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# Testing Internal Mechanical Stresses in Flash-butt Welded Rail Joints

Ireneusz MIKŁASZEWICZ[1], Jakub SIWIEC[2]

**Summary**
The paper presents the results of internal stress tests in rails and flash-butt welded rail joints. Stress patterns were tested in rail joints just after flash-butt welding, as well as after fatigue tests. Stress tests were performed using the destructive strain gauges based test method. Stresses emerging in rails and in rail joints were compared for the steel grades R260 and R350HT. Stress measurements were performed in accordance with the requirements of PN EN 13674 1:2011+A1:2017.

**Keywords:** mechanical stress, rail joints, strain gauges, fatigue test

## 1. Introduction

Internal stresses existing in the rails as well as in railway rail joints play an important role in the exploitation of rails in tracks. Utilization of rails with stresses over 250 MPa [7] causes the potential risk of split shear cracks, conducive to increases in propagation of edge shear cracks [1, 2, 8] and internal rail head checks. Similar results in tracks may be caused by internal stresses emerging in rail joints.

The internal rail stress emerging process, applicable to rail production and rail joints i.e. to places where the rails are joined together, can be subdivided into several phases:

1) Internal structural stresses emerge after rail rolling and cooling processes and are linked with plastic strain and phase changes in material. It manifests itself mainly by the lack of linearity after cooling on the cooling bed in rail production plants (see Figure 1),
2) Then, cold straightening in straighteners, with an XX and YY arrangement, cause straightening stresses i.e. multi-plane cold work of the rails (see Figure 2) causing changes in the patterns and types of stress. A stress pattern on the cross-section of a new rail head is shown in Figure 3;
3) Finally, during creation of the rail joints utilizing flash-butt welding, stresses disappear at the ends of welded rails thanks to an increase in the temperature to about 1350°C. However, structural stresses emerge during cooling of the joints and straightening stresses emerge due to straightening of the joints using a press before the required grinding of the joints, which is performed to maintain the linearity of the flash-butt welded locations.

Fig. 1. Cooling of the rails after rolling on the cooling bed [authors' own photo]

[1] Eng.; Railway Research Institute, Materials & Structure Laboratory e-mail: imiklaszewicz@ikolej.pl.
[2] M.Sc. Eng.; Railway Research Institute, Materials & Structure Laboratory; e-mail: jsiwiec@ikolej.pl.

Fig. 2. Rails straightening in a nine-roller straightener [authors' own photo]

Fig. 3. Cross-section of the rail head after cutting with a saw blade [authors' own photo]

## 2. Test method

### 2.1. Test goal

The main aim of the tests was to determine stresses in rail joints i.e. joints utilised in continuous welded rail tracks after stationary flash-butt welding (see Figures 4 and 5) and after fatigue tests of the samples. The obtained results of the rail joints internal stress measurements, especially those obtained from fatigue samples, enabled assessment of the size of stresses in flash-butt welded rail joints.

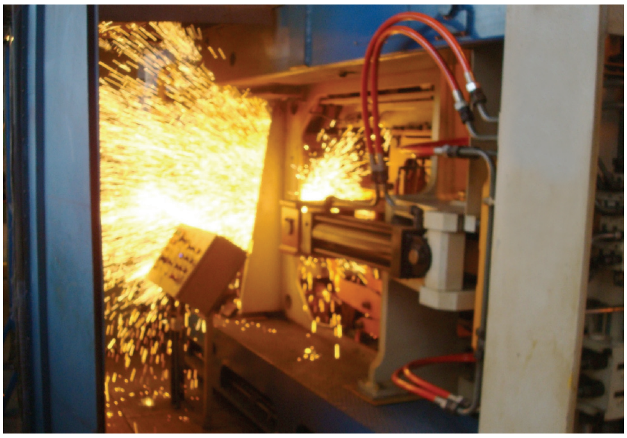

Fig. 4. Working flash-butt welding machine – sparking out phase [authors' own photo]

