Impact of Decarburization on the Hardness of the Rails Running Surface

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Abstract. Possible causes of rail head defects related to decarburization of the rolling surface are presented. The surface of the rail head was tested directly from the manufacturers and the decarburization of this surface was determined by measuring the hardness and observing the microstructure of the surface layer. The tests were carried out on the basis of requirements included in PN-EN 13674-1 + A1: 2017 [1] and Technical Conditions Id-106: 2010 [2].

Introduction.

Rails are one of the most important components of the railway superstructure [4], so the requirements for the quality of the rails and their producers are high. Qualification and acceptance tests of rails must meet the requirements of EN-PN 13674-1 + A1:2017, i.e. have the appropriate chemical composition and the level of gas content, including oxygen of up to 20 ppm and hydrogen of up to 2.5 ppm. Appropriate strength properties and hardness HBW depend on the type of steel, proper level of non-metallic inclusions determined by the K3 index, pearlitic structure of the steel without traces of bainitic-martensitic microstructure, decarburization of the surface of the head up to max. 0.50 mm, proper profile, straightness and dimensions of the rails, and also should not have defects in the rolling surface with a depth of exceeding 0.30 mm, not allowed by the above standard.

The size of decarburization of the rail head on the running surface plays quite a significant role in the quality of rails, which is often overlooked. This phenomenon occurs during the production of rails, mainly at the stage of heating and heating of slabs in heating furnaces at a temperature of about 1150 °C, and during cooling of rails in a cold store. The process causing surface decarburization, i.e. changing the concentration of carbon content in steel, involves gas corrosion at high temperature in an oxidizing atmosphere, causing oxidation of the surface with the formation of a scale surface, simultaneously connected with the diffusion of carbon dissolved in the steel from the surface layers of the material into the environment in the gaseous form. Due to the high carbon content in rail steel, high strength and hardness are obtained. At the same time, a higher carbon content may increase the decarburized steel layer, while the thickness of the decarburized layer depends on many factors, including mainly the atmosphere in the heating furnaces [6, 7].

The initial operation of new rails that have not undergone preventive grinding, i.e. removal of the decarburized layer from the running surface of the rail head is deeply interesting [5]. Rails having decarburization of the surface to the limit permitted by the abovementioned standard and technical conditions are vulnerable to the formation of all types of surface defects as well as defects in the rail head profile during their service life. This is due to the reduced carbon content in the surface layer, resulting in lower hardness and lower surface strength. Thus, the material is softer, prone to wear of the rail running surface, formation of shape defects and, as the track life extends, subjected to strong strengthening of the rail head surface. During this period, the surface layer wears out as a result of wheel-rail interaction, while creating defects in the form of rolling edge cracks occurring mainly in track curves with small radii and straight sections in places with unstable track surface. This kind of defect occurs frequently during operation, to a varying degree connected with decarburization, which can be classified as a fatigue-type defect. Minor cracks in the rail head edges arise in the track curves as a result of wheel flange action, which develop in further operation. These cracks are formed as a result of strong deformation of the softer surface layer of the rail head (Fig.1).

At this stage, there also appears a phenomenon of wave formation and wear of the rail surface, partly linked to decarburization (Fig. 2). This particularly applies to the formation of short waves with low amplitude which probably originate from the uncushioned masses of rolling stock in reaction with the decarburized surface of the rail [8].

Then defects of squat (Fig. 3) and shelling (Fig. 4) types can be distinguished. They are also connected with the surface decarburization, usually arising as a result of the local delamination of the surface layer of the rails and its chipping, as the rails previously underwent so-called spinning or sudden braking of the wheels of the power unit. Also the sticking and flaking of the running surface is related to the micro-slip and friction energy in the wheel-rail interaction and the quality of the rail surface structure.

Fig. 1. Rail edge defect

Fig. 2. Defect in rail waviness

Fig. 3. Squat rail defect

Fig 4. Shelling rail defect

Material for research

The research material were samples of unused rails from the R260 grade of five major European manufacturers, which were marked with letters from A to E. The chemical composition of the tested rails is presented in Table 1.

Samples were cut from the rail sections, whose running surface of the rail head was ground from 0.10 mm to 0.50 mm using 0.10 mm increments. HV5 and HBW hardness measurements were made on samples prepared in this way [3]. The prepared test samples are shown in Fig. 5. Then, after grinding, polishing and etching samples in 4% nital, the decarburized layer of the selected rail manufacturer was shown, indicating the lowest and highest hardness.

