

EFFECT OF COMPOSITION AND HEAT TREATMENT ON THE PROPERTIES
OF TiC-STEEL ALLOYS

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UDC 621.762:669.018.25

It is well known that strength and ductility of heterogeneous hard alloys are governed to a considerable extent by composition and the properties of the cementing (binder) phases. Properties of steels vary over wide limits depending on carbon content and also the form and conditions of heat treatment. By varying the composition of steel binders with respect to carbon and selecting the appropriate heat treatment schedule it is possible to regulate the structure and properties of alloys of titanium carbide with steel.

At the same time, presence in TiC-steel alloys of a large amount of carbide phase has a considerable effect on phase transformation and structure of the steel binder, which is indicated by the results of work in [1, 2], and also on its properties.

In view of this, comparative analysis of the phase composition and structure is desirable, and it is also necessary to study the change in physical and mechanical properties of steel binders and TiC-steel alloys* differing in titanium carbide and carbon content after treatment forms and schedules of heat treatment.

A study was made of alloys with 0.1,† 10; 40 and 50% TiC with a constant content of alloying elements with respect to 100% binder. The chemical composition of the steel binder# is 7% Cr; 2% Cu; 5% Mo; 0.6% Si; balance iron. Alloy composition with respect to carbon was regulated by additions of carbon black.

As original materials for preparing alloys use was made of titanium carbide prepared by the thermic carbon method containing 18.8% binder and 0.4% free carbon; iron reduced from iron oxide in a hydrogen atmosphere, and also powders of the alloying elements Cr, Mo, Cu, Si. Alloys were prepared by powder metallurgy methods. Sintering of pressed specimens was carried out in a vacuum ($P = 1.33$ Pa) at 1150-1400°C depending on carbon content and also on the ratio of iron and titanium carbide in the alloys.

Sintered specimens were heated at 820°C for 2 h with the aim of spheroidizing eutectoid carbides and making the steel structure in an identical original condition, and then quenched for martensite. After quenching, specimens were tempered at different temperatures.

The structure of sintered steels and TiC-steel alloys differed in volumetric ratios of excess TiC carbides,** ferrite, pearlite, and secondary M_xC_y carbides. According to data from the Fe-Cr-Mo-C composition diagram [3] the carbide formula is $(Fe, Cr, Mo)_7C_3$.

In alloys with 40 and 50% TiC the products of austenite decomposition are very dispersed, and therefore there are certain difficulties in identifying them. The structure of the binder in the alloys is most probably sorbitic pearlite according to the classification in [4]. After annealing at 820°C the steel binder component of TiC-steel alloys has the structure of fine-grained pearlite.

Metallographic analysis of steels and alloys with 10% TiC showed that lath martensite forms in them; this is also typical for cast low-carbon steels. In alloys of eutectoid and hypereutectoid composition depending on binder composition ductile (acicular) martensite forms.

*Alloys of the composition studied are used as a wear resistant material for preparing components of rotary piston engines. They are often called 'carbide steel'.

†Titanium carbide content corresponds to its solubility in iron at 900°C according to data in [2].

#Simply steel subsequently throughout the text.

**Average titanium carbide grain size in alloys with different TiC content was approximately the same and it was ~3 μm .

All-Union Scientific-Research Institute of Hard Alloys (VNIITS). Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 5, pp. 45-48, May, 1990.

