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Optimization of Heat Treatment in Aspect of Production's Costs Reducing and Improving of Casting Quality from Duplex Cast Steel

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Abstract

The paper determines possibilities of cost optimisation in the production of GX2CrNiMoCu25-6-3-3 type duplex cast steel castings through selection of appropriate solution heat treatment temperature, which value depends on the content of alloying elements. Metallographic analysis was carried out for as-cast and heat treated cast steel. Hardness and impact strength of the cast steel were determined, which were correlated with the volume fraction of phases determined by means of ImagePro computer image analyser. It has been shown that increased carbon content creates a need to use higher treatment temperatures, thereby increasing the production cost. With increasing carbon content the cast steel hardness after solution heat treatment increases, however, crack resistance decreases

Keywords: Heat treatment, Duplex cast steel, Mechanical properties, Ferrite - δ , Austenite - γ , Volume fraction

1. Introduction

Austenitic-ferritic duplex stainless steel (DSS) is very attractive as a structural material in the fields of energy/environmental systems where both high mechanical strength and excellent resistance to localized and stress corrosion are required [1,2]. In DSS the corrosion properties of both ferrite and austenite depend strongly on the actual chemical composition. The main alloying elements chromium, molybdenum, nickel and nitrogen are not equally distributed in ferrite and austenite. The austenite is enriched in nickel and nitrogen, while the ferrite is enriched in chromium and molybdenum. The partitioning of these elements affects the corrosion resistance of both, the single phase and the entire alloy [3].

Generally, these alloys have two to three times higher yield strength and exhibit greater resistance to localized and stress corrosion than type 300-series austenitic stainless steels at a

comparable cost [4,5]. It is well known that such good properties of duplex stainless and cast steels related on the two-phase microstructure comprised of a mixture with approximately equal amounts of ferrite (δ) and austenite (γ) [6,7]. However, a number of undesirable phases such as carbides, nitrides and intermetallic compounds may appear in δ -ferrite areas and at the δ/γ interfaces if the manufacturing process are not carefully controlled [8-11]. Among these secondary precipitates, σ -phase, R-phase and carbides with fast formation kinetics have been particularly noticed because they can cause dramatic deterioration of the toughness and the corrosion resistance of duplex stainless steel [12-14].

The stainless and cast steels typically have an annealed structure that is roughly half austenite and half ferrite, although the ratios can vary from roughly 35/65 to 55/45. The difficulty in precipitating the microstructure is due essentially to the effects of the alloying elements, which modify the Fe-Cr-Ni phase diagram [15]. Alloy producers use empirical formula, in which

proportionality coefficients are attributed to each element, and the later are grouped together, depending on their tendency to stabilise either the ferrite (Cr, Mo, Si, etc.) either the austenite (Ni, N, C, etc.). In practise, the annealing temperature is chosen as low as possible, but sufficient to take into solution any precipitate phases. The relative amounts of the δ - ferrite and γ - austenite phases is then essentially determined by the chemical composition, particularly as regards the balance between δ - stabilizers and γ - stabilizers [16].

The paper determines possibilities of cost optimisation in the production of GX2CrNiMoCu25-6-3-3 type duplex cast steel castings through selection of appropriate solution heat treatment temperature, which value depends on the content of alloying elements.

2. Methodology and materials for research

The chemical composition of the highly alloy ferritic-austenitic duplex cast steel used for the present work is listed in table 1.

Table 1.

The chemical composition of examined cast steel [%]

C	Cr	Ni	Mo	Mn	S	Si	P	Cu
heat No. 1								
0.028	24.20	8.82	2.30	0.46	0.010	0.85	0.011	0.02
heat No. 2								
0.055	24.40	6.71	2.40	0.14	0.020	0.81	0.020	3.08

Samples were solution annealed in water after 2h of soaking at a temperature of 1050°C, 1080°C, 1150°C

The microscopic analysis of the cast steel after heat treatment was performed on a Zeiss Axiovert 25 optical microscope. In order to disclose the structure, the cast steel was chemically etched with reagent Mi21Fe (30g potassium ferricyanide + 30g potassium hydroxide + 60ml distilled water).

Volume fraction of ferrite austenite and sigma phase was performed on ImagePro Plus computer program.

Hardness was measured by the Brinell method. Impact resistance was measured on Charpy V specimens at ambient temperature on a hammer of an initial energy of 300 J.

3. Results and discussion

Examinations of raw cast steel structure have shown that with decreasing carbon content the amount of unfavourable intermetallic phases precipitates goes down. Those precipitates, creating a characteristic network at the boundaries of primary solidification grains (Fig. 1c,d), substantially deteriorate the impact strength of raw cast steel, which for a cast steel containing 0.055% C amounted to only 7J. In the cast steel from heat 1, containing C=0.028%, a uniform ferritic-austenitic structure has been obtained (Fig. 1a,b), ensuring a high, ~60J, impact strength in the as-cast state.

