ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.2478/v10266-012-0103-0
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 12
Issue 4/2012
31 – 38

Cast Steels for Creep-Resistant Parts Used in Heat Treatment Plants

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Received 12.06.2012; accepted in revised form 03.09.2012

Abstract

Creep-resistant parts of heat treatment furnaces are in most cases made from high-alloyed chromium-nickel and nickel-chromium iron alloys, both cast and wrought. This paper presents the types of casting alloys used for this particular purpose, since the majority of furnace components are made by the casting process. Standards were cited which give symbols of alloy grades used in technical specifications by the domestic industry. It has been indicated that castings made currently are based on a wider spectrum of the creep-resistant alloy grades than the number of alloys covered by the standards. Alloy grades recommended by the technical literature for individual parts of the furnace equipment were given. The recommendations reflect both the type of the technological process used and the technical tasks performed by individual parts of the furnace equipment. Comments were also made on the role of individual alloying elements in shaping the performance properties of castings.

Keywords: Innovative foundry technologies and materials, Cast Ni-Cr austenitic steel, Castings for heat treatment plants

1. Introduction

Polish technical staff uses the documents in which the creep-resistant cast steel designations are consistent with the recommendations given in one of the following standards mentioned below:

1. *Steel casting, Iron-Chromium and Iron-Chromium-Nickel, Heat resistant, for general application* − ASTM A 297/A 297M-97.
2. *Staliwo stopowe żaroodporne (Heat resistant alloy cast steels)* − PN-62/H-83159 and *Staliwo stopowe żaroodporne i żarowytrzymałe (Heat resistant and creep resistant heavy duty alloy cast steels)* – PN-73/H-83159.
3. *Staliwo stopowe żaroodporne i żarowytrzymałe (Heat resistant and creep resistant heavy duty alloy cast steels)* − PN-90/H-83159.
4. *Hitzebeständiger. Stahlguss. Technische Lieferbedingungen* − DIN 17 465.
5. *Odlewy ze staliwa żaroodpornego* (*Heat resistant steel castings*) − PN-EN 10295:2004.

Standard No. 1 is a direct continuation of the first in the world standard describing the creep-resistant casting alloys based on iron and nickel. It was developed by American Casting Institute (ACI) as early as in the 50s of the last century. In alloys designation, the standard uses the nomenclature adopted by ACI – the designation of the alloy grade begins with the letter H (heat resistant) (Tab. 1). The next letter: E, K, T, ... etc., means the content of chromium and nickel [1]. In some designations of the alloy grade, numbers are also used to indicate mean carbon content (e.g. HK40 – 0.35-0.45 wt-% C). Technical literature and other types of documents also give the cast steel designations with reference to ASTM A 297/A 297M-97, indicating the presence of other alloying additives not included in the standard, e.g. HT-mod [2].

