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ОСОБЛИВОСТІ ВЛАСТИВОСТЕЙ ТЕРМІТНИХ ХРОМОКРЕМНІЄВИХ СТАЛЕЙ

У роботі розглянуто синтез високолегованих термітних хромокремнієвих сталей на основі порошкових матеріалів. Розглянуто вплив особливостей термітного синтезу на властивості синтезованих матеріалів і на особливості їх хімічного складу. Компонування металотермічної шихти надало змогу синтезувати висококремнієві сталі – аналоги промислових сталей 4Х10С2М та 3Х13Н7С2. Авторами встановлені для термітних сильхромів залежності границі міцності на розтяг, умовної границі текучості при допуску на пластичну деформацію 0,2% та границі повзучості, а також зміни витривалої міцності від температури. Отримані результати дослідження способу синтезу та властивостей термітних сильхромів призводять до суттєвого розширення можливих областей їх використання.

Ключові слова: *термітні сталі, властивості, сильхроми, металотермія, синтез, залежності, структура*.

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ОСОБЕННОСТИ СВОЙСТВ ТЕРМИТНЫХ ХРОМОКРЕМНИЕВЫХ СТАЛЕЙ

В работе рассмотрено синтез высоколегированных термитных хромокремниевых сталей на основе порошковых материалов. Рассмотрено влияние особенностей термитного синтеза на свойства синтезируемых материалов и особенности их химического состава. Компоновка металлотермической шихты позволила синтезировать высококремниевые стали – аналоги промышленных сталей 4Х10С2М и 3Х13Н7С2. Авторами установлены для термитных сильхромов зависимости предела прочности на растяжение, условной границы текучести при допуске на пластическую деформацию 0,2% и предела ползучести, а также изменения выносливой прочности от температуры. Полученные результаты исследования способа синтеза и свойств термитных сильхромов приводят к существенному расширению возможных областей их использования.

Ключевые слова*: термитные стали, свойства, сильхромы, металлотермия, синтез, зависимости, структура*.

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FEATURES OF PROPERTIES OF TERMITIC CHROME-SILICON STEELS STEEL

The work describes the synthesis of high-alloy thermal chromium-silicon steels based on powder materials. It is looked at the infusion of the features of thermite synthesis on the power of synthesizing materials and on the features of their chemical warehouse. The composition of the metallothermic charge gave the ability to synthesize high-silver steels – analogues of industrial steels "4X10C2M" and "3X13H7C2" The authors defined for thermite silicochromes the dependences of the tensile strength, conditional yield strength with a plastic deformation tolerance of 0.2% and creep strength, as well as changes in endurance strength with temperature. The obtained results of the study of the method of synthesis and properties of thermite silicochromes lead to a significant expansion of the possible areas of their use.

Key words: *thermal steel, dominance, silicochrome, metalothermy, synthesis, fallow, structure.*

Introduction. It is known that industrial chromium-silicon steels, so-called silicochromes, are most often used to manufacture valves for reciprocating engines, diesels, and heat-resistant material of heat exchangers for heating air, recuperators, grate [1,2], and others. A detailed study of the problem of creating new materials and improving the properties of traditional indicates that it can be solved by using special synthesized alloys obtained by thermite [3] and combined (self-propagating high-temperature synthesis [4] and metallothermy) processes.

Such technologies differ from traditional ones in several obvious advantages: no need for power sources of electricity; the possibility of using simple, cheap equipment; high productivity of the process (the time of synthesis of the alloy can last only a few minutes); the possibility of using secondary production waste, namely grinding graphite electrodes, aluminium or magnesium shavings, iron scale [5], etc.

Formulation of the problem. Despite these advantages, significant limitations for the use of these technologies are the lack of developed compositions of charges for thermite synthesis of high-alloy silicon steels and new properties of the synthesized materials. All this has caused an urgent need to conduct a series of studies to establish the performance properties of high-silicon steels – analogues of industrial steels "4X10S2M" and "3X13H7C2".

The aim of the study. The aim of the study was to establish the composition of metallothermic mixtures for thermite synthesis of high-silicon steels – analogues of industrial steels "4X10S2M" and "3X13H7C2", research and analysis of service properties of the obtained silicochromes.

Materials and methods of the experiment. In performing the work were used materials: soot (carbon black "TU 14-7-24-80"), aluminium powder PA-3–PA-4 "GOST 6058-73", iron scale with average chemical composition (in wt.%): 0,05 C; Cr_2O_3 – 36.4; Fe_2O_3 and FeO – 19.9 (at a ratio of 50% Fe_2O_3 to 50% FeO); CaO – 5.4; 0.10–0.35 Si; 0.10–0.35 Mn; 0.01–0.03 S; 0.01–0.03 P; other non-reducing compounds – the rest.