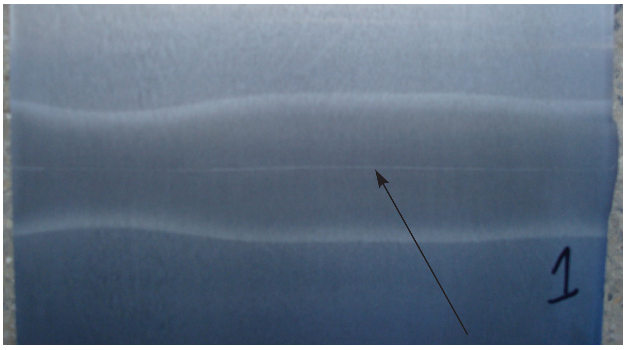


Fig. 5. Rails flash-butt welding line on the longitudinal cross-section [authors' own photo]

### 2.2. Chosen ways to measure stresses

Shortening train running times, thereby increasing running speeds, causes enhanced requirements regarding rail linearity. This is associated with straightening of the rails by rail producers, as well as obtaining the lowest internal stresses in rails after straightening. Two out of several widespread longitudinal rail stress measuring methods [4] were mostly applied:

- Destructive strain gauges based test method, which relies on measuring internal stresses released during cutting of the chosen sections of the rails between strain gauges. This technique offers very precise measurements of the displacements and also calculations of the values of the stresses. This method requires, however, very precise and accurate placement of the strain gauges on the surface of the tested element.
- Non-destructive ultrasonic method, utilizing acoustic phenomena i.e. measuring ultrasonic waves in rail propagation time. The size of the stresses in rails is displayed depending on the amount of internal stresses in the structure of the material of the tested rail section. The equipment utilized for the stress tests based on that method is Debro-30.

One work [8] presents the results of rail stress tests obtained thanks to the ultrasonic method before straightening and after straightening by a roller straightener. The highest internal compressive stresses of about 150 MPa were found in the rail web, while tension stresses in the rail head and foot were between (240–300) MPa. After the rail rolling and cooling processes, internal stresses varied between (–50 to +35) MPa. This shows that cold rail straightening significantly influences the level of internal stresses in new rails.

The latest tests regarding internal rail stresses show that straightening methods presently developed by rail producers enable tensile stresses to be obtained in rail foots on the level of (100–200) MPa [6]. During exploitation of the railway rails, the influence of neutral temperature is also observed. Changes in the temperature values along a defined length of the track within 24 hours, for different rail temperatures, causes significant differentiation in the longitudinal stress patterns in tracks [3].

Stress tests were performed using the destructive strain gauges based test method recommended by the PN-EN 13674-1:2011+A1:2017 standard. This standard defines the permissible stress value in a rail foot equal to (max 250) MPa. The method consists of placing on the rail surface 3.0 mm long electric resistance wire strain gauges having 120 Ω resistance. Then, cutting laterally a 20.0±1.0 mm shield with placed strain gauges. The result is the difference between the strain gauges readings before and after cutting the shield i.e. the amount of internal released stresses multiplied by Young's modulus, which is equal to 2.07 $10^6$ for the rail steel grade.

## 2.3. Tested material

Rail samples of the steel grades R260 and R350HT provided by a rail producer as well as flash-butt welded rail joints of the same steel grades were used as the test material. All samples were 1600 mm long with a symmetric location of the flash-butt welded rail joints. Samples of the grade R260 were marked as A1, A2 and A3; while samples of the grade R350HT were marked as B1, B2 and B3. Samples A1 and B1 were rails of the grades R260 and R350HT, respectively. Samples A2 and A3 as well as B2 and B3 were flash-butt welded rail joints after welding and after fatigue tests, respectively. The number of fatigue cycles for samples of the grades R260 and R350HT, in accordance with the PN-EN 13674-1:2011+A1:2017 standard, was equal 5.0 million having 190 MPa stress in the rail foot caused by a loading force equal to 215 kN. The force depends on the spacing of the supports on the fatigue test stand as well as on the strength of the rail material.