Table 1.
Creep-resistant alloy grades used for parts of heat treatment furnaces

Standard specification				
ACI	**PN-62/H-83159 PN-73/H-83159**	**PN-EN 10295:2004**	**DIN 17 465 (1992)**	**Germany Company POSE-MARE**
Cast austenitic steel				
		G-X25CrNiSi18-9	G-X25CrNiSi18-9	Pyrotherm G 18/8
				Pyrotherm G 18/8 Nb
				Pyrotherm G 16/13 Nb
		G-X40CrNiSi22-10	G-X40CrNiSi22-9	Pyrotherm G 22/10
				Pyrotherm G 27/10
				Pyrotherm G 27/10 Al
HE				
HF		G-X25CrNiSi20-14	G-X25CrNiSi20-14	Pyrotherm G 20/15
				Pyrotherm G 22/14 H
				Pyrotherm G 22/14 Nb
				Pyrotherm G 26/14
				Pyrotherm G 28/14
				Pyrotherm G 22/14
				Pyrotherm G 28/15 W
HH		G-X40CrNiSi25-12	G-X40CrNiSi25-12	Pyrotherm G 25/12
HK	LH23N18 LH25N19S2	G-X40CrNiSi25-20	G-X40CrNiSi25-20	Pyrotherm G 25/20 H
HI				
HL				
				Pyrotherm G 28/20 Al
				Pyrotherm G 30/20 Co
		G-X40CrNiSiNb24-24	G-X40CrNiSiNb24-24	Pyrotherm G 24/24 Nb
HN		G-X35NiCrSi25-21		Pyrotherm G 24/24 NbTZ
				Pyrotherm G 30/30
	LH17N37S2G	G-X40NiCrSi35-17		
		G-X40NiCrSiNb35-18		
HT		G-X40NiCrSi38-19	G-X40NiCrSi38-18	Pyrotherm G 18/36 H
HU		G-X40NiCrSiNb38-19	G-X40NiCrSiNb38-18	Pyrotherm G 18/36 Nb
		G-X10CrNiSiNb32-20		Pyrotherm G 20/32 Nb
HP		G-X40NiCrNb35-26	G-X40NiCrNb35-25	Pyrotherm G 25/35 H
		G-X40NiCrSiNb35-26	G-X40NiCrSiNb35-25	Pyrotherm G 25/35 Nb
				Pyrotherm G 25/35 NbSi
				Pyrotherm G 25/35 NbTZ
				Pyrotherm G 25/35 CoWNb
				Pyrotherm G 26/36 Mo
				Pyrotherm G 28/40/4
		G-X50NiCrCo20-20-20		
		G-X50NiCrCoW35-25-15-5		
		G-X40NiCrNb45-35		
Cast nickel alloy				
		G-NiCr28W	G-NiCr28W	Pyrotherm G 28/48/5
		G-NiCr50Nb	G-NiCr50Nb	Pyrotherm G 50/50/Nb
HW				
HX				

The next three standards (items 2, 3) were used in Poland. Although they ceased to apply quite a long time ago, they are quoted here because the cast steel designations proposed by those standards are still used in technical contacts, and in quotations and orders for castings. By 1990, the Polish standard contained only two types of the creep-resistant cast alloyed steel, i.e. LH23N18 and LH25N19S2 (see Tab. 1) with a minimum nickel content, designated for the construction of industrial furnaces. In a revised form, this standard additionally included an LH17N37S2G grade which reduced, but did not eliminate, the disparities between the state of knowledge on the selection of cast steel for parts of machines and equipment operating at high temperatures and alloys recommended by the Polish standard. Only the European standard on *Heat resistant steel castings* (item 5), introduced to Poland eight years ago, has changed this unfavourable situation. The, contained in this standard, cast steel grades and alloys based on nickel and cobalt (Tab. 1) have introduced to our country the European standards in the field of casting alloys used for creep-resistant applications.

Owing to always extensive cooperation with German partners, the domestic manufacturers and designers of creep-resistant castings have also been using alloys recommended by the German standard DIN 17 465 (Item 4 – Tab. 1). Thus, even before the introduction of the PN-EN 10295:2004, a significant change was observed in the Polish foundries as regards the number of cast steel grades used for creep-resistant steel components.

In addition to the steel grades recommended for castings by the standards mentioned above, the range of cast alloys offered by foundries involved in the production of creep-resistant parts of machines and equipment is definitely much wider, and a good example of this statement are alloys used by the German Company POSE-MARE (Tab. 1).

In the catalogues of casting manufacturers [3] who are also designers of castings, there are always a dozen or more of various grades of the cast steel and cast alloys based on nickel, both standardised and developed as a result of in-plant studies. Only such a comprehensive set of alloys can meet the technical requirements imposed on different creep-resistant castings, ensuring at the same time a rational use (reasonable consumption of alloying elements) of individual cast steel grades.

2. Alloys recommended for creep-resistant parts of heat treatment furnaces

The decision on the selection of alloy grade, which will be used in the manufacture of a specific creep-resistant part, is one of the most critical decisions made by the designer, because its consequences will affect the reliability and durability of the whole heat treatment plant [4, 5].

Mechanical properties of alloys at ambient temperature (Table 2) given by various standards are of no major value when it comes to the selection of material for the equipment of heat treatment furnaces, but still can serve as a point of reference to check the quality of materials used in the manufacture of this equipment. Among the mechanical properties commonly used in strength calculations of a casting design, the value of the material creep resistance (1%-10 000 h) is the one most commonly applied (Tab. 2) [6-8].

