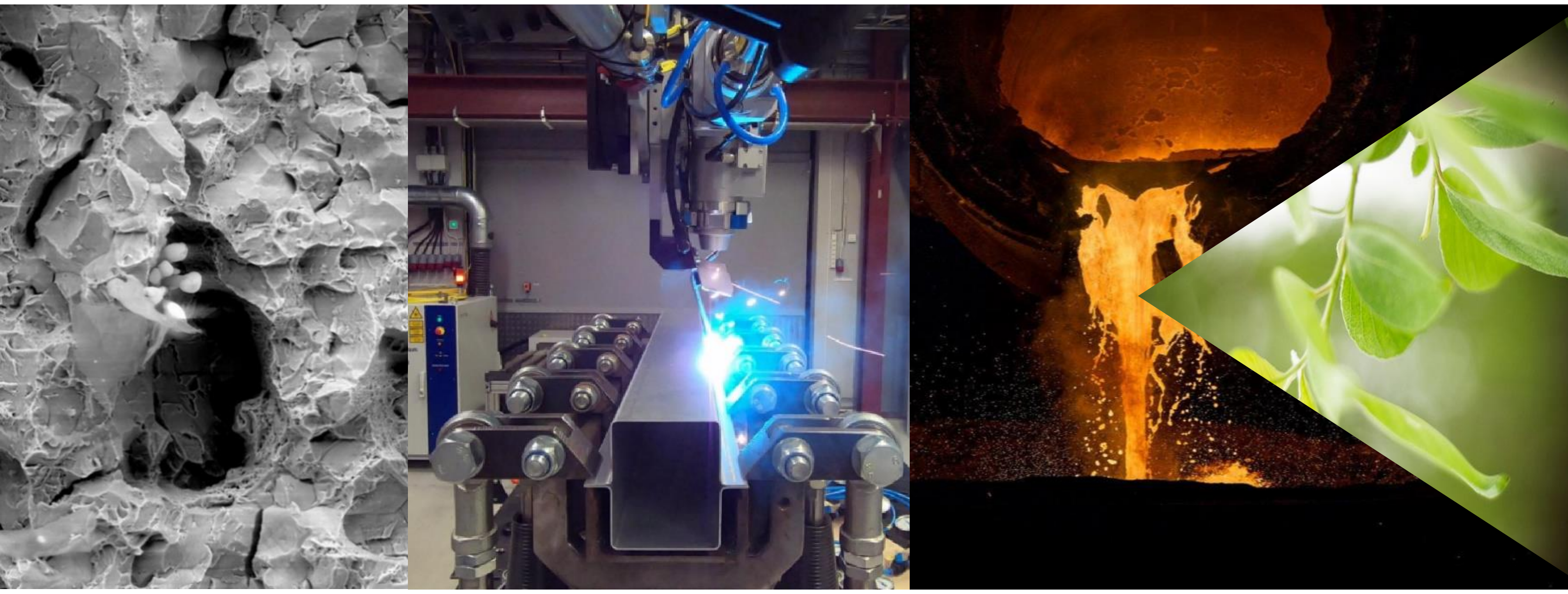

LIVAR – Livslängsoptimering av räler

David Franklin, Alexander Lundstjälk

Report number. 101407

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Abstract

A Life Cycle Analysis prior to this project shows that repair of rails using electroslag twin strip cladding, instead of replacing rails, will drastically lower the environmental impact (CO_2 level). This project will therefore investigate the potential with repair from an LCC- analysis, and productivity perspective.

Welding trials were performed with Electroslag twin Strip Cladding (ESC), Flux Cored Arc Welding (FCAW) and Submerged Arc Welding (SAW) using wires and strips. The result shows that ESC is a high productivity welding process suitable for rail repair and could be used without pre-heating, which is not the case in FCAW and SAW.

The LCC was divided into an analysis of repair of long worn rails in the track, and in a workshop. Both analyses showed that repair using welding is not cost efficient.

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1 Introduction

Swerim had a collaboration with RISE within the field of repair of rails and investigated the potential to repair rails instead of replacing them, from a Life Cycle Analysis (LCA) perspective. The result from this study is the origin of project LIVAR. The LCA showed that repair of the rails could drastically benefit the environmental impact, see Figure 1. The project LIVAR therefore further investigated a Life Cycle Cost (LCC) to visualize the economical aspect, as well as the repair welding process that require high productivity and quality.

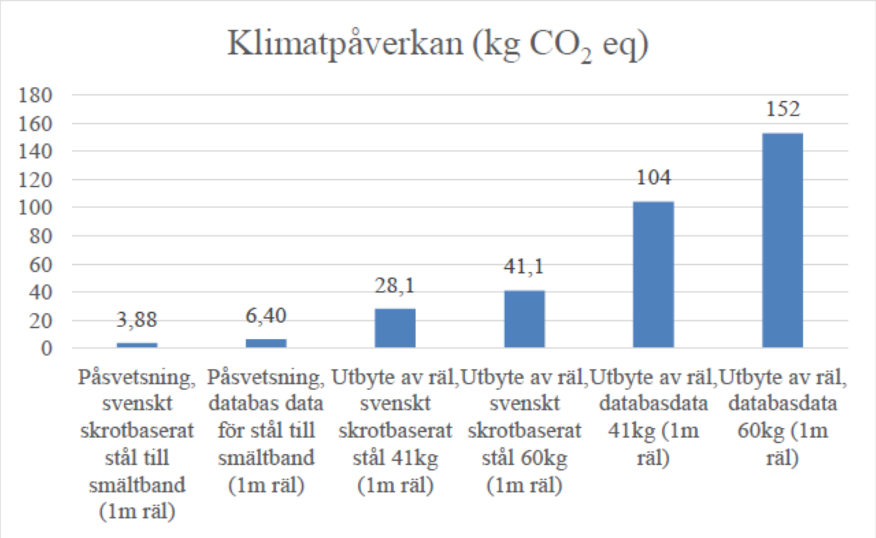


Figure 1: LCA comparing repair and replacing rails in the track [1]

Part of the railway network is today repair welded on site by Flux Cored Arc Wire (FCAW, self shielded) or Manual Metal ARC (MMA), where the rail has been worn or fractured. This project LIVAR intend to investigate the possibilities with repairing long rails on site in the railway network. The target is to investigate the technical aspects by evaluation of process stability, productivity, limitations on site, etc. The experience within the project group was that electroslag twin strip cladding (ESC) had the highest potential to fulfil the requirements. Unfortunately, this new high productivity process had not been used for repair of rail materials before and thus there were no such filler materials available. Therefore, the planning for the welding trials were divided into two parts: the first part was evaluation of the productivity and practical approach of using the electroslag twin strip cladding process using "conventional" stainless steel strips (not perfect fit for repair of rails) and evaluation of penetration/dilution. The second part was to mimic this process with more conventional processes as FCAW, with the wire used today for repair, however, to understand and predict the impact on the material.

Depending on where in the railway network you look there are different kinds of wear damage to the rails and the main focus in this project was repair of the top of the rail head. Rolling contact fatigue (RCF) and cracks are defects that can be found on the top of the rail and be repaired. However, in the initial LCC analysis it was concluded that the main cost savings could be done in the curved rails where the wear is on the side of the railhead. Therefore, tests were also performed with Submerged Arc Welding (SAW) with wire on side of the railhead, to understand the possibilities and limitations with that.

Short time for the repair welding is essential to minimize stops in the traffic.

2 Weld trials procedure

The welding trials were performed on the flat top of the rail head. There were no commercially available strips in Electroslag twin strip cladding (ESC) found to match the rail head material, therefore three processes were used. First the ESC process was used to estimate the productivity. Then the Flux cored arc wire (FCAW) to evaluate the material properties in the interface between railhead and filler material. In the end of this project ESAB found matching cladding strips for the Submerged arc welding process (SAW) – this is a process that act in between FCAW and ESC, regarding heat input and productivity. However, the focus was to both investigate if this is approved regarding material properties and the productivity of the electroslag cladding, as an input to the LCC analysis.

It was concluded in a workshop that the side of the railhead could be more beneficial to repair – from an economical perspective. Therefore, also welding on the side of the railhead was tested. This was performed by narrow gap setup with submerged arc welding – as multi pass welding.

The recommendations regarding material properties and approved welding procedures is presented in "TDOK 2013:0392 presenting repair of rails using Manual Metal Arc (MMA) and FCAW". Recommended pre-heating temperature for the R260(UIC 900A) is 400°C and interpass temperature max 350°C. [2] Lower or no pre-heating is beneficial from a productivity perspective but can be detrimental to the material properties. This is therefore further tested. A summary of all welding trials is presented below, Table 1.

*Table 1: Summery of weld trials. *from start with pre-heating to final weld.*

Process\ setup	Filler material	Pre heating	Interpass temperature	Weld position	Estimated no of weld runs required for full repair.	Time for "full" repair *
Electroslag cladding trials	Stainless steel, 309LNB	0 °C	-	Top of head	1	Medium.
FCAW Welding trials	OK Tubrodur 35 O M	400 °C	350°C	Top of head	2	Long
SAW band	Band 430 (11.82)	100/200 °C	N/A	Top of head	3	Long
SAW wire	OK 13.43	100/200 °C	130 °C	Side of head	8	Very long

The rail steel used is in all welding trials is a standard rail R260 which has a chemical composition presented in Table 2. [3]

Table 2: Chemical composition of rail R260

%C	%Mn	%Si	%P	%S	Max H ppm	Max O ppm
0.62-0.80	0.7-1.2	0.15-0.58	Max 0.025	0.008-0.025	2.5	20

2.1 Electroslag cladding (ESC)

The Electroslag cladding process uses twin strips to drastically increase the volume of deposited material. The first warm strip is vital to create the melt bath and the second cold strip is added to increase the deposition rate. The melt bath is covered in a flux that act as a protection from surrounding air and include alloying elements for the weld metal. After welding, the flux creates a slag covering the surface on top of the weld, which is removed by a weld hammer. The welding was only performed with one pass due to the high deposition rate of the process, resulted in layers approximately 5 mm thick and with a width of the 65 mm. The welding was performed on top of the rail head without any pre-machining or other preparations. In a full repair operation this would have been done to remove surface damage. The filler material used was stainless steel since no matching filler could be found on the market. Therefore, only the HAZ was evaluated in these trials.

The welded rails were 1 m long and welded in the welding lab at ESAB, Laxå. The rail was clamped with high force to the work bench and Cu-backings were mounted vertically on the sides of the rail head, to control the melt and powder from overflow, see Figure 2.

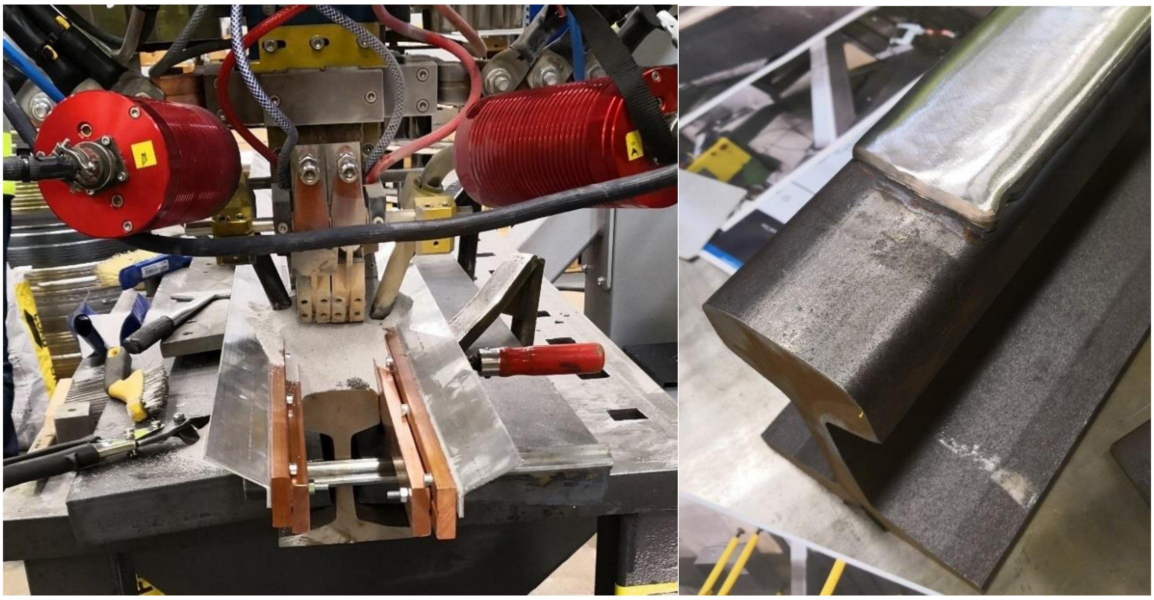


Figure 2, (left) weld setup for ESC welding, (right) finished weld.

