Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 17
ISSUE 1-2
July-August
2006

Hypereutectoid cementite morphology and mechanical properties of Cr-Ni-Mo cast steel

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Received 15.03.2006; accepted in revised form 30.04.2006

Materials

ABSTRACT

Purpose: The paper presents evaluation of the influence of grain normalization (refinement as a result of repeated austenitizing), cooling rate after repeated austenitizing on the morphology of hypereutectoid cementite and fracture toughness of G200CrMoNi4-6-3 cast steel. Moreover, the elimination of hypereutectoid cementite in structure of Widmannstätten type precipitates from the structure of investigated cast steel has been undertaken.

Design/methodology/approach: Basic research of G200CrMoNi4-6-3 cast steel included metallographic analysis and fracture toughness research (impact strength, stress intensity factor K_{Ic}). The heat treatment has been planned on the basis of CCT diagram prepared for that cast steel.

Findings: Heat treatment of investigated cast steel allows to refine the grain and eliminate from it's structure the hypereutectoid cementite in structure of Widmannstätten type. At very low cooling rate the precipitates of hypereutectoid cementite become partially coagulated. The study of the influence of cooling rate on the mechanical properties of G200CrMoNi4-6-3 cast steel had proven that elimination of hypereutectoid cementite in structure of Widmannstätten type from the investigated cast steel structure to small degree increases it's fracture toughness.

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

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

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

cementite in structure of Widmannstätten type [8-10]. 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 [11].

Within the framework of the paper an attempt of refinement of prior austenite grain, evaluation of the influence of the refinement and cooling rate within the range of austenite existence on the hypereutectoid cementite morphology and fracture toughness of G200CrMoNi4-6-3 cast steel, and particularly evaluation of the elimination of hypereutectoid cementite in structure of Widmannstätten type precipitates from the structure of investigated cast steel has been made.

2. Material and heat treatment

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 hyper-eutectoid cementite in structure of Widmannstätten type (Fig. 1).

On the basis of the research results referring to kinetics of phase transformations of undercooled austenite (CCT diagram) and the influence of austenitizing temperature on the structure and hardness of G200CrMoNi4-6-3 cast steel in work [12] it's upper austenitizing temperature and in works [13, 14] the solidus temperature have been determined.

The solidus temperature (the beginning of partial melting) of investigated cast steel according to [13, 14] is 1150°C.

Cast steel samples have been heated to given above temperature, sustained for an hour and than have been cooled at the following rates: 200, 48, 30 and 12°C/h to the room temperature.

The influence of cooling rate from the temperature of 1150°C on the structure of investigated cast steel have been presented in Fig. 2.

It is evident that repeated austenitizing at 1150°C had resulted in distinct grain refinement (result of the normalization) while at higher cooling rates (200 and 48°C/h) hypereutectoid cementite and ledeburitic cementite network is clearly intermittent. Lowering the cooling rate to 30 and 12°C/h causes that the network becomes continuous and at 12°C/h the needle-shaped precipitates of hypereutectoid cementite in structure of Widmannstätten type vanish.

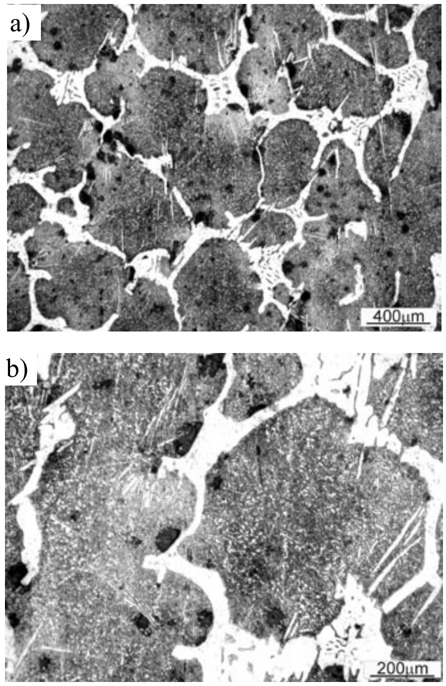

Fig. 1. Microstructure of G200CrMoNi4-6-3 of investigated cast steel (as-delivered condition)

3. Research methods

Fracture toughness of investigated cast steel has been determined by impact strength (KCU2, KCV) and by means of linear elastic fracture mechanics method (by measurement of stress intensity factor K_{Ic}).

