

Effect of annealing on mechanical properties of ledeburitic cast steel

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Materials

ABSTRACT

Purpose: The paper presents evaluation of influence of grain normalization (refinement as a result of repeated austenitizing), and the inclination to precipitate the hypereutectoid cementite in Widmannstätten structure in G200CrMoNi4-6-3 cast steel. Four temperatures of heat refining have been applied.

Design/methodology/approach: Basic research of G200CrMoNi4-6-3 cast steel included metallographic analysis, and hardness and impact strength tests. The heat treatment has been planned on the basis of CCT diagram prepared for that alloy cast steel.

Findings: The test material has been G200CrMoNi4-6-3 hypereutectoid cast steel. The evaluation has been carried out for four annealing temperatures, i.e. 850°C, 900°C, 950°C and 1050°C. At all annealing temperatures in the structure of cast steel the precipitation of hypereutectoid cementite along grain boundaries of former austenite took place. At the temperature of 850°C one may observe the coagulated hypereutectoid cementite precipitates inside of primary grains of austenite. Whereas beginning from the temperature of 900°C the cementite in G200CrMoNi4-6-3 cast steel forms distinct „subgrains” inside of primary grains of austenite.

Research limitations/implications: Research financed by the Ministry of Scientific Research and Information Technology, grant No. 3 T08B 057 29.

Practical implications: G200CrMoNi4-6-3 cast steel of ledeburite class is used mainly for rolls production. Any data related to the structure and mechanical properties of that cast steel are precious for the manufacturers and users of the mill rolls.

Originality/value: The new heat treatment of G200CrMoNi4-6-3 cast steel

Keywords: Tool materials; Cast steel; Heat treatment; Hypereutectoid cementite

1. Introduction

It is very often that the hypereutectoid cementite in hypereutectoid cast steel is present in form of continuous network along grain boundaries of former austenite and in Widmannstätten structure. The presence of thick needles of hard cementite in the structure of these cast steels leads to significant decrease of their mechanical properties. The creation of cementite precipitates in Widmannstätten structure depends on the cooling rate and the size

of austenite grain, similar like ferrite precipitates in hypoeutectoid steels. In the foregoing steels the ferrite in Widmannstätten structure is eliminated on the way of heat refining. In poured alloys (cast steels) with the concentrations of carbon close to E point on Fe - Fe₃C phase diagram, elimination of disadvantageous precipitates of hypereutectoid cementite in Widmannstätten structure is a serious technological problem which is related with the selection of the right cooling rate, as well as (for the sake of high temperature) the risk of partial melting (material softening) [1 - 12].

Table 1.
Chemical composition (weight %) of the cast steel used in the investigation

C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Al
1,90	0,58	0,65	0,025	0,010	1,08	0,52	0,23	0,004	0,14	0,06

Within the framework of this study the evaluation of influence of grain normalization and the inclination to precipitate the hypereutectoid cementite in Widmannstätten structure in G200CrMoNi4-6-3 cast steel has been made.

2. Test materials

Material for research was highcarbon cast steel G200CrMoNi4-6-3 of ledeburite class which composition is presented in Table 1.

It is evident that this is hypereutectoid cast steel, chromium – nickel – molybdenum. For the sake of the presence in it's structure of Cr, Ni, Mo and Mn, which move the point E on Fe-Fe₃C system towards the lower carbon concentrations there is ca. 11% mass of transformed ledeburite in the structure of investigated cast steel.

In delivery condition (just after casting) in G200CrMoNi4-6-3 cast steel there is continuous network of hypereutectoid cementite and transformed ledeburite as well as precipitates of hypereutectoid cementite in structure of Widmannstätten type (Fig. 1).

