MINISTRY OF TRANSPORTS AND INFRASTRUCTURE
ROMANIAN RAILWAY AUTHORITY - AFER
ROMANIAN RAILWAY INVESTIGATING BODY

INVESTIGATING REPORT

to establish the conditions and determine the causes that led to breaking a large number of rails, during 2010-2011,
on the range of activity of C.F. Iasi Regional Branch – Section L4 Bacau, on the main line no. 500, on the lines I and II between the railway stations Adjud and Bacau

Final report
The 23rd of January 2012

NOTICE

In the case of the 2 technical failures of the interoperability constituent “rail” recorded during the period 01.01.2010 – 01.02.2011 on the range of activity of CF Iasi Regional Branch, the running section Adjud – Bacau, consisting of the breaking of the rails – 61 cases and rails defects of I category - 237 cases, Romanian Railway Investigating Body carried out an investigation, according to the provisions of the Regulations for the investigation of the accidents and incidents, for the development and improvement of Romanian railway and subway safety, approved by Government Decision no. 117/2010.

Through the investigation, the information on the 61 rails breakings and the occurrence of the 237 rails defects of I category was gathered and analyzed, the conditions were established and the causes determined.

Romanian Railway Investigating Body investigation did not aim to establish the guilty or the responsibility in this situation.

Romanian Railway Investigating Body considers necessary to take corrective measures in order to improve the railway safety and to prevent the accidents, so it included in the report a series of safety recommendations.

Bucharest, 23rd of January 2012

Approved by

Dragoş FLOROIU
Director

I agree the compliance with the legal provisions on the investigation performance and drawing up of this Investigation Report, that ***I submit for approval***

Chief Investigator

This approval is part of the Investigating report to establish the conditions and determine the causes that led to braking of a large number of rails, during the period 2010-2011, on the range of activity of C.F. Iasi Regional Branch – Section L4 Bacau, on the main line no. 500, on the lines I and II between the railway stations Adjud and Bacau

SUMMARY

I. PREAMBLE

I.1. Introduction

Romanian Railway Investigating Body being notified about the occurrence of some failures of the infrastructure subsystem, categorized according to the provisions of the ***Regulations for the investigation of the accidents and incidents, for the development and improvement of Romanian railway and subway safety***, approved by Government Decision no. 117/2010, hereinafter referred as *Regulations* in the investigation report, according to the art. 48 paragraph (2) appointed the president of the investigation commission to start the investigation to establish the conditions, determine the causes and issue some several recommendations to prevent incidents with similar causes.

The investigation did not aim to establish the guilty or the responsibility in this situation, its objective being to improve railway safety and to prevent railway accidents or incidents.

I.2. Investigation course

Through the Decision no. 53 of the 10th of March 2010, of the OIFR Director, according to the provisions of the art. 19, paragraph (2) of the Law no. 55/2006 on railway safety, the investigation commission was appointed, consisting of:

- Eduard STOIAN - head of OIFR - main investigator
- Dumitru SFÂRLOS - OIFR investigator - member
- George Radu PIPA - head of lines division-SRCF Iasi - member
- Petre SCHIPOR - regional inspector SCL-SRCF Iasi - member
- Constantin BĂRBINȚĂ - engineer in SNTFM "CFR Marfa" SA-Moldova Branch, Associated professor at the Technical University "Gh Asachii" Iasi - member

The investigation process imposed the stage of performing mechanic tests, chemical and metallographic analysis on samples of the rail type R65.

Because OIFR does not have the technical equipment and specialized staff to complete this stage, according to the provisions of the art. 20 paragraph (4) of the Law no. 55/2006 on railway safety and of the art. 52 of the din Regulations for the investigation of the accidents and incidents, for the development and improvement of Romanian railway and subway safety, approved by Government Decision no. 117/2010, OIFR turned to the Romanian Railway Notified Body, which has authorized staff and laboratories with the necessary equipment to perform the mechanic tests, the chemical and metallographic analysis on samples of the rail type R65.

A. BRIEF RESENTATION OF THE TECHNICAL FAILURES

A.1. Brief presentation

During the period 01.10.2010-01.02.2011 on the running section delimited by the railway stations Adjud and Bacau, on the current line wire I and II, between the km 248+000 - 300+000 occurred a number of 61 technical failures of the interoperability constituent "rail" consisting of the rails breaking, being recorded a number of 32 broken rails on the running wire I and a number of 29 broken rails on the running wire II.
During August and September 2011 another 2 rails broke, the total amount of broken rails recorded at the end of September 2011 being of 63 pieces of rails.
The rails breaking occurred at negative temperatures recorded during winter, but also at positive temperatures recorded during summer-autumn. In the breaking section was found the formation of a silver or dark color spot, specific to the failure 20, categorized according to the provisions of the *Instruction to determine the rails failures and to check the rails in the path no. 306/1972.*

On the same running section, between the same railway stations and on the same kilometric area, at the nondestructive check of the rails performed with the ultrasonic defectoscopy in October 2010, was found a number of 237 defective rails, that according to the provisions of the Instruction to determine the rails failures and to check the rails in the path no. 306/1972 are categorized as I category failures.
During the investigation at the nondestructive check of the rails performed in September 2011 was found another number of 371 defective rails of I category, so that the total amount of defective rails of I category at the end of September 2011 was of 608 rails.
All these rails of I category have the same defect type and the same evolution with the failure that led to breaking of the 63 rails.

All the broken rails and the defective rails of I category, to which was referred are rails type R65 manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991. These rails were introduced in path at the capital repair works (RK) performed during the period 1989-1992.

A.2. Direct cause, contributing factors and root causes

A.2.1. Direct cause

The direct cause of the occurrence of the two technical failures of the interoperability constituent "rail" was the decrease of the resistance to breaking of the rails under the conditions of application over time of several variable loads from the traffic that led to the rails breaking, at the tensions lower than the resistance to breaking of the steel in the rails.
The breaking occurring under the conditions of application over time of several variable loads is a fatigue breaking.
The steel fatigue from the rail consists of the occurrence and the development of the cracks in the contact area wheel-rail and of the plastic deformations associated with the hardening phenomena.
The nature and especially the evolution of the failures indicated that they have as cause the material fatigue (steel) by repeated dynamic stresses.

A.2.2. Underlying causes

1. Non compliance with the provisions of the art. 21, point 1 of the Instruction of standards and tolerances for the construction and maintenance of the rail - standard gauge lines no. 314/1989, providing that it is not allowed the maintenance in the path of the rails with I category defects, these having to be replaced as soon as possible, respectively in maximum 5 days from the observation.
2. Non compliance with the provisions of the *Instruction to determine the rails failures and to check the rails in the path no. 306/1972,* regarding the measures to be taken when there is identified the defect type 20, respectively: *"From the broken rail will be sent a sample to the*

Institute of transports Studies and Research for analysis and DGLI will ask to be taken measures based on the results”.

A.2.3. Root causes

None.

A.3. Safety recommendations

The addressee of the safety recommendations is the National Railway Company “CFR” S.A as manager of the railway infrastructure.
The recommendations aim to solve the following issues:

1. On the lines which superstructure is built with rails type R65 manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991, until the performance of the rails rehabilitation works, it is recommended to avoid the performance of the works of stuffing, shifting, dynamic stabilization and mechanized sifting with heavy rail machines in order not to determine the occurrence of the failures by the dynamic stresses transmitted by the machines to the rails during the technological process.
2. Avoiding the performance of weld repairs of the rails surfaces with defects under the conditions in which the material of which they are made is affected by the fatigue process.
3. Addition to the provisions of the instruction no. 306/1972:
   - by introducing in the current classification of the rails failures the defects caused by the fatigue phenomenon and of the terms existing in the document UIC no.712 to define the rails failures with the defects caused by the fatigue phenomenon (ex. squats, head checks, shelling, belgrospis);
   - with methods of identification, checking, monitoring over time and correction of the ondulatory wear;
   - with the establishment of the running conditions depending of the rails defects category.
4. Introducing in the nomenclator of rails maintenance and repairs works, included in the current instructions, the works and the technological processes regarding: the grinding, the milling or the planning of the rails within the maintenance works.

Measures regarding the rail type R65manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991

1. The inventory on the entire railway network of the line sections built with rail type R65 manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991, their detailed check to identify any rails with defects similar to those occurred on the line Adjud-Bacau and therefore setting measures to be taken to insure railway safety.
2. Identify the rail devices that had been built with rails having the same manufacturer and therefore setting measures to be taken to insure railway safety.

This investigating report will be sent to the public railway infrastructure manager the National Railway Company “CFR” S.A and to the Romanian Railway Safety Authority.

B. INVESTIGATING REPORT

B.1. Description of the interoperability constituent "rail" failures occurrence

B1.1. Checks performed before the 10th of March 2011

Starting with the 1st of January 2010 and to the 1st of February 2011 on the double line, electrified, built with rail type R65 superficially thermal treated, path without joints (welded path), from the running section delimited by the railway stations Adjud-Bacau, between the km 248+000 - 300+000, was recorded a number of **61** rails breakings, of which 32 breaking occurred on the running wire I and 29 breakings occurred on the running wire II.
Location of the area of the defects occurrence is presented - figure 1

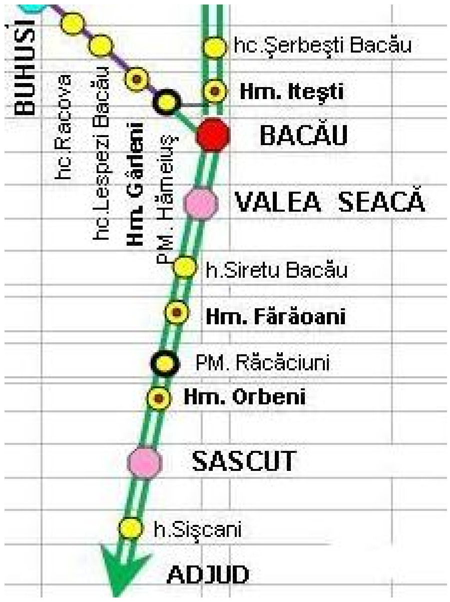


figure 1. *area of the defects occurrence*

All the 61 broken rails were manufactured by the same company from the ex URSS between 1989 and 1991.
The rail breakings occurred outside the joints have a common feature, namely the existence of a silver or black spot in the section of the heart or of the rail head, which led to an initial categorization of the breaking defect at 20 or 70 according to the *Instruction no. 306/1997 (republished in 1997) to determine the rails failures and to check the rails in the path.*
In order to control this unfavorable evolution of the rail without joints condition on the distance mentioned above in the autumn of 2010 were checked all the rails in the path with the self-propelled ultrasonic defectoscopy RFD the measurements highlighting the following situation on the current line Adjud-Bacau wire I and II:

- on the running wire I were found 120 defective rail of I category and on the running wire II were found 117 defective rails of I category;
- most of the defects of I category found were categorized according to the provisions of the *Instruction to determine the rails failures and to check the rails in the path no. 306/1972* correspond to the defect 20.2d, respectively "transverse cracks in the rail head (silver or black spot)".

The rails check with the ultrasonic defectoscopy performed during winter 2010-2011 reconfirmed the number of defective rails of I category recorded in the autumn of 2010.

The rails that broke and the rails on which were registered the I category defects are rails type 65R, manufactured during the period 1989-1991 by the same manufacturer from URSS, actually

Azovstal from Ukraine and that were introduced in the path during the period 1989-1992 with the occasion of the capital repair works (RK) and re-welding of the path without joints.

B1.2. Checks performed after the 10th of March 2011

During the investigation program, in May 2011 was performed an additional check of the rails with the ultrasonic defectoscopy on the running wires I and II on the running section Adjud-Bacau, check that was remade also in September 2011 during the checking program established according to the provisions of the Instruction for the nondestructive control of the rails no. 348/1972.
As a result of these checks the number of defective rails of I category newly found was of 371 defective rails.
In August and September 2011 on the current lines from the same spaces 2 rails had also broken, so that at the end of September 2011 the situation of the broken rails and of the defective rails was the following:

broken rails

- 63 rails of which: - 33 broken rails on the running wire I;
  - 30 broken rails on the running wire II;

defective rails of I category

- 608 defective rails of I category of which: - 454 rails on the running wire I;
  - 154 rails on the running wire II

We mention that the term rail used above defines the rail in the path without joints (continue welded line) between two welding. Throughout a rail can be several defects, so that the number of defective rails is lower than the number of defects.
After the analysis of the results obtained at the end of September 2011, according to the provisions of point 4.5 of the Instruction to determine the rails failures and to check the rails in the path no. 306/1997, on the running section limited by the railway stations Adjud - Bacau, was identified a number of 6 areas with rails problems on the running wire I and 2 areas with rails problems on the running wire II. According to the provisions of point 4.5 of the Instruction no. 306/1972, each kilometer of path on which was found or occurred during 3 years cumulated minimum five broken rails or defects of I or II category is considered as area with rails problems and is recorded in the track of defective rails with the letter Z written in blue and encircled in red.

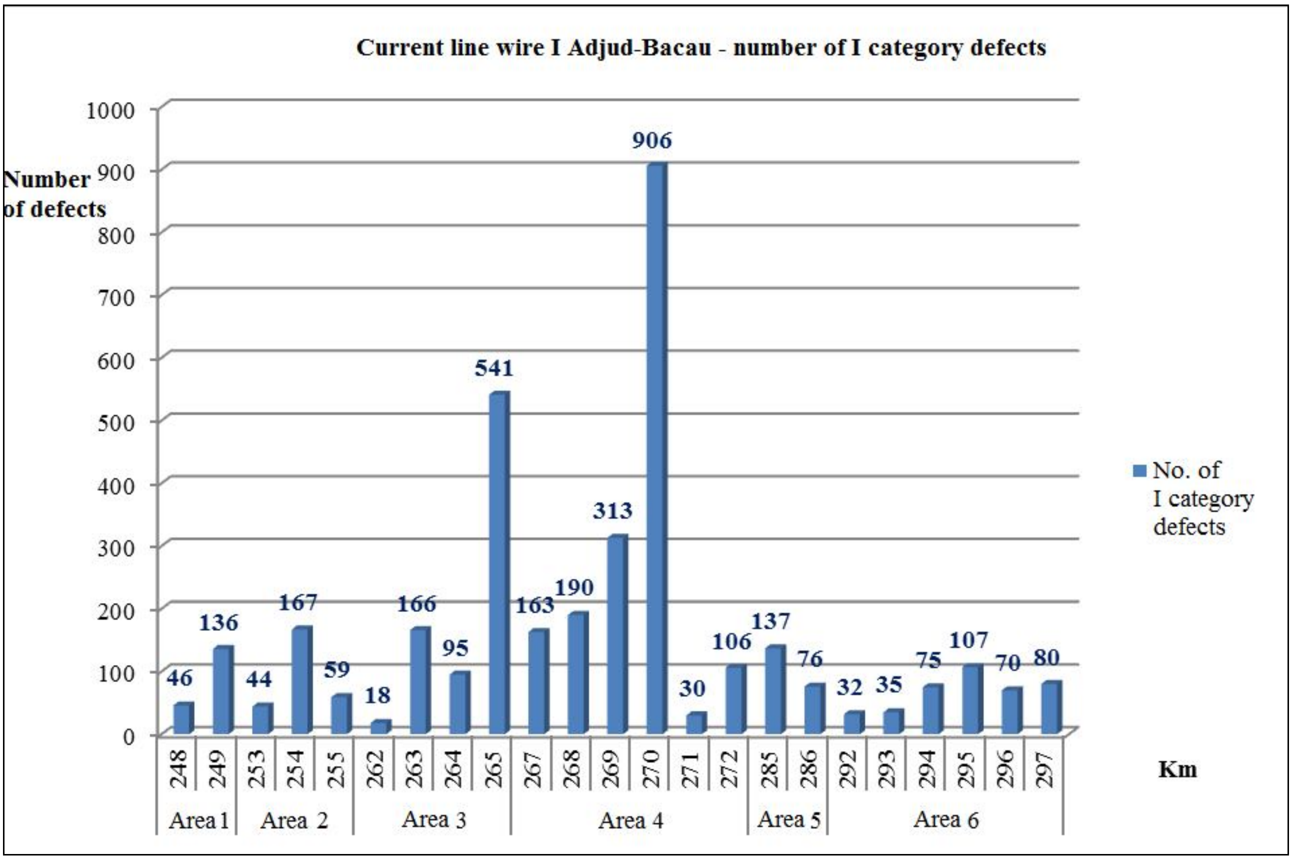
Current line wire I Adjud **-** *Bacau* ***Table 1***

No. crt.	Kilometer	No. of broken rails	No. of defective rails of I category	No. of I category defects throughout the rails	Areas with rails problems (Z_i)
1	**248**	0	21	46	**Z_1 Adjud-Siscani**
2	**249**	1	12	136	
3	**253**	2	11	44	**Z_2 Siscani-Sascut**
4	**254**	0	10	167	
5	**255**	0	9	59	
6	**262**	0	15	18	**Z_3 Sascut-Orbeni**
7	**263**	0	12	166	
8	**264**	3	29	95	
9	**265**	0	21	541	
10	**267**	1	15	163	**Z_4 Orbeni-Racaciuni**
11	**268**	2	24	190	
12	**269**	3	24	313	
13	**270**	0	15	906	
14	**271**	3	15	30	

15	**272**	1	9	106	
16	**285**	1	7	137	**Z_5 Faraoani-H.Siret**
17	**286**	2	16	76	
18	**292**	0	10	32	**Z_6 Valea Seaca-Bacau**
19	**293**	0	14	35	
20	**294**	0	18	75	
21	**295**	0	23	107	
22	**296**	1	10	70	
23	**297**	1	7	80	
Total		**21**	**347**	**3592**	

Graphical representation of the number of defects
on the current line wire I Adjud – Bacau

chart no. 1



Current line wire II Adjud – Bacau ***Table 2***

No. crt.	Kilometer	No. of broken rails	No. defective rails of I category	No. of defects of I category throughout the rails	Area with rails problems (Z_i)
1	**248**	1	24	157	Z 1 **Adjud-Siscani**
2	**249**	0	13	42	
3	**250**	3	20	5	
4	**253**	4	12	0	Z 2 **Siscani-Sascut**
5	**254**	5	11	0	
6	**255**	3	18	0	
Total		**15**	**98**	**204**	

B1.3. Visual study, on spot (in situ), on the failures occurrence and their evolution to the rails braking

There were viewed and photographed all the defective rails, found in the path on the area 4 (Z4) on the line I between the railway stations Orbeni and Faraoani and those on the area 2 (Z2) on the line II between the railway stations Adjud and Sascut.
From the study of the outside aspect of the areas with defects and of the areas next to these and their comparison with the defects types listed in the Instruction to determine the rails failures and to check the rails in the path no. 306/1972 there could be identified the following stages of the technical condition of the rail in operation, until the occurrence of the breaking.

