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NATURAL AGEING EFFECTS ON MICROSTRUCTURE AND PROPERTIES OF RAIL FASTENING ELEMENTS SKL-12

Summary. Rail transport is presently one of the most supported means of transport in Europe; it existed from the end of the 18th century. However, some issues especially concerning materials and its exploitation are still actual and are a matter of scientific projects or developments. In this paper, analyses concerning the characterisation of used track infrastructure elements in form of sleepers of the popular rail fastening system SKL 12 were performed. Specifically, the main objective of the work was the characteristics of the material microstructure and properties after long-term usage and natural ageing, reaching over a few decades. In this paper was conducted investigations concerning the non-used and used fasteners by reason of classic material research methods. The analysis was carried out based on the results obtained through research using mainly light, scanning electron microscopy (SEM) and transmission electron microscopy (TEM), as well as electron diffraction for the lattice structure determination, EDS chemical microanalysis and Rockwell hardness testing were also carried out in terms of identification of the chemical analysis changes that occurred after long-term application. The main reason was to characterise the long-term usage for

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the microstructure changes on the surface layer of the used fasteners compared to newly produced material.

Keywords: microstructure, rail fastening system, sleepers, mechanical properties, rail steel, electron diffraction

1. INTRODUCTION

This work is in the mainstream of current activities to analyse the quality of materials leading to improvements not only in the quality of the material itself but also to streamline production, reduce susceptibility to damage, increasing the economic factors of the product use and other aspects of the material, that is, its processing and usage.

A rail fastening system is a means of fixing rails to railroad ties (United States) or sleepers (international). The terms rail anchors, tie plates, chairs and track fasteners are used to refer to parts or all of a rail fastening system. Various types of fastening have been used over the years. Their role is to keep the rails on the sleepers and ensure that rails have an adequate tilt angle. Among the types of rail track fastening can be distinguished such types as [1-3]:

- direct fastening (screw spike, rail screw or lag bolt),
- screw fastening of the K type,
- spring spikes or elastic rail system SKL 12,
- elastic fastening SB – 3, SB – 4, SB7.

The least frequently used fastening is the direct fixing, which is only applicable for low-speed trains, because at higher speeds they will loosen the screws and also if the rails are badly fixed. Fastening of this type do not provide adequate clamping rail to the sleeper, therefore, it is not suitable for standard rail. All these disadvantages are eliminated in the elastic fastening, however, one thing that should be investigated is the use in a long term perspective concerning the stability of the obtained microstructure and properties.

While the fastening screw - elastic system SKL 12 is a modern solution for rail elements fastening. Thanks to the application of the elastic system, vibrations are effectively absorbed. This is a universal system for fastening of wood, steel or concrete blocks. The most modern solution is the application for fastening of prestressed concrete to the sleepers. They are easy to install, decrease vibrations and act as electrical insulation [4-7].

However, even in an innovatory fastening solution, there are several issues, which should be monitored and/or improved. One of them is the long-term durability of the microstructure obtained after the production process, as well as the mechanical properties stability.

For this reason in this paper are presented basically, the investigation results of a structural element used in rail transport, which is the elastic track fasteners as a part of the SKL 12 rail fastening system. During the development of the rail transport system, changes occurred not only in the drive methods by which the railway machines were moved but also in improvement in the rail infrastructure as well. In this work are presented particular investigations concerning the research about the structure and properties, which have been subjected to the material obtained from a used as well as non-used SKL fastener (obtained from the Gliwice Railway Station during its renovation), after few decades of usage. Samples of the material passed through a series of laboratory tests such as ordinary light microscope examination, scanning electron microscope microstructure evaluation (SEM), transmission electron microscope (TEM), chemical microanalysis testing (EDS) and measurement of

Rockwell hardness. This work is placed in the mainstream of current activities to analyse the quality of materials leading to improvements not only of the quality of the material itself but also to streamline production, reduce susceptibility to damage, increase the economy of use of the product and other aspects of the material and its processing or application [7-8].

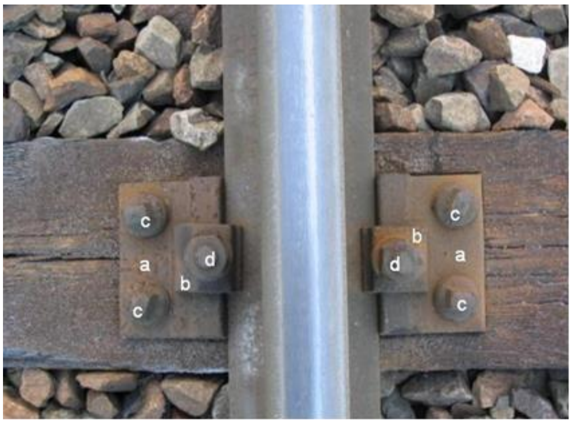

Fig. 1. Screw fastening of the K type, a-the rib plate, b-trap hook, c-fastening screw of the rib plate, d-bolt with nut [3]

