CHANGES IN STRUCTURE AND PHASE COMPOSITION IN THE SURFACE OF TRAM RAIL

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Abstract

We have investigated structure and phase composition of surface layer of tram rails after long time running and the results were compared with those obtained on the original part of material. Changes due to effects of severe plastic deformation together with thermal shocks by friction process were expected. The information about structure and phase composition was obtained by optical and scanning electron microscopy, X-Ray Powder Diffraction, Mössbauer Spectroscopy and Glow Discharge Emission Spectroscopy (GDOES) and this was completed by microhardness measurements. The results show that the surface layer in comparison with the original material exhibits important changes in grain structure, an increase in microhardness and high content of iron oxide and hydrooxides. According to the depth profile of the chemical composition measured by GDOES there is an increase in carbon content in the surface layer which can be effect of up-hill diffusion.

Keywords: Tram rail, microstructure analysis, surface

1. INTRODUCTION

The most common materials used at railway are fully pearlitic rail steels. Increasing interlamellar spacing between cementite and ferrite correspond with increase hardness and decrease wear rate. The other main rail steels are steels with bainitic microstructure. These steels have low wear resistance at a fixed tensile strength, but on the other hand better rolling contact fatigue resistance in comparison with pearlitic steels [1, 2, 3].

The other facts they have an influence of lifetime and wear out of rails besides type and quality of steels are operation mode on the railway (e.g. speed of the train, density of traffic, gradient and inequality of the rails), construction of the train, atmospheric condition (e.g. season of year, humidity), contaminants (dead leaves, sand, ballast stone), location and microclimate of rails (e.g. tunnel, tram lines together with road in the city). The influences, it have impact to wear out of steel and initiation of crack and fracture, are complexes. Many studies took accounts of it. Perez-Unzueta and Beynon [2] were focus on sliding and rolling-sliding conditions during wear test for four pearlitic rail steels with different interlamellar spacing. Deters [4] has study wear and creep by simulation the wheel-to-rail contact. The similar study, but oriented on rolling contact fatigue was publish by Mazzù [5]. Lyu at all [6] study wear between wheel and rail at various condition of temperature and humidity. Description of wear mechanism together with wear measurement and testing particle emission are containing in article by Olofsson [1]. Lakušic and Ahac [7] was look into study of hardness distributions over cross-section of rails. Lee [3] also study hardness, but they compare results for pearlitic and bainitic rail steel before and after testing truck with different tonnage.

The aim of this work was study surface layer created by wear as a result of use in real condition. The grooved rail was part of the tram network in Brno (middle Europe). It was expose broad interval of temperature fluctuation during a year and contamination as sand, dust and de-icing soil, because this type of rail are commonly use embedded in city streets.

2. MATERIALS AND METHODS

Grooved rail type NT3 provided from local public transport company in Brno (DPMB) was used as a sample. Samples were sawing up from grooved rail according **Figure 1**. Part of them were grinding, polishing and etching by 2 % Nital.

Microscope observations were made by optical microscope (Neophot 32 by Carl Zeiss Jena) and scanning electron microscopy JEOL 6460 with Oxford Instruments analytical equipment INCA Energy (EDX). Hardness was testing by Vickers method on Zwick's micro-hardness testing instrument connected with image analysis.

The X-ray powder patterns were collected on X'Pert diffractometer and CoKα radiation with qualitative analysis by HighScore® software and the JCPDS PDF-4 database. For a quantitative analysis HighScore plus® with Rietveld structural models based on the ICSD database was applied.

The measurements of ^{57}Fe Mössbauer spectra were carried out by detection of conversion electrons (scanning depth up to 300 nm) and by detection 14.4 keV gamma radiation (scanning depth about 30 micrometers), both in scattering geometry.

Bulk analysis and depth profiling of sample was performed by method Glow Discharge Optical Emission Spectrometry (GDOES) by GD-Profiler 2 instrument with the Quantum™ XP software (Horiba Jobin Yvon, France).

