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THE ROLE OF MICROSTRUCTURE IN HIGH TEMPERATURE TRIBOLOGY OF IRON ALLOYS

The present paper describe the issue of tool materials wear in a high temperature conditions. The investigations were performed at the cast steel tool material at the tribological contact to the structural steel. The investigations aim was to determine the role of microstructure in a tribological properties between the structural steel and tool material. The results of such investigation could be referenced to the industry conditions and could answer about the problems of tool materials wear. The observations of the wear mechanisms were referred to the microstructure of the mill rolls. The laboratory tests ware aimed at evaluating the thermal treatment modification effect on the cast steels properties. A significant role of the morphology of ledeburitic cementite and secondary cementite on the tribological properties was exhibited. The investigations assumed the presence of an austenitic matrix with primary and secondary cementite. Influence of varying morphology carbides was described. in the cast steel microstructure. The investigation results make possible to point to a direction of carbide morphology change with the purpose of obtaining the assumed properties of hot operation tools.

Keywords: Microstructure, Tribology, Iron alloys, Cast steel, Wear, Cementite

1. Introduction

Tool materials used for mill rolls, that are used to plastically deform metals, are exposed to especially demanding exploitation conditions. Changes in temperature distribution during rolling processes could affect stress and strain conditions within the tool's surface area, especially non-homogenous longitudinal stresses in the rolling direction. Moreover, temperature distribution during the rolling process could damage the material's surface. Thermal damage results in surface degradation, which is then transported to the surface of the machined material. The process's parameters can result in high stress conditions within the mill roll's surface, potentially damaging it [1-6]. The tool's complex shape, extended surface and mass cause the economic aspect of this part's manufacture to come to the fore. The main production materials for rolls are: steels, cast steels and cast irons [7,8]. Depending on the chosen production material, different wear mechanism could be observed [8-11]. It is important to take into consideration the material's microstructure in order to achieve proper mechanical properties for the finished tool. Sub-quenching tool materials in liquid nitrogen could result in the increase of the material's hardness after tempering. This is related to the volume fraction of the retained austenite and its transformation during tempering. Additionally, the independent nucleation of MC type carbides during tempering increases the material's hardness. Furthermore, the applied heating rate during tempering results in a material hardness increase, which is related to the changes in the carbides' nucleation kinetics [12-15]. These microstructural correlations were investigated not only in high alloyed tool steels, but also in one of the biggest groups of materials used for the production of mill rolls, namely cast materials, such as: cast steel and cast iron. One of the most significant types of hot working tool materials are hypo-eutectic cast steels [16,17]. It was determined that the carbides' morphology has a substantial influence on tribological properties of these materials at room temperature [17-19]. Increasing the temperature (especially up to the austenitic range) can significantly affect the material's tribological properties [20].

The aim of this study was the analysis of the tribological properties of a cast iron material at elevated temperature (austenite formation range). Structural steel was used for the material of the counter sample [21] in order to approximate test conditions to real work conditions during the steel hot rolling process.

2. Research material

The esearched material was a high carbon G200CrNiMo4-3-3 cast steel belonging to the ledeburite class. The material's chemical composition is presented in Table 1. For the purpose of these investigations, the material used was cast in laboratory conditions. The investigated materials consisted of

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TABLE 1

Chemical compositions of G200CrNiMo4-3-3 cast steel, [% mass]

Material	Signature	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Al
Laboratory samples											
Unmodified cast steel	(2.0)	2.10	0.48	0.61	0.024	0.058	1.24	0.75	0.34	0.10	0.14
FeSi modified cast steel	(1.1)	2.00	0.46	0.61	0.025	0.067	1.23	0.76	0.35	0.10	0.09
FeB modified cast steel	(1.2)										
Test mill rolls											
As cast state (without a modification or heat treatment)	WOT	1.97	0.70	0.57	0.040	0.020	1.06	0.78	0.29	0.11	0.10
Subjected to a heat treatment (incomplete normalizing)	WNT										
During casting, FeCaSi deoxidizing was applied, followed bya complex inoculant modification and argoning	WMT										

samples modified by the addition of FeSi and FeB and samples without modifications. The research also included semi-industrial cast steel materials, taken from working mill rolls. The investigated materials were sampled from mill rolls without modifications or heat treatment, rolls without modifications but after heat treatment and mill rolls with the iron-boron and iron-silicon additions (modified). The investigated materials' microstructures are presented in Figure 1. The materials have been characterized by varied carbide morphologies (ledeburitic cementite and secondary cementite).

