ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Issue 4/2008

181 – 184

34/4

Improving the resistance to carburising of creep-resistant castings

B. Piekarski
Szczecin University of Technology , Al. Piastów 17, 70-310 Szczecin, Poland
Corresponding author. E-mail address: bogdan.piekarski@ps.pl

Received 15.05.2008; accepted in revised form 27.06.2008

Abstract

The study presents the results of own investigations and of the investigations described in technical literature regarding various methods of improving the resistance to carburising of the creep-resistant structural parts of carburising furnaces. Most of the studies referred to were carried out in a Foundry of the Szczecin University of Technology. The results of the investigations on the effect of chemical composition of austenitic cast steel on its resistance to the carburising effect controlled through application of the anti-carburising coatings based on aluminium and constituted on high-alloy steel substrate were summarised. The possibility to use machining of castings as a means to raise their performance life in carburising atmosphere was also mentioned.

Keywords: Innovative foundry technologies and materials, Ni-Cr cast steel, Carburising, Anticarburising coatings

1. Introduction

Modern technique knows numerous cases when the cast parts operating at high temperatures are exposed to the effect of carburising atmosphere [1, 2].

When castings are operating, the adverse changes in their structure caused by the ageing process are additionally enhanced by changes in the properties of surface layer, caused by carbon diffusion from the atmosphere. As a consequence of the carburising process, casting degradation is speeded up [2, 3].

The degradation of casting properties can be counteracted by:

- introducing to cast steel or increasing in this steel the content of elements reducing or eliminating the diffusion of carbon to alloy matrix,
- changing the technological condition of the casting surface through application of protective coatings or by machining.

This study summarises the results of investigations carried out in a Foundry of the Szczecin University of Technology regarding the above mentioned methods of increasing the resistance to carburising in creep-resistant structural parts of the carburising furnaces.

2. Chemical composition

From the results of studies in which the effect of chemical composition of the austenitic cast steel on an improvement of the casting resistance to carburising effect has been investigated, a general conclusion can be drawn that increasing the content of most of the added alloying elements gives positive results. In impeding the diffusion of carbon from the atmosphere to the alloy, the alloying additives are operating in the following way:

- they reduce the solubility of carbon and its diffusion rate in the alloy matrix, e.g. Ni, Co,
- they form a protective layer on or below the surface of material, thus impeding the diffusion of carbon from the atmosphere and reducing also its solubility in the alloy matrix– e.g. Si, Al, Cr.

Nevertheless, there are two barriers worth mentioning that demand reducing the content of alloying elements. These are the following handicaps:

- economy; increasing the content of alloying elements must increase the cost of material in a proportion too high respective of the effects obtained from increasing its carburising resistance,
- usefulness; increasing the carburising resistance of alloy may mean deteriorating its other properties, e.g. its resistance to thermal fatigue.

The information we actually possess on how to select the chemical composition of castings operating under the carburising atmosphere is ordered and well understood.

Nickel is the leader in increasing the austenitic cast steel resistance to carburising, and to achieve this purpose, its optimum content in cast steel is generally considered to be 40÷60% (Figs. 1 and 2). It is also generally known that in austenitic cast steels with Fe/Ni ratio equal to ¼ the alloy resistance to carburising reaches its maximum level [4].

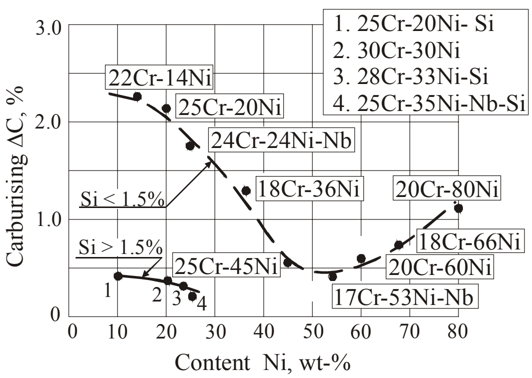

Fig. 1. The carburising rate in various types of austenitic cast steel; solid carburiser: 1100°C/ 200 hours [5]

Chromium is the alloying element which confers to the cast steel the required heat-resistance. Its content in alloy may go well in excess of 30% (see PN-EN 10295:2004). Chromium raises the alloy resistance to carburising mainly by reducing the thickness of the carburised layer [3] and forming on the casting surface a protective layer of chromium oxides [6] (providing, of course, the layer of oxides is not damaged during casting operation). Unfortunately, increasing chromium content in cast steel may also give way to local „overcarburising" of the casting surface layer (Fig. 3), which means that in a unit volume of the carburised layer the concentration of chromium carbides will locally reach a very high concentration, making physico-chemical properties of this layer differ too much from the properties of the uncarburised core [3].