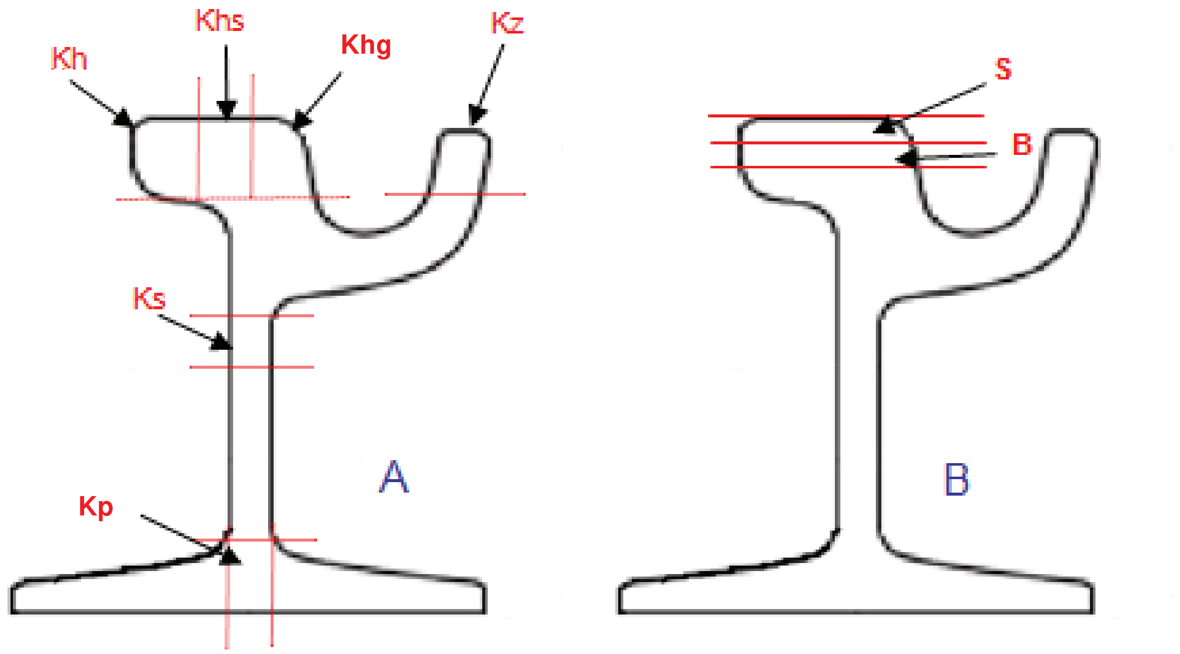


Figure 1 Acronyms of prepared samples: A - Sample for microscope observation, B - sample for MS and XRD

3. RESULTS

The chemical analysis was done by GDOES bulk analysis. The result correspond to the composition common steel rail material grade UIC 900A. This type of steel has full pearlitic structure and commonly is use without heat treatment or addition alloy element as for example chromium.

The rail evinced only the change over the working period. The cracks were not observed in the investigated part of rail. The rail head showed the plastic deformation of pearlitic microstructure (**Figure 2**), where interlamellar spaces have been blended, broken and deformed. The zone with plastic deformation which was influenced by traffic, have around 60-80µm according to their position on the rail head.

Hardness was observed close to surface of the rail head and approximately 15 mm below this site. The detail place of hardness measurement was shown together with an arithmetic mean of a value for each place int **Figure 2**. The values of hardness close to the surface are higher than in bulk material [3]. Increase value of hardness was observed closely to running surface that could be impact of decreasing of interlamellar space create by working condition. Approximate range of hardness observed at a running surface was higher than a value 260 to 300 HBS presented by Lukašič [7].

