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LABORATORY HEAT TREATMENT OF THE SHELL MATERIAL OF THE CENTRIFUGALLY CAST ROLL FOR THE LAST FINISHING STAND OF HOT STRIP MILLS

The rolls for the hot rolling finishing stands are cast centrifugally as two or three-layer rolls. The working layer is called a shell. The material of the shell is selected according to the position of the respective roll in the final finishing stand of the rolling mill. Typically, a combination of rolls made of a high-chromium cast iron + indefinite cast iron or high-speed steel + indefinite cast iron is commonly used. Great attention has been paid to indefinite cast iron in recent years and this material received a number of modifications that led to the increase of material properties up to 20% in comparison to the ordinary indefinite cast iron. But the goals of the new generation of material for hot rollers were chosen higher: increasing of production about 30% and more. This material has specific physical properties, heat treatment requirements as well as rolling mill requirements as is stated in the paper. It is expected that introduction of this material will reduce the difference between wear of the front and finishing stands, which can extend rolling campaigns and have a positive effect on the reduction rolls exchanges, the grinding of the rolls and the reduction of downtime.

Keywords: Centrifugally cast roll, High speed steel, Indefinite iron, Heat treatment, Residual austenite

1. Introduction

Manufacture of centrifugally cast rolls is based on a strong and stable connection between two different materials, high-alloyed working shell with high hardness and damage resistance during rolling and material of roll necks and body under the working part of the roll, where nodular cast iron is typically used with specific requirements for mechanical and physical properties [1]. The combination of these materials is schematically shown in Fig. 1.

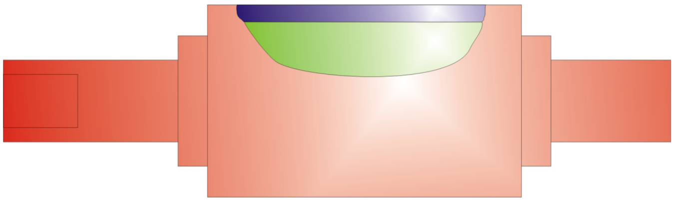

Fig. 1. Sketch of centrifugally cast roll, combination of shell (violet) and core (green) material

The change of material of the rolls in the first part of the final finishing stands of hot strip mills from high-chromium cast iron into so-called high-speed steel (HSS) brought about a double increase in the performance of the rolls. The logical requirement of hot strip producing mills is then to replace the existing rolls made from ICDP (Indefinite Chill Double Pour) cast iron. The use of such a material prolongs the roll operation time and reduces frequency of grinding and repairs. This has positive financial as well as environmental impacts. For this purpose, a new generation of material for the finishing stands of hot strip mills was proposed. This material combines the properties of high-speed steel and ICDP cast iron, such as toughness, thermal conductivity, resistance to thermal fatigue, self-lubricating properties and much more. It has chemical composition close to the eutectic composition in binary diagram Fe-C and is modified by the combination of alloying elements, inoculants and modifiers. Mechanical properties can be further increased by heat treatment [2].

2. Experimental material and procedures

Experimental study was thus focused on the assessment of the effect of heat treatment on the material properties of the shell part of a centrifugally cast roll. The work was carried out on samples prepared from the material intended for use in the final finishing stands of the hot rolling mill 2.5-3.5 wt. % C, 1.0-3.0 wt. % Cr, 3.0-7.0 wt. % Ni, 0.6-8.0% Mo + V + Nb + W. The effect of heat treatment on the material properties was

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studied after three different heat treatment modes; in the as-cast condition and after simulated high temperature annealing followed by single or double tempering, see Figs. 2 and 3 [3]. Ledeburitic cementite is stable up to graphitizing temperature, which lies, according to the literature, in the temperature range of 950-1000°C.

