HEAT-RESISTANCE OF HEAT-RESISTANT Cr-Al STEELS FOR WORK UNDER EXTREME CONDITIONS

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Abstract. *Results of influence of aluminum, titanium and niobium on thermal resistance and coefficient of elongation of molded samples from high chromium steels are presented. The optimal concentration ranges of aluminum and titanium in the heat resistant steel for providing maximum thermal resistance of molded parts with taking into account the technological properties of the alloys are determined. The influence of metallurgical and technological defects are determined. In particular, it was found that the greatest negative influence have microshrinkage cavities and nonmetallic inclusions in the structure. It was defined that for a reliable evaluation of heat-resistance for steels of different chemical content it makes sense to accept the amount of cycles until models' disruption.*

Keywords: *Heat resistance, thermal resistance, high chromium steel, alloying, aluminum, titanium.*

The main feature or characteristic of heat-resistant alloys for work under extreme conditions is their oxidation resistance. In other words it is the ability of the material to resist the formation of dross on the surface of the object under conditions of high temperatures and aggressive environments. However, it is determined by the practice of heat - resistant details' exploitation, that choice of an alloy with high level of oxidation resistance is necessary, but not enough for providing long - term operation of a piece because most details under conditions of high temperatures work with the periodic heating and cooling, in such way they respond to temperature changes. Such details go out of operation mainly due to the appearance of cracks caused by temperature changes of a piece and accumulation of thermal stresses, that exceed reasonable for given conditions of exploitation. In addition, the continued work of heat-resistant details is accompanied by the change of sizes of the last ones.

So according to modern concepts heat-resistance must be viewed as three properties of metal: oxidation resistance, heat-resistance and resistance to grain growth, that's why the development of new or improvement of existing heat - resistant steels and alloys should be done with taking into account these characteristics.

The processes of oxidation of alloys are determined by complexity of both alloys and working environment. The same factors have substantial influence on heat-resistance as well.

The heat-resistance of alloys mainly depends on sizes of grains [1]. The alloys which are characterized by grains' boundaries disruption are less heat-resistant than alloys, in which thermal fatigue cracks are developed in the volume of the grain.

The large sizes of grains and presence of carbides can promote the formation of thermal fatigue cracks on interfacial boundaries, as a result of weaking of binding forces between hard solution and carbide [2]. Chrome steels with ferrite structure have poor resistance to plastic deformation at high temperatures. During continuous heating at temperatures higher than 850 °C ferrite steels have a tendency for grain's growth, resulting in falloff in hardness and plasticity, and this in turn contributes towards heat-resistance reduction.

Numerous theoretical and experimental works related to heat - resistance of metals and alloys and which have attempts to link together the amount of cycles of heat changes with disruption of a detail with physical and mechanical properties of alloys and characteristics of heat cycle do not give an absolute answer for a question as for common factors of heat-resistant alloys development.

From the works [3…5] basic factors which determine the heat - resistance of a detail are the level of variable temperatures, inhomogeneity of the temperature field in the volume of the detail, and also construction of the detail: a heat-resistance goes down with the increase of maximal temperature of a cycle and temperature drop in the volume of the detail. Poured heat-resistant details with reinforcement ribs and heat centers are especially sensible to heat-resistance. In such details additional temperature contrast in their volumes appears very quickly and the local areas of concentrations of stresses and deformations are developed. The harder the construction of the detail is the quicker its disruption from thermal fatigue will happen. The manufacture of rigid construction detail is possible only in case when the lifecycle of the detail does not depend on the change of its form and sizes while operating.

The typical feature of details' disruption from thermal fatigue is their susceptibility to cracking. It is a distinctive characteristic for details of heat - power equipment, especially for heat - resistant boilers, that is caused by rough temperature variations of details during the change of the thermal mode of boiler's operation, by routine and emergency stoppage of heat-power blocks. Thus, while developing new heat-resistant alloys special attention must be paid to providing propagation of thermal fatigue for metal of high resistance.