The mechanical properties ($R_{0,2}$, R_m and A_{10}) of various cast steel grades do not reflect the differences in the content of alloying elements. The only clearly visible difference in the properties of alloys is higher elongation (A_{10}) of G-X25CrNiSi18-9 or G-X10CrNiSiNb32-20 cast steels as compared to other alloys (Tab. 2), resulting mainly from the reduced carbon content. The effect of strengthening the cast steel matrix with cobalt is also noted (the value of $R_{0.2}$ in G-X50NiCrCo20-20-20 or G-X50NiCr CoW35-25-15-5). On the other hand, the creep resistance values obtained for individual alloys indicate that, used for castings, these alloys will enable a significant weight reduction (reduced wall thickness) under the known loading conditions or will increase the casting loading capacity.

A comparison of the physical properties of alloys (Tab. 3) shows that parts of the equipment operating at temperatures of up to 1000°C can be made from several materials of similar characteristics (expansion and thermal conductivity), but with different contents of nickel and / or chromium, as well as silicon and niobium.

Creep properties of all types of austenitic alloys meet the general requirements that are formulated for materials operating as parts of the furnace equipment [6-8]. The proper choice consists in finding an optimum combination of alloy grade (the chemical composition and properties – Tab. 1-3), casting function in the furnace, maximum temperature of the heat treatment, and aggressive effect of the furnace atmosphere, all this referred to the material of which the casting will be made [6-8].

The cost of creep-resistant furnace equipment represents a significant part of the overall cost of its operation, while price of a particular element will increase quite considerably when it is made of high-alloyed grades. Therefore, the choice of alloy grade for a casting requires a well-balanced decision on properties that are needed– price that can be paid.

The choice of chromium-nickel steel for castings is much more advantageous in terms of finances, but during operation it may give higher costs due to replacement of components and reduced furnace production capacity (frequent downtimes caused by defective equipment).

The choice of nickel-chromium or nickel alloy for castings will bring the following advantages:

– reduced part weight due to the use of material with higher creep resistance,

– longer performance life of the component and / or lower operating cost of the furnace to compensate for the higher cost of purchase,

although the following drawbacks should also be expected:

– only short-term increase in component life at a much higher cost of purchase,

– improved resistance to one of the factors responsible for failure of the component (e.g. high temperature corrosion resistance), but parallel deterioration of other properties (e.g. resistance to thermal fatigue).

When selecting an alloy for furnace equipment, the first choice should focus on the generally recommended materials (Tab. 4-6), well-developed and already checked in industrial practice. At the same time, the number of alloy grades used in the construction of furnace systems (see Tab. 1, Germany Company

POSE-MARE) extends far beyond the grades recommended and included in the already existing standards.

Table 2.
Properties of heat-resistant casting alloys, PN-EN 10295:2004

Alloy	$R_{0.2}$, N/mm^2 min.	R_m, N/mm^2 min.	A_{10}, % min. ($L_o = 5d_o$)	1%-10000 h – creep limit in N/mm^2 at			
				700°C	800°C	900°C	1000°C
Cast austenitic steel							
G-X25CrNiSi18-9	230	450	15	44,0	22,0	9,0	–
G-X40CrNiSi22-10	230	450	8	46,0	23,0	10,0	–
G-X25CrNiSi20-14	230	450	10	46,0	23,0	10,0	–
G-X40CrNiSi25-12	220	450	6	50,0	26,0	13,0	6,0
G-X40CrNiSi25-20	220	450	8	65,0	36,0	17,0	7,0
G-X40CrNiSiNb24-24	220	450	4	80,0	46,0	22,0	7,5
G-X35NiCrSi25-21	220	430	8	80,0	45,0	22,0	7,5
G-X40NiCrSi35-17	220	420	6	55,0	30,0	17,0	6,0
G-X40NiCrSiNb35-18	220	420	4	–	–	–	–
G-X40NiCrSi38-19	220	420	6	55,0	32,0	18,0	7,0
G-X40NiCrSiNb38-19	220	420	4	60,0	38,0	20,0	8,0
G-X10CrNiSiNb32-20	180	440	20	64,0	36,0	15,5	5,0
G-X40NiCrNb35-26	220	440	6	70,0	40,0	20,0	8,0
G-X40NiCrSiNb35-26	220	440	4	72,0	41,0	22,0	9,0
G-X50NiCrCo20-20-20	320	420	6	–	–	27,0	17,0
G-X50NiCrCoW35-25-15-5	270	480	5	–	–	–	17,0
G-X40NiCrNb45-35	240	440	3	–	–	–	8,0
Nickiel alloy DIN 17 465 (1992)							
G-NiCr28W	240	440	3	70,0	41,0	22,0	10,0