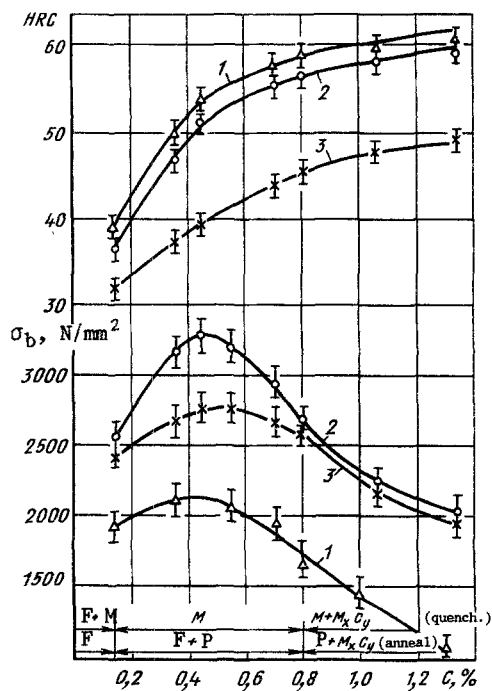


Fig. 1

Fig. 1. Effect of carbon content on steel properties after quenching (1), tempering at 150 (2) and 480°C (3) (M is martensite, F is ferrite, P is pearlite, M_xC_y are carbides).

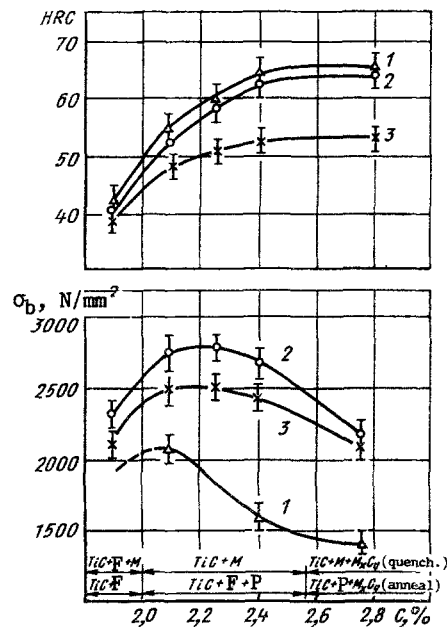


Fig. 2

Fig. 2. Effect of carbon content on the properties of 10% TiC-steel alloy after quenching (1), and tempering at 150 (2) and 480°C (3).

With a high content of titanium carbide (50%) it is extremely complicated to determine martensite morphology in a light microscope as a result of its high dispersion. In alloys containing residual austenite in the structure the lamellar form of martensite is readily distinguishable.

After tempering at 150-500°C the acicular nature of the structure of sintered steels is retained, which is also typical for cast steels [5]. In TiC-steel alloys with a small titanium carbide content (10%) the acicular structure of the binder is only retained up to 150°C. After tempering at 450°C the binder acquires a dispersed granular structure. Identification of the structural components of the binder for alloys with 40 and 50% TiC after tempering at 150-600°C is impossible as a result of the high dispersivity.

Results of mechanical tests for steel and TiC-steel alloys are presented in Figs. 1-5. On the abscissa axis (Figs. 1, 2, 3) phase regions are shown which correspond to alloys in the annealed and quenched conditions differing in total carbon concentration. Results of studies (Fig. 1) showed that with an increase in carbon content the steel binder hardness increases after all forms of heat treatment. Bending strength varies along a curve with a maximum with a carbon content of 0.3-0.5%, which is also typical for cast steels.

Properties of alloys with 10% TiC depending on carbon content and the form of heat treatment (Fig. 2) vary similarly to steels. In alloys with 50% TiC regularities for the change in hardness and bending strength (Fig. 3) in relation to carbon concentration are also generally similar to steels, which confirms the results in [6-8]. It is only necessary to note the weak increase in hardness with respect to steel which is probably connected with presence of a large amount (61%) of carbide component and its effect on the change in hardness.

Presented in Figs. 4 and 5 are dependences of microhardness, Vickers hardness, and bending strength on different tempering temperatures for steels and TiC-steel alloys with about the same content of carbon in martensite. Studies showed that tempering at 150°C for steels and alloys with 10% TiC leads to a small reduction in hardness and a marked increase in bending strength as a result of partial removal of quenching stresses. An increase in tempering temperature to 480°C or more causes a reduction in hardness and bending strength for the steel and alloys with 10% TiC in view of completion of martensite decomposition.

