

# Determining the degradation in-service of mechanical characteristics of railroad tracks type “65 SB”

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**Abstract.** This paper focuses on highlighting eventual degradations of mechanical characteristics in the use of railroad tracks type “65 SB”, which were first put into use in 1985 and 1985, as well as determining if and how these lines can still be exploited now. In order to determine the carrying capacity still available for the 65 SB railroad track, according to the standard SR EN 13674 and other derived standards, a series of tests and experiments were performed, which follow this particular standard, as well as other standards specific to each determination. Based on the results, certain parameters were determined, which are able to pinpoint the degree of operation deterioration. We took into consideration the parameter for the rate of crack propagation as the characteristic which can cause changes, as a result of loading under a number of fatigue cycles.

## 1. The global degradation of railroad track characteristics

The degradation or deterioration of characteristics is a concept which allows us to evaluate the possibility of determining the lifetime of a part, structure etc., which were exploited for a certain timeframe. Degradation can occur due to: mechanical fatigue, prolonged usage beyond the allowed parameters, exposure to temperature variations, external actions through corrosion or erosion, errors in execution or assembly. Based on the phenomenon of mechanical fatigue of a metallic material, the degradation process has three stages:

- a) initiation of a mechanical flaw (microscopic crack)
- b) continuous and slow propagation (in a high number of cycles) of a crack, until the cracked cross section (the load section) becomes insufficient for taking the load
- c) the final, sudden propagation of the crack leads to fracture and to separating the sections which form the initial sides of the crack. The degradation can also take place via: plastic deformation (where the affected area becomes bigger and bigger the more loading cycles take place), excessive usage (which leads to un-allowed deviations of the geometrical characteristics), the change in quality and structure of the material. Regardless of the deterioration type, we must put into question the lifetime left for exploitation, either in terms of remaining cycles, either in terms of remaining lifetime in conditions of guaranteed reliability.

For railroad tracks, it's difficult to determine which of the deterioration mechanisms described above has a higher likelihood of consideration in order to determine the lifetime. It is obvious that, if a crack occurs in the track, the calculus needs to be conducted according to the mechanism described by fracture mechanics. Utilization without crack occurrence and with the sole observation of an apparent usage also leads to the degradation of operating characteristics. In order to determine the global



degradation of characteristics, a series of mechanical tests need to be performed, which will be able to highlight a decrease in the initial material properties, as well as chemical and structural tests. In this paper, we considered the **rate of fatigue crack propagation** as the main characteristic able to cause changes, as a result of the load of mechanical fatigue in the train track.

## 2. Materials, samples, devices used for testing

The determinations were made according to the SR EN 13674-1 standard, as well as other standards needed for specific tests. The samples were provided by the beneficiary, the **National Railway Company "CFR" - S.A.** Three railroad track types were tested: 2 in exploitation since 1985 and 1986 respectively, which were loaded to more than  $250 \cdot 10^6$  tons of force, and one new railroad. In the following, we will refer to these types with the following names: railway '85, railway '86 and railway 'NEW'. The reference values are those determined for railway 'NEW'. It is specified that both the material and the geometric configuration of the three rail types is the same. Previous determinations were made for the evaluation of the longitudinal elastic modulus as well as the Poisson coefficient, as their values needed to be entered in the Fracture Mechanics software to determine the crack propagation rate. For the determinations, the INSTRON 8801 type universal machine (Figure 1), was used, where the Fracture Mechanics software "da/dN" (Figure 2) is installed.

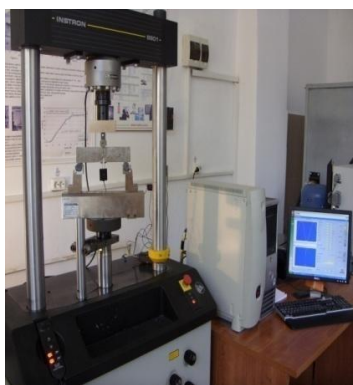


Figure 1. Testing machine with sample.

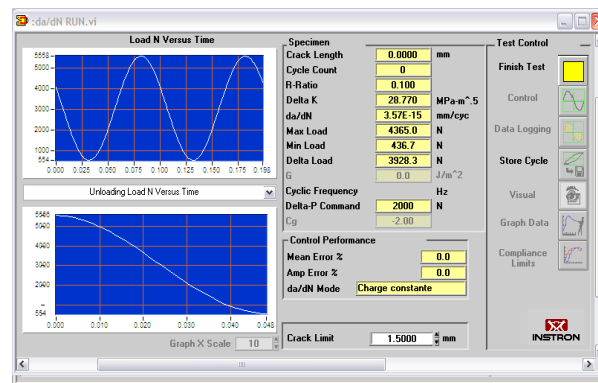


Figure 2. The test menu – secondary.