The analyses of the chemical composition and mechanical properties of the tested rails are shown in Table 1, while Figure 6 shows a block diagram representing placement of the strain gauges on the tested samples. In the case of rail joints, strain gauges were located in flash-butt welding locations (see Figure 7).

Table 1

**Chemical composition and mechanical properties of the tested rails**

| Sample (steel grade) | Chemical composition [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P, max | S, max | Cr | Ni, max | Cu, max |
| **Rail A (grade R260)** | 0.71 | 1.11 | 0.31 | 0.014 | 0.012 | 0.02 | 0.004 | 0.01 |
| **Rail B (grade R350HT)** | 0.78 | 1.11 | 0.40 | 0.020 | 0.010 | 0.03 | 0.02 | 0.010 |
| **R260 in accordance with PN-EN 13674-1** | 0.60–0.82 | 0.65– 1.25 | 0.13–0.60 | 0.030 | 0.030 | ≤0.15 | – | – |
| **R350HT in accordance with PN-EN 13674-1** | 0.70–0.82 | 0.65–1.25 | 0.13–0.60 | 0.025 | 0.030 | ≤0.15 | – | – |

Elaborated on the basis of [7].

Table 1 cont.

**Chemical composition and mechanical properties of the tested rails**

| Sample (steel grade) | Chemical composition | | | | Tested rail properties | | |
|---|---|---|---|---|---|---|---|
| | $O_2$ [ppm] | Al, max [%] | *V*, max [%] | $H_2$ [ppm] | Rm [MPa] | A5 [%] | HBW |
| **Rail A (grade R260)** | 16 | 0.002 | 0.003 | 1.2 | 953 | 14.2 | 274 |
| **Rail B (grade R350HT)** | 9 | <0.005 | 0.003 | < 0.5 | 1201 | 10.6 | 359 |
| **R260 in accordance with PN-EN 13674-1** | 20 | 0.004 | 0.030 | 2.5 | min 880 | min 10 | 260–300 |
| **R350HT in accordance with PN-EN 13674-1** | 20 | 0.004 | 0.030 | 2.5 | min 1175 | min 9.0 | 350–390 |

Elaborated on the basis of [7].

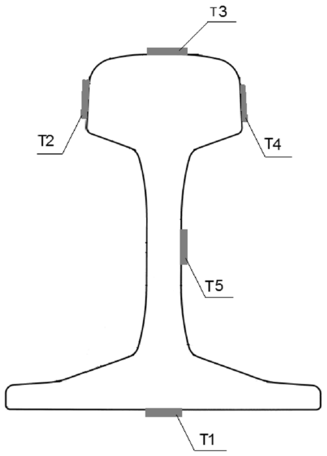


Fig. 6. 60E1 rail profile with strain gauges [authors' own elaboration]

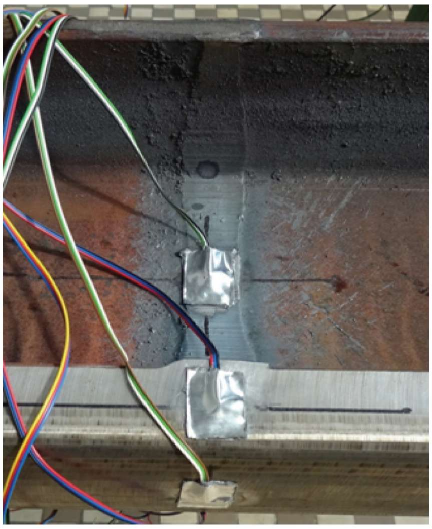

Fig. 7. Rail joint with located strain gauges [authors' own photo]

## 3. Test results

Electric resistance wire strain gauges were firmly located on the rail samples marked A1 and B1 and on the rail joints A2, A3, B2 and B3, on rail foots, rail webs and rail heads. In the case of the rail joint samples, strain gauges were located in the line of the flash-butt welding (see Figure 7). Then, the measuring half-bridge system with continuous registration of the stresses in individual parts of the rails and rail joints was assembled. Readings of the stresses released by the material were registered during the cutting of a 20.0 mm thick shield by a band-saw. Stress pattern graphs for different areas of the rail joints for the first and second cut by the band-saw are shown in Figures 8, 9, 12 and 13. Figures 10, 11 and 14 present cumulated curves of the maximum stresses registered by strain gauges during cutting of the rails and rail joint samples of the grades R260 and R350HT.

