



Project no. TIP5-CT-2006-031415O

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D4.6.6 – Weld Performance in Track Test – Supervision of Weld Properties in Terms of Rail Profile, Rail Straightness and Neutral Temperature *PRELIMINARY REPORT*

Due date of deliverable: 31.08.2009

Actual submission date: December 2009

Start date of project: 1 September 2006

Duration: 36 months

Organisation name of lead contractor for this deliverable:

Goldschmidt

Revision **[draft 2]**

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of Contents

Glossary	2
1. Executive Summary.....	3
2. Introduction	4
3. Aluminothermic Welding	5
3.1 Geislinger Steige, Germany	5
3.2 Ofot Line, Norway.....	27
3.2.1 Hardness Profile	27
3.2.2 Cross Profile Measurements	27
3.3 Sterbfritz, Germany	30
4. Flash Butt Welding	31
4.1 xxxx	Error! Bookmark not defined.
5. Conclusions	40
5.1 Aluminothermic Welding.....	40
5.2 Flash Butt Welding	41
6. Bibliography	Error! Bookmark not defined.

Glossary

HAZ	heat affected zone
HPW	high performance weld
FB	flash butt
SEC	Straight Edge Compact (straightness measuring device)
SED	Straight Edge Dual (straightness measuring device)

1. Executive Summary

In this report the behaviour of Flash Butt Welds (narrow HAZ FBW) as well as the behaviour of the aluminothermic welding process HPW during service in track will be addressed. The performance of a track test is a major issue in evaluating welding processes. Here, the influence of the HAZ on the degradation mechanisms like resistance against wear and rolling contact fatigue (RCF) is of high interest.

In the case of Flash Butt Welds, this degradation mechanism has been countered by reducing the thickness of the HAZ, particularly, the thickness of the band of lower hardness so that the weld is no longer visible to the wheel. Although aluminothermic welding enables to offer welding procedures that create a heat affected zone of slightly different widths only one welding procedure has been chosen to be investigated in the track test. The HPW welding procedure is characterized by a selective alloying system to achieve different properties in the head and in the foot of the weld. This welding procedure is mainly used to weld head hardened rails.

The monitoring of a track test in general and the monitoring of the behaviour of the welds during the track test can be done in terms of a visual inspection as well as using measuring techniques to measure rail profile, rail straightness and neutral temperature. The application of strain gauges is not a standard procedure, but it allows measuring local stress conditions and the neutral temperature of the rail can be determined. The development of the neutral temperature during the lifespan of the track is of high interest.

In this report results will be addressed that have been achieved both during track tests executed in the past and from "new" track tests that started at the end of the INNOTRACK project. Consequently, the final results for these new track tests cannot be included in this report.

Thus, this report is a »*PRELIMINARY REPORT*« - the new track tests mentioned will be monitored for a period of at least two years. A final report will therefore be available after 30 months at the latest (July 2012).

2. Introduction

With respect to the INNOTRACK project the working group WP4.6 focussed on welding processes, flash butt welding and aluminothermic welding.

The heat affected zone (HAZ) of the welds is found to be the reason for localized wear and battering on the running surface. Typically, the HAZ has a lower hardness compared to the rail steel and the weld metal. Thus, the resistance against wear of the HAZ is reduced and the material in the HAZ is subjected to an increased plastic deformation during service in track.

This, in turn leads to the generation of high impact loads, which increase in magnitude with both increasing depth of weld dipping and increasing train speed. The high impact loads generated by dipped welds have been observed to lead to additional track related problems such as increased wear/tear of wheel sets and bogies, development of corrugation and increased noise levels.

In the case of Flash Butt Welds, this degradation mechanism has been countered by reducing the thickness of the HAZ, particularly, the thickness of the band of lower hardness so that the weld is no longer visible to the wheel. In the aluminothermic welding process the HAZ is produced by the heat input during preheating and by the superheated molten steel. By modification of the preheating parameters and the pouring system the width of the HAZ can be influenced. An additional possibility to influence the HAZ is a post treatment of the weld after the final grinding process.

In this report the main focus is on the behaviour of Flash Butt Welds (narrow HAZ FBW), patented by Corus, as well as the behaviour of the aluminothermic welding process HPW during service in track.

Here, the performance of a track test is a major issue to evaluate a welding process. Although aluminothermic welding enables to offer welding procedures that create a heat affected zone of slightly different widths only one welding procedure has been chosen to be investigated in the track test. The HPW welding procedure is characterized by a selective alloying system to achieve different properties in the head and in the foot of the weld. This welding procedure is mainly used to weld head hardened rails.

The monitoring of a track test in general and the monitoring of the behaviour of the welds during the track test can be done in terms of a visual inspection as well as using measuring techniques to measure rail profile, rail straightness and neutral temperature. The application of strain gauges is not a standard procedure, but it allows measuring local stress conditions and the neutral temperature of the rail can be determined. The development of the neutral temperature during the lifespan of the track is of high interest.

In this report results will be addressed that have been achieved during track tests executed in the past. Further "new" track tests will be addressed that started at the end of the INNOTRACK project. Consequently, the final results for these new track tests cannot be included in this report.

Thus, this report is a »*PRELIMINARY REPORT*« - the new track tests mentioned will be monitored for a period of at least two years. A final report will therefore be available after 30 months at the latest (July 2012).

3. Aluminothermic Welding

With regard to the aluminothermic welding process HPW two track tests have been executed in the past that can be used to give a first impression about the applicability of the welding process.

- ➔ Geislinger Steige, Germany
- ➔ Ofot Line, Norway

Head hardened rails of grade R350HT and 370LHT have been used for the above mentioned track tests. However, the traffic conditions are quite different. The German track "Geislinger Steige" is a track with mixed traffic, moderate loads and comparably low traffic speed, whereas the Ofot Line in Norway represents a typical heavy haul line.

