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Effect of annealing on structure and properties of ledeburitic cast steel

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Materials

ABSTRACT

Purpose: The paper presents evaluation of effect annealing on structure and mechanical properties of ledeburitic ast steel. The paper presents evaluation of influence of grain normalization and the inclination to precipitate the hypereutectoid cementite in Widmannstätten structure in G200CrMoNi4-6-3 cast steel.
Design/methodology/approach: The heat treatment has been planned on the basis of CCT diagram prepared for that alloy cast steel. Four temperatures of heat refining have been applied. Basic research of G200CrMoNi4-6-3 cast steel included metallographic analysis and mechanical properties (hardness and impact strength tests).
Findings: The evaluation has been carried out for four annealing temperatures, i.e. 850°C, 900°C, 950°C and 1050°C. The test material has been G200CrMoNi4-6-3 hypereutectoid cast steel. 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: The annealing for four temperature and the new heat treatment of G200CrMoNi4-6-3 cast steel.
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 (annealing) of G200CrMoNi4-6-3 cast steel.
Keywords: Tool materials; Cast steel; Heat treatment; Annealing; Hypereutectoid cementite

1. Introduction

The chromium – nickel – molybdenum cast steel of ledeburite class is mainly used for working mill rolls. These rolls are one of the most expensive instruments employed in mechanical working of metals. A very serious problem for large-size cast rolls (including rolls made of cast steels of ledeburite class) is the risk of their fracture [1-7].

Probable cause of cast steel rolls fracture is the presence in their structure of continuous network of hypereutectoid cementite and transformed ledeburite precipitated along prior grain boundaries of former austenite and precipitates of hypereutectoid cementite in structure of Widmannstätten type. The network, formed in the roll's structure just after casting is a way for easy propagation of the fractures and decreases the mechanical properties of the rolls, especially fracture toughness, so important for the users of that instrument [8-11].

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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

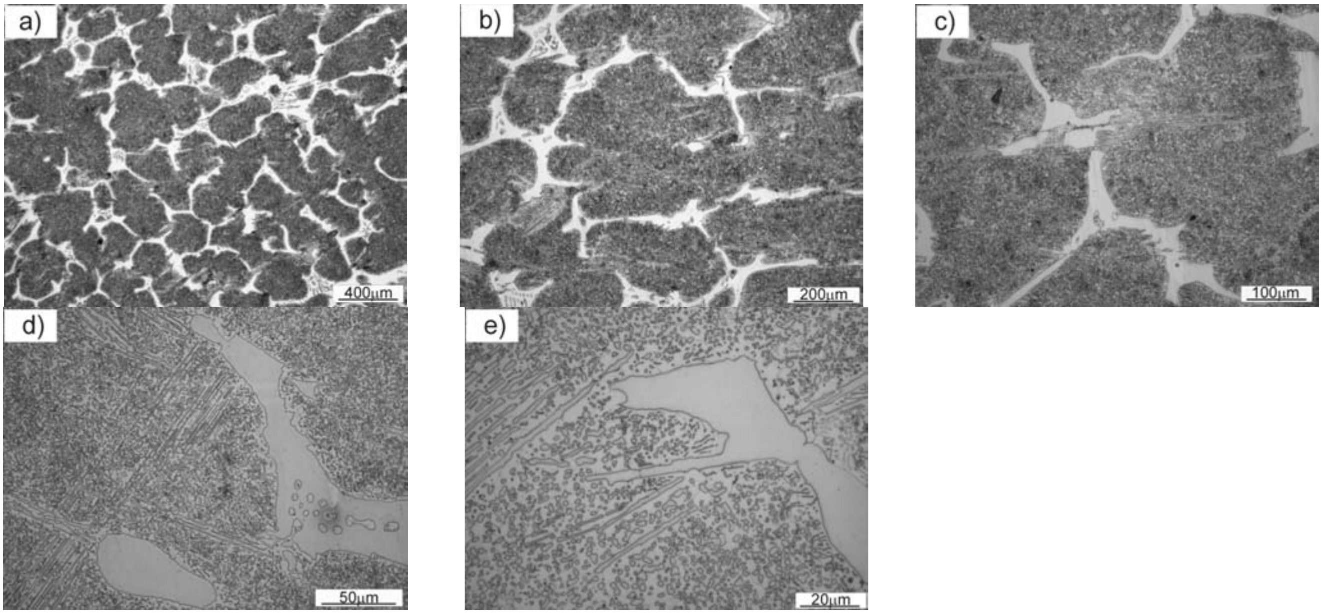


Fig. 1. Microstructure of G200CrMoNi4-6-3 of investigated cast steel (as-delivered condition)

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–Fe_3C system towards the lower carbon concentrations there is ca. 11% mass of transformed ledeburite in the structure of the 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).

