

Investigation of three SkV welds with defects in the head of the weld metal / Heavy reactivity of Thermit®-portions

- Infranord AB -

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This report is a preliminary assessment based on the current factual and legal situation. It was prepared in all conscience and has to be handled strictly confidential and as proprietary know-how of the Elektro-Thermit GmbH & Co. KG.

Rev. 09/13



1 Subject

The Development and Application Technology department of the Elektro-Thermit GmbH & Co. KG (ET) was asked by Infranord AB to investigate three SkV welds with defects in the head of the weld metal. The weld samples were received on 14th November 2013.

The following information regarding the weld samples are known:

Welding process	SkV-Salino
Thermit [®] -portion type	60/Z90SkV-E
Portion, Batch-No.	0018551
Reactivity of Thermit [®] -portion	Heavy
Crucible	Single use crucible
Rail profile	60E1_E2
Rail grade	R260

To be able to trace the samples they were marked with S1, S2 and S3 by Elektro-Thermit. This identification is used in this report.

The executed investigations and the conclusions are described below.

2 Investigations and Results

2.1 Visual examination

2.1.1 Visual examination – S1

The weld sample S1 as delivered is shown in the following figures (**Figure S1-1** to **Figure S1-6**). All views on the sample (view on cut surfaces, side views, top and bottom view) are displayed in these figures. Close-up views of the head area (side views) and foot riser areas are shown in the **Figures S1-7** to **Figure S1-10**.

During visual examination of the weld sample the following distinctive features were noticed:

- Smooth weld collar surface in the web area (see Figures S1-3 and S1-4, green mark),
- Deformed riser at the foot riser window section (see Figures S1-9 and S1-10),
- One riser did not break of at the foot riser window due to the deformation of the riser,
- Oxidized, dendritic surface structure of hot-cracks in the head area (see Figures S1-7 and S1-8, red mark).

Other relevant features were not detected by visual examination.



Figure S1-1: Cut surface A



Figure S1-2: Cut surface B



Figure S1-3: Side view 1



Figure S1-4: Side view 2



Figure S1-5: Top view (Running surface)



Figure S1-6: Bottom view

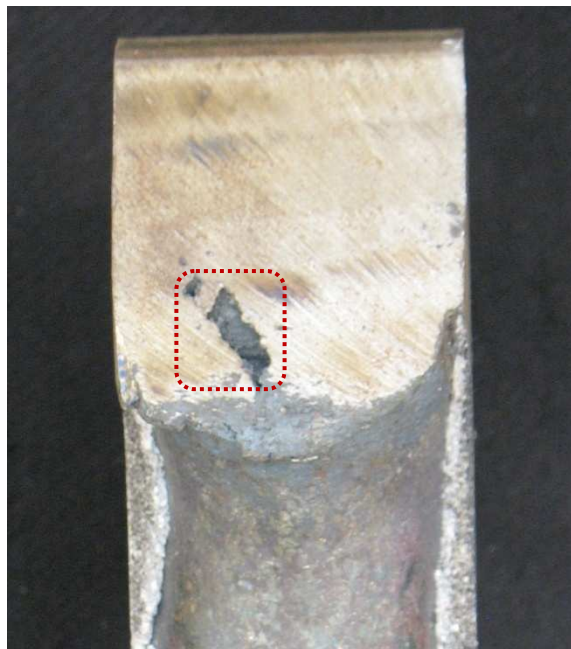


Figure S1-7: Detail – Side view 1



Figure S1-8: Detail – Side view 2



Figure S1-9: Detail - View on
foot riser window section 1



Figure S1-10: Detail - View on
foot riser window section 2

Further investigations carried out on this weld sample are described in the following chapters.

2.1.2 Visual examination – S2

The weld sample S2 as delivered is shown in the following figures (**Figure S2-1** to **Figure S2-6**). All views on the sample (view on cut surfaces, side views, top and bottom view) are displayed in these figures. Close-up views of the outer head areas, gauge corner region and one foot riser area are shown in the **Figures S2-7** to **Figure S2-10**.