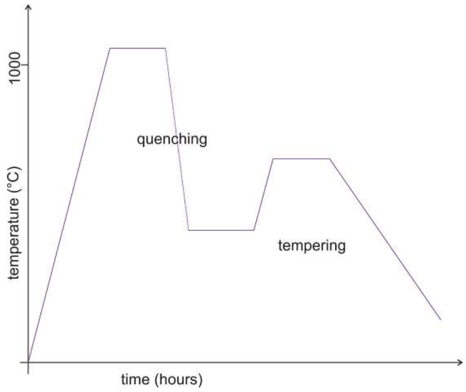

Fig. 2. Simulated high temperature annealing followed by single tempering regime

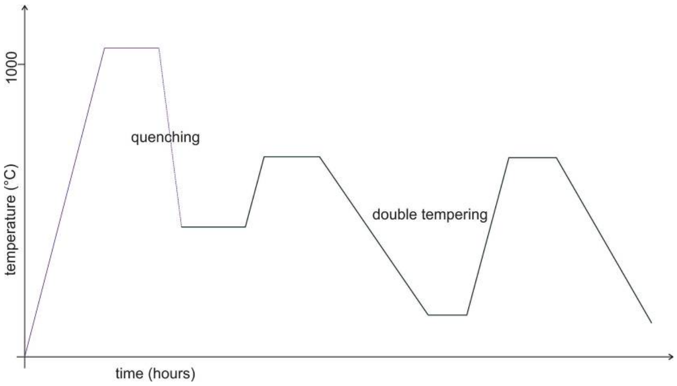

Fig. 3. Simulated high temperature annealing followed by double tempering regime

The experimental work thus consisted of:

- laboratory heat treatment,
- determination of hardness profile from the outer surface towards the inner part made of nodular iron,
- determination of content of residual austenite,
- analysis of macrostructure and microstructure of the shell after the simulation heat treatment in comparison to the as-cast condition.

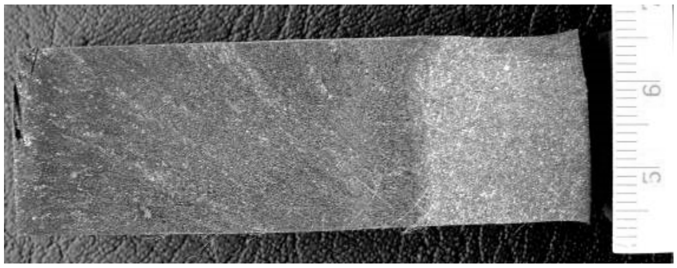

Fig. 4. Macrostructure of the sample in the as-cast state

3. Results of the performed analysis

Fig. 4 shows the macrostructure of the specimen prepared in a direction parallel to the longitudinal axis of the roll in the as-cast state where the dark shell part is clearly detectable from the bright core part of the roll.

4.1. Hardness profile measurement

The hardness profile was measured in all three material states by using Vickers method (HV 50) in two lines from the outer surface of the roll inwards with a distance of 5 mm among the individual indentations, see Fig. 5. The results of hardness measurements are shown in Table 1.

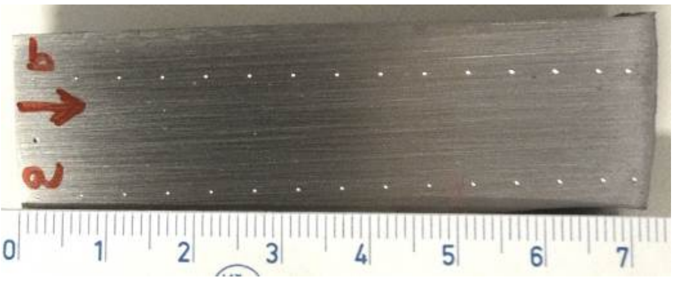

Fig. 5. HV50 hardness measurement from the front of the shell in two lines

TABLE 1

Hardness profile (HV 50) of the tested samples

Distance [mm]	As-cast-state*	1st step of heat treatment*	2nd step of heat treatment	3rd step of heat treatment
2	704±25	377±5	395	433
12	691±6	376±6	394	395
22	698±17	356±1	392	389
32	690±12	355±8	371	374
42	661±25	333±6	362	338
52	341±18	**	**	**
62	234±6	**	**	**
72	229±1	**	**	**

