THE ROLE OF MICROSTRUCTURE IN THE FORMATION OF THERMAL FATIGUE CRACKS IN CAST STEEL METALLURGICAL ROLLS

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Abstract

The development of fatigue cracks is often analyzed on the basis of their geometry and is explained merely by the state of tensions, without the consideration of the microstructure. The crack resistance is, however, strictly connected with the microstructure.

An analysis of the course of the crack development on the working surface of cast steel metallurgical rolls was performed. It was stated that the precipitations of ledeburitic and secondary cementite are the ways of an easy propagation of the above mentioned cracks. We can observe an especially strong dependence between the lattice of ledeburitic cementite precipitations and the lattice of cracks which forms on the surface of the metallurgical rolls. In the case of a continuous lattice of ledeburitic cementite precipitations, there is a possibility of chipping of large fragments of the material which correspond to the volume of the primary austenite grain. It was stated that the graphite precipitations have an ambiguous role in the formation and development of thermal fatigue cracks. The graphite precipitations present on the surface of the roll can provoke the nucleation of cracks, whereas the spheroidal graphite precipitations can also block the development of the crack.

Keywords: Wear, metallurgical rolls, cast steel, cementite, graphite

1. INTRODUCTION

The working conditions of metallurgical rolls set high requirements in respect to the heat resistance and heat-mechanical resistance of the materials used in their construction. This results from the contact of the roll's surface in the roll gap with the hot (above 900 °C) band and next, the same place being exposed to water sprinkling. Such cyclic heating and cooling of the surface layer cause thermal stresses which exceed the thermal fatigue resistance and, sometimes, even the yield stress of the material [1]. The development of fatigue cracks is often analyzed on the basis of their geometry and explained only by the state of stress, without the consideration of the microstructure [2-11]. The fracture toughness of materials is, however, closely connected with the microstructure [12-15]. The crack develpoment path can thus be dependent on the phase morphology [16-20]. A phase-complex material used in the constrcution of metallurgical rolls is hypereutectoid and hypoeutectic cast steel, including the graphitized one [12]. The aim of this work was thus the determination of the effect of the sructural elements of metallurgical rolls on the develpoment of crack forming in those rolls during operation.

2. MATERIALS FOR INVESTIGATION

The tests were performed on 5 metallurgical rolls made of various cast steels. The chemical compositions of the examined cast steels are presented in **Table 1**, whereas their microstructures are compiled in **Fig. 1**. **Fig. 2** shows the schematics of the passes with the places where the specimen were sampled. The metallurgical rolls were made of the following cast steels: G120CrNiMo4-3-3 2116 Mg, G150SiCrNi4-4-3 1502 Mg, G200CrNiMo4-3-3 4095 Mg, G200NiSiCr8-4-4 1561 Mg and G200SiCrNi4-4 2578 Mg.

Table 1 Chemical compositions (% wt.) of the cast steels used to make the metallurgical rolls

Cast steel	C	Mn	Si	P	S	Cr	Ni	Mo	V	Fe
G120CrNiMo4-3-3	1.22	0.73	0.51	0.030	0.022	0.99	0.47	0.42	0.02	Bal.
G150SiCrNi4-4-3	1.34	0.65	1.12	0.022	0.010	0.83	0.60	0.19	-	Bal.
G200CrNiMo4-3-3	1.83	0.64	0.56	0.024	0.008	1.30	0.47	0.33	0.01	Bal.
G200NiSiCr8-4-4	1.99	0.80	1.30	0.022	0.019	1.24	1.81	0.35	-	Bal.
G200SiCrNi4-4	2.00	0.70	1.12	0.027	0.025	0.84	0.51	0.33	0.02	Bal.