3.1 Geislinger Steige, Germany

- execution of 8 HPW welds in April 2005
- track: Geislinger Steige (Amstetten-Geislingen)
- rail grades R350HT, 370LHT
- profile 60 E 1
- load: 50000 – 60000 to/day
- traffic speed: 70 km/h

In the period of one year, three straightness measurements have been executed (see Table 1 and Figures 2 to Figure 21). For the given track (track category P230) all straightness measurements are within the tolerance regarding the acceptance criteria for aluminothermic welds. An evaluation of the straightness measurements is given in Figure 1. Here average values for the maximum (Spitze), the minimum (Senke) and the resulting difference (Differenz Spitze-Senke) are given. The value for the difference between minimum and maximum value increases slightly, which is an expected behaviour for the welds.

No defects of the welds been observed during the period of the test.

Table 1 HPW, straightness measurements, Geislinger Steige

weld	rail grade	rail grade	May 2005			March 2006			June 2006		
			max.	min.	diff.	max.	min.	diff.	max.	min.	diff.
34-1 HPW1	350HT	370LHT	0,00	-0,11	0,11	0,00	-0,11	0,12	0,02	-0,12	0,14
32-1 HPW2	350HT	370LHT	0,00	-0,17	0,18	0,02	-0,19	0,17	0,04	-0,22	0,26
33-1 HPW3	350HT	370LHT	0,23	0,00	0,23	0,00	-0,26	0,27	0,00	-0,22	0,22
31-1 HPW4	350HT	370LHT	0,015	0,00	0,15	0,00	-0,24	0,24	0,01	-0,26	0,27
18-1 HPW5	370LHT	370LHT	0,00	-0,16	0,16	-	-	-	0,05	-0,09	0,14
17-1 HPW7	370LHT	370LHT	0,11	0,00	0,11	-	-	-	0,04	-0,02	0,06
18-2 HPW6	370LHT	370LHT	0,00	-0,11	0,11	-	-	-	0,07	-0,03	0,10
17-2 HPW8	370LHT	370LHT	0,05	0,00	0,05	-	-	-	0,06	-0,05	0,11

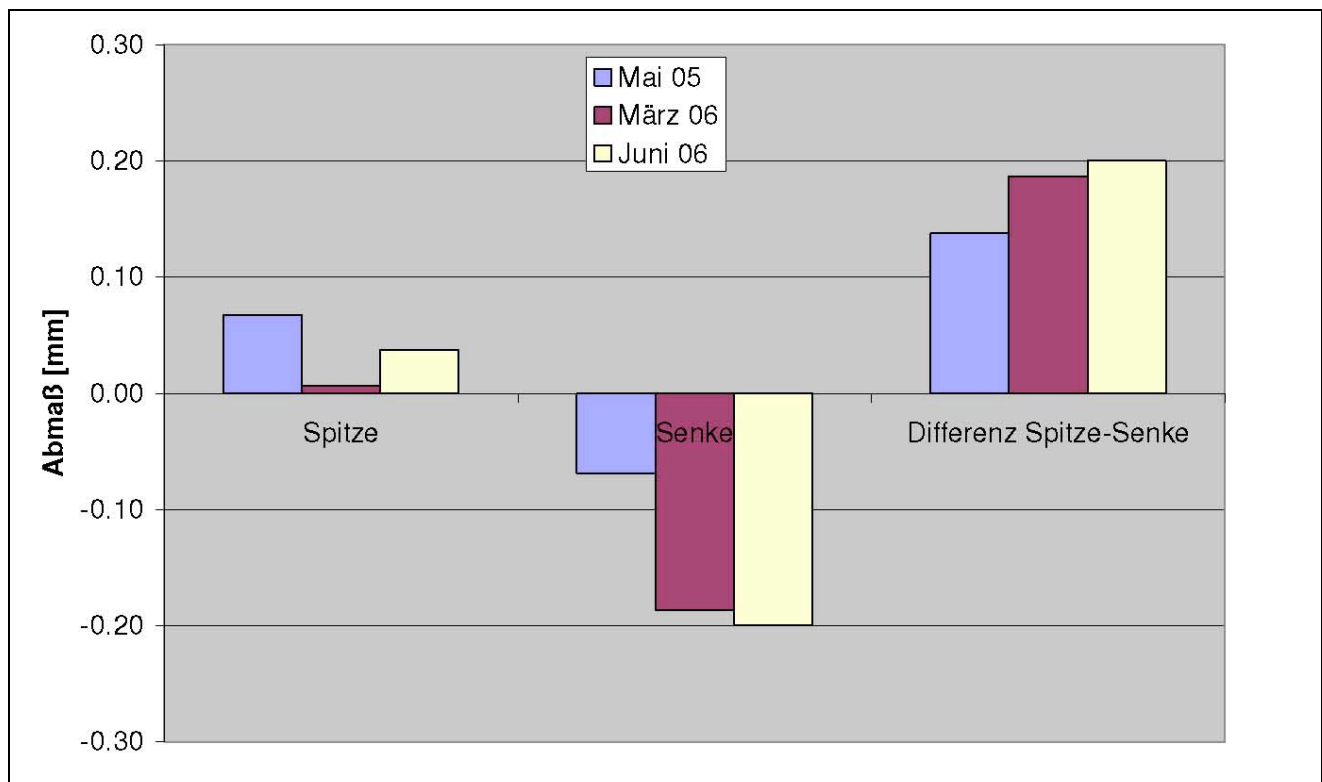


Figure 1 HPW, straightness measurements Geislinger Steige – average values (max, min, diff.)