Table 3.
Physical properties of heat-resistant casting alloys, PN-EN 10295:2004

Alloy	Working temperature, °C	Thermal expansion (10^{-6}/K^{-1}) between 20°C and			Heat conductivity (W/(m×K)) at	
		400°C	800°C	1000°C	800°C	1000°C
Cast austenitic steel						
G-X25CrNiSi18-9	900	17,4	18,3	18,8	26,0	30,0
G-X40CrNiSi22-10	950	17,2	18,3	18.5	25,4	28,8
G-X25CrNiSi20-14	950	17,2	18,3	19,3	25,4	28,8
G-X40CrNiSi25-12	1050	17,5	18,4	19,3	25,4	28,8
G-X40CrNiSi25-20	1100	17,0	18,0	19,0	25,0	28,0
G-X40CrNiSiNb24-24	1050	16,8	18,0	18,5	24,5	27,7
G-X35NiCrSi25-21	1000	16,4	17,5	18,2	23,8	27,7
G-X40NiCrSi35-17	1000	15,3	17,0	17,6	23,0	26,8
G-X40NiCrSiNb35-18	1000	15,3	17,0	17,6	23,0	26,8
G-X40NiCrSi38-19	1020	15,3	17,0	17,6	23,3	26,5
G-X40NiCrSiNb38-19	1020	15,3	17,0	17,6	23,3	26,5
G-X10CrNiSiNb32-20	1050	17,6	18,7	19,5	25,1	–
G-X40NiCrNb35-26	1100	15,7	17,4	18,3	23,8	27,7
G-X40NiCrSiNb35-26	1100	16,0	17,8	18,6	23,5	27,7
G-X50NiCrCo20-20-20	1150	15,2	16,5	17,0	25,0	–
G-X50NiCrCoW35-25-15-5	1200	–	–	17,3	–	28,0
G-X40NiCrNb45-35	1160	14,3	15,3	15,7	30,6	36,1
Nickel alloy DIN 17 465 (1992)						
G-NiCr28W	1150	14,4	15,7	16,3	30,6	36,1

Table 4.
Recommended cast materials for furnace parts and fixtures for hardening, annealing, normalizing, brazing, and stress relieving [8]

Working temperature, ^oC	Furnace parts		
	Retorts, muffles, radiant tubes	Chain link	Sprockets, rolls, guides, trays
	Alloys: ASTM A 297/A 297M – 97 / PN-EN 10295:2004		
595−675	HF / G-X40CrNiSi22-10		
575−760	HF / G-X40CrNiSi22-10, HH / G-X40CrNiSi25-12		
760−925	HH / G-X40CrNiSi25-12, HL / G-X35NiCrSi25-21, HT / G-X40NiCrSi35-17		
	HK / G-X40CrNiSi25-20 HW		HK / G-X40CrNiSi25-20
925−1010	HL / G-X35NiCrSi25-21, HX		
	HK / G-X40CrNiSi25-20 HW	HT / G-X40NiCrSi35-17	
1010−1095	HL / G-X35NiCrSi25-21, HX		
	HK / G-X40CrNiSi25-20	HT / G-X40NiCrSi35-17	
1095−1205	HX		
	HL / G-X35NiCrSi25-21 HU / G-X40NiCrSi38-19		HL / G-X35NiCrSi25-21

Table 5.
Recommended cast materials for parts and fixtures for carburizing and carbonitriding furnaces [8]