During visual examination of the weld sample the following distinctive features were noticed:

- Smooth and deformed weld collar surface in the web area (see Figures S2-3 and S2-4, green mark),
- Deformed riser at the foot riser window section (see Figures S2-1 to S2-4 and S2-10),
- The risers did not break off at the foot riser window due to the deformation of the risers,
- Oxidized, dendritic surface structure of hot-cracks in the head area (see Figures S2-7 and S2-8, red mark),
- Weld metal displacement at the outer head area (see Figures S2-3 and S2-4, red mark),
- Hot-crack structures with oxidized, dendritic surface on the running surface, gauge corner region and gauge face (see Figure S2-9),
- Cavities in the underfoot collar (max. Ø: 13 mm, max. depth: 5 mm, see Figure S2-6).

Other relevant features were not detected by visual examination.



Figure S2-1: Cut surface A



Figure S2-1: Cut surface B

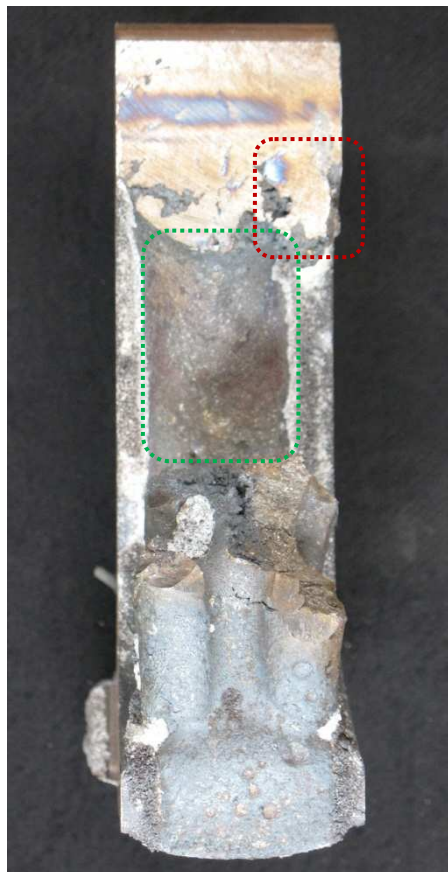


Figure S2-3: Side view 1

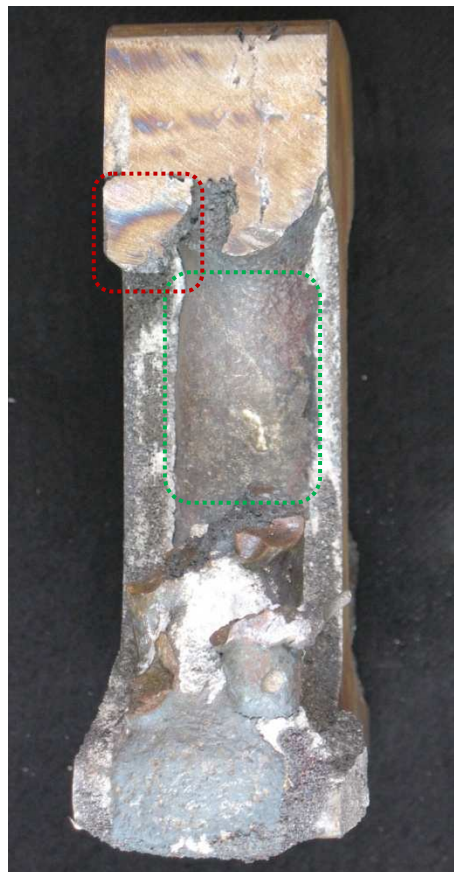


Figure S2-4: Side view 2



Figure S2-5: Top view (Running surface)