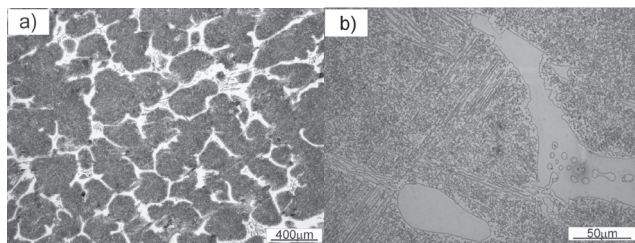


Fig. 1. Microstructure of G200CrMoNi4-6-3 of investigated cast steel (as-delivered condition)

3. Research objective

The objective of this study was to propose the technology of G200CrMoNi4-6-3 cast steel annealing leading to the changes in its structure consisting in the breakage of continuous network of hypereutectoid cementite through its partial coagulation and creation of fine subgrains with barely outlined network of hypereutectoid cementite. According to the research [9, 12, 15] such structure should allow obtaining advantageous tribologic properties of the rolls made of this cast steel.

4. Research results and discussion

In order to determine the upper temperature of austenitizing of G200CrMoNi4-6-3 cast steel and its solidus temperature some test have been performed, popularly called „hardening series”, consisting in the measurements of observations of the structure and hardness of samples quenched hardened from the increasing temperature, of which the detailed results are presented in papers [13] and [14]. The samples with dimensions of 20x30x40 mm have

been austenitized at temperatures of 700÷1100°C (with temperature step of 50°C up to T_A = 900°C, and than every 25°C up to T_A = 1100°C), and after that have been cooled down in oil.

The figure 2 presents the influence of austenitizing temperature on hardness of quenched in oil samples of test cast steel. As it is noticed, along with the increase of austenitizing temperature to 1075°C the hardness of the samples decreases. Hardness decrease is the result of volume fraction increase of retained austenite which at the highest temperatures is accompanied by primary ledeburite only (Fig. 3). Beginning from the temperature of 1075°C, the hardness of cast steel starts to increase, which probably is connected with partial melting formation as the result of exceeding its solidus temperature (Fig. 3d).

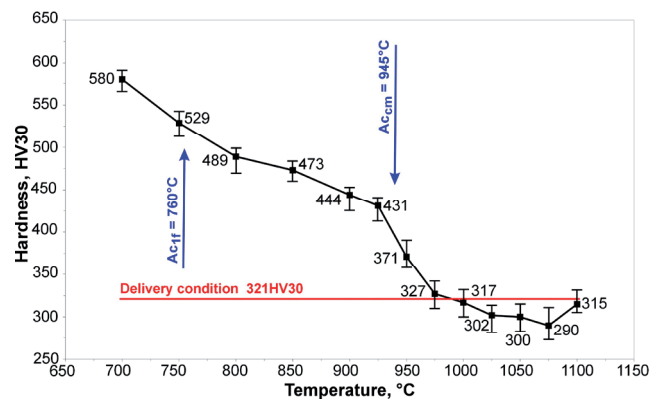


Fig. 2. The effect of austenitizing temperature at hardness samples G200CrMoNi4-6-3 cast steel quenched in oil

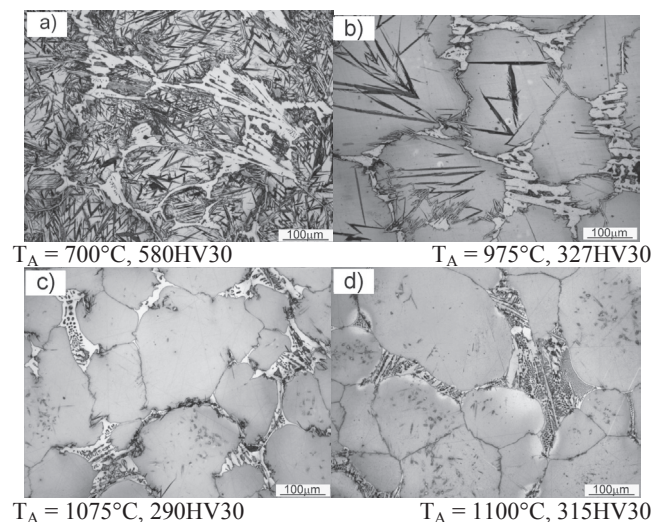


Fig. 3. Selected microstructure of samples G200CrMoNi4-6-3 cast steel quenched in oil from temperature: a) 700°C, b) 975°C, c) 1075°C, d) 1100°C. Etched with 3% HNO₃

The figure 3 presents selected structure micrographics of test cast steel samples quenched in oil for successive austenitizing temperatures

However on the basis of kinetics of phase transitions (CCT diagram) the following temperatures have been determined: $A_{c_{cm}}$ and $A_{c_{1f}}$ of test cast steel, which are $A_{c_{cm}} = 945^{\circ}\text{C}$ and $A_{c_{1f}} = 760^{\circ}\text{C}$ respectively [10].