Fig. 2. Spring spikes or elastic rail system SKL 12, a-ribbed plate, b-screws that secure the backing plate rib, c-hex nut, d-elastic clip SKL 12 [3]

2. INVESTIGATION PROCEDURE

The analysis of changes in the material of the elastic fastening element SKL 12 and comparing the results to the state of a new element not used in railway transport was based on microstructural analysis as well as mechanical properties investigation. From each of them was cut off 6 samples-longitudinal and cross-section (12 samples, Fig. 3a), which are then mounted and prepared for further studies. The samples were tested for the reason of comparing the corresponding pair in terms of their microstructure and properties as well as changes that occurred during long-time usage under real conditions. The following investigations were particularly carried out for the purpose of investigating the microstructural changes that occurred after the long-term use of the rail steel fasteners:

- light microscope - comparison of the macrostructure of the material obtained from samples taken from the used and non-used fastener, the samples have been cut in the same adequate places in the horizontal and longitudinal direction, polished and then etched in 10% nital in room temperature,
- scanning electron microscope (SEM) – comparison of microstructure,
- transmission electron microscope (TEM) – determination of the structure in nanoscale,
- chemical composition investigation using the EDS method - an analysis of possible changes occurred in the chemical composition of the used material,
- optical emission spectroscopy using the Stationary Metal Analyzer SPECTROLAB type LAB 05 according to the PN-H/04045 for exact analysis of the chemical composition,
- Rockwell hardness measurement – analysis of micro-hardness measurements,
- comparison and analysis of changes occurring after usage of the SKL 12 fastener.

3. MATERIAL FOR INVESTIGATION

A new elastic fastener SKL 12 as well as a ca 40 years used fastener SKL 12 obtained during the repair work of the railway station in Gliwice were as materials for these investigations (Fig. 3b). According to the standard EN 10089:2002 the steel 50S2 is named as 46Si7 with the chemical composition presented in Table 3. Steel 50S2 is the most commonly used steel to produce elastic rail fasteners. It is characterised by a yield point equal or higher than 1080 MPa, tensile strength equal or higher than 1280 MPa, an elongation equal or higher than 6%, and a waist equal or higher than 30% (data presented for room temperature). SKL 12 fasteners should have a downforce of about 8 kN, while the deformation of the central part should not be higher than 1 mm [4].

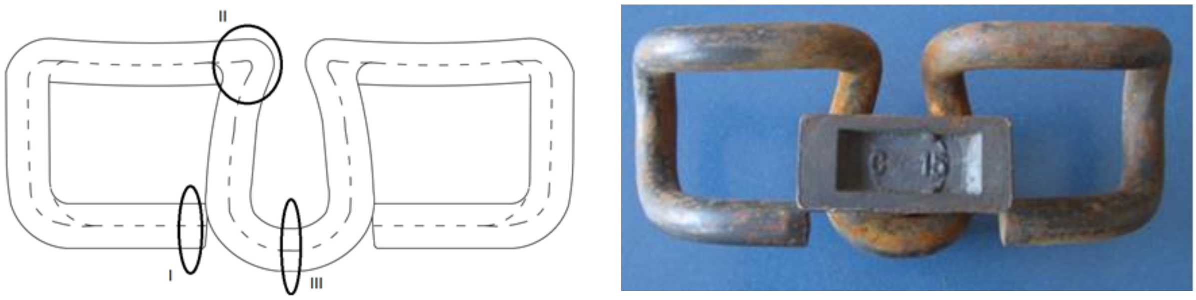

Fig. 3. The investigated fasteners of the SKL 12 system (a),
places chosen for microstructure and hardness analysis (b)

Tab. 1

Chemical composition of the steel 46Si7 according to the PN-EN 10089 standard

Element	Concentration, min. vol. %	Concentration, max. vol. %
C	0.42	0.50
Mn	0.50	0.80
P	-	0.025
S	-	0.025
Si	1.50	2.00

The technological production process of the SKL 12 fasteners consists of eight steps according to data obtained from the producer:

- cutting - drawn rods with a diameter of ø13 are cut by guillotine at parts wit a length of approximately 514 mm,
- cold flat bending – bending takes place in two steps on a hydraulic machine,
- cleaning – the rods are treated in a shot-blasting machine for about 3 min,
- resistance heating – the process of resistance heating takes place at 750-800°C in the resistive heater,
- spatial bending – bending of the rods is carried out on a high-speed hydraulic one rack press marking using an eccentric press,
- heat treatment – the heat treatment of rods consists of quenching for 35 min at 860°C, with cooling in polymer, and annealing for 55 min at 450°C with cooling in the water,
- deposition of a protective coating – a protective coating in the form of a cataphoresis with a minimum thickness of 20 μm, which is applied at a temperature of 350°C. The coating thickness should be about 50 microns.

