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Influence of the microstructure and loads on tribological properties of G155CrNiMo4-3-3 cast steel

J. Krawczyk
Faculty of Metals Engineering and Industrial Computer Science, AGH University of Science and Technology, Mickiewicza 30, 30-059 Kraków, Poland
Corresponding author. E-mail address. jkrawczy@metal.agh.edu.pl, jkrawczy@ruczaj.pl

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Abstract

Materials for mill rolls, fulfilling high requirements due to difficult exploitation conditions, are cast steels of adamite grade. Those are cast steels of pearlitic matrix with uniformly distributed cementite precipitations (e.g. hypereutectoid). In respect of a microstructure and a chemical composition these steels are hypereutectoid steels. They contain chromium (app. 1 %) and nickel (app. 0.5 %) and sometimes have an increased content of silica. Admissible is also a content of Mo (app. 0.4 %). An uniformly distributed carbide phase can be obtained by the proper heat treatment.

The determination of the heat treatment influence on tribological properties - in dependence of the applied load - of adamite hypereutectoid G155CrNiMo4-3-3 cast steel, used for mill rolls - was the aim of the hereby paper. The purpose of the applied heat treatment was to change the hypereutectoid cementite morphology.

Tribological tests were carried out at a room temperature by means of the T-05 tester, at loads of: 50, 100 and 150 N. Bearing steel 100Cr6 of a hardness 57 HRC was used as a counter sample. Testing time was 400 seconds. During the test the abrasion products were being removed from the counter sample.

The performed investigations allow to draw conclusions regarding the influence of the hypereutectoid cementite morphology and loads on a wear mechanism and intensity of wearing of hypereutectoid adamite cast steel.

Keywords: wear resistance alloys, mill rolls, tribology, cast steel, hypereutectoid cementite

1. Introduction

Out of various materials being used for working rolls, cast materials on ferrous matrices, due to their tribological properties and costs, have specially good reputation [1-4]. An essential problem constitutes still designing of the microstructure of these materials in such a way as to achieve the required functional properties [5-8]. Microstructures of cast tool materials can be designed due to their strength properties and fracture toughness [9-23]. Obtaining nearly optimal values of these properties is difficult, however possible. In addition, such material should have good tribological features [1,2,24,25].

The determination of the influence of heat treatments on tribological properties - in dependence of the applied load - of adamite hypereutectoid G155CrNiMo4-3-3 steel, which is used for metallurgical rolls – was the aim of the present study. The purpose of various variants of the applied heat treatment was to change the morphology of hypereutectoid cementite.

2. Material for investigations and a heat treatment

Cast steel G155CrNiMo4-3-3 used for mill rolls, of a chemical composition given in Table 1, constituted the material for investigations. Microstructure of this cast steel in as-cast condition is illustrated in Figure 1. As it is seen, this steel in as-cast condition is characterised by irregular grains. A continuous network of hypereutectoid cementite occurs on grain boundaries while in areas near grain boundaries of prior austenite the precipitates of hypereutectoid cementite in the Widmannstätten structure occur.

Table 1.
Chemical composition (weight %) of G155CrNiMo4-3-3 cast steel

C	Mn	Si	P	S	Cr	Ni	Mo
1.50	0.48	0.41	0.022	0.010	1.19	0.90	0.30

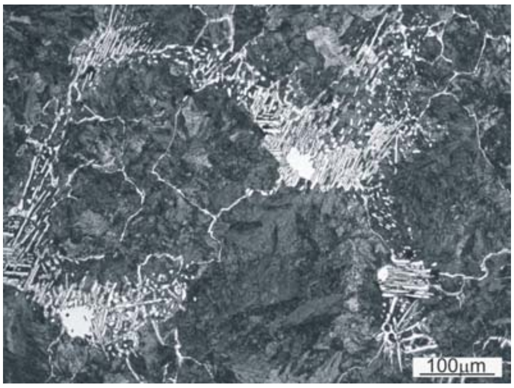
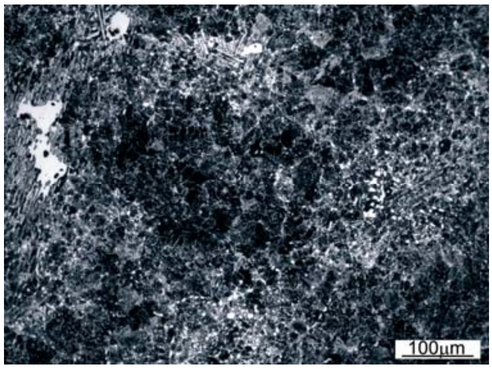