* these values represent the arithmetic mean of the two measurements
** data are not an object of the article

The arithmetic mean was calculated from the measured hardness values. The results of the measurements and the graphical representation in Fig. 6 show that the hardness of the shell is very stable to the depth of about 47 mm, followed by an abrupt drop in the bonding zone and again stable but significantly lower hardness in the core iron of the roll body. From the presented results it is clear that the hardness values in both lines show a slight variation. Similarly as in the shell part of the roll it can be explained by the chemical heterogeneity of the cooling casting.

The heat treatment led to hardness decrease of the shell material, see Fig. 7. Significant reduction in hardness of this material can probably be explained by the high content of residual

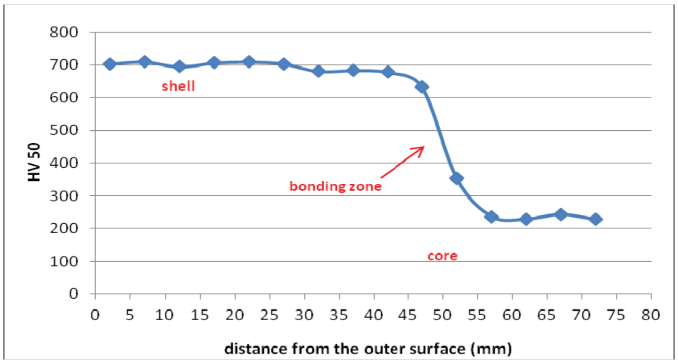

Fig. 6. Graphical interpretations of hardness drop in depth of cast-state sample

austenite. In order to verify this presumption, residual austenite was determined in the as-cast state, after high temperature annealing and after double tempering. The amounts of the residual austenite determined by the magnetometric method are shown in Table 2.

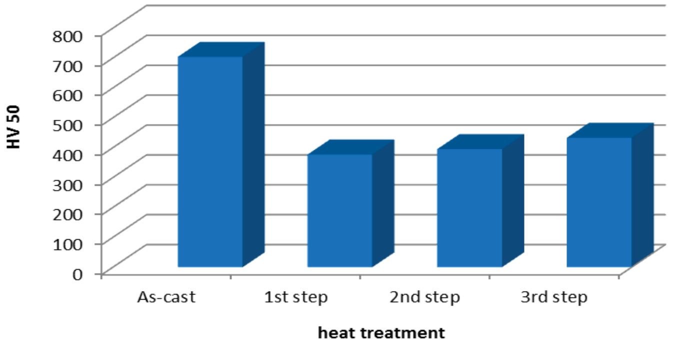

Fig. 7. Change of shell hardness after different modes of heat treatment

TABLE 2

Amount of residual austenite (%)

Heat treatment of samples	Residual Austenite (%)
As-cast state	14.3
After high temperature annealing	66.1
After high temperature annealing + single low tempering	50.7
After high temperature annealing + double low tempering	43.4

From the obtained results it is clear that the residual austenite content was the smallest in as-cast state, after high temperature annealing the material was composed almost solely by austenite and after double tempering this content decreased down to about 43%.

4.2. Evaluation of microstructrue

Granular particles of graphite were found in the metal matrix of the shell in the polished state. The size and amount of the graphite particles slightly increased with increasing distance from the outer surface of the roll. Besides graphite were frequently detected in the metal matrix also carbide particles of bright contrast with varying sizes and shapes, see Figures 8,9.