Stage 1
In this first stage occurres an ondulatory wear with the short wavelength of 3-4 cm with the following features:

- the concave surface occurres on the rolling surface of the railhead starting from its axis towards the axis of the line;
- between the concave areas on the length of 3-4 cm occurres a convex wear with a length of 1-2 cm

The defect corresponds to that identified with the symbol 49.2a of the Instruction to determine the rails failures and to check the rails in the path no. 306/1972 and is of category III.

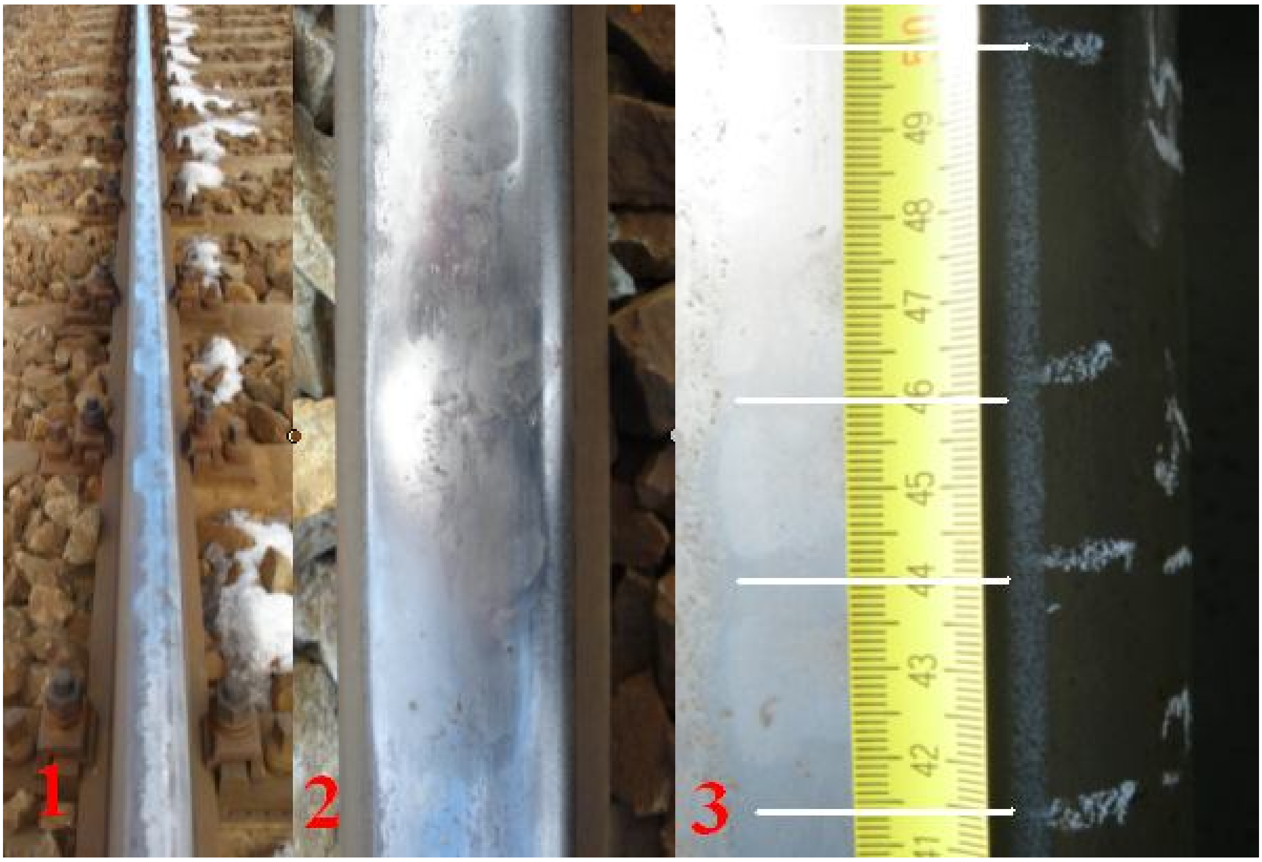


***photo no.1-** ondulatory wear line II Km 248+335 the rail on the left*

Stage 2

The concave parts of the ondulatory wear develop and occur more visibly on the lateral side along the rail, at the inner side of the line. The distance between the concavities is of 50-60 cm. In this stage the defect corresponds to that identified with the symbol 40.2a of the Instruction to determine the rails failures and to check the rails in the path no. 306/1972. If the concavity depth is lower than 2 mm the defect is of II category.

photo no. 2- *concavities arrangement line II Km 248+335 the rail on the left*

On the rolling surfaces the cracks grow more and more, simultaneously with them occurring also material exfoliations.

According to the provisions of the Instruction to determine the rails failures and to check the rails in the path no. 306/1972, this defect is categorized as 40.2.c defect, being a defect of category I.

The letter “c” corresponds according to the same instruction to an ondulatory wear with long wavelength.

photo no.3 – *the occurrence of the cracks in concavity (type squats) line II Km 248+080 the rail on the left*

These cracks grow and develop more and more gaining the appearance of inclined cracks type “head checks”.

photo no.4 – *the occurrence of the inclined cracks (type head checks) line I Km 248+080 the rail on the right*

Stage 3

In this stage the concave parts of an ondulatory wear, placed at 50-60 cm, are widening having an aspect of dark spot. These early pits in the rolling surface of the rail have depths of 0.1-0.5 mm - photo no. 5.

photo no. 5 - *line II Km 254+760 the rail on the left*

Stage 4

The holes in the rolling surface of the rail, corresponding to the concave areas of the ondulatory wear, develop by crack propagation and material exfoliation from the rolling surface. The size of the hole can progress reaching 3-4 mm - photo no. 6.

photo no. 6 – *the vertical expansion of the cracked concave areas*
line II Km 256+670
the rail on the left

The defect extends also along the rolling surface and could reach lengths over 15-20 cm.
In these stages the defects corresponds to that identified with the symbol 40.2c of the Instruction to determine the rails failures and to check the rails in the path no. 306/1972 and corresponds to a defect of category I - photo no. 7.

photo no.7- *the horizontal expansion of the length of the cracked concave areas*
line II Km 256+200
the rail on the right

Stage 5

In this stage occurred the rail breaking due to touching the limit condition to breaking. In this stage could correspond to one of the following defects classified according to the provisions of the

Instruction to determine the rails failures and to check the rails in the path no. 306/1972: 20.2, 21.2 or 70.2.

The causes of the 3 rails breaking could be established only through examinations, determinations and laboratory tests.

From the visual study of the breaking sections there could be observed:

- a layer of 2-5 mm where developed the cracks, situated on a well defined boundary glossy and ribbed at the bottom;
- the existence of a black spot (of oxidation) or a silver one at the top of the breaking section; - photo no. 8

***photo no.8** – breaking cross sections*

It is observed the crack start area, the crack propagation area with smooth glossy aspect and the final breaking area with granular crystalline aspect.

From the 63 analyzed rails breakings, in 90% of the cases the section formed at the rail breaking has the aspect shown in photo no. 8. The rail breaking in this way is due to the occurrence and development of the cracks in the areas of maximum effort together with the plastic deformations and the hardening phenomenon.

The first conclusion in this stage of the research was that in order to answer the questions resulted from the visual study on spot are needed laboratory tests on samples of defect and broken rails, removed from the path.

The next stage followed stage was of performance of the mechanic tests, metallographic and chemical analysis made on samples removed from the rail type R65.

B.2. Circumstances of the defects occurrence

B.2.1. Condition of the rail superstructure and infrastructure on the running section Adjud-Bacau at the start of the investigation

<u>*Performance of the RK works*</u>

On the 6th areas identified as areas with rails problems on the running wire I (areas that expand on 23 km) the last RK works were performed as follows:

- for the areas Z1, Z2 and Z3 the works were performed in 1991;
- on the area Z4 the works were performed during the period 1989-1990;

- for Z5 and Z6 the works were performed in 1990.

On the running wire II, on the 2 areas identified with rails problems Z1 and Z2 (areas that expand on 6 km of path) the last works of RK were performed in 1977 and in 1989 on these areas were performed works of replacing the rails and their re-welding.

Performance of the last RPc works – periodic repair with the complete sifting of the prism of broken stone.
On the line I, on the 6th areas the last RPc works were performed during the period 2000 for Z2-Z4, 2001 for Z5, 2002 for Z6 and 2010 for Z1.
On the line II, on the 2 areas the last RPc works were performed in 2003.

The tonnage since the introduction of the rails in the path
On the areas where the rail was introduced in 1989 the tonnage until the start of the investigation exceeded 230 millions of tones.
On the areas where the rail was introduced in 1990 the tonnage until the start of the investigation exceeded 200 millions of tones.
On the areas where the rail was introduced in 1991 the tonnage until the start of the investigation exceeded 180 millions of tones.

The line condition according to the results of the measurements with the rail measuring wagons
From the evaluation of the measurements performed with the rail measuring wagon on the line I and also on the line II Adjud-Bacau during the last 5 years, resulted the following situation regarding the condition of the path in operation according to the provisions of the Instruction for the use of rail measuring wagons no. 329/1995:

- the measurements were performed quarterly;
- the maximum cumulative scores were found in quarter IV 2009, year with low temperatures above the average in that period;
- the average score per kilometer did not exceed the value of 47
- 90% of the measured kilometers have the rating “very good”
- no measured kilometer was rated with satisfactory or unsatisfactory ratings

Evolution of the velocities during the period 2010-2011
Starting from the 28th of January 2011 on the line II Adjud-Sascut from the km 243+930 to the km 257+650 the running speed was limited to the maximum of 80 km/h from the maximum speed of 120 km/h.
Starting from the 17th of March 2011 on the line I Orbeni Farauani from the km 266+875 to the km 282+060 the running speed was limited to the maximum value of 80 km/h from the maximum speed of 120 km/h.

B.2.2. Involved parties
The running section where the rails breakings occurred and where were discovered rails with defects of I category Adjud -Bacau is managed by CN CF “CFR” SA and maintained by its employees.

The railway infrastructure on which the rail breakings and the rail defects occurred belongs to CN CF “CFR” SA and is maintained by the staff of Section L4 Bacau belonging to CF Iasi Regional Branch.

B.3. Consequences of the failures occurrence
The rails breaks led each time to the interruption of the automatic line block until the restore of the rail continuity by performing the provisional repair.

Making temporary repairs on the rail without joints by removing from the path the coupon of broken rail and replacing it with a buffer panel was performed at each intervention in line closing with the running disruption between two sectioning points.
Any temporary repair on the rail without joints has to be followed by a final repair with bringing the rail fixing temperature across the rail without joints in the spread of 17˚-27˚C and eliminating the disruptions by welding the rails.

Starting from the 28th of January 2011 on the line II Adjud-Sascut from the km 243+930 to the km 257+650 and starting from the 17th of March 2011 on the line I Orbeni Farauani from the km 266+875 to the km 282+060 the running speed was limited to the maximum value of 80 km/h, the maximum speed of the line being of 120 km/h. The direct consequence speed limit is the increasing of the running time between the two station intervals with 5 minutes for each passenger train.

B.3.1. Material damages
The material damages consist of the value of the broken rail coupons removed from the path, of the new rail coupons introduced in the path, of the manpower to perform the works of temporary repair and of the manpower to perform the works of final repair by welding the rails.

- According to the estimate no. 2.1/276-1/2011 of the Lines Division Iasi, a temporary repair to a broken rail without stress releasing of the breathing areas has an average value of the materials and manpower of about 2550 lei. For the 63 breakings temporary repaired the works value exceeded **160 650 lei**
- According to the estimate no. 2.1/276-2/2011 of the Lines Division Iasi, a temporary repair to a broken rail with stress releasing of the breathing areas and fixing of the buffer panel in the temperature neutral spread has an average value of the materials and of the manpower of about 4980 lei. For the 63 breakings temporary repaired the works value exceeded **318 720 lei**
- According to the estimate no. 2.1/276-2/2011 of the Lines Division Iasi, a final repair to a broken rail with stress releasing of the breathing areas and fixing of the buffer panel in the temperature neutral spread and eliminating two joints with two aluminothermy weldings has an average value of the materials and of the manpower of about 6000 lei. For the 64 disruptions to be final repaired the works value would have exceeded **313 740 lei.**
- If the 608 defective rails of I category had been removed from the path according to the provisions of the Instruction to determine the rails failures and to check the rails in the path no. 306/1972 and replaced by introduction in the path of a new rail coupon and its integration in the rail without joints (welding) the average value of such a replacement would cost about 6 000 lei and for all the defective rails **364 8000 lei.**

During the speed limits the damages consist of the increase of the energy and fuel consumption for all the passenger trains running on these areas with the speed of 80 km/h instead of 120 km/h.

B.4. Investigation course

B.4.1. Safety management system
At the beginning of the investigation process, CNCF “CFR” SA as public railway infrastructure manager had implemented its own railway safety management system, according to the provisions of the Directive 2004/49/CE on the community railway safety, of the Law no. 55/2006 on railway safety and of the Order of the Minister of Transport no. 101/2008 on granting the security authorization to the administrator/management of railway infrastructure in Romania, being in possession of:

- Safety Authorization - Part A with the identification no. ASA09002 delivered on the 21st of December 2009 – through which the Romanian Railway Safety Authority from AFER confirms the acceptance of the safety management system of railway infrastructure manager;
- Safety Authorization - with the identification no. ASB9007 delivered on the 21st of December 2009 – through which the Romanian Railway Safety Authority from AFER confirmed the

acceptance of the provisions adopted by the railway infrastructure manager to meet specific requirements necessary to ensure safety of rail infrastructure, in the design, maintenance and operation, including where appropriate, maintenance and operation of traffic control and signaling system.

B.4.2. Norms and regulations. Sources and references for the investigation

In the investigation of the railway incident one took into account:

- Instruction to determine the rails failures and to check the rails in the path no. 306/1972 (reprinted in 1997);
- Instruction for the non-destructive inspection of the rails no. 348/1972 (reprinted in 1997);
- Instruction to compose, maintain and monitor the rail without joints no. 341/1980 (reprinted in 1997);
- Instructions for speed limits, lines closing and de-energizing no. 317/2004;
- Instruction of standards and tolerances for the construction and maintenance of the rail - standard gauge lines no. 314/1989;
- Instruction for the use of rail measuring wagons no.329/1995;
- Railway technical regulation “Railway infrastructure. Reuse of the rail materials recovered from the railway maintenance and repair works”;
- SR EN 13674-1/2003 – Railway applications. Path. Rails. Part 1: Vignole Rails with the mass higher or equal to 46 kg/m;
- CURRENT R&D ON RAIL DEFECTMANAGEMENT TECHNOLOGY- authors Mitsunobu Takikawa, Fusayoshi Aoki;
- Technical approval no. 011 – 08 / 057 – 1998 for heavy rails type 49 and R65 manufacturer AZOVSTAL Ukraine;
- Specter I., Rails for modern railways, Railway Publishing House, ISBN 978-973-8923-07-2, Bucharest, 2008;
- Munteanu C., Study of the Materials, “Gheorghe Asachi” Publishing House, ISBN 973-8050-92-8, Iasi, 2009;
- SR EN ISO 148-1:2011 “Metallic materials. Bending test by shock on test piece Charpy. Part 1: Test method”;
- SR EN ISO 6892-1:2010 “Metallic materials. Test at traction. Part 1: Test method at ambient temperature”;
- STAS 11464-80 “Steel and iron. Spectro-chemical analysis”, point 2;
- STAS 4203-74 “Metalography. Sampling and preparation of the metallographic samples”, point 1.2.1.1, 1.2.2, annex 1- point 2;
- SR ISO 4968:1993 “Steel. Macro-graphic examination by sulfur print (Baumann method)”;
- STAS 11961/1-83 “Metalography. Highlighting methods and assessment of steel macrostructure”;
- STAS 4203-74 “Metalography. Sampling and preparation of the metallographic samples”;
- STAS 7626-79 “Metalography. Microstructures. Standard scales for steel”;
- ISO 4967:1998 “Steel. Determination of nonmetallic inclusions. Micrographic method with pattern-images”.

