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Consistent patterns of silicide coatings formation on titanium at various rates of mixture heating

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Abstract
The researches results of structure and properties of titanium alloys silicide coatings obtained in the conditions of self-propagating high-temperature various-rate heating of saturating mixture are presented. It is established that the increase in rate of heating of mixture from 5 to 15 º C/min increases microhardness of silicide coatings by 1.2-1.4 times.
Key words: RATE OF HEATING, SELF-PROPAGATING HIGH-TEMPERATURE SYNTHESIS, TITANIUM, COATINGS, STRUCTURE, MICROHARDNESS

The obtaining of protective coverings on titanium alloys is one of topical question of materials science. The additional alloying of these coatings allows increasing of their service properties [1].

It should be noted that in line with alloying, the surface hardening of titanium alloys is not less important direction of increase of their durability and reliability at both room and high temperatures. For example, in papers of V. N. Fedirko and co-authors [2, 3], it is shown that nitriding and oxidizing of industrial α and (α +β) titanium alloys leads to substantial increase of their tribotechnical and mechanical properties. The time and energy intensity of process of thermochemical treatment (TCT) are the principal disadvantage of coatings obtained under isothermal conditions. Thus, obtaining of multicomponent protective coverings under the conditions of self-propagating high-temperature synthesis (SHS) becomes relevant and economically reasonable [4].

The use of self-propagating high-temperature synthesis (SHS) for protective coverings is based on the use of powder exothermic mixtures. SHS is strongly exothermic interaction of chemical elements in the condensed phase; this interaction is capable of spontaneous spreading in the form of combustion wave [5].

The ignition temperature (t_*, ^{o}C), maximum temperature (T_m, ^{o}C), isothermal temperature (t_τ, ^{o}C), isothermal time (τ, min) and rate of heating (ω, ^{o}C/min) are the basic technological parameters influencing the processes of coverings formation in the mode of thermal self-ignition during SHS [6, 7].

The research of quality and properties of coatings obtained at various rates of heating of saturating mixture under the conditions of SHS was the purpose of this paper.

The formation kinetics of siliconized coatings was studied by means of microstructural analysis. The researches were conducted on samples with dimensions of $h \times b \times l = 10 \times 10 \times 20$ mm. The coating thickness was determined in cross-section using microscope "Neophot-21". Microhardness over the thickness of the layers obtained in the mode of thermal self-ignition was measured by the microhardness tester PMT-3 (GOST 23.208-79).

In order to investigate quality, thickness and properties of coatings on titanium alloys, the experiments on hardening of titanium samples by silicon in the mode of thermal self-ignition at various rates of heating (from 3 to 48º C/min) were conducted.

Results of dependence of ignition temperature and maximum temperature of process on rate of heating (temperatures is measured in the centre of reactor) are presented in Fig. 1.

It is seen that in case of tendency of heating rate to value of about 4-5º C/min, the system tends to degeneration. In case of increase in rate of heating, the system get farther and farther from critical conditions; thus, the maximum temperature is increased, and ignition temperature is reduced.

At heating rates less than 10º C/min, the diffusive silicide layers of smaller thickness (Fig. 2) are obtained during further saturation; at heating rate higher than 20º C/min, we can observe very active interaction of mixture in the course of growing heating rate with walls of the metal reactor, where the mixture is packed. First of all, this causes the short life; and, secondly, the saturating mixture is enriched by alloy elements, of which the reactor is made.

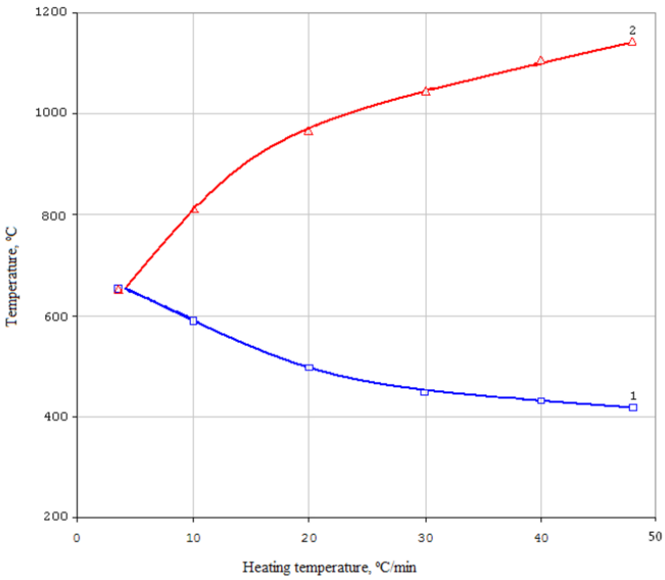
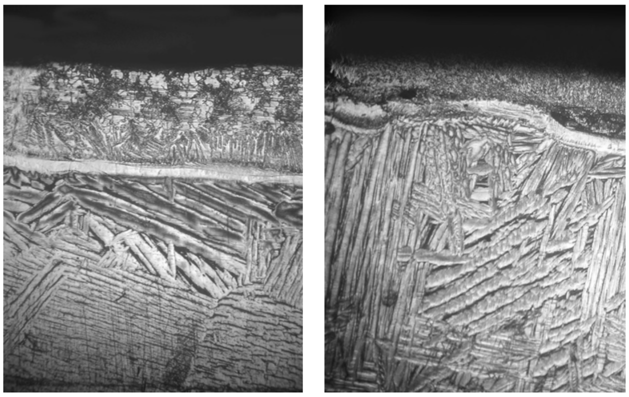


Figure 1. Dependence of ignition temperature (1) and maximum temperature (2) on heating rate of mixture

The experiments have shown (Fig. 2) that thickness and quality (uniformity over thickness, soundness) of the obtained coatings depends significantly on the heating rate of mixture. The coatings obtained at growing heating up to 20º C/min are of the best quality.

