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Janusz Krawczyk*, Rafał Dziurka**, Edyta Rożniata*

THE HIGH-TEMPERATURE TRIBOLOGY OF IRON MATRIX HYPOEUTECTIC ALLOY AFTER UNDER-ANNEALING NORMALIZING

1. INTRODUCTION

An example of adamite cast steel [1–4] is G200CrNiMo4-3-3 cast steel which is widely used for tools that are used in metallurgy. Tests of this cast steel [1, 5, 6] confirm its great potential as a material for working mill rolls. It is characterized by good resistance to thermal fatigue, as well as wear resistance. It was found, however, that the microstructure of G200CrNiMo4-3-3 cast steel, just after casting, is not optimal in terms of mechanical properties and fracture toughness [7–12].

Microstructure modification of this material is done on the way of heat treatment by so-called under-annealing normalization [7, 8]. It allows to improve mechanical properties by obtaining of appropriate morphology of carbide precipitates [7]. On the basis of so far carried studies of wear mill rolls [13–15] made of G200CrNiMo4-3-3 cast steel as well as laboratory tests [16–20] it was found that the mechanism of wear is strongly dependent on carbides morphology.

During hot processing in surface layer of mill rolls made of G200CrNiMo4-3-3 cast steel a change of matrix takes place in the structure from pearlitic to austenitic, what may alter the influence of secondary carbides morphology and ledeburite on tribological properties. Thus, within the frames of this work the tribological tests of G200CrNiMo4-3-3 cast steel were carried out at the temperature that guaranteed the presence of austenitic matrix.

2. TEST MATERIALS

Test material was high-carbon G200CrNiMo4-3-3 cast steel of ledeburite class with chemical composition presented in Table 1.

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* Ph.D., ** M.Sc.: Faculty of Metals Engineering and Industrial Computer Sciences, AGH University of Science and Technology, Kraków, Poland; jkrawczy@metal.agh.edu.pl

Table 1. Chemical composition (weight %) of G200CrNiMo4-3-3 cast steel

C	Mn	Si	P	S	Cr	Ni	Mo	Fe
1.97	0.60	0.65	0.053	0.006	1.01	0.75	0.28	rest

Based on testing of kinetics of phase transformations of super-cooled austenite, quenching series and metallographic analysis [7] a heat treatment was applied that consisted of heating of G200CrNiMo4-3-3 cast steel samples to four annealing temperatures: T_A= 850, 900, 950 and 1050^{o}C, maintaining them for 10 hours and cooling at constant rate of 48^{o}C/h to room temperature. Figure 1 presents microstructures of test cast steel after mentioned above variants of under-annealing normalization.

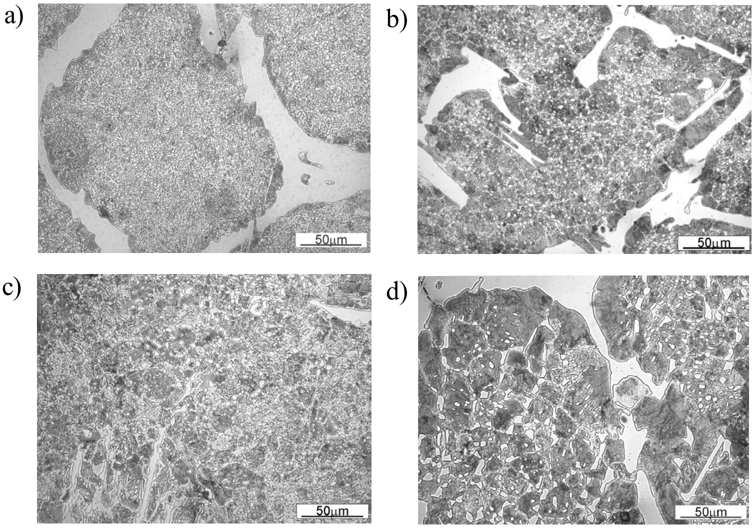

Fig. 1. *Microstructure of G200CrNiMo4-3-3 cast steel after heat treatment: a)* T_A*=* 850^{o}*C; b)* T_A*=*900^{o}*C; c)* T_A*=*950^{o}*C; d)* T_A*=*1050^{o}*C. Etched with 2% nital*