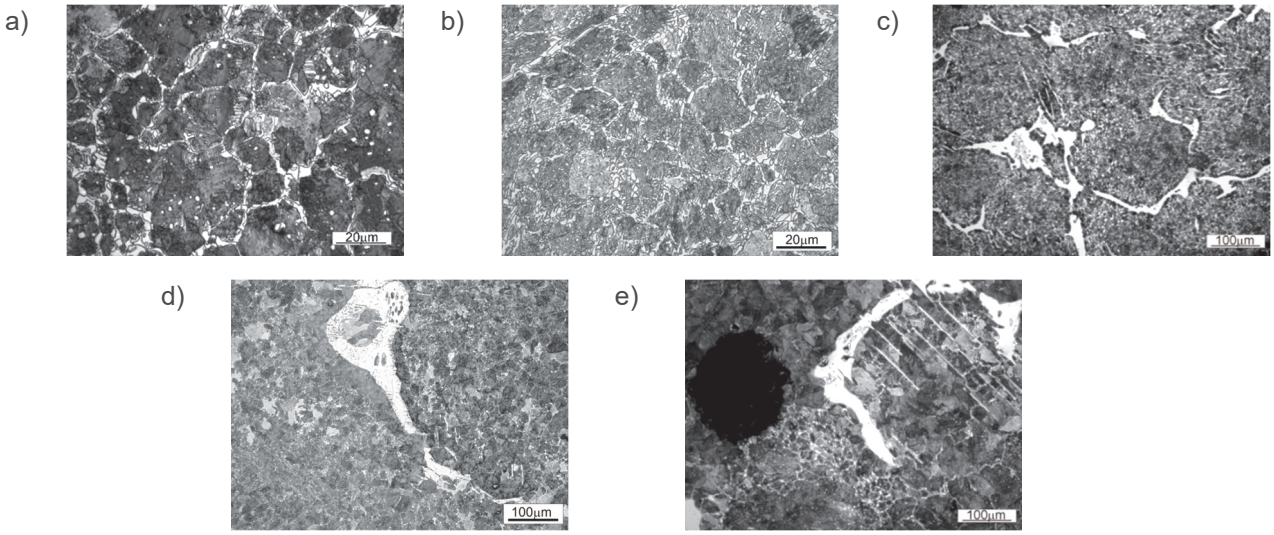

Fig. 1 Microstructure of the metallurgical roll materials: a) G120CrNiMo4-3-3 cast steel, b) G150SiCrNi4-4-3 cast steel, c) G200CrNiMo4-3-3 cast steel, d) G200NiSiCr8-4-4 cast steel, e) G200SiCrNi4-4 cast steel. Etched with 2 % nital

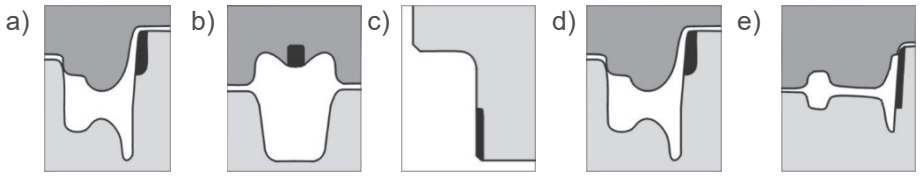

Fig. 2 Shapes of the rolls passes with marked places of sampling the specimen: a) G120CrNiMo4-3-3 cast steel roll, b) G150SiCrNi4-4-3 cast steel roll, c) G200CrNiMo4-3-3 cast steel roll, d) G200NiSiCr8-4-4 cast steel roll, e) G200SiCrNi4-4 cast steel roll

3. RESULTS AND DISCUSSION

Favourable conditions for the formation of cracks though precipitations of ledeburitic cementite are proven by the observations of the surface layers in cast steel section rolls after operation (**Fig. 3 and 4**). It can be assumed that the second-best facilitators of the nucleation and development of cracks are acicular precipitations of secondary cementite (precipitated in the Widmannstätten system). A confirmation of this are the examples of cracks presented in **Figs. 3c and 4b**. As the third development path in respect to facilitating the mentioned propagation we can assume to be the lattice of spheroidal precipitations of secondary cementite (precipitated on the boundaries of former secondary austenite grains). An example of such crack development is shown in **Figs. 3d and 3e**. The cracks can develop along the lattice of the above precipitations towards the inside of the roll (**Fig. 3a**) but also under its surface (**Fig. 4).** The second type of crack develops mainly when the working surface goes through the volume of the primary austenite grain (surrounded by precipitations of

ledeburitic cementite). A result of such crack formation can be large fragments of materials being spalled off the surface of the device during its operation (**Fig. 4**).