Figure S2-6: Bottom view

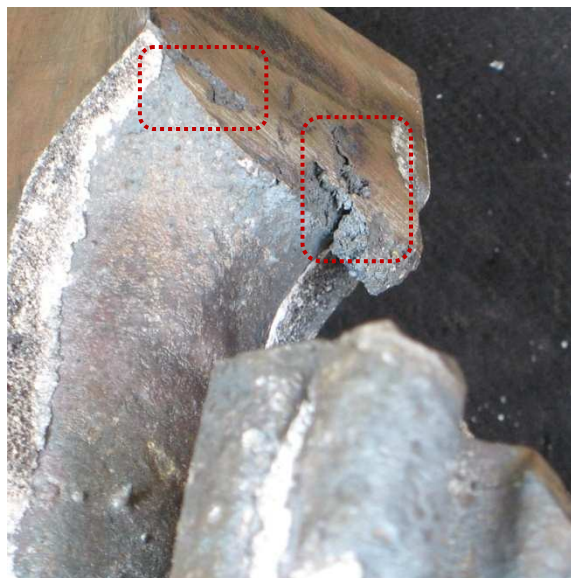


Figure S2-7: Detail – View on outer head area
(Bottom view, Side 1)

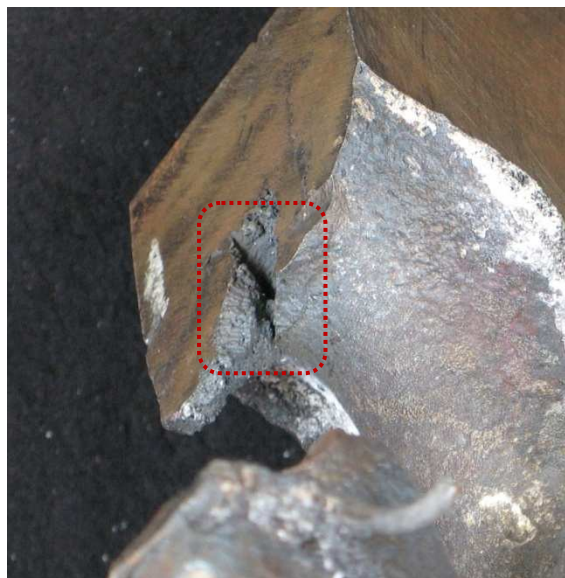


Figure S2-8: Detail – View on outer head area
(Bottom view, Side 2)



Figure S2-9: Detail – View on
Gauge corner region



Figure S2-10: Detail – View on
foot riser window section

Further investigations carried out on this weld sample are described in the following chapters.

2.1.3 Visual examination – S3

The weld sample S3 as delivered is shown in the following figures (**Figure S3-1** to **Figure S3-6**). All views on the sample (view on cut surfaces, side views, top and bottom view) are displayed in these figures. Close-up views of the foot riser areas are shown in the **Figures S3-7** and **Figure S3-8**.

During visual examination of the weld sample the following distinctive features were noticed:

- Transition weld worn rail – new rail,
- Deformed riser at the foot riser window section (see Figures S3-7 and S3-8),
- One riser did not break of at the foot riser window due to the deformation of the riser,
- Oxidized, dendritic surface structure of hot-cracks in the outer head area (see Figures S3-3, red mark).

Other relevant features were not detected by visual examination.



Figure S3-1: Cut surface A



Figure S3-2: Cut surface B



Figure S3-3: Side view 1



Figure S3-4: Side view 2



Figure S3-5: Top view (Running surface)



Figure S3-6: Bottom view



Figure S3-7: Detail - View on
foot riser window section 1



Figure S3-8: Detail - View on
foot riser window section 2

Further investigations carried out on this weld sample are described in the following chapters.

2.2 Longitudinal vertical section

The longitudinal vertical section is used to examine whether the fusion and heat affected zone display the typical appearance of an aluminothermic weld. The **Figures S1-11**, **S2-11** and **S3-9** show the etched longitudinal vertical sections on the centre line of the weld samples S1, S2 and S3.

		
Figure S1-11: Longitudinal vertical section on centre line - S1 Sample width: ≥ 41 mm	Figure S2-11: Longitudinal vertical section on centre line - S2 Sample width: ≥ 48 mm	Figure S3-9: Longitudinal vertical section on centre line - S3 Sample width: ≥ 52 mm

The fusion line (transition weld metal / HAZ) did not become visible in the longitudinal vertical section on the centre line on the etched samples.