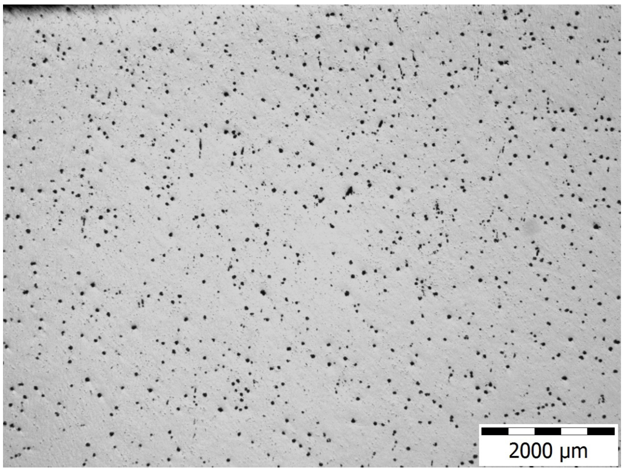

Fig. 8. Graphitic particles in the shell 5 mm under surface, polished state

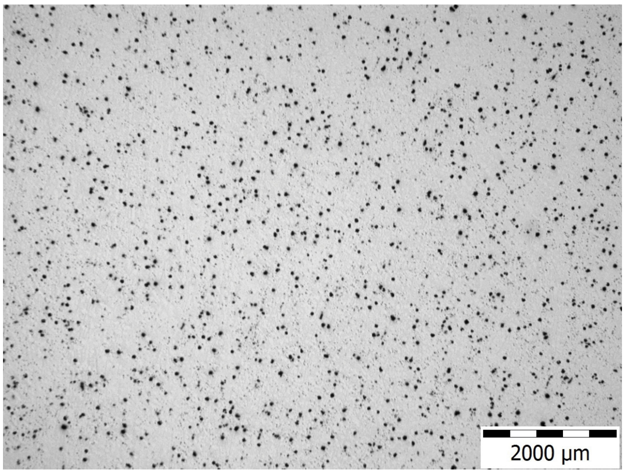

Fig. 9. Graphitic particles in the shell 20 mm under surface, polished state

The process of graphite formation depends on the chemical composition, melting technology, the method of inoculation and the solidification rate. In the materials like ICDP, used in the last finishing stands of hot rolling mills, the content of graphite ranges from 1-6% [4]. The amount of graphite close to the shell surface, 20 and 40 mm from this surface was determined by optical microscopy using the Quick PHOTO Industrial software. The results are summarized in Table 3 and shows that the amount of graphite slightly increases from the shell surface inwards.

TABLE 3

Amount of the graphite in the shell

Depth (mm)	Graphite quantity* (%)
5	1.43±0.3
20	2.76±0.3
40	3.86±0.5

* average value from 5 measurements

Microstructure of the shell part of the roll was revealed after etching in 4% of Nital. The microstructure was dendritic and was composed of martensite with a certain amount of residual austenite, network of eutectic carbides with transformed ledeburite inside them. Also there was observed a small amount of granular graphite, see Figs. 10 and 11. Needle-like martensitic particles having microhardness HV0.02 = 870 ± 26 were observed in the martensite, see Fig. 12.