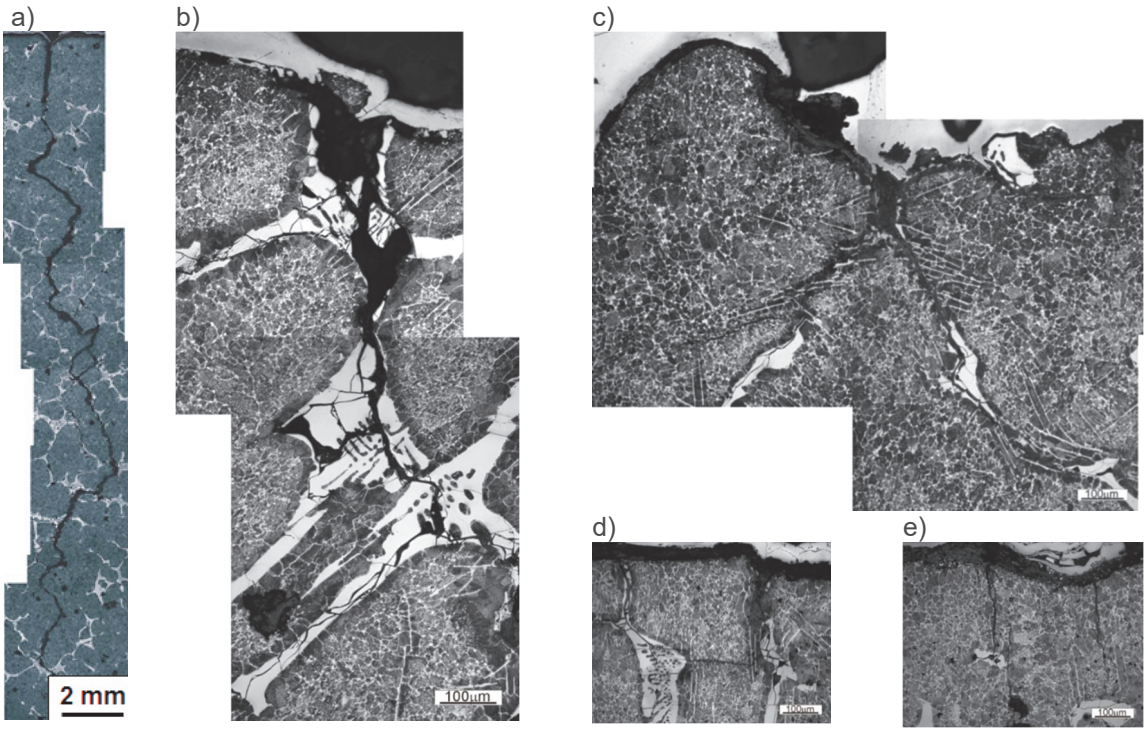

Fig. 3 Development of a crack in a metallurgical roll made of G200CrNiMo4-3-3 cast steel: a) deep crack, b-c) examples of nucleation and development of cracks along ledeburitic cementite precipitations, c-e) examples of development of cracks along secondary cementite precipitations. Etched with 2 % nital

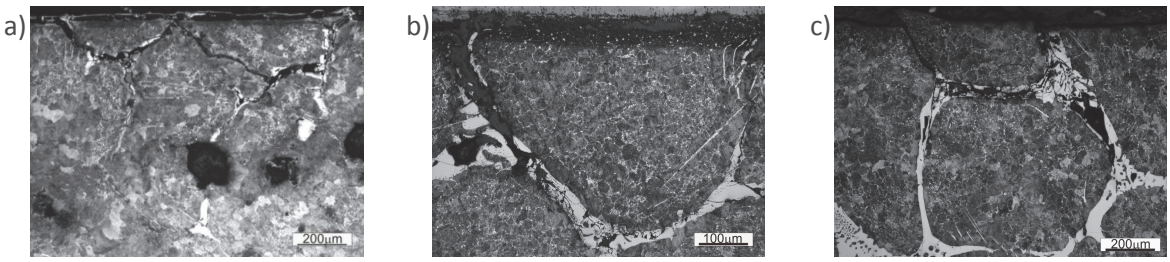

Fig. 4 Development of cracks along ledeburitic cementite precipitations in the surface layer of metallurgical rolls a) G200SiCrNi4-4 cast steel roll, b) G200NiSiCr8-4-4 cast steel roll, c) G200CrNiMo4-3-3 cast steel roll. Etched with 2 % nital

When there are no ledeburitic cementite precipitations in the microstructure of cast steel metallurgical rolls, the role in the development of cracks is played by secondary cementite (**Fig. 5 and 6**). Secondary cementite precipitations also facilitate the crack development under the surface of metallurgical rolls in the areas with the Bielayev's point (**Fig. 7**).

The effect of ledeburitic cementite precipitations on the formation of thermal fatigue cracks is so significant that the lattice of those precipitations corresponds to the lattice of the fire cracks on the working surface of a cast steel metallurgical roll (**Fig. 8**). The morphology of carbides precipitations can thus determine the density of the fire cracks occurring on the surface of the device.