Carbon reduces the process of cast steel carburising (Fig. 2), but also promotes the precipitation of chromium carbides, and this, in turn, reduces the mechanical properties and thermal shock resistance [3]. When casting is put in service, its carburised and brittle surface layer must "cooperate" with the plastic and uncarburised core. In [7], investigating the effect of carbon content in alloy along with the effect of carburising and annealing on the hot impact resistance of the 36%Ni-18% Cr cast steel, it has been stressed that the content of about 0.4% carbon is a limit that enables preserving good plastic properties in alloy with the carburised layer.

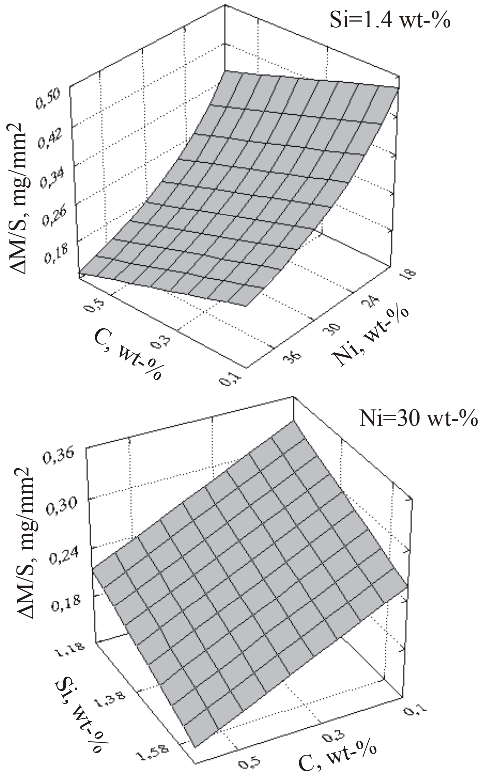

Fig. 2. Effect of Ni, Cr, C and Si on an increment in the cast steel weight (ΔM/S); gas carburising, temp. 900°C [3]

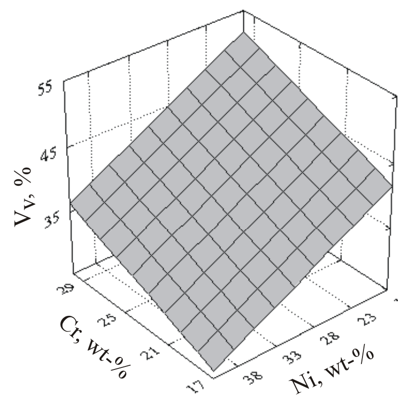

Fig. 3. Effect of Cr and Ni on carbide volume fraction (V_V%) in cast steel after carburising; 900°C/ 500 hrs [3]

Silicon increases the cast steel resistance to carburising (Fig. 2), because it reduces the solubility of carbon in austenite and is forming on or below the alloy surface a tight layer of silicon oxides. Silicon in a content above 2% is particularly effective in reducing the cast steel carburising [8], and therefore the 25Cr-20Ni-2.4Si cast steel is characterised by better anti-corrosive behaviour than its 25Cr-35Ni counterpart (Fig. 1). According to the authors of [6], obeying the inequality %Cr + 2% Si > 24 means arresting and eliminating the carburising process. On the other hand, increasing the silicon content may reduce the mechanical properties of cast steel, especially at ambient temperature, and therefore this element is usually added to cast steel in amounts of up to 2.5% (see PN-EN 10295:2004).

Manganese in cast steel should not go above 1.5% (see PN-EN 10295:2004). Everybody knows that manganese may act as a substitute to nickel, but no information has been available on investigations carried out in this scope currently.

Niobium and titanium added to cast steel individually or jointly reduce the process of its carburising [3, 9]. These elements form carbides in the alloy structure, simple or complex [10]. Changes in cast steel structure caused by an addition of niobium and/or titanium may as well prove unfavourable for the mechanical properties and thermal shock resistance [3, 11]. Positive effect of both elements on reducing the carburising process follows from their precipitation on the privileged crystallographic planes of austenite, impeding carbon diffusion to the inside of grains and building an oxide layer [12].

Aluminium reduces, or eliminates even, the cast steel carburising [9], but at the same time it causes very rapid drop of mechanical properties, impact resistance in particular [3].

Tungsten is used mainly in alloys expected to operate at carburising atmospheres at temperatures above 1000^{o}C. Added to cast steel in an amount of 3÷6% it has a reinforcing effect on the matrix [1].

Cobalt, like nickel, improves the cast steel creep resistance and resistance to carburising [1]. Yet, in view of its strategic role and price, its wide use in materials assigned for parts of the carburising furnaces can hardly be expected.