As foot tips are the location with the minimal fusion width of SkV-Salino welds, additionally longitudinal vertical sections of foot tips of the samples with a larger sample width (S2 and S3) were investigated. This investigation was done in accordance with EN14730-1, chapter 7.4.1 and 7.4.2. The plain of the longitudinal vertical section of the foot tips is located 20 mm away from the foot tip itself.

Figure S2-12 and **Figure S3-10** document the polished and etched longitudinal vertical section of foot tips of the samples S2 and S3.

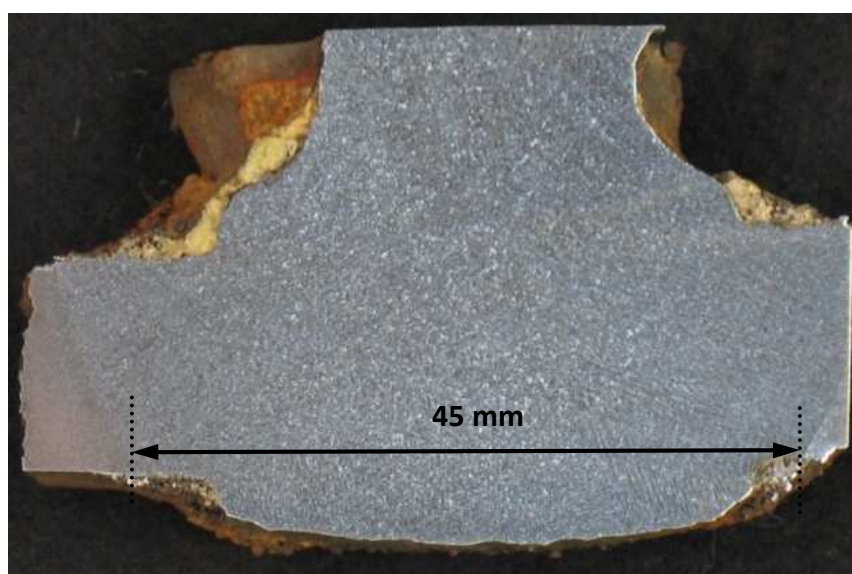


Figure S2-12: Longitudinal vertical section of one foot tip - S2

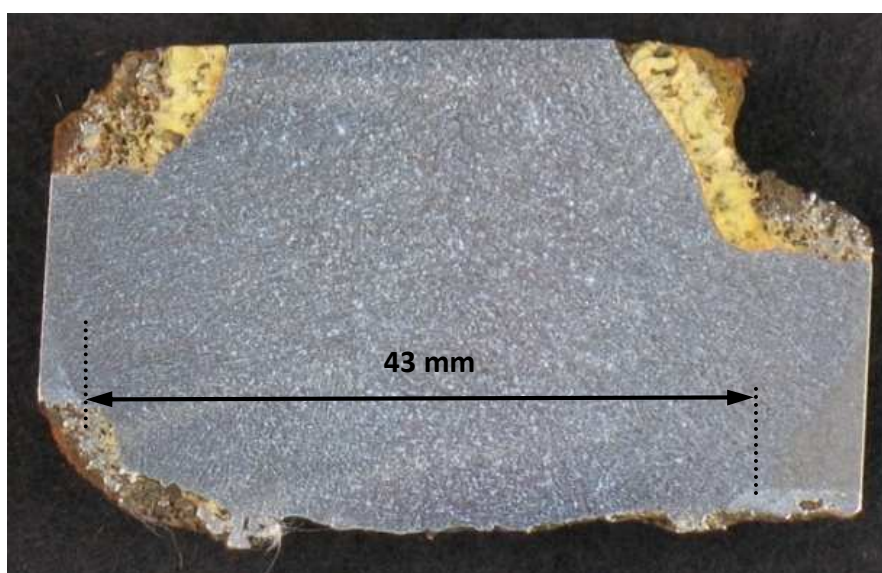


Figure S3-10: Longitudinal vertical section of one foot tip – S3



In general SkV-Salino welds on the rail profile 60E1_E2, welded with the Single use crucible, gap width 25 mm, have a minimal fusion width of approx. 40 – 42 mm in the plain of the longitudinal vertical section on the centre line.