Furnace parts	Alloys: ASTM A 297/A 297M – 97 / PN-EN 10295:2004
Construction elements	HK / G-X40CrNiSi25-20, HT / G-X40NiCrSi35-17 HU / G-X40NiCrSi38-19 HX
Functional accessories	HT / G-X40NiCrSi35-17, G-X40NiCrSiNb35-18 HU / G-X40NiCrSi38-19, G-X40NiCrSiNb38-19 HX

Table 6.
Recommended cast materials for parts and fixtures for salt baths [8]

Proces	Alloys: ASTM A 297/A 297M – 97 / PN-EN 10295:2004
Neutral hardening at 675–870^oC	HT / G-X40NiCrSi35-17 HU / G-X40NiCrSi38-19
Carburizing at 870–940^oC	HT / G-X40NiCrSi35-17

This indicates that the designers of castings featuring an appropriate database of relationships between the expected casting properties and casting cost can also choose different chemical compositions of the alloy for a specific item.

3. Choice of alloy chemical composition

The role of individual alloying elements in shaping the properties of castings used under the conditions equivalent to those operating in heat treatment furnaces is well-known and allows the following description.

Carbon. Its high content in creep-resistant alloys (Tab. 1) is the result of efforts to provide the cast part with the highest possible creep resistance (Fig. 1).

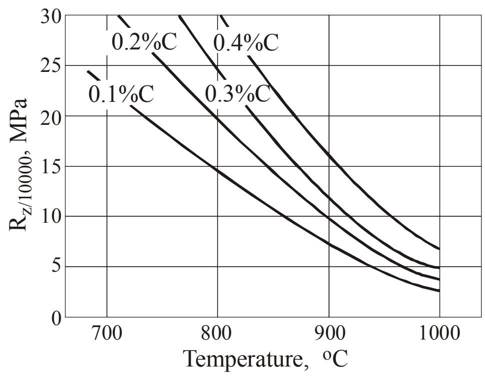

Fig. 1. Effect of temperature and carbon content (wt-%) on the creep behaviour of cast HK steel [9]

However, any increase of carbon content in cast steel will favour the precipitation of carbides. Then, the grain boundaries in steel as-cast (Fig. 2) and after annealing are "decorated" with large carbide precipitates of the primary origin and with finer secondary precipitates, forming continuous bands, when the carbon content exceeds 0.2% [5]. Any increased content of the carbide phase within the grain boundaries will reduce the plastic properties of the material (e.g. impact strength - Fig. 3), cause an increase in brittleness and deteriorate the thermal shock resistance and weldability [10, 11], which in this particular case of application will have an adverse effect on the performance life of the cast parts. So it is advisable to reduce the carbon content in cast steel to lower levels indicated in respective standards, as it allows obtaining better plastic properties. Higher carbon content (about 0.4-0.5%) is, however, necessary when the casting is expected to carry high mechanical loads and / or when its surfaces are ex-posed to heavy wear. Yet, it should be remembered all the time that this is achieved at the expense of reduced ductility of the material, sometimes below the acceptable standard levels.