The powder metal-thermal charge with a dispersion of 5 to 100 μm was dried, mixed, compacted, and then placed in a metallothermic crucible. Sections for metallographic analysis were made from used samples for tensile testing.

In the developed synthesis technology, powdered ingredients of the charge were filled into the metal-thermal reactor, which was ignited with a special fuse. To determine the mass of the ingot and the yield of the alloy from the charge at the first stage of the study was micro-fused at a mass of 100-150 g in a metal crucible. The combustion process was initiated by a special titanium igniter made of titanium chemical powder "ПХ-2 ТУ 48-10-78-83".

Obtaining high-silicon steels by metallothermic using powdered ingredients for the composition of the charge was performed according to the scheme:

$$Fe_3O_4 + SiO_2 + Al \rightarrow Fe + Si + Al_2O_3. \quad (1)$$

After determining the composition of the charge according to the stoichiometric coefficients of the chemical reaction and its correction by the coefficients of assimilation of the components [4,6], the adiabatic combustion temperature of the metallothermic reaction was calculated.

In order to reduce the impact of high temperature on the thermite metal and to eliminate the associated high porosity and shrinkage in the castings, the charge was incorporated with inert impurities - grinding chips of the corresponding steel and ferroalloys. In order to increase the stability of combustion and improve the kinetic characteristics of the reaction, 1-2% (by weight of the charge) fluorspar CaF_2 was also added to the charge, which not only reduced the ignition temperature of the exothermic powder mixture but also increased steel yield.

Theoretical and experimental research. In termite sylicochromes, a significant content of silicon leads to an increase in the ferrite region and a decrease in austenite on the state diagram. This contributes to the fact that even for medium-carbon steels, semi-ferrite steels are formed at more than 6% chromium, and ferritic steels increase with the increasing silicon content. Unfortunately, ferrite termite steels are very prone to grain growth at high temperatures, which directly affects their high brittleness and, as a consequence, unsuitability for further pressure treatment.

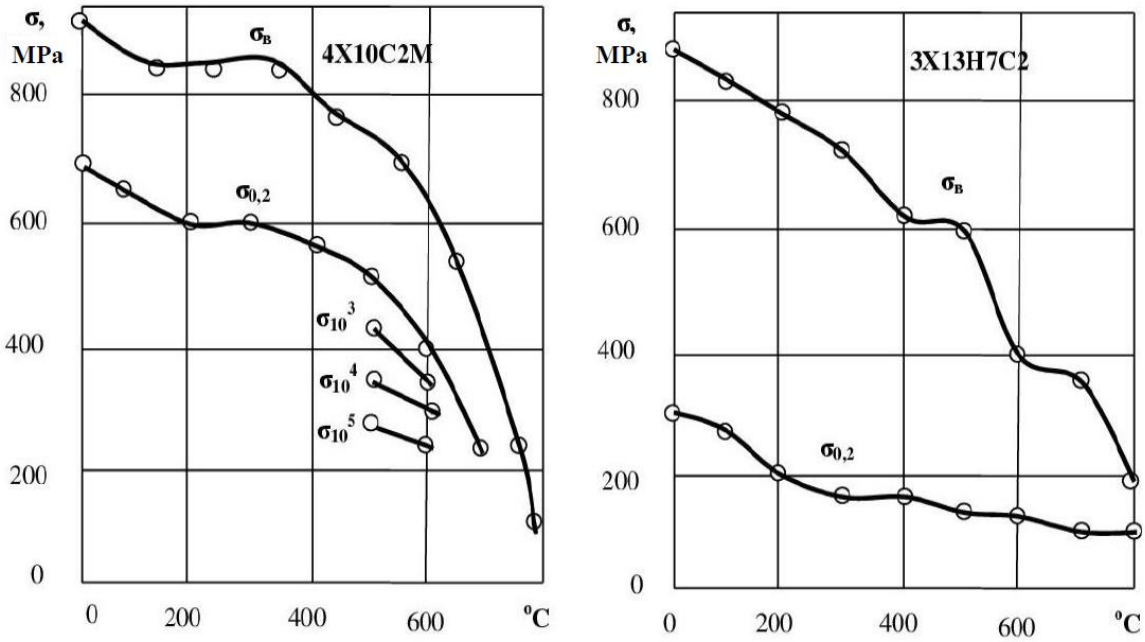
A microstructural study of one of the synthesized thermite steels, namely, an analogue of the industrial brand "4X9C2", revealed a martensitic structure. It is known that in the metallothermic synthesis of materials there are high cooling rates [2], which leads to the formation of martensitic structure. The study found that the critical points A_3 and A_{ST} for termite sylicochromes are at the level of 1000°C.