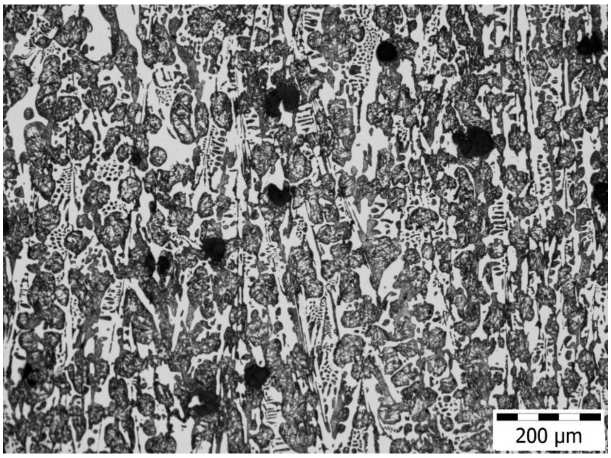

Fig. 10. Microstructure of the shell, 5 mm under surface

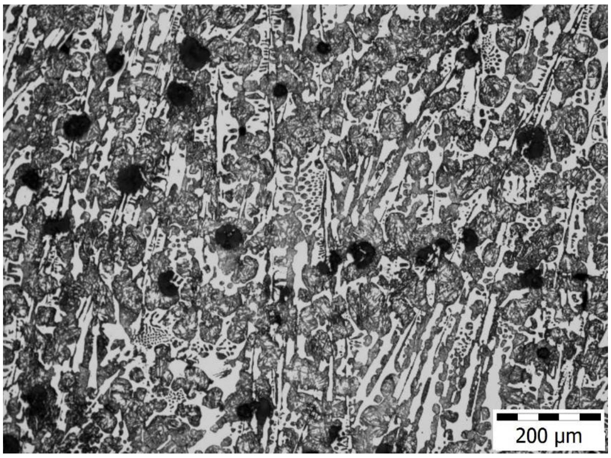

Fig. 11. Microstructure of the shell, 20 mm under surface

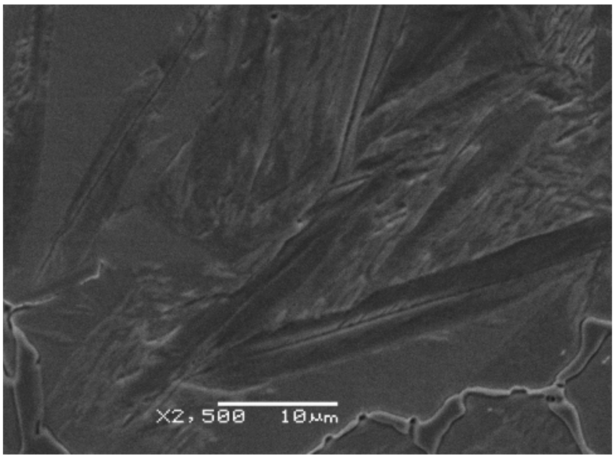

Fig. 12. Needle-like martensite

Ledeburite is a high-temperature mixture of austenite and cementite. During cooling austenite transforms into martensite while cementite remains unchanged. The resulting mixture can be called transformed ledeburite. The determined amount of ledeburite was approximately 25% in the depth of 25 mm, see Fig. 13.

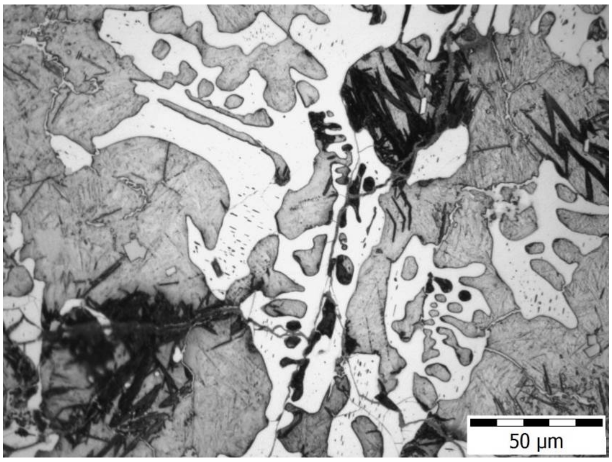

Fig. 13. Detail of microstructure of the shell, 25 mm under surface

5. Discussion

Working rolls for the finishing stands of hot rolling mills are cast composite components made of a wear-resistant outer shell and a core made of ductile iron or steel. The evolution of the materials used in the work rolls for hot strip mills can be summarized as follows: at first Adamite cast steels replaced the indefinite cast iron, but now the Adamite rolls were replaced by high chromium iron (HCI) rolls that are at present replaced by high speed steel (HSS) rolls [5,6]. The evolution of materials for work rolls in the first stands of the hot strip mills is shown in Table 4 [6].