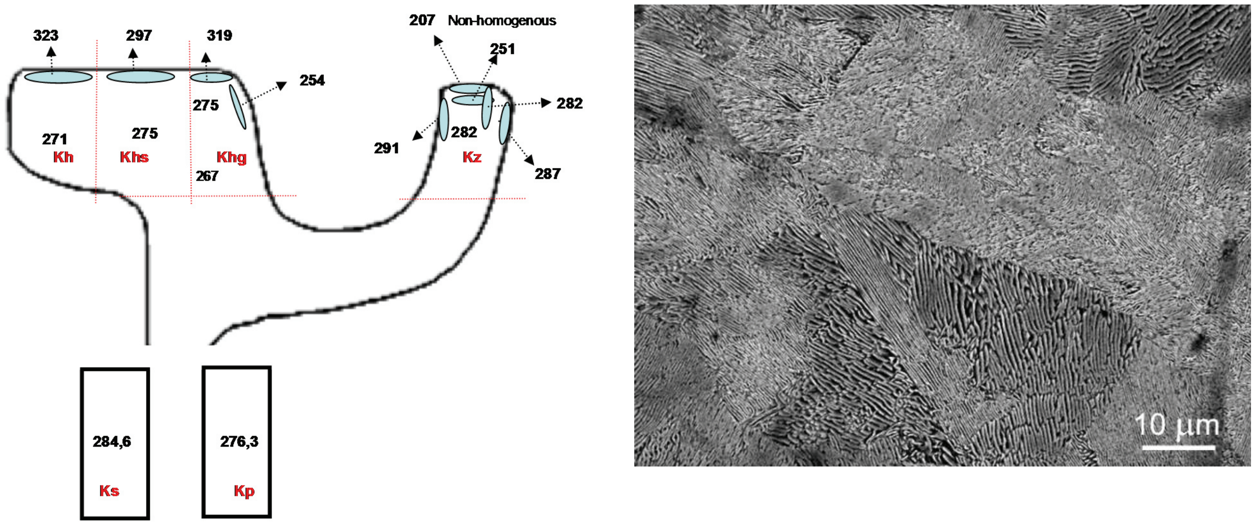


Figure 2 Left: Place and value for measurement of the micro hardness.
Right: fully perlitic microstructure of the rail

The SEM image (**Figure 3**) shown very diverse surface of the rail head. The surface layer containing by EDX analysis mainly iron, oxygen, carbon, silicone, aluminium, cooper and zinc in variable concentration. This result corresponding with XRD analysis, where the main component were α-Fe (60 wt. %), lepidocrocite γ-FeO(OH) (23 wt. %), graphite (13 wt. %), quartz SiO_2 (2 wt. %), goethite FeO(OH) (1.5% wt) and very low concentration (> 1% wt) of hematite Fe_2O_3. The XRD analysis as well as find out another impurity the Copper Acetate Hydroxide Hydrate, which structure model are not available for further quantitative analysis. The potential source of this compound could be brake pads of tramway which contained around 11 wt. % of cooper. The XRD determined in the original material of the rail the ferrite and carbides only.

Mössbauer spectra of the surfaces (~20 micrometer thick) of the original material and the used rail are shown in **Figure 4**. The original material contains ferrite and carbides (Fe_3C and $Fe_{2.2}C$) and also XRD shows the presence the two types of carbides Fe_3C and $(Fe_{1.8}Mn_{1.2})C$ which is in good agreement with the perlite structure showed on metallography pictures (OM+SEM). The phase composition of the surface after using in traffic is changing. Content of carbides is decreasing from 9.7 to 6.6 (in at. %) due to diminishing portion of $Fe_{2.2}C$ carbides. On the other hand the content of alloying elements in ferrite is slightly increasing which can be the result of a partial dissolving of the carbides. In agreement with XRD components belonging to the hydroxides can be found there.