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

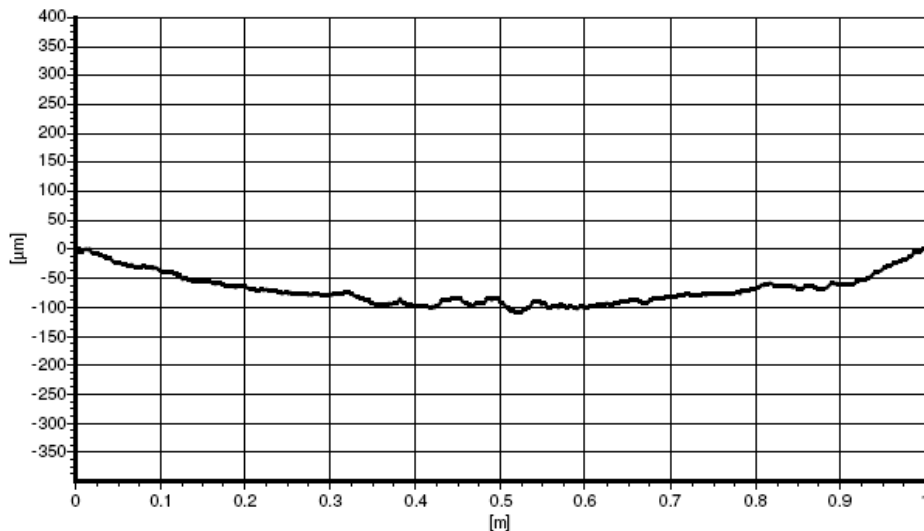
MESSPROTOKOLL

Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 132

Streckennummer :	Messdatum : 22/05/2005
Streckenname : Ulm-Stuttgart	Stoßnummer : 34-1 HPW 1
Bahnhof : Geislingen Talgleis	Kilometer : 62.000
Niederlassung : bleibt frei	Schweißstoß : VerbindungThermit
Prüfer : Schyra/Wegner	Profil : UIC60
Bemerkung : Güte 370LHT	Gleis : Links
	Strang : Links

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.11 mm
Differenz : 0.11 mm

Prüfer

Bemerkung

29/08/2006 15:59:34

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\CAL03 b Messungen2005Geislingen.r2s

Figure 2 weld 34-1 HPW1, measurement May 2005



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co. KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

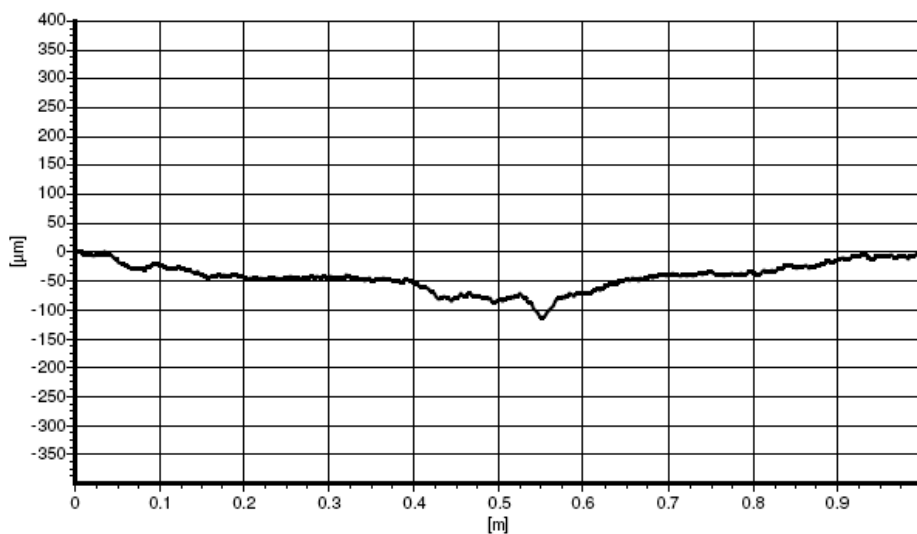
Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 156

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen
Niederlassung : bleibt frei
Prüfer : Schramm
Bemerkung :

Messdatum : 02/03/2006
Stoßnummer : 34-1 HPW 1
Kilometer : 62.000
Schweißstoß : Verbindung Thermit
Profil : UIC60
Gleis : Links
Strang : Links

