“ POLITEHNICA “ University of Bucharest
RESEARCH CENTRE OF ECO-METALURGICAL EXPERTISES –
ECOMET
Spl. Independenței street 313, sector 6, postal code 060042, Bucharest
Phone/Fax: 021 316 95 64; Tel. 021 402 95 92; E-mail:

TECHNICAL REPORT

Extension of the investigations on the breaking surface and on the adjoining area of the breaking surface of the broken axle at the wheel 5 of the wagon no. 315354943062, from the freight train nr. 41651, belonging to Romanian Railway Freight Company “CFR Marfa “ SA, involved in the railway incident from the 13th of March, 2008 in the Railway County Craiova area

BENEFICIARY: Romanian Railway Authority – AFER
AFER order no. 1080/870/14.04.2009

DIRECTOR UPB – CCEEM
Christian PREDESCU

Scientific responsible,
Eugeniu VASILE

MAY 2009

1. **OBJECT**: extension of the investigations on the breaking surface and on the adjoining area of the breaking surface of the broken axle from the wheel 5 of the wagon no. 315354943062, from the freight train 41651, belonging to Romanian Railway Freight Company „CFR Marfa” SA, involved in the railway incident from the 13th of March 2008, in the Railway County Craiova area.

2. **BENEFICIARY: ROMANIAN RAILWAY AUTHORITY – AFER**

3. **INVESTIGATION METHODS AND TECHNICS**

3.1 Visual macroscopic examination by optical stereomicroscopic and electronic scan microscopy (SEM) at small zooms, at the electronic scan microscope QUANT INSPECT F;
3.2 Microscopic examination of the breaking surface and of the material from its adjoining area at the same electronic microscope;
3.3 Material investigation by X-ray microanalysis energy dispersive (EDAX) in order to characterized it, from the micro-composition point of view;
3.4 The chemical analysis by the optical emission spectrometry, made on different samples drawn from the adjoining area of the breaking surface, was performed with the equipment GNR METALAB (authorized by RENAR).

4. **RESULTS**

4.1 **Macro-vision examination of the breaking surface of the axle journal**
In the picture no. 1 is presented the breaking surface of the axle journal, consisting in parts (samples), cuts from the axle journal section as disc, containing the breaking surface. At the performer (ECOMED) was cut only the sample 1.4 from the picture 1, the other sections from this disc was being cut by the customer before starting this investigation.

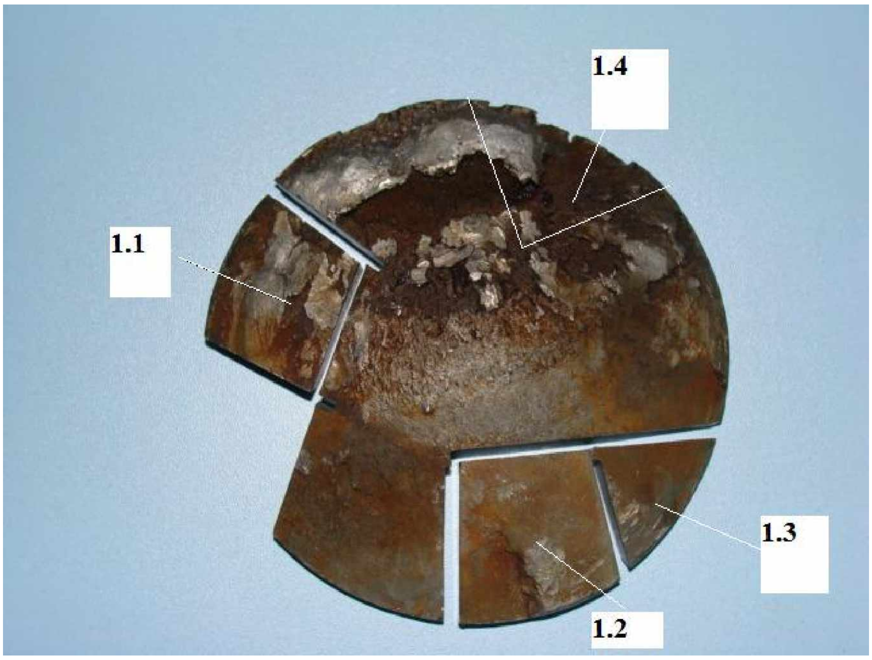


Fig. 1

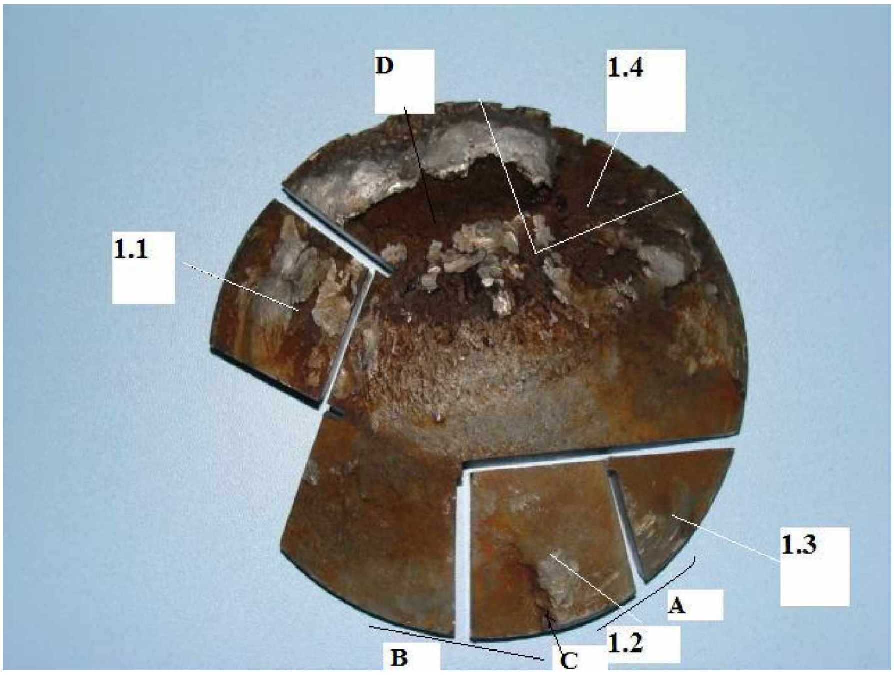


Fig 1a

The aspect of the breaking surface is characteristic to a fatigue breaking process with multiple cracks. Deterioration both of the breaking surface and of the edge of the breaking surface (axle journal exterior) that happened either during the railway event or in the process of drawing and keeping of the samples does not allow to identifying clearly the breaking cracks.

The surface aspect suggests the beginning of the breaking process (and so at least 2 cracks) first from the area A (very deteriorated) and then from the area B.

The two breaking processes met in the threshold C that limits them, by the level differences. To the area D, the breaking surface becomes more undulated, this suggesting an increase of the breaking spreading speed up to the area D, where happened the final breaking, with material plucking.

The sample 1.2 contains a part of the initial breaking (area B). The radial spreading (as lens) of the breaking in the area B looks central on the point E of the sample 1.2.

The image of the electronic scan microscopy (picture 2) has a part of the area B of the breaking starting. In the point E (maybe one of the cracks) the visible mechanical deterioration does not permit to identify the crack. One can see the existence of the fronts F1, F2, F3 of the breaking spreading speed change, specific to a fatigue breaking.

In the picture no. 2, the edge corresponding to the axle journal outer surface is distorted from the mechanical point of view, in a deep of about 0,3 – 0,4 mm (maybe after the axle journal breaking), having cracks and also material detachments to the inside of the breaking surface.