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 [12, 13] 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

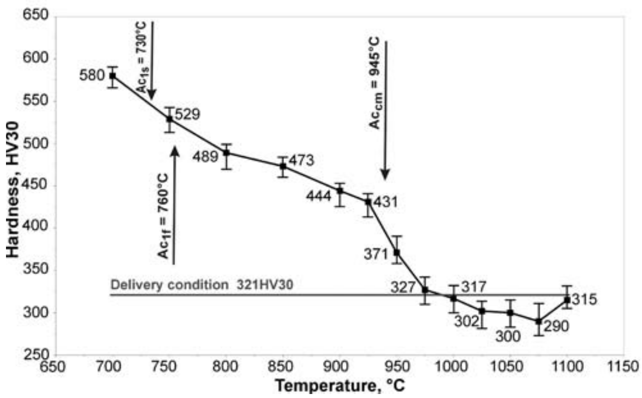
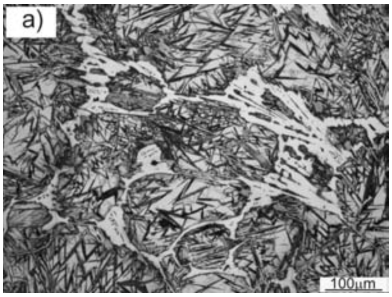
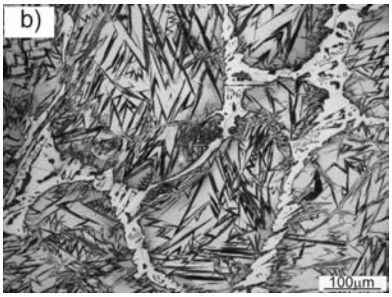


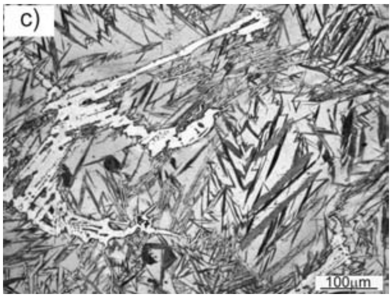
Fig. 2. The effect of austenitizing temperature at hardness samples G200CrMoNi4-6-3 cast steel quenched in oil



T_A = 700°C, 580HV30



T_A = 750°C, 529HV30



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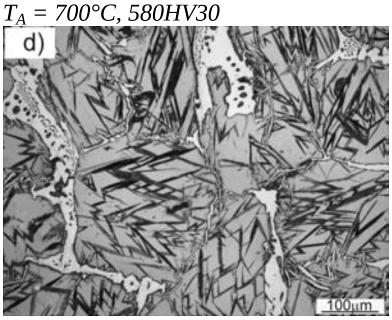
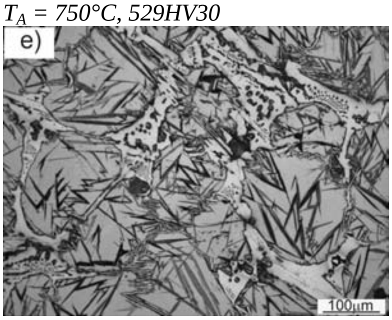
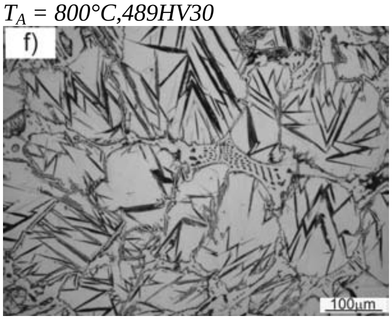