The shape of the curves (Fig. 10) shows that the highest compressive stresses, reaching nearly 300 MPa, were registered in the rail head of the flash-butt welded rail joint of the grade R260, while in the rail web of the joint tensile stresses reached 200 MPa. However, in the case of fatigue-treated joints (Fig. 14), the highest tensile stresses were registered in the head, while compressive ones were registered in the rail joint web. These stresses reached 300 MPa.

In the case of the flash-butt welded rail joint of the grade R350HT (Fig. 11), compressive stresses appear in the foot and the head of the joint, while tensile stresses are in the web of the joint. These stresses exceed or are on the border of permissible stresses foreseen for new rails i.e. 250 MPa. Meanwhile, in the rail joint after fatigue tests (Fig. 13), the stress pattern

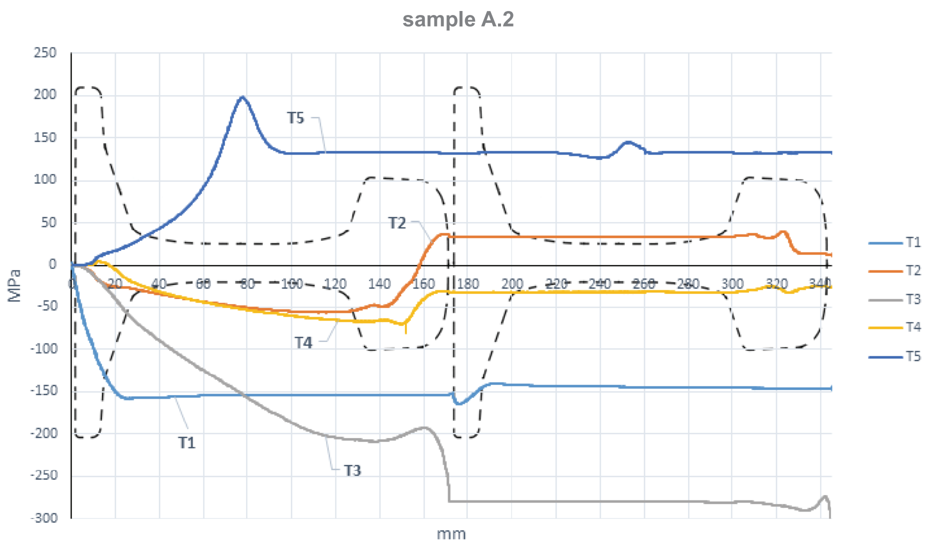


Fig. 8. Stress pattern in the rail joint of the grade R260 [authors' own elaboration]