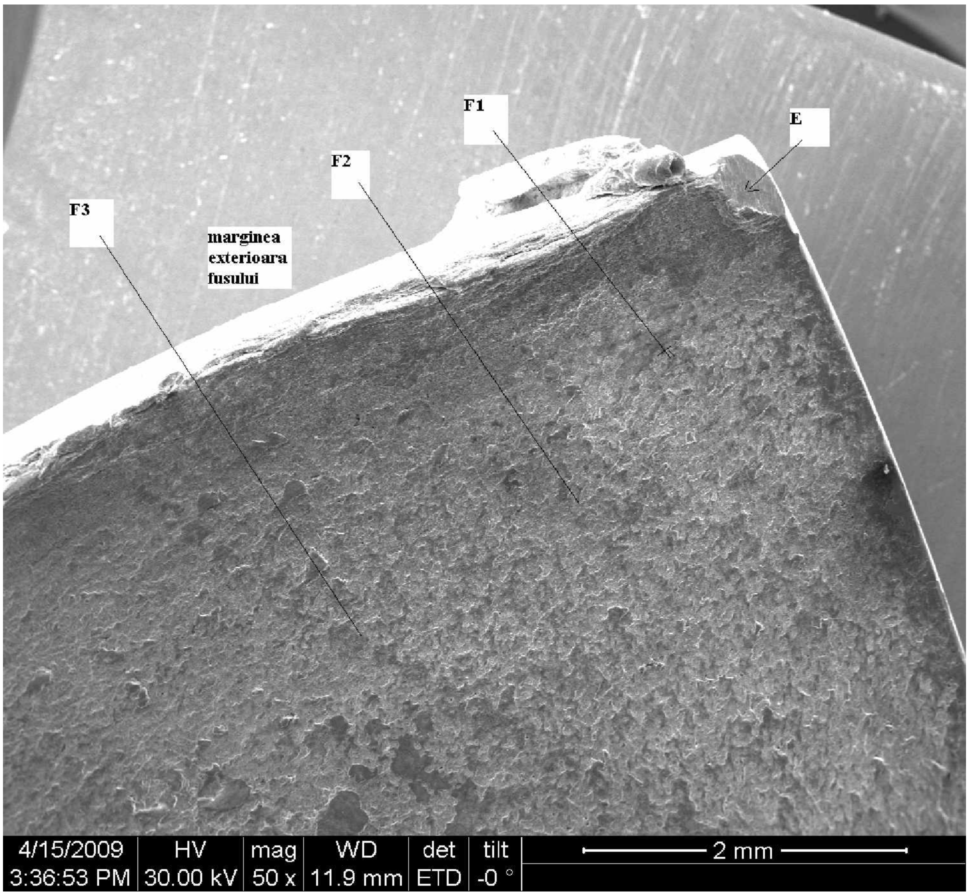
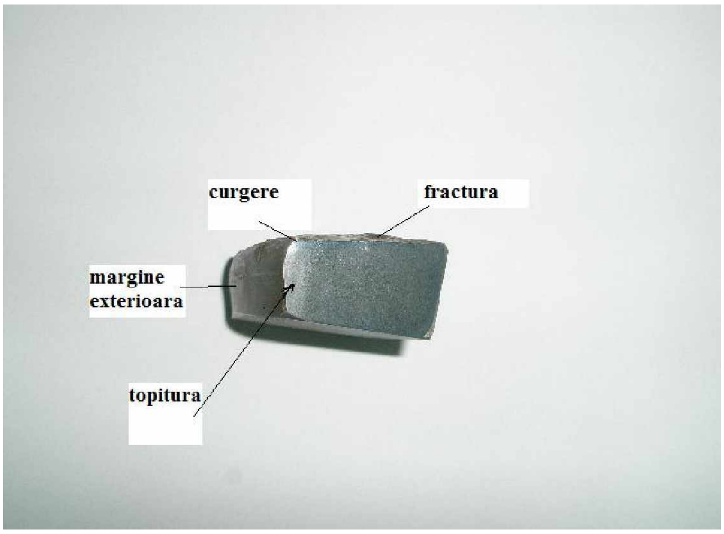


Fig. 2

During the visual inspection of the disc outer surface (cut from the axle journal) that contains the breaking surface was identified a change of its thickness. This is observed (picture 3) in the cross section of the sample 1.1 (see picture 1) from the final breaking area, section made at the performer in order to watch the micro-structure in the breaking surface area and to characterize the micro-area that contains this dimensional change of the axle journal diameter.

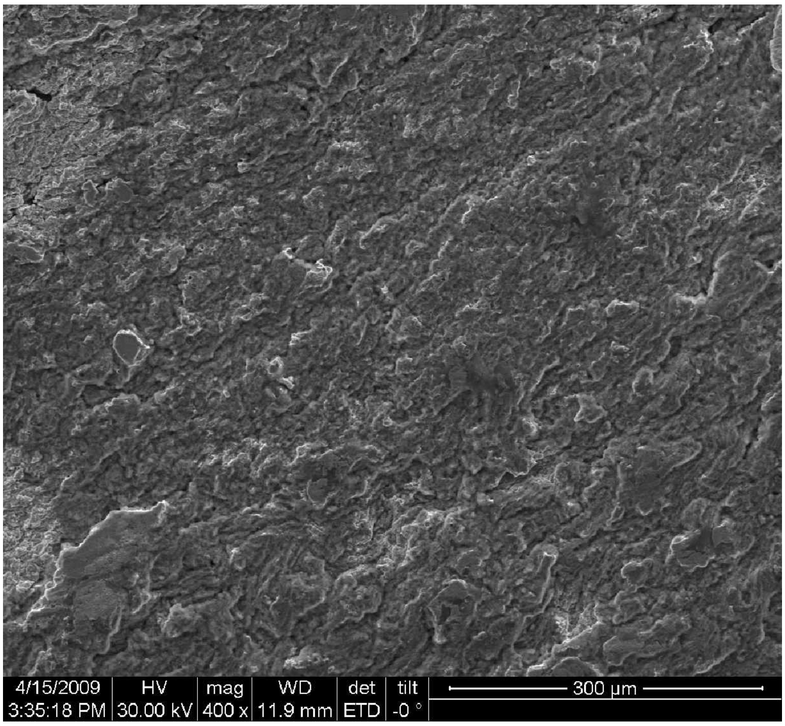


Picture 3 Sample 1.1

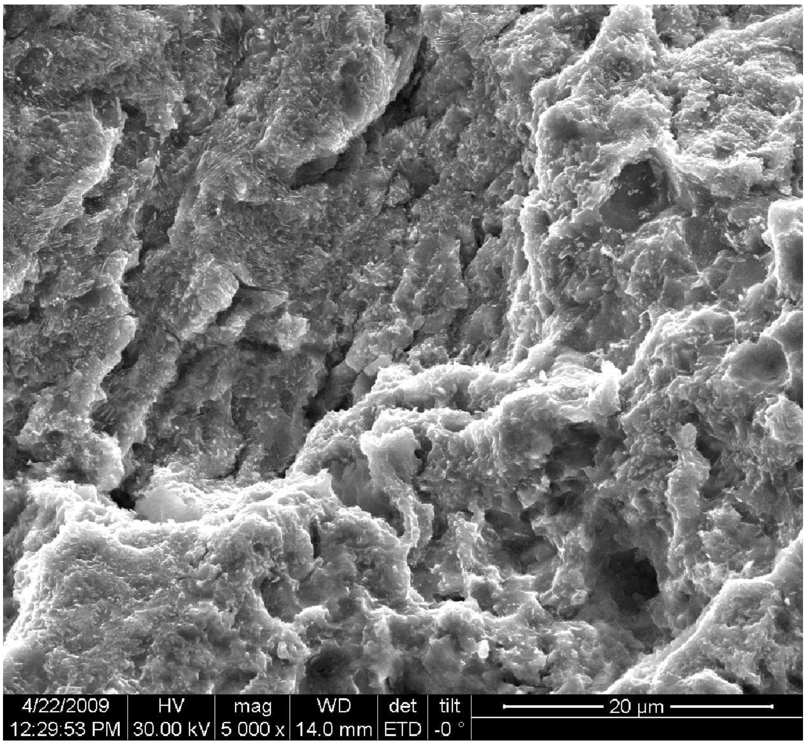
4.2 **Microscopic inspection** was performed with the electronic scan microscope QUANTA INSPECT F. One intended to characterize from the micro-structural point of view the material and to establish the type of the material failures (inclusions, thermo influence) using also the energy dispersive X-ray micro-analysis (EDAX) that allows to establish the local chemical micro-composition and the distribution of the very important elements in interesting micro-areas.