3. Protective coatings

Anticarburising coatings constituted on castings operating in carburising furnaces should satisfy the following criteria: heat resistance at least the same or better than the heat resistance of the substrate, high thermal conductivity, the coefficient of thermal linear expansion similar to that of the substrate. Using these guidelines, the applicability of aluminium-based coatings of the Al-Cu and Al-Si type was evaluated. Coatings were fabricated by the following methods (Fig. 4): pack and slurry cementation, and casting. The substrate for the coatings was austenitic cast steel of the 36%Ni-18%Cr type.

Detailed information on the investigations, including description of the technology of coating fabrication and an assessment of the resistance to carburising effect and thermal fatigue behaviour, is given in [13÷17].

The method of coating fabrication has an important effect on its thickness and the content and morphology of individual structural constituents (Fig. 4). The differences result in different durability of coatings constituted by the tested methods, when operating under the conditions of a carburising atmosphere and thermal shocks [13÷17].

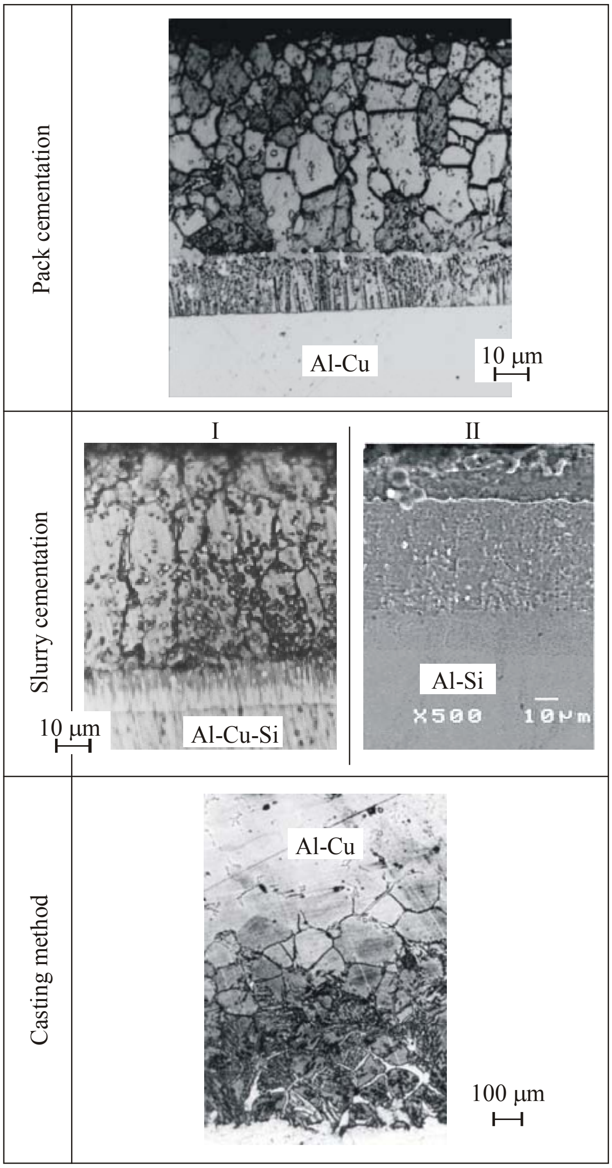

Fig. 4. Microstructure of coatings constituted on the casting surface by various methods [14÷18];
I – mixture of coating in the form of dense paste applied on the casting surface, II – castings immersed in a properly prepared mixture of coating

4. Machining

Machining removes the casting skin characterised in respect of the deeper parts of alloy by an increased number of defects (among others, by micro-shrinkages), and therefore it is said to improve the casting resistance to carburising (Fig. 5). Some share in reducing the carburising effect has also the cold work and the formation of Beilby layer on the surface of casting subjected to this type of working.

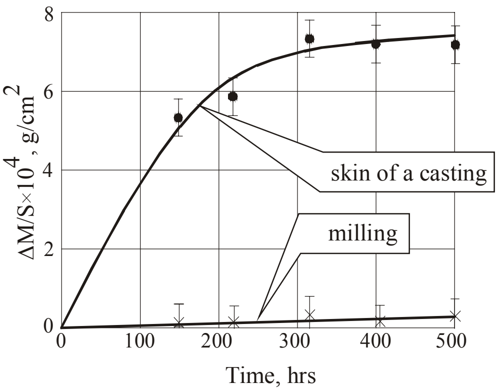

Fig. 5. Kinetics of the carburising process in samples of 18Cr-36Ni cast steel; different surface conditions; gas carburising – 900°C [3]

Given the intricate shape of the majority of structural parts, reducing the carburising effect by machining of the casting surface (Fig. 5), though very effective, is quite often also too expensive. Therefore, in practice, machining is applied only to small casting mate surfaces [3]. The exception are radiant pipes. Their machining does not cause any technical problems, and due to this it has been made an obligatory operation.