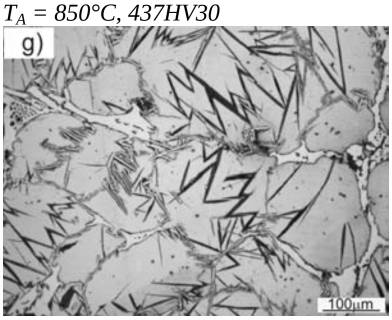
T_A = 850°C, 437HV30



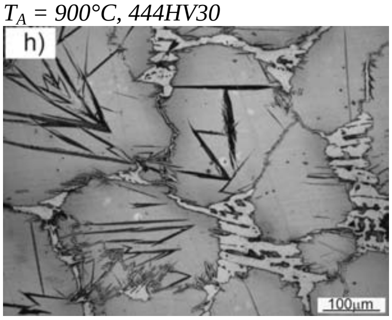
T_A = 900°C, 444HV30



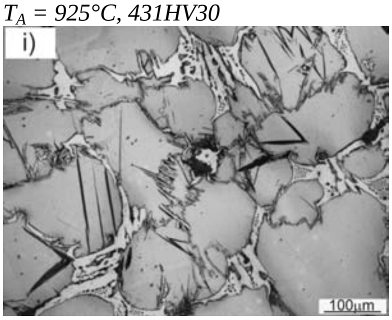
T_A = 925°C, 431HV30



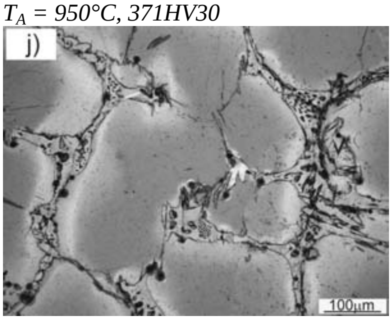
T_A = 950°C, 371HV30



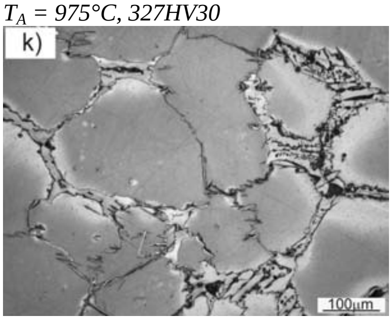
T_A = 975°C, 327HV30



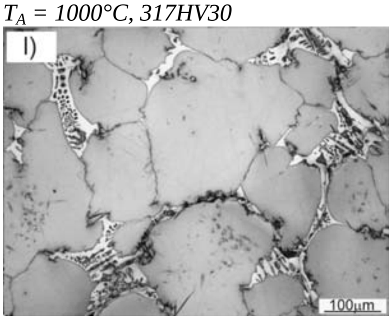
T_A = 1000°C, 317HV30



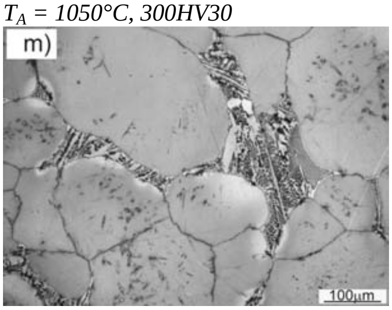
T_A = 1025°C, 302HV30



T_A = 1050°C, 300HV30



T_A = 1075°C, 290HV30



T_A = 1100°C, 315HV30

Fig. 3. Microstructure of samples G200CrMoNi4-6-3 cast steel quenched in oil from temperature: a) 700°C, b) 750°C, c) 800°C, d) 850°C, e) 900°C, f) 925°C, g) 950°C, h) 975°C, i) 1000°C, j) 1025°C, k) 1050°C, l) 1075°C, m) 1100°C. Etched with 3% HNO_3

test have been performed, popularly called „hardening series", consisting in the measurements of observations of the structure and hardness of samples quench hardened from the increasing temperature, of which the detailed results are presented in papers [14] and [15]. The samples with dimensions of 20x30x40 mm have been austenitized at temperatures of 700÷1100^{o}C (with temperature step of 50^{o}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^{o}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^{o}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. 3m).

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: Ac_{cm}, Ac_{1s} and Ac_{1f} of test cast steel, which are Ac_{cm} = 945°C, Ac_{1s} = 730°C and Ac_{1f} = 760°C respectively [12].

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.

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 (Fig. 4b, 4e, 4h, 4k).

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. 4f, 4i, 4l). 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. 4c).

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. 4d).

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

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 [13, 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. 4f, 4i) 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 [13, 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 [12-15] performed on the same material.

Figure 7 presents the micrographs (made using scanning electron microscope) of impact strength samples fractures of test cast steel in delivery condition (just after casting) and after application of „normalizing" annealing in temperature range of 850 ÷ 1050°C.

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.

The study evaluates the influence of grain normalization on the morphology and susceptibility to precipitation of hypereutectoid cementite in Widmannstätten structure in G200CrMoNi4-6-3 cast steel. The evaluation has been made for four austenitizing temperatures.

