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WELDING TECHNIQUES TRAM RAIL 54G2 OF R260 AND BLOCK OF COGIDUR USING FCAW-S PROCESS AND FATIGUE TESTING OF WELDED JOINT

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Abstract *– This paper explores the welding technology used for joining tram-rail 54G2 (1.0623 Group ISO/TR 15608-11.3.) with a block of Cogidur (1.8715 Group ISO/TR 15608-3.2) using a self-shielded flux-cored wire in a butt welding process, supplemented by copper washers. The study includes a comprehensive analysis of the welded joint, NDT testing as visual testing (VT) and penetrant testing (PT), as well as macrostructure and hardness evaluations. Furthermore, the paper details the final fatigue testing of the welded specimen, conducted at the Technology Center in Reichshoffen, France. The results of fatigue testing offer valuable insights into the structural integrity of welded joints done advanced welding techniques in rail systems.*

Keywords – tram rails 54G2/R260, block of crossings/cogidur, FCAW-S process, fatigue testing.

1. INTRODUCTION

Vossloh Laeis, a manufacturer of railway points, makes use of a material known as “Cogidur” for the purpose of lengthening the service life of points. Cogidur is a material that is harder than the steel normally used for rails. Moreover, it lends itself to welding even at low preheating temperatures.

The welding processes used to connect 54G2 (EN 14811)/R260 tram rails to the Cogidura block for switches and crossings are as follows: Aluminothermic welding (AT), Electric resistance welding (ET) and Flux-cored arc welding (FCAW). Electric resistance welding of rails (ET) is most commonly used in workshops, although mobile equipment for field welding is also available today. However, aluminothermic welding (AT) is currently the most widely used method for rail welding, both in workshops and in the field. Since 1996, flux-cored arc welding (FCAW) has been employed for rail joining. This process was developed by Lincoln Smitweld GmbH and received approval from Deutsche Bahn AG for welding rails and turnouts with tensile strengths ranging from R_m=685 MPa to R_m =885 MPa, for tracks with axle loads up to 10 tons and speeds below 80 km/h.

FCAW is a welding process that utilizes a flux-cored wire and generally employs similar equipment to the MAG process, but without the use of shielding gas. The welding characteristics are comparable to those of the E process (Fig. 1).

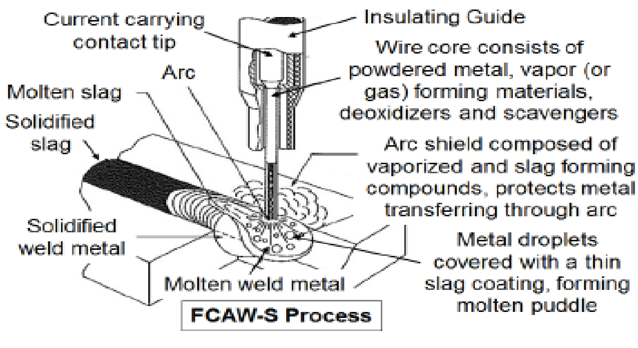

Fig. 1. FCAW-S self-shielding wire welding procedure

The flux-cored electrode wire can be considered a continuous electrode with a protective material inside a steel sheath, enabling a constant electrical contact between the wire and the copper contact tube in the