The structure of raw cast steel, and in particular the presence of σ phase precipitates, has major influence on the choice of optimum solution heat treatment temperature.

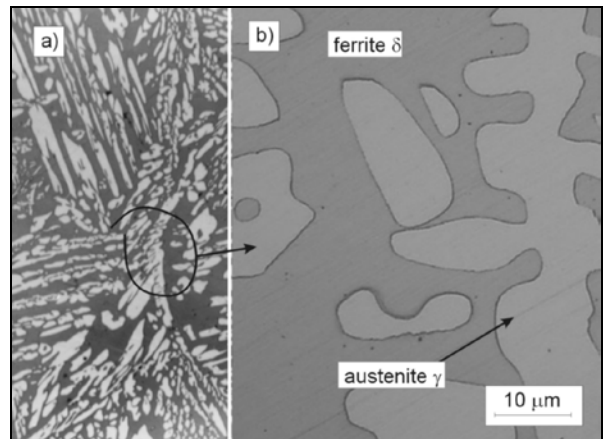


Fig. 1. The ferritic-austenitic microstructure of cast steel in as-cast condition: a,b) heat No. 1, c,d) heat No. 2

To determine parameters of heat treatment, the cast steel examined was solution heat treated in water after two-hour annealing at 1050°C, 1080°C and 1150°C. Example of structure images are presented in Figure 2, and changes in ferrite and austenite fractions versus temperature in Figures 3 and 4.

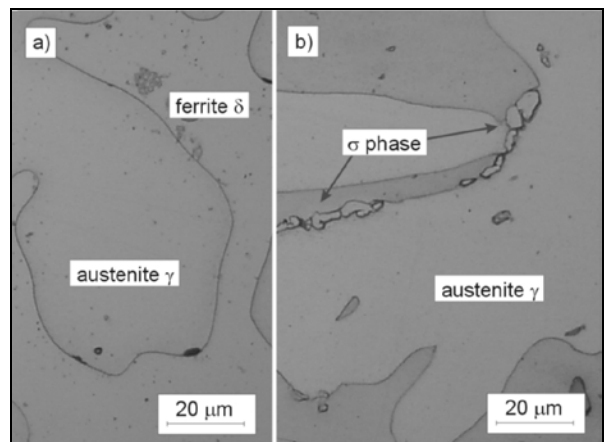


Fig. 2. The ferritic-austenitic microstructure of cast steel after the solution heat treatment in 1050°C: a) heat No. 1, b) heat No. 2

In the structure of cast steel from heat 2, solution heat treated from 1050°C, around 3% of σ phase existed apart from ferrite and austenite (Fig. 2b, Fig. 3). This proves too low annealing temperature, which did not allow its full dissolution, and a high stability of part of σ phase is related to a high content of molybdenum existing in it, what has been described at length in authors' papers [17]. The structure of cast steel solution heat treated from 1080°C consisted of around 55% of ferrite and 45% of austenite, while solution heat treated from 1150°C – of 65% of ferrite and around 35% of austenite (Fig. 3).

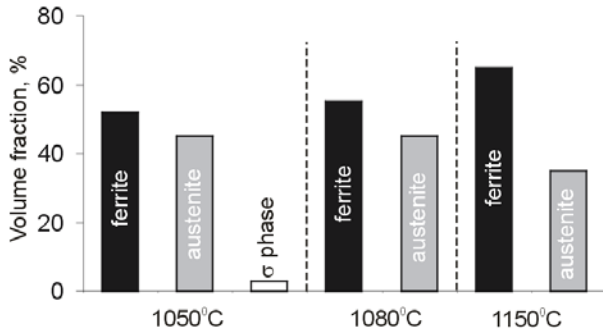


Fig. 3. Volume fraction of phase occurred in heat No. 2 depended on temperature of solution heat treatment

Solution heat treatment of cast steel from heat No. 1 in the temperature range between 1050°C and 1150°C did not have significant influence on ferrite and austenite fractions in the structure (Fig. 4), what is related to high nickel and manganese contents in the alloy, i.e. elements which strongly stabilise the austenite (Tab. 1). The structure of cast steel solution heat treated from 1050°C consisted of around 55% of austenite and 45% of ferrite, while as a result of solution heat treatment from 1150°C the amount of ferrite increased slightly by around 3%, at the cost of austenite (Fig. 4).