The differences in structure of cast steel after incomplete „normalizing" annealing in temperature range of 850 ÷ 1050°C have been indicated.

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 Ac_{1f} ÷ Ac_{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.

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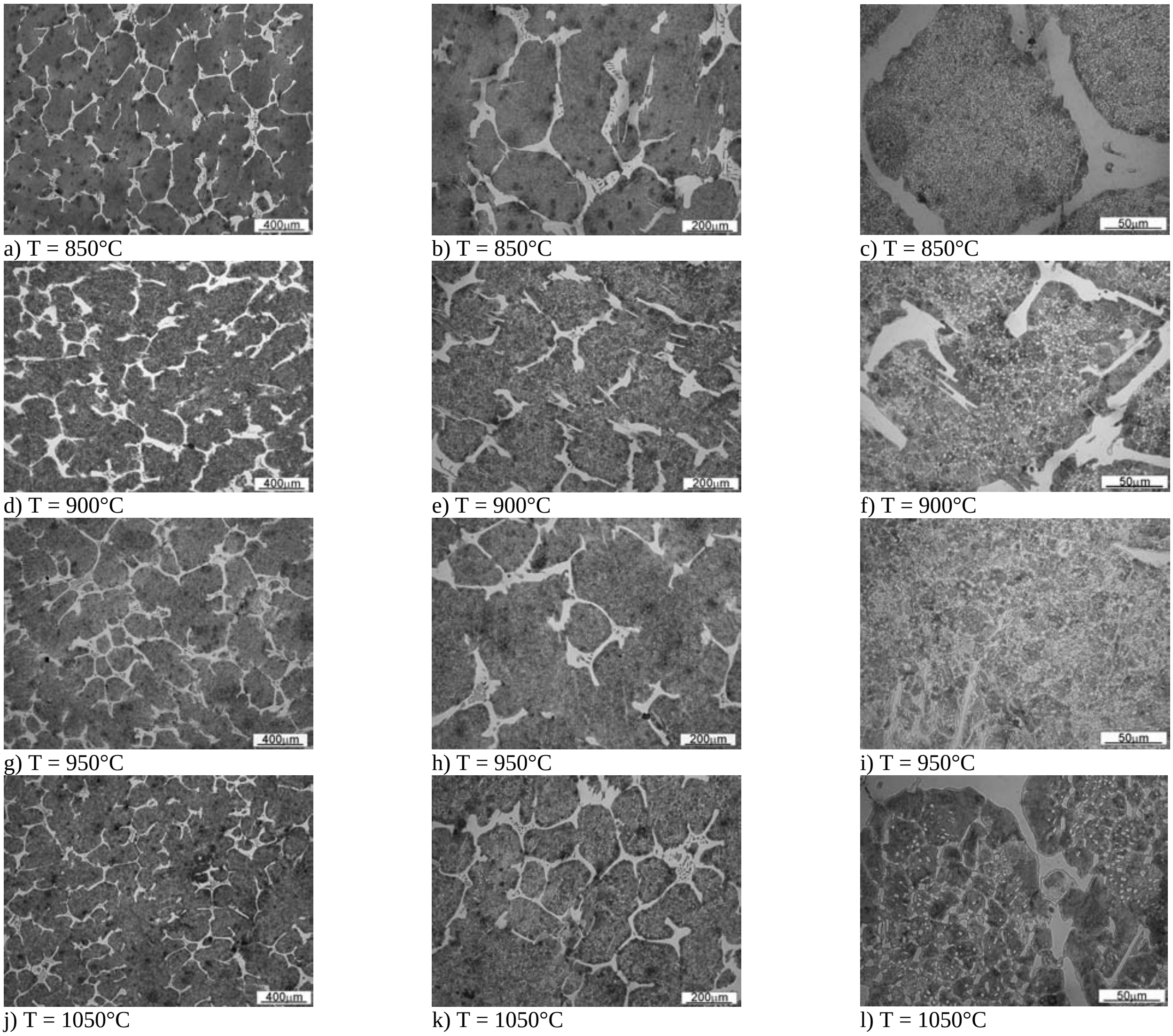


Fig. 4. Microstructure of G200CrMoNi4-6-3 cast steel heated to 850°C (a – c), 900°C (d – f), 950°C (g – i) and 1050°C (j – l) and cooled at 48°C/h. Etched with 3% HNO_3.