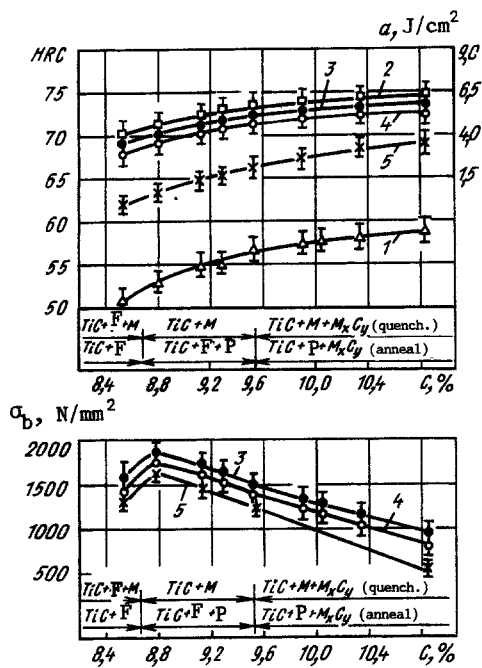


Fig. 3

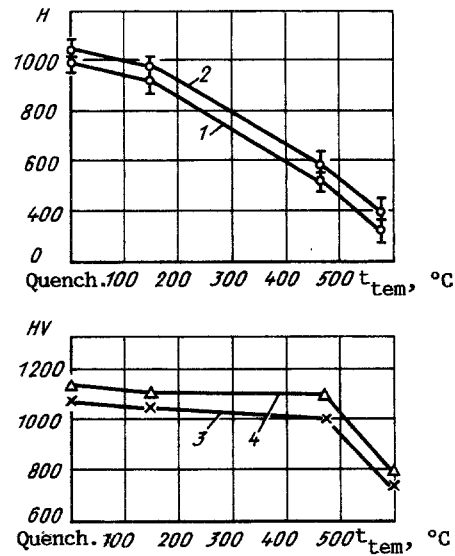


Fig. 4

Fig. 3. Properties of 50% TiC-steel alloy after annealing (1), quenching (2), tempering at 150 (3), 480 (4), and 600°C (5) depending on the total carbon content.

Fig. 4. Microhardness of steel (1) and 10% TiC-steel alloy (2) and Vickers hardness for alloys with 40 (3) and 50% TiC (4) in relation to tempering temperature.

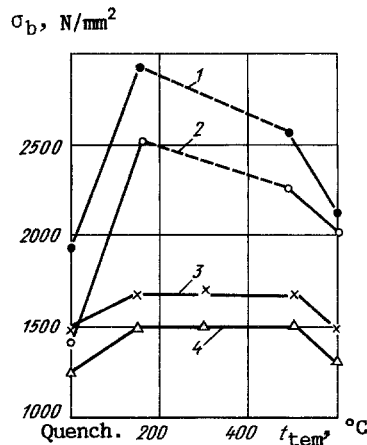


Fig. 5. Dependence of bending strength on tempering temperature for steel (1), TiC-steel alloys with 10 (2), 40 (3), and 50% TiC (4).

The mechanical properties of alloys with 50% TiC vary as follows (Figs. 3, 4, 5): the hardness of quenched alloys after tempering at 150 and 480°C in contrast to steel is almost unchanged and it only depends on carbon concentration. A marked reduction in hardness is observed in TiC-steel alloys after high-temperature tempering at 600°C. The same as for hardness, bending strength is almost the same for alloys tempered at 150 and 450°C (Fig. 5). It is only possible to note a tendency towards a reduction in σ_b for quenched alloys compared with tempered alloys, which distinguishes them from the steel binder and is apparently due to the much lower effect of quenching stresses on alloy strength with a large TiC carbide content. Bending strength only decreases after high-temperature tempering at 600°C.