3. Methodology of tribological studies

The tested samples were prepared in the form of pins, 3 mm in diameter and 20 mm long, 3 from each material. The counter samples were in the form of discs, 25.4 mm in diameter and 5 mm thick, made from construction steel, whose chemical composition is given in Table 2.

TABLE 2

Chemical composition of the S235JR steel used as a counter sample, [% mass]

C	Mn	Si	P	S	Cr	Ni	Mo	Cu	V
0.15	0.61	0.22	0.023	0.022	0.06	0.08	0.02	0.24	0.003

The wear tests were performed by the use of high temperature pin-on-disc tribotester. A friction couple was placed in an isolated chamber, equipped with a heating element. The tests were performed as per ASTM G 99-05 standard. For the investigations, a flat uniform contact in a pin-on-disc system

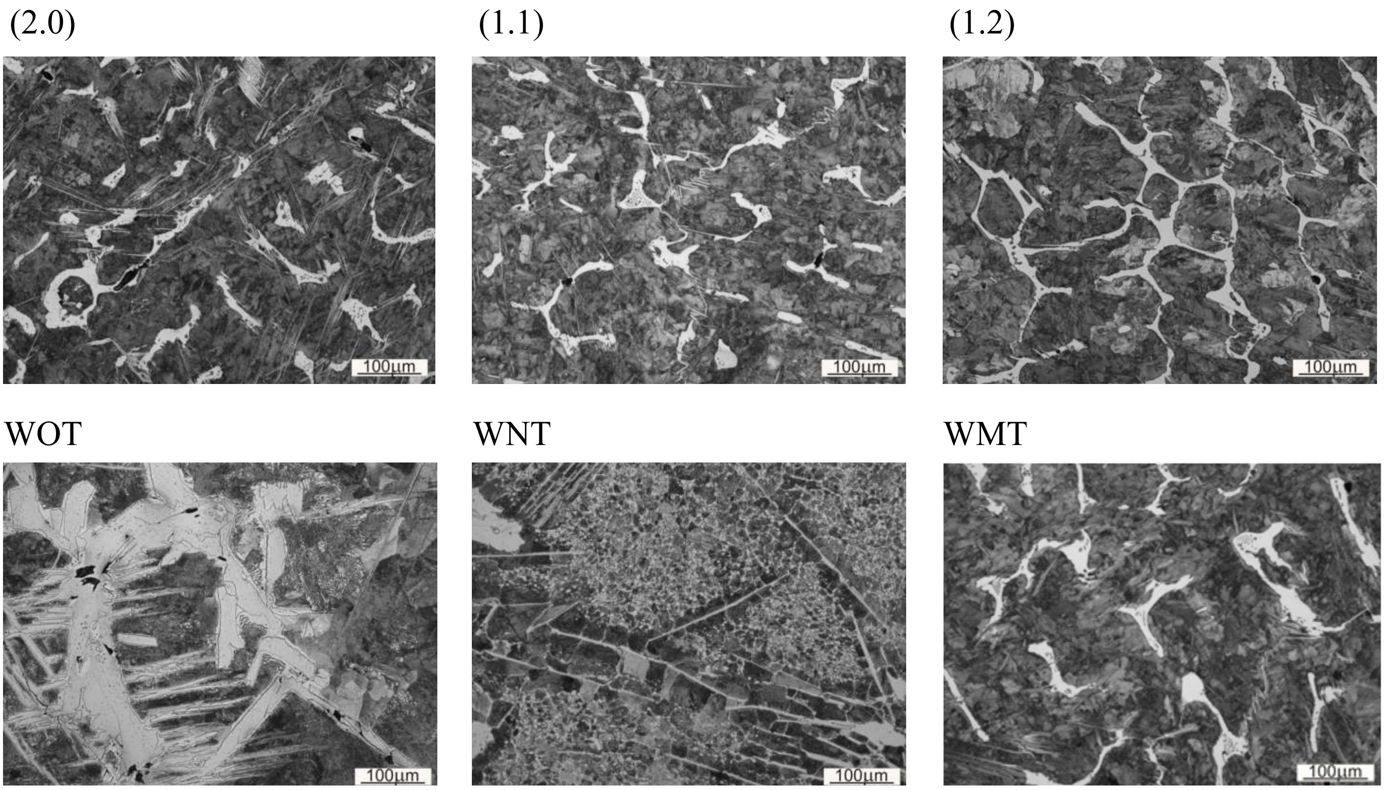


Fig. 1. The microstructures of tested materials produced on the basis of the G200CrNiMo4-3-3 cast steel. Etched with 3% vol. HNO_3 in C_2H_5OH

was used with the same parameters for each friction pair. During tests, the counter sample rotated, whereas the loaded sample was motionless.

The tests were performed following a strictly designed procedure, which included surface preparation, maintenance of identical co-acting conditions and the test's consecutive stages. A new counter sample was used for each sample. As the measure of sample wear was mass loss, each test was preceded and followed by sample weighing using laboratory scales, where the measurement accuracy was approx. 0,0001 g.

Test procedure:

I. Determining test parameters,

II. Measuring sample mass before the test,

III. Fastening the samples – the counter sample was fastened in a special holder placed on a rotational keep plate of a drive spindle, the sample was fastened in a lever holder, on which a load was applied,

IV. Adjusting the contact surfaces – before the beginning of the chamber heating process, the contact surfaces of the co-acting elements were adjusted. The grinding-in process was performed at room temperature, for the time of 120 s-150 s and at the same load as actual wear tests. The grinding-in process was stopped when clear friction force stabilization was observed.