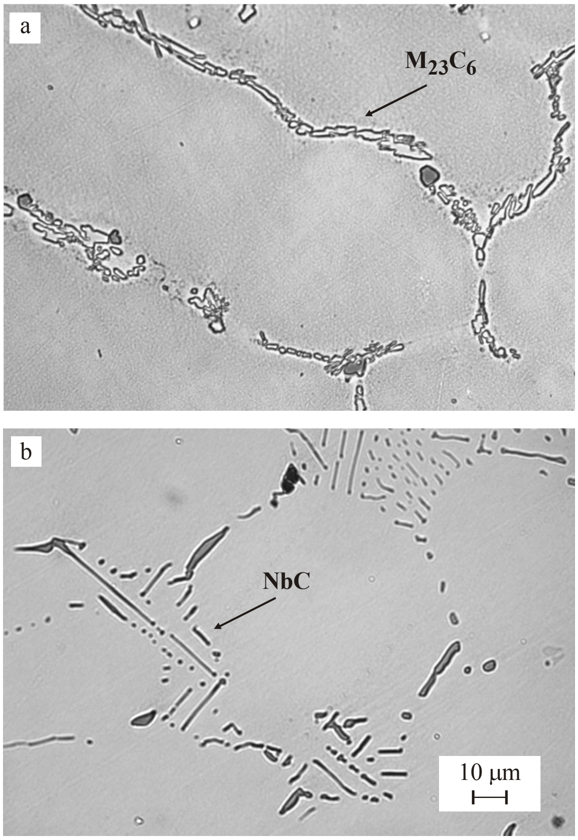

Fig. 2. Carbides morphology in cast alloy type 0,3%C-30%Ni-18%Cr in cast state [5]: a) − 1,69%Si, 0,03%Nb i 0,03%Ti, b) − 1,82%Si, 1,84%Nb i 0,05%Ti

Silicon. In the majority of cast steel and nickel alloy grades, the content of this element is from 1 to 2.5% [8]. The increase in silicon content (within the indicated range) in the commonly used creep-resistant alloys slightly lowers the mechanical properties and increases the plastic ones. No negative effect on the thermal fatigue resistance has been observed [5].

In practice, the silicon content in the cast material is kept close to a medium level within the range of values recommended by a standard. An exception to this rule are those steel grades of which castings used in carburising furnaces are made. In this specific case, higher silicon content (2-2.5%) is advantageous because of its positive impact on reducing the casting carburising process [5, 8].

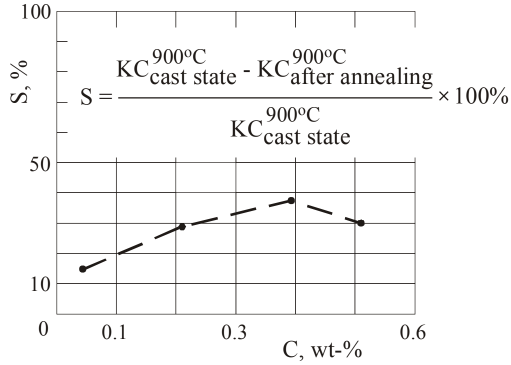

Fig. 3. Effect of carbon content and annealing process on the value of S parameter determined for cast steel of the 17%Cr-36%Ni type [11]. Key to symbols: $KC_{\text{as-cast state}}$ – the impact resistance of specimen cast at 900°C, $KC_{\text{after annealing}}$ – the impact resistance of specimen annealed at 900°C/ 400 hours

Manganese. In creep-resistant alloys its content is about 1-2% [8]. Due to the fact that this element is a nickel substitute (so called, cost-effective steel / cast steel), various attempts were made in Poland in previous years to use cast Cr-Ni-Mn steels for parts operating in the heat treatment furnaces [5]. Currently there are no reports in the literature, either Polish or foreign, on this type of research. Likewise, there are no references that would challenge the use of manganese in an amount indicated in the standards, or that would describe an attempt to use it as an alloying addition improving functional properties of the aforementioned castings.

Chromium. In cast steel, this element is present in a very wide range of values, i.e. 17-38% (Tab. 1). Chromium is a very important element, as its content in the alloy guarantees high heat resistance of structures operating at elevated and high temperatures. Generally, cast austenitic steel and nickel alloys have very good resistance to oxidation [4]. It is due, first of all, to the presence of the main alloying elements, i.e. chromium and nickel (Fig. 6).

The commonly used addition of chromium not only confers to alloys good oxidation resistance, but also the resistance to other types of high-temperature corrosion, resulting also in hardening of the matrix and formation of carbide phases.

Chromium is a strongly carbide-forming element. Depending on the carbon content in cast steel it co-creates with carbon different types of carbides (Fig. 2) which, present in a large number and scattered along the grain boundaries, can reduce some of the material performance properties (see earlier comments on the carbon content in cast steel). When the primary criterion in the selection of the chemical composition of cast austenitic steel is the high resistance of casting to thermal fatigue, it is recommended to have the chromium - carbon content ratio of 18% Cr-0.3% C [5].