Heat treatment of the SKL 12 fastener. The elastic SKL 12 system in one of the final stages of its production was subjected to hardening and tempering. In the case of hardening, present in the microstructure of the fasteners was the formation of fine-grained pearlite and martensite, with a content of at least 97.5%. A sorbate structure was present after tempering.

4. INVESTIGATION RESULTS

At the beginning of the investigations, the chemical composition was analysed in order to determine the material property in terms of alloying additives (Table 1). The measured values slightly differs from the PN standard additive concentrations of the investigated fasteners, especially the carbon concentrations, which is higher and exceed the standard value of more than 25%. Worth mentioning is the fact that the phosphorus and sulphur content is below the permissible content defined in the standard, hence, the quality of the original material was ensured, and the higher carbon content could be caused by the long term usage reaching even 30 years.

Tab. 2

Chemical composition analysed using the emission spectrometer according to the PN-H/04045 standard.

Chemical composition, vol.%									
element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Concentr., min-max	0.562-0.569	1.65-1.70	0.699-0.706	0.001	0.0133-0.0186	0.0705-0.0728	0.0783-0.0876	0.0942-0.0959	0.0020-0.0228
Element	Co	Cu	Nb	Ti	V	W	B	Fe	
Concentr., min-max	0.00515-0.00774	0.149-0.153	0.00182-0.00273	0.00692-0.00725	0.00236-0.00349	0.006	0.001	96.59-96.70	

For microstructure, investigations from each fastener were taken six samples from different places presented in Fig. 3a, both in the longitudinal and cross-section direction. After cut off of the sample material, the first study was related to a simple analysis of the microstructure using light microscopy. Figure 4 shows the results of the structure analysis of the elastic SKL 12 fastener carried out on a light microscope. On the obtained images is shown a clearly visible perlitic-martensitic microstructure, both in the used and non-used material. Between diverse locations of the sampling collection, the samples revealed no major differences. Only the sample take from point III had smaller grains, whereas in the sample No. I are more microstructure discontinuities.

Additionally in the microstructure of the long-term used material are found slightly dark coloured places of some impurities and many discontinuity places were revealed, so this material is not of the best possible quality. This indicates low-grade steel used for the production of elastic tabs SKL 12 in the past decades (Figures 4b, d, and f). The measured grain size of the material ranges from 8 to 10 μm.

The microstructures presented on Figures 4d, e, and f of the used elastic SKL 12 fastener shows a higher degree of complexity in terms of the size of the martensitic areas compared with the non-used fastener. This is probably due to the slightly different heat treatment as well as some more amount of impurities. The detected amount of the microstructure discontinuity is also higher due to the lower material quality. The measured grain size of the new fastener range from 10 to 12 μm. In addition, small precipitations can be seen especially in Figure 6b. In the new fastener material was also detected a higher grain size variations compared to the used fastener material.

Based on the light microscopy analysis of the microstructure of the fastener surface located on the protective coating was revealed the structure of the upper surface area in the new SKL12 fastener, consisting of a ferrite mesh, which is characteristic of this type of railway fasteners material (Figs. 5a and b). In the microstructure are highly visible changes that occurred after carburizing and application of cataphoresis of the material surface during the manufacturing process of the fastener. The ferrite area is visibly very clear, the closer the surface of the material, the more compacted and structured it is, and the deeper into the material, the more visible the so-called ferrite grid. The grid is typical of ferrite in the steel, which contains about 0.6 to 0.7%, and has the form of a clear mesh that surrounds the perlite grains. The visible surface of the material is smooth and consistent. Generally, it can be seen that the microstructure of the sample in the place No II and III reveals a clearly visible ferrite grid compared to other places in the fastener, especially on the end part of the fastener (place No. I), where the grid occurs in a residual form.

In Fig. 5b, there is presented the material structure taken from the elastic SKL12 fastener, which was used, can be observed a smaller area of the ferrite grid compared to the new fastener material. In Fig. 5b there are only remnants of the ferrite grid. More so, it can be noticed that the surface of the material has significant corrosion signs, which proceeds to the core material. Additionally, in the microstructure of both the new and used fastener material can be recognised some precipitates in the steel microstructure of the size of ca. 5 μm.

Another investigation method, which was used for the microstructure analysis is scanning electron microscopy. In Fig. 6 are presented microstructures obtained during the examination of samples from the non-used and used elastic tabs SKL 12 fastener. In these structures is very visible the fine-grained martensite present in this investigated railway steel, used for the production of the SKL12 elements. The non-used material samples contain almost no precipitates in the micro-scale, the entire microstructure in all the investigated places is relatively homogeny with minor changes only resulting in a slightly different size of the structure compounds. Within the sample structure are not detected any impurities.