V. Heating the chamber to about 710°C – the chamber was heated together with the friction couple, but the sample and the counter sample did not touch each other (the sample with the lever was elevated 2-3 mm above the surface of the counter sample). In order to level the temperature, the heating process was conducted for 5000 s with the disc in rotation.

VI. Main test – after the chamber was heated, the drive motor was stopped, the pin was placed close to the disc and the force sensor and the displacement sensor were placed in the axis of the sample. The measurement was activated.

VII. Disassembly of the friction couple – after the end of the measurement, the lever with the pin was lifted above the surface of the counter sample and the chamber was left to cool down to room temperature. After the disassembly of the friction couple elements, the chamber and measurement equipment was cleaned.

VIII. Measurement of the samples' mass after the test – the samples were weighed not until 24 hours after the removal from the chamber.

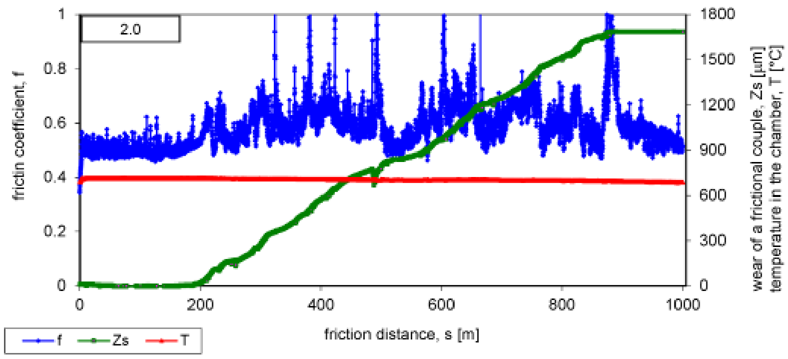
The temperature during the test (710°C) accounts for some amount of austenite in the microstructure of the counter sample ($Ac1s \approx 710°C$). Additionally, friction increased the material's temperature in the contact zone. Beside the isothermal annealing of counter sample in the chamber, a certain volume fraction of ferrite and second cementite ($Ac1f \approx 730°C$, $Ac3 \approx 860°C$) should be observed in the microstructure. The perlite to austenite start and perlite to austenite finish phase transformation temperatures for the G200CrNiMo4-3-3 are: $Ac1s = 730°C$ and $Ac1f = 760°C$, respectively [21]. This suggested that it may be possible to obtain an austenite matrix in the area of tribological contact by means of isothermal annealing at 710°C, especially when considering friction's exothermal effect. It should be expected that the morphology of the cementite precipitations (secondary and ledeburitic cementite) will not significantly change with respect to its initial morphology.