4.2.1 One also tried to characterize from the microscopic point of view the breaking surface. So, in the picture 4, at an increased zoom (x400) is shown that the breaking surface (images from the crack area) is covered by a continuous thick bed of oxides with micro-cracks in the bed. This bed is clearly resulted following the corrosion of the breaking surface after the event.

In order to observe the micro-structural details of the breaking surface one try to remove carefully the oxide bed by replies method. One noticed (picture 5) at a higher zoom (x5000) that, practical, the breaking surface is very corroded (existence of the corrosion pitting (small holes) and even the continuous corrosion of the limits of ferrite-pearlite grains). It is the reason for which one could not obtain micro-structural details of the breaking surface.



Picture.4 The beginning of breaking area – oxide bed (x 400)



Picture.5 Microstructure of the breaking surface after replies pull up – surface very corroded (x 5000)

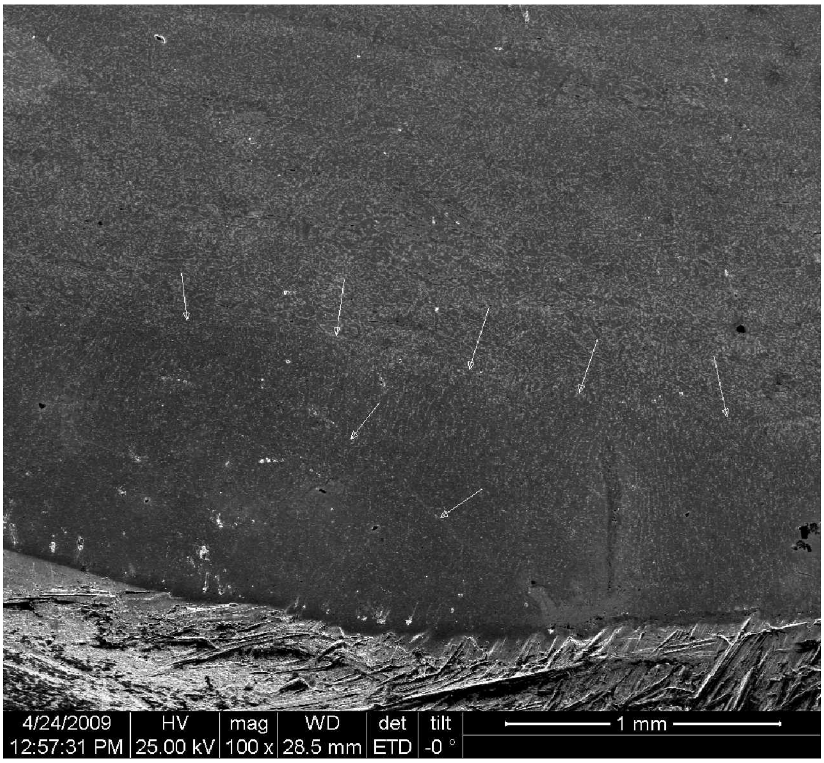
4.2.2 The microscopic description of the micro zone that has a change of the axle journal diameter in the breaking zone

In the picture 3 is observed this micro zone (sample 1.1). In the next images (picture 6) is observed micro-structural details of this micro zone. The edge zone (corresponding to the narrower zone of this section) has micro structural aspects characteristic to an area of local molten material, with the increase direction of the pearlite-ferrite grains perpendicular on the longitudinal axis of the axle. One observes solidification fronts, existence of micro-cracks in the material of this zone.

In the images 7a and b is presented the micro-structure of the basis material of the axle journal – micro-structure disposed on tapes, areas with a lot of pearlite that alternate with those ferrite. One also can notice plastic inclusions of long MnS on the distortion direction.

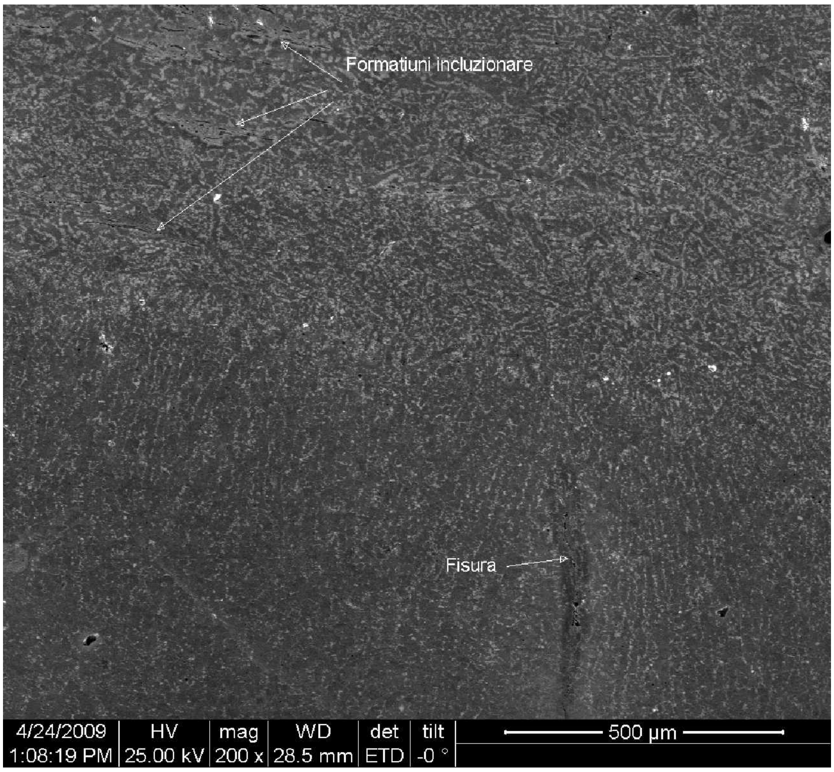
In the thicker zone, one notices a material folding (on the outer surface of the axle journal) to the breaking surface (picture 8a). The images of electronic scan microscopy from the pictures 8b and c put clearly in evidence, long micro-structure (flow) to the breaking surface.

SAMPLE 1.1 (longitudinal section in the disc 1, containing the breaking surface)

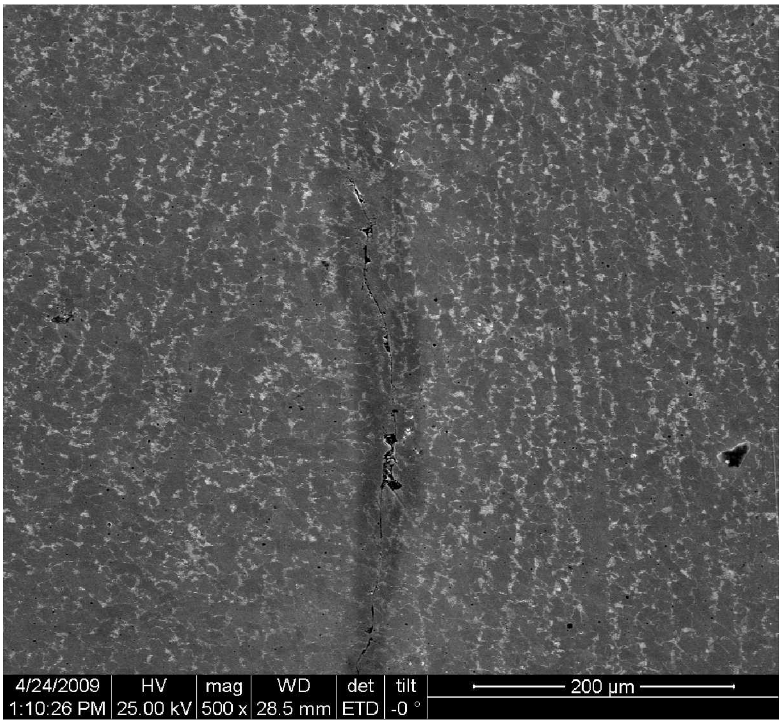


Picture 6a Edge zone putting in evidence the molten material. The arrows show the starting lines of the solidification fronts (x100)

