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Effect of tool microstructure on the white layer formation

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Materials

ABSTRACT

Purpose: Purpose of this paper: This work supplements the knowledge concerning formation of the white layer on the surface of the tools being utilized in high temperature metal forming processes. Eight iron-based materials were tested: 3 ledeburitic cast steels, 2 hypereutectoid cast steels, normalized and stress relief annealed steel, hardened and tempered steel and nodular mottled cast iron.
Design/methodology/approach: The exploitation tests were performed on the hot rolling mills for selected rolled sections, rolling stands and roll passes. The samples were cut out of the roll in such a way that they contained the roll working surface and were used for metallographic observations of the subsurface zone.
Findings: It was found, that uniform distribution of dispersed precipitates of hypereutectoid cementite in the alloy matrix prevents the formation of the white layer on the surface of the rolls.
Research limitations/implications: The white layer definition was given. An influence of the microstructure of iron base alloys on the susceptibility to form the white layer on their surface due to tribological contact was also determined.
Practical implications: The procedure for obtaining rolled products of better quality as well as for restricting the probability of roll cracking was proposed. Obtained results should allow proper design of the microstructure of the materials for tools.
Originality/value: This work contains several new aspects, which are: the unique tribological conditions for performing the tests, wide range of investigated materials, and combining the microstructure of the material with the susceptibility of the formation of the white layer on its surface. The results of this research may be used by the producers of tools for high temperature metal forming.
Keywords: Tool materials; Mill rolls; High temperature tribology; White layer

1. Introduction

Common phenomenon accompanying the tribological contact of iron base alloys is the formation of the white layer [1-6]. The white layer is difficult to define. Basing on previous research and on the relevant literature it has been proposed in [1] to describe the white layer as a hard-to-etch surface layer of the material, having high hardness (above 1000 HV) and high brittleness. This layer is considered to be formed in the result of very fast heating up to high temperatures (austenitic temperature range), accompanied by strong deformation (lattice defects), followed by immediate cooling, usually to room temperature. Within the white layer area, this material is usually considered as nanocrystalline martensite [7-11]. Contentious issues are whether this martensite is formed in the result of transformation of strongly deformed, but still having crystal structure, austenite or it is a result of crystallization out of completely degenerated as regards its crystal structure (amorphous) material. It cannot be excluded, that the white layer area, taking into account its high (even in low carbon steels above 1200 HV) hardness and brittleness, may be (at least in some cases) to significant extent amorphous.

Table 1.
Chemical composition (mass %) of investigated materials

materials	roll No.	C	Mn	Si	P	S	Cr	Ni	Mo	V
adamite cast steel with transformed ledeburite	1	2.00	0.70	1.12	0.027	0.025	0.84	0.51	0.33	0.024
	2	1.99	0.80	1.30	0.022	0.019	1.24	1.81	0.35	-
	3	1.83	0.64	0.56	0.024	0.008	1.30	0.47	0.33	0.010
adamite cast steel without transformed ledeburite	4	1.34	0.65	1.12	0.022	0.010	0.83	0.60	0.19	<0.016
	5	1.22	0.73	0.51	0.030	0.022	0.99	0.47	0.42	0.022
normalized steel	6	0.74	0.61	0.49	0.011	0.011	0.09	0.06	0.16	0.119
hardened and tempered steel	7	0.37	1.93	0.35	0.014	0.003	1.60	0.09	0.43	0.123
	8	0.35	1.94	0.35	0.015	0.007	1.56	0.07	0.43	0.110
	9	0.34	1.93	0.36	0.010	0.007	1.57	0.11	0.42	0.120
cast iron	10	3.23	0.52	2.22	0.080	0.012	0.69	3.56	0.62	-
	11	3.24	0.56	1.98	0.070	0.011	0.66	3.54	0.63	-

Specially advantageous tribological conditions for the formation of the white layer occur on the surface of rolls during processing of steel at high temperature. As a result of the contact with hot rolled material and friction between roll and the material being rolled, the surface layer of the roll, in the roll gap area undergoes a fast heating up to high temperatures. Roll surface in the roll gap area at the same time is subjected to a very high unit pressures. When rolled material exits the roll gap, heated up to high temperature surface layer of roll is rapidly cooled down due to water spraying and fast heat transfer from the surface to the center of roll.

Specific tribological conditions existing on the surface of rolls combined with wide range of iron base materials used for rolls are very interesting with reference to the analysis of the influence of the microstructure of investigated material on its susceptibility to form the white layer. In this work, an attempt was made to evaluate an effect of the microstructure of 8 iron base alloys, chosen for this research, on their susceptibility to form the white layer.