4. Research results

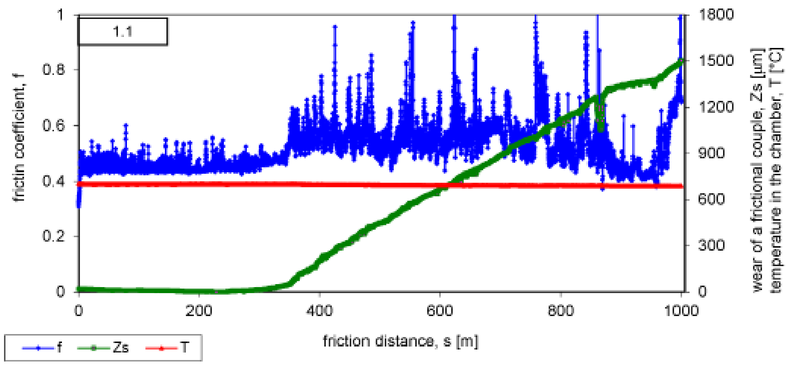
During the tribological test, the continuous signal processing of friction force, temperature and linear wear in the tribotester chamber was performed. The representative results of the tribological tests are presented in Figure 2. It should be noted, that some period without visible wear occurred in all tests. This is related to the presence of FeO oxides on the surfaces of both the sample and the counter sample. FeO oxide reduces the friction coefficient (about 0.5) due to the lubricating properties of this compound. After the oxide layer had broken down, linear wear of the tribocouple was observed. The time by which the oxide breaks down depends on the material. For example, for material 2.0, the linear wear began after 200 m of the track length, material 1.1 after 300 m, 1.2 material – 600 m, WOT material – 500 m, WNT – 750 m, WMT – 450 m. This indicated that the carbides' phase morphology and volume fraction have an effect on time of oxide layer degradation. It could be observed that in the case of the material containing secondary cementite, the cementite precipitated in a Widmanstätten pattern and the oxide layer breakdown time was quicker. Sharp and long interphase boundaries between the Widmanstätten cementite and the material's matrix act as cutting edges and could damage the oxide layer. Prior austenite grain size has a similar effect.

The analysis of sample mass changes after tribological tests was performed. The results of the mass decrement analysis are presented in figure 3. The most significant part of the mass decrement value was obtained during the second period of the tribological trial after the breakdown of the oxide layers. Moreover, there were cases where the sample's holder geometry blocked any further linear wear of the friction couple (e.g. sample (2.0) after 870 m), which should also be eliminated from the wear evaluation. Wear indexes were used in order to better describe mass decrement results. The wear index is defined as a relation of mass loss to applied load and wear track length in the second part of the tribological tests. The wear index values for the investigated materials are presented in figure 4. Qualitatively, the wear index corresponds to the mass decrement (compare Fig. 3 and Fig. 4). One can notice that the presence of secondary cementite in the Widmanstätten pattern in the microstructure limits the abrasive wear of the cast steel (compare samples (2.0), (1.1) and (1.2)). Secondary cementite grain boundary precipitations significantly increase material mass loss (sample WNT). High average diameter of the prior austenite grain size decreases the abrasive wear resistance (sample WOT). Furthermore, a coarse grain microstructure and secondary cementite Widmanstätten precipitations increase the friction coefficient of the cast steel during high temperature tribological tests (Fig. 5).