Flux used were OK Flux 10.14 from ESAB which is a Fluoride basic CaF_2-Al_2O_3, with composition according to Table 3.

Table 3 Flux composition

Al2O3	CaF2	Mn+Cr
20%	70%	10%

The composition of the two strips were slightly different. The heated band (w) was OK Band 309LNb(60x0.5mm) and the cold band (c) were OK Band 309LNb ESC (60x0.5mm), find the compositions in Table 4.

Table 4 filler strip composition

Strip\Composition	C%	Cr%	Mn%	N%	Nb%	Ni%	Si%	Si+Fe%
OK BAND 309LNB	0.01	23.83	1.98	0.03	0.7	12.5	0.23	23
OK BAND 309LNB ESC	0.01	21.14	1.74	0.04	0.6	11.0	0.20	15

Parameters for welding were optimized with focus on a stable process, full covering of railhead surface and productivity. The final parameters are presented in Table 5.

Table 5 ESC welding parameters. v(w)= speed warm strip, v(c)=speed cold strip.

Q (ave. kJ/mm)	Current (A)	Voltage(V)	Travel speed(cm/min)	Stickout (mm)	v(w) (cm/min)	v(c) (cm/min)
30,6	2996	24	61	35	269	251

2.2 Flux Cored Arc Welding (FCAW)

The FCAW trial were performed to create a reference and validation of what material properties that is desired, using the WPS (Welding procedure specification) that are being used to repair rails by Infranord today. The results will be used to compare the ESC results regarding material properties. However, it should be noted that the welding condition differ quite a lot for instance regarding heat input and pre-heating temperatures.

The WPS specifies a preheat to 400°C and a working temperature of 350°C, to solve the preheat an oven was used and placed at the same hight as the welding table see Figure 3

Figure 3, Pizza oven used for preheating.

The temperatures of the specimen were measured and logged with type S thermocouples connected to a national instrument NI-DAQ, see Figure 4.

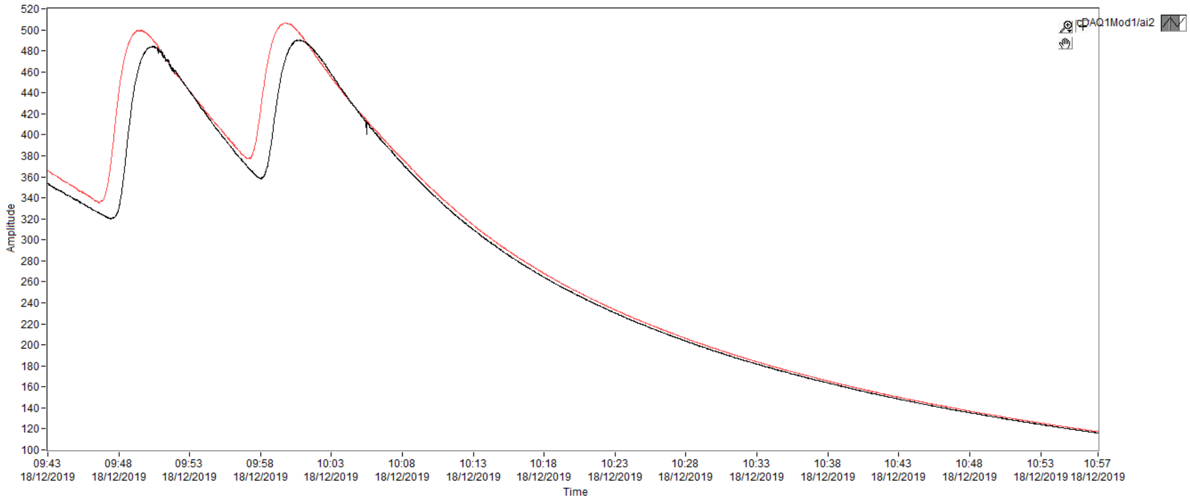


Figure 4, temperature log of the FCAW welding

A Motoman HP20-B00 robot was used and equipped with a EWM PHOENIX 521 PROGRESS PULSE coldArc power source to which a PHOENIX PROGRESS DRIVE coldArc wire feed unit was connected.

The weld pattern was done by welding traverse to the rail, see Figure 5. The time to weld the full length in one layer was approximately 15 minutes. Two layers were welded to achieve the same thickness of added material as is created with the ESC.

Figure 5, weld pattern

The filler used was a self-shielding used to repair surface damages in rails Called OK Tubrodur 35 O M, and the composition can be found in Table 6

Table 6 Filler composition

Filler composition	C%	Cr%	Mn%	Al%	Mo%	Ni%	Si%	Fe%
OK Tubrodur 35 O M	0.14	1.04	1.10	1.5	0.48	2.23	0.28	Bal.

The welding parameters used for both welding is presented in Table 7.

Table 7 welding parameters

Power source	**Material**	**Filler**	**Wire diameter [mm]**	**CTWD [mm]**	**Travel speed [cm/min]**	**Torch work angle [°]**	**Torch travel angle [°] [+ Push]**	**Job No (Synergy, Program)**
EWM Phoenix	60EI/R260	OK Tubrodur 35 O M	1,6	25	40	0	-20	238
Wire speed [m/min]	**Voltage [V]**	**Current [A]**	**Heat input inst mean [kJ/mm]**	**Pre heat [°C]**				
6	26,5	221	0,56	350				

2.3 Submerged arc welding (SAW) – Strip

SAW single pass trials with strip were performed on top of the rail head. The trials were performed with the target to use a suitable strip filler material (made for welding rails) and investigate its properties at lower pre-heating temperatures, 100 °C and 200 °C. This can be compared to the TDOC recommendation 400 °C for FCAW.

The strip is 30mm width and 0.5mm thickness and of type Band 430 (11.82), find specification ESAB presented in Table 8. The flux used is ESAB OK Flux 10.92, a Cr-alloyed with Calcium silicate SiO2-MgO-Al2O3-(CaF2).

The welding was performed on 0.5m rail parts and the parameters used is presented in Table 9.

Table 8 Composition of filler strip

C%	Cr%	Mn%	Si%
0.04	17	0.66	0.4

Table 9: Welding parameters – pre-heating with 100 °C respective 200 °C.

Current(A)	Voltage(V)	Weld speed (cm/min)	Stick out (mm)	Band	Flux
350	27.5	30	30	OK 430	10.92

2.4 Submerged Arc Welding (SAW) – Wire

From the FCAW and ESC trials it was concluded that the focus of rail repair should be on the parts with highest level of wear, which is the inside of rails in curves. Therefore, a final test was performed: Welding the side of the rail where the most wear can be found. This is not possible with ESC due to the large melt pool and limitation to PA positioning of the weld head. These trials were performed on rail heads machined according to Figure 6 (dotted rectangle is removed material). The green curve shows the worst wear profile which may arise in a railway curve. The image also describes how the incident angle of the filler wires were pointing. The angle in travel direction is always 90 ° to the base plate. Cu-backings were used to control the melt and flux from overflow, see Figure 7.

It was assumed that a high heat input, as in ESC, resulted in slow cooling and no need for pre-heating was necessary. This SAW process has a heat input in between the processes FCAW and ESC. Therefore, a mediate pre-heating was used: 100 and 200 °C. The interpass temperature was also set based on the pre-heating.

This process is less productive compared to ESC and requires many passes to build up the required material for a complete repair. This is time consuming.

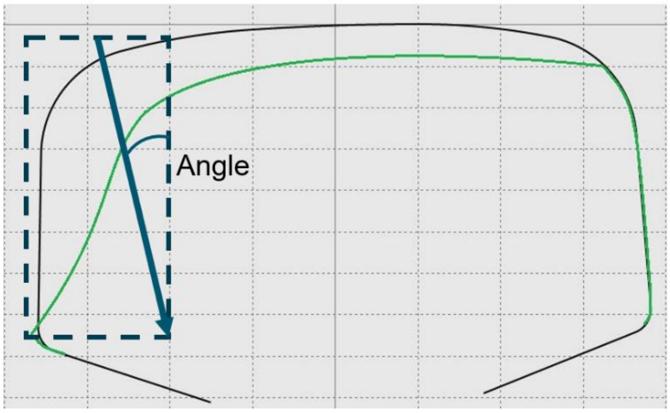


Figure 6, wear profile of a rail with a dotted line illustrating the joint preparation.

ESAB´s ICE Aristo 1000 AC SAW process was used with 3 wires. 2 warm/hot wires and 1 cold wire in the centre.

Figure 7, the setup for SAW welding.

All SAW welds were welded with wire 13.43 (3 pcs 2.5mm in diameter) see Table 10, and a fluoride-basic OK FLUX 10.62.

Table 10 Filler composition for SAW welding.

	C%	Cr%	Mn%	Mo%	Ni%	Si%
OK AUTROD 13.43	0.12	0.67	1.55	0.47	2.29	0.19

All tests were performed with controlled and measured pre-heating and interpass temperature, find more details in Table 11Table 12. The test setup started with incident angles 12-17 ° (C1-C2) in a PB position. Then(C3-C5) another approach was tested to build faster, called narrow gap. This mainly mean that the incident angle of the wires was changed to only 2° and the distance from the corner was set to 2 mm.

Table 11 SAW welding parameters.

Name	Q (ave. KJ/cm)	Current (A)	Voltage(V)	Travel speed(cm/min)	Stickout(mm)	2 wires, v(w) (cm/min)	v(c) (cm/min)
C1	18.6	758	27	74.9	25-30	230.3	173.2
C2	18.6	758	27	74.9	25-30	230.3	173.2
C3	19.5	838	30.5	85	25-31	262.3	171.2
C4	19.5	838	30.5	85	25-31	262.3	171.2
C5	19.5	838	30.5	85	25-31	262.3	171.2

Table 12 SAW electrode positions, pre-heating and balance/offset.

Name	Pre-heating temp °C	Interpass temp. °C	No of pass	Incident angle °	mm from corner	AC Balance%	AC offset (V)
C1	100	130	3	12/17/17	0	25	-3
C2	100	130	1	18	0	25	-3
C3	100	130	8	2/2/2/2/2/2/2/2	2	25	-3
C4	100	130	3	2	2	25	-3
C5	200	230	3	2	2	25	-3

3 Results

In this project two standards have been used to evaluate the properties of the welds. The SS EN 15594:2009 (Railway applications. Track. Restoration of rails by electric arc welding) and the TDOK 2014:0586 (Svetsning av räler och rälskomponenter. Godkännande av svetsprocedurer) [4]. These standards were used together to specify the demands of the welded rails.

The TDOK recommends a hardness of 275-370 HV on top of the rail head (weld metal, WM) when it has been repaired by welding - this hardness is only specified for the surface of the weld.

For sub-surface hardness of the weld or any other part of the railhead it is specified in SS EN 15594:2009 that the hardness must not exceed 400 HV10. Recommended measuring spots for hardness is illustrated in Figure 8.