4. Research results

Elimination of the primary network of ledeburitic and hypereutectoid cementite as well as elimination of the precipitations of hypereutectoid cementite in structure of Widmannstätten type through normalization treatment (which resulted in distinct grain refinement of former austenite) of investigated cast steel, had not brought about the increase of it's impact strength for any of applied cooling rate compared to delivery condition. On the contrary, for the lowest cooling rate (12°C/h), which refines the grain and eliminates the precipitations of cementite in structure of Widmannstätten type the fracture toughness is the lowest (Fig. 3, 4).

The reason for that is intergranular nature of the fracture and very small zone of plastic deformation accompanying the fracture of this cast steel. If the grain is large than the fracture tip propagates away from the direction of highest stress and higher force is needed to break the sample. In case of small grain the easy fracture path is more consistent with the direction of highest stress and the cracking along the cementite network is facilitated. Details of this phenomenon had been described in works [15, 16].

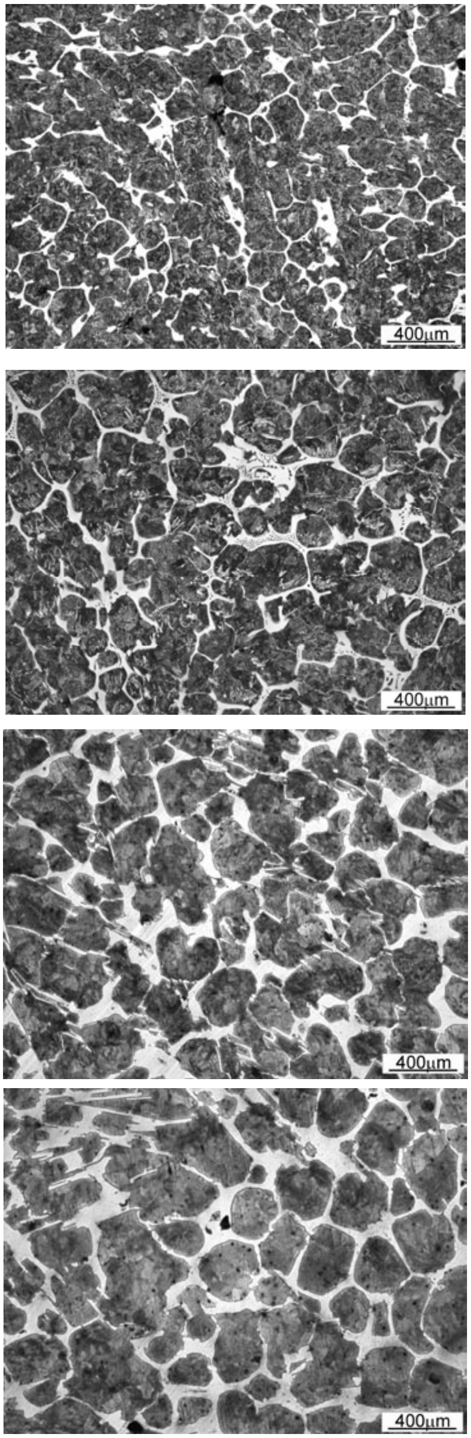

Fig. 2. Structures of G200CrMoNi4-6-3 cast steels heated to 1150°C and cooled at various rates

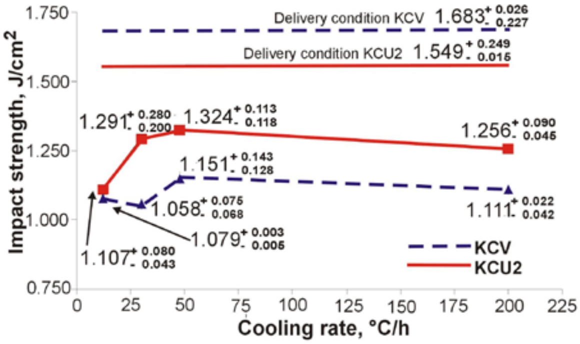

Fig. 3. The effect of cooling rates upon heat treatment on the impact strength of G200CrMoNi4-6-3 cast steel

