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# Effect of structure on mechanical properties of Cr-Ni-Mo cast steel

E. Różniata [a,*], J. Pacyna [b]

[a] Faculty of Foundry Engineering, AGH University of Science and Technology, Al. A. Mickiewicza 30, 30-059 Kraków, Poland

[b] Faculty of Metals Engineering and Industrial Computer Science, AGH University of Science and Technology, Al. A. Mickiewicza 30, 30-059 Kraków, Poland

* Corresponding author: E-mail address: erozniata@poczta.onet.pl

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## ABSTRACT

**Purpose:** The paper presents evaluation of the influence of 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:** The heat treatment has been planned on the basis of CCT diagram prepared for that cast steel. Basic research of G200CrMoNi4-6-3 cast steel included metallographic analysis and fracture toughness research (impact strength, stress intensity factor $K_{Ic}$ and of course hardness).

**Findings:** The test material has been G200CrMoNi4-6-3 hypereutectoid cast steel. 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:** 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) and mechanical properties of G200CrMoNi4-6-3 cast steel.

**Keywords: Tool materials; Cast steel; Hypereutectoid cementite; Heat treatment; Mechanical properties**

## PROPERTIES

## 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 hypo-eutectoid steels. In the foregoing steels the ferrite in Widmannstätten structure is eliminated on the way of heat refining. In poured alloys

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 |

(cast steels) with the concentrations of carbon close to E point on Fe – $Fe_3C$ 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 – 6].

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 [7-9]. 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 [10].

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. Test 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 hypereutectoid 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 [11] it's upper austenitizing temperature and in works [12] the solidus temperature have been determined (Fig. 2).

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. 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.

The solidus temperature (the beginning of partial melting) of investigated cast steel according to [11, 12] is 1150°C.

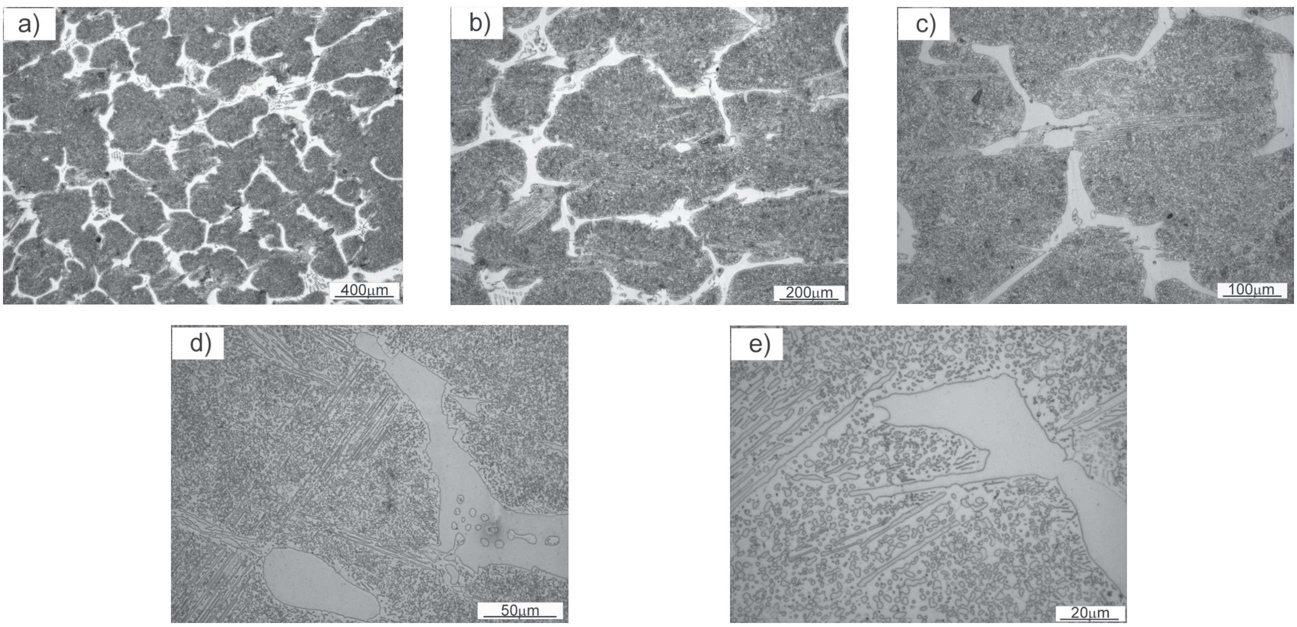



Fig. 1. Microstructure of G200CrMoNi4-6-3 of investigated cast steel (as-delivered condition)