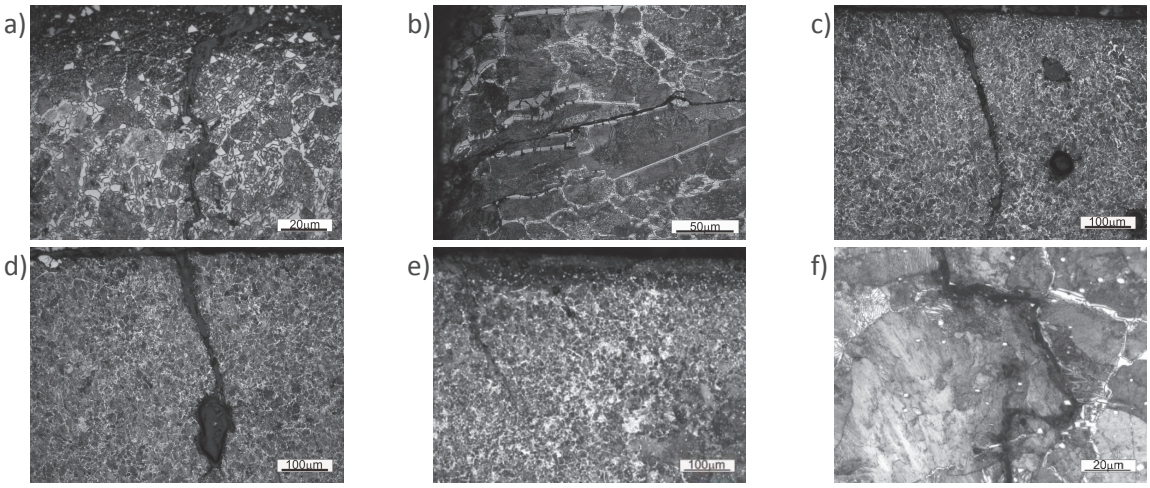

Fig. 5 Cracks on the working surface of metallurgical rolls developing along the secondary cementite precipitations: a) G200NiSiCr8-4-4 cast steel roll, b) G200CrNiMo4-3-3 cast steel roll, c,d) G150SiCrNi4-4-3 cast steel roll, e,f) G120CrNiMo4-3-3 cast steel roll. Etched with 2 % nital

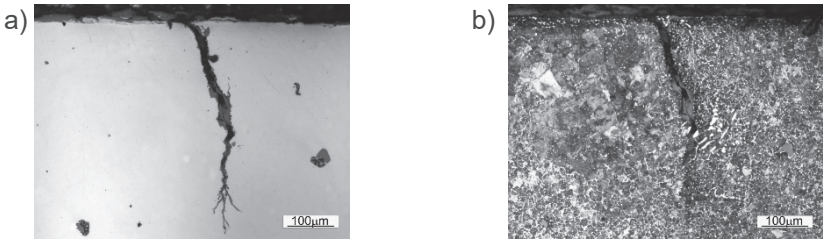

Fig. 6 Role of agglomerations of secondary cementite precipitations in the crack development in a metallurgical roll made from G120CrNiMo4-3-3 cast steel: a) non-etched microsection in the place of the occurrence of a single crack, b) place from Fig. a after etching. Etched with 2 % nital

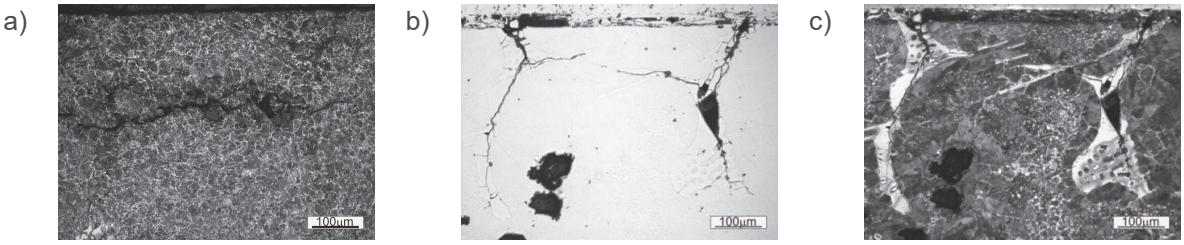

Fig. 7 Cracks parallel to the working surface of metallurgical rolls developing along the secondary cementite precipitations: a) G150SiCrNi4-4-3 cast steel roll, b) G200SiCrNi4-4 cast steel roll - non-etched microsection, c) place from Fig. d after etching. Etched with 2 % nital