The "da/dN" program (software) for determining the crack propagation rate through fatigue leads to a fatigue test producing crack propagation in the side notch sample. The test method provides cyclic loading of the notched samples that have been pre-fissured by fatigue. The length of the crack is measured by the number of fatigue cycles performed so far and the data is subjected to numerical analysis to determine the crack propagation rate. The type of specimen used, as well as the sampling mode, is those prescribed by standard SR EN 13674-1 and by ASTM E647, (Figure 3). It is noted that the milling of the notch must also be performed on the side of the sample facing the direction area of the railway track.

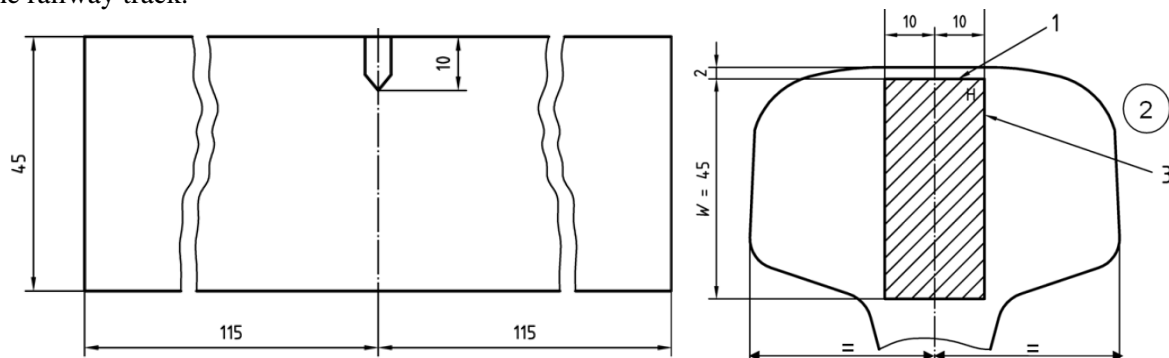
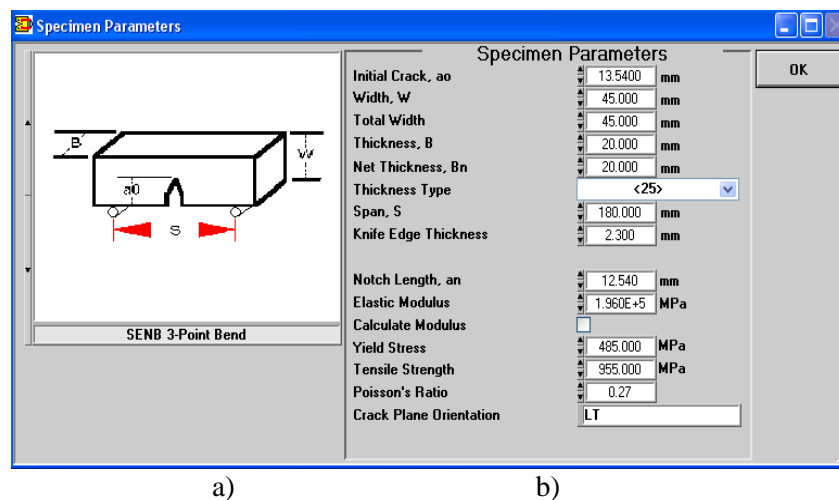


Figure 3. The sample type to for the da/dN determination and the sampling mode.