Fig. 1. Microstructure of G155CrNiMo4-3-3 cast steel in as-cast condition. Etched with 2% nital

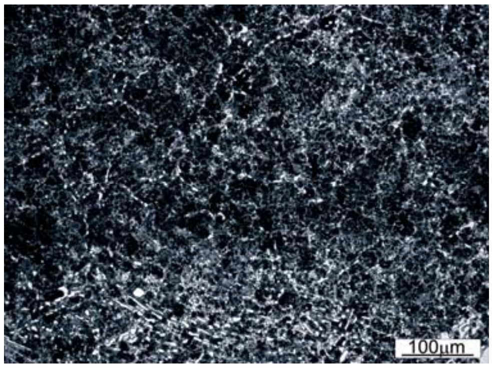
In order to change the morphology of hypereutectoid cementite this material was heat treated. Cast steel was first heated to a temperature of 980 °C. This temperature was chosen on the basis of analysis of microstructures of samples from the so-called 'quenching series' (stabilisation of high quenching) and technical possibilities of producers of cast steel rolls. After heating to 980 °C the sample was cooled to a temperature below the pearlitic transformation end and then hold in this temperature. Then cast steel was reheated, but only to 820 °C, in order to dissolve a part of secondary carbides in austenite as well as to normalize prior austenite grains in the matrix. The cooling rate from 820 °C to a temperature of the beginning of the pearlitic transformation was selected in such a way as to make possible the formation of hypereutectoid cementite in a form of spheroidal precipitates uniformly distributed in the whole volume. Then the cooling rate, in the range of the pearlitic transformation, was accelerated to obtain fine-lamellar pearlite, characterized by better hardness and crack resistance. Isothermal holding below the pearlitic transformation temperature combined with slow cooling to a temperature of the beginning of the bainitic formation as well as arrestment the cooling before a temperature of the bainitic transformation beginning constituted the simulation of temperatures in the heat treated metallurgical rolls under industrial conditions.

Microstructures after the heat treatment, described above, for three variants of heating and cooling rates are shown in Figure 2. The total time of the individual heat treatment was: short variant – 161 hours, medium variant – 169 hours, long variant – 242 hours.

a)



b)



c)

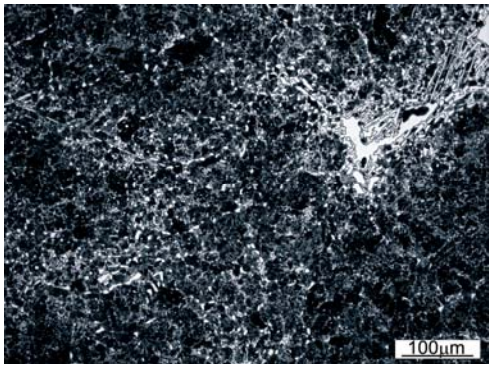


Fig. 2. Microstructure of G155CrNiMo4-3-3 cast steel after the heat treatment: a) short variant; b) medium variant; c) long variant. Etched with 2 % nital

The application of the heat treatment significantly influenced the cast steel microstructure. The network of hypereutectoid cementite - precipitated after casting along the grain boundaries of prior austenite - was destroyed after the heat treatment. The occurrence of this cementite in the Widmannstätten structure was also significantly decreased.