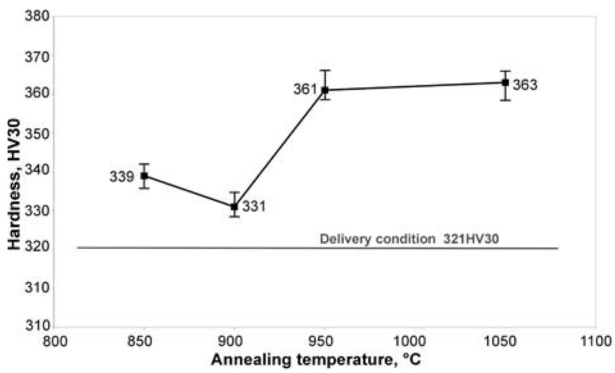


Fig. 5. The effect of annealing temperature on the hardness of samples G200CrMoNi4-6-3 cast steel

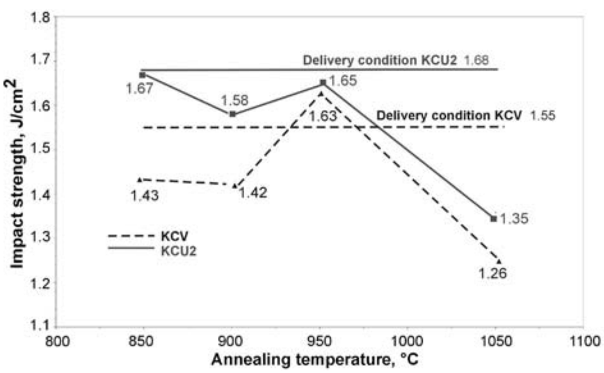
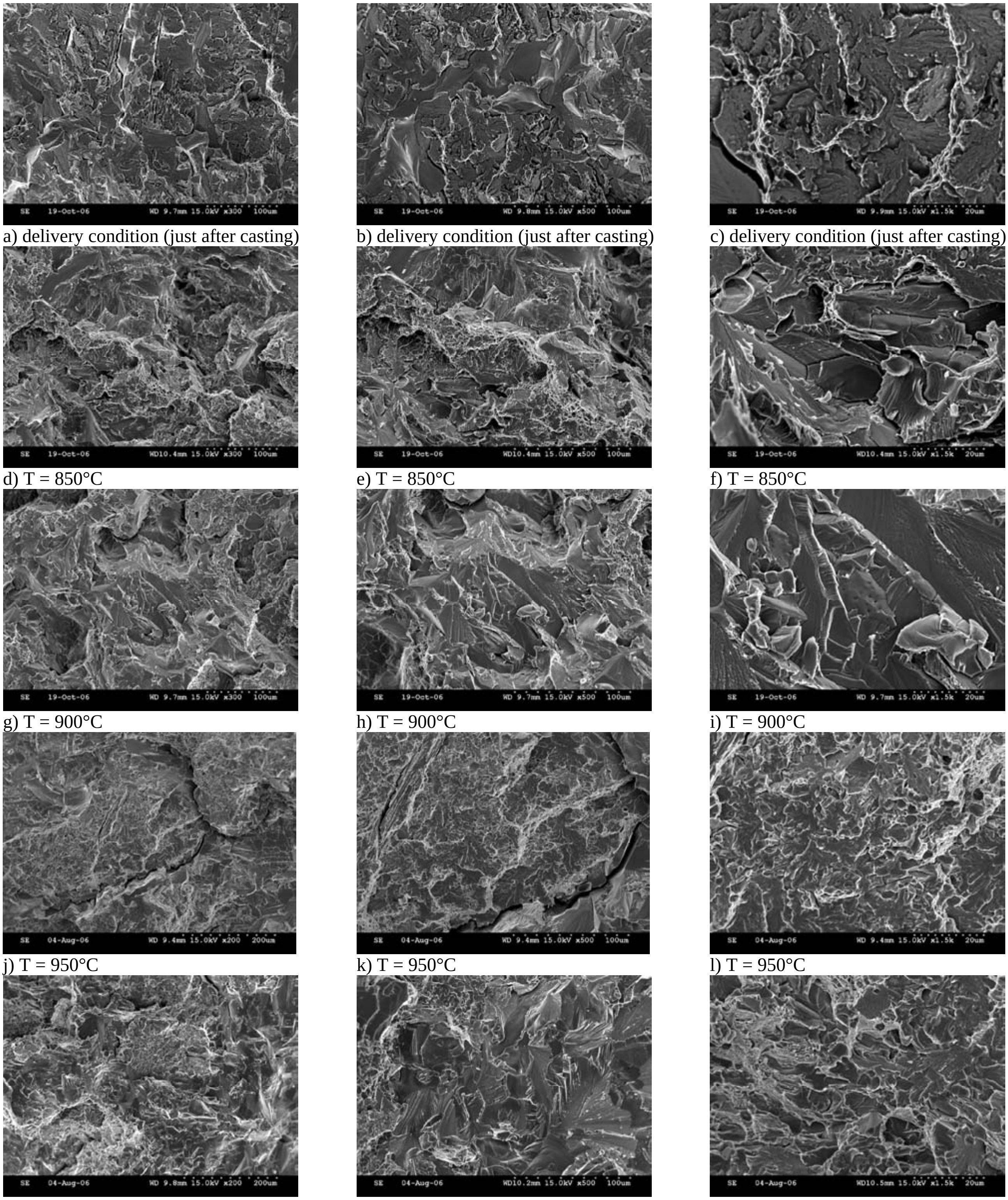