Nickel. Besides chromium, nickel is another essential component of cast austenitic steels, and as such affects their structure, stability and phase behaviour during the heat treatment carried out in industrial furnaces. However, because the effect of other alloying elements on the cast steel properties is also very strong [5, 8], various grades differ significantly from each other, and thus complement each other.

Increasing the nickel content in cast steels / nickel alloys used for parts of the furnace equipment (18-68%) (Tab. 1) results in an improvement of nearly all the properties beneficial for the casting durability [4, 5, 7, 8]: it increases the stability of austenite and improves the mechanical properties (Tab. 2) as well as high-temperature corrosion resistance (see Figs 4-7), allowing also the use of castings at high temperatures (Tab. 3).

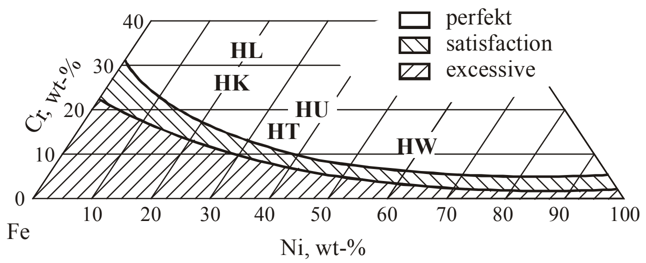

Fig. 4. Corrosion behaviour of heat-resistant alloy castings in air at 1095°C [8]; cast steel designations as in Table 1

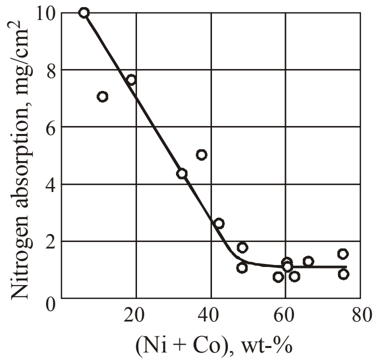

Fig. 5. Effect of the Ni + Co content in iron-, nickel-, and cobalt-base alloys on nitridation resistance at 650°C/168 hrs in ammonia [8]

The disadvantage may be poor carbon solubility in the austenitic matrix due to an increased content of this element in the alloy [5], which creates favourable conditions for the precipitation of carbide phases.

An important limitation in the use of cast high-nickel steel / nickel alloys is their high price as compared to the cast chromium-nickel steel (nickel cost may reach even 70-80% of the value of all the metallic materials used for melting). The simplest and most general philosophy concerning the use of cast nickel steel / nickel alloys for parts of the heat treatment furnaces is comprised in the following statement: for castings less exposed to the risk of thermal shocks during operation (construction elements [13]), it is recommended to use cheaper grades of alloys from the cast Cr-Ni steel family.

