Terotechnology XII Materials Research Forum LLC
Materials Research Proceedings **24** (2022) 247-253 https://doi.org/10.21741/9781644902059-36

Testing of Flash Butt Welded Rail Joints

MIKŁASZEWICZ Ireneusz

Instytut Kolejnictwa (Railway Research Institute), Chłopicki 50, Street, 04-275 Warsaw, Poland

imiklaszewicz@ikolej.pl

Keywords: Bending, Fracture of The Joint, Fracture Discontinuity

Abstract. This article presents selected aspects of testing flash butt welded rail joints that have a decisive impact on the rails' operational strength, including cracking in the track. Bending tests of rail joints, fatigue tests, hardness HV30, residual stress results, and microstructure of welded joints are presented. The introduction shows sporadically occurring joint defects revealed on broken fractures related to the technological process of flash butt welding. The above tests were based on the requirements of PN-EN 14587-1:2019-03 [1] and PN-EN 13674-1+A1:2017-07 [2].

Introduction

The safety of running trains and the increasing speed of travel forces the use of suitable quality materials, including rails and flash butt welded rail joints. The existing railway superstructure, especially on the routes with the volume of train traffic, requires monitoring mainly in the form of visual and ultrasonic tests in the tracks, whose purpose is, among others, to assess the condition of rails and rail joints as one of the most important factors of safe transport [3].

In addition to rail defects revealed during operation, including hazardous defects of the head check type [4], which arise on the surface of the railhead, then penetrate deep into the material and constitute a dangerous source of cracks, we may also include occasionally occurring defects of rail joints arising in the process of flash butt welding with stationary and mobile welding machines (Fig.1), also posing a potential danger of distribution cracks.

Rail welding is performed using the flash butt welding method with the process of flashing the surfaces to be joined and subsequent upsetting with force, enabling the front surfaces to be welded [5]. The rail joining process is fully automatic, operating according to computer-controlled programs, depending on the grade and profile of the flash butt welded rails, with a complete registration of technological parameters. An example of the rail flash butt welding diagram for the R260 grade is shown in Fig. 2.

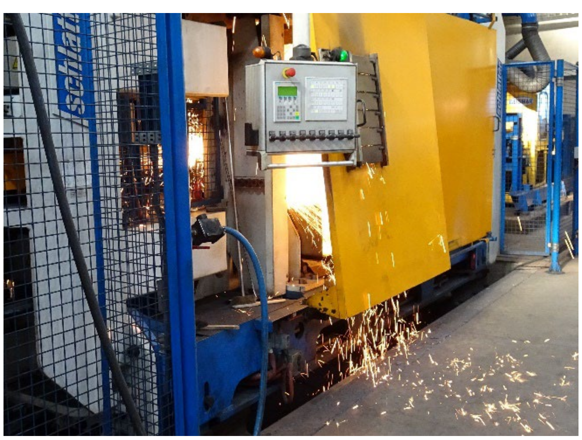

Fig. 1. *Stationary rail flash butt welding machine during flashing (Photo: Author)*

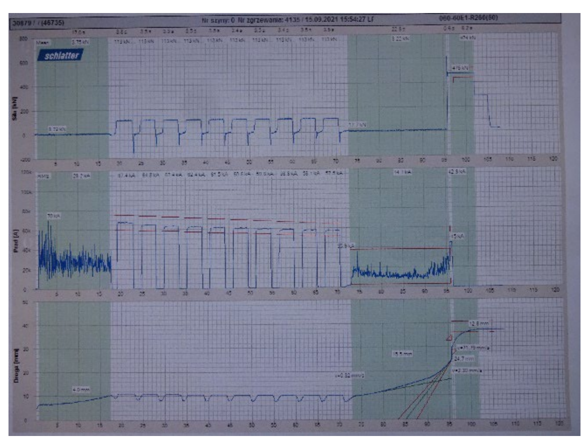

Fig. 2. *Flash butt welding parameters of R260 grade rail (Photo: Author)*

Materials Research Proceedings **24** (2022) 247-253 https://doi.org/10.21741/9781644902059-36

The course of force, current and pre-heating period paths, and flashing and upsetting periods are represented by the corresponding lines in the diagram. Abrupt differences in the above values are visible. This is due to the developed flash butt welding technology. Several times, the flashing period is characterized by the ejection of molten metal due to the formation of current bridges of the emerging electric arc and metal vapor pressure. This results in cleaning and leveling the surfaces of the rails to be flash butt welded and further heating of the ends and upsetting in the final part of the joint flash butt welding process. As a result of joining, the rails are shortened by about 35-45 mm, and the flash butt welding time closes in the range of 80-110 seconds.