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.11 mm
Differenz : 0.12 mm

Prüfer

Bemerkung

30/08/2006 12:15:39

P:\Messtechnik\Gleisversuche\Geislinger Steige\20060302\GE06.R2S

Figure 3 weld 34-1 HPW1, measurement March 2006

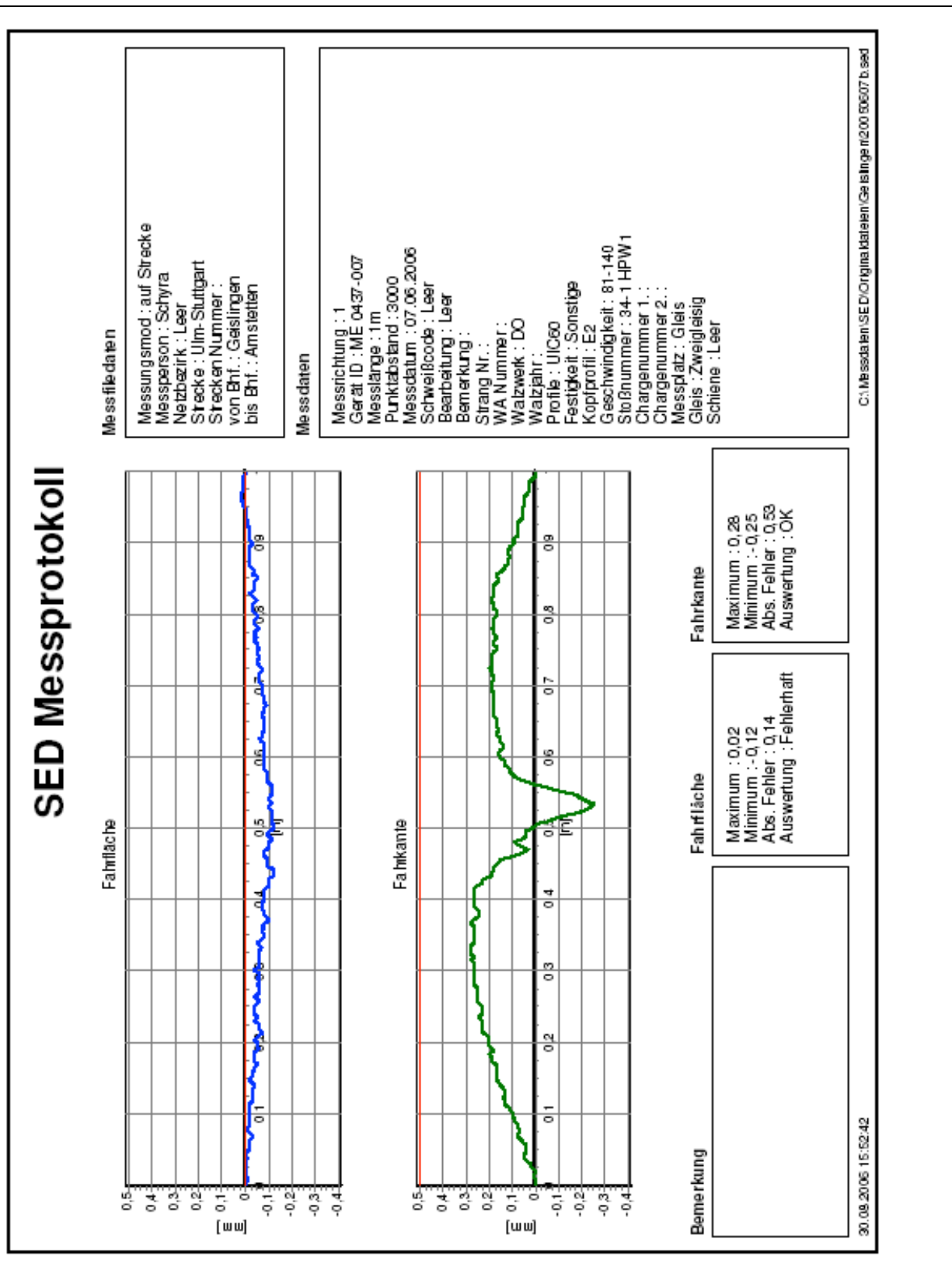


Figure 4 weld 34-1 HPW1, measurement June 2006



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

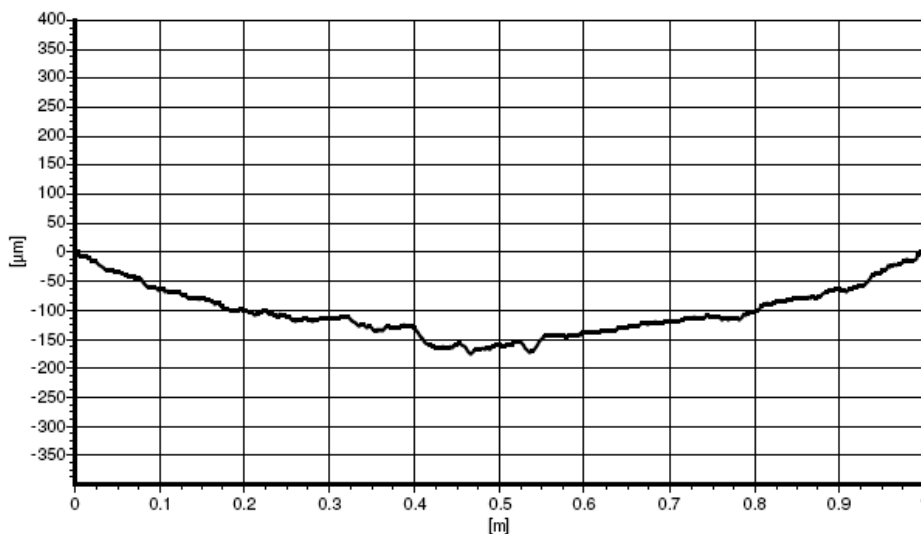
MESSPROTOKOLL

Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 132

Streckennummer :	Messdatum : 22/05/2005
Streckenname : Ulm-Stuttgart	Stoßnummer : 32-1 HPW2
Bahnhof : Geislingen Talgleis	Kilometer : 62.000
Niederlassung : bleibt frei	Schweißstoß : VerbindungThermit
Prüfer : Schyra/Wegner	Profil : UIC60
Bemerkung : Güte 370LHT	Gleis : Links
	Strang : Links

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.17 mm
Differenz : 0.18 mm

Prüfer

Bemerkung

29/08/2006 15:57:52

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\CAL03 b Messungen2005Geislingen.r2s

Figure 5 weld 32-1 HPW2, measurement May 2005



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co. KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