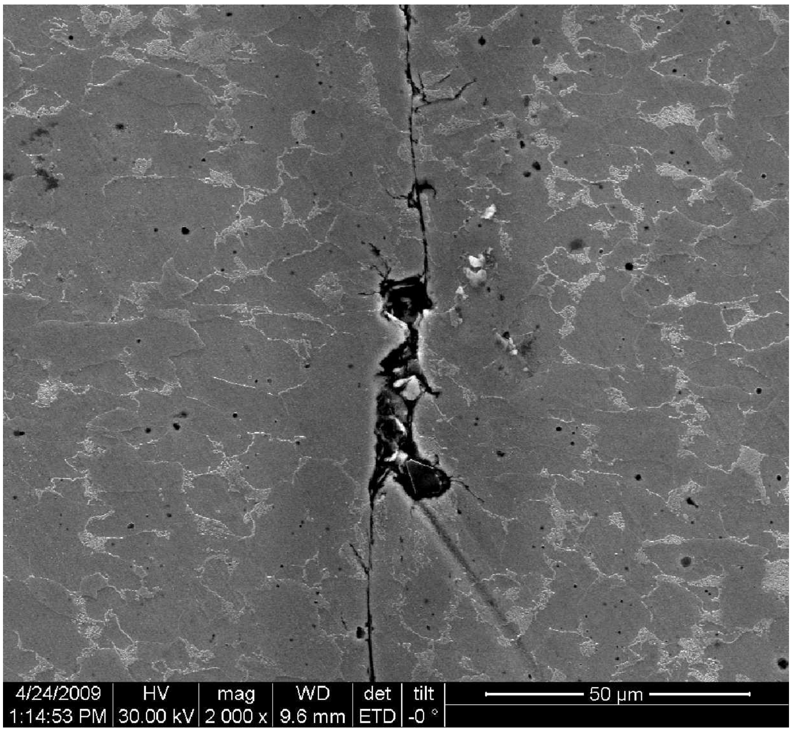
b)



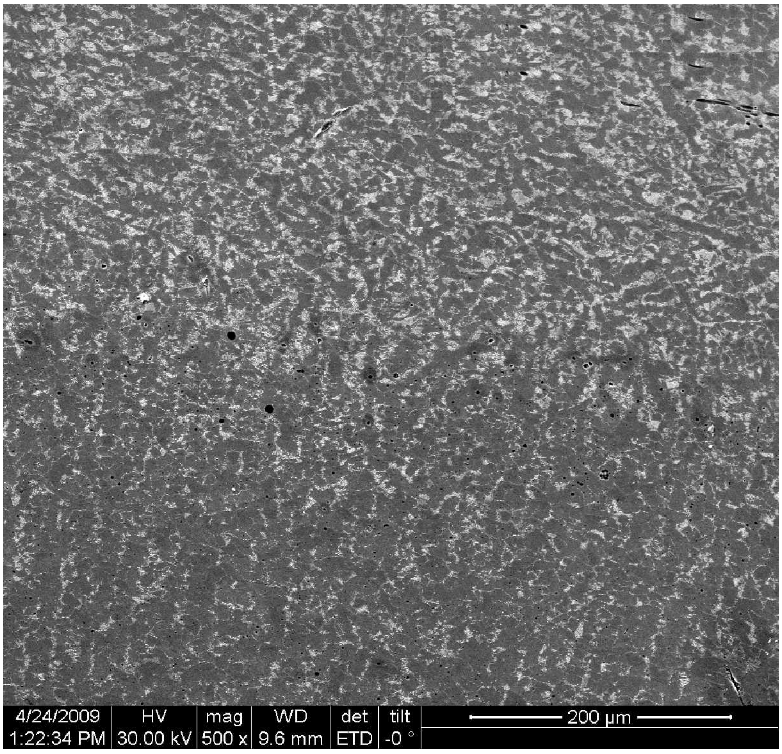
c)



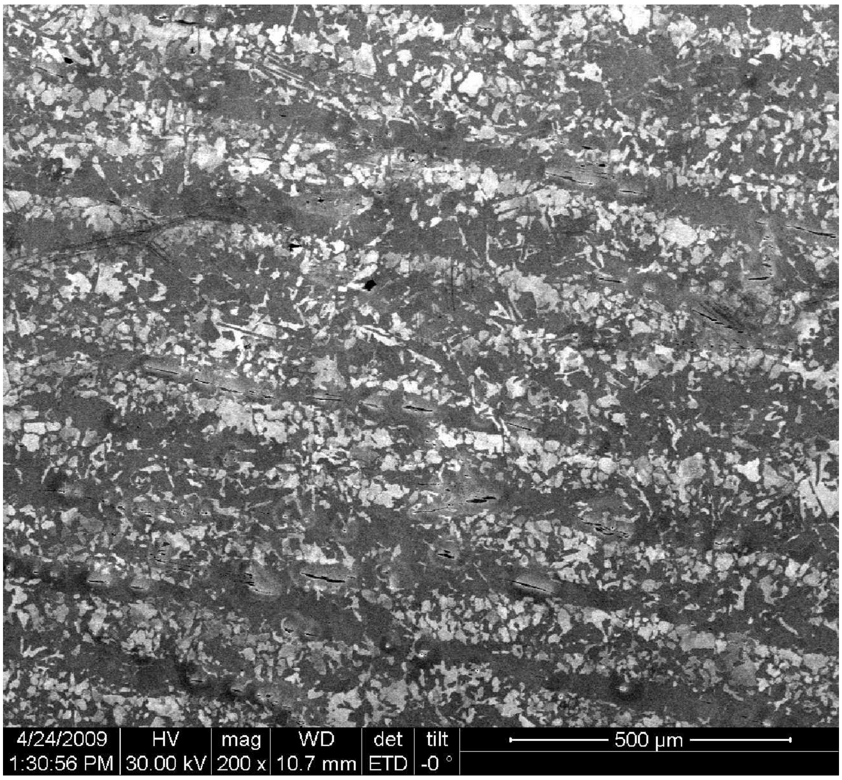
Picture 6 b, c Details from the picture 1.The parallel crack with the temperature gradient at the solidification (x200). One can notice the oriented character of the solidified material structure.



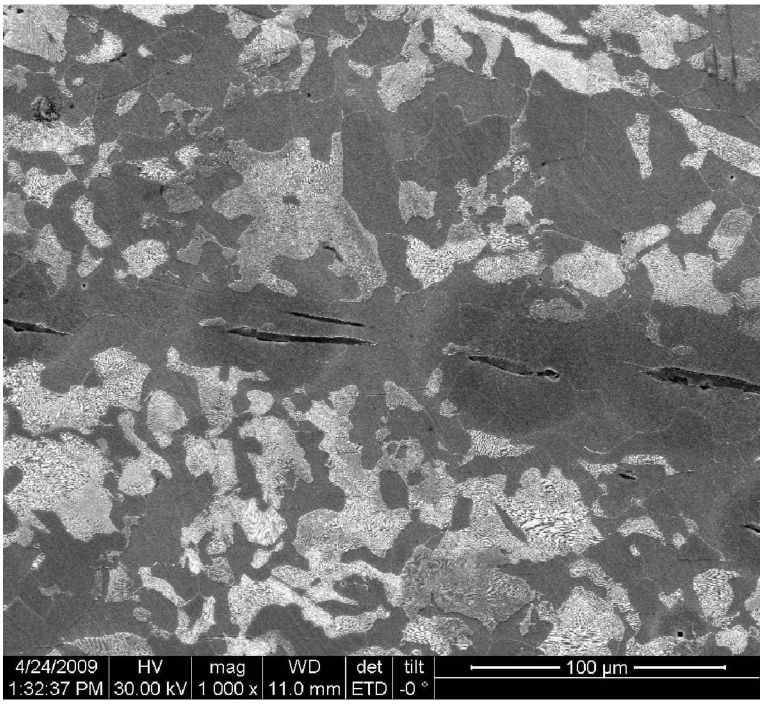
Picture 6d Higher order of zoom putting in evidence the crack intra-granular spreading(x2000).