The grains of the used material are slightly elongated compared to the non-used fastener material. In Fig. 6c, some impurities are visible, as well as precipitate particles. Compared with the new fastener, the grains are also more densely distributed within the material.

According to the EDS investigation results, which states the changes that have occurred within the material compared between the sample material obtained from the non-used and used SKL12 fastener. The most important issue is the change in the chemical composition of the material phases occurred as impurities as well as intermetallic phases or precipitates. Figures 6a and d show the elements detected in the sample from the non-used 6a and used 6c. The used material sample (Fig. 6c, point No. I) reveals numerous precipitates, consisting from the following elements such as O, Mg, Al, S and Ca (Fig. 6d).

Based on Rockwell hardness measurement, comparing the data from the producer, the hardness value of the material should be in the range 42-46 HRC. Figure 9 presents the results obtained for each sample. The measured average hardness of the non-used elastic SKL12 fastener is equal 48 HRC and in used element 45 HRC. Both values are within the established properties of the 50S2 steel, as the material for the SKL 12 fastening system. The analysis of the results reveals that the mean hardness value of the non-used fastener and the used one is very similar, and does not exceed 3%, however, with different distribution along the entire element.

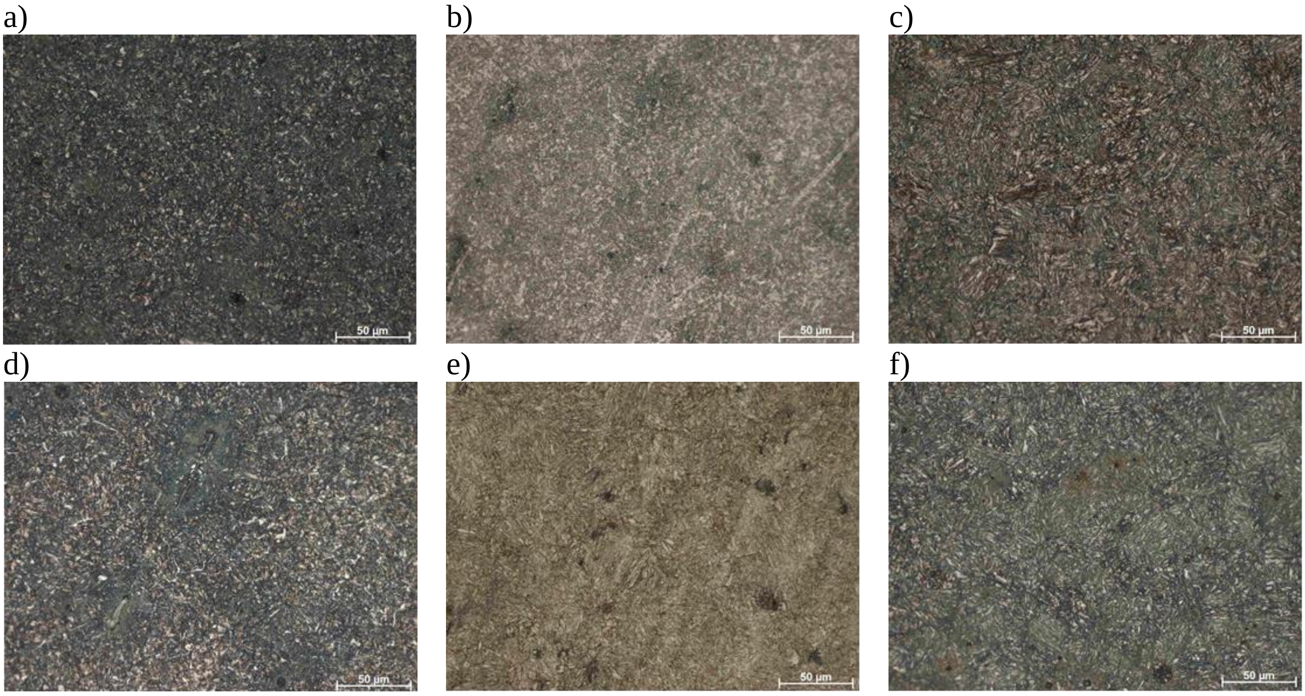

Fig. 4. Microstructure of the non-used: a), b), c) and used d), e), f) fasteners of the SKL 12 system, depending on the sampling place and direction, where: a) is from place no. I in Fig. 3a; b) is from place II in Fig. 3a and c is from place III in Fig. 3a

