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INFLUENCE OF MnS INCLUSIONS IN STEEL PARTS ON FATIGUE RESISTENCE

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This paper presents examinations, checks and tests made on train axles in order to establish the mechanism and causes resulting in breaking after a short period of operation. Researches included analyses onto breaking surface and adjacent area of this, consisting in macroscopic visual examination, microscopic examination of fracture surface of the material and its adjacent area by optical stereomicroscopy and scanning electron microscopy (SEM) at low magnification and investigation of the material by energy dispersive X-ray microanalysis (EDX) for micro scale composition.

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1. Introduction

Mechanical properties of steels are highly damaged by nonmetallic inclusions, because they are discontinuities in the metallic mass reducing active section, are local power concentrators, reducing the mobility of dislocations and having indenture's effect [1,2]. Nonmetallic inclusion has the ability to be crack primers and reduce the strength, plasticity, toughness, resistance to fatigue, corrosion, wear and weld ability.

Mechanical properties are influenced by quantity, chemical composition, shape, size and mode of distribution of nonmetallic inclusions [3].

Properties are negatively influenced by the intercrystalline inclusions and also by the coarse intercrystalline inclusions which are in higher concentrations. Plastic inclusions keep a better grip on the request matrix. The hard inclusion, especially the rough oxide inclusions favors local concentrations of stress and the occurrence of cracks. Crack propagation speed is influenced by the nature of inclusion: the fragility, which can be broken by the stress field, forming secondary cracks and accelerating crack propagation. Hard inclusions that remains supportive on the matrix, decreases velocity of the crack propagation [4].

Thermal contraction difference between the mass and inclusion, especially hardening can lead to the emergence of fields of stress or structural discontinuities [2,3]. Thus, if the contraction coefficient is low compared with the matrix (Al_2O_3, Cr_2O_3 on steel) appear tension fields on the surface of inclusion, if it is high (MnS, MnSe on steel) vacancies appear, with especially negative action on fatigue resistance [5,6,7].

MnS inclusions have high melting temperature (1610^{o}C) and these are a form of primary idiomorphic crystals [8].

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2. Experimental

Researches carried out to establish the causes that led to the axle breaking, the analysis focused on breaking the surface and its adjacent area and consisted of:

- Macroscopic visual examination by optical;
- Microscopic examination of fracture surface of the material and its adjacent area by scanning electron microscopy (SEM);
- Investigation of the material by energy dispersive X-ray microanalysis (EDX) for micro scale composition.

The morphology and structure of the analyzed samples were made with X'Pert PRO MPD PANalytical X-ray powder diffractometer, with X-ray tube anode Cu, $K\alpha$ radiation (λ = 1.54065 Å) with the 2θ range from 10^o to 90^o.

Scanning electron microscopy (SEM) investigations were performed with a Quanta INSPECT F microscope equipped with field emission gun (FEG) at a resolution of 1.2 nm and EDX with the resolution for $MnK\alpha$ of 133 eV.

3. Results and discussions

Macrovisual examination of fracture surface of axle shaft shown in figure 1 presented fracture surface, composed from fragments (samples), cut from the section of shaft in the form of a disk, containing the fracture surface.