As one may notice, along with rising annealing temperature there are „sub-grains" being created in microstructure of G200CrMoNi4-3-3 cast steel, boundaries of which are made of partially coagulated secondary cementite „transported" there (inside of grains) from boundaries of primary austenite grains. Only austenitizing temperature of 850^{o}C turned out to be too low to create a net of cementite "sub-grains". At this temperature the coagulated precipitations of secondary cementite are noticeable inside of primary austenite grains. A distinct net inside of primary austenite grain is being created after austenitizing at 900^{o}C.

3. TESTING METHODOLOGY

Microstructures and tribilogically used surfaces were subjected to metallographic testing.

Tribological tests were conducted under load of 10 N and at the temperature of 750^{o}C using T-21 testing machine (Fig. 2a) applying tribological contact scheme of friction pin on disc type (Fig. 2b). As a counter-samples the friction discs made of 100Cr6 bearing steel, heat treated in order to receive the highest hardness, were used. During the test a continuous sampling of friction factor was made.

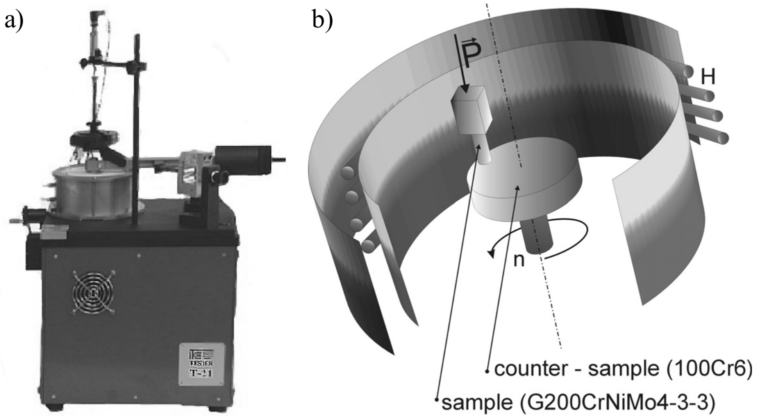

Fig. 2. *Laboratory stand for the tribological tests: a) T-21 testing equipment; b) tribological contact scheme*

4. TESTING OF TRIBOLOGICAL WEAR

Abrasive wear during the test was continuously measured and defined as decrease of distance between grips of sample and counter-sample. Therefore it is a sum of sample and counter-sample wear and it is named as linear wear.

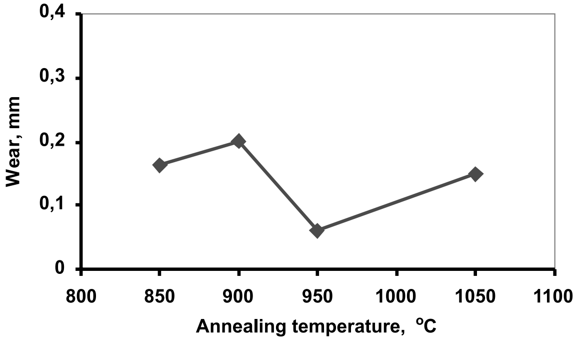

Fig. 3. *Dependence of wear from annealing temperature for a load of 10 N, time 2900 s, distance 290 m at the temperature of 750°C*

Linear wear grades as a function of annealing temperature are presented in Figure 3. Analysis of diagram presented in Figure 3 allows to state that the most advantageous tribological conditions from sample and counter-sample wear point of view correspond to annealing temperature of 950°C. Yet, the least advantageous carbides morphology, from this point of view, was obtained as a result of under-annealing normalization at the temperature of 900°C.

It is, most probably, the result of differences in degree of discontinuity of ledeburitic cementite network and the size and morphology of precipitates of secondary cementite. On the basis of the above, one may state, that in order to ensure the least wear of rubbing pair consisting of G200CrNiMo4-3-3 cast steel and bearing steel in present test conditions, the morphology of ledeburitic cementite and secondary cementite should be properly "balanced".