When magnesite is used for lining the reactor and the heat dissipation is reduced and the cooling rate of the alloy is slowed down in the temperature range of 450–600°C, complex carbides such as cementite $(Fe,Mn)_3C$, etc and this gives the alloy considerable brittleness and significantly reduces the toughness.

One of the tasks of the study was to establish the mechanical properties of thermite sylicochromes and their dependence on temperature. The results of the study are shown in Fig. 1 and 2. A characteristic feature of thermite sylicochromes, analogs of industrial steels "4X10C2H" and "3X13H7C2", is that these steels quickly lose strength (σ_b) with increasing temperature, conditional yield strength when allowed for plastic deformation of 0.2% ($\sigma_{0,2}$), the limit of endurance strength (σ_{10}^3, σ_{10}^4, and σ_{10}^5) and relative elongation (δ), and relative constriction (ψ), toughness (a_n) show a complex dependence with increasing temperature, shown in Fig. 2.

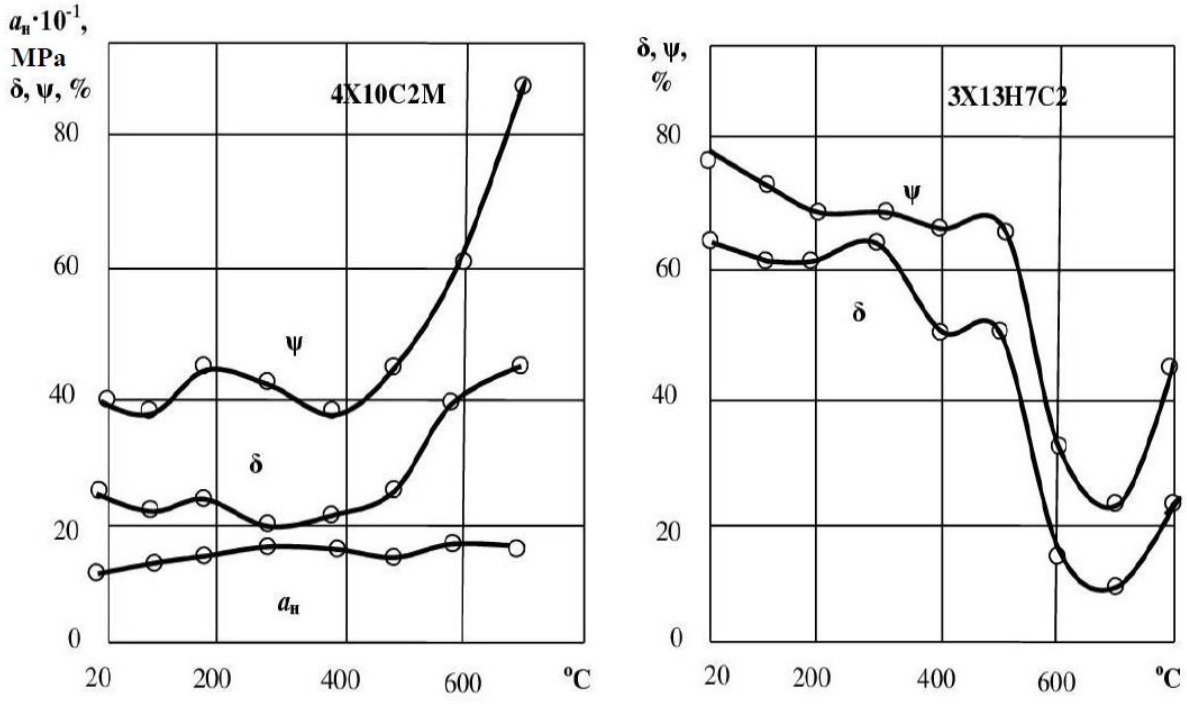
In continuation of the study of thermite sylicochromes, the dependence of the tensile strength limit σ_{10}^2 with increasing temperature was established. Thus, σ_{10}^2 for the thermite analog of steel "4X10C2M" at 900°C is 32 MPa (Fig. 3). Both grades of thermite sylicochromes after hardening have a hardness in the range of 50-55 HRC.

Analysis of the obtained experimental data confirms that the high content of chromium in thermite steel, which is a thermite analogue of the industrial brand "3X13H7C2", has greater resistance to oxidation at high temperatures, and with increasing carbon and nickel in its composition – higher heat resistance compared to industrial steel “4X9C2” and still worse than austenitic steels.



a b

Fig. 1. **Dependence of tensile strength (σ_b), conditional yield strength at tolerance to plastic deformation of 0.2% ($\sigma_{0,2}$) and creep limit (σ_{10}^3, σ_{10}^4, and σ_{10}^5) of thermite sylicochromes on temperature: a – for thermite analogue of steel "4X10C2M”; b – for the thermite analogue of steel "3X13H7C2"**



a b

Fig. 2. **Dependence of relative ductility (δ) and constriction (ψ) and toughness (a_n) of thermite sylicochromes on temperature: a – for thermite analogue of steel "4X10C2M"; b – for the thermite analogue of steel "3X13H7C2"**

During the cooling process, thermite sylicochromes detect a linear shrinkage of 51–58 μm for every 25 mm of length, or 2.0–2.3%. According to the coefficient of linear expansion, these steels occupy an intermediate position between austenitic and martensitic steels.