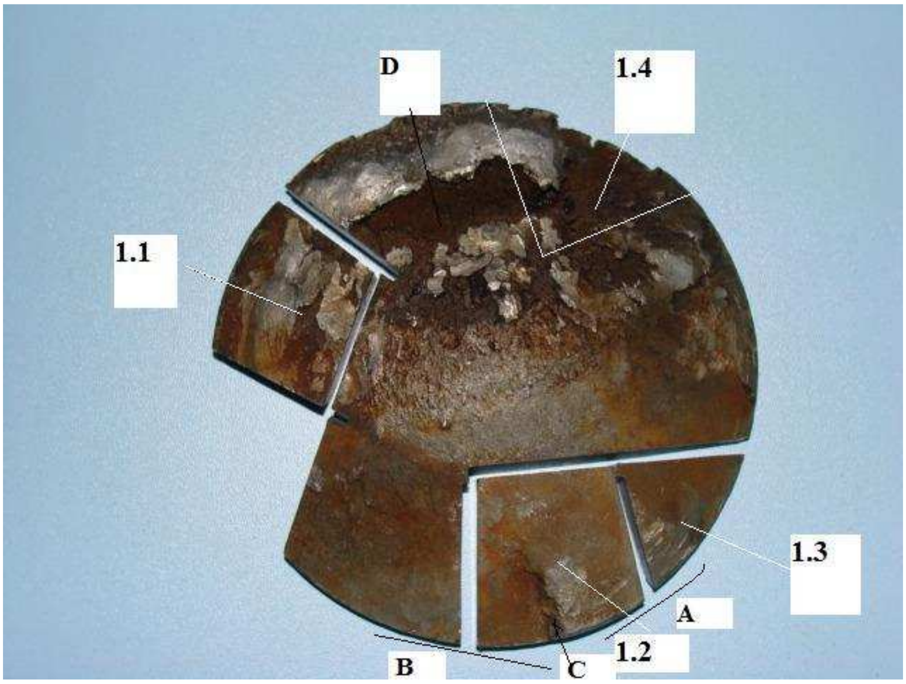

Fig. 1. Aspect of fracture surface of axle shaft

Fracture surface aspect is characteristic of a fatigue fracture process with multiple primers. Damage of both breaking surface and edge breaking surface (outside the zone) that took place during the train accident event or in the process of sampling and evidence preservation does not allow clear identification of the percussion break.

Surface aspect suggests that the initiation of the breaking process had appeared first in area A (very damaged) and then in area B.

Both breaking processes met in the threshold C, which separates them through level differences. Towards zone D, fracture surface becomes more uneven, which suggests the fracture propagation speed increases until the zone D, where the final rupture took place, with uprooting of material.

Microscopic examination realized on scanning electron microscopy lead us to microstructure characterization of material and establishes the nature of material weakness (inclusions, thermal influence) using energy dispersive X-ray microanalysis (EDAX) allowing determination of local micro – chemical composition and significant elements distribution interesting micro regions [9,10].

Scanning electron microscopy image (Figure 2) shows a part of the fracture initiation from zone B. In point E (probably one of the primers) existence of visible mechanical damage prevents identification of the primer. We can see the existence of fronts F1, F2, F3 of changing the propagation fracture rate, characteristic of a fatigue fracture. The edge zone corresponding to circumference of the shaft is deformed mechanically, on a depth of about 0.3-0.4 mm (probably after the rupture on shaft axle) showing cracks and even separation of material to the inner area of the breaking surface.

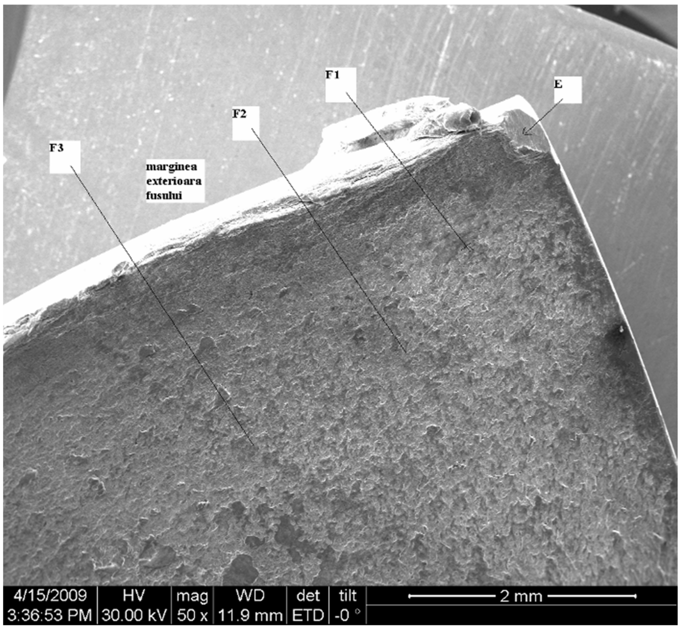

Fig. 2. Microscopic image of the fracture initiation zone

In figures 3, 4 and 5 we can clearly see microstructure details of the micro – area presenting a variation in diameter of the axle shaft in the breaking zone. Marginal area which corresponds to the narrow zone of the section presents characteristic microstructure aspects of a region with local molten material, with the ferrite – pearlite grains growth directions perpendicular on the longitudinal axis of the axle.