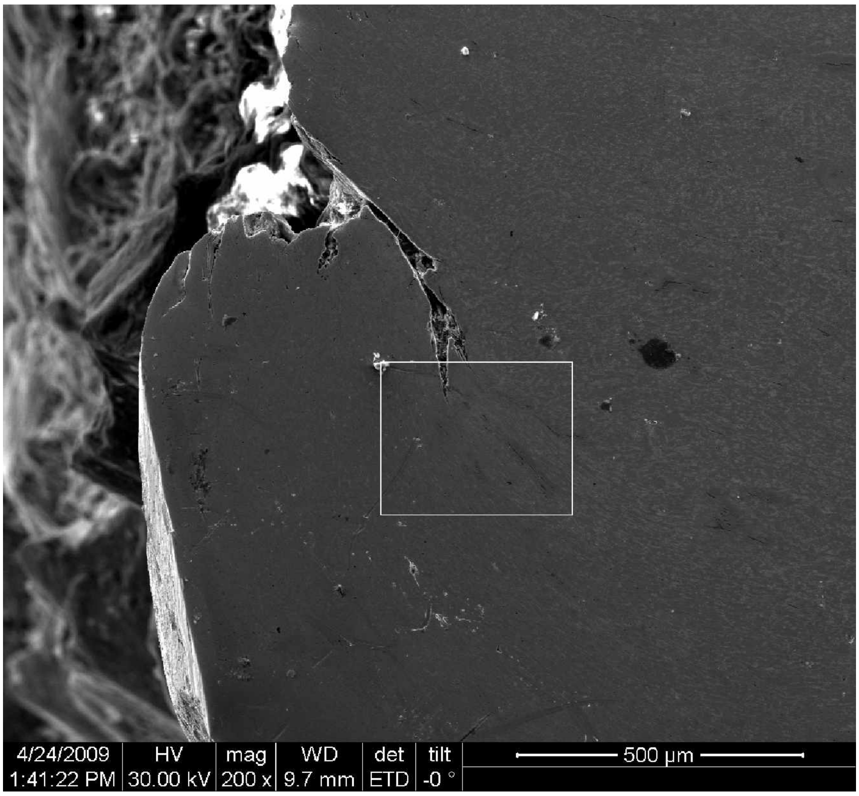
Picture 6e The picture got on the passing point from the basis material to that molten (x500). One can notice the direction difference of the structural formations and more reduce pearlite part in the molten zone (due to the carbon loss). One can also notice pores and micro-inclusions at the interface between these two material volumes.



Picture 7a The micro-structure of the axle journal basis material (x200). Oriented structure, in tapes, with areas with a lot of pearlite alternating with that ferrite. One can notice the presence of plastic inclusions especially in the areas with ferrite.

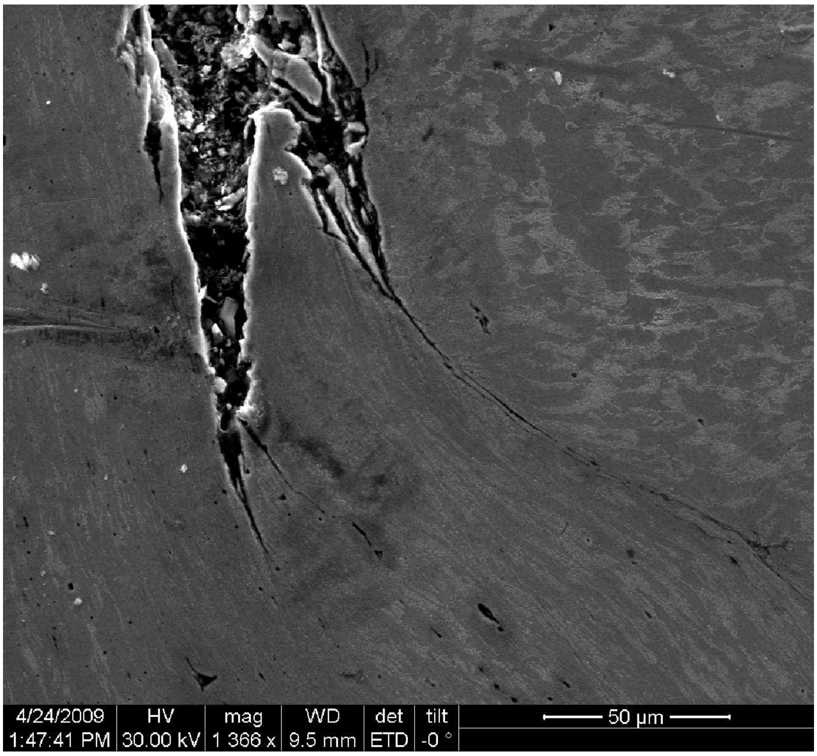


Picture 7b. Detail from the image of the picture 7a. Plastic inclusions placed on the distortion direction (x1000)

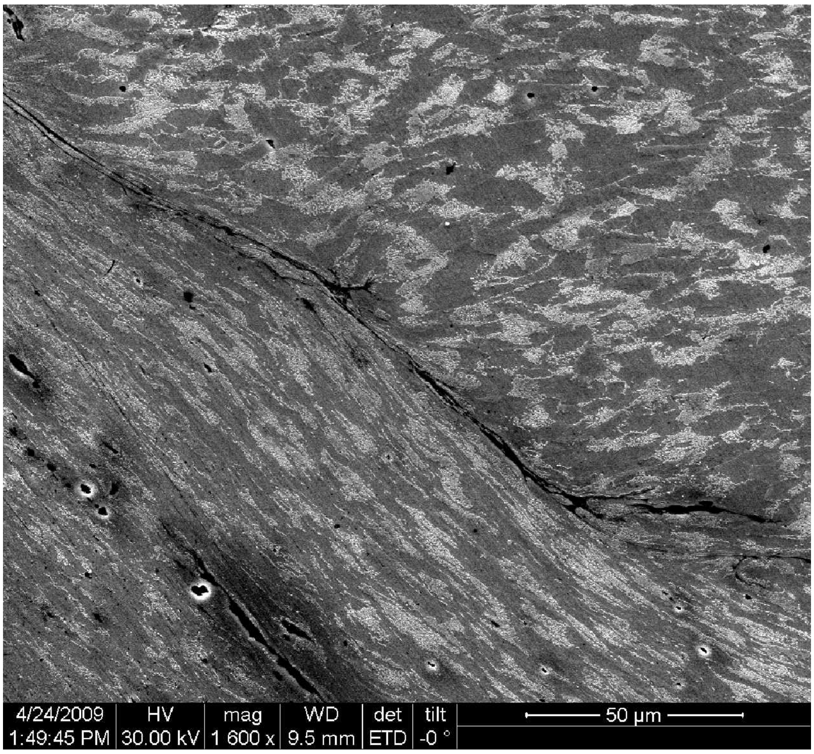


Picture 8a Material „folding", observed near the breaking surface (x200)