### 3. The testing program for determining fatigue crack propagation rate

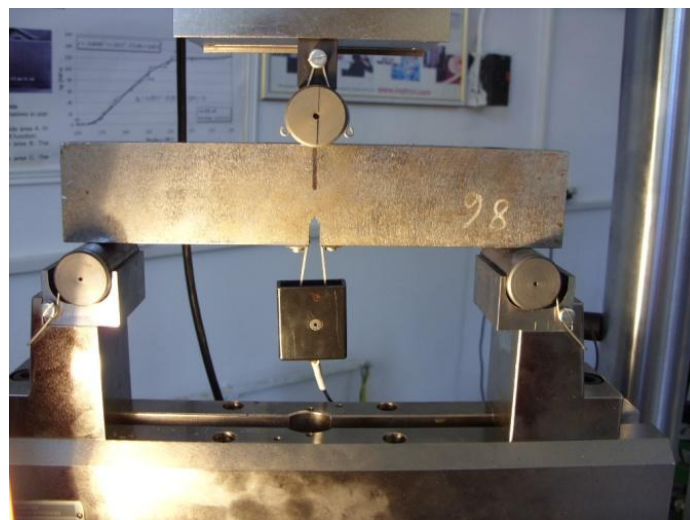
One of the basic parameters to determine the fatigue break is the crack propagation rate  $da/dN$ , which represents the length with which the crack propagates over a stress cycle. For different crack lengths, the propagation rate can be obtained by calculating the **slope of the a-N diagram**. The crack propagation rates  $da/dN$  depends on the length of the initial crack,  $a_0$ , as well as on the applied stress level or magnitude, which intervene in the determination of the stress intensity factor  $K$ .

The fatigue crack propagation rate determination method meets the requirements of the ASTM E647 standard. This program uses the compliance method to determine the propagation crack length growth, and on this basis, it will automatically calculate the propagation crack length for a given number of load cycles. In the "da/dN" Fracture Mechanics software, corresponding to the determination of the crack propagation rate, a series of sizes must be introduced, some of which are geometrically representative of the sample, others being material characteristics (Figure 4). Figure 4b displays the characteristics for one of the samples used in these determinations.



**Figure 4.** The menu for the geometry and characteristics of the da/dN software.

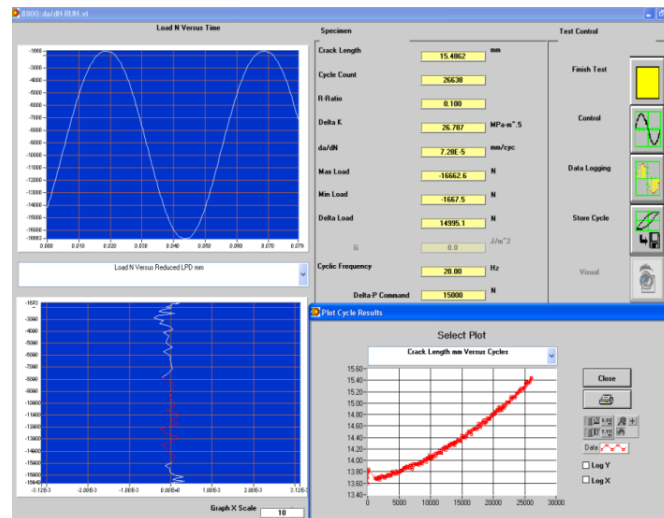
The value for  $v$  (crack tip opening displacement - CTOD) was automatically taken from the extensometer mounted on the front of specimen and the force is taken from the execution of the program that appears in the secondary menu - when the test is performed, Figure 5.



**Figure 5.** Mounting the extensometer on the bending sample.

As stated above, the tests were carried out on three types of material taken from three different tracks: railway '85, railway '86 and railway 'NEW'.

A pre-cracking of approximately 1-3 mm was performed on samples. After the final crack, it was noted that all samples were predominantly fragile, with no significant plastic deformation of the cross-section. Because of this, some of the samples were totally broken off from the pre-cracking stage and obviously could not be used anymore. However, a sufficient number of samples remained, to which the method for determining the rate of crack propagation has been applied. After entering the data presented above and setting up some test parameters, the test was carried out, consisting of a fatigue test after a pulsating (bending) cycle where the following parameters were set: loading amplitude approx. 7500 N, the ratio between the minimum and maximum force 0,5 and the loading frequency (20 Hz), Figure 6.



**Figure 6.** The Dashboard for the test.

On each of the rail types ('85, '86 and NEW), three tests were carried out. The results provided below are the average of the values obtained. The test temperature was approximately 240° C. The program uses the compliance method to determine the growth of the propagated crack length. The relationship between compliance and crack length  $a$  is in the form:

$$\frac{a}{W} = \sum_{i=0}^5 C_i \cdot U^i \quad (1)$$

where:

- $a / W$  is the length of the normalized crack;
- $W$  is the width of the sample;
- $C_{0...5}$  or  $C_i$  are the compliance coefficients shown in Figure 7;
- $U$  is the compliance of the sample given by the relation:
- 

$$U = \frac{l}{l + \sqrt{\frac{E \cdot v \cdot B \cdot W}{P \cdot S}}} \quad (2)$$

where:

- $E$  - Young's module;
- $v$  is the displacement between the measuring points given by the extensometer mounted on the sample, Figure 8;
- $P$  is the applied force;
- $B$  is the thickness of the sample;
- $S$  is the distance between the supports.