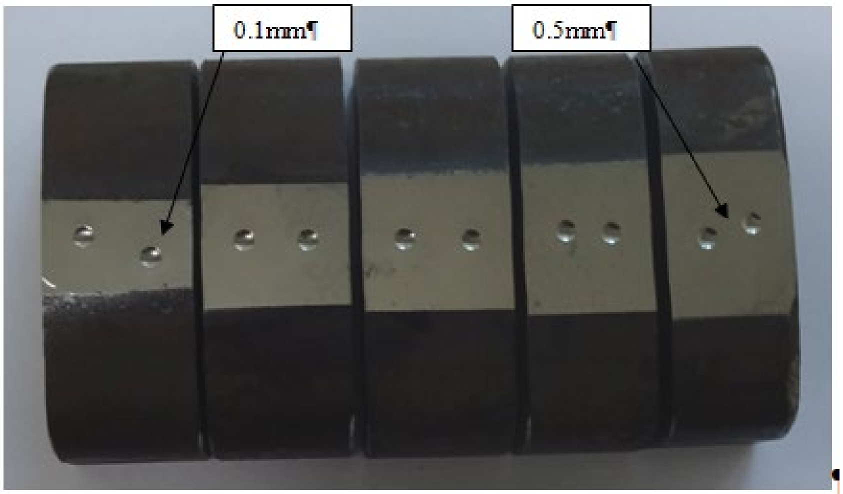

Fig. 5. C-smelt rails with a ground running surface

The chemical composition of all tested samples of new R260 rails is within the range of elements provided for in the PN EN 13674-1: 2017 standard. Due to the obligatory vacuum treatment of grades intended for the production of rails, the level of gas content in the tested samples was not determined, assuming that they are in accordance with the abovementioned standard.

The level of carbon content in the R260 grade is highly responsible for strength parameters and the wear rate of rail running surface. The content of carbon is in the range of 0.696% to 0.763%, which indicates the possibility of a difference in hardness of individual rail samples. The contents of the other elements in the melts show slight differences within the limits provided for this grade, which do not have a significant effect on the rail operating parameters.

Figures 6 and 7 present the results of measuring the Vickers HV5 and Brinell HBW hardness depending on the thickness of the ground layer from which surface decarburized was removed. The graph (Fig. 6) shows that the tested rail samples showed hardness in the range of 260 to 310 HBW depending on the thickness of the ground layer. Therefore, the minimum thickness of the layer removed from the rail running surface, guaranteeing the achievement of the required hardness of minimum 260 HBW, should be 0.30 mm.

HV5 measurements, i.e. 260 to 363 HV5 hardness units, show a greater difference in hardness of the tested samples (Fig. 7). Also in this case, the minimum thickness of the ground layer that guarantees the required hardness of the rail running surface should be 0.30 mm.

Figure 8 shows the microstructure of the decarburized surface of the manufacturer's rail sample marked with the letter A. The line indicates the permissible decarburization for the rail of 0.50 mm, and the minimum 0.30 mm securing the required hardness, and Fig. 9 shows the microstructure of the sample decarburized layer 0.30 mm of the rail marked with the letter E. Bainitic-martensitic microstructure was not found in the tested samples.

Table 1. Chemical composition of tested rails in the R260 grade

Sample determination	**Content of elements in [%] by weight**										
	C	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Al**	**Mo**	**V**
A	0.96	1.08	0.255	0.018	0.017	0.048	0.019	0.033	0.000	0.004	0.000
B	0.712	0.95	0.332	0.016	0.014	0.055	0.033	0.018	0.000	0.009	0.001
C	0.763	1.04	0.309	0.025	0.014	0.061	0.020	0.029	0.000	0.007	0.000
D	0.699	1.07	0.356	0.016	0.017	0.026	0.026	0.036	0.000	0.003	0.001
E	0.749	0.98	0.271	0.015	0.015	0.069	0.025	0.022	0.000	0.006	0.000
R260 acc. PN EN 13674-1:2011	0.60 – 0.82	0.65 – 1.25	0.13 – 0.60	max 0.030	0.008 – 0.030	max 0.15	-	-	max 0.004	-	max 0.030