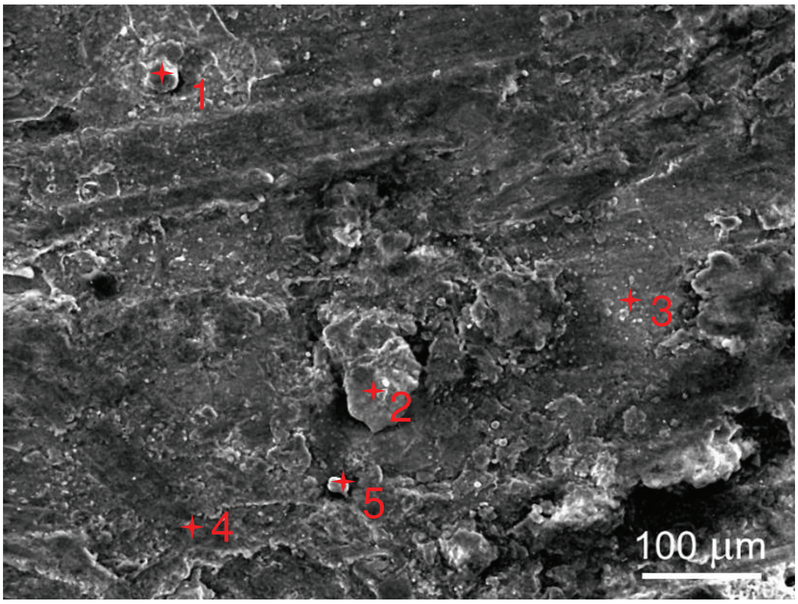


Figure 3 Surface of the rail head with data of EDX analysis. Chemical analysis showed various concentration of Fe (85 - 16%wt), O (27-3 wt. %) and C (17 - 9 wt. %, 0 for point 4) at all point. Other element was also observed: 1 -S and Cl (~1.5 wt. %), 3, 4 - Si (2.7-4.5 wt. %), 5 - Al (1.3 wt. %), Cu (54 wt. %), Zn (11.2 wt. %)

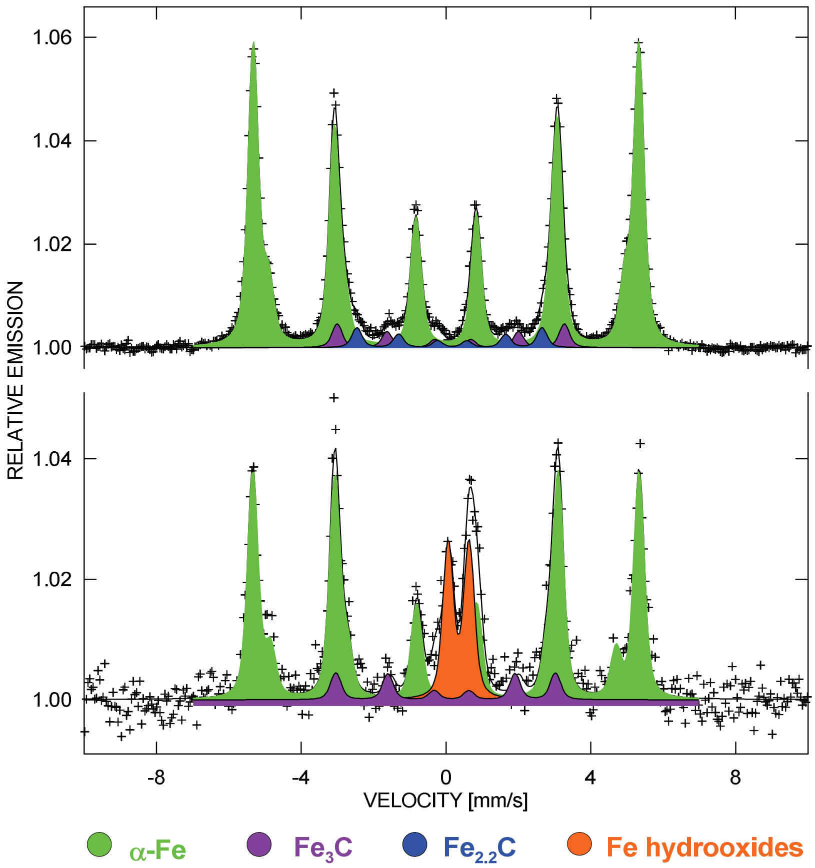
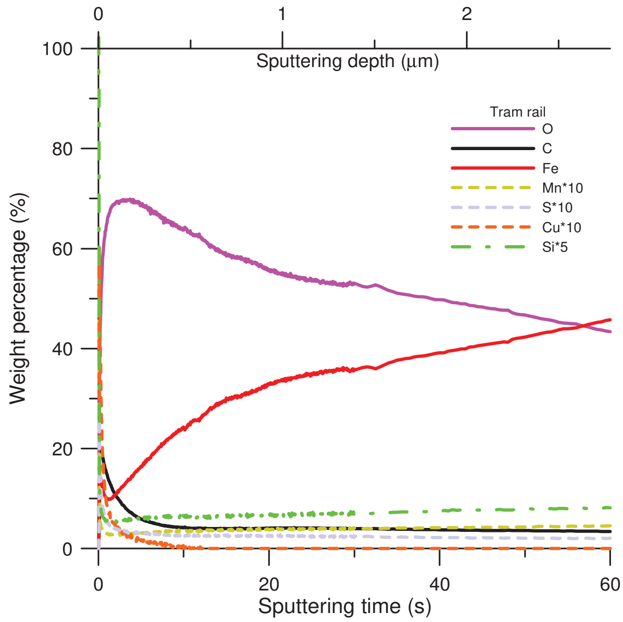