On the basis of the foregoing results of phase transitions kinetics tests as well as hardening series, and metallographic analysis the heat treatment has been applied consisting in heating the samples (20x30x40mm) of G200CrMoNi4-6-3 cast steel to four annealing temperatures: 850, 900, 950 and 1050°C, sustaining them for 10 hours and cooling down at constant rate of 48°C/h to room temperature.

The figure 4 presents the structures of test cast steel heated to the above mentioned temperatures.

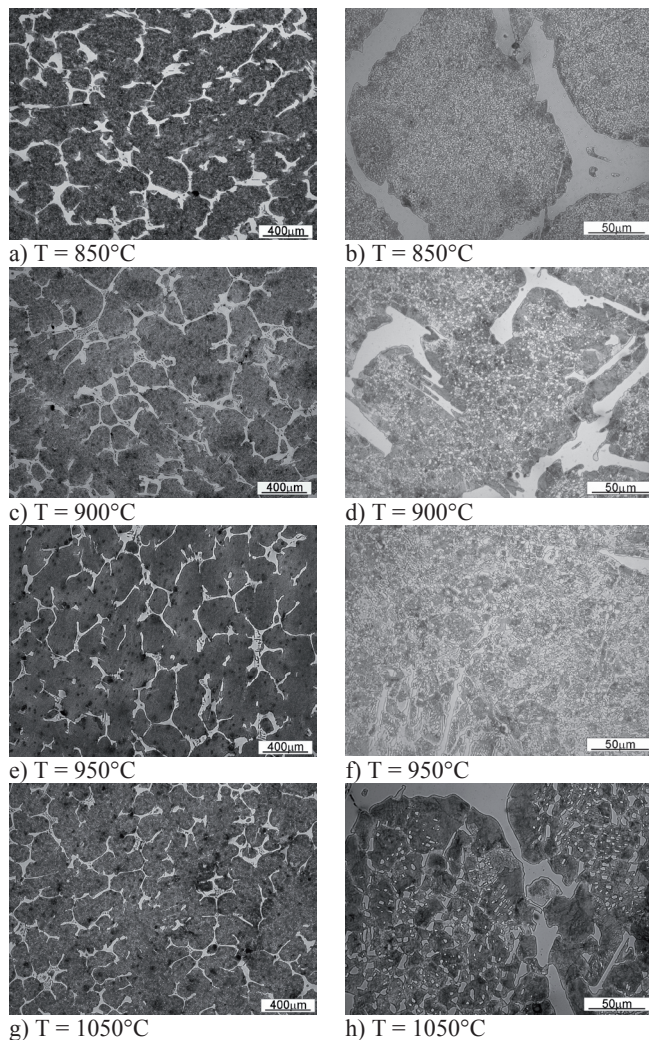


Fig. 4. Microstructure of G200CrMoNi4-6-3 cast steel heated to 850°C (a, b), 900°C (c, d), 950°C (e, f) and 1050°C (g, h) and cooled at 48°C/h. Etched with 3% HNO₃

As one may notice, in comparison with delivery state (Fig. 1) the network of hypereutectoid cementite ledeburite became thinner and more fractured in case of all applied austenitizing temperatures. However the hypereutectoid cementite in Widmannstätten structure can be observed.

However with the increasing annealing temperature in G200CrMoNi4-6-3 cast steel structure “subgrains” are being formed, which boundaries are made of partially coagulated hypereutectoid cementite „transferred” there from the primary boundaries (Fig. 4d, 4f, 4h). Only the austenitizing temperature of 850°C has been found to be too low to allow the formation of „subgrains” network of cementite. At this temperature the completely thing observed inside of primary austenite grains are coagulated hypereutectoid cementite precipitates (Fig. 4b).