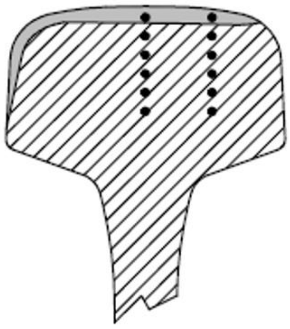


Figure 8: Hardness measurement on cross-section surface

A summary of the weld trials and hardness results are presented below in Table 13

*Table 13: Summery of best results. *C3*

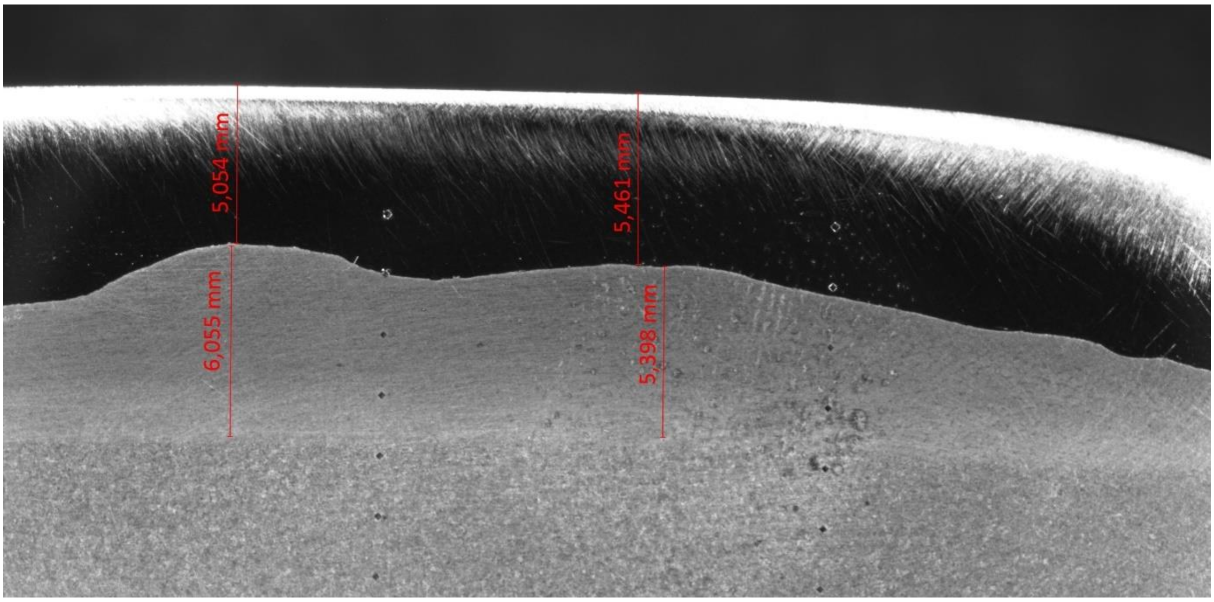
Process\ setup	Filler material	Pre heating	Inter pass temperature	Defects	HAZ close to WM max HV10	HAZ close to unaffected BM max HV10	Weld metal HV10
Electroslag cladding trials	Stainless steel, 309LNB	0 °C	-	No	300	230	200
FCAW Welding trials	OK Tubrodur 35 O M	400 °C	350°C	No	320	240	330
SAW band	Band 430 (11.82)	200 °C	-	No	330	290	520
SAW wire*	OK 13.43	100 °C	130 °C	Yes	620	411	370

3.1 Electroslag cladding (ESC)

The filler strip for the ESC welded specimen was a stainless-steel material that does not fit to the hardness specified by the different standards. Therefore, the evaluation only focus on the Heat Affected Zone (HAZ) of the material to examine the effect of the high heat input from the ESC process to the rail material.

3.1.1 Defects

No defects were found.



3.1.2 Hardness

The results are given in Figure 9. A maximum hardness of 310 HV10 is measured. The highest values are obtained 6-8 mm from the surface in the transformation zone close to the fusion line.

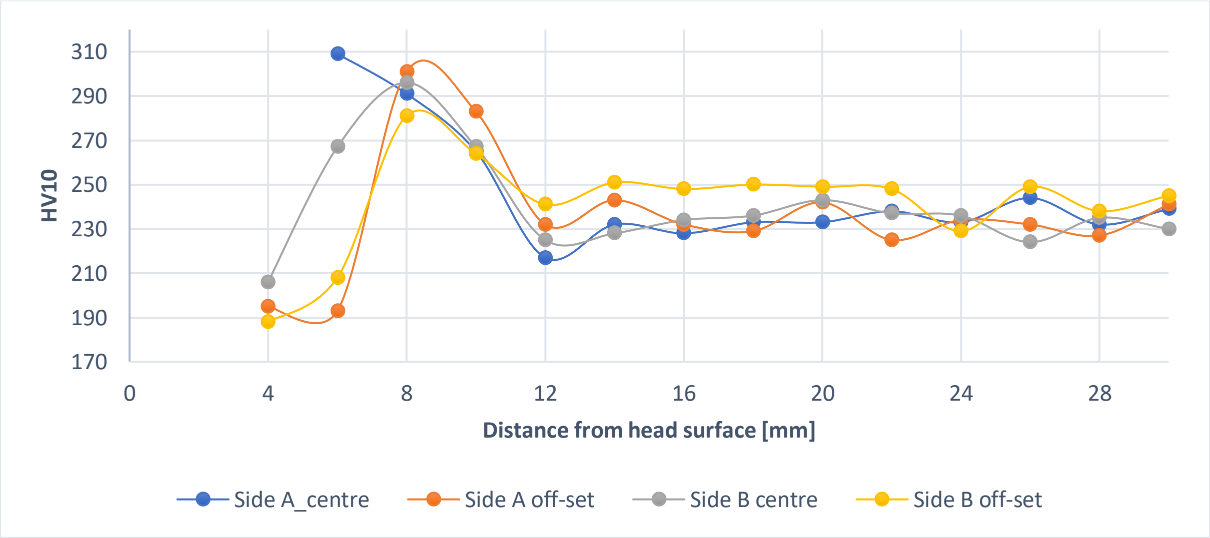


Figure 9: Hardness measurement of electro slag welded rail.

3.2 Flux Cored Arc Welding (FCAW)

From the FCAW welded rail, a cross section was examined regarding penetration, HAZ and the hardness profile. As seen in Figure 10 and in Figure 11, the first weld layer was approximately 3 mm thick, likewise the second layer. The HAZ in the rail was approximately 3,5 mm thick with small variations across the weld.

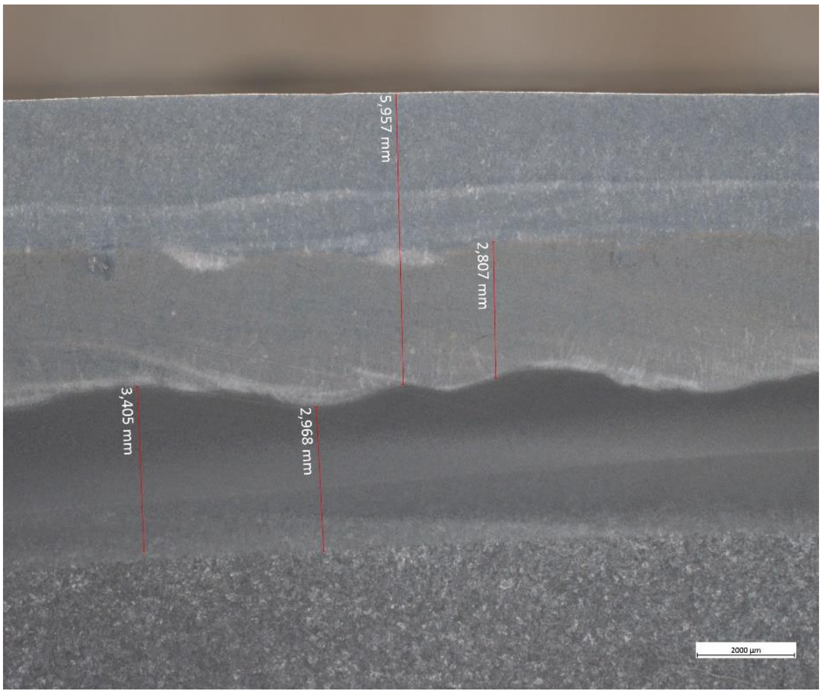


Figure 10, cross section of the middle of the rail.

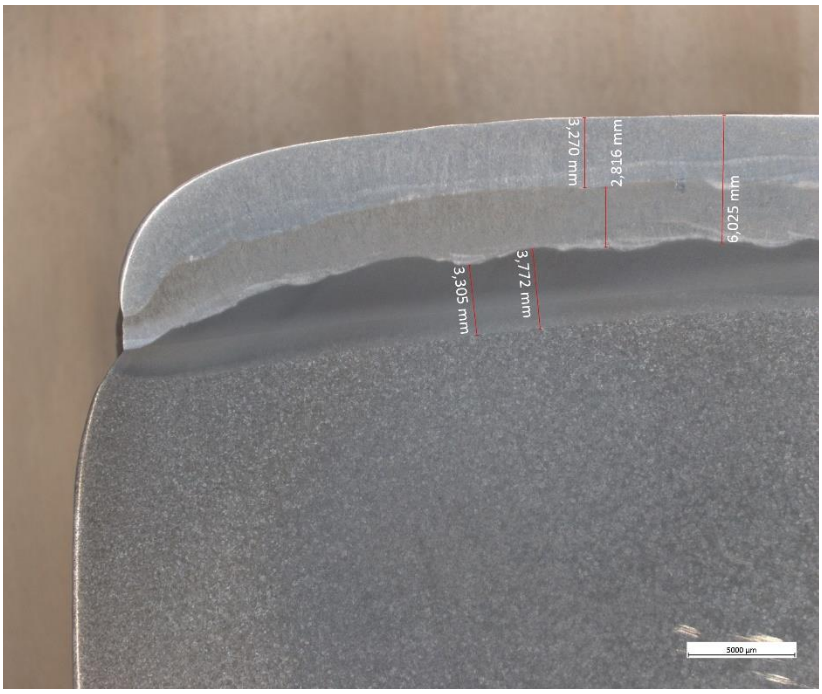


Figure 11, cross section from the edge of the rail.

3.2.1 Microstructure after welding according to WPS

Post welding evaluation of the microstructure was made to examine harmful phase transformations in the material. To reveal the microstructure, a cross section of the welded sample was ground, polished and etched in Nital. The sample showed four separate zones and microstructures as a result from the welding: The original R260 material, heat affected R260, first layer of filler and second layer of filler.

Starting with the unaffected R260 material. It consists of mainly coarse perlite with elements of bainite, see Figure 12.

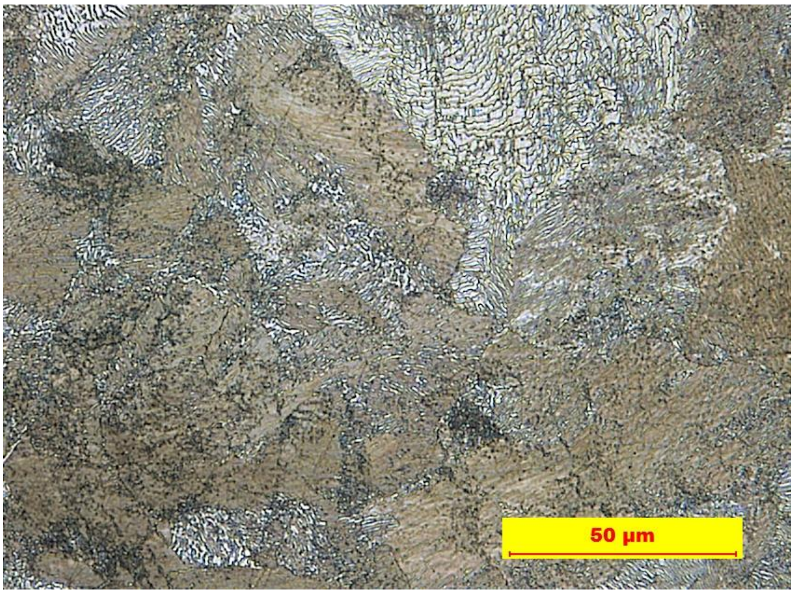


Figure 12, unaffected R260 material

The HAZ consists of mainly perlite. Close to the substrate, the perlite is very fine but gets coarser with more elements of bainite closer to layer 1, see Figure 13 and Figure 16. A drop in hardness can be observed as the bainite content decreases.