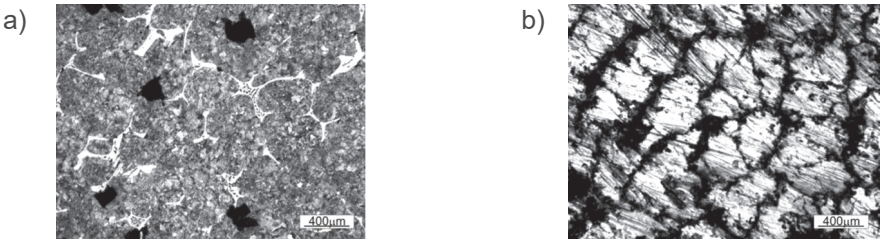

Fig. 8 Comparison of the lattice of ledeburitic cementite precipitations and the lattice of cracks on the surface of a G200SiCrNi4-4 cast steel metallurgical roll: a) microsection - microstructure - etched with 2 % nital, b) roll's working surface

In the case of cast steel metallurgical rolls which contain graphite in their microstructure, it was stated that, under tribological conditions which they are exposed to, the graphite from the precipitations on the working surface of metallurgical rolls can burn out, and the remaining empty areas become the places of crack nucleation (**Fig. 9a**). The graphite precipitations occurring on the working surface of metallurgical rolls can also participate in the nucleation of thermal fatigue cracks as a result of the formation of an indentation by way of facilitating the rolling of the material's matrix in those places. However, the graphite precipitations located on the surface take a lesser part in initiating the thermal fatigue cracks than the precipitations of transformed ledeburite (**Fig. 9b**). It should also be noted that the transfer of the thermal fatigue cracks into the matrix takes place much more easily from the carbide precipitations than the graphite ones, as the spheroidal shape of the graphite precipitations „blunts" the blade of the crack (**Fig. 9c**). Graphite precipitations can, however, facilitate the spalling off of fragments of the roll's material (**Fig. 9d**).

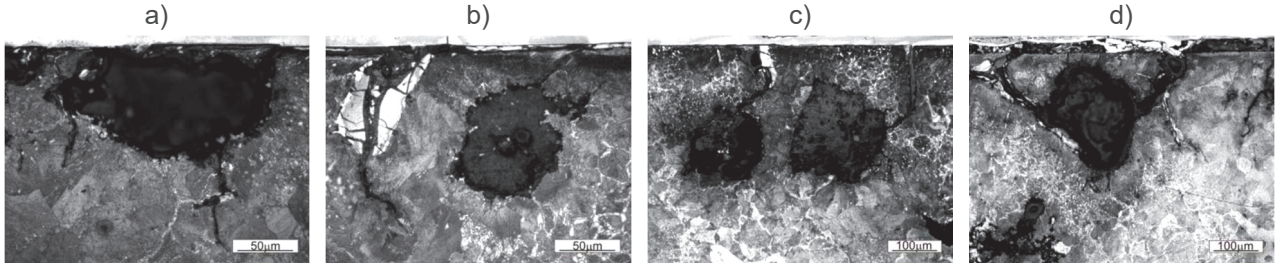

Fig. 9 Role of graphite in the wear of a G200SiCrNi4-4 cast steel metallurgical roll. Etched with 2 % nital

CONCLUSION

Through the appropriate shaping of the microstructure of the cast steels used in the production of metallurgical rolls, one can hinder the development of fatigue and/or thermal fatigue cracks. This is confirmed by many examples of a correlation between the path of the crack development and the microstructure. In this aspect, the morphology of the carbide precipitations is especially important. It has been proven that e.g. the lattice of the ledeburitic cementite precipitations can shape the lattice of the thermal fatigue cracks, and parallel to the working surface, the precipitations of the ledeburitic cementite facilitate the crack development in the place of the occurrence of high shear stresses. In regard to the graphite precipitations, they can be either beneficial or disadvantageous in their effect on the above mentioned cracks. That is why the obtained test results provide the possibility to point to the directions of optimizing the microstructure of the cast steels used for metallurgical rolls with the purpose of hindering the nucleation and development of fatigue and thermal fatigue cracks formed as a result of their operation. To that end, one should aim at:

- fragmenting the continuous carbide lattice,
- limiting the formation of a lattice of secondary carbide precipitations at the grain boundaries,
- limiting the existing tendency for grain size reduction, which most often results from the assumed
- theory of a beneficial effect of grain refinement on the crack resistance,
- spheoridization and refinement of graphite precipitations.

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