b



c

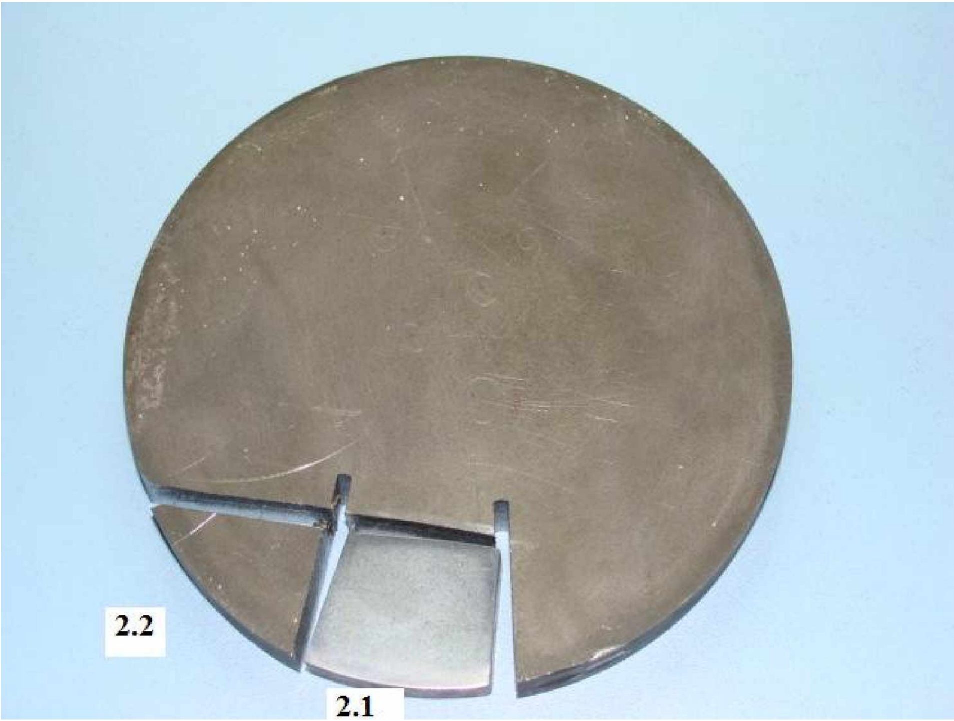


Picture 8 b and c. Details from the picture 8a. The material volumes, with different flow directions (x1366; x1600)

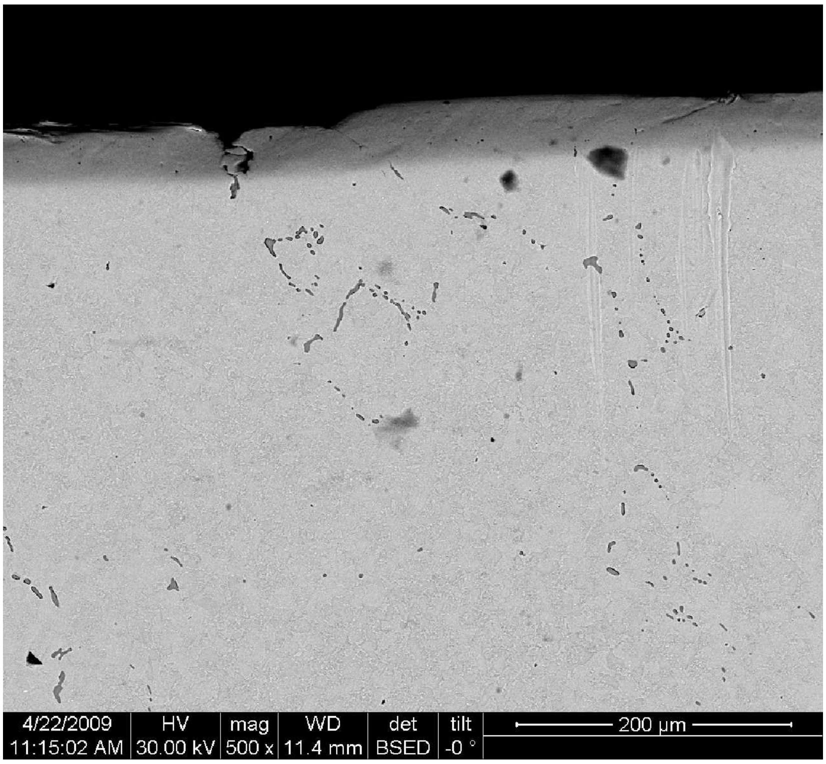
X-ray microanalysis performed on the local melting micro-zone, on the material-folding micro-zone and on the basis material (inside micro-zone) of the axle journal did not show micro-structural differences between these micro-zones.

4.2.3 Characterization of the material micro-structure in the zone adjoining the breaking surface was performed on the sample 2.1 picture 9.

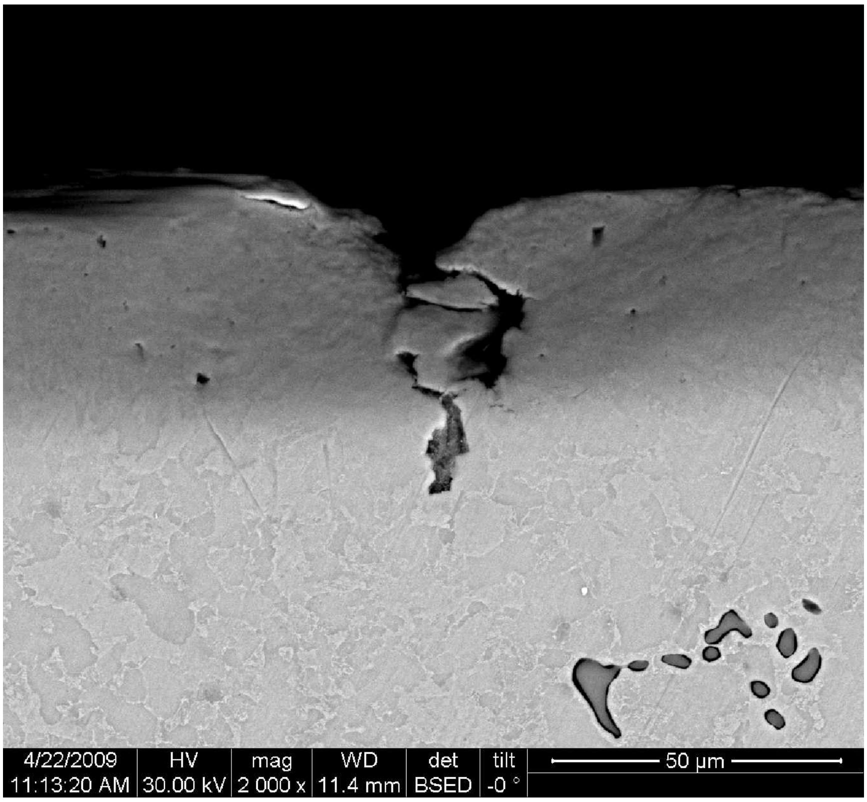
The picture 9 presents a disc cut (by the customer) cross from the axle journal close to the breaking surface.



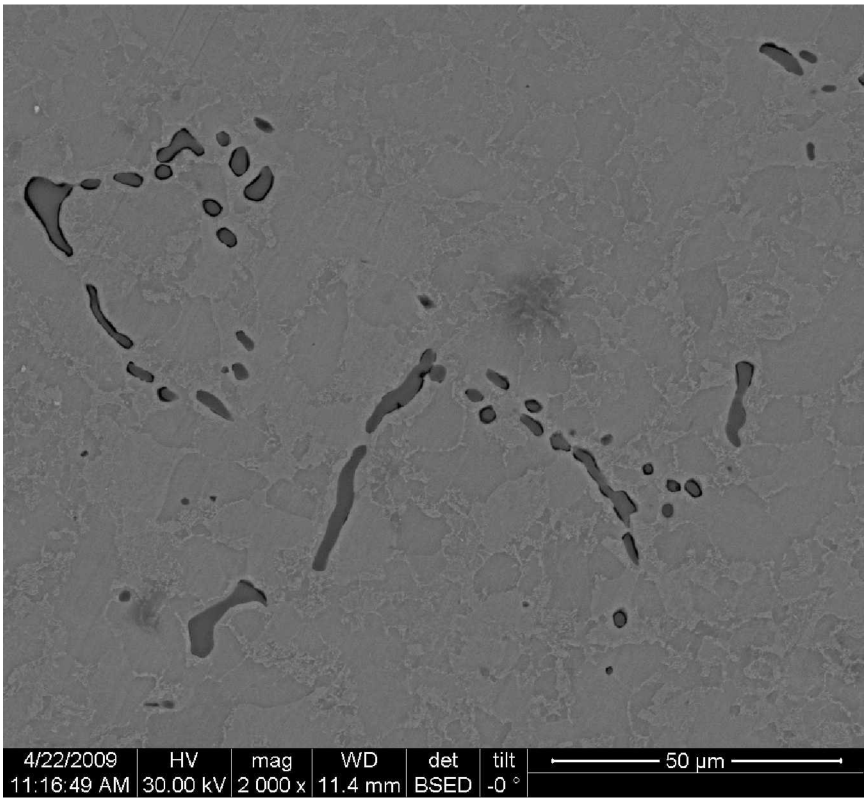
The images from the picture 10 (from a to d), images with secondary electrons retro-scattered, present the micro-structure of the material got on the sample 2.1. One can notice, against the pearlite / ferritie micro-structure, existence of inclusions MnS, irregularly distributed in the material. Unfavourable for its mechanical characteristics, these inclusions are generally grouped in discontinuous networks. One can also notice the existence of MnS inclusions rows that appear on the axle journal surface. Such edge inclusions can be tendencies to fracture of the respective marks in force, the inclusions rows that are come out from the surface are preferential areas for the spreading and development of the micro/cracks.