Fig. 6. The effect of annealing temperature on the impact strength of G200CrMoNi4-6-3 cast steel



a) delivery condition (just after casting) b) delivery condition (just after casting) c) delivery condition (just after casting)
d) T = 850°C e) T = 850°C f) T = 850°C
g) T = 900°C h) T = 900°C i) T = 900°C
j) T = 950°C k) T = 950°C l) T = 950°C
m) T = 1050°C n) T = 1050°C o) T = 1050°C

Fig. 7. Micrographs fractures in impact strength samples of G200CrMoNi4-6-3 cast steel in delivery condition (just after casting) – (a – c) and after application of annealing in temperature range of 850 ÷ 1050°C – (d – o)

References

[1] Z. Stradomski, A. Pirek, S. Stachura, P. Chmielowiec, The effect of the mount of primary carbides on the wear resisitence of the G200CrMoNi4-6-3 cast steel, Materials Engineering 3 (2004) 20-23.

[2] A. Barbacki, M. Kawalec, Structural alterations in the surface layer during hard machining, Journal of Materials Processing Technology 64 (1997) 33-39.

[3] J. Głownia, Metallurgy and Foundry Engineering 111 (1987) 215-220 (in Polish).

[4] A. Barbacki, M. Kawalec, A. Hamrol, Turning and grinding as a source of microstructural changes in the surface layer of hardened steel, Journal of Materials Processing Technology 133 (2003) 21-25.

[5] E. Skrzypczak, J. Pacyna, The influence of heat treatment on Widmannstätten structure in cast steel, Proceedings of the XXXI School of Materials Engineering, Kraków-Krynica, 2003, 187-193 (in Polish).

[6] R. Honeycombe, H. K. D. H. Bhadeshia, Steels: microstructure and properties, Edward Arnold, London, 1995.

[7] M. Blair, T.L. Stevens, Steel castings handbook, Materials Park: Steel Founders: ASM International, 1995.

[8] J.W. Mullin, Crystallization, Butterworth –Heinemann, Oxford, 2001.

[9] M. Durand-Charre, Microstructure of Steels and Cast Irons, Berlin-Heidelberg-New York, 2004.

[10] Steel-A Handbook for Materials Research and Engineering. V1 Fundamentals, VDE, Berlin-Heidelberg-New York-London-Paris, 2004.

[11] J. Krawczyk, J. Pacyna, The rolle of transformed ledeburite in high temperature tribology on the example of adamite rolls, Proceedings of the 11th Scientific Conference "Contemporary Achievements in Mechanics, Manufacturing and Materials Science" CAM^{3}S`2005, Gliwice-Zakopane, 2005, 535-540.

[12] J. Krawczyk, E. Rożniata, J. Pacyna, Hypereutectoid cementite morphology and mechanical properties of Cr-Ni-Mo cast steel, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 145-148.

[13] J. Pacyna, The structural and technological aspects of production and exploitation of heavy weight cast mill rolls, Proceedings of the XI Conference of Huta Buczek Ltd, Ustroń-Jaszowiec, 2006, 85-99 (in Polish).

[14] E. Rożniata, J. Pacyna, Hypereutectoid cementite morphology and mechanical properties of Cr-Ni-Mo cast steel, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 145-148.

[15] E. Rożniata, J. Pacyna, Effect of annealing on mechanical properties of ledeburitic cast steel, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 187-190.