Figure 4 Mössbauer spectra of the surfaces (~20 micrometer thick) of the original material and the used rail

Beside bulk analysis by GDOES also depth profiling was performed. These results have shown change of concentration for chemical elements from surface to depth of material. **Figure 5** had shown the decrease concentration of oxygen (oxides on the surface) with increasing sputtering time. The higher concentration of silicone and carbide was observed close to running surface at depth profile and also by a confirmed by SEM/EDX analysis of surfaces. It could be explaining as contamination from city surroundings.



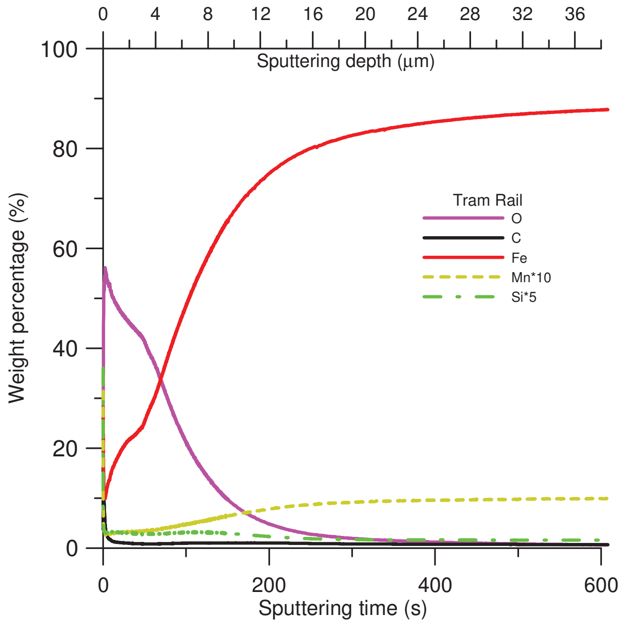


Figure 5 Depth profile from running surface to bulk of the rail head. Left - detail situation at interface running surface and surroundings. Right - longer profile to depth (depth calculate by GDOES software). Concentration of some element was multiply by five (Si) or ten times (Mn, S, Cu) for better recognition.

4. CONCLUSION

The experiment result shows that severe plastic deformation together with thermal shocks by friction processes and influences of surrounding induce changes in structure and chemical composition of the surface layer of rail head. Besides the changes in the grain structure of the original material, XRD and MS results show presence of different type of iron oxides and hydroxides in the surface layer. In addition to copper was identified there by XRD probably due contact with brake pads. The depth profile analysis obtained by GDOES shows an increase in carbon content in the surface layer which can be an effect of up-hill diffusion caused by thermal shocks during braking.

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