Discussion of research results. Thus, it can be reasonably stated that the synthesized termite sylchromes are not worse than industrial sylicochromes in terms of basic properties (σ_b, $\sigma_{0,2}$, σ_{10}^3, σ_{10}^4, σ_{10}^5, a_n, δ, ψ).

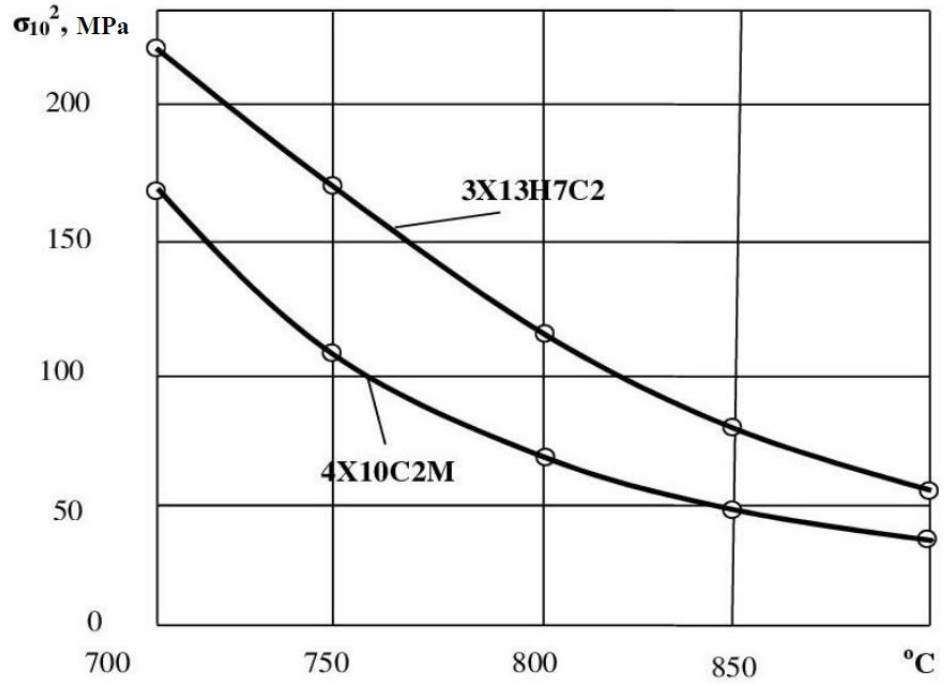


Fig. 3. **Change in endurance strength (σ_{10}^2) with increasing temperature for analogue steels "4X10C2M" and "3X13H7C2"**

The conducted experimental work speaks of significant prospects for the use of powder materials for the synthesis of alloys. Given that the method of manufacturing these alloys has full autonomy, namely, does not require power sources, or complex equipment (synthesis devices that maintain the required temperature, pressure, and ratio of reactive components), it can be widely used in non-specialized production and other industries. The advantages of the proposed method of synthesis of high-alloy chrome-plated steel and the composition of the exothermic charge make it possible to obtain repair casting of these steels in workshops and other production facilities not adapted to conventional methods of melting steel; gradient.

When considering the economic effect of the introduction of metal-thermite melting technologies, it is necessary to take into account the environmental effect associated with reducing the duration of the casting process, the use of industrial waste, reducing emissions of gases formed during metal melting; reduction of areas used in production for storage of industrial waste.

Conclusions. 1. As a result of the conducted research works, high-alloy steels analogues of industrial grades "4X10C2M" and "3X13H7C2" were smelted in a thermite way. 2. The technique of composition of metal-thermal mix for synthesis of the specified steels is developed. 3. The composition of the charge for the synthesis of thermite analogues of steels "4X10C2M" and "3X13H7C2" is established. 4. The authors identified the features of the microstructure of the studied steels. 5. The study of the properties of these thermite alloys showed that they differ from similar traditional alloys due to high combustion temperatures of mixtures, the specific method of reaction of charge components, and microalloying with aluminium powder. 6. Perspective directions of continuation of research of thermite steels and areas of their most expedient use are revealed. 7. The authors established the service properties of silicochromes σ_b, $\sigma_{0,2}$, a_n, ψ, δ and their dependence on temperature.

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