3. Results of investigations and their discussion

Tribological investigations were performed in a room temperature on a tester T-05, at loads: 50, 100 and 150 N. 100Cr6 bearing steel of a hardness of 57 HRC was used as a counter sample. Testing time was 400 seconds. Products of friction were being removed from the counter sample during the whole tribological test. The tribological test at a load of 150 N was not performed on a sample in as-cast condition since this sample had already problems (instantaneous stability loss of a sample in a holder) at a load of 100 N.

Microphotographs of surfaces of the investigated samples, after the tribological tests are presented in Figures 3-6.

a)

b)

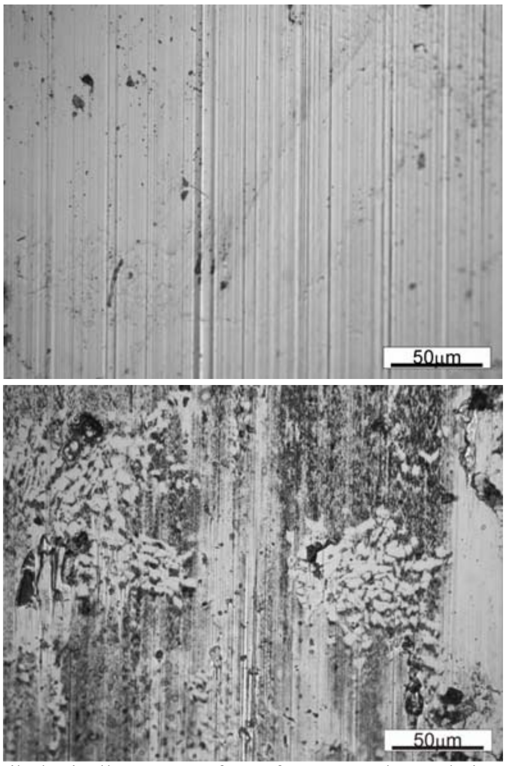


Fig. 3. Tribologically worn surface of a cast steel sample in as-cast condition: a) load: 50 N, b) load: 100 N

Observations of tribologically worn surfaces indicate that only in the case of cast steel in as-cast condition at a load of 50 N the influence of hypereutectoid carbides on a mechanism of sample wear was not seen. In the remaining cases – on surfaces undergoing tribological tests – particles of hypereutectoid carbides are acting as an abrasive material in the wearing process of samples.

A load increasing – in the case of a sample in as-cast condition – causes revealing of the microstructure (morphology of hypereutectoid cementite precipitations) during the tribological test. Thus, increased loads favour starting up of new wear mechanisms in samples in as-cast condition. In place of a dominating grooving there is an abrasive and adhesive wear. Particles of crumbled cementite from the Widmannstätten structure relocating themselves on a cast steel sample are revealed. These particles are acting as an abrasive material.

a)

b)

c)