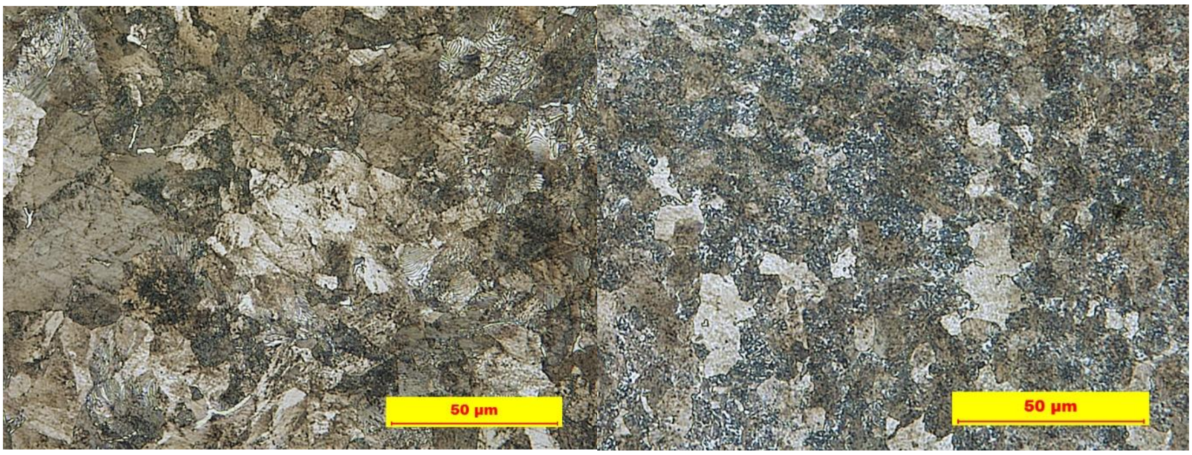


Figure 13, left, microstructure in the top of the HAZ, right the bottom of the HAZ.

Layer 1 and Layer 2 have very similar microstructure consisting of almost 100% bainite and fractions of martensite. The difference in colour after etching is probably due to higher carbon content since layer 1 (see Figure 14) have higher degree of mixing with the substrate material compared to layer 2 (see Figure 15).

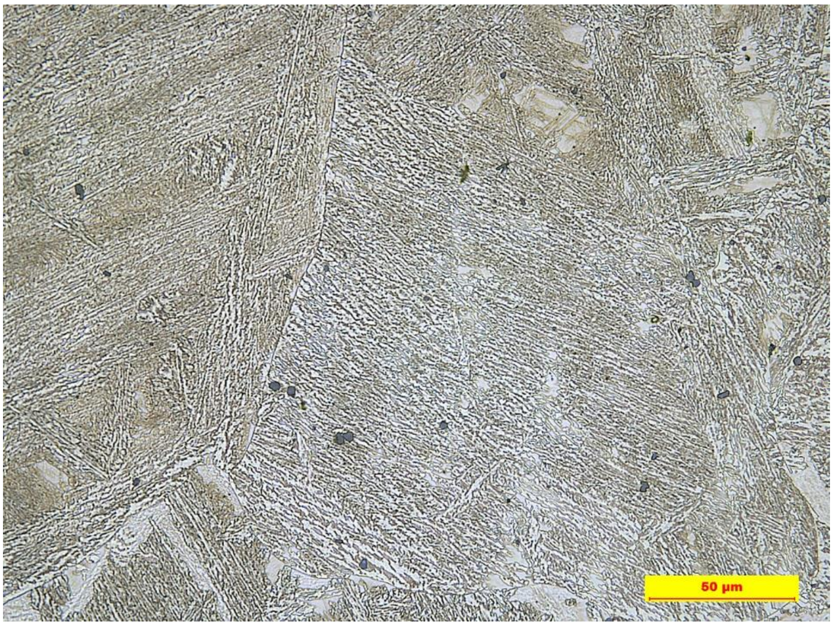


Figure 14, Microstructure of (first) layer 1 after FCAW welding

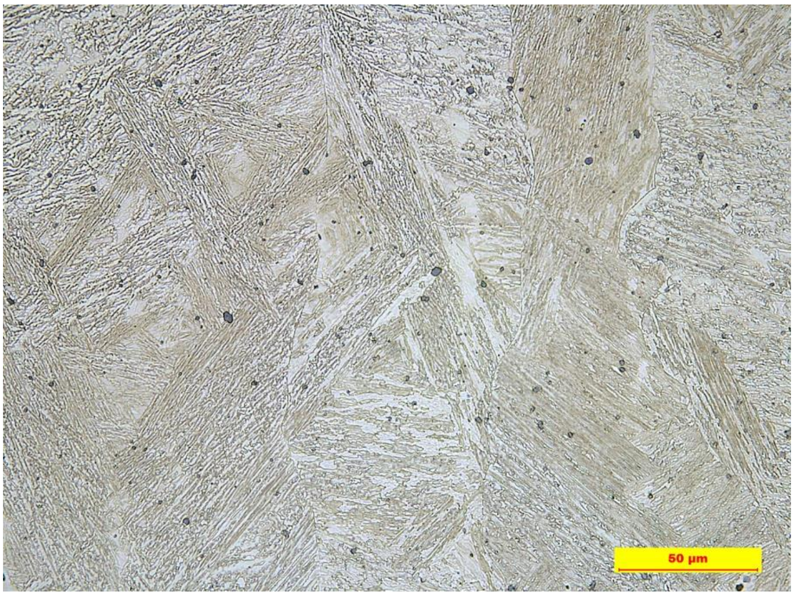


Figure 15, Microstructure of layer 2 after FCAW welding

3.2.2 Defects

No inclusions, cracks or pores could be found in the weld.

3.2.3 Hardness

The maximum hardness in the cross section of the FCAW welded specimen were between 320 HV10 and 330 HV10 in the two welded layers. These values are below the maximum allowed sub surface hardness of 400 HV10. The hardness of the rail head top surface is about 320 HV10 and is within the boundary 275-370HV10 specified in the standards.

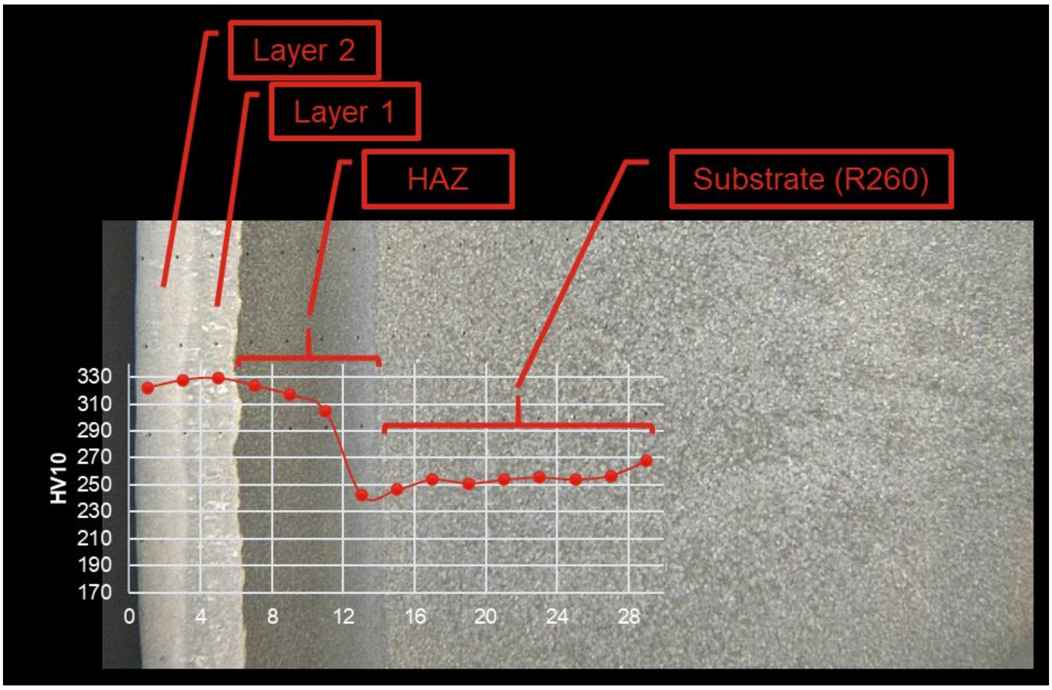


Figure 16, hardness measures from the FCAW welded rail

3.3 Submerged Arc Welding (SAW) – strip

Additional welding tests were performed using single strip cladding on top of the rail head, to simulate the condition of the electroslag process. The strip used was not suited for electroslag cladding but has the desired properties for weld repair of rails. The hardness, microstructure and penetration profile were investigated in two cases, the first with 100 °C pre-heating and the second with 200°C pre-heating. This is performed with the intention to understand if pre-heating is necessary using this process and setup. The focus of the evaluation was the HAZ since that is where the limitations mainly occur.

3.3.1 Microstructure

The microstructures were evaluated in the fusion line, upper HAZ, lower HAZ and base material for both 100 °C and the 200°C pre-heating. This evaluation mainly focus on finding martensite in the HAZ. It is expected to find bainite. All images are in 500x magnification.

The fusion line showed similar microstructure with widemanstätten ferrite, see Figure 17.

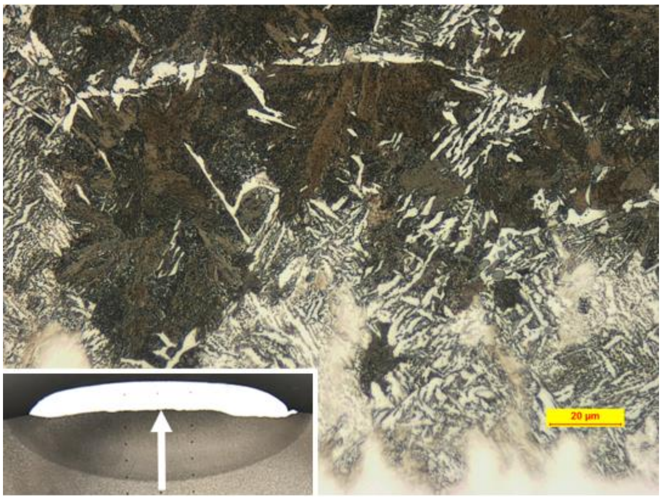


Figure 17: Fusion line

The upper HAZ is also called the "Grain growth zone" and the microstructure is presented in Figure 18 (illustrated with arrows). In the left microstructure (Pre-heat 100°C) it is almost 100% bainitic structure with small amounts of grain boundary ferrite. Pre-heat 200°C shows more perlite and more grain boundary ferrite.

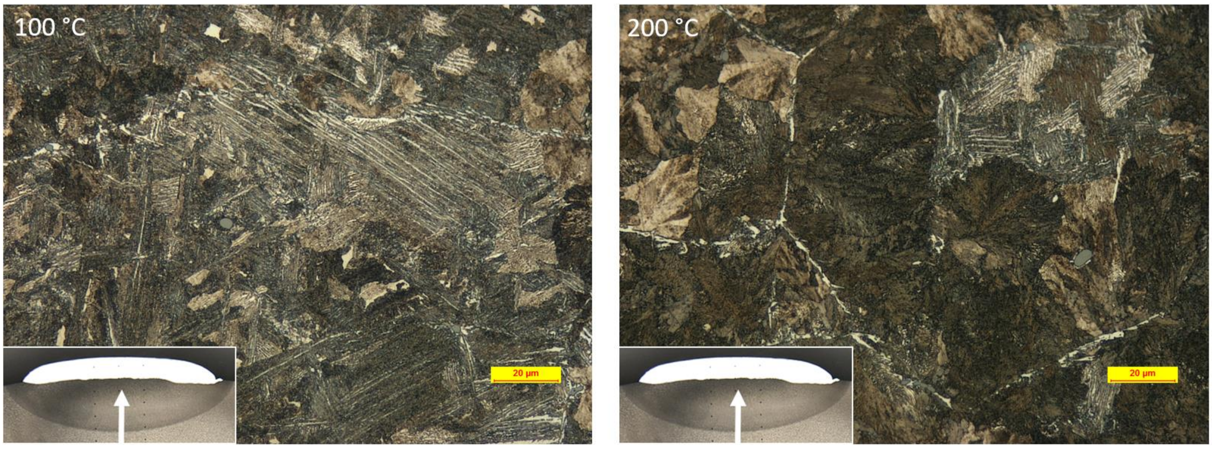


Figure 18: Microstructure of upper HAZ. Pre-heating temperature 100°C to the left and 200°C to the right. White arrow illustrates position of image.