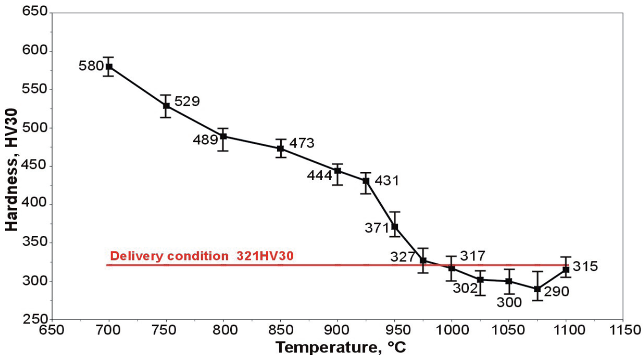
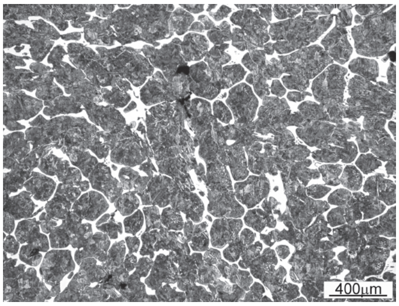



Fig. 2. The effect of austenitizing temperature at hardness samplesG200CrMoNi4-6-3 cast steel quenched in oil

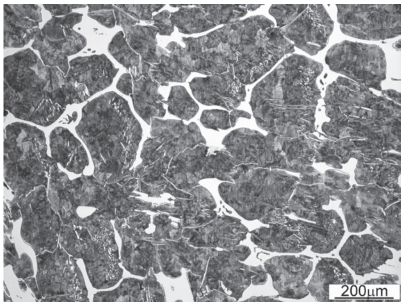
Cast steel samples have been heated to given above temperature, sustained for an hour and than have been cooled at the following rates: 200, 48, 30 and 12°C/h to the room temperature.

The influence of cooling rate from the temperature of 1150°C on the structure of investigated cast steel have been presented in Fig. 3.

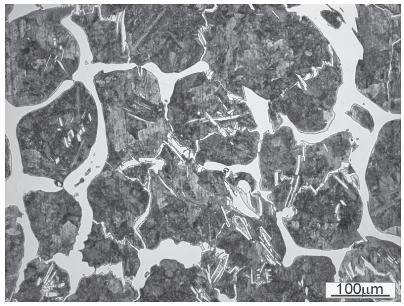
It is evident that repeated austenitizing at 1150°C had resulted in distinct grain refinement (result of the normalization) while at higher cooling rates (200 and 48°C/h) hypereutectoid cementite and ledeburitic cementite network is clearly intermittent. Lowering the cooling rate to 30 and 12°C/h causes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