2. Test materials

The investigations were performed on the samples cut out from the used-up sections of rolls. In order to determine the role of microstructure of rolls in the white layer formation, the authors compared the results of investigations performed on cast steel rolls with transformed ledeburite and hypereutectoid cementite, cast steel rolls without ledeburite and only with hypereutectoid cementite and on the quenched and tempered steel rolls as well as on the heat refined and relief annealed rolls, containing neither ledeburite nor hypereutectoid cementite, and also on the cast iron rolls containing transformed ledeburite but without hypereutectoid cementite. Table 1 lists the chemical compositions of the tested rolls.

3. Experimental procedure

The exploitation tests were performed on the hot rolling mills for selected rolled sections, rolling stands and roll passes.

The samples were cut out from the roll in such a way that they contained the roll working surface and were used for observations on metallographic specimens of the subsurface zone.

4. Research results and discussion

The white layer can readily be formed and remains stable on the surface of rolls made of hypoeutectoid steel (Fig. 1). It is rarely formed on normalized and stress relief annealed steel, having pearlitic structure. This results from high susceptibility of such roll to adhesive wear resulting from the formation of roll material sticking to its surface. The white layer may yet be still present under such layer (Fig. 2).

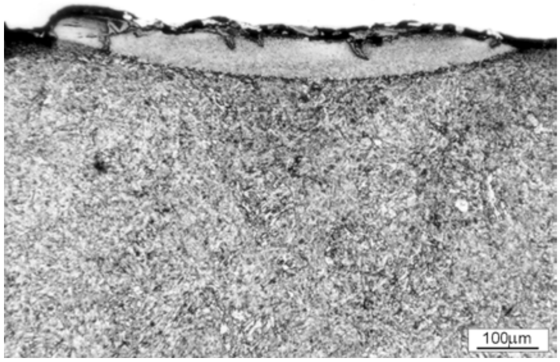


Fig. 1. White etching layer on the surface of roll No 9. Light microscopy, etched with 2% nital

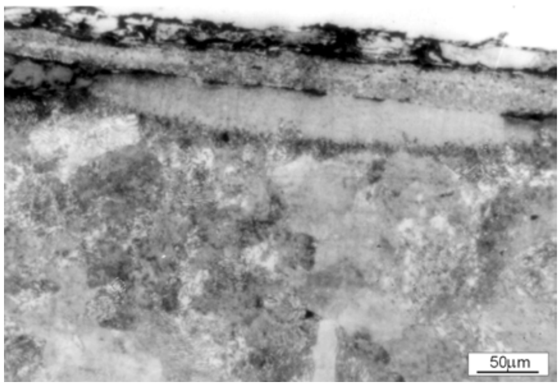


Fig. 2. White etching layer on the surface of roll No 6. Light microscopy, etched with 2% nital

However, the net of hypereutectoid cementite in hypereutectoid cast steels and, additionally, transformed ledeburite in high carbon alloy cast steels strongly lower the susceptibility to the white layer formation and stabilization on the roll surface. It may be considered as a result of lower friction coefficient between rolled material and those roll materials as well as susceptibility of their surfaces to wear. However, the white layer formed on the surface of these materials can still be observed (Fig. 3).

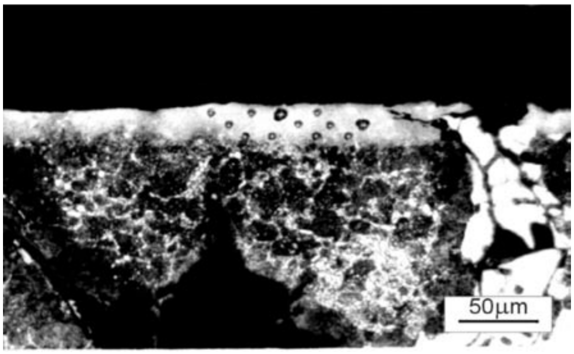
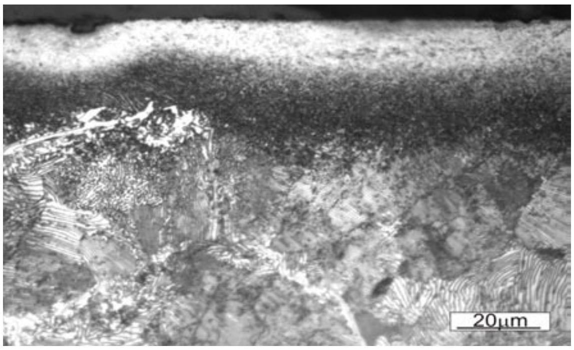


Fig. 3. White etching layer on the surface of roll No 2 and microhardnes testing indentation marks. Light microscopy, etched with 2% nital

Thickness of the white layer existing on the surfaces of these materials is much smaller than in the case of investigated steel rolls. It is usually formed in the areas free of secondary cementite (for example in the center of primary austenite grain – Fig. 4).

