{-2}, \qquad (7)$$

where j is the crack resistance limit; σ_1 and σ_2 are correspondingly the maximum main stress in the stress concentration area and the hardness limit.

In case of similar values of contact pressure in the friction pair, the time of formation of a critically long crack increases together with the increase of efficient surface energy (γ_e), which includes the plastic deformation energy.

The influence of temperature on the weld toughness is shown on Fig. 6.

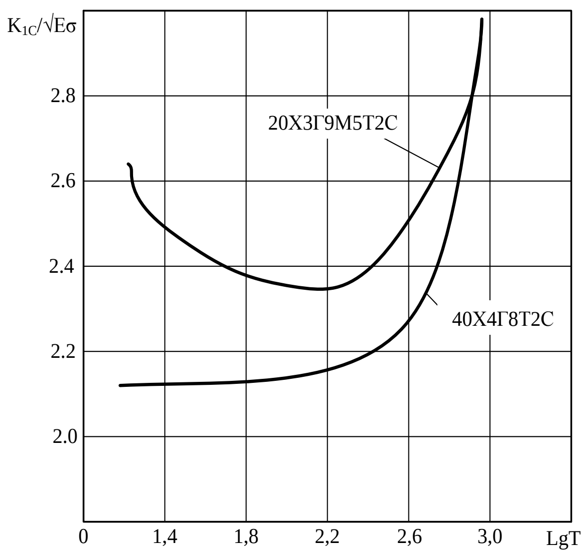


Fig. 6. Dependence of the calculation experimental destruction criterion ($K_{1C}=\sqrt{AEGT\varepsilon\alpha\beta}$) on the temperature

Therefore, the crack resistance indicators (K_C, j-integral and δ_C), which means wear resistance as well, of martensite-ageing steels is higher than those of metastable and instrument steels.

CONCLUSIONS

1. The diffusion coefficient in the deformed subsurface layer, which is up to some dozen micron thick, is one of the values providing the kinetics of growing of nuclear cracks and development of destruction crack.

2. The crack resistance indicators (K_C, j-integral and δ_C), which means wear resistance as well, of martensite-ageing steels is higher than those of metastable and instrument steel.

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ДОСЛІДЖЕННЯ ЗНОШУВАННЯ ЗОНИ НАПЛАВЛЕННЯ МАРТЕНСИТНО-АУСТЕНІТНИХ І ВТОРИННО-ТВЕРДІЮЧИХ СТАЛЕЙ СИСТЕМИ Cr-Mn-Ti

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Досліджується зношування зони наплавлення мартенситно-аустенітних і вторинно-твердіючих сталей системи Cr-Mn-Ti (частково легованих Mo, B, V). Додаткове легування досліджуваних сталей титаном у кількості 2…5% сприяло запобіганню сколам по зоні сплавлення. Встановлено, що поблизу лінії сплаву знаходиться зона основного металу шириною 7...15 мкм. Вплив температури на в'язкість руйнування зони наплавлення оцінювався за критерієм Малкіна та Тетельмана. Мікротвердість поверхневих наплавлених шарів та діапазон її розкиду близькі результатам лабораторних випробувань при $T_{Ст}$ ~ 823 К. Це свідчить про формування структури металу контактних об'ємів сукупною дією нагріву, пластичної деформації, дифузії. Експериментально підтверджено, що зміна мікротвердості в приповерхневих шарах на стадії зносу зумовлено паралельно процесами взаємної дифузії матеріалів пар тертя, виборчого окислення і термодифузійного перерозподілу зміцнюючої фази під дією температур і деформацій. Коефіцієнт дифузії в деформованому приповерхневому шарі товщиною до кількох десятків мікрометрів є однією з величин, що зумовлюють кінетику зростання зародкових тріщин та розвитку тріщин руйнування. Отримані результати дають можливість використовувати мартенситно-аустенітні та вторинно-твердіючі сталі системи Cr-Mn-Ti з наплавленою поверхнею для інструменту гарячого деформування.