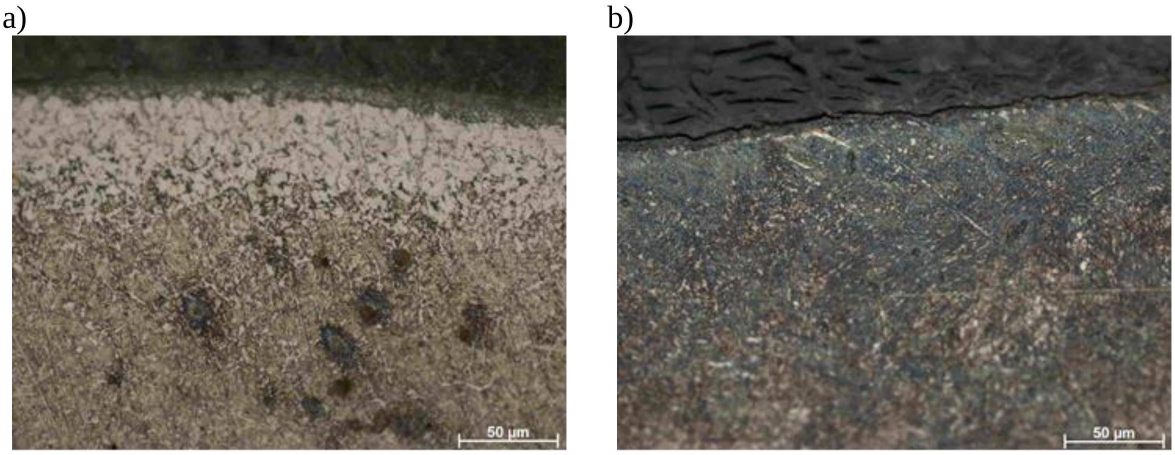

Fig. 5. Microstructure in the cross-section of the surface layer of the non-used (a), and used fasteners (b)