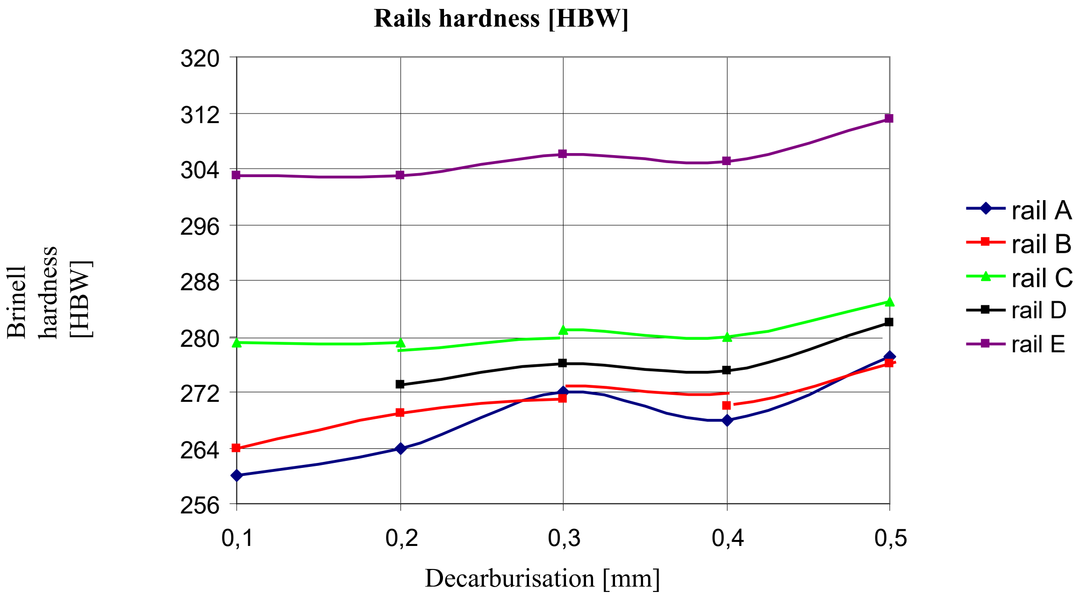

Fig. 6. HBW hardness distribution of tested rails

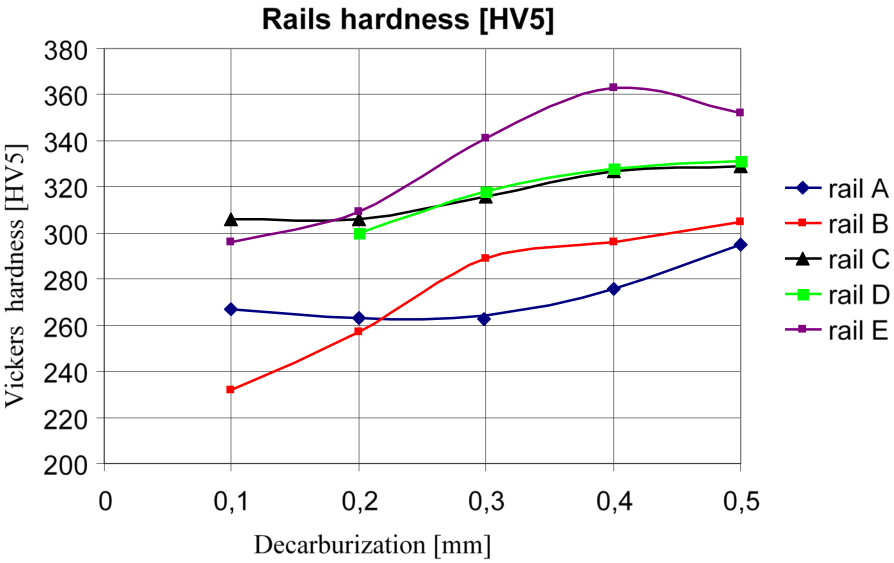

Fig. 7. HV5 hardness distribution of tested rails

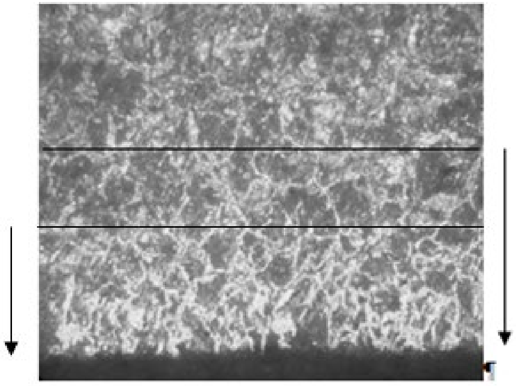

Fig. 8. Sample of rail no. A with 0.50 mm decarburization, area 100x

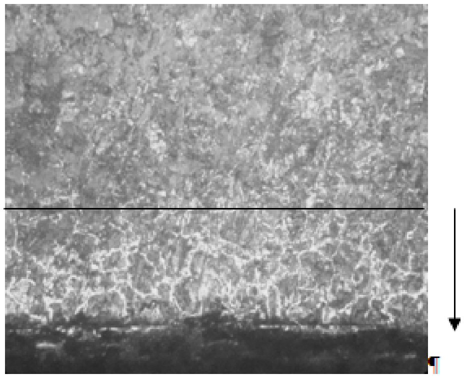

Fig. 9. Sample of rail no. E with 0.30 mm decarburization, area 100x

Summary

The presence of a decarburized layer was confirmed on all the tested rail samples, which is vulnerable to the formation of rail head defects due to its lower hardness. The resulting defects of rails caused by surface crumbling in the form of cracks in the rolling surface and edge of the rails lying at a small depth, short-wavelength waves, a surface white layer appearing on the rails as well as chipping and laminations are the result of microstructure changes occurring on the rail surface.

Currently, the grinding operations of the rail running surface are carried out in running conditions in the tracks using a grinding train. Tests on the volume of the decarburized layer of rails of five European producers confirmed the need of rail grinding. Tests on the hardness and microstructure of new rails showed the thickness of the decarburized rolling surface of the rail head recommended to date for grinding, of minimum 0.30 mm.

However, in the case of rails operated for a longer period, the stage preceding the reprofiling of rails by the grinding method is to check the condition of the track surface and repair the track in order to enable even removal of the defective layer and limit the further development of other rail defects.

References

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