TABLE 4

Chemical composition, microstructure and hardness of roll materials [6]

Material	**Chemical composition (wt %)**	**Microstructure**	**Hardness HSc ASTM E140**
Indefinite Chill Iron	C 3.0-3.4 Ni 4-5 Cr <2 Mo <1	Fe_3C Bainite Intercellular Graphite	70/85
Adamite Steel	C 0.1-1.4 Ni 1.2-1.5 Cr <2 Mo <1	Tempered Martensite Pearlite	45/60
High Chromium Iron	C 1-3 Ni 1-2 Cr 10-25 Mo 1-3	M_7C_3 Tempered Martensite	70/90
High Speed Steel	C 1.5-2.4 Cr 2-10 Mo 2-10 V 2-10 W 2-10 Co <10	MC + M_6C Tempered Martensite	80/90

The new material is under development for its very good wear resistance and hardness, which exceeds ICDP irons and is not far away from HSS roll steels, although it is cheaper than they are. The microstructure of new material in the as-cast state is martensitic with a small amount of residual austenite and the performed experimental heat treatment confirmed that the high temperature annealing cannot further increase the hardness of the working layer of the centrifugally cast roll because due to the large amount of retained austenite. The resulting hardness dropped down to approximately 60% of the original value in the as-cast state and remained nearly the same even after single or double tempering. A slight gradient of hardness through the shell material of the roll can be probably related to the chemical heterogeneity of the casting.

Large amount of residual austenite means that high temperature annealing significantly stabilizes austenite, probably due to its enrichment with carbon dissolved from the secondary cementite. The residual austenite still remains in the microstructure even after tempering, however in the less but still important amount, again perhaps as a result of its saturation with carbon. This explains the fact that it was not possible to achieve the required hardness after final heat treatment.

6. Conclusion

The developed material exploits the benefits of both HSS and ICDP material groups in order to achieve an increase in the working parameters and life of the working roll for last finishing stands of the hot strip mill. However, performed experimental work has shown that material properties of this new material cannot be further improved by the high temperature heat treatment, as is usual in the case of HSS materials [7].

Operational experience performed so far confirmed very promising material properties and this new high speed iron is the very perspective material for replacement of ICDP iron in the last finishing stands of hot strip mills.

Acknowledgement

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REFERENCES

[1] T. Válek, P. Šimon, L. Střílková, The Comparison of Selected Methods of Cast Iron Spheroidization in Industrial Conditions, Archives of Foundry Engineering **12** (2), 89-92 (2012).

[2] L. Čamek, P. Lichý, I. Kroupová, J. Duda, J. Beňo, M. Korbáš, F. Radkovský, S. Bliznyukov, Effect of cast steel production metallurgy on the emergence of casting defects, Metalurgija **55** (4), 701-704 (2016).

[3] J.H. Lee, J.C. Oh, J.W. Park, H.C. Lee, S. Lee, Effects of Tempering Temperature on Wear Resistance and Surface Roughness of a High Speed Steel Roll. ISIJ International (8), 859-865 (2001).

[4] J. Hampl, T. Válek, P. Lichý, T. Elbel, Control of the metallurgical processing of ICDP cast irons, Materiali in tehnologije **48** (5), 685-688 (2014).

[5] T. Koseki, K. Chino, Y. Kataoka, Y. Nakano, K.Yuda, Development of high speed steel rolls made by centrifugal casting. in Proceedings of the 38th Mechanical Working Steel Processing Conference, Oct. 1996 (Iron and Steel Society of AIME, Warrendale) pp. 59.

[6] H. Hashimoto, et al. Development of High Performance Roll by Continuous Process for Cladding, ISIJ International **32** (11), 1202-1210 (1992).

[7] V. Šumšal, V. Vodárek, P. Kawulok, Heat Treatment of HSS and SEMI HSS Steels for Production of Centrifugally Cast Rolls, Hutnické listy Ostrava: Ocelot **63** (4), 34-40 (2010).