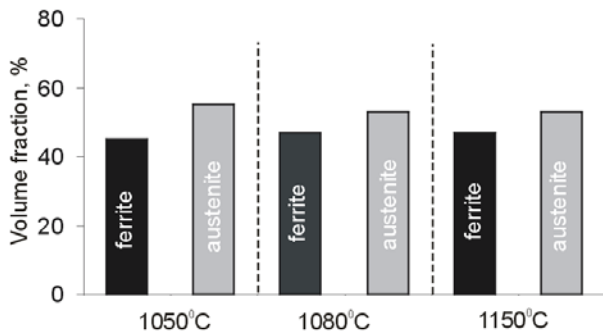


Fig. 4. Volume fraction of phase occurred in heat No. 1 depended on temperature of solution heat treatment

The hardness measurements specified in Fig. 5 show that with increasing solution heat treatment temperature the alloys' hardness increases, what is related to higher volume fraction of harder ferrite in the structure. A clear increase in hardness of cast steel from heat No. 2, from 241 HB for the cast steel solution heat

treated from 1050°C to 264 HB for the cast steel solution heat treated from 1150°C, is caused just by $\gamma \rightarrow \delta$ transformation and related presence of around 60% of ferrite in the alloy structure. Small changes in the hardness of cast steel from heat No. 1 (Fig. 5) result from small changes in ferrite and austenite fractions resulting from solution heat treatment in the temperature range 1050–1150°C (Fig. 4).

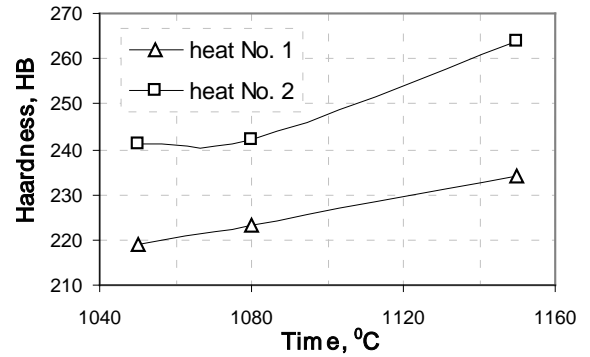


Fig. 5. Hardens of the investigated cast steel after the solution heat treatment

Impact strength measurements specified in Fig. 6 show that in the solution heat treated cast steel, even at higher carbon contents, very high impact strength may be obtained, comparable to cast steels containing less than 0.03 carbon. However, the existence of even small amounts of σ phase has significant and adverse influence on the impact strength of solution heat treated cast steel. For the cast steel from heat No. 2 after solution heat treatment from 1050°C, at the presence of around 3% of σ phase, the impact strength of the cast steel amounted to 70J as against 142J obtained for pure ferritic-austenitic structure after solution heat treatment from 1080°C.

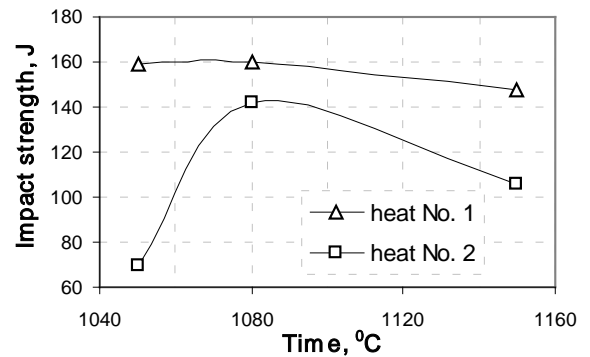


Fig. 6. Impact strength of the investigated cast steel after the solution heat treatment

Cast steel with low carbon content (heat No. 1) features high energy of breaking, equal to ~160J for cast steel solution heat treated from 1050°C. The increase in solution heat treatment temperature does not have a significant influence on the energy of breaking (Fig. 6), what is connected with small mutual changes in ferrite and austenite fractions in the structure (Fig. 4).

4. Conclusions

The examinations carried out allow formulating the following statements and conclusions:

- duplex cast steels provide high possibilities of structure optimisation from the point of view of castings' operating properties. Mutual ferrite and austenite fractions in the structure and hence final properties of components may be controlled through appropriate selection of solution heat treatment temperature. With increasing solution heat treatment temperature the amount of ferrite increases, what results in increased alloy hardness at simultaneous maintenance of good resistance to cracking;
- heat No. 1, with the lowest carbon content, features impact strength of around 160J, while in heat No. 2, with higher carbon content, the minimum impact strength amounted to 60J, what anyhow is higher than the required minimum of 27J for structural materials. However, increased carbon content in a duplex cast steel results in the need to use higher solution heat treatment temperature, ensuring dissolving of undesired intermetallic phases. Optimum arrangement of properties and comparable volume fraction of ferrite and austenite in the structure of cast steel from heat No. 1 was obtained as a result of solution heat treatment form 1050°C, while of cast steel from heat No. 2 after solution heat treatment form 1080°C;
- the guaranteeing of low carbon content creates a possibility to lower the solution heat treatment temperature by around 40°C, what will have a significant influence on reducing the production costs of castings.

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