Compared to this, the samples S2 and S3 indicate a significantly larger fusion width. S2 has a fusion width of ≥ 48 mm and S3 a fusion width of ≥ 52 mm. These values are the determined sample widths in the plain of the longitudinal vertical section on the centre line. The minimal fusion widths in the plain of the longitudinal vertical section of the foot tips were determined with 45 mm (S2) and 43 mm (S3).

It was not possible to visualise the fusion line of the sample S1. Accordingly it was not possible to determine the dimension of the fusion zone of sample S1. The sample width is ≥ 41 mm in the plain of the longitudinal vertical section on the centre line.

Other relevant defects in the weld metal are not visible in the plains of the longitudinal vertical sections.

2.3 Chemical analyses and hardness

The following table, **Table 1**, documents chemical analyses of the weld metal of the samples S1, S2 and S3 as well as data of the ET-internal quality control of the used Thermit®-portion batch 0018551.

The chemical analyses were determined on the running surface in the centre of the weld metal.

Table 1: Chemical analyses of the weld metal (running surface)

Element [weight-%]	C	Si	Mn	P	S	Cr	V	Al
Weld sample S1 Batch 0018551	0,54	1,01	0,73	0,023	0,008	0,13	0,01	0,09
Weld sample S2 Batch 0018551	0,56	1,00	0,75	0,018	0,004	0,12	0,01	0,19
Weld sample S3 Batch 0018551	0,53	1,02	0,74	0,022	0,007	0,14	0,01	0,12
ET-Quality control Batch 0018551 – Portion No. 0022	0,57	1,03	0,67	0,024	0,005	0,12	0,01	0,10
ET-Quality control Batch 0018551 – Portion No. 0510	0,56	1,08	0,71	0,023	0,005	0,12	0,01	0,07

The hardness of the weld metal of the weld samples is given in **Table 2**. Additionally the hardness values of the ET-internal quality control of the Thermit®-portion batch 0018551 are included in Table 2.

The hardness values were determined on the running surface in the weld centre.

Table 2: Hardness of the weld metal (running surface)

HBW [10/3000]	Value 1	Value 2	Value 3	Average (Target: 260 – 300 HB)
Weld sample S1 Batch 0018551	271	274	268	271
Weld sample S2 Batch 0018551	266	265	271	267
Weld sample S3 Batch 0018551	277	278	269	275
ET-Quality control Batch 0018551 – Portion No. 0022	297	295	295	296
ET-Quality control Batch 0018551 – Portion No. 0510	288	290	286	288

The hardness of the weld samples are lower than the hardness of the ET-quality control samples.

But both, the chemical analyses as well as the hardness of the weld samples and our quality control weld samples show normal / standard values that are within relevant specifications for the rail grade R260 (EN14730-1, ET-internal quality control spec.).

The reactivity of the Thermit®-portions is summarized in **Table 3**.

Table 3: Reactivity of the Thermit®-portions

	Assessment
Weld sample S1 Batch 0018551	Heavy
Weld sample S2 Batch 0018551	Heavy
Weld sample S3 Batch 0018551	Heavy
ET-Quality control Batch 0018551 – Portion No. 0022	Calm
ET-Quality control Batch 0018551 – Portion No. 0510	Normal

3 Conclusion

The Development and Application Technology department of the Elektro-Thermit GmbH & Co. KG (ET) was asked by Infranord AB to investigate three SkV welds with defects in the head of the weld metal.

The investigations on these weld sample led to the findings and conclusions that are summarized in the following text:

Defects in the head of the weld metal

All three welds (S1, S2 and S3) show several distinctive features:

- Smooth (S1 and S2) and deformed (S2) weld collar surface in the web area,
- Deformed risers at the foot riser window section (S1, S2 and S3),
- Risers did not break off at the foot riser window due to the deformation of the risers (S1, S2 and S3),
- Oxidized, dendritic surface structure of hot-cracks in the head area of the weld metal (S1, S2 and S3),
- Weld metal displacement at the outer head area (S2),
- The longitudinal vertical sections on the centre line indicate too large fusion zone widths (S2, S3),
- Cavities in the underfoot collar (S2),
- Chemical analysis and hardness of the weld metal are typical and on good levels (S1, S2 and S3).