The rail flash butt welding diagrams of the R350HT and R400 grades are similar, with a slight difference in the amount of the applied current strength and path.

Rail joints flash butt welded to the shape of the rails to be joined by straightening and grinding treatment to ensure smooth running. In addition, penetrant, magnetic powder, and ultrasonic tests are used to evaluate the flash butt welded rail joints. However, there are occasional cases of irregularities caused mainly by unforeseeable jumps in the technological parameters of flash butt welding, related, among others, to inadequately prepared rail ends for flash butt welding. This is manifested through the appearance of so-called dull spots in the flash butt welding line. These spots are revealed at the fractures of broken rail joints during bending tests. Fig. 3 and Fig. 4 show instances of dull spots at different locations of the fractures.

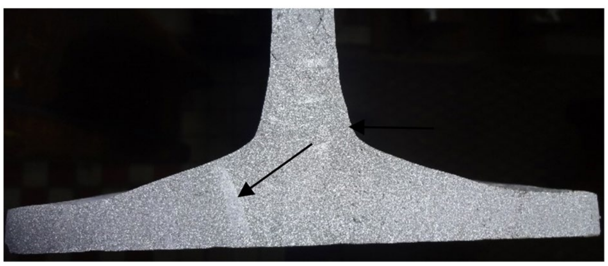

Fig. 3. *Dull spots on the fracture of a broken joint (source: author)*

Fig. 4. *Dull spots on the fracture of a broken joint (source: author)*

Fatigue testing of flash butt welded rail joints is a perfect way of verifying the correctness of the rail flash butt welding process. Any defects occurring during that process affect the strength and ductility of the joints, causing them to crack. These cracks were observed at different times during the dynamic fatigue tests. In the presence of larger dull patches, joint cracking occurs in the range up to 1.0 million fatigue cycles, while with small patches above 3.0 million cycles. These discontinuities are the source of fatigue cracking of rail joints. Figures 5 and 6 show the fractures of flash butt welded joints that underwent separation cracks during fatigue tests at cycles up to 3.0 million.

Internal stresses in rails and rail joints are also crucial for the behavior of these components during further operation in tracks [6] [7]. High stresses in rails and rail joints, i.e. above 250 MPa [1], maybe the source of fatigue cracking during operation in tracks.

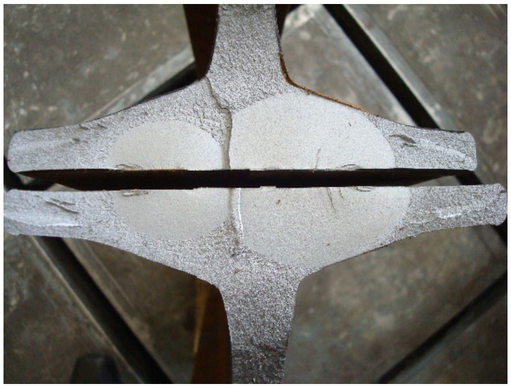

***Fig. 5.** Fatigue crack of flash butt welded joint of R260 grade rails (source: author)*

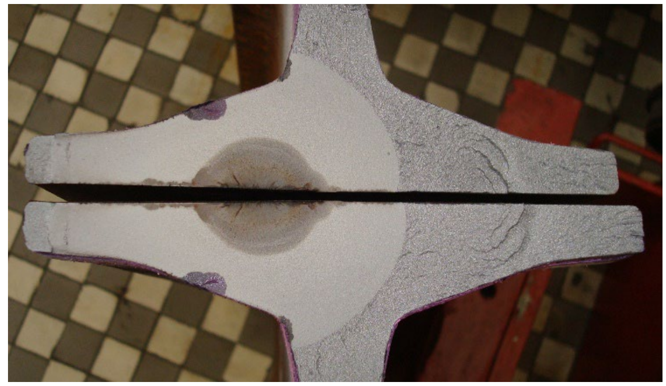

***Fig. 6.** Fatigue crack of a flash butt welded joint of R350HT grade rail (source: author)*

Strain gauge testing of R260 and R350HT grade rails and rail joints before installation on the track is shown in Fig. 7 and Fig. 8. The graphs show the presence of tensile stresses in rails and compressive stresses in rail joints. The highest stresses in the rails were recorded in the railhead above ±200 MPa and the rail foot at +195 MPa and +230 MPa, respectively, while in the joints at -175 MPa and -90 MPa, respectively.