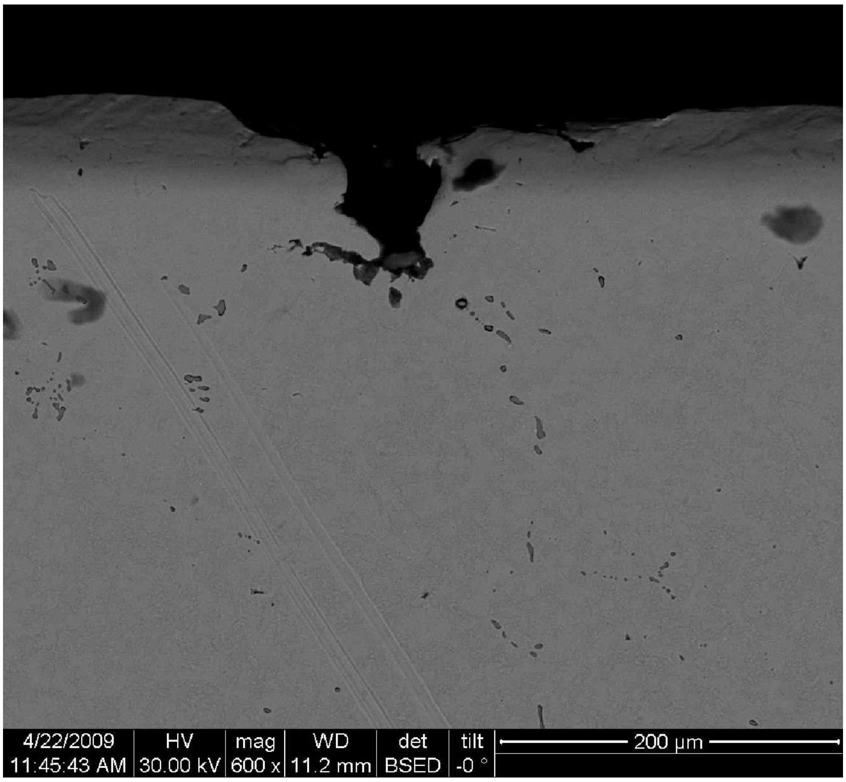
Picture 10a The axle journal micro-structure (image with retro-spread electrons) – cross-sections on the axle journal (x500). MnS inclusions both insulated and in discontinuous networks; MnS inclusions rows that are coming out in the exterior edge of the axle journal.



Picture 10b Detail in the picture 10a (x2000) – corrosion at the cracked edge on inclusions row

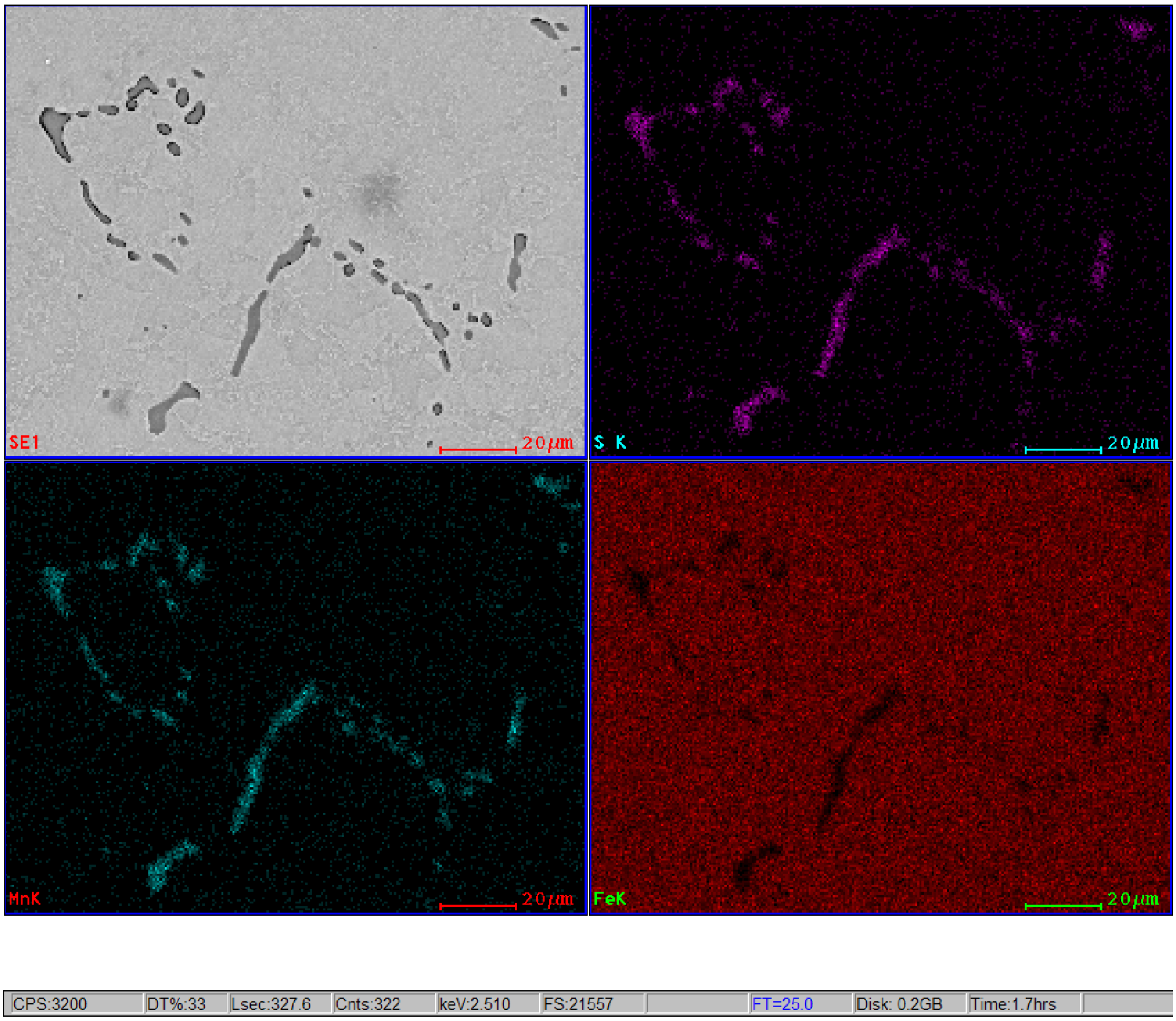


Picture 10c Detail in the picture 10a – discontinuous network of MnS inclusions (x2000)