B.4.3. Work of the infrastructure
B.4.3.1. Data found on the rail

The program of mechanical testing, metallographic and chemical analysis for rail type R65 damaged coupons removed from the path

The testing purpose is to determine rails material characteristics for technical expertise.

The program and the testing types were established according to the standards and to the specifications in force for the rail type Vignole with the mass higher or equal to 46 kg/m.
The following testing types were scheduled:

- Determining Brinell hardness of the running surface
- Determining Brinell hardness on cross sections
- Test at breaking by shock
- Test at traction
- Determining the material chemical composition by spectral analysis
- Identification and inspection of the rails
- Macroscopic metallographic analysis
- Macrographic metallographic analysis
- Microscopic metallographic analysis

Choosing for testing the defective rails removed from the path, sampling and marking the rail coupons for testing and making the samples

For the laboratory tests and for the metallographic and chemical analysis to establish the causes of the rails defects occurrence, from the rails type imported from URSS between the years 1989-1990 were chosen 3 broken rails (that had the defect type 70.2) and a defective rail with the defect of I category (defect type 20.2d).

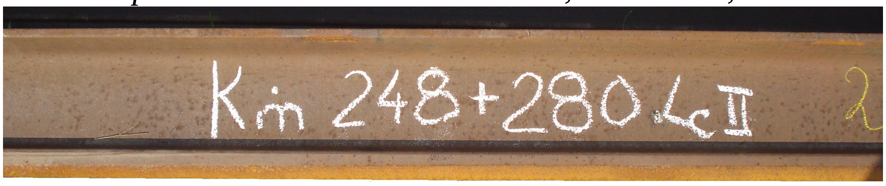
Technical data on the rails analyzed ***Table no.3***

coupon no.	Km (wire on the left/right)	Current line wire I / II	Rail type	Year of manufacture	Year of introduction in the path	Stored tonnage (mill. tons gross)	Defect nature	Date of the defect occurrence	Defect type
coupon I	264+995 right	I	65	1990	1991	162,35	broken rail	27.11.2010	70.2
coupon II	248+280 right	II	65	1989	1989	181,84	broken rail	29.09.2010	70.2
coupon II	264+920 right	I	65	1990	1991	162,35	broken rail	09.03.2010	70.2
coupon IV	260+370 left	II	65	1989	1989	181,84	defective rail	24.09.2010	20.2d

There was also established the necessary number of tests, the sampling method, the transport, the numbering and the testing laboratories.

coupon I - broken rail 27.11.2010 , URSS 1990, 70.2

coupon II - broken rail 29.09.2010 , URSS 1989, 70.2



coupon III - broken rail 09.03.2010 , URSS 1990, 70.2

coupon IV - defective rail of I category, URSS 1989, 20.2d

***photo no.9** – Identifying and marking of the rail coupons*

Cutting the rails coupons into pieces of 1.0 m, numbering of the new resulted coupons and their destination

The rail was cut in coupons of 1 m length, using a rail cutting machine. The cut was performed without thermal affectation of the material structure of which the rail is made.

The resulted rails pieces were marked with Roman numerals I, II, II and IV and each of these rails was divided and cut into 3 smaller pieces, marked with Arabic numerals from 1, 2 and 3 so that the rail defect to be found on the piece of rail marked with number "1". Therefore the rails pieces marked with I1, II1, III1 and IV1 were containing the defect that led to the remove of the coupon from the path.

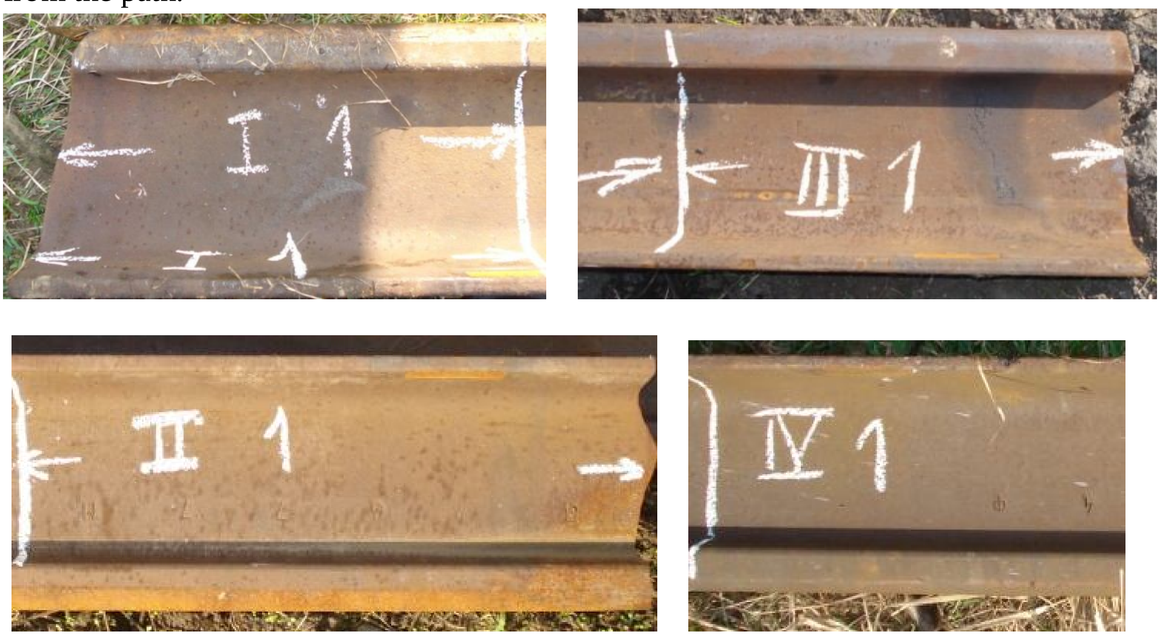


***Photo no.10** – rail coupons that have the defect included*

The rails coupons marked with I2, II2, III2, IV1 had as destination for study and tests the laboratory from the Faculty of Mechanical Engineering, of the Technical University "Gh. Asachi" Iasi and the rails coupons marked with I1 (A), II1 (B), III1(C), IV2(D), I3(E), II3(F), III3(G) had as destination for study and tests the laboratory belonging to Romanian Railway Notified Body in the Romanian Railway Authority-AFER.

Laboratory tests performed

Determining Brinell hardness of the running surface

There were performed two testing types. One in the laboratory in order to compare the hardness obtained by measuring with the one required by the “Terms of reference for railway heavy rails” for the Brinell hardness on the center line of the running surface and another test was performed on spot, in the path, in order to confirm the hypothesis of occurrence of ondulatory wear on the running surface of the rails in operation on the studied section.

a. Laboratory test

The test consisted of printing of a series of 5 marks on the testing surface of about 300 mm length of each coupon by appliance of a compressive force of 1.839 kN with a piercing (hard metal ball with the diameter of 2.5 mm). The rail coupons were rectified to avoid drosses and any decarbonizes areas. Before the tests was checked the measurement accuracy using the standard Brinell hardness 274 HBW, type 2.5-187.5.

Average values of Brinell hardness ***Table no.4***

Coupon no.	A	B	C	D	E	F	G
Brinell hardness [HBW] average	358	382.8	337.8	392.4	355.8	348.8	388.2

Comparative values imposed ***Table no.5***

Values imposed by “C.S. for railway heavy rails” for Brinell hardness on the center line of the running surface	
Steel mark: 900A	(270…330) HB
Steel mark: M 74 (76) T	min 355 HB
The difference between the values measured at different points must not exceed 30HB.	

b. Test on spot

There were performed measurements with the micro-hardness-meter type HLN-11A Hardness Tester.

The measurements were performed on the line II Adjud –Sascut, under traffic, at three kilometer positions on defective rails found at the measurement with the ultrasonic defectoscopy on areas with ondulatory wear of the running surfaces at km 248+335 rail on the left, km 248+340 rail on the right and at km 248+341 rail on the left.

In figures 11 and 12 is shown the area measured on the right wire of the current line wire II between the railway stations CFR Adjud-Sascut from the km 248+340 - photo no. 11

photo no. 11*- km 248+340 wire II rail on the right*

The hardness on the running surface of the rail was measured in the elevated points (convex) and in the fallen ones (concave) of the deformed surface - photo no.12.

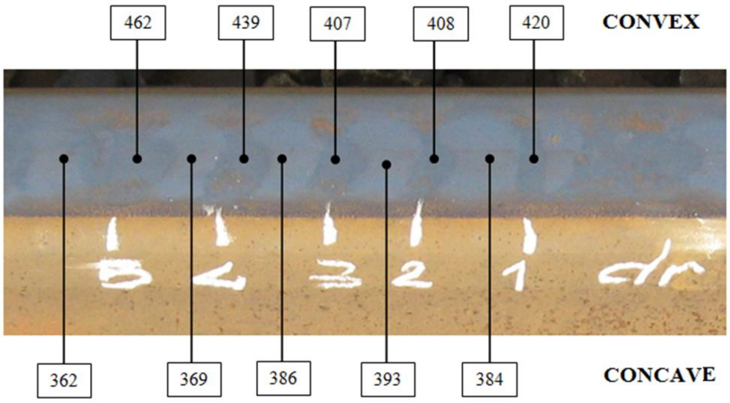


photo no.12 - *km 348+340 rail on the right*

The measured values confirm that the convex points have higher values than the ones measured in the concave points.

Determining Brinell hardness on cross sections

The tests were performed in two different laboratories with different equipments at AFER and the Faculty of Mechanical Engineering in Iasi.

a. The test performed in AFER laboratory

The test was performed according to SR EN ISO 6506-1:2006 and consists of printing a series of marks starting from the running surface towards the rails sole through a piercing CV 998 (hard metallic ball with the diameter of 2.5 mm), by applying a compressive force of 1.839 kN. Before performing the tests was checked the measurement accuracy using the Brinell hardness standard 274 HBW, type 2.5-187.5.

The placement of hardness prints on the 7 cross slices used in the test is shown in figure no. 13.

There was used one slice of all the coupons provided to the testing laboratory.

As a general characteristic, common to the 7 measured sections, is that the hardness measured value decreases vertically, from values of 370-390 HBW at the running surface to values of 270-290 HBW in the points at the bottom level of the rail sole.

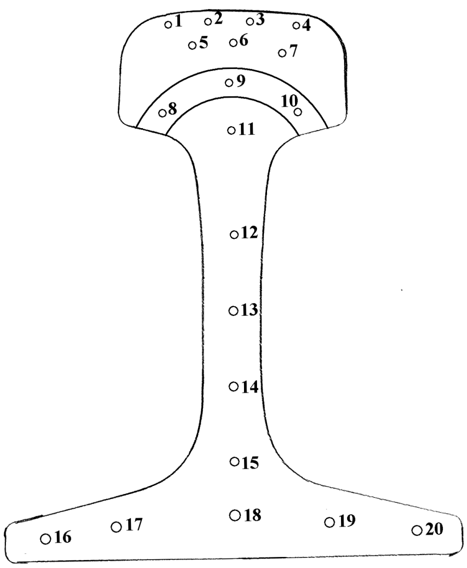


photo no. 13 *– placement of the measurement points*

Comparative values imposed *Table no. 6*

Imposed values for Brinell hardness on cross slices, By the “Terms of references for railway heavy rails” approved by REFER in 1994	
Steel mark: 900A	(270…330) HB
Hardened layer in rail-head, to 16 mm of the running surface	min. 300 HB
The difference between the values determined in different points must not exceed 30HB.	

b. The test performed in the laboratory of the Faculty of Mechanical Engineering

There was used the micro-hardness-meter type EMCOTEST M1C - EmcoTest Austria (photo no. 14), with which was determined the hardness, in 14 points (photo no. 15) representative for the four samples analyzed. Cutting from the coupons and the coupons preparation was performed by the specialized department of SC Chambon SRL.

Results of the test at hardness **Table no. 7**

Point	**Test 2 I 1990**	**Test 2 II 1989**	**Test 2 III 1990**	**Test 1 IV 1989**
1.	317	369	359	385
2.	337	371	342	400
3.	306	372	354	369
4.	372	372	364	356
5.	318	369	346	397
6.	339	363	361	387
7.	370	369	357	415
8.	352	366	365	391
9.	373	353	351	360
10.	372	352	346	372
11.	371	337	338	367
12.	343	316	322	370
13.	367	370	341	388
14.	383	351	345	387

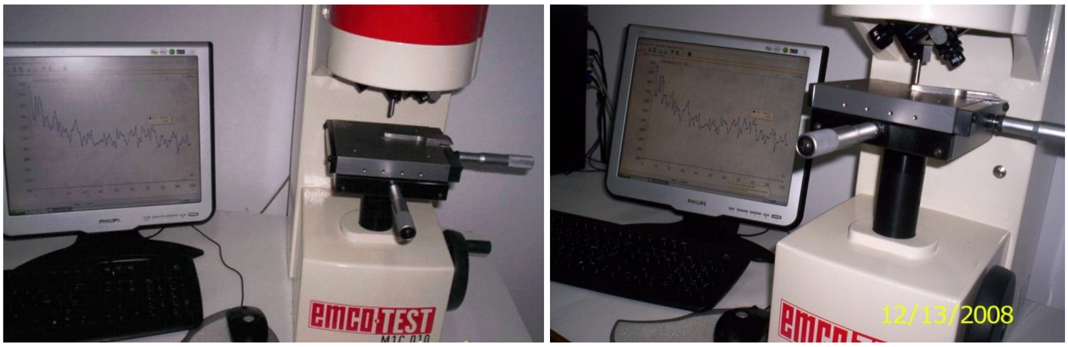


photo no. 14. *Micro-hardness-meter type EMCOTEST M1C - EmcoTest Austria*

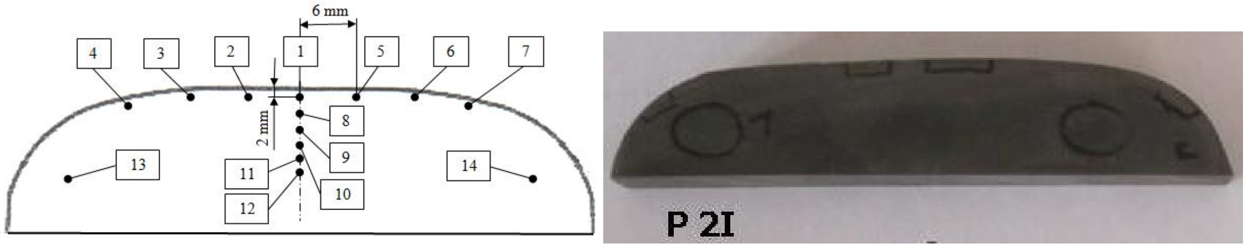


***photo no. 15** – the 14 points in which the hardness was determined*

In points 1-7 were placed at a distance of 2 mm from the running surface and the distance between two points, in cross plan is of 6 mm. Points 8-12 are placed at a distance of 2 mm from each other and are placed on the axis of symmetry of the rail.
Points 13 and 14 are placed in the area from which samples were taken for the test at traction.

The results obtained lead to the conclusion that the hardness values are within the limits imposed by the “Terms of reference for railway heavy rails” approved by REFER in 1994.

Test at breaking by shock
The test performed according to the SR EN ISO 148-1:2011 at the AFER laboratory consists of the breaking by a single blow with a hammer-pendulum of a standard test piece with notch in the middle placed freely on two supports.
There were performed tests with the Hammer-pendulum 150J tip JBW – Charpy on 3 samples manufactured for each of the 7 little coupons.
For each sample was determined the absorbed energy by breaking, KU, [J] and the resistance KCU, [J/cm^2] and the data was compared to the admitted values shown in table no. 8.

Comparative values imposed ***Table no. 8***

Values imposed for the resilience (at the temperature of 20^{o}C) by the “Terms of reference for railway heavy rails” approved by REFER in 1994	
Steel mark: 900A	min. 25 J
Steel mark: M 74 (76) T	min. 25 J

Six of the resilience average values, of the 7 samples, are under the admitted average value of 25J. Only the value of the sample D exceeds the value of 25J.

Test at traction
The tests were performed in two different laboratories with different equipment at AFER and at the Faculty of Mechanical Engineering in Iasi.
a. Test performed in the AFER laboratory
The test consists of applying a traction force over a test piece to the breaking in order to determine the mechanical characteristics (resistance at breaking and elongation after breaking). The traction test pieces are taken longitudinally and processed at the sizes of a test piece with the circular section of l_o = 50 mm, d_o =10 mm and the circular sectional area of 78.54 mm^2, according to the table D1, annex D of the SR EN ISO 6892-1:2010.
There were taken 2 samples from each of the 7 used coupons.