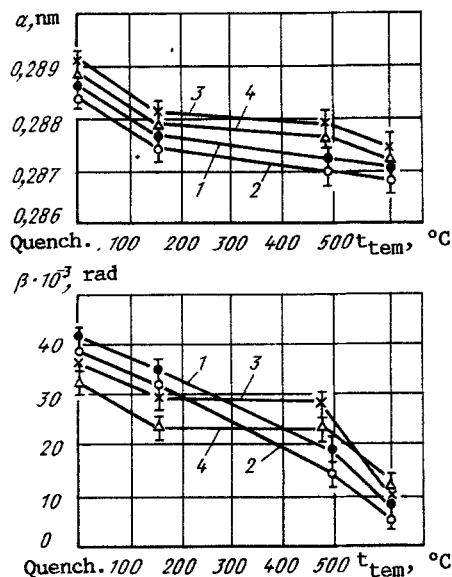


Fig. 6. Lattice spacing and physical width of x-ray line (211) for steel (1) and alloys with 10 (2), 40 (3) and 50% TiC (4) in relation to tempering temperature.

In order to explain the reasons causing the difference in features of the change in mechanical properties of TiC-steel alloys and steels depending on tempering temperature x-ray studies of alloy specimens were carried out.*

X-ray analysis was used to determine the phase composition of alloys, integral imperfection of α -solid solution and its lattice spacing. Recording was performed in a DRON-3 diffractometer in cobalt K_{α} -radiation. The physical width of the x-ray line $(211)_{\alpha}$ was calculated by the equation [9]:

$$\beta = B - \frac{b^2}{B},$$

where B is total width of the x-ray line, b is instrument broadening.

The accuracy of determining the width of the x-ray line is 5%, and for the lattice spacing it is 0.0001 nm. Before exposure microsections were electrolytically polished in order to remove the stressed layer with a thickness of about 0.2 mm.

Results of x-ray structural analysis are presented in Fig. 6 from which it can be seen that after tempering at 150°C the lattice spacing and width of the x-ray line for α -Fe are markedly reduced both in steels and in TiC-steel alloys in view of the start of martensite decomposition and partial removal of quenching stresses.

The microhardness of steel and alloys with 10% TiC, and also the Vickers hardness for alloys with a high titanium carbide content (see Fig. 4) varied little since ϵ -carbide ($Fe_{2.4}C$) precipitating from martensite at low tempering temperatures is still coherent with the martensite lattice [5].

With an increase in tempering temperature to 480°C the lattice spacing and width of the x-ray line for α -Fe decrease for steels and alloys with 10% TiC, which is due to further decomposition of martensite (precipitation of M_xC_y carbides) and development of recovery processes [5]. In alloys with 40 and 50% TiC the width of x-ray line $(211)_{\alpha}$ is almost unchanged, i.e., the imperfection of the martensite structure is retained at the level of the lightly tempered condition of the alloys. This can probably explain the retention of high hardness and strength for TiC-steel alloys (Figs. 4 and 5). The microhardness of steels and bending resistance after tempering at 480°C are markedly reduced compared with low-temperature tempering.

*Steel and the binder of TiC-steel alloys selected for study had an identical eutectoid structure.

With a further increase in tempering temperature to 600°C the width of x-ray line (211)_α and hardness (microhardness in steels) of TiC-steel alloys is markedly reduced, which is connected with intensification of recovery processes and recrystallization in the steel binder.

Thus, the carbide component of TiC-steel alloys has a marked effect on the structure of the steel binder, phase transformations in it, and correspondingly on other properties as a whole. It is established that recovery processes in the steel binder during tempering of TiC-steel alloys are retained under the effect of a considerable amount of carbide phase based on TiC (volume fraction more than 45%), as a result of which bending strength and hardness are almost unchanged after tempering in the range 150-500°C and they are intensified at higher temperatures.

Regularities of the change in mechanical properties (hardness and strength) in relation to carbon content of steels and TiC-steel alloys are similar.

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