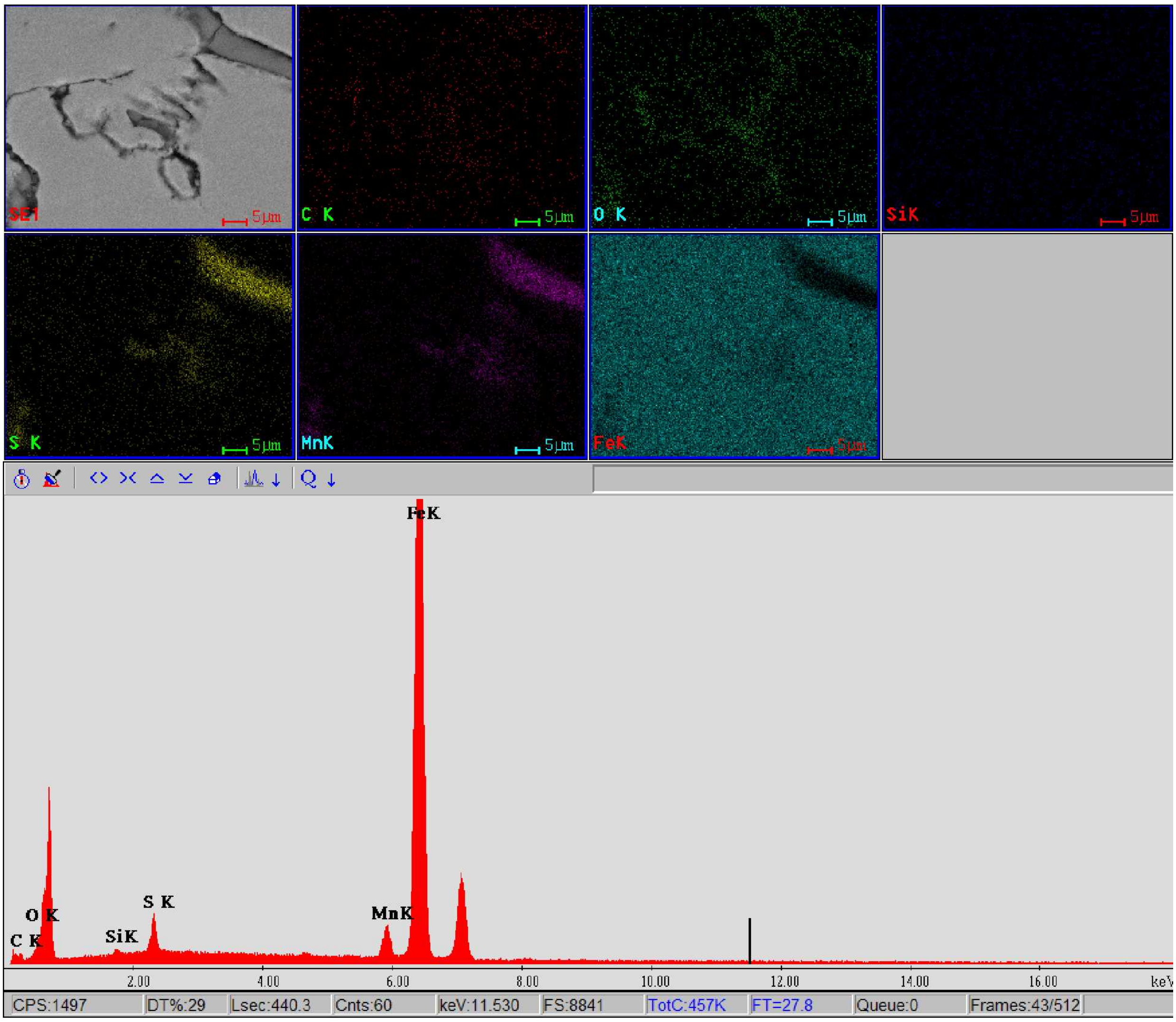


Picture 10d Aspect of other edge micro-zone with the initial corrosion on inclusions row (x600)

4.2.4 Dispersive x-ray micro-analysis in energy (EDAX) puts in evidence the type of the interesting micro-structural parts from the material.
So in the picture 11 is presented the distribution of the elements Mn, S and Fe in the micro-zone put in evidence in the up right corner of the picture. One can notice the main presence of the elements Mn and S in the long inclusions (manganese sulphide).
Favouring of the micro-cracks development by the MnS inclusions networks rows is proved by the images from the picture 12.



Picture 11 – Distribution of the elements Mn, S and Fe in the zone put in evidence in the up left corner



Picture 12 Distribution of the elements put in evidence by the dispersive X-ray spectrum in energy in the micro-area of the up left corner. The micro-area is adjoining the breaking surface and corresponds to the sample 1.4

4.3 The results of the chemical micro-composition analysis

The results of the chemical micro-composition analysis by the optical emission spectrometry, performed on spectrometer GNR metal LAB 75-80J (authorised by RENAR) are presented in the table bellow for each sample:

Element	Concentration			
	Sample 1.1	Sample 2.1	Sample 2.2	Sample 3.1
C	**0.289**	**0.299**	**0.300**	**0.297**
Si	**0.301**	**0.299**	**0.290**	**0.293**
Mn	**0.893**	**0.921**	**0.911**	**0.908**
P	**0.032**	**0.035**	**0.031**	**0.036**
S	**0.050**	**0.060**	**0.056**	**0.057**
Cr	**0.045**	**0.043**	**0.043**	**0.049**
Mo	**0.010**	**0.008**	**0.007**	**0.004**
Ni	**0.081**	**0.082**	**0.081**	**0.081**
Nb	**0**	**0**	**0**	**0**
Al	**0.008**	**0.008**	**0.008**	**0.008**
Cu	**0.364**	**0.351**	**0.350**	**0.346**
Co	**0.009**	**0.009**	**0.008**	**0.006**
B	**0**	**0**	**0**	**0**
As	**0.013**	**0.012**	**0.009**	**0.011**
Ca	**0.001**	**0.001**	**0.001**	**0.001**
Pb	**0.005**	**0.002**	**0.001**	**0**
Sn	**0.016**	**0.017**	**0.016**	**0.017**
Ti	**0.001**	**0.001**	**0.001**	**0**
V	**0**	**0**	**0**	**0**
W	**0.016**	**0.004**	**0**	**0**
Fe	**97.862**	**97.847**	**97.887**	**97.886**

The analysis of the above presented results shows that the sulphur concentration in the drawn samples from the breaking surface exceeds the up limit of the sulphur concentration accepted in the material (maximum 0,04%). The up limit of the accepted copper concentration (0,3%) is exceeded.

5. CONCLUSIONS

- the visual inspection of the breaking surface shows that this is a fatigue breaking;
- the microscopic inspection of the breaking surface could not supply new elements because the advanced corrosion situation (the corrosion that happened after the event) of the breaking surface;
- the microscopic inspection and the investigation by the X-raze micro-analysis of the material from the zone adjoining the breaking surface of the axle journal puts in evidence the next unfavourable factors:

a) existence in the cross section on the axle journal of the discontinues networks of MnS inclusions, unfavourable factor for the mechanical characteristics of the material;

b) existence of the inclusions rows (observed in cross section on the axle journal) that are coming out in the edge, can be breaking cracks and corrosion cracks of the material;

- analysis of the chemical composition shows that the sulphur (S) is present in the analysed samples in higher composition (from 0,05 to 0,06%) than the maximum accepted limit (0,04%, according to the material norm). Also the higher limit of the copper (Cu) composition (0,3%) is exceeded.

6. REMARKS

Against a material that has sulphur in the concentration accepted by the norm, this sulphur surplus attracts more manganese (forming MnS inclusions) from the ferrite existing in the material and so the reduction of the ferrite in the manganese affects the fatigue breaking characteristics of the material.

The presence of the copper, though the accepted higher limit is slightly exceeded, can be an unfavourable factor. So, forging at temperatures higher than 1050^0 C can lead to the appearance of superficial cracks, even at a copper content of about 0,2%, this due to the melting of the constituent with a lot of copper that is under the scale bed as result of the steel oxidation and scale forming, the steel bed immediately under the scale bed growing rich in copper.

Colectiv de lucru,

Prof.dr.ing. Cristian PREDESCU
CS1 dr.ing. Eugeniu VASILE