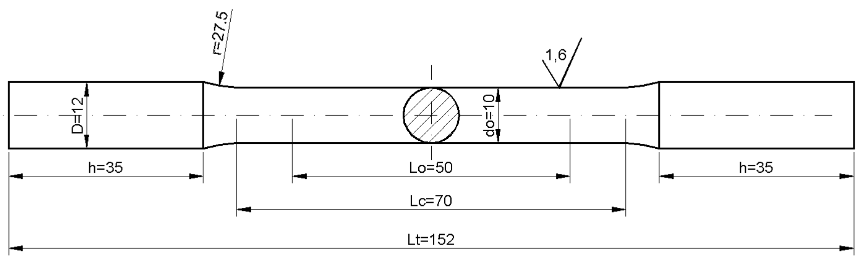


***photo no.16** - Test piece sizes*

Comparative values imposed *Table no. 9*

Value of the mechanical characteristic imposed by the “Terms of reference for railway heavy rails” approved by REFER in 1994	**R_M** [N/mm^2] (resistance at breaking)	**A_5 [%]** (elongation associated to breaking)
Steek mark: 900A	880…1030	min. 10
Steek mark: M 74 T	min. 1098	min. 10
Thermally treated steel	Min- 1190	Min.10

b. Test performed in the laboratory of the Faculty of Mechanical Engineering Iasi

There were manufactured 3 test pieces of each of the 4 little coupons used by the specialized department of SC Chambon SRL. (photo no. 17)

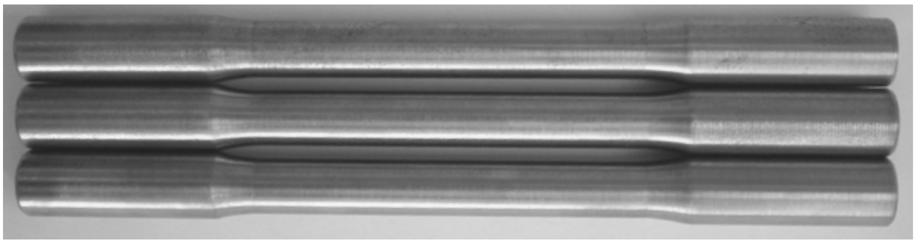


***photo no. 17** – test pieces before the test*

There was used a testing at traction device Instron 8801 (photo no.18) which broke by tension the 12 test pieces (photo no. 19).

***photo no. 18** - Testing at traction device*

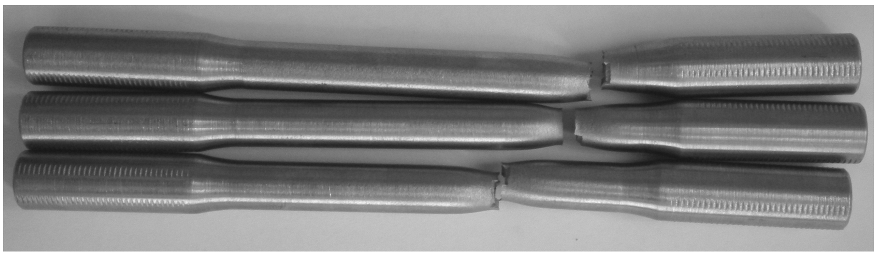


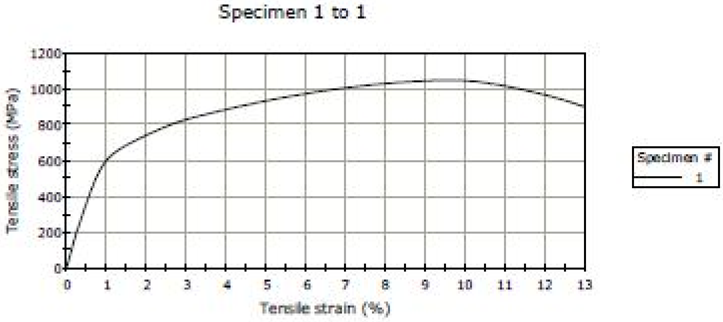
photo no. 19 – Test pieces after the test

For each test piece tested was created a test sheet filled with the plotting of the traction force variation (photo no. 20).

Sina I.1

Proba Compozit

Operator ID	GOANTA
Company	UTI
Laboratory Name	RezMat
Rate 1	2.00000 mm/min
Number of specimens in sample	10
Export raw data	True
Export results	True



	0% of Break (Tensile extension) (mm)	Tensile strain at 0% of Break (Tensile extension) (mm/mm)	Tensile stress at 0% of Break (Tensile extension) (MPa)	Tensile extension at Break (Standard) (mm)
1	0.00000	0.00000	0.26883	8.96671

	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Break (Standard) (MPa)	Energy at Break (Standard) (J)	Energy at 0% of Break (Tensile extension) (J)
1	0.13063	890.94879	620.53115	0.00000

	Energy at Maximum Tensile extension (J)	Tensile strain at Maximum Tensile extension (mm/mm)	Tensile stress at Maximum Tensile extension (MPa)	Energy at Yield (Zero Slope) (J)
1	620.53115	0.13063	890.94879	445.09791

	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	UYS at YPE/ Ae (Automatic) (MPa)	Modulus (Automatic) (MPa)
1	0.09734	1045.79419	-----	40091.28608

	Tensile strain at Tensile Strength (mm/mm)	Tensile stress at Tensile Strength (MPa)	Energy at Tensile Strength (J)
1	0.09105	1043.24426	410.01239

***photo no. 20** – sheet of the rail coupon I1*

For the 12 tested samples were obtained the resistance to breaking and the elongation. The values of resistance to breaking were under the minimum level of 1190 N/mm^2 (MPa) and the elongation exceeded the value of 10%.

Determining the chemical composition of the material by spectral analysis

The tests were performed in two different laboratories with different equipment at AFER and at the Faculty of Mechanical Engineering in Iasi.

a. Test performed in the AFER laboratory

The test was performed according to the STAS 11464-80 “Steel and iron. Spectro-chemical analysis”, point 2. The method is based on the automatic processing of spectra obtained by electric spark excitation of the sample in a controlled atmosphere. Radiant energy of the analytical lines is measured with photoelectric transducers that provide signals proportional to the concentration of the elements in the sample.

To determine the chemical composition were used 2 samples from the rail head B, where the analysis was performed on the superficial layer of the railhead, and on the middle of the railhead section of each of the 7 rails.

There was used a Spectometer with optical emission Foundry Master 01G0055.

The samples taken from the slice B, that contains the breaking surface, were the only ones that shown a thickness of material deposited on the running surface sufficient to determine its chemical composition. There resulted the chemical composition from table 10.

Chemical composition at the running surface ***Table no.10***

Rail head sample	Determined values [%]										
	C	**Mn**	**Si**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Cu**	**V**
B1.1	0.80	11.0	0.78	0.02	0.01	0.003	0.03	2.88	0.30	0.02	0.006
B1.2	0.78	11.3	0.83	0.02	0.02	0.003	0.03	3.05	0.30	0.02	0.009

The values of the chemical compounds from the material layer deposited on the running surface are similar to the chemical composition of the manganese austenitic steel (STAS 3718-76).

Manganese austenitic steel ***Table no. 11***

Chemical element	**Carbon**	**Manganese**	**Silicium**
	0.9…1.2	11.5…13.5	0.5…1.0

The chemical composition of the material from the layer deposited on the running surface lead to the conclusion that on the running surface of the rail head was an intervention by welding using an austenitic stainless steel electrode.

The chemical analysis on the middle of the section through the rails head:

The chemical composition in the middle of the section through the rail head ***Table no. 12***

Rail head sample	Determined values [%]										
	C	**Mn**	**Si**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Cu**	**Ti**
A	0.76	0.87	0.27	0.017	0.022	0.034	0.005	0.036	0.0046	0.043	0.022
B	0.74	0.82	0.25	0.017	0.011	0.045	0.005	0.048	0.0029	0.044	0.018
C	0.76	0.84	0.23	0.015	0.028	0.047	0.012	0.007	0.0017	0.066	0.015
D	0.77	0.88	0.22	0.022	0.031	0.038	0.006	0.053	0.0023	0.060	0.016
E	0.72	0.87	0.27	0.018	0.020	0.035	0.005	0.037	0.0035	0.047	0.018
F	0.72	0.82	0.25	0.013	0.022	0.044	0.005	0.048	0.0028	0.043	0.018
G	0.75	0.84	0.23	0.015	0.030	0.047	0.012	0.077	0.0020	0.066	0.015

Comparative values imposed ***Table no. 13***

Values imposed for the chemical composition by "Terms of reference for railway heavy rails" approved by REFER in 1994 [%]						
Chemical element	**C**	**Mn**	**Si**	**P**	**S**	**Ti**
Steel mark: 900A	0.60…0.80	0.80…1.30	0.10…0.50	max. 0.04	max. 0.04	-
Steel mark: M 74 T	0.67…0.80	0.75…1.05	0.18…0.40	max. 0.035	max. 0.04	0.007…0.025

The chemical composition confirms that the steel in the tested coupons is equivalent with the mark 900A.

b. Test performed in the laboratory of the Faculty of Mechanical Engineering Iasi

The chemical composition of the four samples taken from the coupons 2 I, 2 II, 2 III and 1 IV, made by the specialized department of SC Chambon SRL was determined using the spectrometer with optical emission ARL 3460.

Chemical composition ***Table no.14***

Sample coupon no.	Determined values, [%]										
	C	**Mn**	**Si**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Cu**	**Ti**
2 I	0.7674	0.8399	0.2474	0.0100	0.0261	0.0401	0.0061	0.0381	0.0040	0.0208	0.0155

2II	0.7802	0.8465	0.2212	0.0136	0.0295	0.0428	0.0177	0.0694	0.0037	0.0375	0.0126
2III	0.7834	0.876	0.2566	0.0194	0.0262	0.0277	0.0051	0.0247	0.0044	0.0208	0.0160
1IV	0.8329	0.923	0.2208	0.0222	0.0389	0.0333	0.0073	0.0459	0.0037	0.0348	0.0136

It is found that in the case of the sample taken from the coupon 1 IV the carbon concentration (0.8329) is not within the limits imposed for the steel 900 A.

Macroscopic and macro-graphic metallographic analysis

The tests were performed in AFER laboratory.

For the macro-graphic analysis was used a cross slice, on which surface was performed the Baumann test, in order to highlight the possible segregation of sulfur.

At most of the samples was found a relatively uniform repartition of the sulfur on the section and a segregation of sulfur positive and negative, small, central, in heart element.

For the macroscopic analysis were used, additional to the cross slices that contain the breaking surfaces (from the rails A, B and C), a cross slice from all the coupons, on which surface was performed the hot attack in solution 50% HCl, in order to highlight the possible defects of material (gaps, macro-shrinkage pipes, macro-segregations, flakes, nonmetallic inclusions etc.) or hot plastic deformation (overlaps of material, cracks etc). The test was performed according to STAS 11961/1-83 „Metalography. Methods of highlighting and appreciating the steel macro-structure”.

For the tests from the coupon A and C in the breaking section of the rail in the path one found the following:

In the rail-head associated to sample A1 it is noticed an area of **breaking at fatigue** (with fine granulation, in two shades of gray) on about 20% of the breaking surface. The last portion of the breaking, with large granulation, is characteristic to a sudden breaking.

photo no. 21. *– Sample coupon A1*

photo no. 22. *– breaking outbreak at fatigue sample A1*

The breaking outbreaks at fatigue consisted of cracks started and developed from the running surface.

In the rail-head associated to sample C1 it is noticed an area of breaking at fatigue (smooth) on about 12% of the breaking surface. The last portion of the breaking, with coarse granulation and material bond, is characteristic to a sudden breaking.

photo no. 23. *Sample coupon C1*

photo no. 24. – *Breaking outbreak at fatigue sample C1*

The breaking outbreaks at fatigue consisted of cracks approximately parallels to the running surface, started and developed at a depth of 3…5 mm under the surface of the rail-head.
It is confirmed that the rail breakings that have in the breaking section areas with fine granulation, in shades of gray correspond to an area of **breaking at fatigue**.

For the samples taken from the body of the 7 coupons it was highlighted an area with thermal treatment applied at the upper half of the rail-head highlighted through a concave dark color band of about 7…10 mm thickness.

photo no.25. *– sample coupon B2*

Microscopic metallographic analysis
The tests were performed in two different laboratories with different equipment at AFER and at the Faculty of Mechanical Engineering in Iasi.

a. Test performed in AFER laboratory
The analysis was performed with a metallographic microscope AXIOVERT 200 MAT, according to STAS 4203-74 “Metalography. Sampling and preparation of metallographic samples”, STAS 7626-79 “Metalography. Microstructures. Standard scales for steel” and ISO 4967:1998 “Steel. Determining the content of non-metallic inclusions. Micrographic method with standard-images”.
On the surfaces of the samples taken from the cross slices that contain the breaking surfaces (from the rails marked with no. A, B) and from the slices that contain the macro defects the most significant, one followed:
- the microstructure aspect, starting from the running surface of the rail-head towards the heart element;
- the presence of possible defects at the running surface (structural modifications, decarburizations, cracks) or of thermal treatment.
- the purity level of the material, expressed through the content of non-metallic inclusions, evaluated according to ISO 4967:1998.
The conditions imposed at the microscopic inspection refer only at the hardened area for the rails thermally treated. The structure of the hardening area has to be built of spoon pearlite or bainite**.**
There were performed tests on samples from all the 7 rail coupons. There was checked the microstructure at the running surface, the microstructure in the area of superficial thermal treatment, the microstructure in the middle of the rail-head and the purity level of the material.

For the rail A were found micro-cracks on the depth of 0,040 mm and lengths of 0,102 mm on a harden structural fund, oriented obliquely and parallel to the running surface (photo no. 26), a white layer of thermal hardening with the average thickness of the white layer of 0,021 mm (photo no. 27)

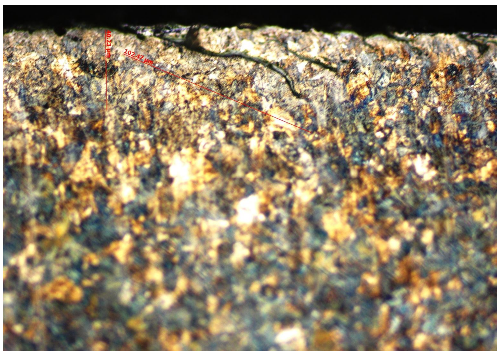


***photo no. 26** – (200:1)*

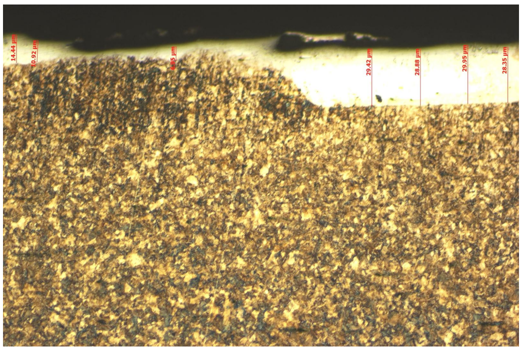


***photo no. 27** – (100:1)*

The structure in the area of thermal treatment is built of signs of interrupted network of ferrite on pearlite fund, which proves an incomplete hardening (photo no. 28) and in the middle of the rail-head the structure is built of lamellar pearlite, placed in rosettes, specific to a material subjected to a normalizing thermal treatment (photo no. 29)

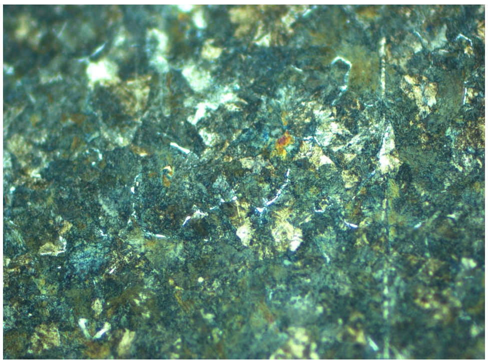


***photo no. 28** - 500:1*

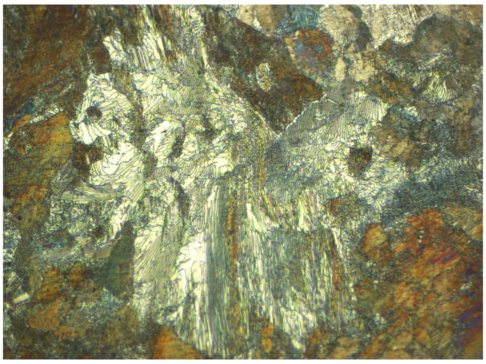


***photo no. 29** - 500:1*

For the rail B was found at the running surface deposited material successively by welding, with structure made of columnar grains of austenite + interrupted networks of carbides, specific to a manganese austenitic steel (photo no. 30) and immediately under the layer of deposited material, it can be observed a crack approximately perpendicular with the length of 1.065 mm (photo no. 31). The decarbonized edges of the crack prove that:

- the crack could occur before the appliance of the superficial thermal treatment;
- the crack could occur before the process of loading with welding.