After an assessment of the findings written above the following conclusion was drawn for all weld samples:

The defects on the weld samples were most probably generated by a too intensive pre-heating.

The intensive pre-heating led to an over-heating of mould material in the web area so that it was partly molten and transferred to a glass like material with a plane, smooth surface. The mould material at the foot-riser window sections (there is the smallest free-cross section for the gas flow during pre-heating) was partly molten and ejected by the gas stream. This should have been visible by sparks (glowing/molten parts of mould material) that were coming out of the risers during pre-heating. The thereby generated deformation of the moulds is visible on the weld metal at the web collar as well as on the weld metal of the deformed risers at the foot-riser window sections. Due to the deformation it was not possible to break off the risers just at the foot-riser window section.

The increased heat input by the intensive pre-heating additionally led to a larger fusion and also a lower cooling rate of the welds. The lower cooling rate increased the time when it was possible to start shearing. So if shearing started at a "standard" time when the weld metal of these samples had not been cooled down adequately the generation of hot cracks (S1, S2



and S3) and weld metal displacements (S2) that are visible on the samples were the logical consequences. The lower cooling rate additionally explains the lower hardness values of the investigated weld samples compared to our quality control weld samples.

A too intensive pre-heating can be caused by too long pre-heating time and/or a not neutral flame (excess oxygen, undersupply of propane) and/or inaccurate gas train equipment and/or inaccurate burner adjustment.

It can't be excluded that the gap widths for these welds were higher than the specified 24 – 26 mm. This may be an additional reason for the too high fusion width of the samples S2 and S3.

The generation of cavities in the underfoot collar (S2) is most probably caused by the too intensive pre-heating. We see a correlation of increased heat input (pre-heating, liquid Thermit®-steel) to the characteristic of the mould material that will most likely have caused the cavities.

Finally we can state that we do not see any indication that the welding process SkV-Salino and / or the welding consumables (e.g. Thermit® portion) are possible reasons for these defect welds.

Heavy reactivity of the Thermit® portions

The weld samples show no indications of humidity (pores within the weld metal) that may have been a reason for a heavy reactivity of Thermit® portions. So it has to be supposed that the portion itself could have had a heavy reactivity.

The visible reactivity of intact Thermit®-portions is influenced by the quality and quantity of Thermit® raw materials and the density of the materials within the crucible.

Another important influence is given by the crucible. The crucibles are designed in a way that the Thermit® reaction is mainly kept inside the crucible. Of course that type of exothermal reaction also needs an opening to the environment so that expanding gases with high temperatures do not generate a critical pressure within the crucible.

In order to produce Thermit® steel with constant chemical analysis and hardness within one batch it is necessary to have a homogenous reaction. This is positively influenced by a higher reactivity that guarantees that the Thermit® reaction between all raw materials is comprehensive as well as that the mixing of all alloying elements is sufficient. If the reactivity is too heavy this can have influences on the process safety as well as on the safety of the environment, especially the Thermit® welders.

Our aim is to manufacture products that guarantee the process safety as well as the safety of the environment but also the generation of a homogenous weld metal (Thermit® steel).



For the investigated weld samples we can state that the visible heavy reactivity did not influence the weld metal and process safety in a negative way. The chemical analyses and hardness's of the weld metal are typical and within relevant specifications. There is no indication that the heavy reactivity had an influence on the generation of the defects in the head areas of the weld metal. In the end there is also no indication for a reason that may have caused the heavy or heavier reactivity.

Nevertheless, there was a different assessment on the reactivity in comparison to our quality control.

After an intensive testing at our laboratory, in which we verified that there is a tendency to heavier reactivity's, we decided to reduce the visible reactivity of 60/Z90SkV-E Thermit® portions by a better matching of the raw materials to each other, e.g. particle size.