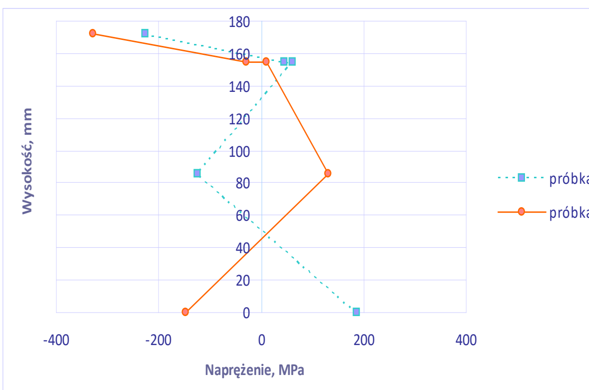

***Fig. 7.** Stress distribution in a rail and flash butt welded joint of R260 grade (source: author)*

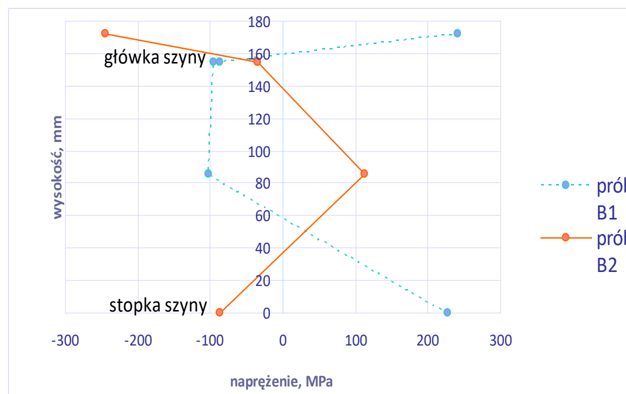

***Fig. 8.** Stress distribution in a rail and a flash butt welded joint of R350HT (source: author)*

Plot description: A1, B1 – rail; A2, B2 – rail joint. Plots labels: Wysokość – height; Próbka – speciment; Stopka szyny – rail foot; Naprężenie – stress; Główka – head rail.

Requirements and Test Results for Flash Butt Welded Rail Joints

Testing of 60E1 profile rail joints of R260, R350HT, and R400HT steel grades was carried out by the PN-EN 13674-1:2019 standard. Chemical analysis and strength properties of rails of these grades showed compliance with the above standard. The quality requirements of the joints included in PN-EN 14587-1;2019 concern joint geometry, penetration, magnetic particle, ultrasonic tests, HV30 hardness, strength tests i.e. bending test and fatigue strength tests, also metallographic tests. The geometry profile significantly impacts the comfort of the train journey, so the straightness of flash butt welded joints should be within a maximum of 0.30 mm. The external quality of the joints was tested using the penetration method, while the internal quality of

Materials Research Proceedings **24** (2022) 247-253 https://doi.org/10.21741/9781644902059-36

the flash butt welded rails was examined using ultrasonic testing. The result of the tests was the absence of internal discontinuity of the joints and the ascertained quality of the rail joints of the investigated steel grades as required by the standards.

The bending strength tests of flash butt welded rail joints of the above grades are presented in Table 1. Three-point support with swing support was used during the bending test. The highest mean forces needed to fracture the joint were recorded for the R400HT grade, i.e. 2081.0 kN, while the displacement for the R350HT grade joints was 48.8 mm. The required bending force for these grades should be at least 1600kN, and the displacement should be at least 15.0 mm and 20.0 mm, respectively. A diagram of the bending test for specimen No. 13 is shown in Fig. 9.

Fatigue tests on rail joints of three steel grades were carried out using the "past-the-post" method, i.e. three specimens of each grade were tested. The forces for dynamic tests were determined using 1500 mm spacing between supports and stress in the foot of solid rail 190 MPa. Table 2 shows the values of applied dynamic forces at 5.0 Hz and the fatigue testing results of 9 specimens.

The stresses in the joints of R260 and R350HT grade rails after fatigue tests simulating the operation of the rails during train running were examined using the strain gauge method. The magnitudes of the internal stresses were continuously recorded while cutting the joints with glued strain gauges. Fig. 10 shows the residual stresses in the joints' foot, head, and web. They do not exceed the 250MPa value required by the standard.