Lower HAZ (100°C pre-heated) shows a mix of bainitic structure and regions of perlite. The 200°C shows a matrix of mainly bainite, see Figure 19. The base material 6 mm outside the HAZ boundary has a similar microstructure in both welded samples, see Figure 20. This microstructure is a mix of fine and coarse perlite and small amounts of grain boundary ferrite, see Figure 20.

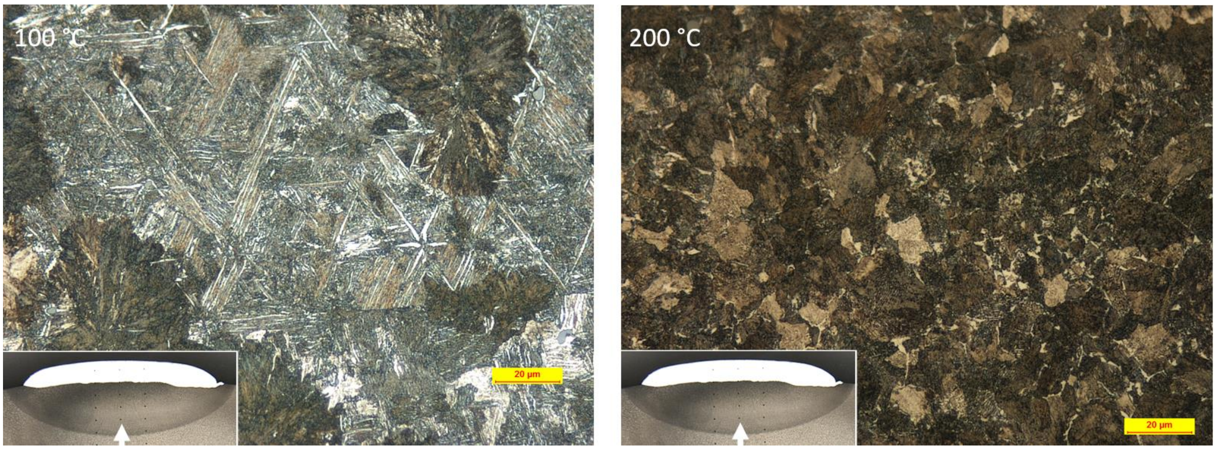


Figure 19: Microstructure lower HAZ. Pre-heating temperature 100°C to the left and 200°C to the right. White arrow illustrates position of image.

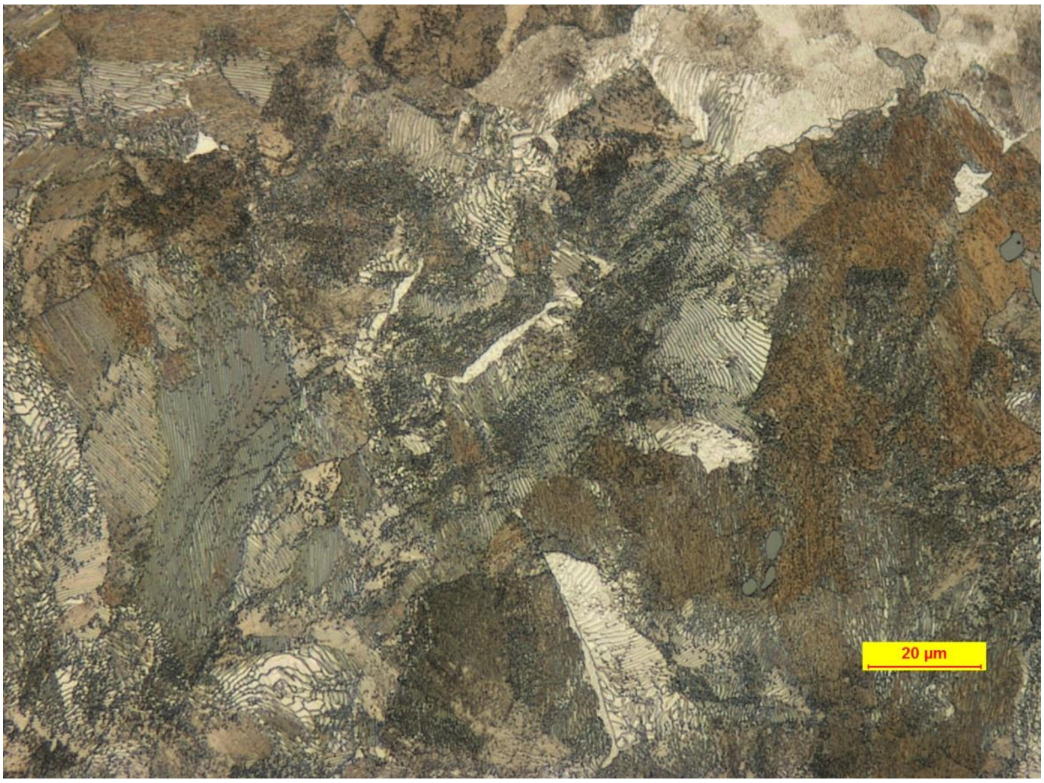


Figure 20: base material 6mm from HAZ boundary.

3.3.2 Hardness

The penetration profiles for the pre-heated rails at 100 °C and 200 °C were similar, and the 200 °C pre-heated illustrate a macro scale, see Figure 21.

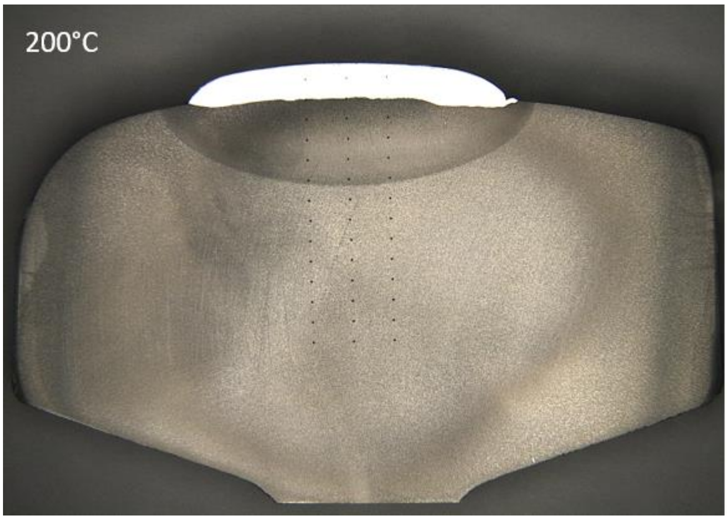


Figure 21: penetration profiles of SAW strip cladded railhead, pre-heated 200°C

The hardness was similar despite the difference in pre-heating, with a maximum hardness around 500HV in the weld metal for both welds. The weld metal thickness was 3,5 mm in both cases, but the depth of HAZ was 6mm in the 100 °C pre-heated and 8.6mm in the 200 °C pre-heated. The penetration and hardness differences are presented in Figure 22. The background-image is the 200 °C cross section, clearly showing the HAZ width. The dashed line represents the HAZ boundary of the pre-heated 100 °C.

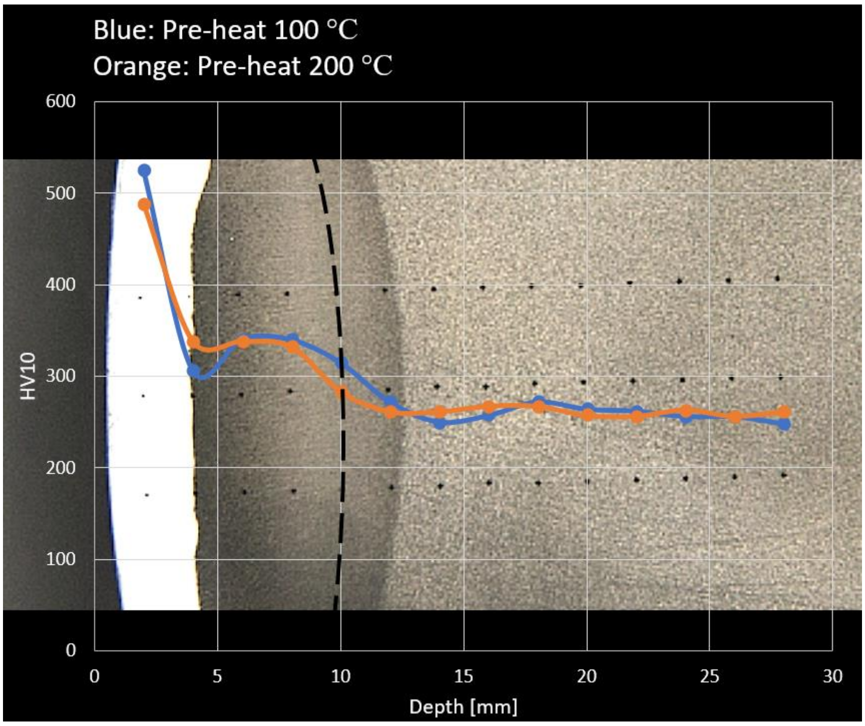


Figure 22: SAW strip mean hardness. Background is cross-section of sample pre-heated to 200 °C. Dashed line is HAZ boundary.

3.4 Submerged Arc Welding (SAW) – wire

All 5 specimens show pores in the first weld run and all except C3-C4 showed solidification cracks. The hardness was only accepted in the C5 case where the pre-heating and interpass temperature was higher. A summary of the results can be seen in Table 14. An example of the pores can be seen in Figure 31, more similar pores in Appendix: C1 Figure 24, C4 Figure 34 and C5 Figure 38.

Table 14: Maximum hardness and defect summery. Gren equals to OK hardness, red equals to not OK hardness.

Sample name	No of passes	Incident angle °	Pre-heating	Inter pass temperature	Crack	Pores	HAZ close to WM max HV10	Weld metal/surface HV10
C1	3	12/17/17	100°C	130°C	**YES**	**YES**	445	360
C2	1	18	100°C	130°C	**YES**	**YES**	600	450
C3	8	2	100°C	130°C	**NO**	**YES**	640	400
C4	3	2	100°C	130°C	**NO**	**YES**	380	340
C5	3	2	200°C	230°C	**YES**	**YES**	350	300

3.4.1 C1

The C1 was welded with three runs. A solidification crack can be seen Figure 23 . Three pores could be found in the root of the C1 weld, see Figure 24. The hardness mapping is presented in Figure 25. The high hardness is most likely due to martensite, similar as in C3.

Figure 23, cross section of weld C1

Figure 24, C1, root pore

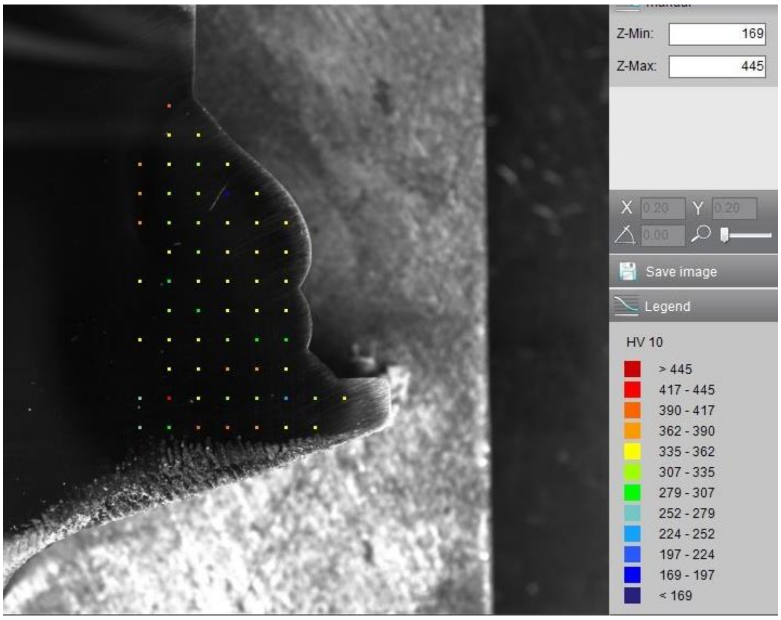


Figure 25, hardness measure of weld C1

3.4.2 C2

The C2 weld was produced with a single weld pass. A solidification crack can be seen in the weld in Figure 26. This image also shows small pores in the weld metal close to the HAZ. The black circle illustrates where the micro images was taken, Figure 27.