Solidification fronts are seen and the existence of micro – cracks in the material from this micro – area.

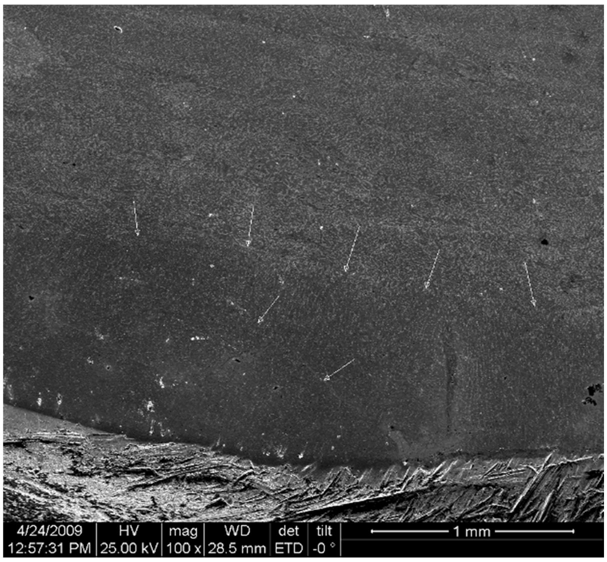

Fig. 3. Marginal area, highlighting areas of molten material. Arrows indicate the start of the front lines of solidification

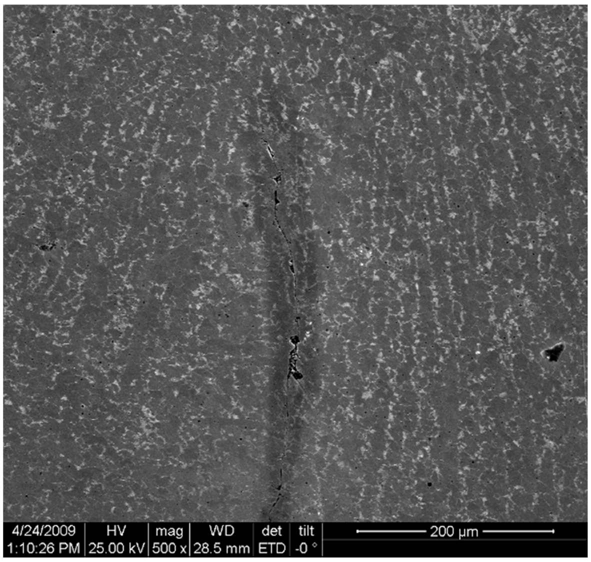

Fig. 4. Crack parallel with the solidification temperature gradient. Is observed the oriented nature of the material solidified structure

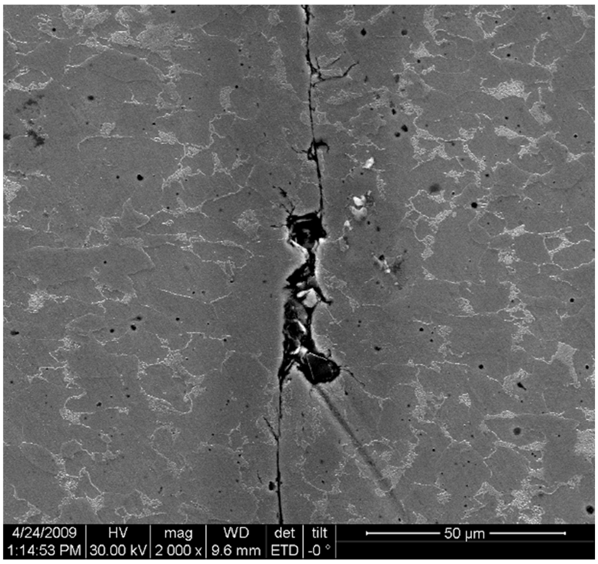

Fig. 5. Emphasizing higher-order enlargement of the crack propagation intragranulare.