a)



b)

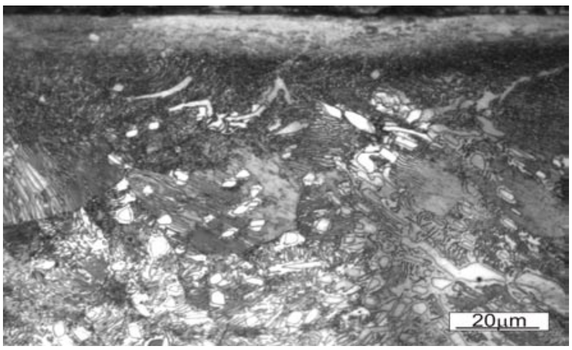


Fig. 4. White etching layer on the surface of roll No 1. Light microscopy, etched with 2% nital

If it is sporadically formed in the area where precipitates of secondary cementite exist, it is usually very thin and has inhomogeneous structure (Fig. 5). Most often it undergoes cracking immediately (Fig. 6). Morphological features of the white layer formed in such area show, that it has been formed of strongly defected austenite, without complete dissolution of secondary cementite. Basing on this, one can expect, that heating the surface layer of roll in such area was heated up to the temperature below A_{Ccm}, or heating and cooling rates for this layer were so high, that cementite could not dissolve in austenite.

The white layer can readily be formed and remains stable on the surface of rolls made of nodular mottled cast iron. Suitable place for its formation seems to be the alloy matrix, which has high hardenability and is free from small precipitates of secondary cementite (Fig. 7).

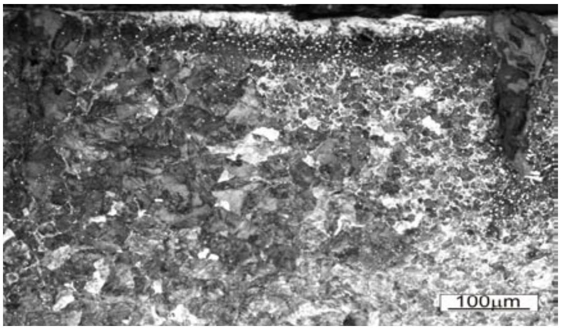


Fig. 5. White etching layer on the surface of roll No 5. Light microscopy, etched with 2% nital

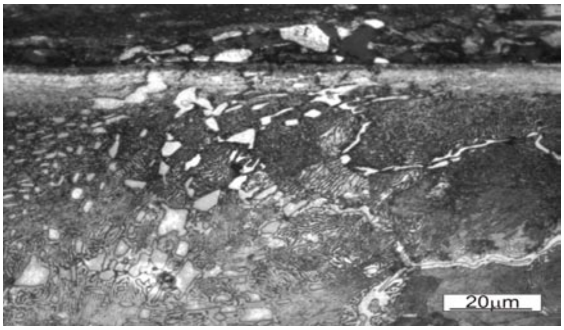


Fig. 6. White etching layer on the surface of roll No 1. Light microscopy, etched with 2% nital

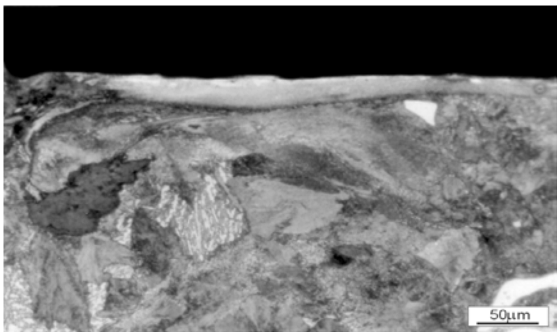


Fig. 7. White etching layer on the surface of roll No 11. Light microscopy, etched with 2% nital

4. Conclusions

Tribological conditions under which metallurgical rolls operate favor the formation of the white layer on their surface. This layer can be readily formed on the surface of heat treated forged steel rolls. This results from the high hardenability of these materials as well as their low susceptibility to form sticking layers. The susceptibility to keep such layer on the surface of the roll is restricted by adhesive wear. Moreover, the presence of uniformly distributed precipitates of secondary cementite totally restricts the formation of the white layer. When the precipitates of secondary cementite are uniformly distributed in the alloy microstructure, or when only precipitates of transformed ledeburite are present in alloy matrix, then the white layer can readily form within the areas free of such structural constituents.

To avoid the consequences of the white layer formation on the rolls surface (as for example crack nucleation), it is necessary to uniformly distribute the precipitates of secondary cementite in the material structure. Hypereutectoid cast steels are potentially very attractive from this respect. Uniform distribution of disperse precipitates of secondary cementite in their structure can be achieved by the application of appropriate modifiers during casting or by suitable heat treatment. Such heat treatments were described in [12-15].

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