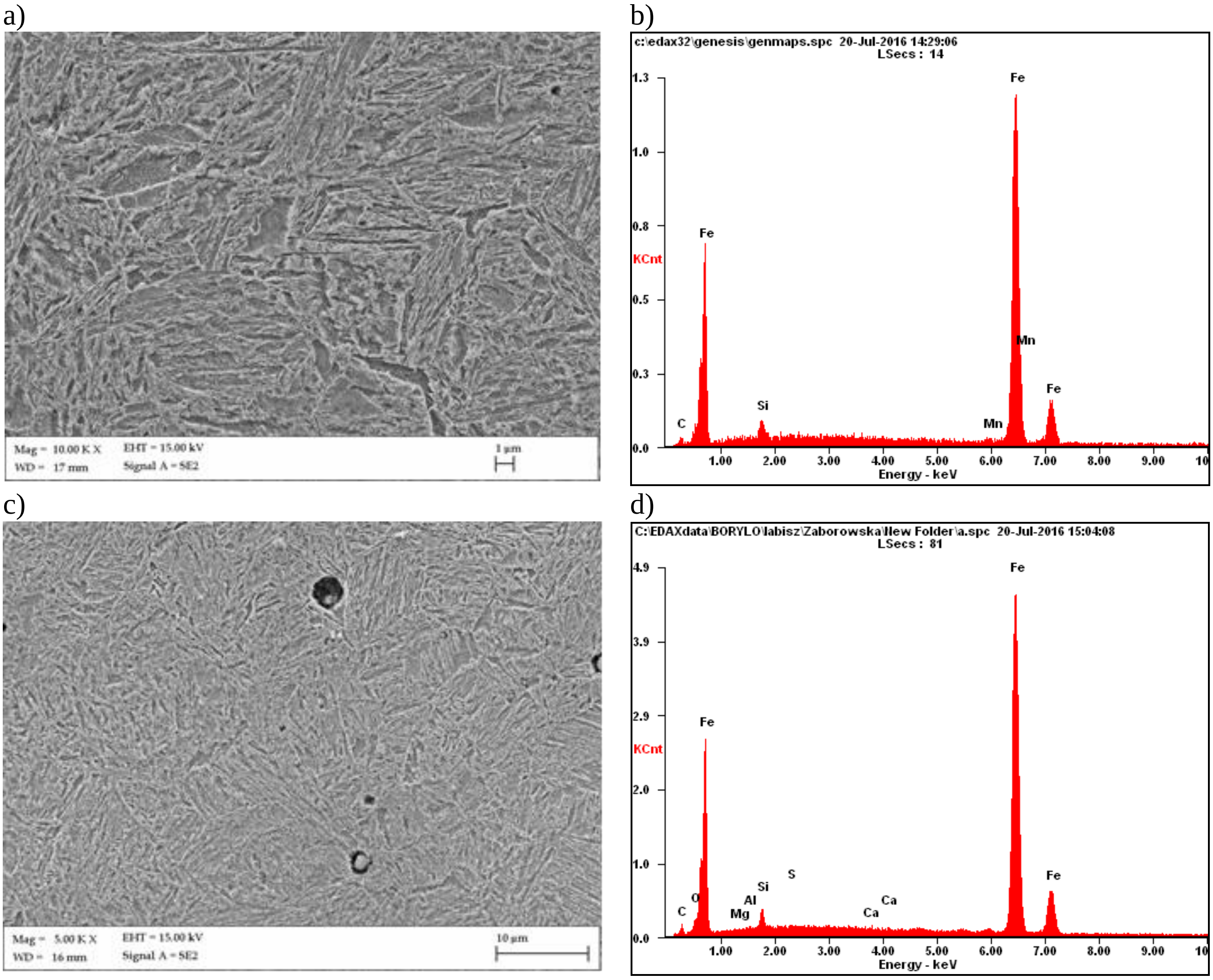

Fig. 6. Microstructure and the corresponding EDS area microanalysis of the non-used: a), b) and used c), d) fastener microstructure, carried out in point III (Fig. 3a), SEM

The final investigations concern on examination of the SKL 12 fasteners using the TEM microscope. On Figs. 7 and 8 are presented test results for the new as well as used element, carried out in the bright and dark field technique for revealing the structure in the nanoscale. The crystallite size estimated from the obtained images is about 0.15 - 0.2 μm. In addition, diffraction investigations were performed both for the used and non-used fastener for determination of the d-spacing (Figs. 7c, d and 8c, d) presenting the SAD diffraction patterns in the [220] and [100] zone axis as well as the solution of this diffraction patterns. Based on the interplanar distance calculations, it was found that there occur a small difference in the (00-1) plane for the used fastener, reaching 0.51%.

In the material of the used SKL 12 fastener was revealed a crystallite size of approximately 140 - 210 nm. It can be seen that in the material of the used SKL 12 fastener, there are compounds of inclusions or contaminations, especially in the non-homogeneous areas of the surface layer, which may come from the low quality of the steel (Fig. 8a). For the sample of the used 50S2 fastener, were calculated the d-spacing values for alfa ferrite Feα and diverse plains occurred in the electron diffraction pattern and compared to the theoretical values (Table 3).