After reheating the test cast steel to temperatures of 900, 950 and 1050°C it is also possible to observe (in comparison with cast state – Fig 1) the effect of normalization, i.e. refinement of former austenite grains. The most refined grains of former austenite in cast steel structure may be observed after annealing at temperature of 900°C (Fig. 4c).

Figures 5 and 6 present the results of hardness and impact strength tests of G200CrMoNi4-6-3 cast steel after such annealing.

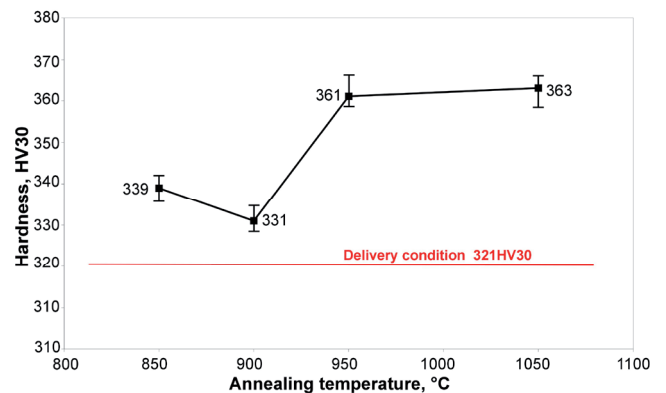


Fig. 5. The effect of annealing temperature on the hardness of samples G200CrMoNi4-6-3 cast steel

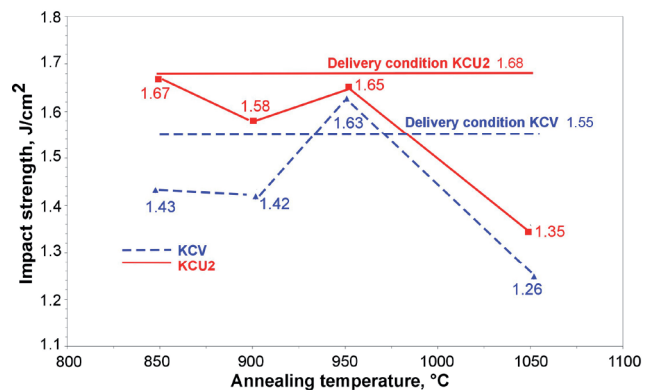


Fig. 6. The effect of annealing temperature on the impact strength of G200CrMoNi4-6-3 cast steel

It is showed (Fig. 5), after applying an additional „normalizing” annealing the hardness of G200CrMoNi4-6-3 cast steel compared with delivery state has even unexpectedly increased. It is so much important because according to the research [15] the minimal hardness of cast steel rolls should be at least of 300HBW.

However the most important thing was to create fine substructure (Fig. 4d, 4f) advantageous from the tribologic properties point of view including wear resistance. Unfortunately, such substructure is disadvantageous from the cracking resistance point of view (compare to Fig. 6), for the reason that new sub-boundaries begin to determine the path of easy crack very close to the acting direction of maximal stress [15]. Results of impact resistance KCU2 and KCV tests presented on figure 6 suggest that the optimal range of „normalizing” annealing temperature might be the one from 900 ÷ 950°C. Although the subgrains after annealing at 1050°C are still fine, the new network determining them becomes too thick (continuous), what begins to significantly reduce crack resistance of the annealed cast steel. It had been already confirmed by previous research [12, 14, 15] performed on the same material.

5. Conclusions

The structure of heavy, cast rolls made of cast steel, used as working rolls (mainly in hot rolling mills) should be characterized by fractured network of hypereutectoid cementite and transformed ledeburite.

From the tribologic properties point of view one should tend to create fine substructure with subtle network of partially coagulated hypereutectoid cementite by application of incomplete „normalizing” annealing in temperature range of $A_{c1f} \div A_{cm}$. In case of G200CrMoNi4-6-3 test cast steel the temperatures are 900 ÷ 950°C. Unfortunately, such treatment leads to a small decrease of impact strength though with a little hardness increase of this cast steel.

Acknowledgements

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