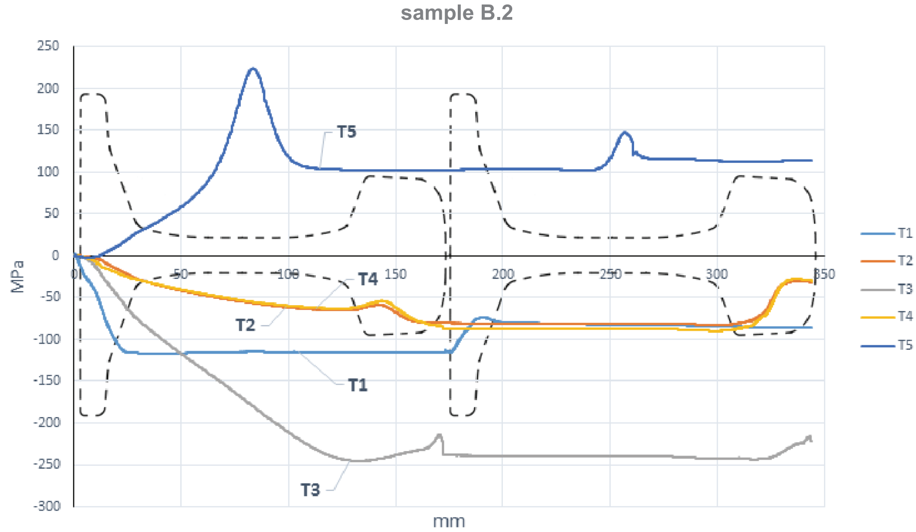


Fig. 9. Stress pattern in the rail joint of the grade R350HT [authors' own elaboration]

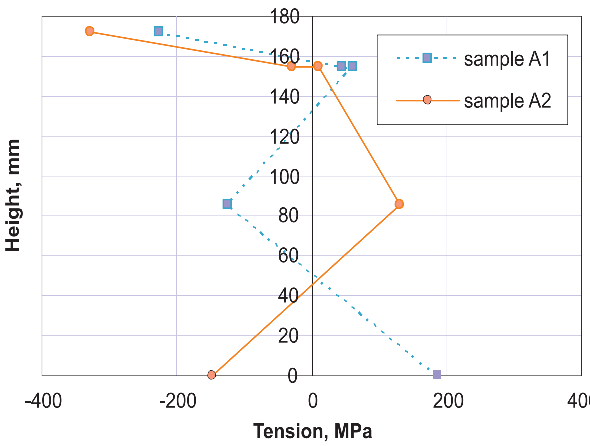


Fig. 10. Stress patterns in the rail and in the rail joint of the grade R260 [authors' own elaboration]

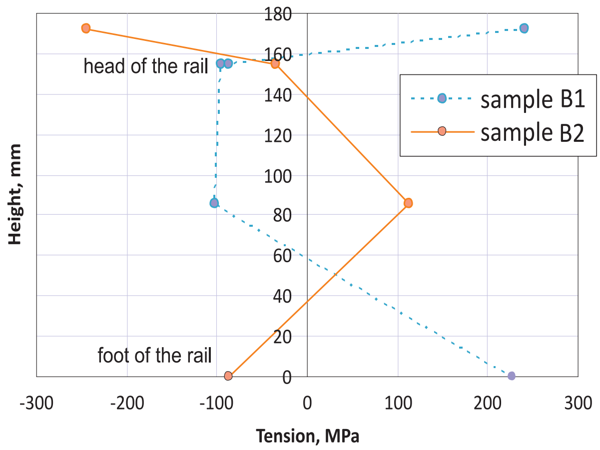


Fig. 11. Stress patterns in the rail and in the rail joint of the grade R350HT [authors' own elaboration]