5. Conclusions

Raising nickel content in austenitic cast steels has a favourable effect on the physical and mechanical properties of castings operating as parts of the carburising furnaces. On the other hand, raising the content of carbon, chromium, and silicon, or titanium and/or niobium may exert a double effect: negative (reducing, for example, the casting resistance to thermal fatigue), or positive (reducing the degree of carburising, increasing the tensile and yield strengths of cast steel). Hence it follows that the content of these elements in cast steel should be an outcome of a compromise between the physical and mechanical properties. Yet, this compromise may differ depending on function that the casting is supposed to perform in a carburising furnace [3].

The examined anticarburising coatings (protective coatings) are temporarily satisfying the requirements of high resistance to thermal fatigue under the conditions of a carburising atmosphere. The recently developed slurry method [17], ensuring in one single operation of preheating and holding the formation on the casting raw surface of a multi-layer coating (Fig. 4 – II) without the necessity to use a protective atmosphere, is expected to raise the interest of users of these parts in this method of increasing the life of creep-resistant castings. The slurry method II is an object of patent application.

References

[1] A. Hernas, Creep strength of steels and alloys. Wydaw. Polit. Śląskiej, Gliwice 1999 (in Polish).

[2] H.J. Grabke, L. Wolf, Carburization and Oxidation. Mater. Sc. Eng., 87(1987)23.

[3] B. Piekarski, Austenitic steel casting used in constructional of carburising furnaces – theoretical and practical aspects of increasing life. Prac. Nauk. PS, nr 573, Szczecin 2003 (in Polish).

[4] A. Schnaas, Veränderung der Eigenschaften hochwarm fester Stähle durch Aufkohlung und karbidens-scheidungen. Diss., Max-Planck-Institut, Düsseldorf 1977.

[5] W. Steinkusch, Aufkohlung von Schleudergußrohren in der petrochemischen Industrie und Erklärung dieses Verhaltens durch Laborversuche mit Chrom-Nickel-Stählen und – Werkstoffen im Temperaturbereich von 800-1150°C. Werkst. u. Korrosion, 1(1977)1.

[6] K. Ledjeff, A. Rahmel, M. Schorr, Oxidation und Aufkohlung hochlegierter Werkstoffe für Crackrohre – Teil 1, 2. Werkst. u. Korrosion, 30(1979)767; 31(1980)83.

[7] B. Piekarski, P. Christodulu, J. Kubicki, Influence of carburising and annealing on hot fracture toughness of LH17N36S cast steel. Ochrona przed korozją, 4(1984) 230-234 (in Polish).

[8] R.H. Kane, Effect of Silicon Content and Oxidation Potential on the Carburization of Centrifugally Cast HK-40, Corrosion-NACE, 4(1981)187.

[9] D. Yamasaki, I. Hirata, Study on the Carburizing Phenomenon of Heat-Resisting Cast Steel for Pyrolysis Tubes. Tech. Rev., 1(1977)294.

[10] B. Piekarski, Effect of Nb and Ti additions on micro-structure and identification of precipitates in stabilized Ni-Cr cast austenitic steels. Mater. Char., 47/3-4(2002)181.

[11] B. Piekarski, The thermal fatigue behavior of creep-resistant Ni-Cr cast steel. Arch. Foundry Eng., vol. 4(2007)155.

[12] J. Hemptenmacher, H.J. Grabke, Einflüsse kleiner Zusätze von Niob oder Cer auf Korrosion und Kriechen von Incoloy 800 in CO-$H_2$0-H_2-Atmosphären. Werkst. u. Korrosion, 34(1983)333.

[13] P. Christodulu, Anticarburising coatings. Diss. Polit. Szczecińska, Szczecin 1984 (in Polish).

[14] J. Kubicki, Casting coatings Al-Cu on creep-resistant cast steel. Prac. Nauk. PS, Szczecin 1996, nr 529 (in Polish).

[15] A. Drotlew, M. Garbiak, J. Kubicki, B. Piekarski, Anticarburising coatings for castings operating under the conditions of thermal shocks. Foundry Rev. 9(2004)742-751 (in Polish).

[16] B. Piekarski, J. Kubicki, Al-Cu coating applied on austenitic cast steels used in carburising atmospheres. Physico-chemical Mechanics of Materials, 5(2006)564–567.

[17] A. Kochmańska, Protective coatings on high-temperature crrep-resistant cast steel obtained by slurry method. Diss., Polit. Szczecińska, Szczecin 2006 (in Polish).