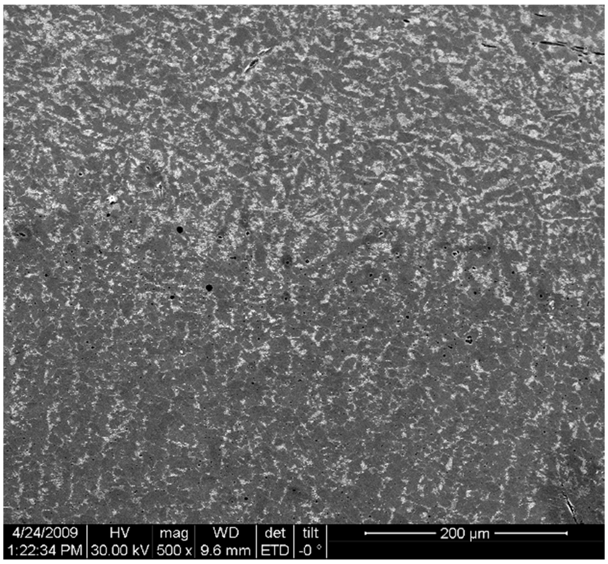

Fig. 6. Image obtained on the transition from the base material to the molten material.

In figure 6 we can observe the orientation differences of the structural formations but also a lower proportion of pearlite in the molten area (due to loss of carbon). We can also observe pores and micro inclusions at the interface between the two volumes of material.

The axle shaft base material microstructure is shown in figure 7 and 8. The microstructure is oriented in bands, rich areas in pearlite alternating with the areas in ferrite. Also are observed the MnS plastic inclusions elongated in the direction of deformation.

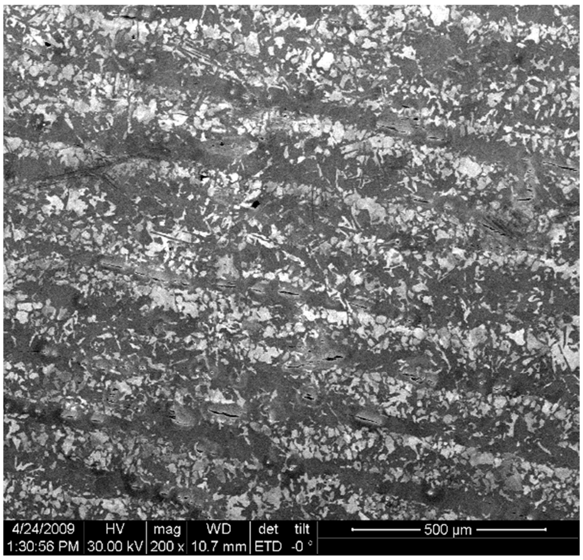

Fig. 7. Microstructure from the base material of the axle shaft.

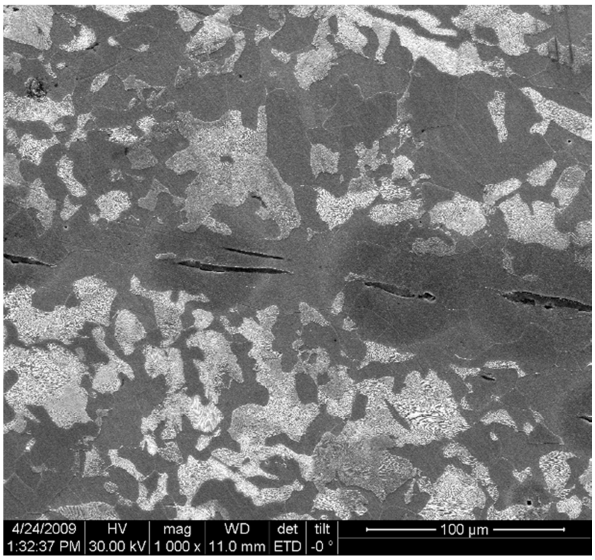

Fig. 8. Detail of image shown in fig. 7. Inclusions arranged in the direction of plastic deformation.