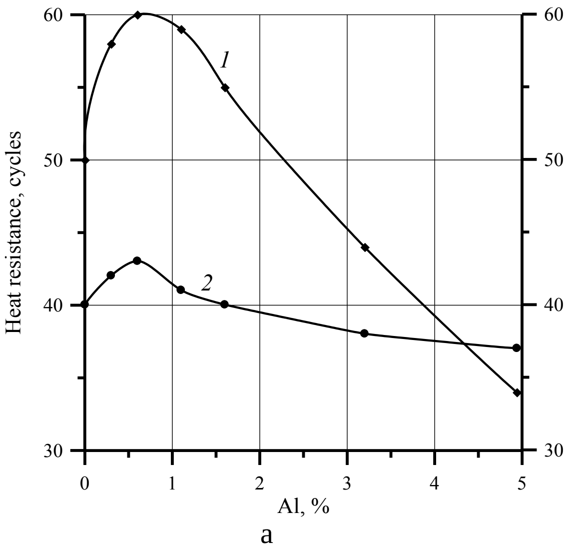
The aim of this work is the research of influence of chrome, aluminium and titatium and casting defects on heat - resistance of chrome and chrome - aluminium steels.

The authors of works [1…4] notice that the cracks of thermal fatigue can appear in places where defects of technological origin (shrinkage and gas holes, coarse-grain structure and non-metal impregnation) are located. At the time, casting defects can not influence metal heat - resistance, if they did not get to the areas with high concentration of stresses and to the boundaries with the maximal nonuniformity of the temperature field during heat changes. So, for achieving high heat-resistance it is necessary to meet demands of the correctly developed technology of castings' production.

All together, on the basis of literary sources analysis it is possible to arrive to the conclusion, that the general heat - resistance of material is to be the higher, the higher mechanical properties and the alloy's heat conductivity at high temperatures, the lower coefficient of linear expansion and the higher alloy's heat-resistance are.

Thus, heat - resistance of the alloy is the function of the whole complex of mechanical, physical, physical and chemical and technological properties.

The influence of aluminium on heat-resistance of high chromium steel 0,3 % C, 30 % Cr in the range of concentrations to 5% has been explored. It is determined that aluminium content to 1,0% in chromium steel improves steel heat-resistance (figure 1) as a result of deep steel deoxidation, stable ferrite constituent increase, metal purification from gases and nonmetallics. Such content of aluminium in some way raises coefficient of elongation that leads to heat - resistance improvement. Further increase of aluminium content in steel, in spite of growth of ferrite constituent contributes towards heat-resistance reducing approximately on 10…12% on every percent of aluminium through the increase of ferrite grains sizes and intergranular link weakening. In addition, it can be explained also by the fact that if such steel contains 0,25…0,30% of carbon, the γ-area closes with about 27% of chrome [4], in other words during heating to 1100 °C in the steel structure some quantity of austenite appears. During cooling of the model, as a result of $\gamma \rightarrow \alpha$ transformation, additional thermal stresses emerge having negative impact on general plasticity.



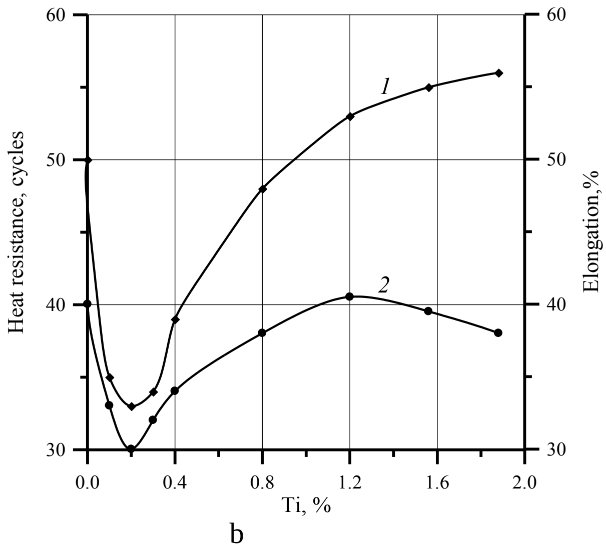


Fig. 1. Change properties of chromic steel (0,3% C, 30% Cr) depending on aluminium (a) content and chrome - aluminium steel (0,3% C, 30% Cr, 2% Al) depending on titanium content (b): 1 - heat-resistance; 2 – coefficient of elongation