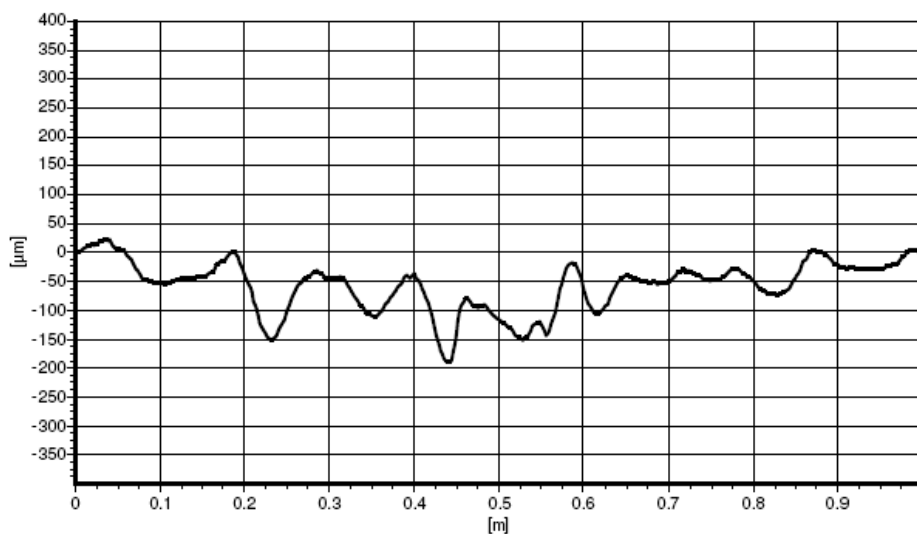
Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 156

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen
Niederlassung : bleibt frei
Prüfer : Schramm
Bemerkung :

Messdatum : 02/03/2006
Stoßnummer : 32-1 HPW2
Kilometer : 62.000
Schweißstoß : Verbindung Thermit
Profil : UIC60
Gleis : Links
Strang : Links

Gleis

Fahrfläche



Maximum : 0.02 mm
Minimum : -0.19 mm
Differenz : 0.21 mm

Prüfer

Bemerkung

30/08/2006 12:19:58

P:\Messtechnik\Gleisversuche\Geislinger Steige\20060302\GE06.R2S

Figure 6 weld 32-1 HPW2, measurement March 2006

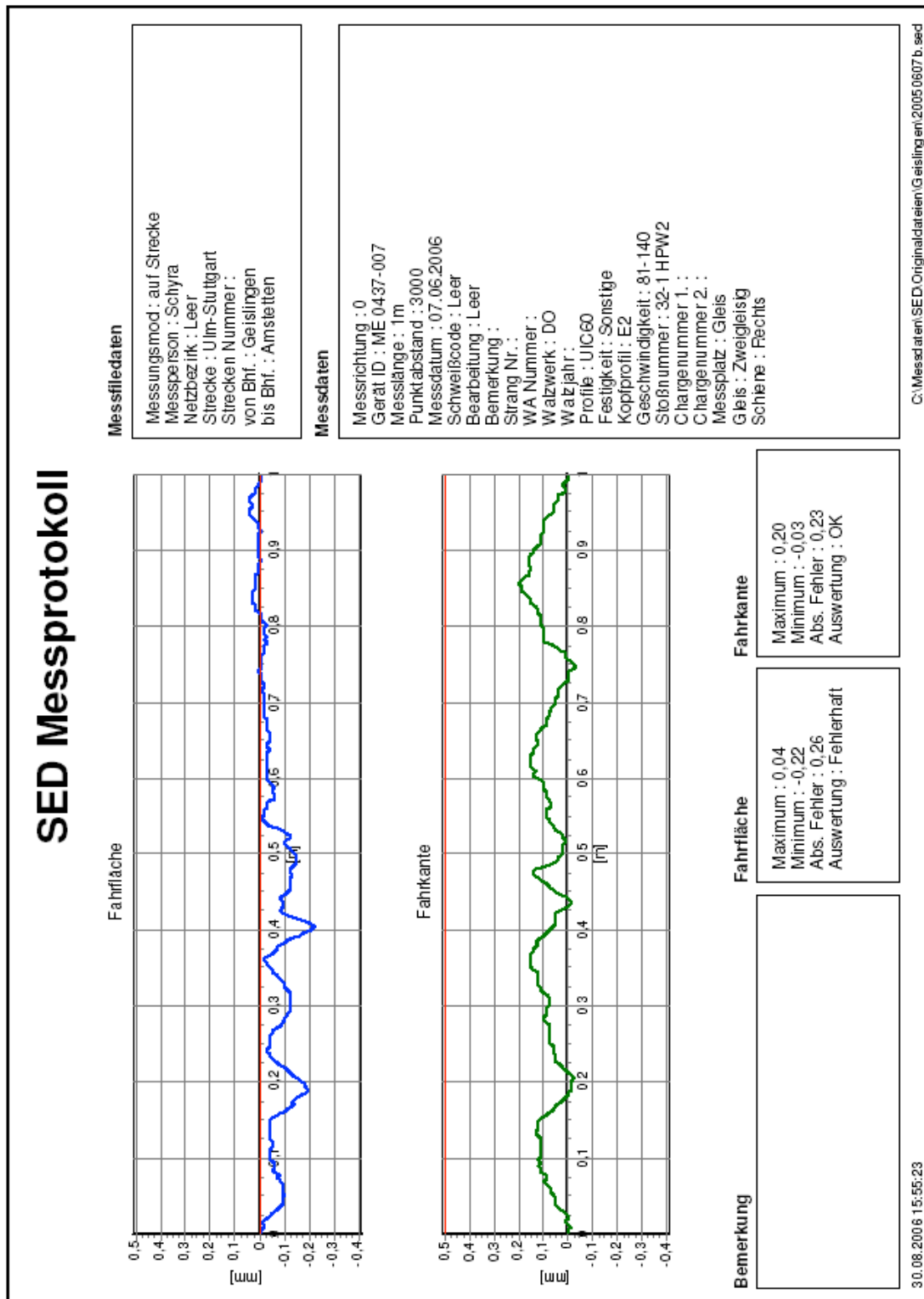


Figure 7 weld 32-1 HPW2, measurement June 2006



SEC

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

Die Messung wurde mit dem SEC Compact Balken durchgeführt.