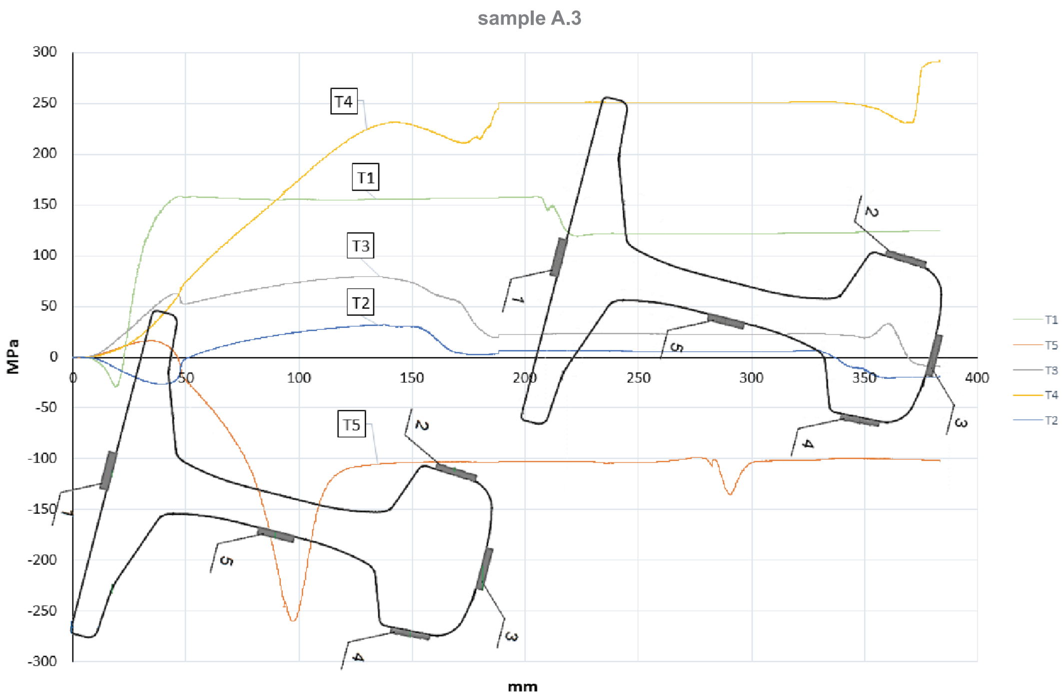


Fig. 12. Stress pattern in the rail joint of the grade R260 after fatigue tests [authors' own elaboration]

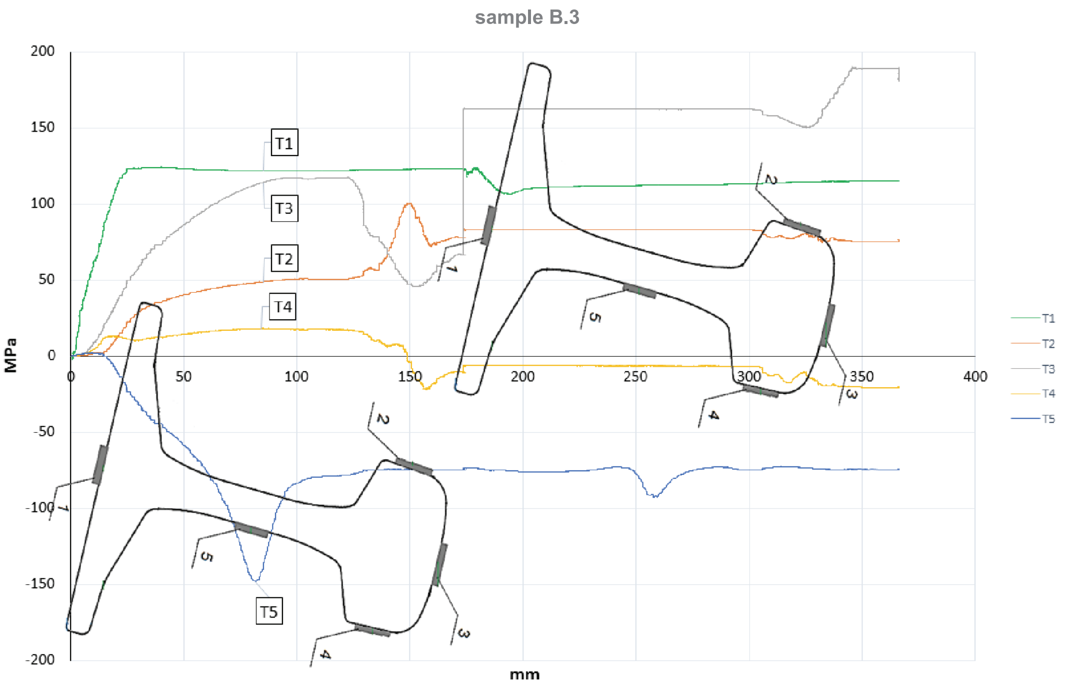


Fig. 13. Stress pattern in the rail joint of the grade R350HT after fatigue tests [authors' own elaboration]

registered by the strain gauges on the head, web and foot of the joint does not exceed 200 MPa. As a result of the tests, the internal stress level in the foot of the rail joint after fatigue tests complies with the PN-EN 13674-1:2011+A1:2017 requirements.