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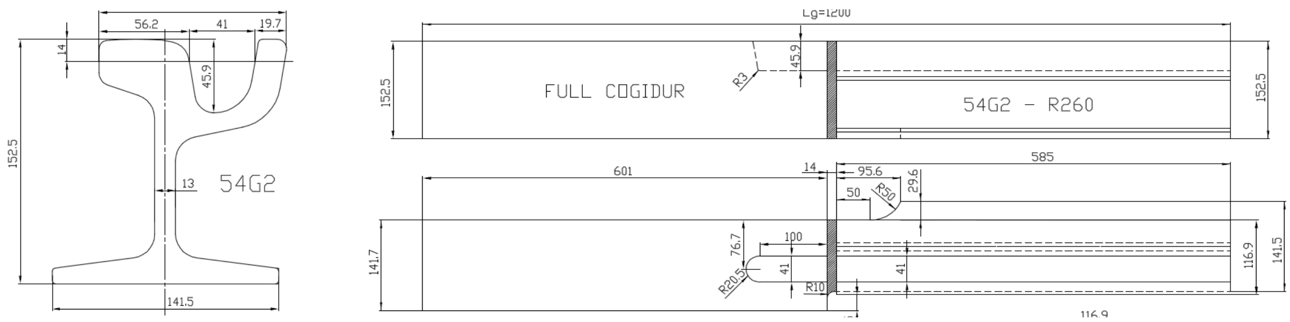
welding gun. This allows for significantly higher current values than those achieved with the MAG or E processes, resulting in higher productivity when welding or surfacing thicker materials. The diameters of flux-cored wires range from 0.9 to 3.2 mm.

2. EXPERIMENT

2.1. Base material

During the production of tram turnouts, it is necessary to weld the 54G2 rail (SRPS EN 14811) (Fig. 2a) - material R260 (Wr.Nr. 1.0623) to a steel known as Cogidur (17MnCr5-3; Wr.Nr. 1.8715) (Fig. 2b). Cogidur is a material that is harder than steel normally used for rails and it is normally used to extend the design life of rails. Moreover, it lends itself to welding even at low preheating temperatures. The crucial advantage of this material resides in the combination of its high wear resistance and its good weldability. Chemical composition of base material of rail 54G2 and material of Cogidur is given in the table 1, and mechanical properties in table 2. The welding was carried out at the "Vossloh MIN Skretnice" factory in Niš.



a) b)

Fig. 2. Cross section of tram rail 54G2 (a); preparation of the joint of the rail and the welding block (b)

Tab. 1. Chemical composition of base material- Mass Fraction in Percent (%)

Base material	C	Mn	Si	Ni	Cr	Mo	Ti	V	Cu
R260	0.62-0.8	0,7-1.2	0.15-0,58						
Cogidur	0.152-0,25	1.305	0.383	0.418	1.653	0.174	0.005	0.002	0.239

Tab. 2. Mechanical properties of base material

Base material	R_m MPa	$R_{p0,2}$ MPa	A %	Tvrdoća HB
R260	933-947	493-510	12.5-14.4	275 - 284
Cogidur	1355	1005	13	388-401

2.2. Filler material for welding and surfacing the tram rail-block joint

For welding the rail-block joint using the FCAW-S process, a self-shielded wire EN ISO 17632-A T 46 Z V N3, commercially known as Innershield NS-3M, manufactured by Lincoln Electric USA, with a wire diameter of Ø 2.0mm is used.

For surfacing using the FCAW-S process, a self-shielded wire EN14700 T Fe 1, commercially known as Lincore 33, also manufactured by Lincoln Electric USA, with a wire diameter of Ø 2.0mm is used. Chemical composition and mechanical properties of filler material are shown in Tab. 3 and Tab. 4.

Tab. 3. Chemical composition of filler material in %

Filler material	C	Mn	Si	P	S	Al	Cr
NS-3M	0,23	0,45	0,25	0,006	0,006	1,4	
Lincore 33	0,15	2,0	0,7			1,6	2,0

Tab. 4. Mechanical properties of filler material

Filler material	R_m MPa	R_e MPa	A %	Rockwell Hardness (RC)	
NS - 3M	640	470	27	No. of Layers	
Lincore 33				1	28-34
				2	32-36
				3	35-38

2.3. Welding process

The welding of the rail to the block is achieved by positioning them with a gap of 14-17mm between them, depending on whether the distance is measured at the base of the rail or at the top of the rail head. The edges of the rail and the block are ground to a metallic shine, and after checking the centricity of the block relative to the rail, a clamp is applied to hold them at the correct distance. After that, copper shims are placed on the sides of the rail in the base area, and a copper shim with a groove is already positioned underneath the rail and the block (Fig 3).