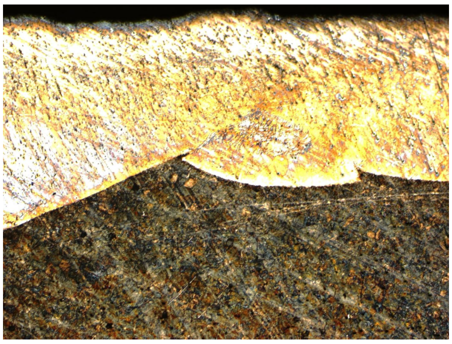


photo no. 30 - *50:1*

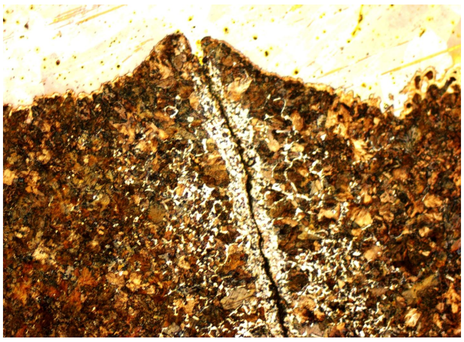


photo no. 31 -*100:1*

The structure in the area of thermal treatment consists of signs of interrupted network of ferrite in pearlitic substance, which proves a thermal treatment of incomplete hardening (photo no. 32) and in the middle of the rail-head the rail is made of lamellar pearlite, ordered in rosettes, specific to a material subjected to a normalizing thermal treatment (photo no. 33)

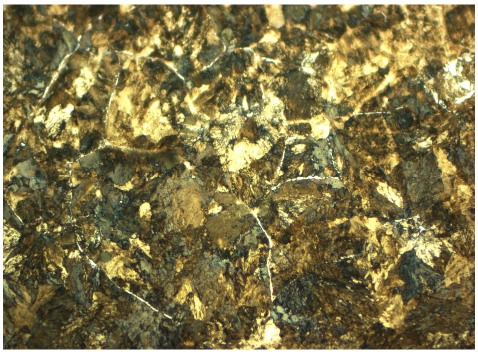


photo no. 32 - *500:1*

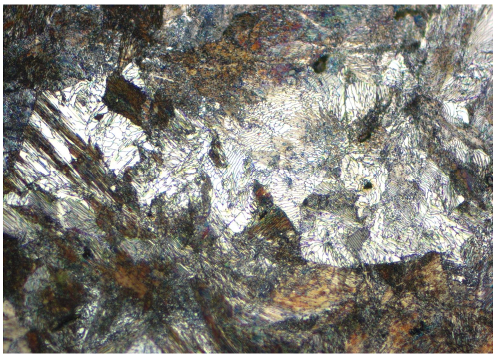


photo no. 33 -*500:1*

For the rail C was found at the running surface deposited material successively by welding, with structure made of columnar grains and numerous cracks that cross the deposited material and the areas thermally influenced by welding (photo no. 34). On the rail-head flanks, the decarburization had the average thick of 0.329 mm (photo no. 35).

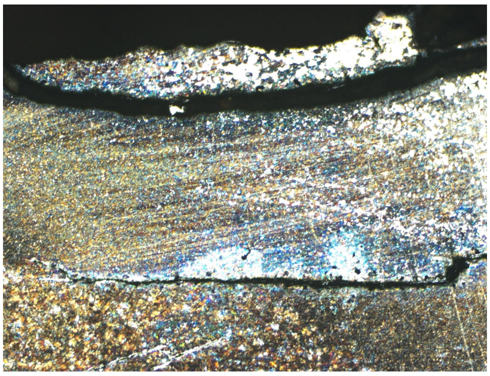


Fig. 34 - *50:1*

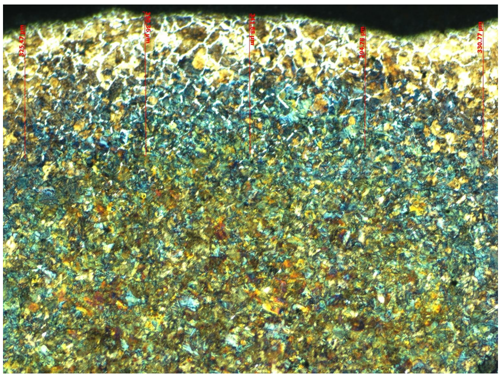


Fig. 35 -*100:1*

The structure in the area of thermal treatment consists of signs of interrupted network of ferrite in pearlitic substance, which proves a thermal treatment of incomplete hardening (photo no. 36) and in the middle of the rail-head the structure is built of lamellar pearlite, placed in rosettes, specific to a material subjected to a normalizing thermal treatment (photo no. 37).

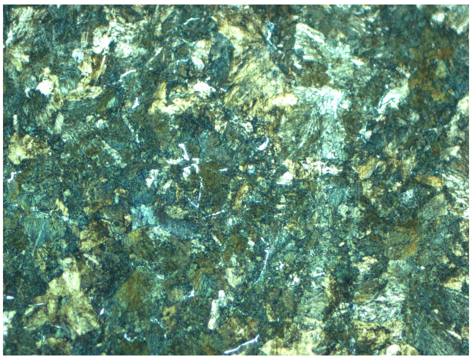


photo no. 36 ***- 500:1***

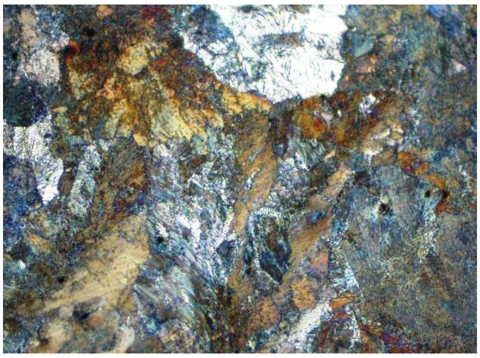


photo no. 37 ***-500:1***

For the rail D was found at the running surface a slightly hardened structure of sorbitized pearlite, obtained after the thermal treatment of superficial hardening (photo no. 38) and on the rail-head flanks is a slight decarburation with the average thick of 0.300 mm (photo no. 39)

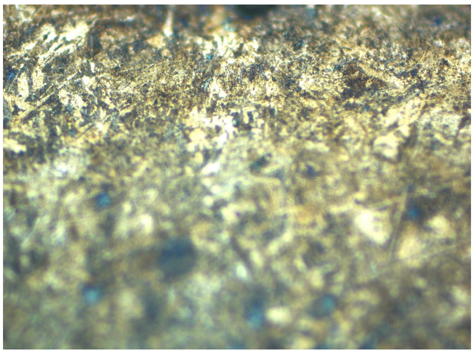


photo no. 38 ***- 500:1***

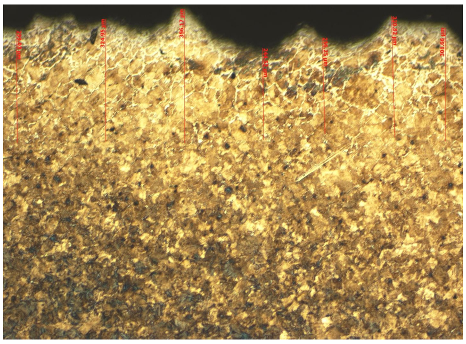


photo no. 39 ***-100:1***

Towards the center of the rail-head section, the structure consists of signs of interrupted network of ferrite in pearlitic substance, which proves a thermal treatment of incomplete hardening (photo no. 40) and in the middle of the rail-head the structure is built of lamellar pearlite, placed in rosettes, specific to a material subjected to a normalizing thermal treatment (photo no. 41)

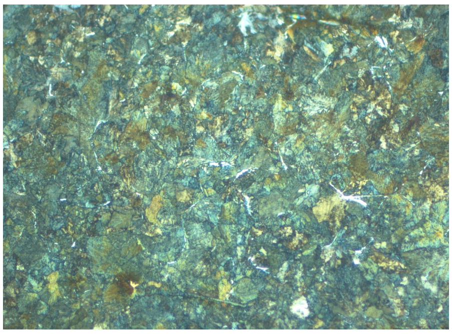


photo no. 40 ***- 500:1***

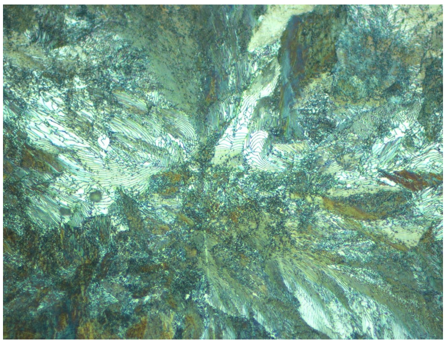


photo no. 41 ***-500:1***

For the rail E was found on the running surface a pearlite structure strongly hardened (photo no. 42) and thermal cracks, opened obliquely to the rolling surface and in the superficial layer, as consequence of the seizure phenomena and thermal hardening (photo no. 43).

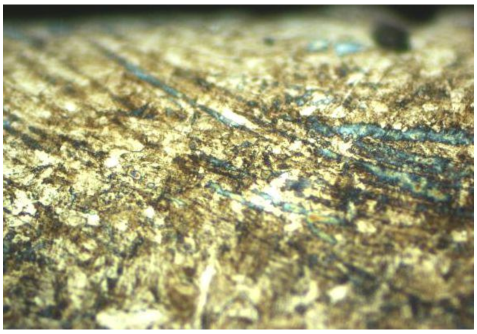


photo no. 42 **-** *500:1*

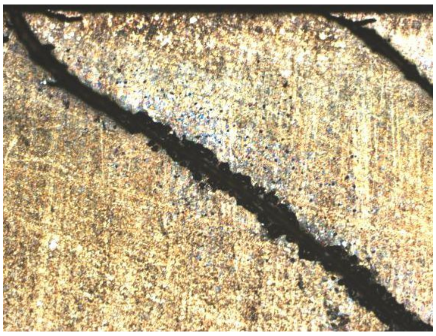


photo no. 43 *-50:1*

In the area of superficial thermal treatment the structure consists of signs of interrupted network of ferrite on pearlite and troostite fund, which proves a thermal treatment of incomplete hardening (photo no. 44) and in the middle of the rail-head the structure is built of lamellar pearlite, placed in rosettes, specific to a material subjected to a normalizing thermal treatment (photo no. 45).

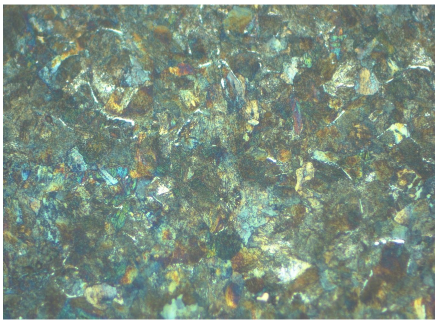


photo no. 44 **-** *500:1*

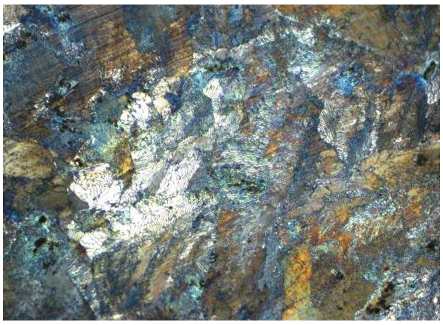


photo no. 45 *-500:1*

For the rail F was found on the running surface a pearlite structure strongly hardened, composed of fine martensite, sorbitized pearlite and troostite, specific to thermal treatment of superficial hardening (fig. 46) and in the area of superficial thermal treatment micro-cracks developed at 2 and 4 mm from the rolling surface (fig. 47).

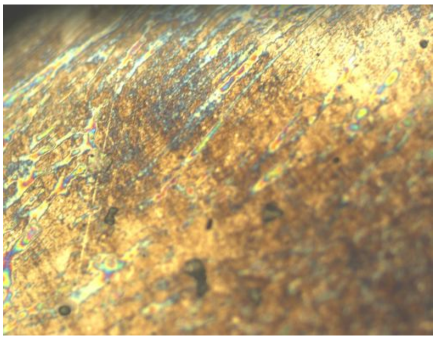


photo no. 46 **-** *200:1*

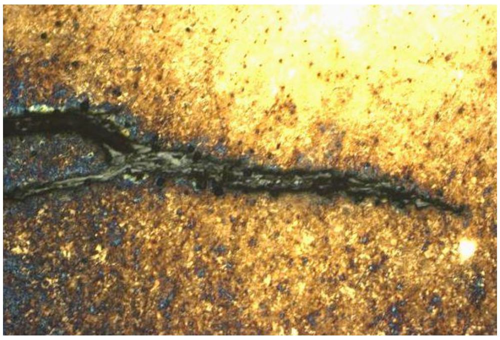


photo no. 47 *-100:1*

For the rail G was found at the running surface a double white layer of thermal hardening with the average thick of 0.175 mm (photo no. 48) and immediately under the running surface are thermal micro-cracks with the length of 0.758 mm (photo no. 49)

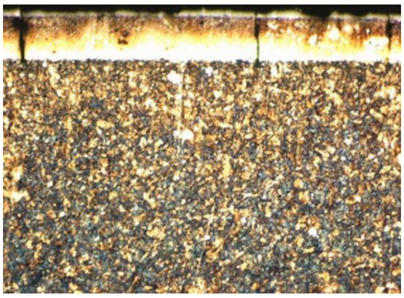


photo no. 48 **-** *100:1*

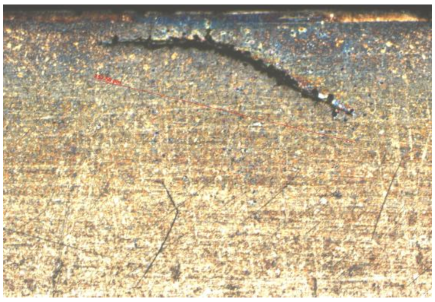


photo no. 49 *-50:1*

In the area of superficial thermal treatment the structure consists of signs of interrupted network of ferrite on pearlite fund and rare rosettes of troostite, which proves a thermal treatment of incomplete hardening (photo no. 50), in the middle of the rail-head the structure is made of lamellar pearlite, ordered in rosettes, specific to a material subjected to a normalizing thermal treatment (photo no. 51).

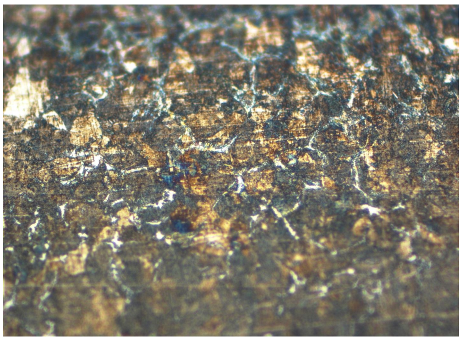


photo no. 50 *- 500:1*

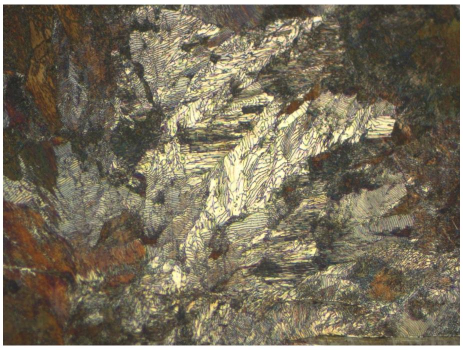


photo no. 51 *-500:1*

For all the studied samples, the purity degree of the material is affected by non-metallic inclusions consisting of rows of sulphides and plastic silicates with score of 1.5.

b. Test performed in the laboratory of the Faculty of Mechanical Engineering Iasi

Taking the samples to determine the microscopic characteristics was made by mechanic cut with overheating avoid. The samples preparation was performed using a metallographic sample preparation system according to the current procedures: planing and sanding the surface to study with sandpaper with grain increasingly smaller (150, 300, 600, 800, 1000, 1200, 2000) followed by polishing with abrasive solution with suspension of $Al2O3$ (with grain of 40 µm) and the attack with natal solution 3.5% to highlight the material microstructure. Taking and preparing the samples was carried out by the specialized compartment of SC Chambon SRL.
To characterize in terms of metallographic the samples taken from the four coupons of rail type R65 was used the scanning electronic microscopy, being used the electronic microscopy type QUANTA 200 3D DUAL BEAM - photo no. 52.
To obtain the images there was used the mode High Vacuum (at pressures within $10^{-3}÷10^{-4}$ Pa) and with an applied tension of 30kV, the sample being mounted on a metallic support.

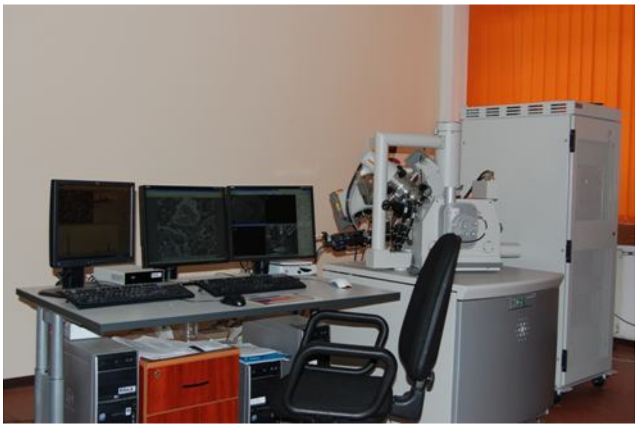


photo no. 52. *Qunta 200 3D Microscope*

photo no. 53. *Sample mounted on the support inside the working box of the Qunta 200 3D microscope*

Sample 2 I 1990

There were analyzed 3 areas of the vertical section through the rail-head – photo no. 54.