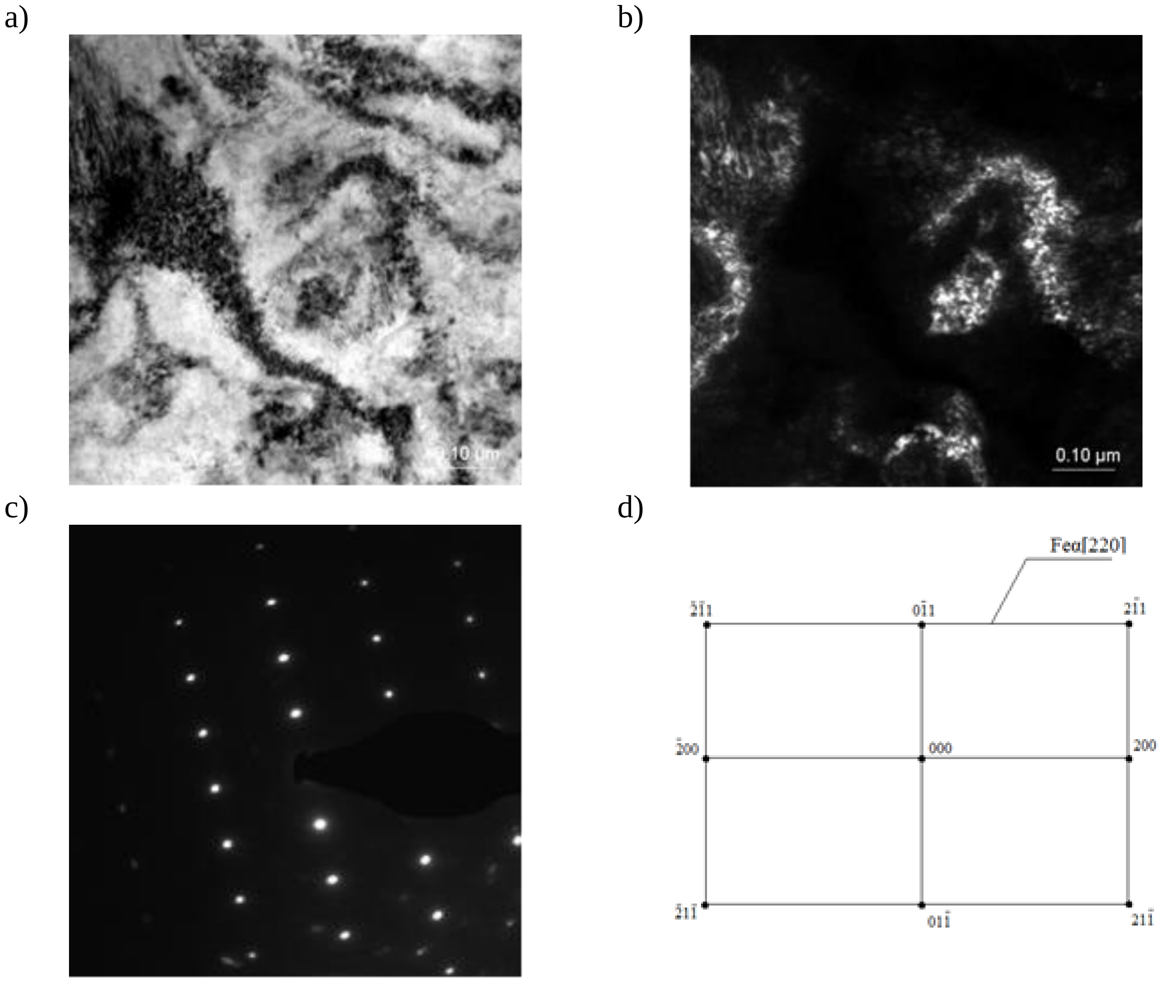

Fig. 7. Structure of the steel 50S2 from the non-used fastener: a) bright field, b) dark field, c) SAD electron diffraction pattern, d) solution of the electron diffraction, Fe_{α} phase, zone axis [220]

Tab. 3

D-spacing of the ferrite Fe_{α} phase, zone axis [100] and [220]

plane	hkl	d_{exp}[Å]	d_{teor}[Å]
Used fastener			
1	00-1	2.0371	2.0268
2	002	1.4267	1.4332
Non used fastener			
3	011	2.0294	2.0268
4	002	1.4356	1.4332

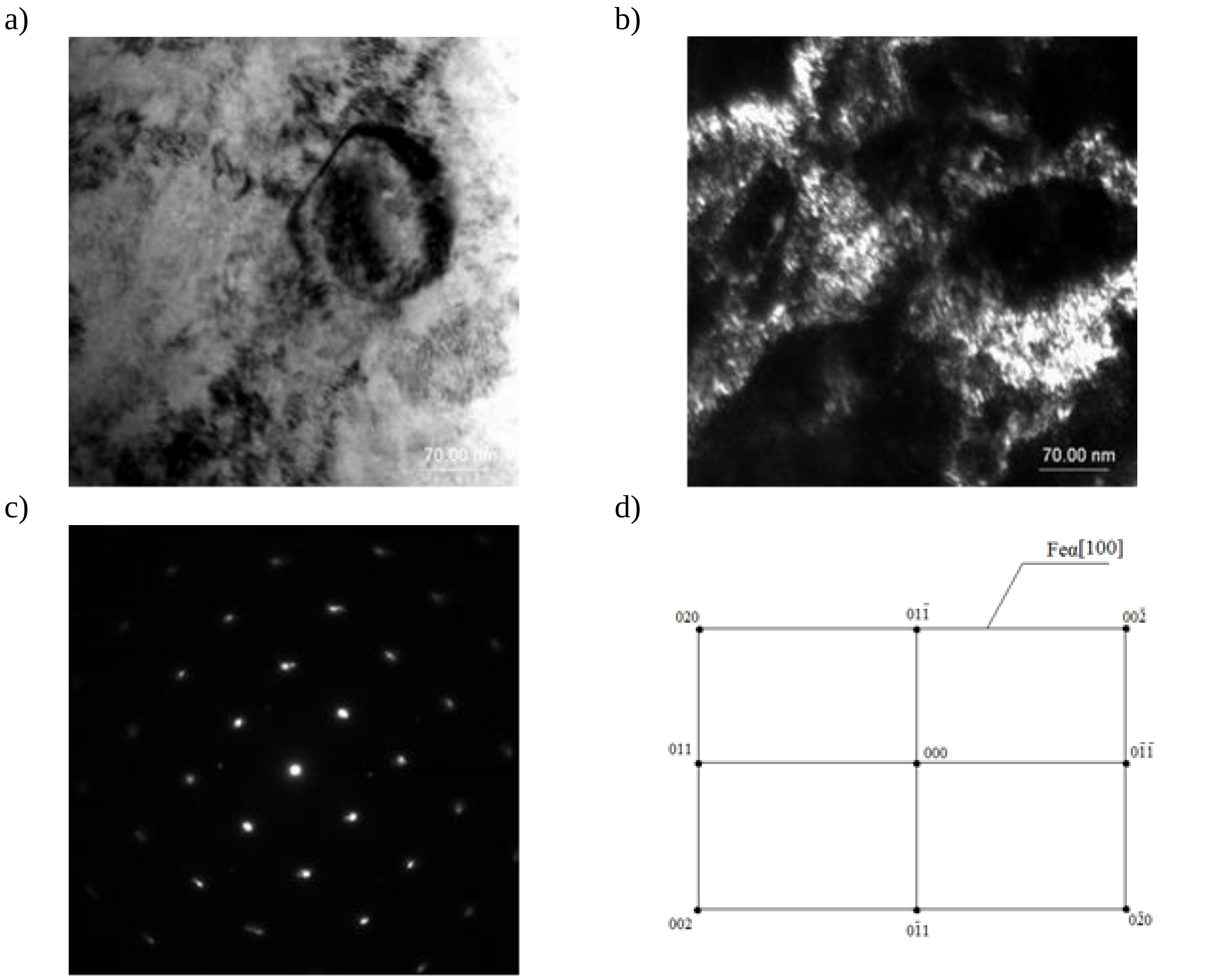

Fig. 8. Structure of the steel 50S2 from the used fastener: a) bright field, b) dark field, c) SAD electron diffraction pattern, d) solution of the electron diffraction, Fe_{α} phase, zone axis [100]