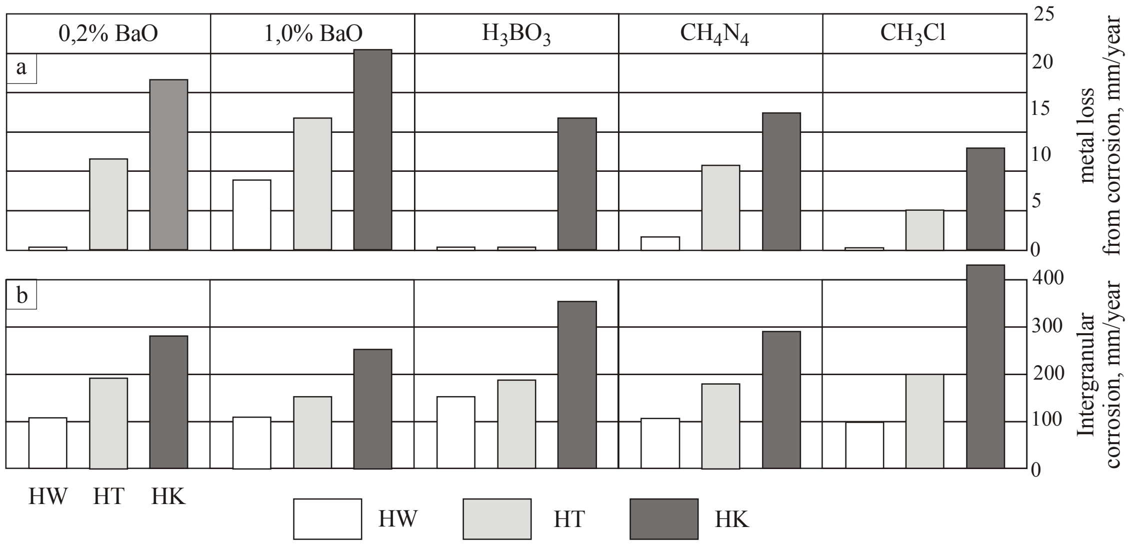

Fig. 6. Corrosion rates in terms of metal loss (a) and intergranular attack (b) observed for three commercial cast alloys in a 20NaCl-25KCl-55BaCl$_2$ salt bath under different conditions of rectification at 850°C [8]*/; cast steel designations as in Table 1

*/ The resistance to corrosion of cast steel in salts strongly increases when carbon content decreases to a level below 0.1% (average carbon content in these alloys is about 0.4%) and as a result of structure refinement. The results also show that cast high-chromium steel has higher resistance to this type of corrosion (according to [8]) .

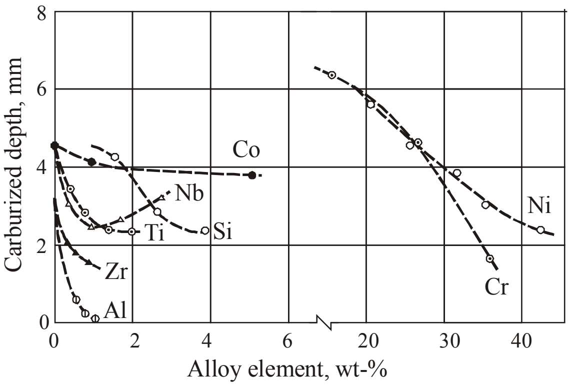

Fig. 7. Influence of alloy elements on carburization resistance of HK cast steel [19]; carburizing conditions: 1100°C/200 hrs, carburizing agent: Dugassa KG6

Other castings (functional accessories [14]) should be made primarily of cast Ni-Cr steel and nickel alloys. In the second group of alloys (Fe-Ni-Cr), the most commonly used materials are cast steels: HT and HU, and G-X40NiCrSi35-17, G-X40NiCr Si38-19, G-X40NiCrSiNb35-18, G-X40NiCrSiNb 38-19 (Tab. 1), characterised by a lower coefficient of thermal expansion as compared to other alloys (Tab. 3).

Niobium. Niobium is introduced to the chemical composition of creep-resistant alloys mainly to:

- improve their resistance to creep (see Tab. 1, for example, G-X40NiCrSi38-19 and GX40NiCrSiNb38-19 alloys) by changing carbides type and morphology [4],
- increase their heat resistance for operation in different types of furnace atmosphere (e.g. in furnaces for carburising – Fig. 7) due to changes in the phase composition of scale and preventing the matrix impoverishment in chromium.

Tungsten and cobalt. Joint / single addition of both these elements to creep-resistant alloys is mainly aimed at further strengthening of the γ matrix. Alloys with these additives, i.e. G-X50NiCrCo20-20-20, G-X50NiCrCoW35-25-15-5, G-X40NiCr Nb45-35 and G-NiCr28W, are characterised by the highest creep resistance (see Tab. 1) and the highest allowable operating temperature, i.e. 1000-1200°C (see Tab. 2), which enables manufacture of castings operating in vacuum furnaces for the heat treatment of tools.

4. Summary

Following the data comprised in literature on cast steel grades used for the manufacture of creep-resistant castings operating as parts of the equipment of heat treatment furnaces, it is clear that the cast austenitic steels remain the preferred material recommended for over 40 years for structures of this type [4, 8].

A new trend in the production of charge-bearing elements in furnaces for heat treatment is the use of composite tooling [15]. Composite tooling allows reducing some cost components in the total cost of the heat treatment, while improving the quality of the heat treated parts. An important limitation in a more widespread use of composite materials is the high cost of purchase compared to the cost of the tooling cast.

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