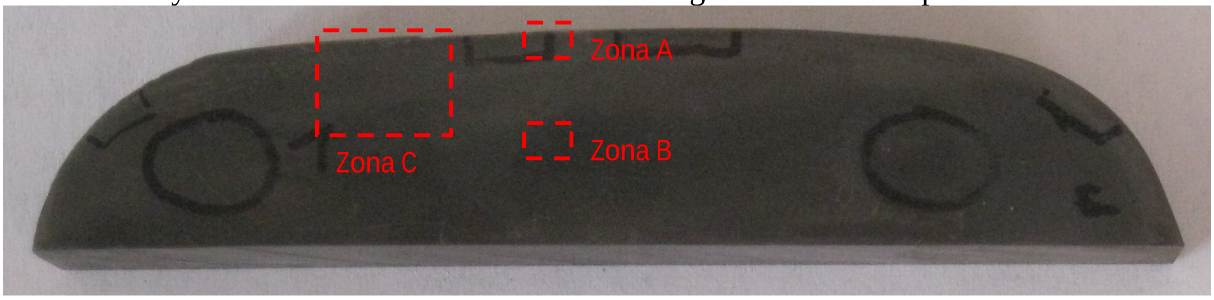


***photo no. 54.** - Sample taken from the coupon 2 I 1990*

a) Area A – the rolling surface of the rail, being prepared microstructures for zooming powers of 600x, 5000x and 10000x, resulting photo no. 55, 56 and 57. It is noticed that along the rolling surface of the rail was observed a combination of black portions, with oxidized areas and small cavities in the material

b) Area B – the core (the rail depth), being prepared microstructures for zooming powers of 600x, 5000x and 10000x, resulting photo no. 58, 59 and 60. It is observed a pearlite structure.

c) Area C – the crack, being prepared microstructures for zooming powers of 38x and 300x, resulting photo no. 61 and 62. In the figure 67 it is observed the distance from the rail surface to the maximum depth of the crack (1.93mm).

In all the three analyzed areas is found the presence of some pores whose diameter varies between 1 and 6 µm.

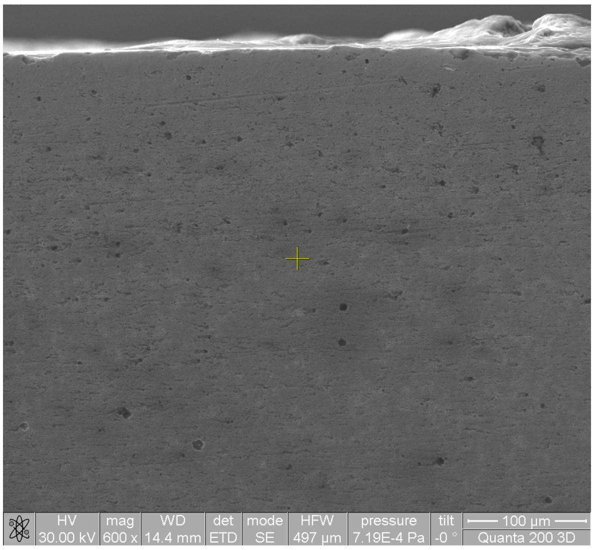


***photo no. 55.** Area A. Microstructure of the rolling surface (600x)*

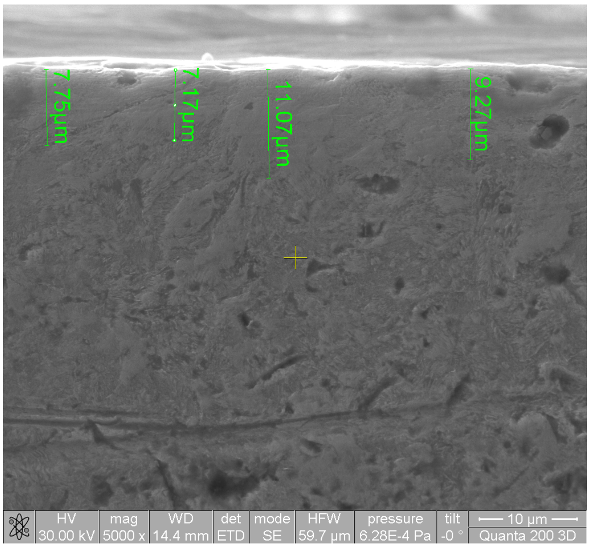


***photo no. 56.** Area A. Microstructure of the rolling surface (5000x). Thickness of the hardened layer*

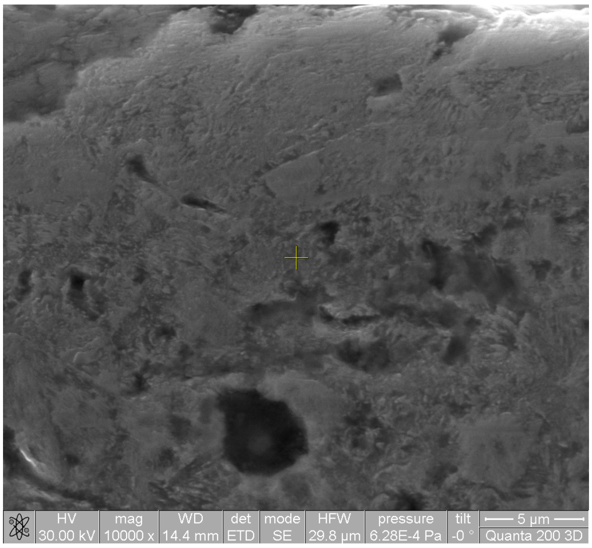


photo no. 57. *Area A. Microstructure of the rolling surface (10000x)*

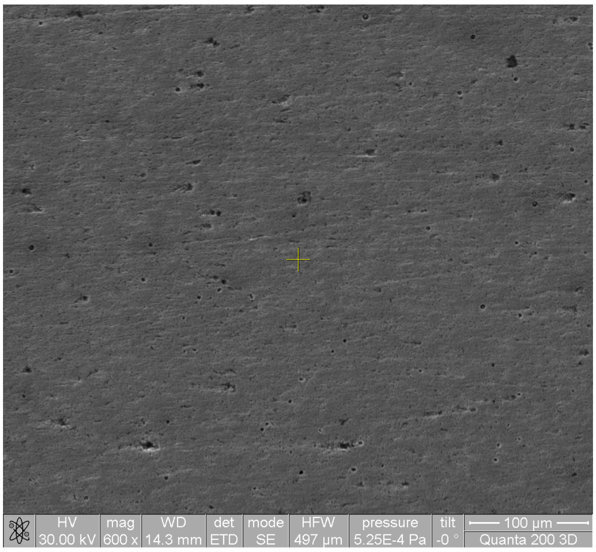


photo no. 58. *Area B. Microstructure of the core (600x)*

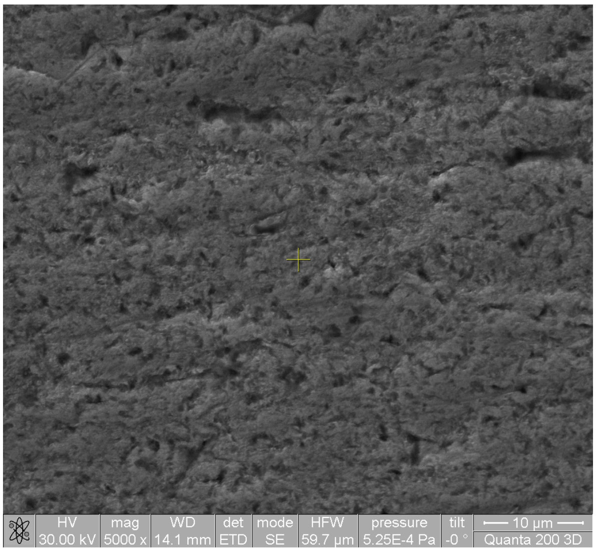


photo no. 59. *Area B. Pearlite microstructure of the core (5000x)*

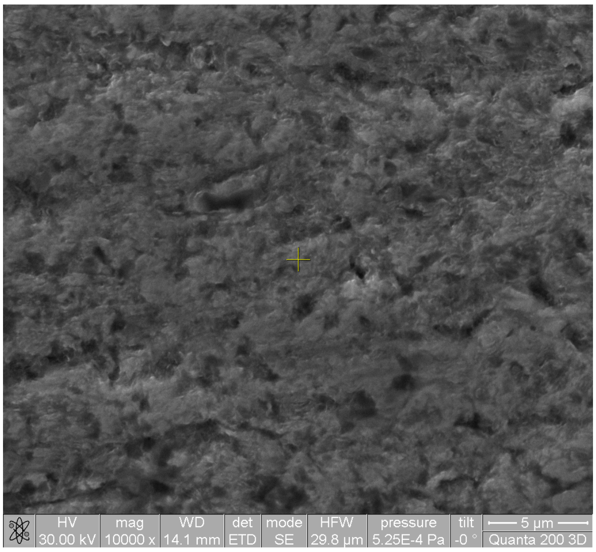


photo no. 60. *Area B. Pearlite microstructure of the core (10000x)*

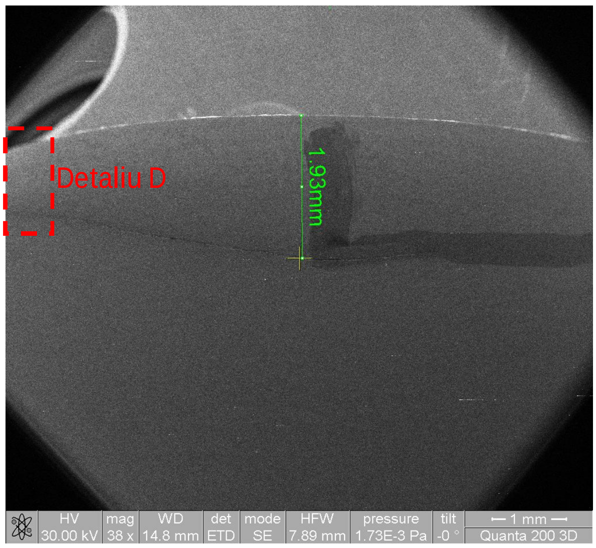


photo no. 61. *Area C. Aspect of the crack placed at 1-2 mm from the rolling surface (38x)*

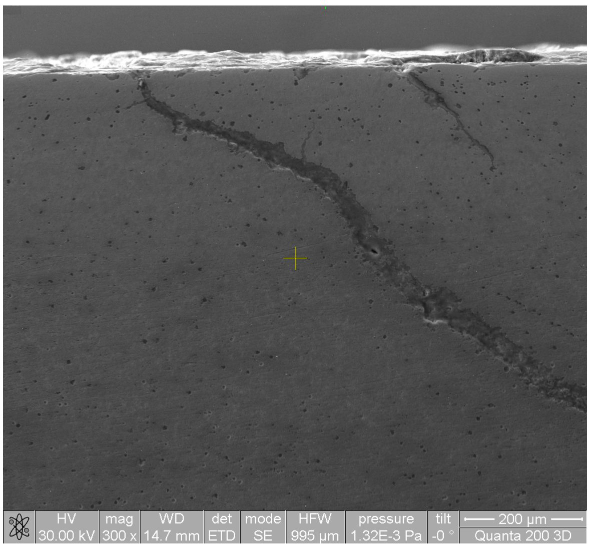


photo no. 62. *Detail D – fig. 10. Aspect of the crack (300x)*

Sample 2 II 1989

There were analyzed 2 areas of the vertical section through the rail-head – photo no. 63.

a) Area A – the rolling surface of the rail, being prepared microstructures for zooming powers of 600x, 2400x, 5000x and 10000x, resulting photo no. 64 and no. 65. It is noticed that the thickness of the hardened layer (with martensite structure) varies between 44 and 51 µm.

b) Area B – the core (the rail depth), being prepared microstructures for zooming powers of 600x, 5000x and 10000x, resulting photo no. 66 and no. 67. It is observed a pearlite structure.

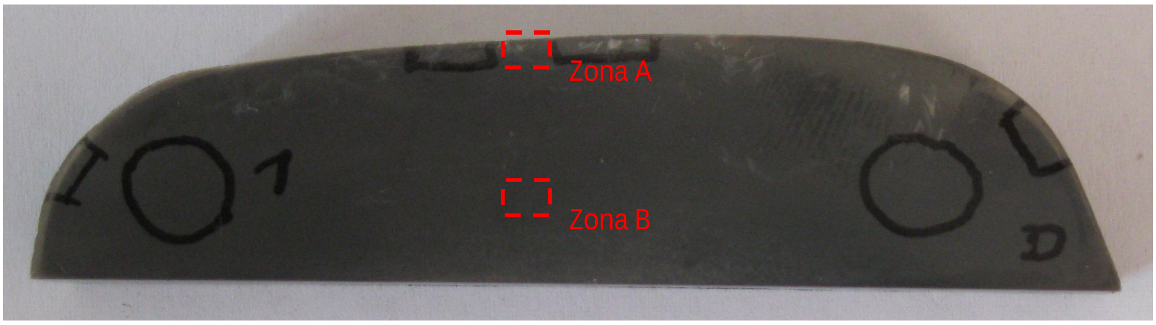


photo no. 63. *Sample taken from the coupon 2 II 1989*

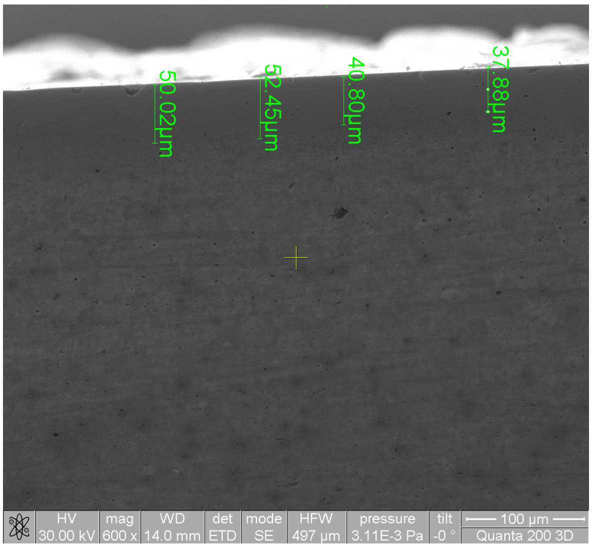


photo no. 64*. Area A. Microstructure of the rolling surface (600x). Thickness of the hardened layer*

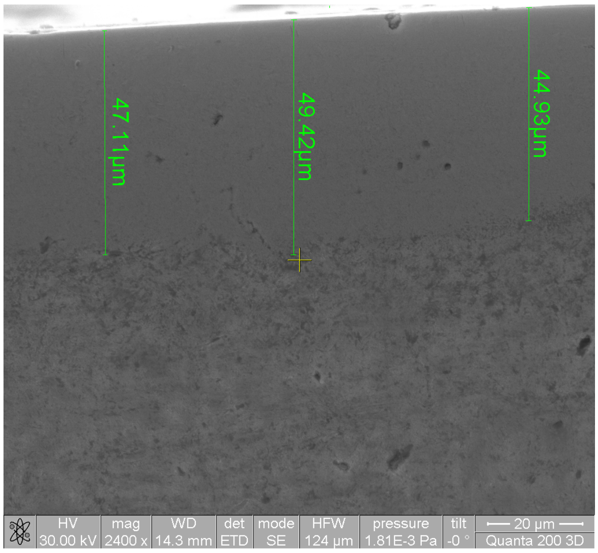


photo no. 65*. Area A. Microstructure of the rolling surface (2400x). Thickness of the hardened layer*

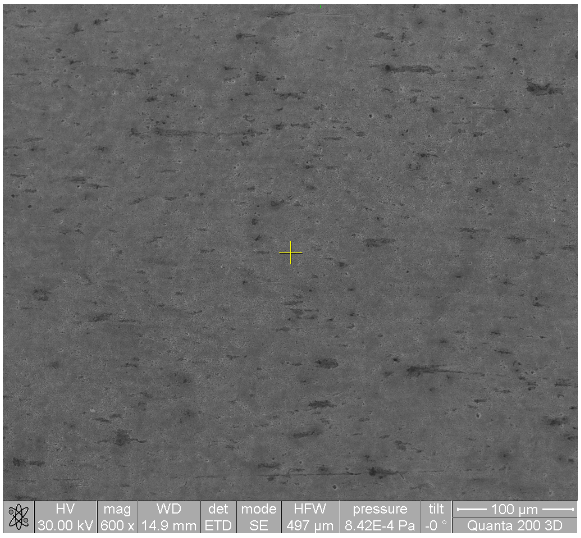


photo no. 66. *Area B. Microstructure of the core (600x)*

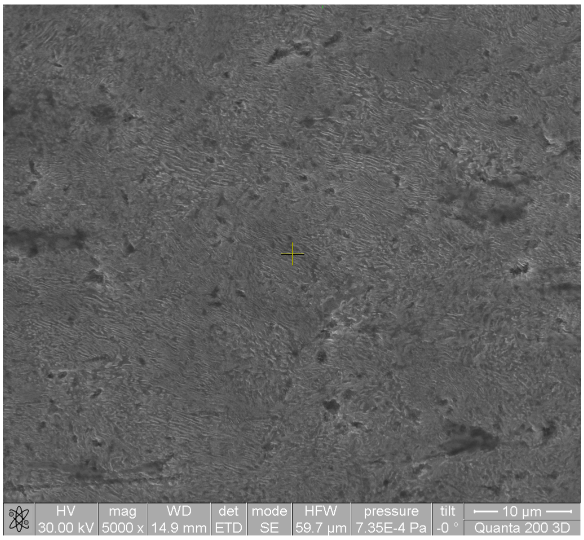


photo no. 67*. Area B. Pearlite microstructure of the core (5000x)*

In the two analyzed areas is found the presence of some pores whose diameter varies between 1 and 6 µm.