In the thicker zone, is observed a folded of material (on the circumference of the zone) to the fracture surface (figure 9). Scanning electron microscopy images from the figure10 and 11 reveals clearly elongated microstructure (flow) to the fracture surface.

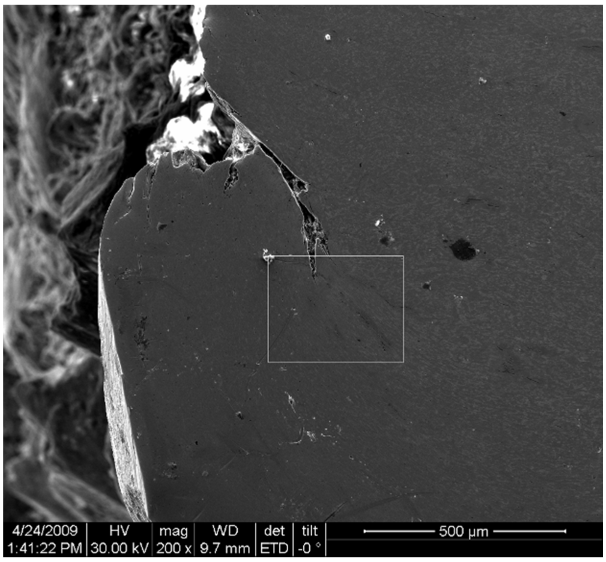

Fig. 9. „Folding" of material observed near the fracture surface.

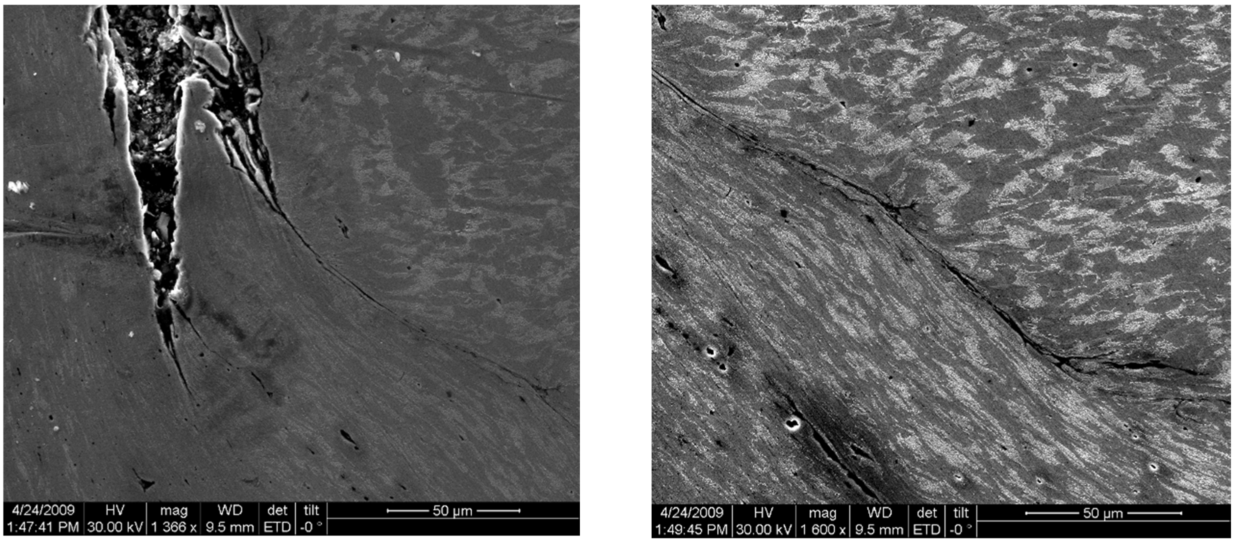

Fig. 10. Details of the selected area in the image of fig. 9 – volumes of material with different flow directions.

X-ray microanalysis performed on micro area of local melting, micro area of folding the material and the base material (inside micro area) to axle shaft showed no micro structural differences between these micro regions.

Characterization of material microstructure in the adjacent area of breaking surface was performed on the sample 2.1, figure 11.