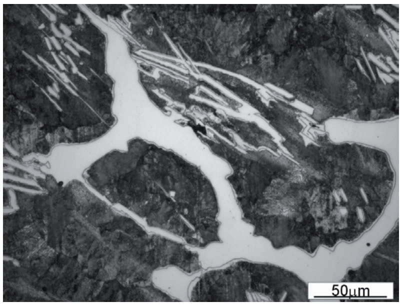

a) 200°C/h



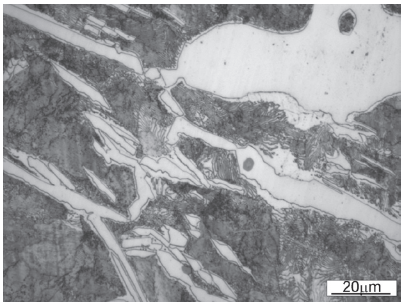

b) 200°C/h



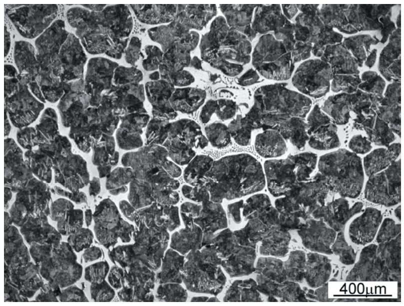

c) 200°C/h



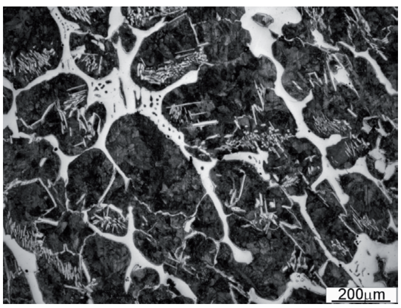

d) 200°C/h



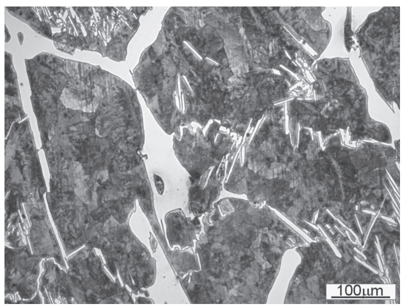

e) 200°C/h



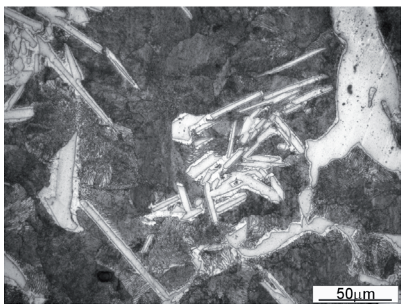

f) 48°C/h



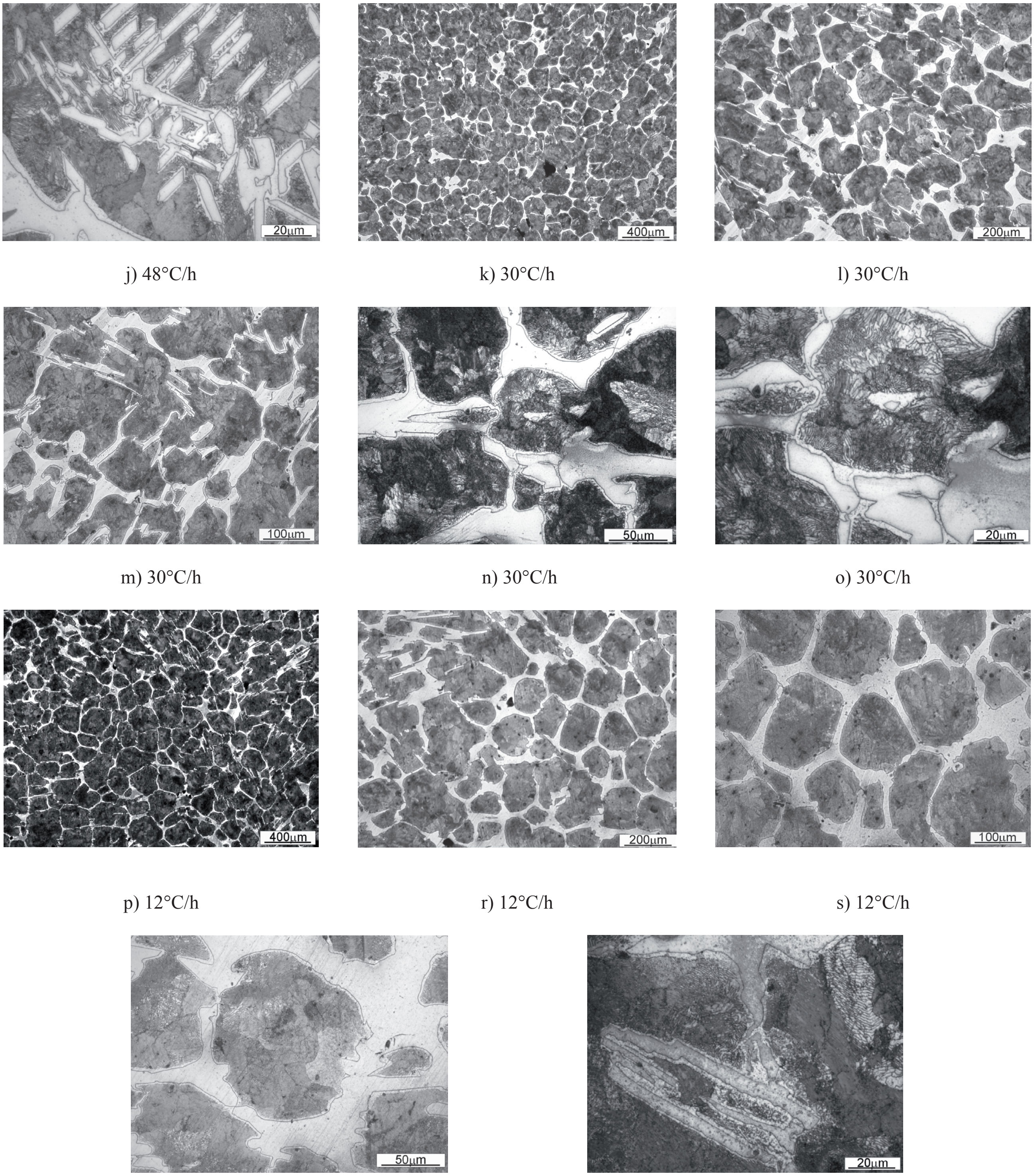

g) 48°C/h




h) 48°C/h




i) 48°C/h



j) 48°C/h    k) 30°C/h    l) 30°C/h

m) 30°C/h    n) 30°C/h    o) 30°C/h

p) 12°C/h    r) 12°C/h    s) 12°C/h

t) 12°C/h    u) 12°C/**h**

Fig. 3. Structures of G200CrMoNi4-6-3 cast steels heated to 1150°C and cooled at various rates: (a – e) cooling at 200°C/h, (f – j) cooling at 48°C/h, (k – o) cooling at 30°C/h, (p – u) cooling at 12°C/h

## 3. Research methods and results

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 $K_{Ic}$).

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. 4 and 5).

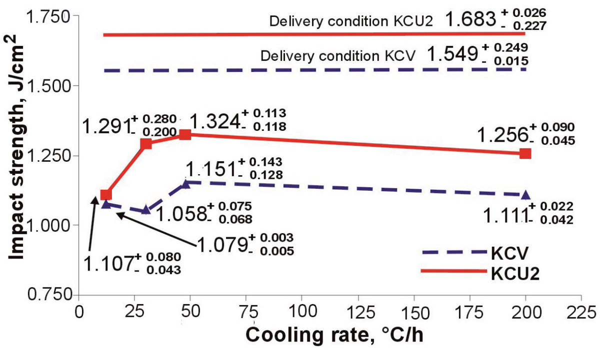



Fig. 4. The effect of cooling rates upon heat treatment on the impact strength of G200CrMoNi4-6-3 cast steel

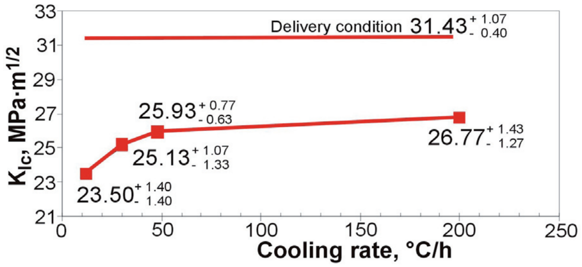
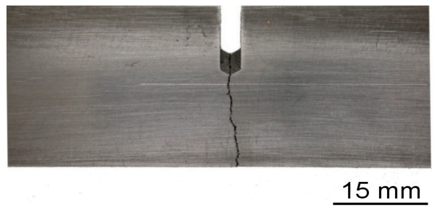