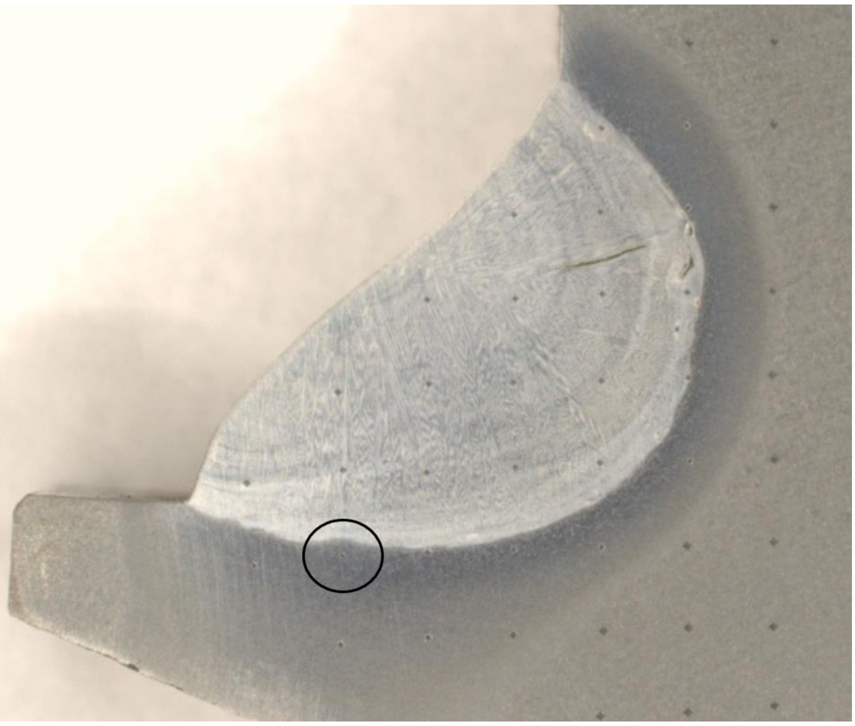


Figure 26, cross section of weld C2

The hardness of the HAZ is very high (565 HV10 in the hardness indentation in Figure 27), microstructure of the HAZ is martensitic as can be seen from Figure 28. There are possibly two regions of martensite visible as black and beige martensitic structures. Note that the etching is different between Figure 26 and Figure 27 which mixes the dark and white colours between the images.

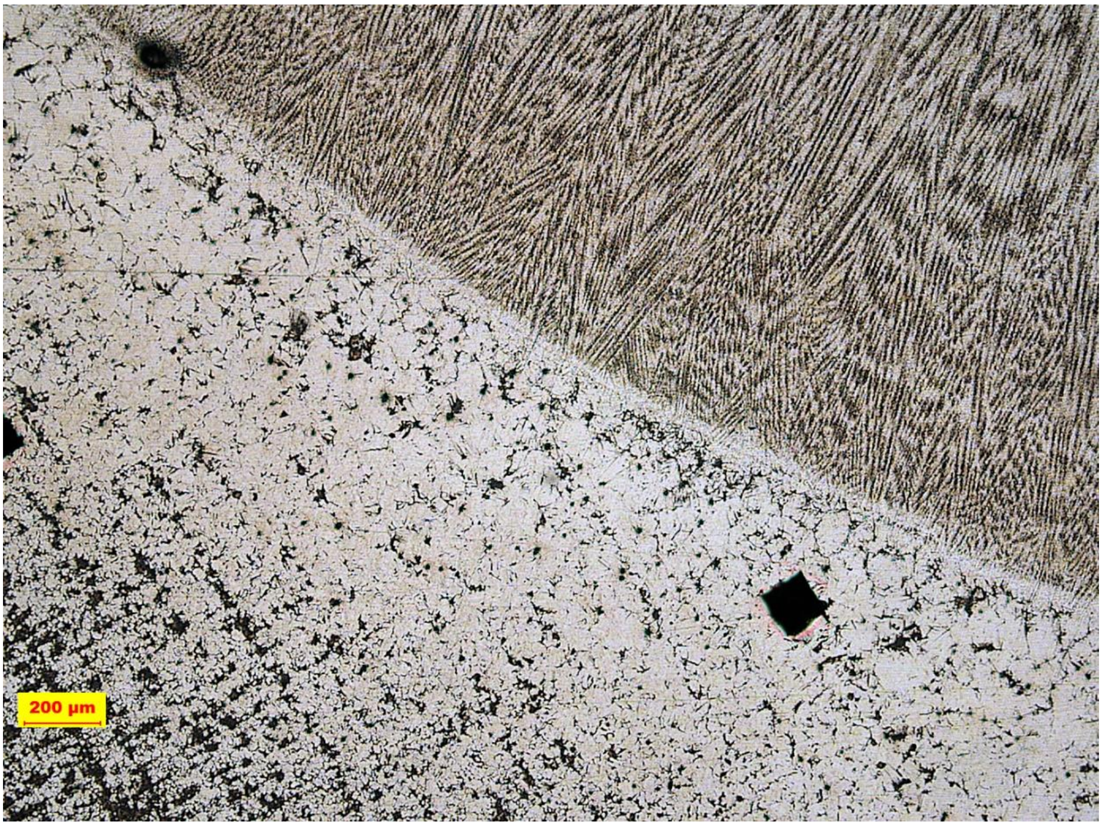


Figure 27: interface between base material and weld metal, with fusion line separating them. The hardness is 565HV10 in the hardness indentation.

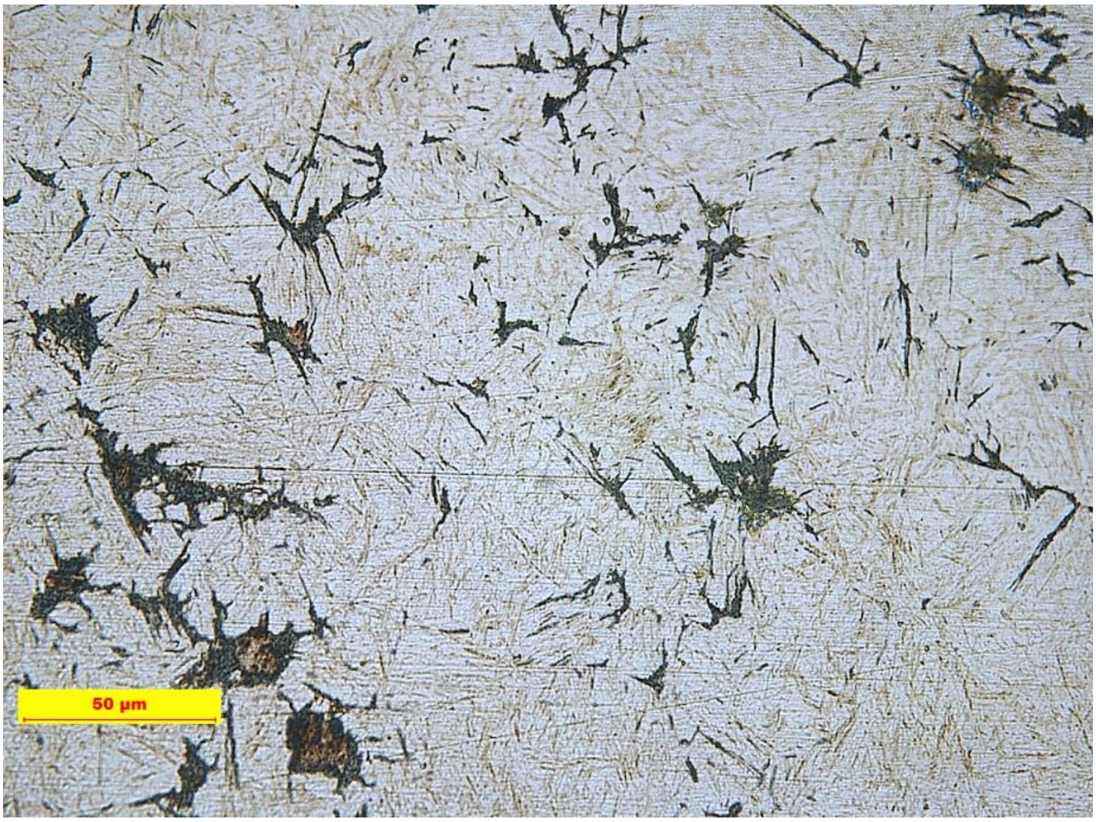


Figure 28: 500x magnification of HAZ – beige and black regions of martensite.

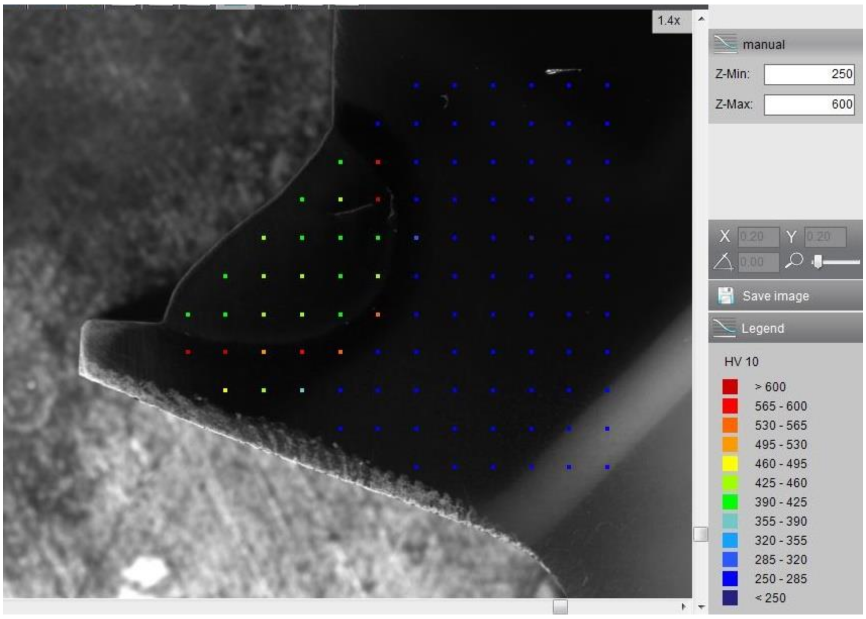


Figure 29, hardness measure of weld C2

3.4.3 C3

C3 is welded with 8 passes (Figure 30) and has no cracks but a few pores visible in Figure 31. The overall hardness in C3 is low in the weld and HAZ because of the heat treatment of the following welds. The surface hardness is approximately 370-400 HV10 and the highest hardness 640 HV10 can be found in the boundary between the last weld pass and the rail head, see Figure 32. This hardness peak is likely a result of high cooling rate due to the positioning of the last weld pass.