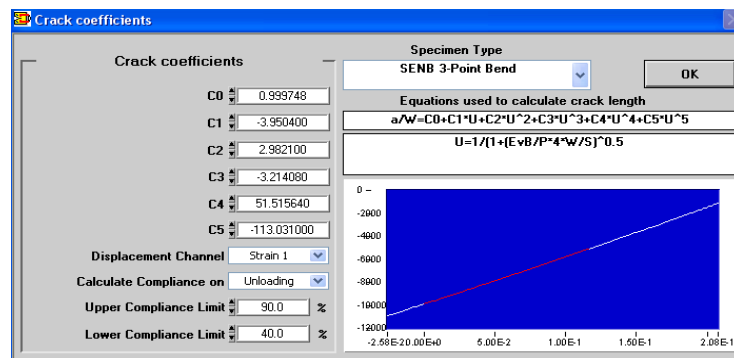


Figure 7. Specific compliance coefficients for the sample subjected to three-point bending.

Some of the fractured samples (one of each rail category, '85 and 'NEW') resulting from the tests can be seen in Figure 9. In the fracture section, you can see the cracked area near the notch, first by introducing the pre-cracking through fatigue and then based on the main "da/dN" test. The fatigue cracked area has finer grains and is not shiny. The thick and shiny grain area is the area of the sudden crack, as it will be seen on future charts. The propagation of the crack in this area is not taken into account when calculating the crack propagation rate.



Figure 8. Mounting the extensometer.

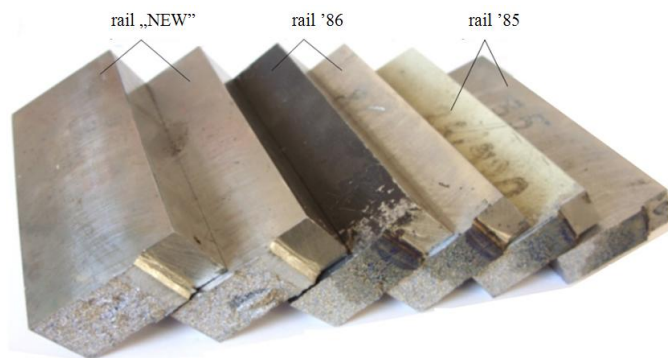


Figure 9. Samples cracked at „da/dN” testing.

#### 4. Obtained experimental results

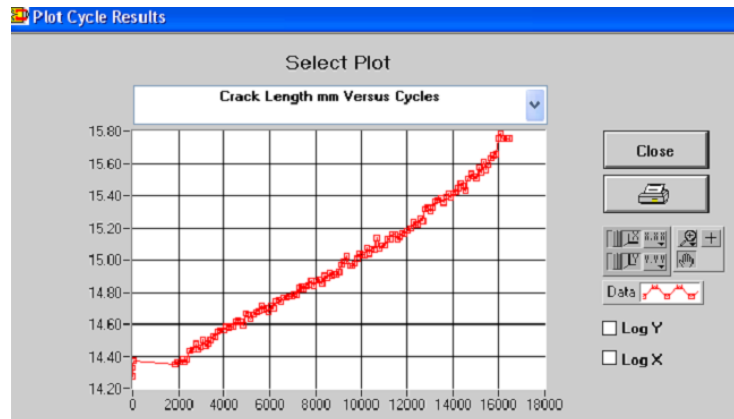
At the end of the test, the "da/dN" program (software) provides the following data and graphs:

- The data table which includes, among other things, the following characteristics: number of cycles, crack length,  $\Delta K$  tension factor, crack propagation rate da/dN, Table 1.
- Graph: The length of the crack (a) relative to the number of stress cycles, Figure 10;
- Graph: Crack growth rate (da/dN) relative to Delta-K ( $\Delta K$ );
- Graph: The length of the crack in relation to the number of cycles;
- Graph:  $\Delta K$  in relation to the number of cycles.

Table 1. Datasheet provided by the "da/ N" software.