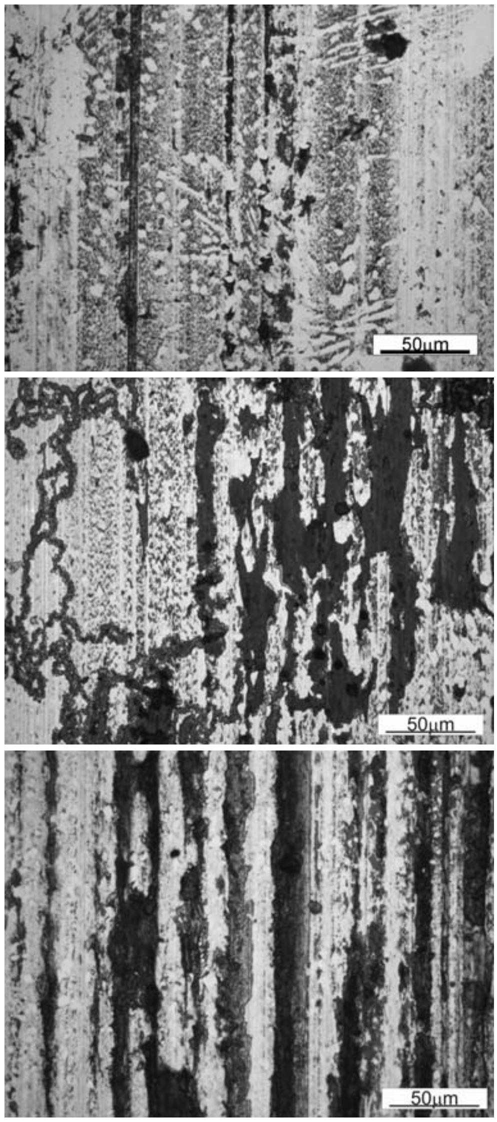


Fig. 4. Tribologically worn surface of a cast steel sample after a short variant of the heat treatment: a) load: 50 N, b) load: 100 N, c) load: 150 N

When analysing surfaces of the heat treated samples after the tribological test at a load of 100 N, one can see differences in between individual variants of the heat treatment. Short and medium variants are characterised by more uniform wear than a long variant. Whereas, in the case of the short variant of the heat treatment dimensions of hypereutectoid cementite particles precipitated inside prior austenite grains acting as an abrasive material (revealed on surfaces which underwent a tribological wear) are smaller than in the case of two remaining variants. Thus, it seems that particles of hypereutectoid cementite precipitated inside primary austenite grains – in the case of samples after the short and medium heat treatment variants – more intensely affect the cast steel surfaces.

a)

b)

c)

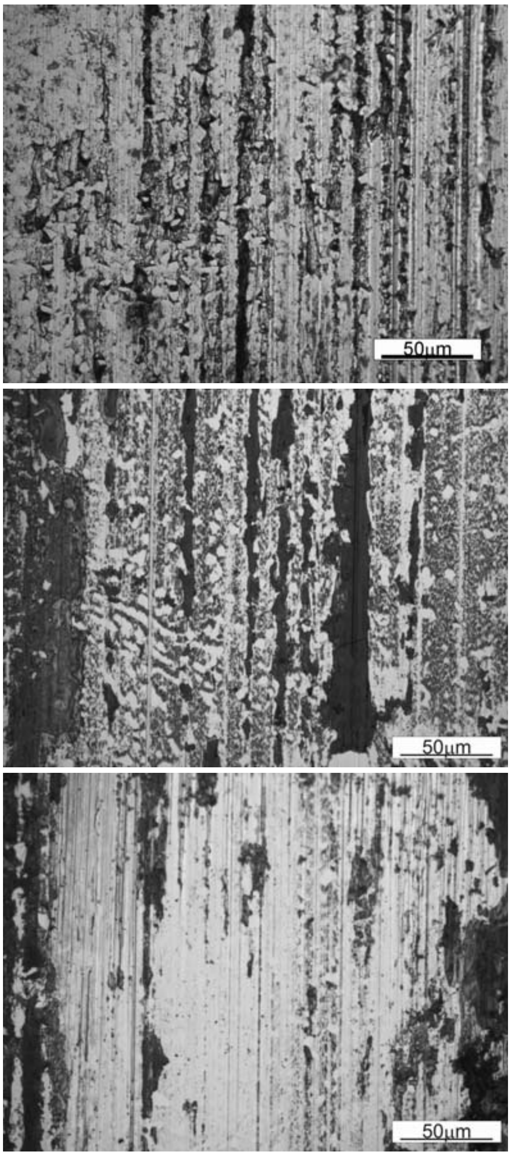


Fig. 5. Tribologically worn surface of the cast steel sample after the medium variant of the heat treatment: a) load: 50 N, b) load: 100 N, c) load: 150 N

A load increased to 150 N causes a decrease of an abrasion activity of hypereutectoid cementite particles precipitated, due to the heat treatment, inside primary austenite grains. The majority of those particles is practically immediately removed from a friction pair. Therefore on the tribologically worn surfaces, to a lesser degree than in the case of the performed tests, the morphology of hypereutectoid cementite precipitates is revealed at lower loads. This indicates that the amount of hypereutectoid cementite precipitations, even in the case of the long variant of the heat treatment at a load of 150 N, is too small to allow keeping those particles on the surface. At such a load and at spalling of large cementite particles mainly fine particles remain on the surface. They are in the highest number in the microstructure of the cast steel sample after the short variant of the heat treatment.