As a result of the tests, it was found that the stresses in the feet and heads were tensile, while in the web of the joints, they were compressive. This is consistent with the stress direction in the new rails coinciding with the stresses shown in Fig. 7 and Fig. 8.

Table 1. *Results of bending tests on rail joints.*

Steel grade/requirements	Specimen number	Bending force, kN	Total bending, mm	Mean value
R260	1	1653.3	36.4	1746.5kN 46.9 mm
	2	1861.7	62.5	
	3	1795.2	53.1	
	4	1638.3	30.4	
	5	1784.1	51.9	
R350HT	6	1686.0	21.0	2026.8 kN 48.8 mm
	7	2291.0	77.0	
	8	1788.0	25.0	
	9	2309.0	80.0	
	10	2060.0	41.0	
R400HT	11	2064.0	30.7	2081.0 kN 31.6 mm
	12	2181.0	37.7	
	13	2160.0	34.2	
	14	2029.0	28.5	
	15	1975.0	27.1	
PN-EN 14587-1:2019		Min. 1600 kN for 60E1/E2	R260, R350HT-min 20.0 mm R400HT- min 15.0 mm	Positive result

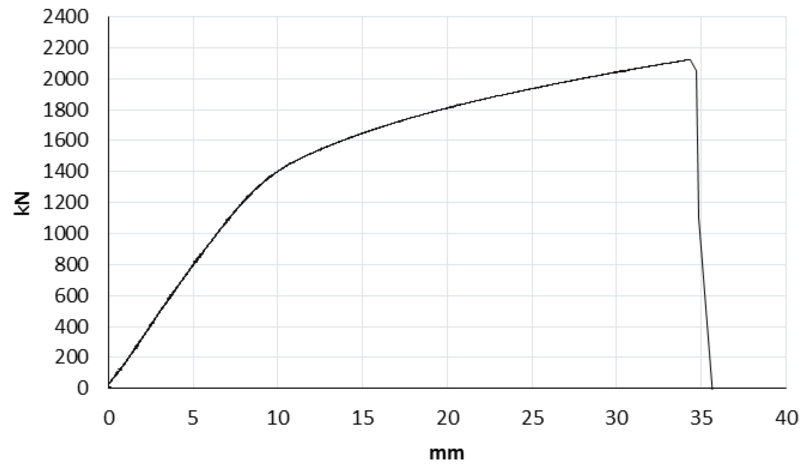

Fig. 9. *Bending diagram of rail joint of specimen No. 13 (source: author).*

Table 2. *Fatigue test results of rail joints*

Steel grade	Specimen number	Bending force, kN	Number of cycles, mln	Result
R260	3	215.0	3 x 5.0	positive
R350HT	3	225.0	3 x 5.0	positive
R400HT	3	224.5	3 x 5.0	positive

The HV30 hardness tests of the rail joints were carried out on the longitudinal section at a distance of 5.0 mm from the rail rolling surface with a measurement every 2.0 mm. The results compliant with the standard requirements [1] were obtained on all samples. The course of HV30 hardness in specimen No. 13 is shown in Fig. 11.

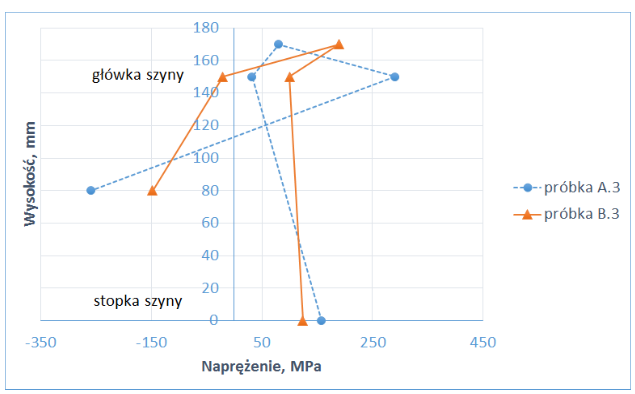

Fig. 10. *Internal stresses in R260 and R350HT joints after fatigue tests, A3 - R260 joint, B3 - R350HT joint (source: author).*

Plots labels: Wysokość – height; Próbka – speciment; Stopka szyny – rail foot; Naprężenie – stress; Główka – head rail.