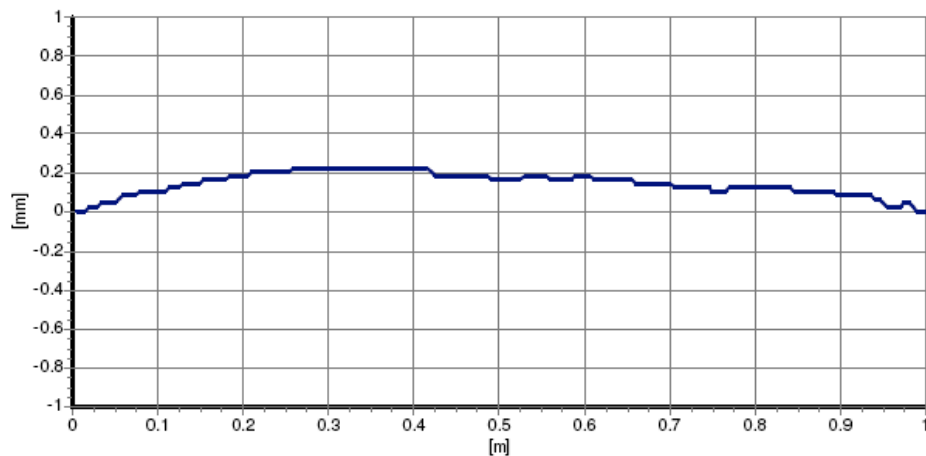
Balken-Identifikationsnummer : 74

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen Talgleis
Niederlassung : bleibt frei
Prüfer : Schyra
Bemerkung :

Messdatum : 17/08/1997
Schweissperson :
Stoßnummer : 33-1 HPW3
Kilometer : 62.000
Schweißstoß : VerbindungThermit
Profil : UIC60
Bemerkung :
: ?
Strang : Rechts

Gleis

Fahrfläche



Maximum : 0.23 mm
Minimum : 0.00 mm
Differenz : 0.23 mm

30/08/2006 08:50:30

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\Geislingen Daten SEC\G.SE

Figure 8 weld 33-1 HPW3, measurement May 2005



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

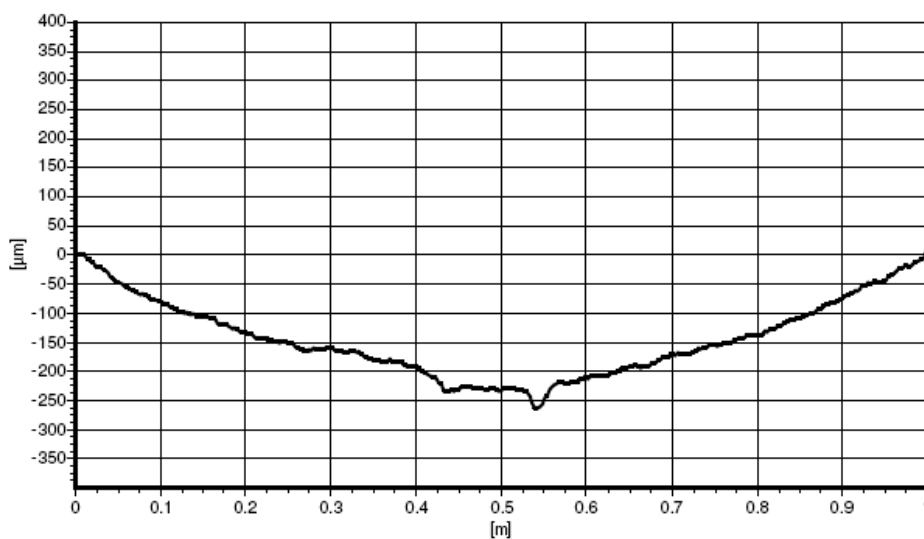
Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 156

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen
Niederlassung : bleibt frei
Prüfer : Schramm
Bemerkung :

Messdatum : 02/03/2006
Stoßnummer : 33-1 HPW3
Kilometer : 62.000
Schweißstoß : Verbindung Thermit
Profil : UIC60
Gleis : Links
Strang : Rechts