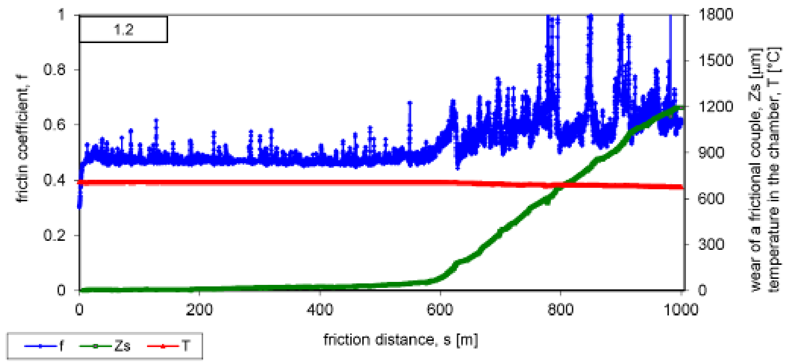
(2.0)



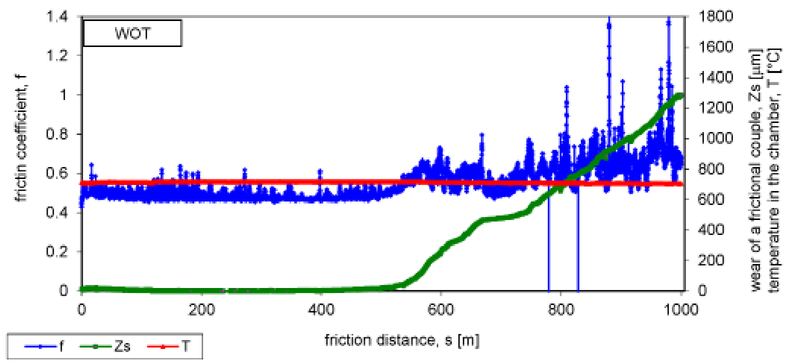
(1.1)



(1.2)



WOT



WNT

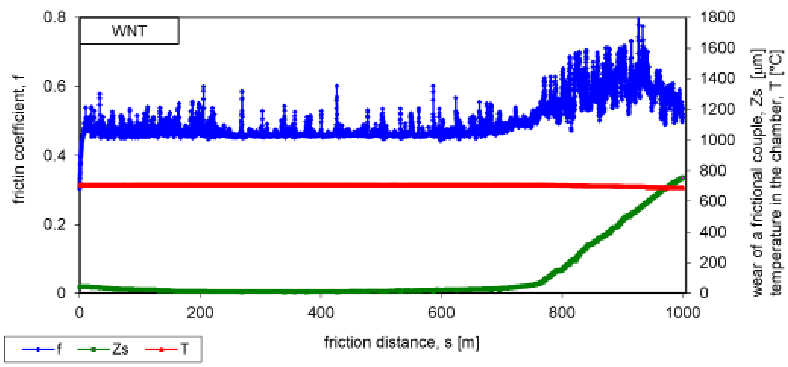


Fig. 2. Representative dependences between the friction coefficient temperature and wear of the friction couples

WMT

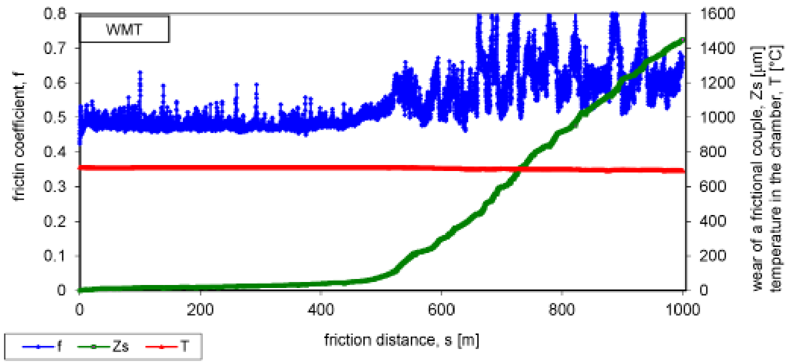


Fig. 2 Continued. Representative dependences between the friction coefficient temperature and wear of the friction couples