Materials Research Proceedings **24** (2022) 247-253
https://doi.org/10.21741/9781644902059-36

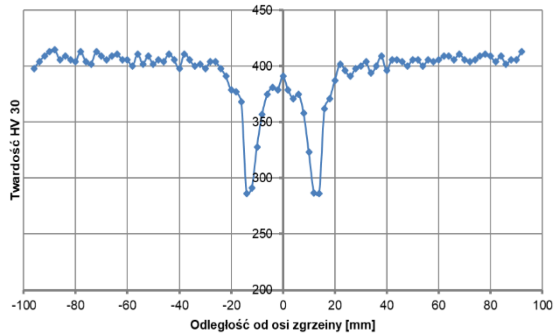

Fig. 11. *HV30 hardness on the longitudinal section of the flash butt welded joint (source: author).*

Plots labels: Twardość – hardness; Odległość od osi zgrzeiny – distance from weld axis.

Examination of the macrostructure for the above grades revealed no internal defects such as nonmetallic inclusions, internal cracks, or unwelded places. The macrostructure of the joint is shown in Fig. 12, with the flash butt weld line and the heat-affected zone visible.

Fig. 12. *Macrostructure of the R260 grade rail joint after flash butt welding (source: author).*

The examination of the microstructure of the joints included the study of the flash butt weld line and the heat-affected zone. In the joints of R260 and R350HT steels, with the carbon content at the lower limit provided by the standard, a differentiated pearlitic structure was found in the flash butt weld line, with separations of ferrite on the borders of former austenite grains (Fig. 13 and 14). In contrast, separations of sorbitol and fine perlite characterized the heat-affected zone.

In rail joints with a higher carbon content of about 0.80 % and above, a pearlitic structure with cementite separations at the boundaries of former austenite grains was found in the flash butt weld line. At the same time, the heat-affected zone had a sorbitic structure. Bainitic-martensitic structures were not found in the joints.

Fig. 13. *Microstructure of the flash butt welded joint head of R260 grade rail after fatigue tests (source: author)*

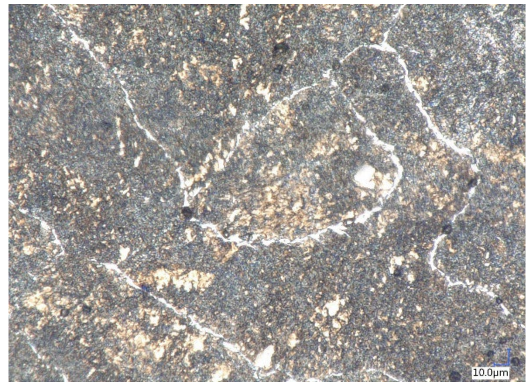

Fig. 14. *Microstructure of the flash butt welded joint head of R350HT grade rail after fatigue tests (source: author)*

Summary

The conducted tests of flash butt welded rail joints of the R260, R350HT, and R400HT grades after stationary flash butt welding in the form of profile geometry tests, penetration and ultrasonic tests, bending strength, fatigue strength tests, and hardness tests showed that the tested flash butt welded rail joints met the requirements included in the standards in question and could be used in railway tracks. At the same time, it was found that the stresses in the tested rail joints after fatigue testing are consistent with the stresses of the rails and rail joints before installation on the tracks. Metallographic tests of the rail joints did not reveal the presence of a martensitic-bainitic structure.

References

[1] PN-EN 14587-1:2019-03. Railway application – Infrastructure – Flash butt welding of new rails – part 1: R220, R260, R320Cr, R350HT, R350LHT, R370CrHt and R400HT grade rails in a fixed plant, 2019.

[2] PN-EN 13674-1+A1:2017-07. Railway application – Track – Rail – Part 1: Vignole railway rails 46kg/m and above, 2019.

[3] H. Bałuch. Trwałość i niezawodność eksploatacyjna nawierzchni kolejowej, Wyd. Komunikacji i Łączności, Warszawa, 1980.

[4] Rolling Contact Fatigue in Rails: a Guide to Current Understanding and Practice, Railtrack PLC Guide-lines: RT/PWG/001, Issue 1, 2001, (13).

[5] I. Mikłaszewicz. Wykonywanie i badanie kolejowych złączy szynowych, Problemy Kolejnictwa 158 (2013) 35-50.

[6] S.J. Wineman, F.A. McClintock. Residual Stresses Near Rail End, Theoretical and Applied Fracture Mechanics 13 (1990) 29-37.

[7] I. Mikłaszewicz, J. Siwiec Badanie naprężeń wewnętrznych w połączeniach szyn kolejowych, Problemy Kolejnictwa 177 (2017) 45-50.