a)

b)

c)

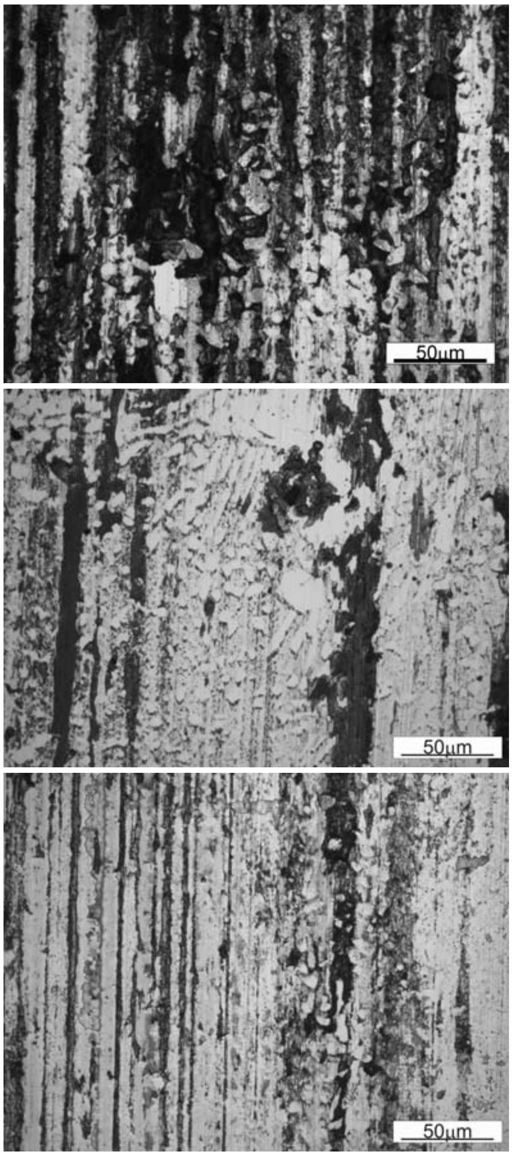


Fig. 6. Tribologically worn surface of the cast steel sample after the long variant of the heat treatment: a) load: 50 N, b) load: 100 N, c) load: 150 N

Differences in sample masses before and after the tribological test are graphically presented in Figure 7.

Mass measurements before and after the tribological test, at a load of 50N not in every test indicated a mass loss. In the case of as-cast condition and the medium variant of the heat treatment a small increase of a sample mass was found. This can be explained – especially in as-cast condition – by a continuous thick network of hypereutectoid cementite in primary austenite grain boundaries and hypereutectoid cementite precipitations in the

Widmannstätten structure, which when acting as microblades (and not being crumbled after a short test and at a small load) are cutting the counter sample material placing a part of it on the sample surface. However, this effect is not large. In a similar fashion as in the short variant of the heat treatment, a small mass increase or decrease after the medium and long variants result from little differences in the cast steel microstructure related to small changes in the heat treatment process. In these cases the hypereutectoid cementite network is not undergoing a strong fragmentation, areas of hypereutectoid cementite in the Widmannstätten structure are still present, and in the zone of the primary austenite grain there are less (than in the case of the long variant of the heat treatment) precipitates of spheroidal cementite. Therefore, at a small load and a short duration time of the test, the cementite precipitates on grain boundaries as well as cementite in the Widmannstätten structure still act as cutting tools (similarly to cast steel in as-cast condition). This effect balances the sample mass loss by a material cut from the counter sample. An introduction of large amounts (and of larger dimensions) of hypereutectoid cementite inside primary austenite grains, and a strong fragmentation of this cementite on grain boundaries and in the Widmannstätten structure causes, in the case of the long variant of the heat treatment even for a small load (50 N), an abrasive action of spalling cementite particles. This does not allow for the intensive cutting activity of these particles on the counter sample material and preserving this material on the sample surface. Therefore in this case, a large mass loss is observed.