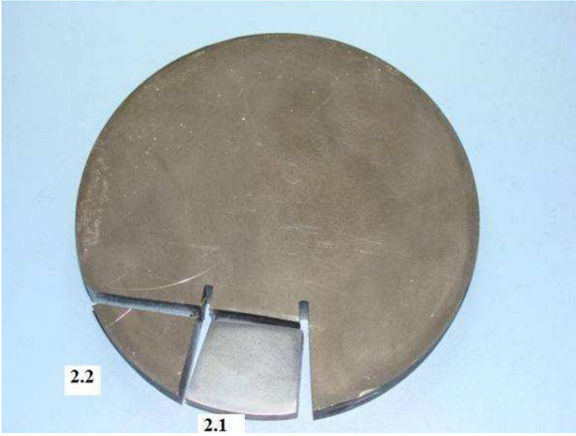

Fig. 11. Transversal cutting disc from shaft near the surface rupture

Images from figure 12 – 15, are images of secondary electrons, presents the material microstructure obtained on the sample 2.1, from figure 11. The existence of MnS inclusions unevenly distributed in the material is remarkable, on the feritte-perllite microstructure background. Unfavorable to its mechanical properties, these inclusions are typically grouped in discontinuous networks. We observed also the rows of MnS inclusions existence, which arrive in the axle shaft surface. Such marginal inclusions may be percussion break of those parts that are in service, rows of inclusions that emerge in the area are preferred regions of propagation and development of microcracks.

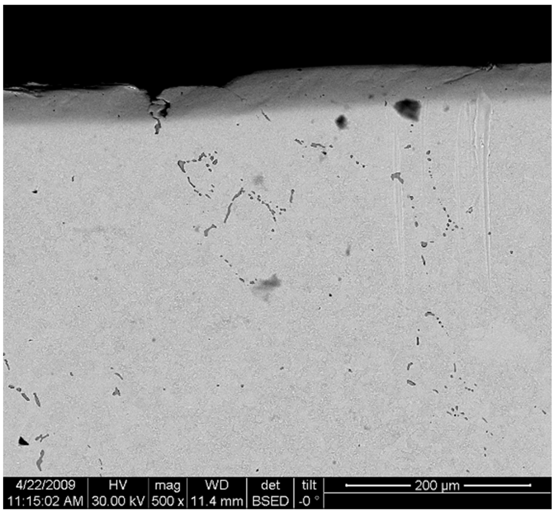

Fig. 12. Microstructure of axle shaft (image of secondary electron), cross section on shaft. MnS inclusions in both isolated and discontinuous networks, number of inclusions MnS come out in the outer edge of axle shaft.

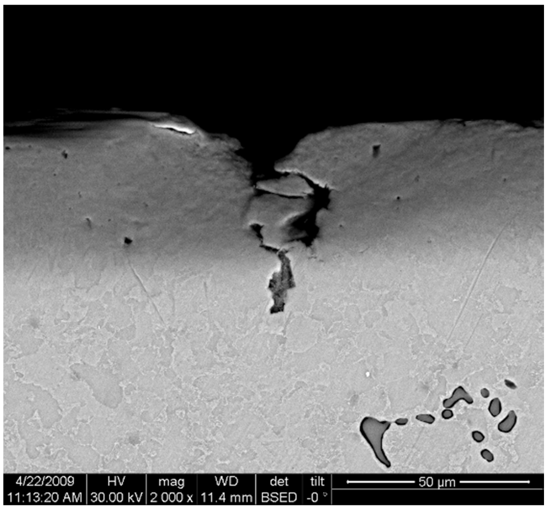

Fig. 13. Detail from fig. 10a- edge corrosion primer on the sequence on MnS inclusions.