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.26 mm
Differenz : 0.27 mm

Prüfer

Bemerkung

30/08/2006 12:21:21

P:\Messtechnik\Gleisversuche\Geislinger Steige\20060302\GE06.R2S

Figure 9 weld 33-1 HPW3, measurement March 2006

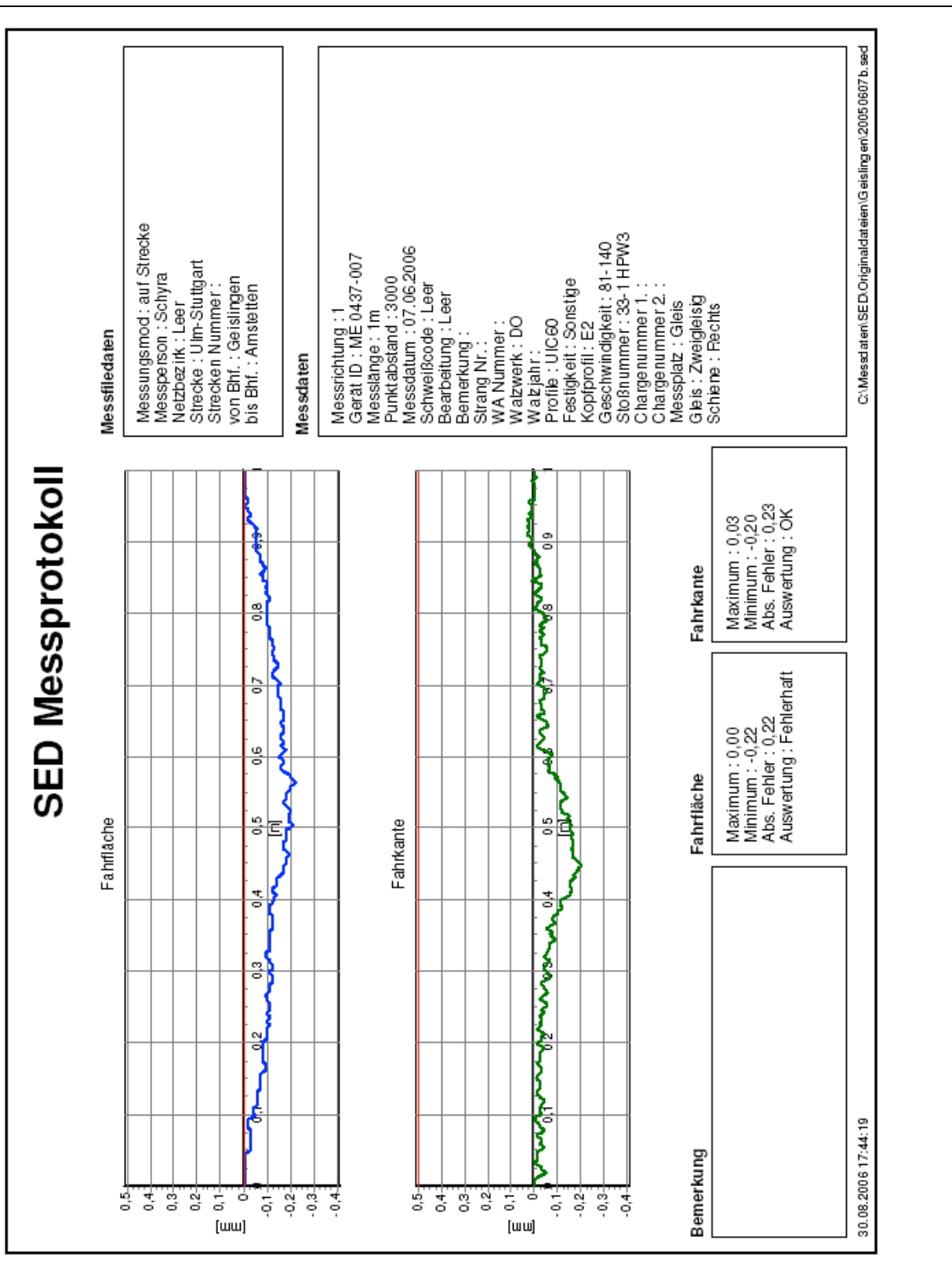


Figure 10 weld 33-1 HPW3, measurement June 2006



SEC

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

Die Messung wurde mit dem SEC Compact Balken durchgeführt.

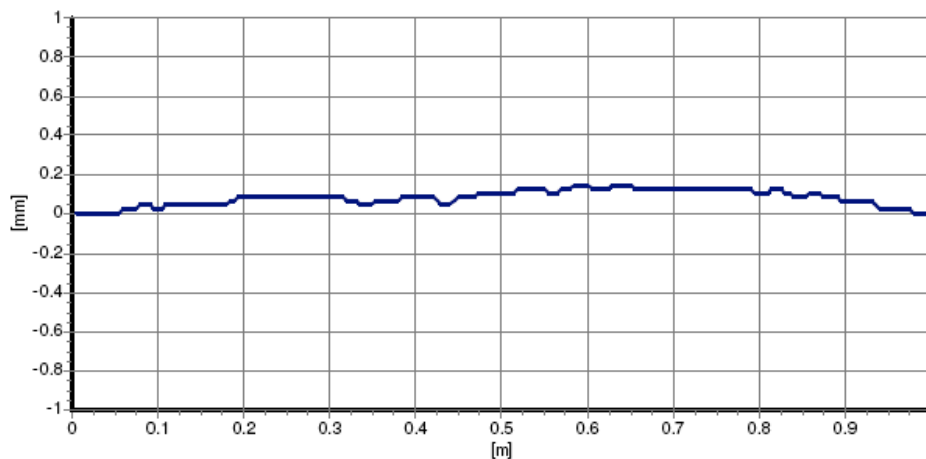
Balken-Identifikationsnummer : 74

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen Talgleis
Niederlassung : bleibt frei
Prüfer : Schyra
Bemerkung :

Messdatum : 22/05/2005
Schweissperson : Schmidt
Stoßnummer : 31-1 HPW4
Kilometer : 62.000
Schweißstoß : VerbindungThermit
Profil : UIC60
Bemerkung :
: ?
Strang : Rechts

Gleis

Fahrfläche



Maximum : 0.15 mm
Minimum : 0.00 mm
Differenz : 0.15 mm

30/08/2006 08:53:15

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\Geislingen Daten SEC\G.SE

Figure 11 weld 31-1 HPW4, measurement May 2005



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

Die Messung wurde mit dem R2S Compact Balken durchgeführt.