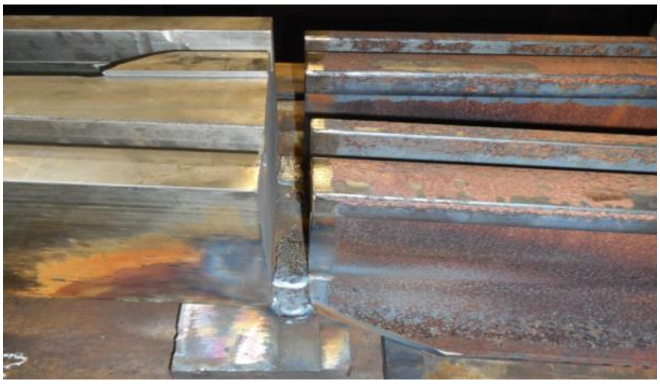


Fig. 3. Preparation for welding the rail base, 3rd pass

Before welding, the rail and block are preheated with propane-butane over a length of 500mm on both sides of the joint, ensuring that the material is heated through the depth of the block. The preheating temperature can reach up to 350°C for the rail and 250°C for the block, which is challenging to achieve in practice. After preheating, the base of the rail is welded to the block in two passes, and after these passes are completed, the copper shims are removed, and an additional pass is welded.

After the copper shims are placed, preheating is repeated due to the heat loss and cooling of the material. Placing the shims on a previously heated joint is challenging and requires the skill of the welder. By measuring the temperature of the rail and block material, and if it does not deviate by more than 10% from the value specified in the WPS sheet, the welding process continues using the FCAW method, continuously welding the neck of the rail to the block until the weld reaches the end of the rail neck. At that point, the copper shims are removed, and the weld is cleaned of slag using a pneumatic tool with vibrating wires. Afterward, at least three more passes are welded, leaving the last 30mm of the rail head unwelded. This is done because the final 30mm is surfaced with a self-shielded wire with a hardness of 33HRC. Throughout the welding process, the current values are closely monitored, ensuring minimal deviation from the values specified in the WPS sheet.

The welding parameters, as specified in the WPS sheet, show current values ranging from 290 to 350 A, depending on whether the base or neck of the rail is being welded. The welding voltage is between 29-31 V, the welding speed varies from 30 to 42 cm/min, and the heat input ranges from 1.2 to 2 KJ/mm.

For surfacing, the parameters are I = 280 A, U=30V, v = 28-30 cm/min, and E = 1.5-1.65 KJ/mm.

After welding the rail-block joint using the FCAW-S process, the joint is reheated to a temperature of 200°C for a duration of 1 hour. After that, it is covered with a fireproof blanket and allowed to cool slowly.

3. EXAMINATION AND RESULTS

3.1. Non-destructive testing

After 24 hours, a visual and dimensional inspection was carried out, examining both the welded joint itself as well as the parallelism of the rail and block, and checking for any possible deformation or shrinkage. Following this, penetrant testing and ultrasonic testing of the welded joint were performed (Fig 4). The critical point of the welded joint is at the end of the rail neck, where the welding stops, the copper shims are removed, and after cleaning and reheating, welding continues. At this stage, defects such as overlaps or non-metallic inclusions may occur.

Fig. 4. Welded rail-block joint

3.2. Destructive testing

Since the results of non-destructive testing were satisfactory, destructive testing was initiated, including macrographic examination and hardness testing (Fig 5). The testing was conducted by the laboratory "RD Dijagnostika d.o.o." in Belgrade, which is authorized by TÙV Thùringen Cert.