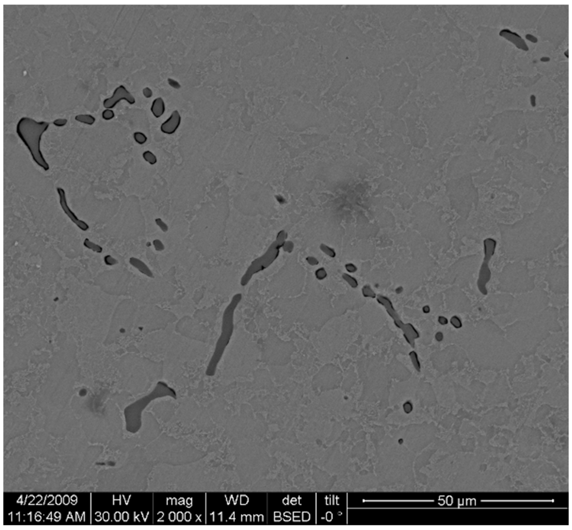

Fig. 14. Detail from fig.10a-discontinuous network of MnS inclusions.

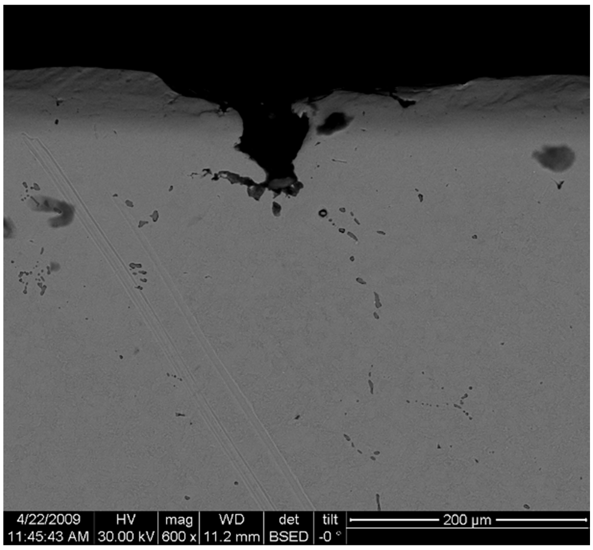

Fig. 15. Aspect of another edge micro area with corrosion initiated on a network of inclusions.

Energy dispersive X-ray analysis (EDAX) highlights the nature of microstructure components interesting in the material.

In this way in figure16 is presented the elements distribution like Mn, S and Fe in the micro area shown in the left up corner of the image. It is observed the majoritary presence of the Mn and S elements in the elongated inclusions (manganese sulfide).

Images in figure 17 demonstrate the microcraks strings and networks start and developing are favored by the MnS inclusions.

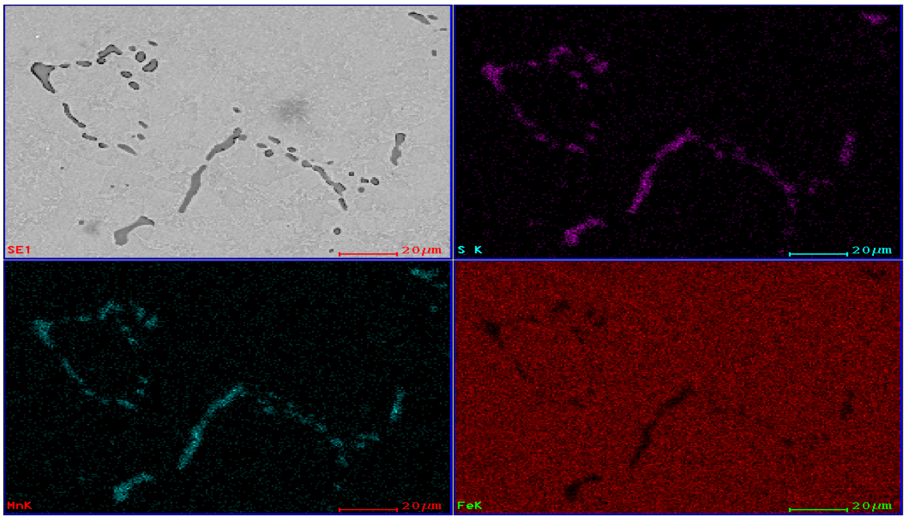

Fig.16. Elements distribution of Mn, S and Fe in the micro area shown in the up left corner