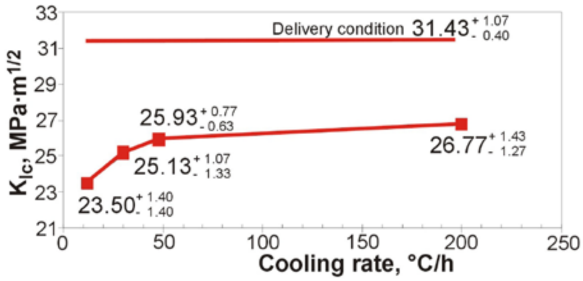

Fig. 4. Effect of cooling rate (upon heat treatment) on K_{Ic} factor

5. Conclusions

Reheating of G200CrMoNi4-6-3 cast steel to the temperature of 1150°C (temperature of the beginning of partial melting) makes possible the refinement (normalization) of former austenite grain and refinement of ledeburitic and hypereutectoid cementite network. At lowering cooling rate in the range of 200÷30°C/h new network becomes less and less discontinuous and the existence of hypereutectoid cementite in structure of Widmannstätten type decays. Total decay of needle-shaped precipitations of cementite has been noticed at 12°C/h, and it's network in that case is entirely continuous. After such cooling both impact strength (KCU2 and KCV) and K_{Ic} are the lowest. The reason for that is high consistence of easy fracture path with the direction of highest stress. Therefore in case of the cast steel with cementite of continuous network type, that determines the easy fracture path, the refinement of former austenite is noxious to it's fracture toughness. Most probably, the elimination of this phase precipitates in structure of Widmannstätten type is also noxious, because the needles (plates) may change the path of easy fracture by directing it inside the grain where the pearlite exists.

Acknowledgement

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

References

[1] J. Głownia: Metallurgy and Foundry Engineering, Kraków-Koninki, XX 1987, V. 111, pp. 215-220 (in Polish).

[2] S. Stachura, T. Borek, J. Jańczyk: Metallurgy and Foundry Engineering, Kraków-Koninki, XX 1987, V. 111, pp. 203-207 (in Polish).

[3] J. Pacyna, J. Krawczyk, A. Kokosza: Specifying reasons for easily appearing fractures in rolls made of L200HNM cast steel, Work of the Faculty of Metallurgy and Materials Science, AGH University of Science and Technology, Kraków 1999 (in Polish).

[4] 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, May-June 2004, No. 3, pp. XX-XXIII.

[5] J. Krawczyk, J. Pacyna, A. Kokosza: 6th International Conference for Mesomechanics „Multiscaling in Applied Science and Emerging Technology – Fundamentals and Applicatis in Mesomechnics", Patras, Greece, 31 May–4 June, 2004, pp. 203-207.

[6] J. Pacyna, J. Krawczyk: Effect of heat treatment upon ledeburite transformed morphology in proeutectoid cast steel, 10th Jubilee International Scientific Conference „Achievements in Mechanical and Materials Engineering" AMME'2001, Gliwice-Kraków-Zakopane, 2001, pp.429-434.

[7] J. Krawczyk, J. Pacyna: The rolle of transformed ledeburite in high temperature tribology on the example of adamite rolls, Mat. Contemporary Achievements in Mechanics and Manufacturing and Materials Science, Gliwice-Zakopane 2005, pp. 535-540.

[8] J. Kurian, M. Šlesár: The effect of Widmannstätten structure on properities of mild steels, Zbiorník Vedeckých Prác, 1978, No. 2, pp.279-292

[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, E. Rożniata, J. Pacyna: The influence of hypereutectoid cementite morphology upon fracture toughness of chromium-nickel-molybdenum cast steel of ledeburite class, Journal of Materials Processing Technology 162-163 (2005) 336-341.

[12] J. Pacyna Performance of CCT-diagram for L200HNM cast steel, Work of the Faculty of Metallurgy and Materials Science, AGH University of Science and Technology, Kraków, May 2003 (in Polish).

[13] E. Skrzypczak, J. Pacyna: The influence of heat treatment on Widmannstätten structure in cast steel, XXXI School of Materials Engineering, Kraków-Krynica 7-10 X 2003, pp. 187-193 (in Polish).

[14] E. Rożniata, J. Pacyna: The influence of cooling rate on inclination to emanation proeutectoide cementite in Widmannstätten structure in Cr-Ni-Mo cast steel, XXXII School of Materials Engineering, Kraków-Krynica 28. IX-1 X 2004, pp. 231-235 (in Polish).

[15] J. Pacyna, A. Mazur: The influence of grain size upon the fracture toughness of the hot-work tool steel, Scandinavian Journal of Metallurgy, vol. 12, 1983, Nr 1, pp. 22-28.

[16] J. Pacyna, A. Mazur: Relationship between the grain size and fracture toughness of tool steel, Steel Research, vol. 57, 1986, Nr 11, p. 577-585.