Cycles	Crack Length mm	Crack Length (reg) mm	EvBP	da/dN mm/cyc	Delta-P N	Delta-K MPa-m <sup>1/2</sup>
1.0000000E+0	1.35981143E+1	0.0000000E+0	1.38931079E+1	0.0000000E+0	4.49631214E+3	0.0000000E+0
2.0000000E+1	1.36968502E+1	0.0000000E+0	1.40530040E+1	0.0000000E+0	5.02768755E+3	0.0000000E+0
3.8000000E+1	1.37784425E+1	0.0000000E+0	1.41865101E+1	0.0000000E+0	5.63374758E+3	0.0000000E+0
7.6000000E+1	1.38017896E+1	1.37539776E+1	1.42249422E+1	9.82449065E-4	6.73902631E+3	1.08957523E+1
1.6900000E+2	1.38219670E+1	1.38199589E+1	1.42582398E+1	4.08879980E-4	9.05984044E+3	1.47032810E+1
2.0500000E+2	1.38445155E+1	1.38158161E+1	1.42955414E+1	5.32317356E-5	9.80331302E+3	1.59061097E+1
1.1780000E+3	1.36881106E+1	1.36975785E+1	1.40387776E+1	-1.15321440E-4	1.48269355E+4	2.38954853E+1
1.2890000E+3	1.36798331E+1	1.36783450E+1	1.40253167E+1	-8.21311510E-6	1.48844481E+4	2.39619087E+1
1.4000000E+3	1.36668845E+1	1.36790048E+1	1.40042852E+1	4.16908413E-5	1.49193883E+4	2.40190603E+1
1.5130000E+3	1.36727880E+1	1.36836830E+1	1.40138699E+1	3.27166572E-5	1.49400592E+4	2.40587484E+1
1.6210000E+3	1.37013618E+1	1.36958688E+1	1.40603536E+1	1.06511997E-5	1.49667025E+4	2.41183883E+1
1.7330000E+3	1.37153578E+1	1.36954384E+1	1.40831777E+1	2.23855899E-5	1.49735808E+4	2.41288811E+1
1.8450000E+3	1.36867405E+1	1.36892595E+1	1.40365486E+1	3.74454606E-5	1.49834991E+4	2.41363671E+1





**Figure 10.** Variation of crack length versus number of cycles.

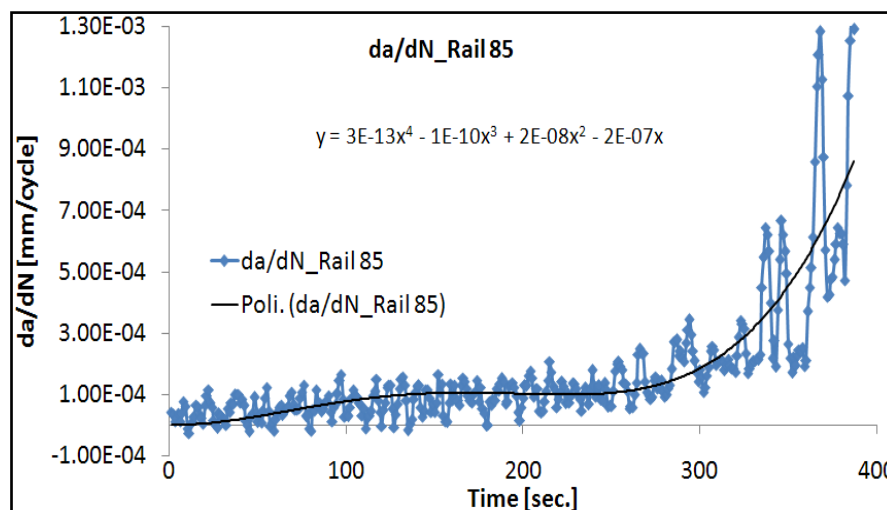
It is noted that the crack length has been computed automatically by the "da/dN" software by the compliancy method (with the compliance coefficients provided by the machine software) at each test moment.

#### 4.1. The da/dN calculation for rail '85'

The method for determining the crack propagation rate is described below.