<u>Sample 2 III 1990</u>
There were analyzed 3 areas of the vertical section through the rail-head – photo no. 68.
a) Area A – the rolling surface of the rail, being performed microstructures for zooming powers of 600x, 5000x and 10000x, resulting photo no. 69 and no. 70. It is notices that the thickness of the hardened layer (with martensitic structure) varies between 200 and 210 µm. It is also noticed the presence in the hardened layer of a superior layer having the thickness of 12.21 µm.
b) Area B – the core (the rail depth), being performed microstructures for zooming powers of 600x, 5000x and 10000x, resulting photo no. 71 and no. 72. It is observed a pearlite structure.
c) Area C – the crack, being performed microstructures for zooming powers of 38x, 600x and 5000x, resulting photo no. 73 and no. 74. In photo no. 73 is observed the distance from the rail surface to the maximum depth of the crack (3.39 mm).

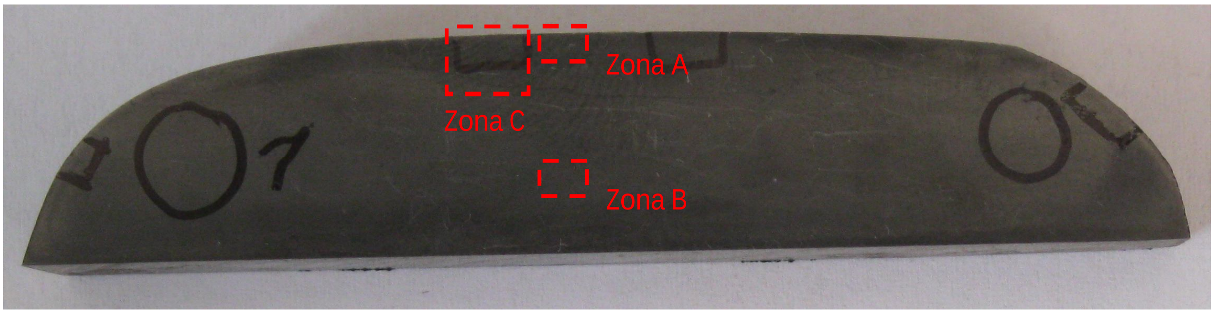


Fig. 68. *Sample taken from the coupon 2 III 1990*

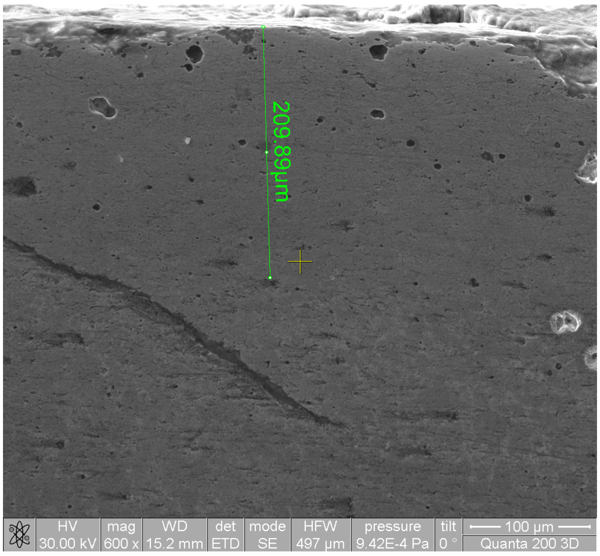


photo no. 69. *Area A. Microstructure of the rolling surface (600x). Thickness of the hardened layer*

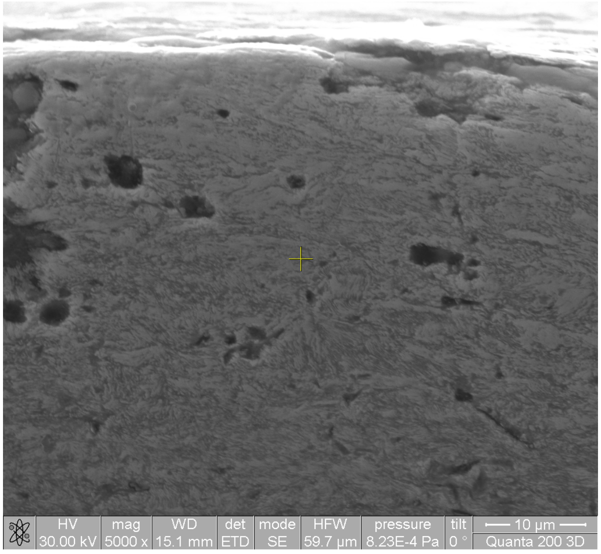


photo no. ***70****. Area A. Microstructure of the rolling surface (5000x).*

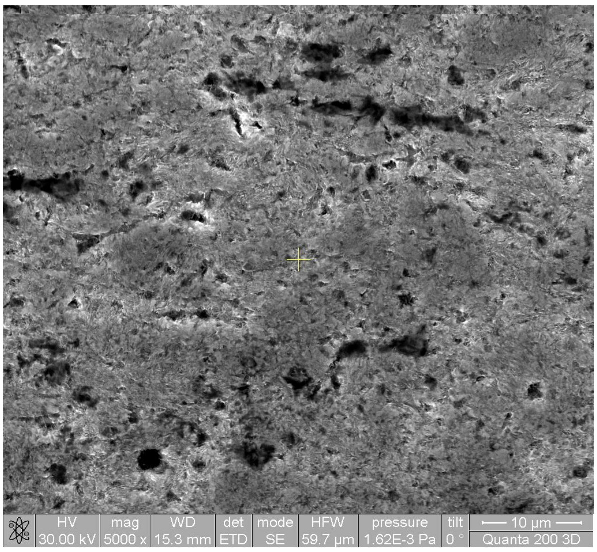


photo no. 71*. Area B. Pearlite microstructure of the core (5000x)*

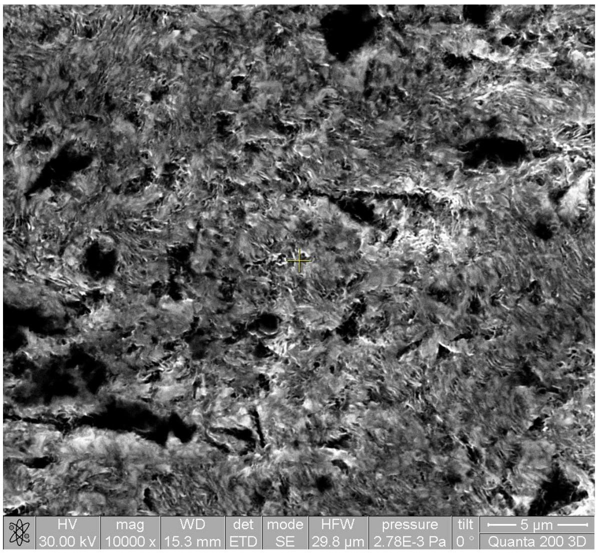


photo no. 72*. Area B. Pearlite microstructure of the core (10000x)*

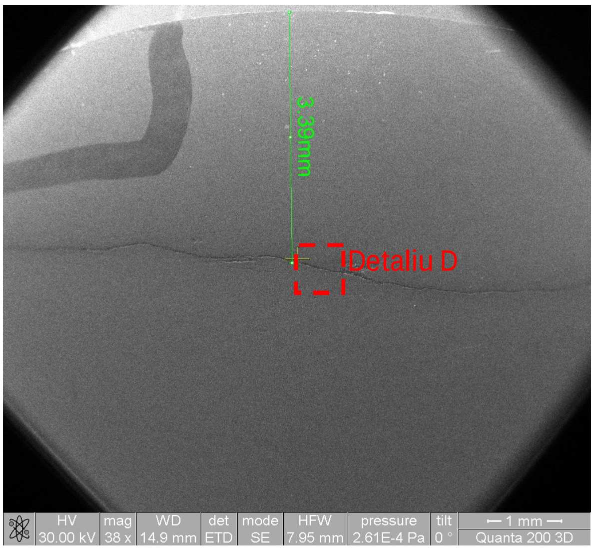


photo no.73. *Area C. Aspect of the crack placed at 3-4 mm from the rolling surface (38x)*

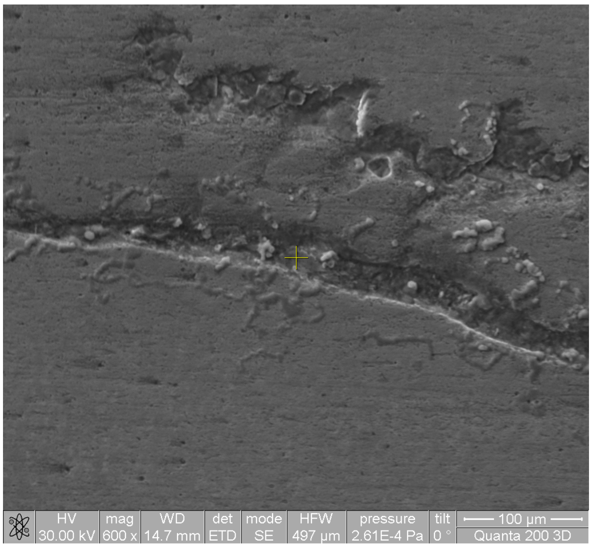


photo no. 74*. Detail D – fig. 21. Aspect of the crack (600x)*

In all the three analyzed areas is found the presence of some pores whose diameter varies between 1 and 6 µm.

<u>Sample 1 IV 1989</u>

There were analyzed 3 areas of the vertical section through the rail-head – photo no.75.

a) Area A – the rolling surface of the rail, being performed microstructures for zooming powers of 600x (two images), 5000x and 10000x, resulting photo no. 76 and no. 77. It is notices that the thickness of the hardened layer (with martensitic structure) varies between 20 and 35 µm.

b) Area B – the core (the rail depth), being performed microstructures for zooming powers of 600x, 5000x and 10000x, resulting photo no. 78 and no. 79. It is observed a classic fine pearlite-ferrite stricture, characteristic to eutectic steel.

c) Areas C, D and E – where are highlighted various portions of the cracks, being performed microstructures for zooming powers of 38x, resulting photo no. 80 and no. 81. In figure 80 is observed the distance from the rail surface to the maximum depth of the crack (5.49 mm). To highlight the thickness of the cracks in this sample, were analyzed the details F, G and H, resulting the figures 89-91

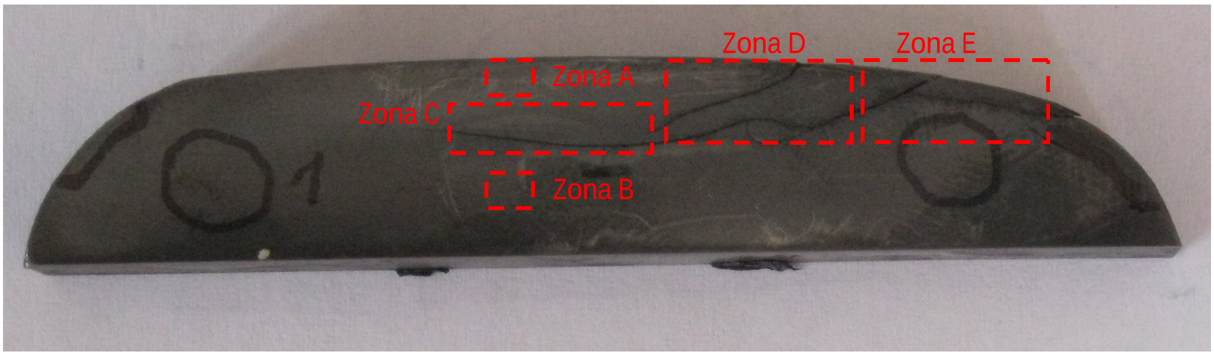


photo no.*75. Sample taken from the coupon 1 IV 1989*

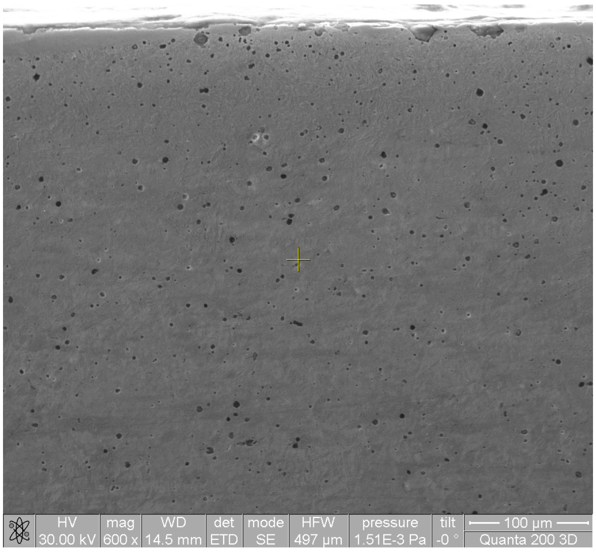


photo no. *76. Area A. Microstructure of the rolling surface (600x)*

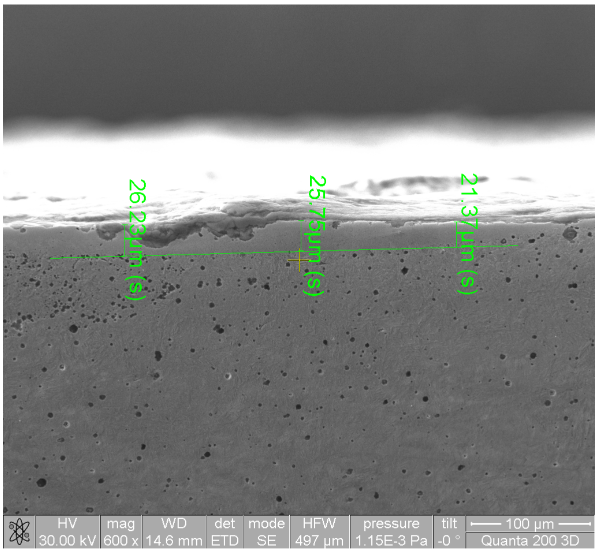


photo no. *77. Area A. Microstructure of the rolling surface (600x). Thickness of the hardened layer*