Addition of aluminium in high-chromium steel encourages deep metal degassing, desulphuration and purification, that increases the limit of steel liquidity and reduces plastic deformation in every heating - cooling period. The speed of deformation accumulation is the least in models from steel with 0,7…1,0% of aluminium. Such content of aluminium improves in some way coefficient of elongation (see fig. 1, a), that in turn results in heat - resistance improvement.

Heat - resistance reducing of steel due to high content of aluminium can be explained by the substantial reducing of heat conductivity of metal, increasing of grain's sizes and coefficient of linear expansion of steel. A coarse-grain structure, as known, is less heat - resistant than fine-grained structure [1, 5]. Besides of that, addition to high-chromic steel a quantity of aluminium leads to formation of thermodynamics conditions for nitrides and oxides of aluminium development, which have an unfavorable form and serve as stress raisers. Such phenomena can be observed in the structure of steel with 4,0% of aluminium content. So, aluminium improves the heat-resistance of chromic steel due to complete transformation of steel into especially ferrite class. Having 1,0…1,5% of aluminium steel with 30% of chrome, becomes stable to the temperature of melting, phase and structural transformations in it are absent.

It is found by comparing of characters of heat-resistance change of steel and coefficient of linear expansion, that heat-resistance of chromium steel with aluminium over 1,0% is practically completely defined by the coefficient of linear expansion level. To provide high heat-resistance of chrome – aluminium steel with 28…32% of chrome, content of aluminium must be limited at the level of 1,0…1,5%, but for details which work at the temperatures higher 1200°C, the content of aluminium should be increased to 2, 0…3,0% aiming to improve its oxidation resistance. Taking into account good oxidation resistance and simplified process of alloying of chromium steel by aluminium, for work at the temperatures 1100…1250°C it is enough to add 1,0…2,0% of aluminium to it.

Structure refinement and heat-resistance improvement of chrome – aluminium steel can be obtained by additional titanium or niobium alloying. The Influence of titanium on properties of chrome – aluminium steel in the range of concentrations to 2,0% is explored. It is determined, that at little additions of titanium (0,1…0,2%) loss of heat-resistance of steel (fig. 1,) is observed as a result of metal contamination by the products of deoxidatio and weakening of intergranular links. Chrome – aluminium steel gets high stable properties at titanium content in the range 0,3…0,5%, keeping high metal oxidation resistance. Moreover its heat-resistance continuously increases with the rise of titanium content, in spite of some increase of linear expansion coefficient.

So, it can be considered that the best variant how to increase chrome – aluminium steel heat-resistance is its treatment both with titanium in the amount of 0,30 to 0,35% or 0,10…0,15% of niobium.

Beside of that it was found, that the most unfaurable effect on heat-resistance have microshrinkage cavities emerged as a result of wrong risering of steel castings during their production. Such cavities accelerate the development of thermal fatigue cracks, as they present finished disruption defects. Samples of all examined steels with microshrinkage cavities were disrupted after 15…20 cycles. So, defects of metallurgical and technological origin indeed have dominant influence on the heat-resistance of details.

As determined by researches of heat - resistance during thermal cycling of chrome – aluminium steel in the mode 1100↔20 °C, to obtain high working characteristics of moulded pieces from heat-resistant steel it is necessary to alloy it additionally by 1,0…2,0% of aluminium, 0,3… 0,5% of titanium or 0,10…0,15% of niobium.

For reliable evaluation of heat-resistance for steels of different chemical content it makes sense to accept the amount of cycles until models' disruption.

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