5. TESTING OF SURFACE LAYER MICROSTRUCTURE

Figure 4 presents microphotographs of test samples after tribological test on distance of 490 m conducted under load of 10 N and at the temperature of 750°C.

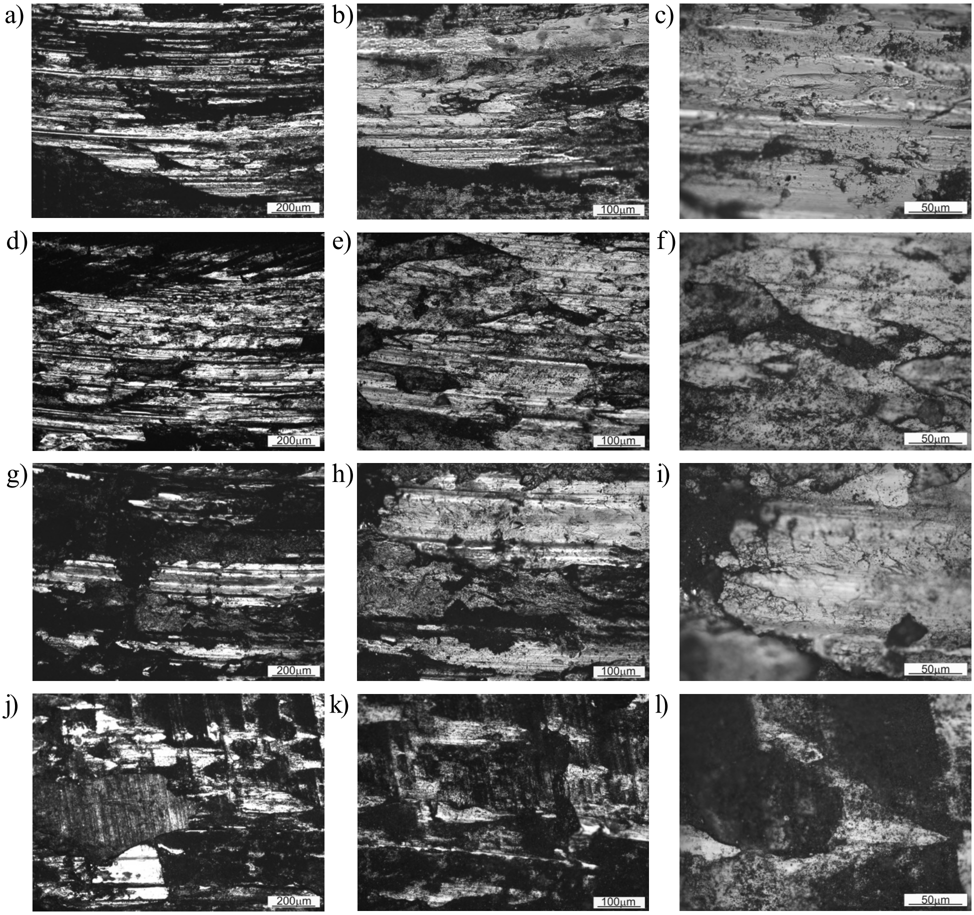

Fig. 4. *Surface of investigated samples after tribological testing for 4900 s and under load of 10 N and the temperature of 750^{o}C; a-c) T_A=850^{o}C; d-f) T_A=900^{o}C; g-i) T_A=950^{o}C; j-l) T_A=1050^{o}C*

It is difficult to distinguish the constituents of the microstructure of test cast steel on the surfaces after high-temperature tribological test. Whereas, one may observe the products of surface oxidation. Surface development of the samples subjected to high-temperature tribological test, is significantly increasing starting from austenitizing temperature of the sample at 950°C. In case of the sample austenitized at 1050°C there is chipping of large fragments during tribological test clearly visible.

6. DETERMINATION OF FRICTION FACTOR

Friction factor was recorded for test duration time from 2000 up to 4900 s, what corresponds to friction distance of 200 to 490 m. Within this range are the most stable conditions of high-temperature tribological test (without grinding in or test ending range).