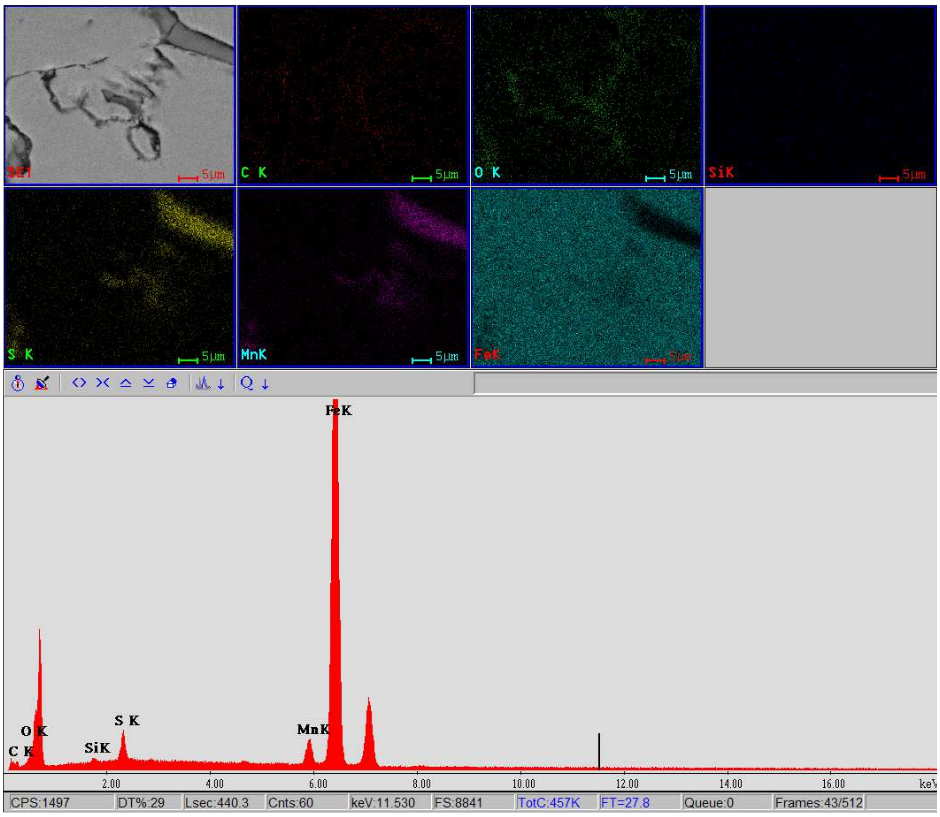

Fig. 17. Elements distribution revealed by the EDAX spectrum in the micro area from the upper left corner. Micro area is adjacent to the breaking surface and corresponds to sample 1.4 (fig.1)

4. Conclusions

The experimental studies performed resulted in following conclusions:

- Visual examination of the fracture surface indicates a fatigue fracture;

- Microscopic examination and investigation by X-ray microanalysis of the material surface area adjacent to the axle shaft breaking highlight the following factors unfavorable in terms of axle material quality:

a) existence in the cross section of shaft of the discontinues networks of MnS inclusions, negative factor for the mechanical properties of the material;

b) existence inclusions rows (observed in transverse section on shaft) that emerge in edge. This may be primers of breaking and corrosion primer of the material.

- Chemical composition analysis shows that sulfur is present in the analyzed samples, in higher concentrations (from 0.05 to 0.06%) than the maximum allowed (0.04%, according to the norm of material). Also the upper limit of the maximum admissible concentration of Cu (0.3%) is exceeded.

Exceeding allowable concentration of sulfur has the effect of attracting greater amounts of manganese from the ferrite existing in the steel (forming MnS inclusions) with implications for the manganese ferrite depletion and impaired fatigue fracture properties of the material.

Existence of copper (although the upper admissible limit is only slightly exceeded) may be a negative factor. Thus, forging at higher temperatures of 1050^0C can lead to the formation of surface cracks, even with copper content of approximately 0.2%, due to melting constituent rich in Cu which is found under the burning layer as a result of steel oxidation and its formation, the immediately steel layer from under the burning layer, thus Cu enriches.

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