The load increase from 50 to 100 N caused, during the tribological test, an intensification of spalling of even quite large fragments of the hypereutectoid cementite precipitations. This caused a mass loss in each of the investigated samples. Smaller mass losses, in the case of the short and medium variant of the heat treatment, can be a result of a coagulation degree of hypereutectoid cementite precipitated in secondary austenite grain boundaries as well as cementite in the Widmannstätten structure (as compared to as-cast condition), which render difficult spalling of these particles. This can also be caused by a smaller amount of hypereutectoid cementite precipitated inside the primary austenite grain as compared to the sample after the long variant of the heat treatment.

It can be observed that, at a load of 150 N during the tribological test, decidedly the highest wear occurs in the case of the sample after the short variant of the heat treatment. This wear is the highest as compared to all performed in this work tribological tests. The fact, that the difference between the short and medium variant is large is quite puzzling, since there was no significant difference between their progress and microstructure. This can be only explained by an increase of heterogeneity of tribological processes after a load increase to 150 N. In this case local differences in the sample microstructure can be decisive. Exactly such differences characterise the sample after the short variant of the heat treatment.

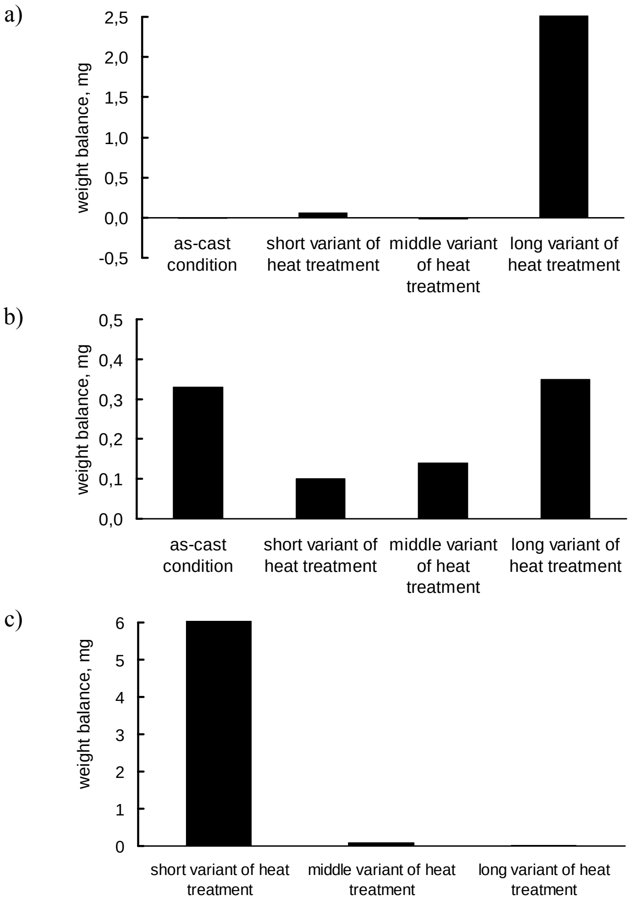


Fig. 7. Weight balance for samples after tribological testing: a) under a load of 50 N, b) under a load of 100 N, c) under a load of 150 N

4. Conclusions

The investigations performed in this study allow for the formulation of the following conclusions:

1. Changes in the morphology of hypereutectoid cementite causes changes of tribological properties of hypereutectoidal adamite cast steel;
   - Refinement of the hypereutectoid cementite precipitations facilitates their spalling and action as an abrasive material;
   - Leaving large precipitations of hypereutectoid cementite favours their actions as blades microcutting a counter sample material;
   - Coagulation of hypereutectoid cementite precipitated in grain boundaries of secondary austenite and cementite in the Widmannstätten structure renders spalling of large particles of hypereutectoid cementite difficult.
2. Increased load causes intensifying of a cast steel abrasive wear in case when hypereutectoid cementite did not undergo a coagulation and precipitation in the whole grain volume.

3. Increased load during a tribological test causes decreasing of wear in the case when hypereutectoid cementite was coagulated and precipitated in the whole grain volume.

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