5. CONCLUSIONS

Summarised, it can be concluded that the material from which the elastic SKL12 fasteners are produced reveals lower quality as it can be confirmed based on the occurrence of structural compounds affecting microstructure and properties. The changes can be observed in terms of the microstructure, where the minor amount of the ferrite mesh at the surface of the material used for few decades due to the wear process of the surface as well as the production process parameters. The research hypothesis was confirmed, the material of the elastic fastener revealed significant damaged and appearing in the microstructure, numerous changes such as the presence of impurities, decrease of mechanical properties and the occurrence of not desired intermetallic phases and/or precipitates. In addition, it determined that the sample material, which was produced a few decades ago, to be of low quality. Particularly, the following issues were found:

- the study of mechanical properties suggests only a slight change in hardness between the material of the non-used and the used SKL 12 fastener. For the non-used elastic SKL 12 fastener, the determined hardness is 48 HRC and for the used element 45 HRC, which is generally in the range of the allowed measurement error. Therefore, the analysis of the presented hardness measurement results draws the conclusion that the long-term usage of the SKL 12 fastening system does not affect the material in any significant way, ensuring originally of the values obtained;

- the occurrence and influence of additional elements, mainly in form of impurities measured by reason of the chemical composition on the hardness in only minimal. However, its impact of the microstructure in form of discontinuities can be crucial for long-term application, and special care devoted to the quality of pure material used for the production of the fasteners is very important;
- diffraction tests based on the Fα phase parameter calculation allowed the determination of the interplanar distances (00-1), (002), (011), (002) of the tested materials. Based on the conducted analyses, differences of 0.51% in the d-spacing parameters were found between the experimental d-spacing value and the theoretical interplanar distance for the (00-1) plane;
- the structure of the non-used elastic SKL12 fastener occur a clear ferrite mesh in the top of the surface layer reaching a depth of 100 μm. However, in the used elastic SKL12 fastener, the ferrite mesh has a residual character and reaches a depth of about 5 μm only;
- the results of the tests carried out by reason of optical microscopy show that the particle size of the non-used elastic SKL12 fastener reaches from 8 to 10 μm, whereas in the used elastic SKL12 fastener, the grain size ranges from 10 to 12 μm, depending on the measurement place in the fastener.

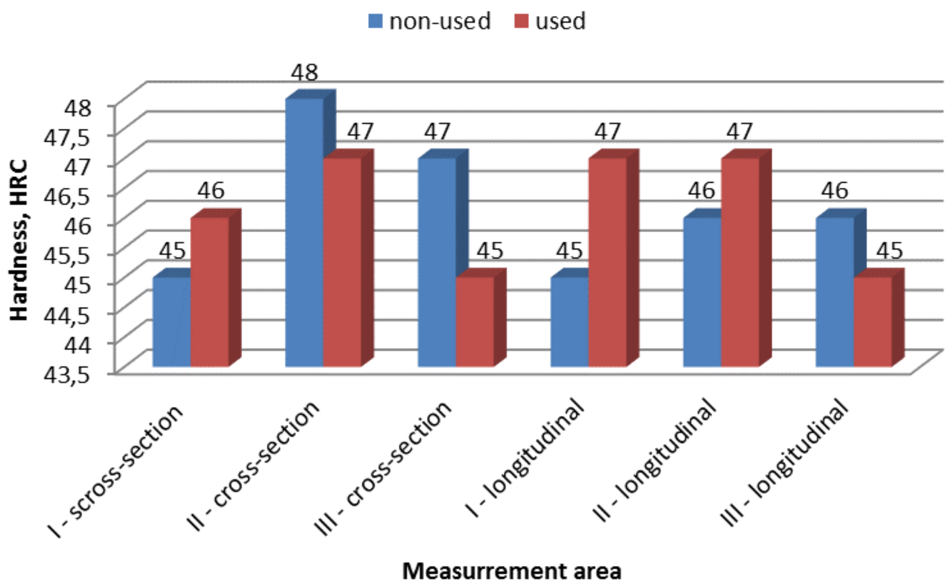

Fig. 9. Hardness measurement results for the chosen places of the fasteners

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