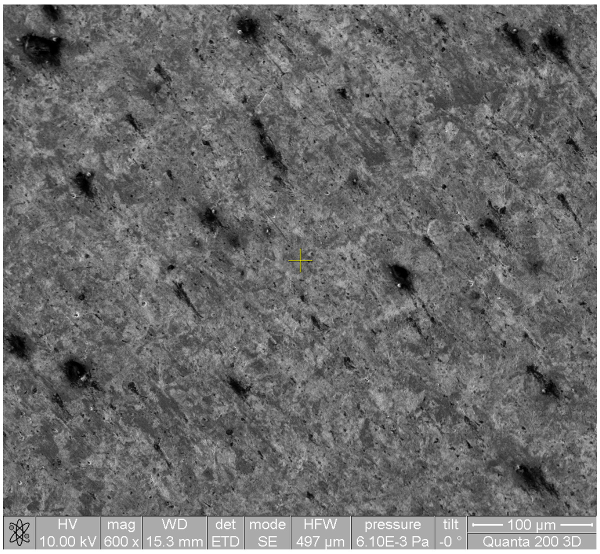


photo no. *78. Area B. Microstructure of the core (600x)*

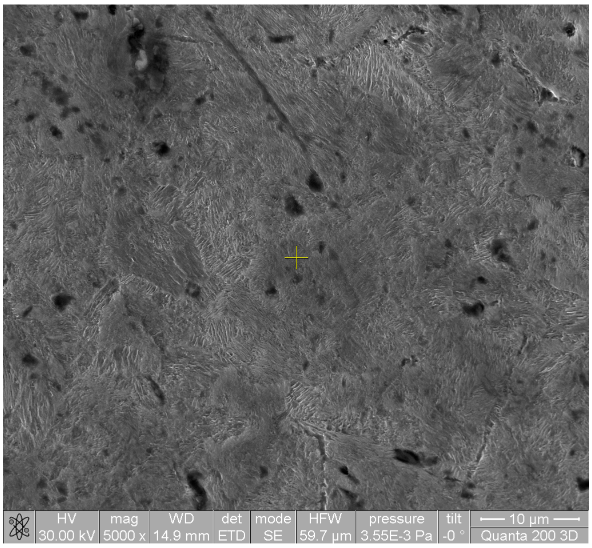


photo no. *79. Area B. Pearlite microstructure of the core (5000x)*

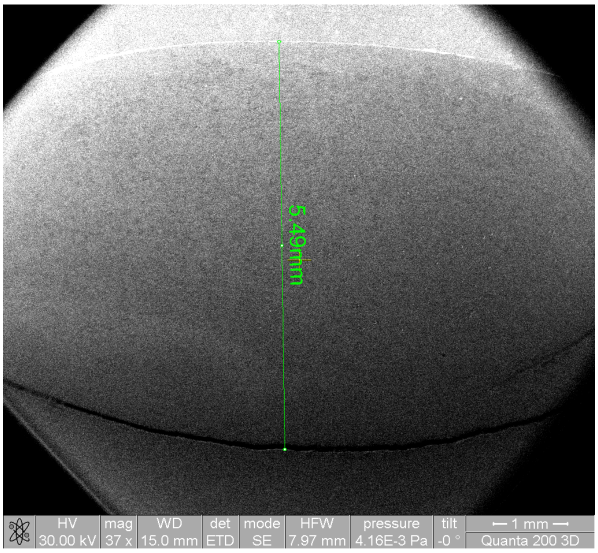


photo no. *80 Area C. Aspect of the crack (24x)*

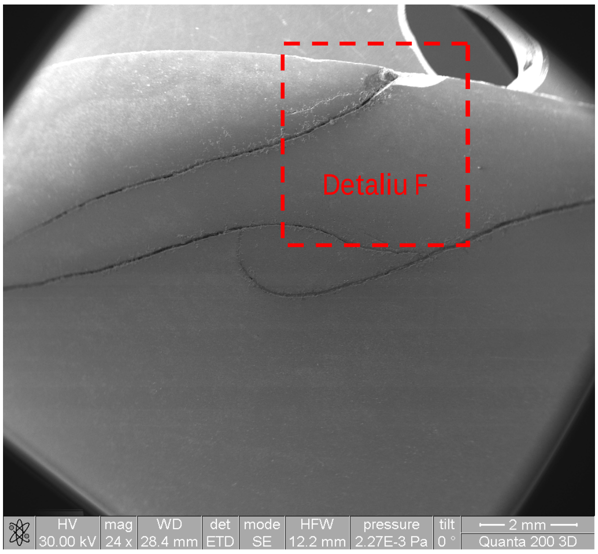


photo no. *81. Area D. Aspect of the crack (24x)*

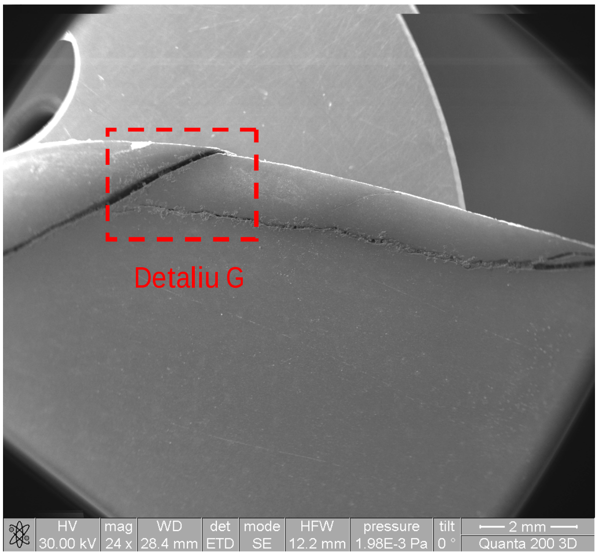


photo no. *82. Area E. Aspect of the crack (24x)*

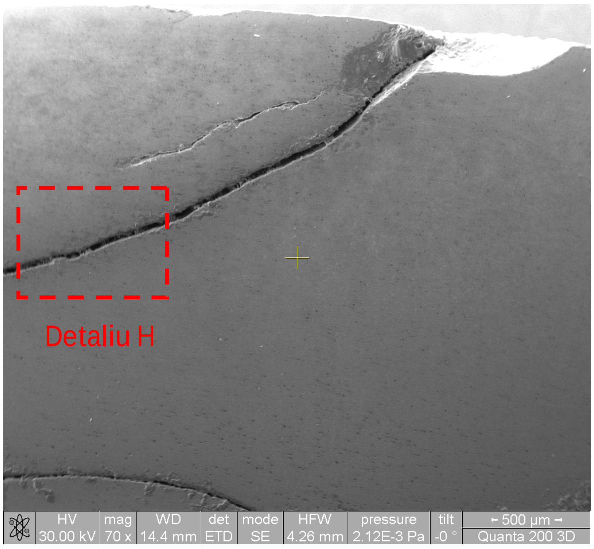


photo no. *83. Detail F – fig. 81. Aspect of the crack (70x)*

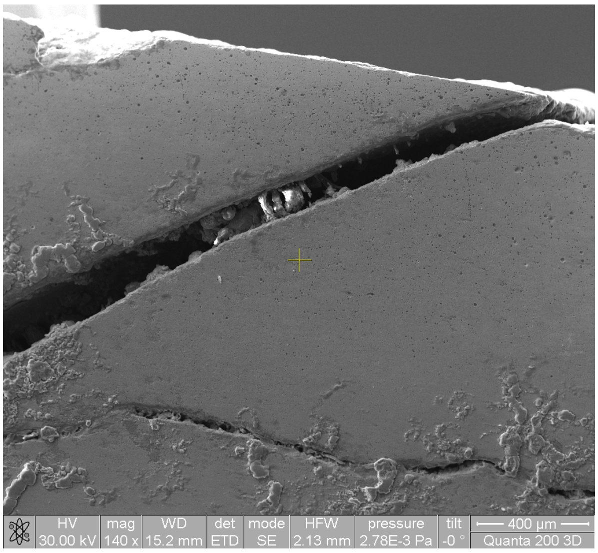


photo no. 84. Detail G – fig.82. Aspect of the crack (140x)

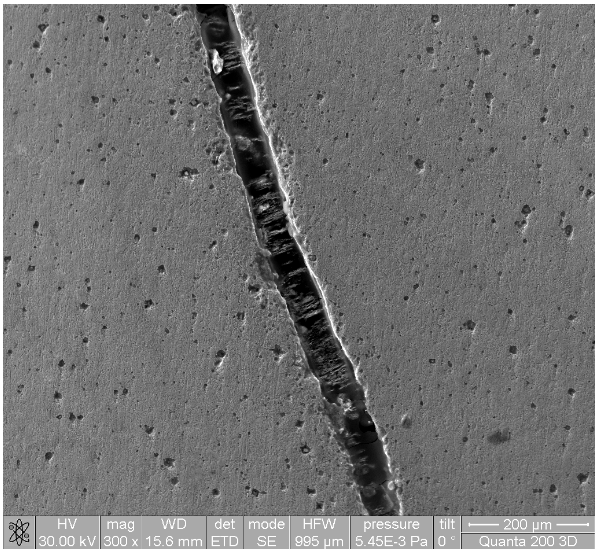


***photo no.** 85. Detail H – fig. 83. Aspect of the crack (300x)*

In all the 5 analyzed areas is found the presence of some pores whose diameter varies between 1 and 6 µm.

For the four analyzed samples, on their entire surface is found a series of pores (with the diameter within 1 and 6 µm), which suggest the existence of some defects at an early stage of rail production (defect of structure of the material to be laminated). Through an EDS analysis performed on these samples was recorded a big quantity of oxygen, which strengthens the assumption of an oxidized area in the material structure, derived from the production phase of the rail. These initial defects, which can be very small, segregated and spread on a bigger surface during operation, under the cyclic action of the rolling stock traffic. This conclusion is reinforced by the fact that the microstructure of the areas on both sides of the crack is similar, with no clear indication of radical changes in the structure.
The cracks on the samples 2 I 1990, 2 III 1990 and especially those on the sample 1 IV 1989 may lead in time, due to operation, to flaking or breaking of the rails.

B.5. <u>Analysis and conclusions</u>

B.5.1. Conclusions on the technical condition of the rails

For all the 11 coupons submitted to the laboratory investigation were obtained the following common data which extrapolated give us information for the rail sections in use, in the path:

- The rail is of steel M-74T thermally treated in the rail-head equivalent to steel 900 A.
- The steel mark was confirmed by the chemical analysis performed through two different methods.
- It is observed that a thermal treatment was applied to the top half of the rail-head highlighted by a concave band of dark color of about 7…10 mm thickness.
- The vertical section in the middle area of the rail-head is a structure consisting of lamellar pearlite, ordered in rosettes, specific to a material subjected to a normalizing thermal treatment.
- The structure in the thermal treatment area consists of signs of interrupted network of ferrite on pearlite fund, which proves an incomplete hardening.
- For all the studied samples, the purity degree of the material is affected by non-metallic inclusions consisting of rows of sulphides and plastic silicates with score 1.5.
- The existence of some cracks parallel to the rolling surface of the rail-head and material detachment at the rolling surface.

- The values for the Brinell hardness correspond to the imposed interval of values M-74T thermally treated in the rail-head equivalent to the steel 900 A.
- The analysis of the samples highlighted that on their entire surface are a series of pores (with the diameter within 1 and 6 µm), which suggest the existence of some defects occurring from the initial production phase of the rail (structural defects of the material to be laminated). *The EDS analysis performed on these samples revealed the presence of large amounts of oxygen, which strengthens the assumption of an oxidized area in the material structure from the initial production phase of the rail.*

From the coupon I, corresponding to the rail broken at km 264+995, was performed investigations on the small coupons I1(A), I3(E) and I2 and was found as follows:

- In the cross section through the core is observed a breaking area at fatigue (fine-grained, in two shades of gray) on about 20% of the entire breaking surface
- The outbreaks of the breaking at fatigue consisted of cracks initiated and developed from the rolling surface
- Along the rolling surface of the rail is observed a combination of black portions with oxidized areas and small cavities in the material
- The resilience values obtained by testing are lower than those imposed by “C.S. for heavy rails of CF” and steel 900A
- The breaking resistance values obtained by testing are lower than those imposed by “C.S. for heavy rails of CF” and steel 900A thermally treated

From the coupon II, corresponding to the rail broken at km 248+280, was performed investigations on the small coupons II1(B), II3(G) and II2 and was found as follows:

- The breaking area is 100% sudden, with more pronounced appearance of material detachment in the rail-head element
- Close to the breaking, on the rolling surface, are 2 goals with diameters between 1.5…3mm.
- Along the rolling surface of the rail was observed an alternation of black portions with oxidized areas
- At the rolling surface is a crack and material detachment, spread on band of thermal influence of 4…5 mm thickness
- Material deposited successively by welding, with structure consisting of austenite columnar grains and interrupted cables networks, specific to a manganese austenite steel.
- The resilience values obtained by testing are lower than those imposed by “C.S. for heavy rails of CF” and steel 900A
- The breaking resistance values obtained by testing are lower than those imposed by “C.S. for heavy rails of CF” and steel 900A thermally treated

From the coupon III, corresponding to the rail broken at km 264+920, were performed investigations on the small coupons III1(C), III3(F) and III2 and was found as follows:

- In the core element is observed a breaking at fatigue area (smooth) on about 12% of the entire breaking surface.
- The last portion of the breaking, with coarse grain and pull of material, is represented by the sudden breaking.
- The outbreaks of the breaking at fatigue consisted of cracks almost parallel to the rolling surface, initiated and developed under a layer of material of 3…5 mm thickness from the rail-head surface.
- At the rolling surface is observed material deposited successively by welding, with structure of primary crystallization consisting of columnar grains.
- Numerous cracks that cross the deposited material and the areas thermally influenced by welding.
- As the removal of the rolling surface, it emphasizes the structural heterogeneity, becoming predominant martensite + troostite.

- Rail-head outline affected by flaking and pulling of material from the rolling surface of the rail-head.
- It is observed also a dark colored band at the rolling surface, with thickness of 2…3 mm.
- The resilience values obtained by testing are lower than those imposed by "C.S. for heavy rails of CF" and steel 900A
- The breaking resistance values obtained by testing are lower than those imposed by "C.S. for heavy rails of CF" and steel 900A thermally treated

From the coupon III, corresponding to the rail broken at km 260+370, was performed investigations on the small coupons IV2(D), IV1 and was found as follows:

- At the rolling surface the structure is slightly hardened by sorbitized pearlite, obtained through the thermal treatment of superficial hardening.
- Signs of flaking and material crumblings, based on which there is also a crack parallel to the rolling surface of the rail-head.
- The distance from the rail surface to the maximum depth of the crack is of 5.49 mm.
- The resilience values obtained by testing are lower than those imposed by "C.S. for heavy rails of CF" and steel 900A
- The breaking resistance values obtained by testing are lower than those imposed by "C.S. for heavy rails of CF" and steel 900A thermally treated

B.5.2. Conclusions on the failures occurrence in the rails

- The results obtained at the tests performed on the 11 rail small coupons lead to unfavorable conclusions for the manufacturing technology.
- The occurrence of the mocro-cracks at the rolling surface of the rails is a consequence of the material fatigue.
- The modification of the steel structure at the rolling surface under traffic led to the occurrence of the phenomenon of ondulatory wear.
- The ondulatory wear developed over time due to the traffic since the first introduction in the path till the failures occurrence.
- The addition of material by welding at the rolling surface of the rails, by using inappropriate electrodes and noncompliance with the technological process of reconditioning by welding, may lead to the acceleration of the phenomenon of degradation of the rail condition by modification of the metalo-graphic structure and also of the physical-mechanic properties of the rail-head.

B.6. Direct cause, contributing factors and root causes

B.6.1. Direct cause

The direct cause of the occurrence of the two technical failures of the interoperability constituent "rail" was the decrease of the resistance to breaking of the rails under the conditions of application over time of several variable loads from the traffic that led to the rails breaking, at the tensions lower than the resistance to breaking of the steel in the rails.
The breaking occurring under the conditions of application over time of several variable loads is a fatigue breaking.
The steel fatigue from the rail consists of the occurrence and the development of the cracks in the contact area wheel-rail and of the plastic deformations associated with the hardening phenomena.
The nature and especially the evolution of the failures indicated that they have as cause the material fatigue (steel) by repeated dynamic stresses.

B.6.2. Underlying causes

1. Non compliance with the provisions of the art. 21, point 1 of the Instruction of standards and tolerances for the construction and maintenance of the rail - standard gauge lines no. 314/1989, providing that it is not allowed the maintenance in the path of the rails with I

category defects, these having to be replaced as soon as possible, respectively in maximum 5 days from the observation.

2. Non compliance with the provisions of the *Instruction to determine the rails failures and to check the rails in the path no. 306/1972*, regarding the measures to be taken when there is identified the defect type 20, respectively: *"From the broken rail will be sent a sample to the Institute of transports Studies and Research for analysis and DGLI will ask to be taken measures based on the results"*.

B.6.3. Root causes

None.

D. SAFETY RECOMMENDATIONS

The addressee of the safety recommendations is the National Railway Company "CFR" S.A as manager of the railway infrastructure.

The recommendations aim to solve the following issues:

1. On the lines which superstructure is built with rails type R65 manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991, until the performance of the rails rehabilitation works, it is recommended to avoid the performance of the works of stuffing, shifting, dynamic stabilization and mechanized sifting with heavy rail machines in order not to determine the occurrence of the failures by the dynamic stresses transmitted by the machines to the rails during the technological process.
2. Avoiding the performance of weld repairs of the rails surfaces with defects under the conditions in which the material of which they are made is affected by the fatigue process.
3. Addition to the provisions of the instruction no. 306/1972:
   - by introducing in the current classification of the rails failures the defects caused by the fatigue phenomenon and of the terms existing in the document UIC no.712 to define the rails failures with the defects caused by the fatigue phenomenon (ex. squats, head checks, shelling, belgrospis);
   - with methods of identification, checking, monitoring over time and correction of the ondulatory wear;
   - with the establishment of the running conditions depending of the rails defects category.
4. Introducing in the nomenclator of rails maintenance and repairs works, included in the current instructions, the works and the technological processes regarding: the grinding, the milling or the planning of the rails within the maintenance works.

Measures regarding the rail type R65manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991

1. The inventory on the entire railway network of the line sections built with rail type R65 manufactured by Azovstal from Ukraine (the ex URSS) during the period 1989-1991, their detailed check to identify any rails with defects similar to those occurred on the line Adjud-Bacau and therefore setting measures to be taken to insure railway safety.
2. Identify the rail devices that had been built with rails having the same manufacturer and therefore setting measures to be taken to insure railway safety.

This investigating report will be sent to the public railway infrastructure manager the National Railway Company “CFR” S.A and to the Romanian Railway Safety Authority.

Members of the investigation commission:

Eduard Stoian - main investigator...................................

Dumitru Sfârlos - investigator...

Radu George Pipa - investigator...

Petre Schipor - investigator...

Constantin Bărbință - investigator...