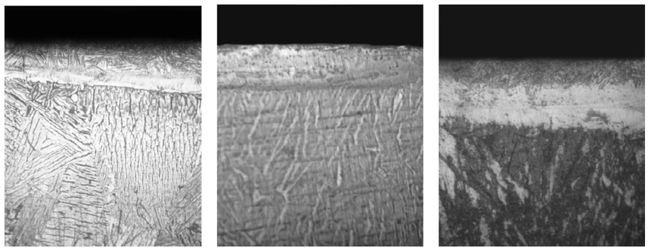
Apparently, the result is a consequence of process carrying out in self-ignition area, where the system possesses the minimum temperature gradients on radius and altitude of the reactor.



(a) (b)

Figure 2. Microstructures of the siliconized coatings on titanium alloy VT1-0 obtained at various rates of heating of mixture, ×200: a – rate of heating 15º C /min; b – rate of heating 5º C /min

The saturation processes on alloys take place more actively, than on technically pure titanium VT1-0; and the thickness of covering is the highest on the alloy VT3-1. This is confirmed by results of the metallographic analysis presented in Fig. 3.

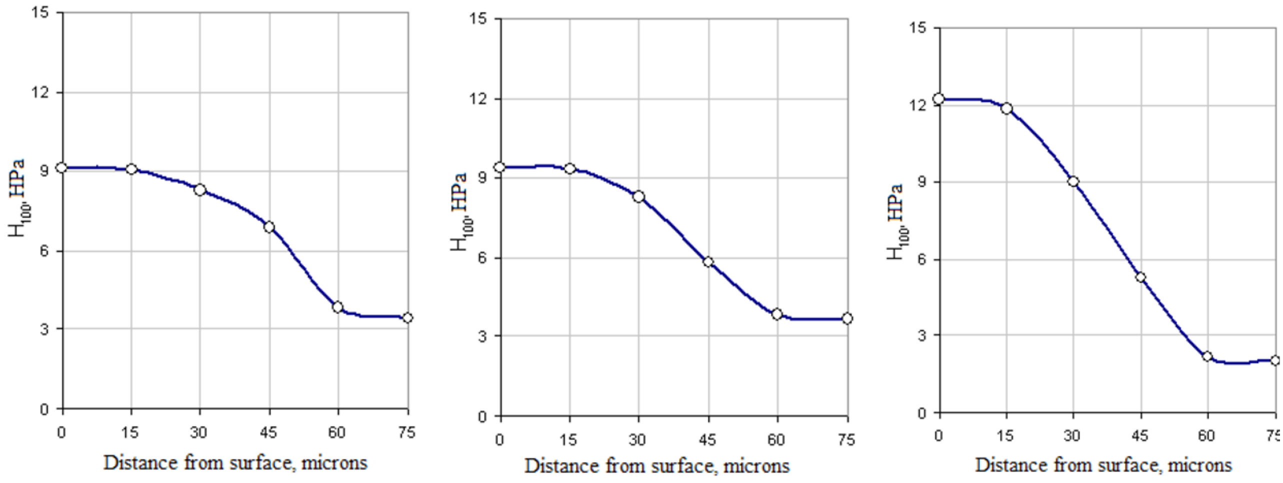


(a) (b) (c)

Figure 3. Microstructures of coatings obtained at heating rate15º C /min, ×100: *a* –titanium alloyVT1-0; b – titanium alloy VT20; c – titanium alloy VT3-1

As durometric measurements of silicide coatings on layer surface have shown, microhardness is 1–12 HPa. The increase in microhardness during removal from surface is indicative of appearing of silicide Ti_5Si_3 of greater hardness than disilicide $TiSi_2$. The increased values of microhardness of silicide layers in comparison with reference data [8] are obviously connected with phase self-hardening. The composition of processed titanium alloys has significant impact on microhardness of hardened layers (Fig. 4). The analysis of experimental results showed that the layers on technically pure titanium VT1-0 possess the greatest hardness.

In case of transition from the pure titanium to titanium alloys VT-20 and VT3-1, the hardness of hardened layers is reduced. It can be explained by the fact that the basic alloying element of these titanium alloys is aluminum (up to 6%), which has the plasticization effect on hardened zones.



(a) (b) (c)

Figure 4. Distribution of microhardness over thickness of the hardened zone obtained in the mode of thermal self-ignition on titanium alloy VT1-0 at rate of heating of mixture: a – 5° C/min; b – 10° C/min; c – 15° C/min

Conclusions

It was proved experimentally that coatings obtained in the range of heating rates from 10 to 20° C/min are of the best quality. This is a consequence of process carrying out in self-ignition area, where the system possesses the minimum temperature gradients on radius and altitude of the reactor.

Distribution of microhardness over thickness of the hardened zone obtained in the mode of thermal self-ignition on titanium alloy VT1-0 at different heating rates of mixture showed that the increase in rate of heating of mixture from 5 to 15 ° C/min increases microhardness of silicide coatings by 1.2-1.4 times.

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