Figure 30, cross section of weld C3

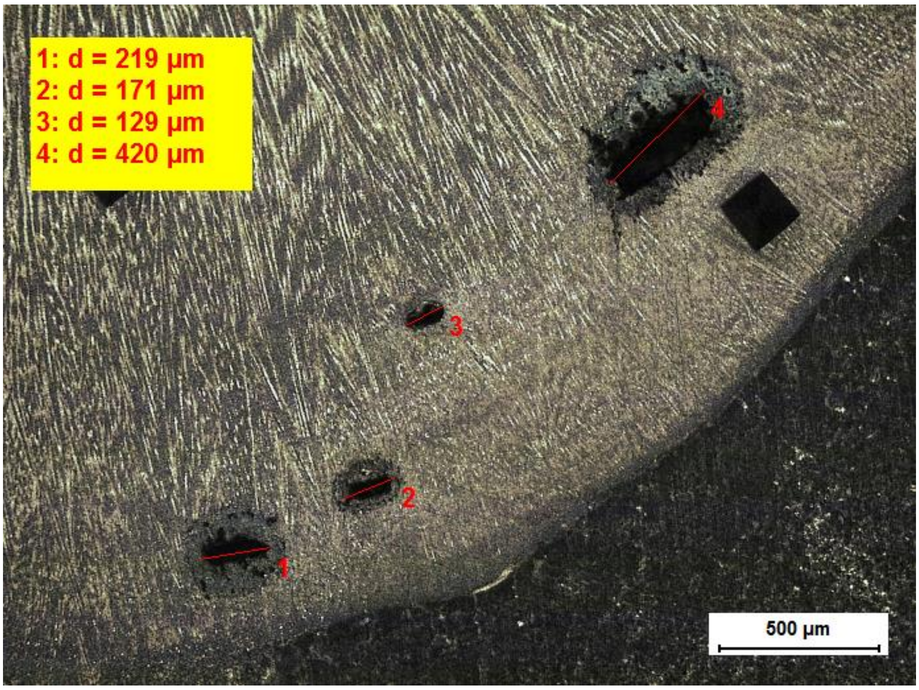


Figure 31, pores in the root of the first weld of C3

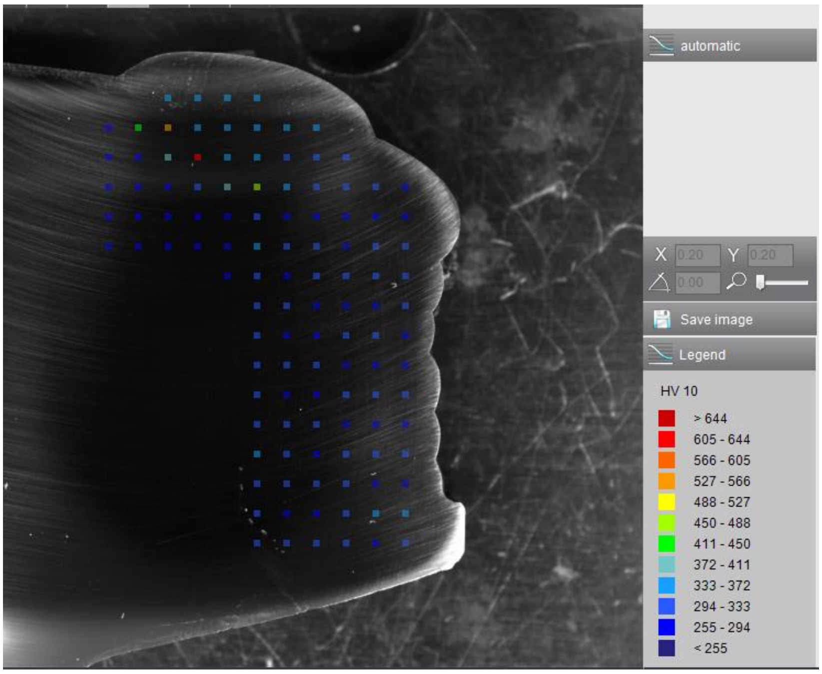


Figure 32, hardness measure of weld C3

3.4.4 C4

The C4 weld was produced with three weld passes, se cross section in Figure 33. In the root of the first weld pass, pores could be found, see Figure 34. The hardness is mapped in Figure 35, showing maximum hardness in HAZ close to the fusion line and weld metal hardness 340HV. The microstructure is presented in Figure 36 and the images are taken on each side of the fusion line, where a hardness indentation in the fusion line show 370 HV10.

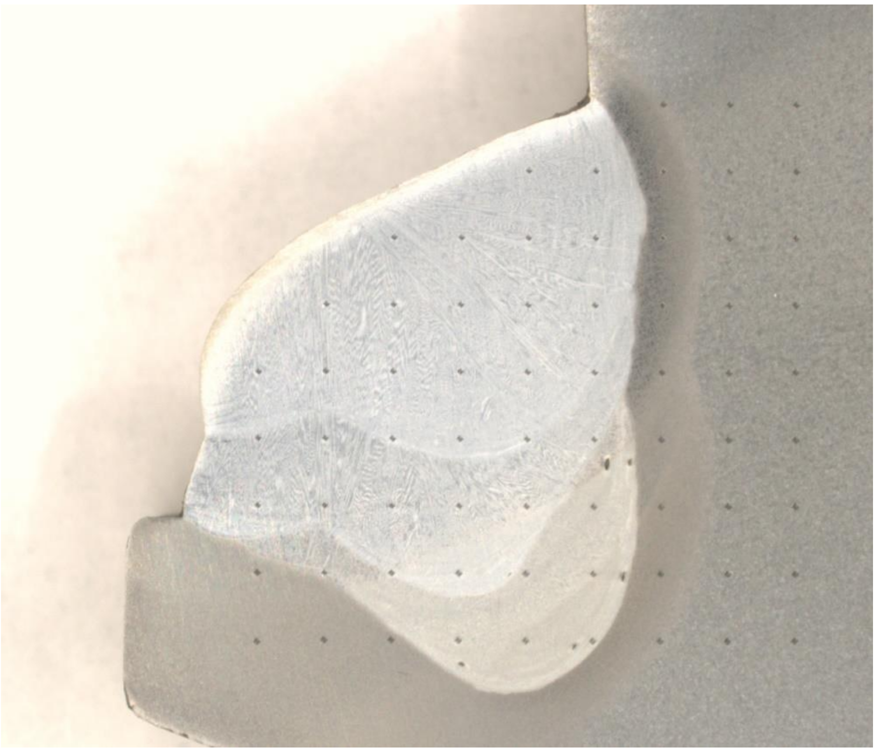


Figure 33, cross section of weld C4

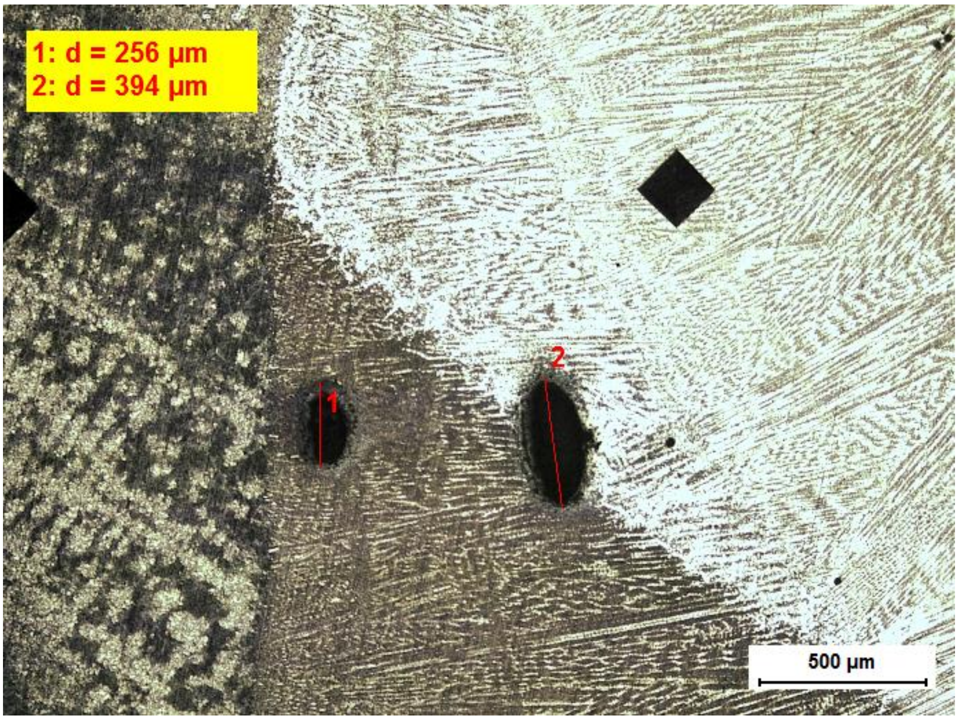


Figure 34, example of pores in weld C4

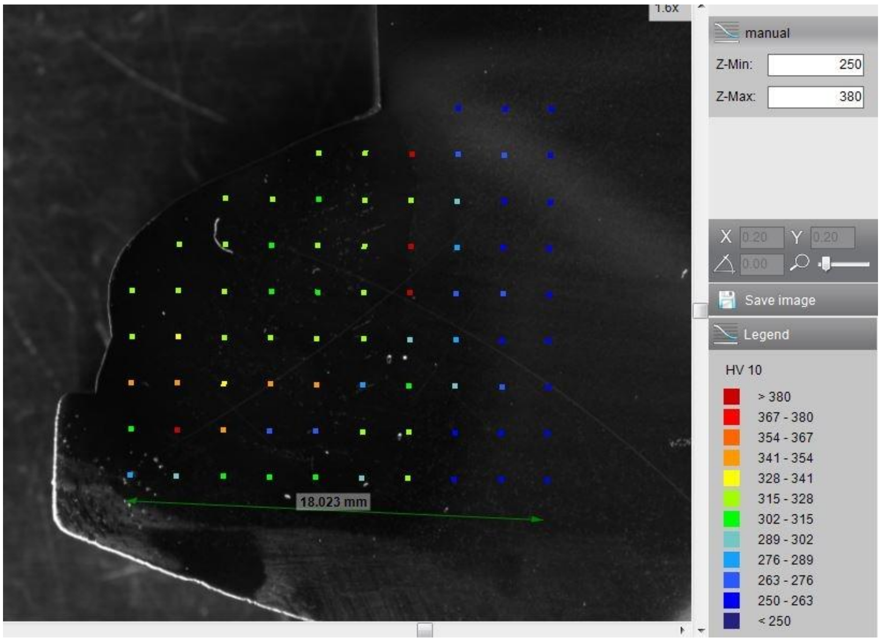


Figure 35, hardness measure of weld C4

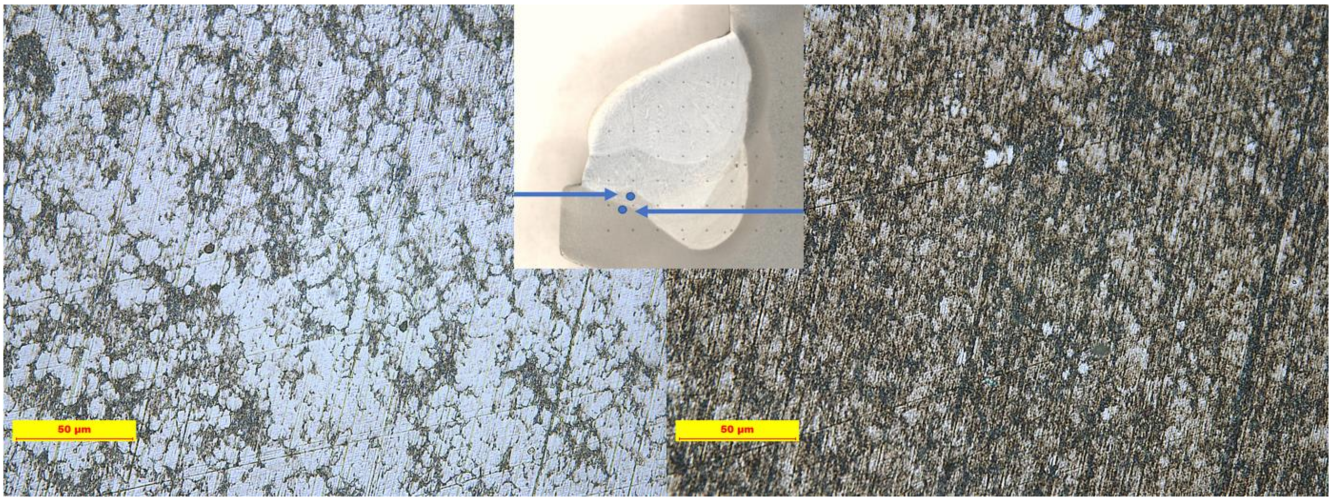


Figure 36: Left- microstructure in first bead, right - microstructure in HAZ close to FL.

3.4.5 C5

The C5 weld was produced with three weld passes. A solidification crack is clearly visible in the last weld pass, see Figure 37. In the root of the first weld pores were found, see Figure 38.

The surface hardness of C5 is approximately 300 HV10 and has the highest hardness of 350 HV10 in the HAZ. Se details in

Figure 39. The microstructure has most likely low amount of martensite.