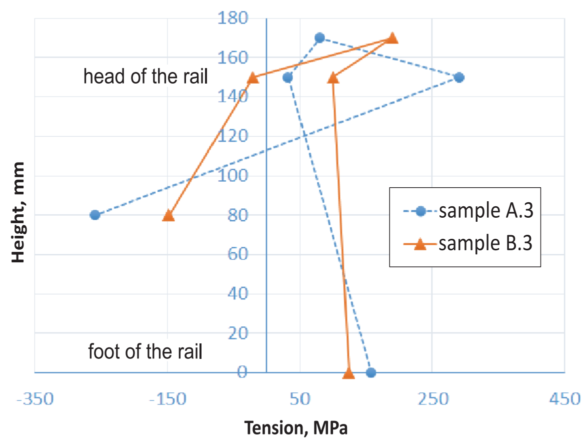


Fig. 14. Stress patterns in the rail joints of the grades R260 and R350HT after fatigue tests [authors' own elaboration]

Figure 15 shows the microstructure of the head of the rail joint of the grade R260 in the flash-butt welding line after fatigue tests. This is a perlite structure with ferrite inclusions on the edges of the grains, while Figure 16 shows the microstructure of the head of the rail joint of the grade R350HT also after fatigue tests. Because of the high content of carbon (0.78%), near the upper border of the standard requirements, this is a fine-grained perlite structure with cementite inclusions on the edges of the grains.


Fig. 15. Flash-butt welding line of the rail joint of the grade R260 after fatigue tests [authors' own photo]

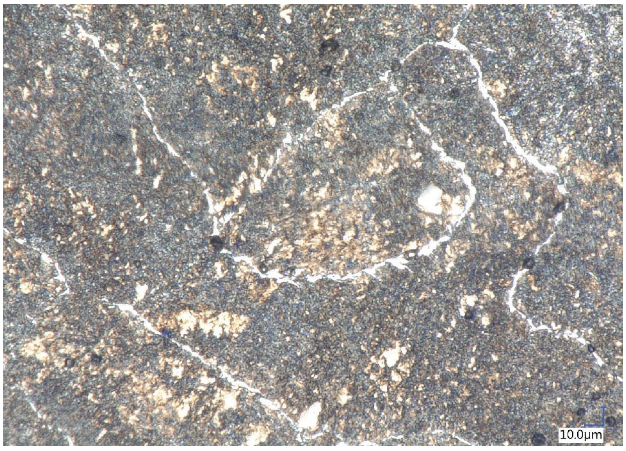


Fig. 16. Flash-butt welding line of the rail joint of the grade R350HT after fatigue tests [authors' own photo]

## 4. Conclusions

On the basis of the performed strain gauge tests of the internal stress patterns in railway rails, using rail joint samples of the grades R260 and R350 HT, it was alleged that flash-butt welded rail joints are affected by compressive stresses in heads and foots of the joints reaching or slightly exceeding the value of 200 MPa, whereas in webs, tensile stresses were registered. In rail joints after fatigue tests, simulating exploitation of the joints on tracks for both grades, it was alleged that tensile stresses in foots and heads of the joints do not exceed 200 MPa, i.e. do not exceed 250 MPa, whereas in webs, compressive stresses were registered.

Coherence between tensile stress values after fatigue tests in the foot of rail joints and tensile stress in the rails fulfils the requirements of the PN-EN 13674-1:2011+A1:2017 standard. Coherency between stresses in rail foots and in rail joints contributes to lowering the risk of railway rails breaking in tracks, thanks to elimination of the accumulations of internal stresses.

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