A set of friction factor changes of samples for high-temperature test within time range from 2000 to 4900 s (friction distance from 200 do 490 m) is presented in Figure 5. Whereas, a set of average friction factor for individual variant of heat treatment for the same range of test duration of above mentioned tribological test is presented in Figure 6.

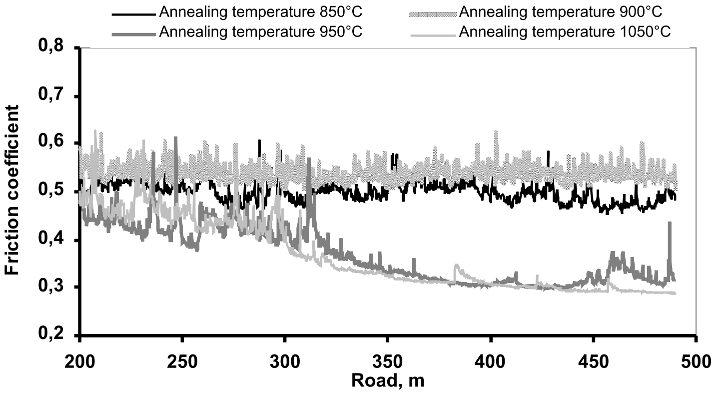

Fig. 5. Diagrams of friction factor changes during tribological tests for the period of 2900 s, and the load of 10 N, and the temperature of 750°C

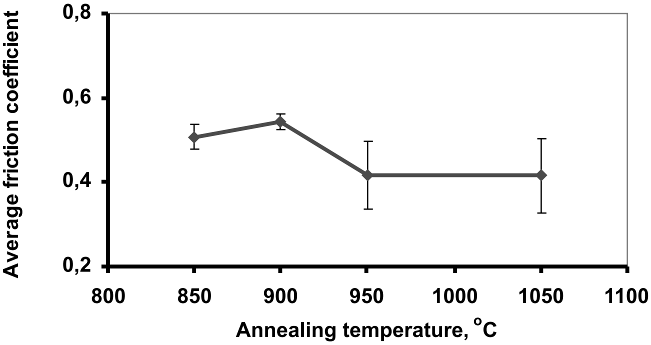

Fig. 6. Average friction factor for individual variant of heat treatment during tribological test for the period of 2900 s

One may notice a distinct decrease of friction factor in case of under - annealing normalized samples at the temperature of 950 and 1050°C on friction distance of 300 m. Also the amplitude of changes of friction factor was decreasing within this range. It resulted in obtaining during tribological test, for these two variants of heat treatments, the lowest average friction factor (Fig. 6). Therefore one may state that in case of high-temperature tests (when carbides matrix is made of austenite), up to a certain moment, the fragmentation of ledeburitic cementite net and increase of amount of spheroidal precipitates of secondary cementite is leading to increase of friction factor. However, further fragmentation of ledeburitic cementite network and increase of amount of spheroidal precipitates of secondary cementite in high-temperature conditions (austenite in matrix) lowers the friction factor and stabilizes it at the level of about 0.35.

7. CONCLUSIONS

Results obtained in present research allow to formulate the following conclusions:

1. Different morphology of carbides precipitates caused by austenitizing temperature change during under-annealing normalization influences the character of wear, its magnitude and tribological properties of cast steel (friction factor).
2. Austenitizing at the temperature of 950°C and higher, during under-annealing normalization, causes that the samples after tribological test are distinguished by significant surface development.
3. The morphology of carbides precipitates obtained for the austenitizing temperature of 1050°C fosters chipping, during tribological test, of large fragments of the sample.
4. Creation of secondary cementite along the boundaries of austenite secondary grains favours the mechanism of tribological wear of G200CrNiMo4-3-3 cast steel.
5. In case if, after under-annealing normalization, the network of carbides, precipitated along the boundaries of primary austenite grains, is adequately shattered in the microstructure of G200CrNiMo4-3-3 cast steel, the conditions of tribological wear become stable.
6. The optimal microstructure of tested cast steel from tribological properties point of view, for its application for mill rolls is after under–annealing normalizing at 950°C.

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