Figure 37, cross section of weld C5

Figure 38, pore in the root of weld C5

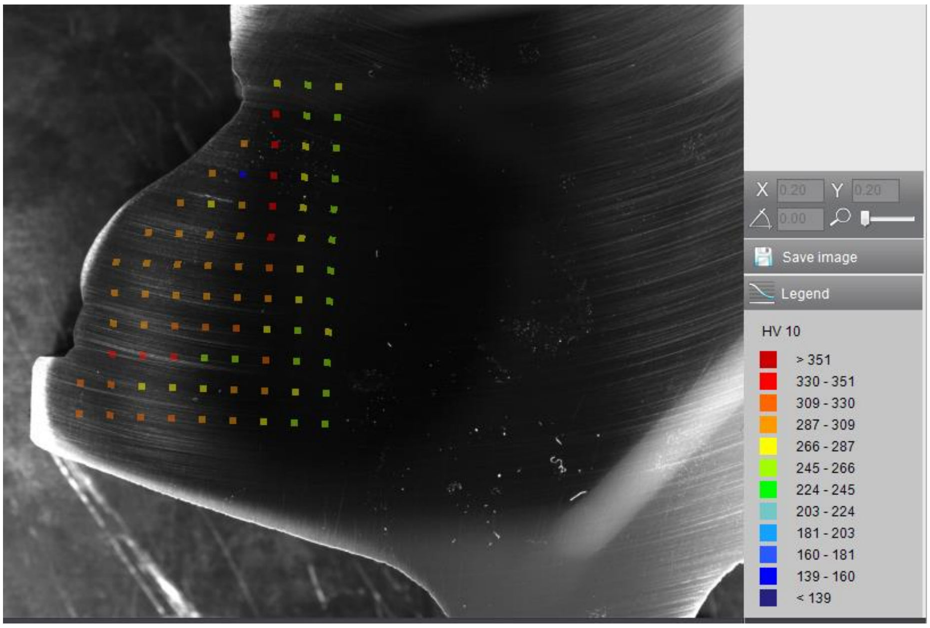


Figure 39, hardness measure of weld C5

4 Discussion

The electroslag welded specimens show high potential for implementation compared to the other welding methods both regarding the material properties and the productivity. But this process is suitable only for cladding on top of the rail. According to the LCC analysis of Restoration in track (see appendix), the full repair process takes too long time compared to replacing the rails. Time allowed is nowadays very short due to higher loads on the traffic. Also, the cost for equipment to perform the repair, including a special two-way vehicle, is very expensive. This equipment must be used minimum 80 times a year to break even, which is a very high figure.

Replacing worn rails with new ones and repair the worn rails in a workshop was also investigated. The LCC analysis show that only small length of rails (20m) could be transported but with a risk of mechanical damage. The logistic cost for this operation is very high which result in a minimum increase in cost of 20%, compared to replace the rails.

Repair of the side of the rail was investigated but showed the need for many weld passes and pre-heating/interpass temperature, which takes long time and makes it therefore impossible to implement on site. However, repair in a workshop is probably possible.

Electroslag twin strip cladding

- It was possible to weld without pre-heating and still get an HAZ that is within recommended hardness range. This is most likely due to the high heat input created by this ESC process, causing a slower cooling rate which supress martensite formation. It should be noted that analyses of hardness and microstructure only was made in the centre of the weld length. A more extensive hardness mapping is necessary to ensure approved hardness in start and end of the weld run.
- What is still a challenge is to understand the hardness and potential defects in the weld metal. More tests with correct filler strip are necessary to better understand the full picture ex. level of deformations, true dilution, changes in process stability etc.

SAW wire

- The pre-heating temperatures tested was not enough to keep hardness in recommended range.
- Solidification cracking was seen in majority of welds but can probably be eliminated by better control of gun angle.
- It is unclear why the pores form in the first bead(close to the fusion line) in all samples.
- C3: the hardness peak is likely a result of the positioning of the last weld pass. If the last weld pass would be put straight on top of the previous pass, it would probably result in lower hardness.
- Building layer by layer resulting in 8 passes take a long time. It is therefore not suitable in the railway track but possible in workshop.
- The lowest hardness was seen in C5 where the higher pre-heating and inter pass temperature was used. Higher pre-heating lowers the hardness.

FCAW

- The FCAW welded specimens were made with recommended filler wire and heat treatments according to TDOC and WPS. Comparing the results with the ESC specimen shows that the HAZ hardness is similar for the two cases, ESC and FCAW. However, a matching filler strip is necessary to confirm this theory.

SAW strip:

- Both using 100 °C and 200 °C pre-heating passed the requirement to leave no obvious sights of martensite in the HAZ. But the hardness was very high in the cladded layer. This process might be suitable to weld without pre-heating if a high surface hardness can be accepted - which is often the case since higher hardness in these alloys are related to higher wear resistance.

5 Conclusions

The purpose of the project was to examine the possibility of using the ESC welding method as a cost-effective way to repair long part of rails instead of replacing them. After welding trials and a LCC analysis it was deemed that repairing the top part of the rail is not yet cost-effective enough due to the time needed to finish both welding and machining of the surface, and the high cost for a customized two-way vehicle. The ESC is still high-productive and suitable for rail welding since no pre-heating is needed.

Electroslag twin strip cladding. Top of rail head.

- The process shows high deposition rates and no need for pre-heating to fulfil the hardness range in HAZ. This is very beneficial when it comes to this high productivity application of welding rails.
- Only one weld pass is needed to clad the full top rail head surface. No need to slower the procedure by controlling inter pass temperatures.

FCAW. Top of rail head.

- The trials to mimic the material influence of the ESC process on the rail head was successful. Similar hardness and penetration was seen in the HAZ for the FCAW welded rail (correctly pre-heated and inter pass controlled temperature) as for the Electroslag welded rail without pre-heating. Still verifying test with correct strips is necessary to validate this theory.

SAW strip. Top of rail head.

- Both 100°C and 200°C passed the requirement to leave no obvious sights of martensite in the HAZ. But the hardness was too high in the cladded layer – according to TDOC and standard.

SAW welded specimens – wire. Side of rail head.

- Pores was not avoided.
- 200°C pre-heating and 230°C interpass temperature resulted in acceptable hardness in HAZ and weld metal. Pores were still present.

LCC

- There is no economical savings possible in repair welding of long rails in the track.
- There is no economical savings possible in repair welding of shorter straight rails in a workshop.

6 Future work

- Deformations in rails – how does the electroslag twin strip cladding process influence the deformations when welding on longer rails (more than 1m)?
- Robustness tests – will the flux be suitable for repair in an outdoor climate. This was assumed but should be investigated.
- Restore crossings has a higher potential to make economical savings according to TRV and Infranord. Methods for repair of crossings could be further investigated.

7 Acknowledgments

We would like to thank all participating project partners for good collaboration and fruitful discussions. Also, a great thanks to Infrasweden2030 for supporting the project in workshops and seminars.

8 References

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9 Appendix

9.1 WPS used for FCAW trials.

Infranord AB 171 21 Solna Utgiven av Lennart Ericson	**Svetsdatablad** **WPS** Hänvisning till WPQR 2-20 enl. EN ISO 15613	**WPS 3-20:01** Reviderad 10-03-09 Datum 2007-06-19

Detta svetsdatablad avser:
Påsvetsning av rälsstål med självskyddad rörelektrod ø 1,2 mm.
Rälsmaterial: 60E 1, stålsort R260 alt. R350LHT.

Förberedelser:
Märk ut läget för det aktuella påsvetsområdet.
Innan påsvetsning påbörjas skall säkerställas att inga inre defekter föreligger i området för påsvetsning.
Renslipa påsvetsytorna och testa ytan med penetrantprovning.
Det påsvetsade området skall svetsas med minst 2 svetslager

Tillsatsmaterial:
Använd rörelektroder enligt klassning.
Tillsatsmaterial lagras enligt gällande föreskrift.

Förvärmningstemperatur samt arbetstemperatur:
Propan/Oxygen brännare och vid behov värmemuldrar.
Temperaturmätning med digital temp.mätare eller tempelstickskritor.
Förvärmningstemperatur 400°C samt arbetstemp. 350ºC samt 100 mm på var sida om påsvetsområdet.

Svetsning:
Kontrollera kontinuerligt att min. arbetstemperatur inte underskrids.
Svetsa hela farbanan med full pendling
Beakta hela tiden rätt trådutstick samt pistolvinkel.

Svetsdata:

Sträng	Svetsmetod	Tillsats-material	Diam / längd	Beteckning	Skyddsgas
Stödstr.	114	OK 15.43	ø 1,2 mm	DIN 8555: MF 1-350	
Sidoförsl	114	-"-	-"-	-"-	
Huvud.	114	-"-	-"-	-"-	
Sidostr.	114	-"-	-"-	-"-	

Sträng	Pol	Ström A	Trådmatn m / min	Kontavst mm	Spänning V	Hastighet mm / min	Str längd mm / elektrod
Stödstr.	DC+	160-170	7-8 m	25-30 mm	23-25	400-500	
Sidoförsl	DC+	160-170	7-8 m	25-30 mm	23-25	400-500	
Huvud.	DC+	190-210	10,5-11,5 m	25-30 mm	27-29	60-75	
Sidostr.	DC+	140-160	7-8 m	25-30 mm	23-25	450-600	

Slipning efter svetsning:
Svetsen grovslipas vid samma arbetstemperatur som kravet vid svetsning.
Finslipning till toleransmått efter 150°C enligt gällande föreskrift.

Övrigt:
Svetsobjektet stämplas med svetsarens spårsvetsnummer direkt på dess utsida på rälshuvudet.

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TRAFIKVERKET

9.2 LCC Analysis – rewelding of rails

Rail renewals is taking place due to wear limits or when the technical lifetime has expired. Rail in curves with higher wear rates needs to be replaced more frequently.

The LCC analysis is based on costs for renewal of rails in curves compared to restoration of side worn rails by welding in track or in workshop.

Restoration in track

The LCC-analysis assess costs for replacing 100 meter rails compare to restoration by welding. The technical lifetime is estimated to be 20 years. Other parameters in the analysis are track possession time, installation costs, staff- and machine costs.

For restoration in track a suitable equipment for all work steps is needed. The rail needs to be prepared before and after welding and the most effective method is milling. Such equipment can be adapt on ”two way” vehicles used for roads and tracks. The welding is also performed by the same machine. This kind of multi equipped vehicles is not on the market and need to be developed.

For restoration in track the machine cost have the highest impact in the analysis. Compare with rail renewal the highest costs are installation and supply of the rail material. A sensitivity analysis has been performed to assess the costs over time which shows that the machine have to be used over 80 times a year to be beneficial. Trafikverket and Infranord ensure that such high volume of yearly rail replacements is not taking place why this method is not cost effective.

Restoration in workshop

LCC-analysis for restoration in workshop have been assessed with similar parameters as for restoration in track. For restoration in workshop the costs for logistics have high impact. The rails need to be transported from and to the workshop safely without any additional defects. To make the handling and logistics more simple the analysis is based on 20 meters of rail lengths.

The analysis assumes 1500 rails with lengths of 20 meters which can be restored each year. The results give increasing costs for at least 20 % compared to rail renewals and restoration in workshop is not cost effective.

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Discussions

Restoration of longer rail sections in track or workshop is not cost effective enough compared to replacement with new rails. For restoration in track it is high machine costs which affect the maintenance costs. For restoration in workshop it is additional costs for transportation and handling which have high impact on LCC. The use of welded rails have also higher risks which can affect the lifetime of the rail compared to use of new unaffected rail materials. Rails are relatively cheap and the component itself is not so expensive. The mechanical properties in welded rails are not the same as in unaffected rails after manufacturing.Another important aspect is availability or track possession time in track for maintenance. Maintenance operations in track have to be so cost effective as possible which means less time in track. Restoration in track demand longer track possession times compared to replacement of the rail. Restoration in workshop also demand longer track possessions due to additional handling and transportation.

The equipment for welding and milling in track must be adapted for the railway infrastructure. Machines that can handle both welding and milling in track are not any products that can be found in the market today which give high initial development costs.

Experiences from this project have identified proposals for future project. Crossings in turnouts are expensive components and are often replaced instead of restoration. Restoration of crossings in workshop can be investigated for extended LCC in turnouts.

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