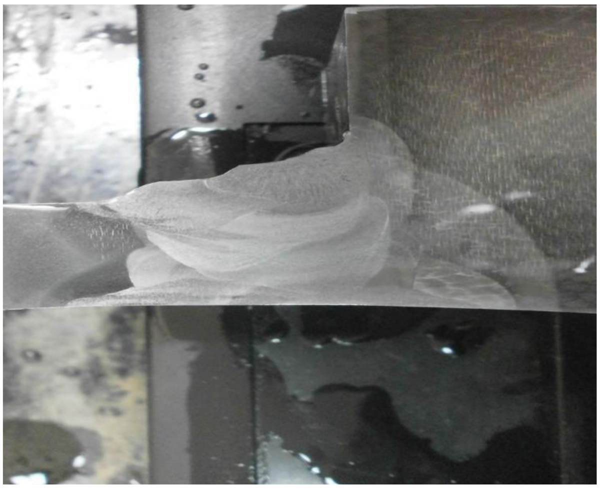


Fig. 5. Macro section in the area rail base

The hardness of the welded joint at the base of the rail made of R260 material and the block made of Cogidur material in the characteristic zones of the welded joint (BM - base material; HAZ - heat-affected zone; WM - weld metal) is presented in Tab. 5.

Tab. 5. Hardness of the welded joint

Rail base (54G2- EN 14811) /R260					
1	BM	280	5	HAZ	290
2	BM	285	6	HAZ	287
11		WM		345	
Block Cogidur /17MnCr5-3; Wr.Nr. 1.8715					
7	HAZ	280	3	BM	408
8	HAZ	288	4	BM	404
13		WM		309	

3.3. Fatigue testing

The fatigue testing was performed on the AW-RBW sample (block/Cogidur – rail 54G2/R260), following procedure T15002P01. The sample was 1200mm in length and was welded using the FCAW-S process at the company VOSSLOH MIN SKRETNICE in Niš. The fatigue test was conducted at the Vossloh Cogifer Technology Center in Reichshoffen, France (Fig. 6). The distance between the supports was 1000mm, and two laser sensors were used to measure the amplitude. Prior to testing, the hydraulic cylinder was certified, and the laser sensors were calibrated.

Fig. 6. Fracture testing machine

Fatigue testing was performed under variable loading with a frequency between 5 and 9 Hz (Tab 6) and an asymmetry factor of R=0.1. The criterion for a good welded joint is that after 3,000,000 cycles, there are no cracks in the welded joint. Calibration was performed directly on the test specimen. A 350Ω single-direction strain gauge was attached to the center of the rail base, 5mm from the weld.

Tab. 6. Fatigue testing parameters

No. cycles	Frekv. (Hz)	L1 Ampl. (mm)	L3 ampl. (mm)	Stress (MPa)
1.000 (calibration)	7	0,91	1,01	12,5-129,8
700.000	5	0,94	0,96	13,5-130,1
3.000.000	9	0,92	0,95	13,2-129,6

Based on the fatigue testing, after 3,000,000 cycles of variable loading (R=0.1) that induced stresses in the welded joint ranging from 13 MPa to 130 MPa, no cracks were observed in the welded joint, as clearly seen on the specimen after penetrant testing (Fig. 7).

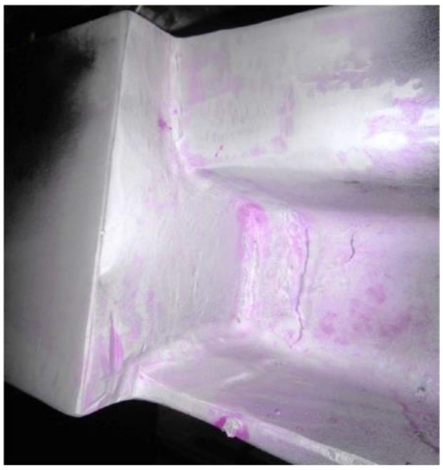


Fig. 7. Appearance of the specimen after penetrant testing

4. CONCLUSION

Grooved rail (also known as girder rail) is a common tram rail used by modern tram. Due to the asymmetric cross-section of the girder rail, the welding process of the girder rail is complex, the technical requirements are high, and the welding is difficult. Compared with standard steel rails, more sophisticated welding techniques are required. The paper presents the successful welding technology of tram rail 54G2 R260 and Cogidur block is a welding process 114 that uses a cored wire and generally uses similar equipment to the MAG process, but without the use of shielding gas, which is confirmed by testing the welded joint by non-destructive methods by determining the profile hardness of the welded joint and dynamic fatigue testing.

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