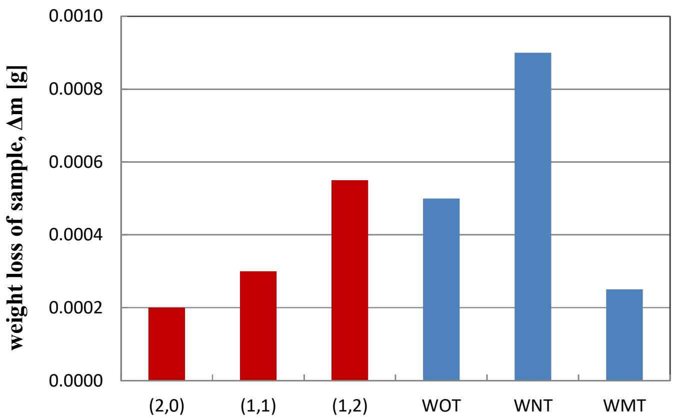


Fig. 3. The weight loss of the samples after the tribological tests

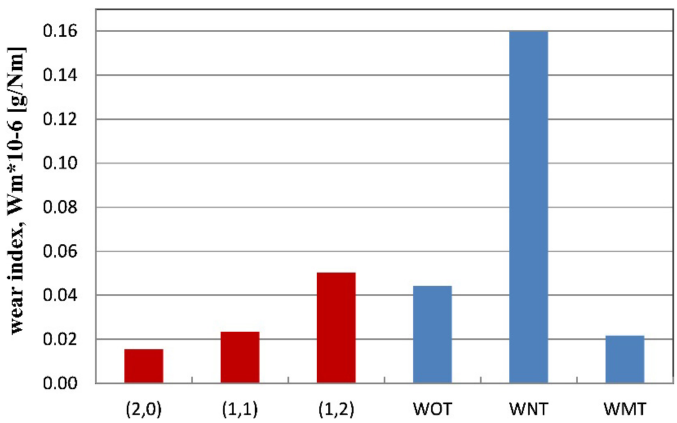


Fig. 4. Wear index for investigated cast irons

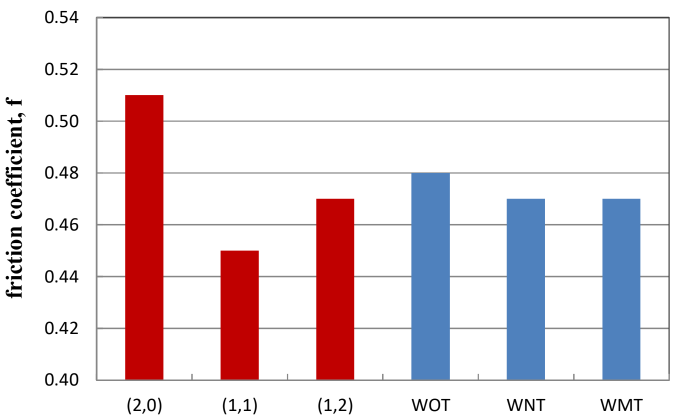


Fig. 5. Average friction coefficient of a frictional couple

5. Conclusions

The results presented in this paper show that modifications, which limit the participation of secondary cementite in the Widmanstätten pattern, decrease high temperature wear resistance. Incomplete normalization annealing has a similar effect. This type of annealing causes the formation of a dispersive secondary cementite precipitate network along secondary austenite grain boundaries. In order to improve the abrasive wear resistance of cast steels under high temperature conditions, modifications allowing for grain refining, with the preservation of the structure of secondary cementite precipitated in the Widmanstätten pattern, should be applied. However, the preservation of Widmanstätten cementite precipitations lowers crack resistance [16]. Additionally, abrasive wear is not the only component of mill rolls wear. In the case of these materials, thermal fatigue wear and wear related to the so-called white layer formation phenomenon are also important [8].

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