From the datasheet provided by the test machine the necessary data is retrieved and the da/dN variation is plotted against time (or number of cycles), Figure 11. As shown in Figure 11, the crack propagation rate varies during the trial. For example, at the end of the test the crack propagation rate increases significantly. We are only interested in the area where the crack propagation rate has an approximately constant value when the crack length is at an intermediate value: neither at the start of the hardening phenomena, nor at the end when the crack length has already reached a value at which it propagates at a rather high, even sudden speed. We can approximate the da/dN variation over time with a grade 4 polynomial. Therefore, for the calculation of the crack propagation rate in this case, we have chosen the 150 second timeframe to be significant for the crack propagation rate. In the graph of Figure 11, the crack propagation rate for sample 85 was calculated at 150 seconds:

$$\frac{da}{dN}_{rail'85} = 0,0002344 \frac{mm}{cycle} \quad (3)$$



**Figure 11.** The variation in time of crack propagation rate - sample '85.

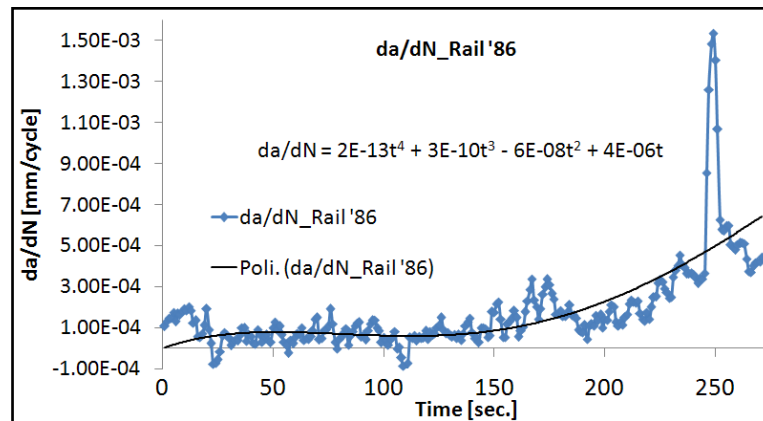
#### 4.2. The $da/dN$ calculation for rail '86

Figure 12 shows the variation in crack propagation rate versus time for rail '86'. The  $da/dN$  variation relative to time was approximated with a grade 4 polynomial. It is noted that the crack propagation rate begins to increase after approx. 160 seconds from the start of the test. As a result, the value for 130 seconds can be regarded as representative to determine the rate of crack propagation. At this value, the start of the growth in crack propagation rate is recorded. In the graph of Figure 12, the crack propagation rate for the '86 sample was found at 130 seconds:

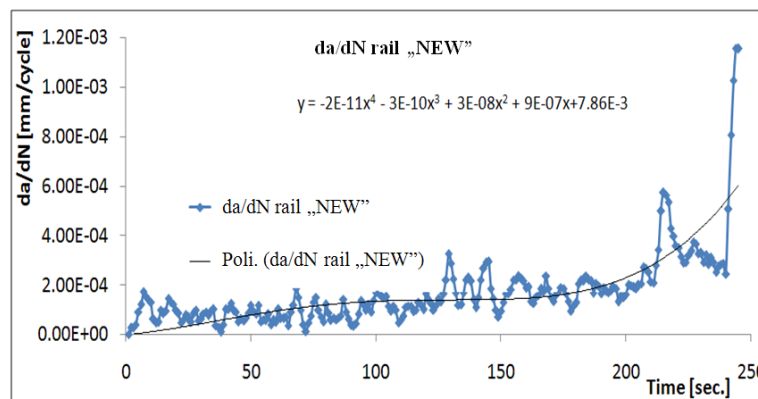
$$\frac{da}{dN_{rail\ '86}} = 0,00022 \text{ mm/cycle} \quad (4)$$

#### 4.3. The $da/dN$ calculation for rail 'NEW'

Figure 12 shows the variation in crack propagation rate versus time for rail 'NEW'.



**Figure 12.** The variation in time of crack propagation rate - sample '86.



**Figure 13.** The variation in time of crack propagation rate - sample 'NEW'.

The  $da/dN$  variation relative to time was approximated with a grade 3 polynomial. It is noted that the crack propagation rate begins to increase after approx. 170 seconds from the start of the test. As a result, the value for 150 seconds can be regarded as representative to determine the rate of crack propagation. In the graph of Figure 13, the crack propagation rate for the '86 sample was found at 150 seconds:

$$\frac{da}{dN_{rail\ NEW}} = 0,0000676 \text{ mm/cycle} \quad (5)$$

## 5. Conclusions and recommendations

The fatigue crack propagation rate (m / Gc) shall not exceed the values indicated in Table 2, as per the SR EN 13674-1: 2011 standard, respectively:

**Table 2.** The fatigue crack propagation rate.

Steel brand	$\Delta K = 10 \text{ MPa m}^{1/2}$	$\Delta K = 13,5 \text{ MPa m}^{1/2}$
All brands except R200 and R320Cr	17 m/Gc=0,000017 mm/cycle	55 m/Gc=0,000055 mm/cycle

From the tests and determinations made on the three rail types, it is clear that the crack propagation rate for all the rails analyzed is higher than those indicated in the SR EN 13674-1: 2011 standard. It is noted that the NEW rail also has values close to those shown in Table 2. Consequently, if we consider a **deterioration** of the "crack propagation rate" characteristic, for the '85 and '86 rails, this **seems to have occurred**. From the tests and determinations carried out on the three types of rail, it shows that the crack propagation rate for all the rails analyzed is higher than those indicated in the standard SR EN 13674-1: 2011, namely:

$$\text{rail '85: } \frac{da}{dN_{\text{rail '85}}} = 0,000234 \text{ mm/cycle}$$

$$\text{rail '86: } \frac{da}{dN_{\text{rail '86}}} = 0,000222 \text{ mm/cycle}$$

$$\text{rail NEW: } \frac{da}{dN_{\text{rail NEW}}} = 0,0000676 \text{ mm/cycle}$$

In relation to the **rail specified by the standard**, for which  $\Delta K = 13,5 \text{ MPa m}^{1/2}$ , the deviations of the crack propagation rate are as follows:

$$A_{da/dN_{\text{rail '85}}} = \frac{da/dN_{\text{rail Standard}} - da/dN_{\text{rail '85}}}{da/dN_{\text{rail Standard}}} \cdot 100 = \frac{0,000055 - 0,000234}{0,000055} \cdot 100 = -325\%$$

$$A_{da/dN_{\text{rail '86}}} = \frac{da/dN_{\text{rail Standard}} - da/dN_{\text{rail '86}}}{da/dN_{\text{rail Standard}}} \cdot 100 = \frac{0,000055 - 0,000222}{0,000055} \cdot 100 = -303\%$$

$$A_{da/dN_{\text{rail NEW}}} = \frac{da/dN_{\text{rail Standard}} - da/dN_{\text{rail NEW}}}{da/dN_{\text{rail Standard}}} \cdot 100 = \frac{0,000055 - 0,0000676}{0,000055} \cdot 100 = -22.9\%$$

In relation to the NEW rail, the deviations of the crack propagation rate for the '85 and '86 rails are as follows:

$$A_{da/dN_{\text{rail '85}}} = \frac{da/dN_{\text{rail NEW}} - da/dN_{\text{rail '85}}}{da/dN_{\text{rail NEW}}} \cdot 100 = \frac{0,0000676 - 0,000234}{0,0000676} \cdot 100 = -246\%$$

$$A_{da/dN_{\text{rail '86}}} = \frac{da/dN_{\text{rail NEW}} - da/dN_{\text{rail '86}}}{da/dN_{\text{rail NEW}}} \cdot 100 = \frac{0,0000676 - 0,000222}{0,0000676} \cdot 100 = -228\%$$

It can be stated that all the studied rails, including the 'NEW' track, exhibit deviations of the crack propagation rates in relation to those prescribed by the standard SR EN 13674-1: 2011. It is noted that the '85 and '86 rails show very high deviations in relation to the values given in the specified standard. Consequently, the possible occurrence of a micro-crack in the operating rails may lead to their



propagation at a fairly high rate, which can lead to unstable propagation. Consequently, we recommend a closer monitoring of the operating rails, and any micro flaws that occur should be checked at shorter intervals. In light of the differences presented above, it is advisable and imperative to monitor these rails more closely than usual. The annual monitoring and verification plans will be corrected so that, for the sections containing rails from the group under analysis, monitoring is done 3 times more often than usual. Monitoring will be done on two directions, **observation** and **determination** of following characteristics, namely:

- **observing** and verifying any changes in geometric characteristics while in operation;
- **observing** and checking the appearance of cracks, damage, pinching, plastic deformation, while in operation.

After the rails are loaded in time, after approx. 10 million tons of force on these sections, the determinations provided in this paper will have to be re-performed in order to ascertain possible increases in crack propagation rate, relative to previous determinations. This avoids a sharp deterioration by taking measures in time to replace some of the track portions which display severely damaged features.

## 6. References

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