Fig. 5. Effect of cooling rate (upon heat treatment) on $K_{Ic}$ factor

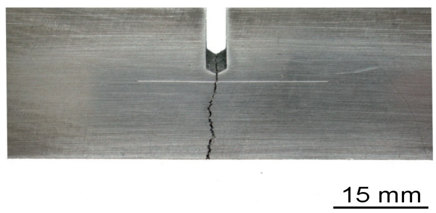
The reason for that is intergranular nature of the fracture and very small zone of plastic deformation accompanying the fracture of this cast steel. If the grain is large than the fracture tip propagates away from the direction of highest stress and higher force is needed to break the sample. In case 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 [13 and 14].

$K_{Ic}$ samples to the condition at delivery and after heat treatment were completely broken after the treepoint bend test (Fig. 6).


a) as-delivered condition

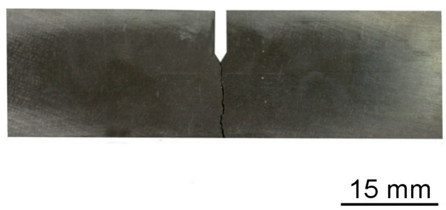



b) 200°C/h




c) 48°C/h


d) 30°C/h




e) 12°C/h

Fig. 6. Picture of fracture after $K_{Ic}$ test: (a) as-delivered condition, (b) after heat treatment (cooling at 200°C/h), (c) after heat treatment (cooling at 48°C/h), (d) after heat treatment (cooling at 30°C/h), (e) after heat treatment (cooling at 12°C/h)

On the basis of the results of impact strengths, and taking advantage of Gulajev's interpretation [15] the work of fracture propagation has been determined. Results of the research are presented on Fig. 7.

As one may notice, none of the applied rates of cooling the investigated cast steel had resulted in increase of energy of fracture spreading compared to the condition just after casting (Fig. 7a).

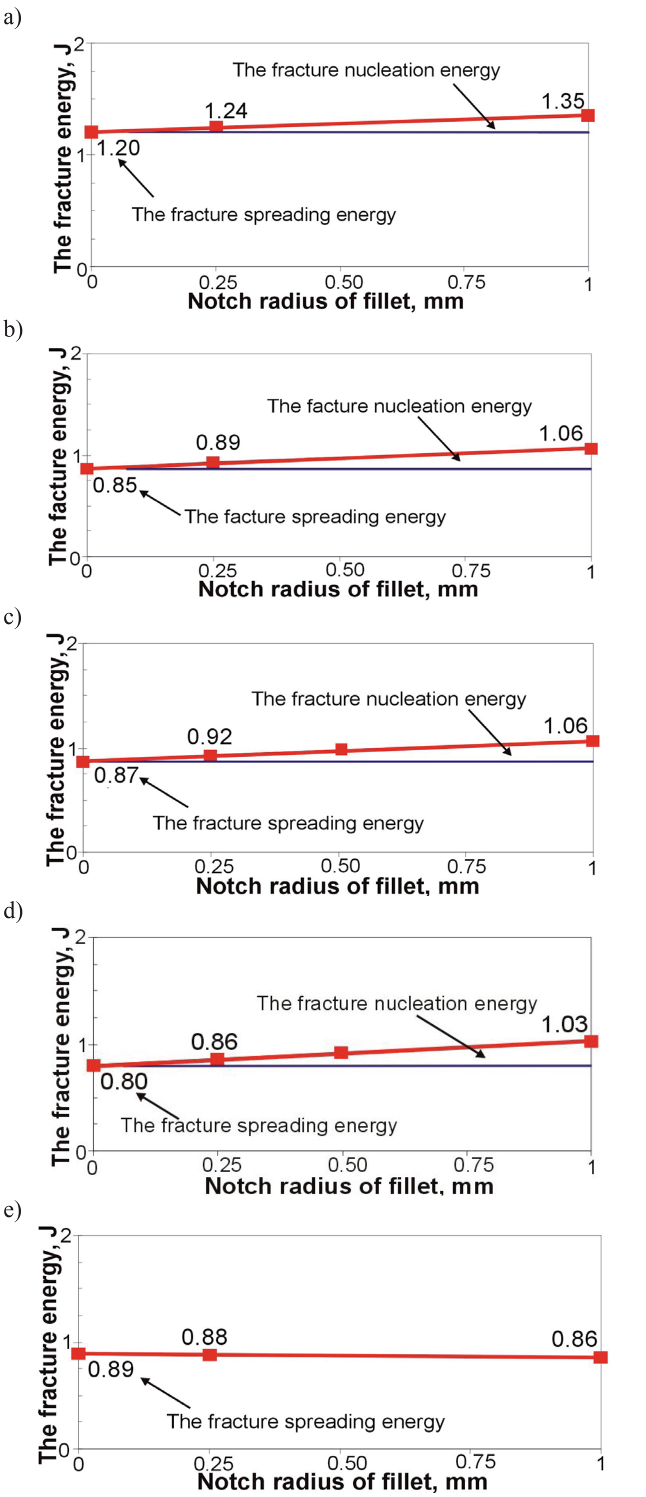



Fig. 7. Method of defining fracture spread work on the basis of the work of breaking KCU2 and KCV using Gulajev's interpretation [15]: (a) delivery condition, (b) cooling at 200°C/h, (c) cooling at 48°C/h, (d) cooling at 30°C/h, (e) cooling at 12°C/h

## 4. 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.

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.

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## Additional information

The presentation connected with the subject matter of the paper was presented by the authors during the 14th International Scientific Conference on Achievements in Mechanical and Materials Engineering AMME'2006 in Gliwice-Wisła, Poland on 4th-8th June 2006.

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