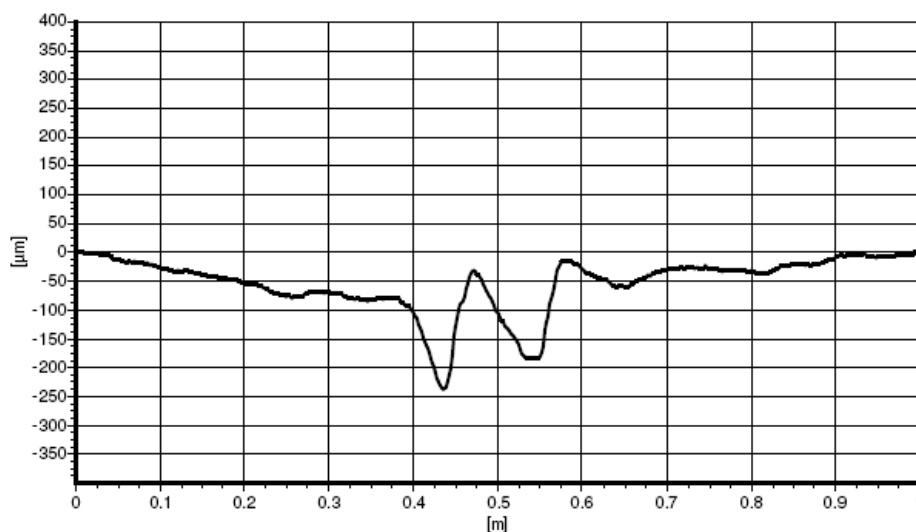
Balken-Identifikationsnummer : 156

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen
Niederlassung : bleibt frei
Prüfer : Schramm
Bemerkung :

Messdatum : 02/03/2006
Stoßnummer : 31-1 HPW4
Kilometer : 62.000
Schweißstoß : VerbindungThermit
Profil : UIC60
Gleis : Links
Strang : Rechts

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.24 mm
Differenz : 0.24 mm

Prüfer

Bemerkung

30/08/2006 12:23:07

P:\Messtechnik\Gleisversuche\Geislinger Steige\20060302\GE06.R2S

Figure 12 weld 31-1 HPW4, measurement March 2006

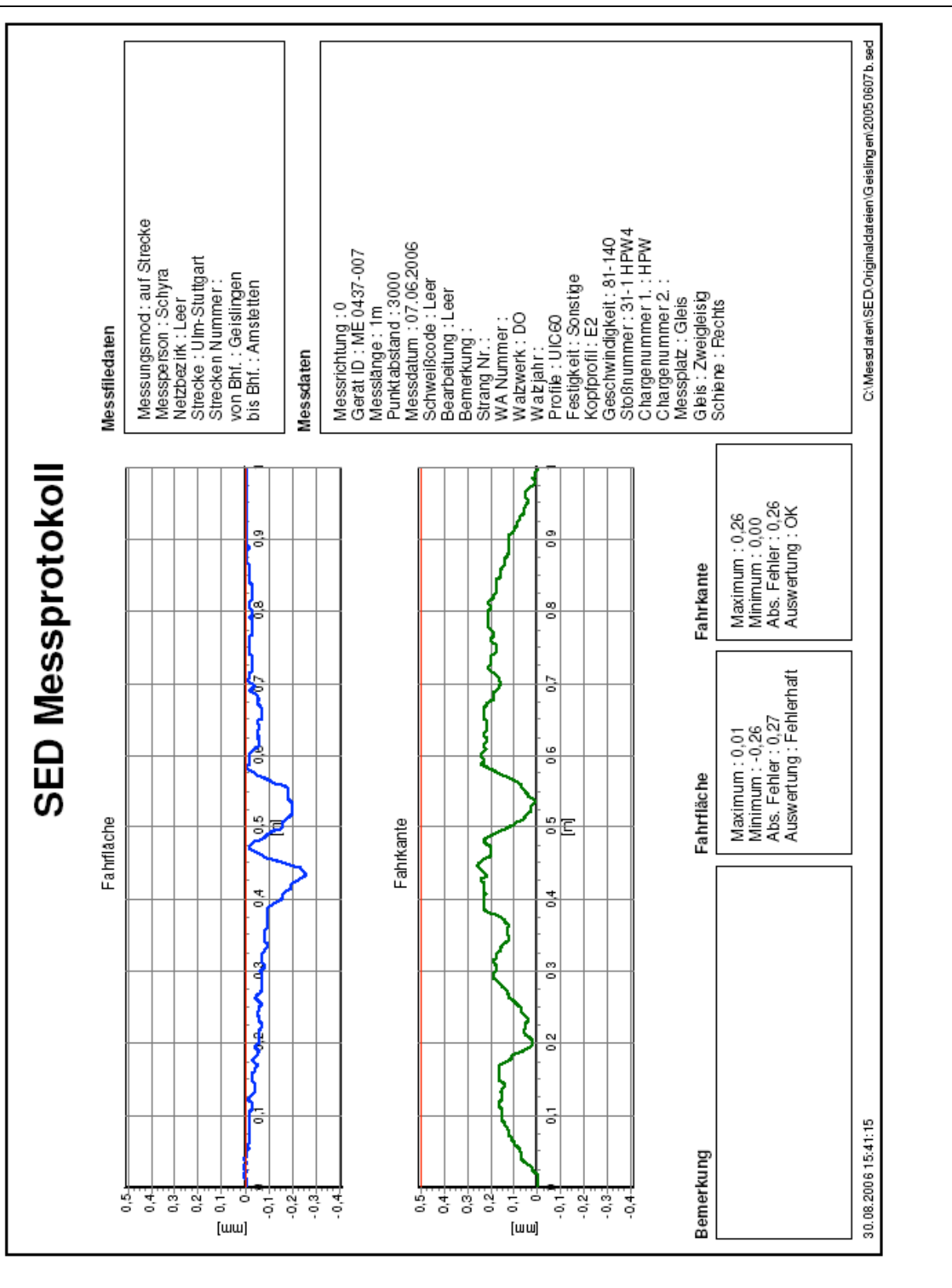


Figure 13 weld 31-1 HPW4, measurement June 2006



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

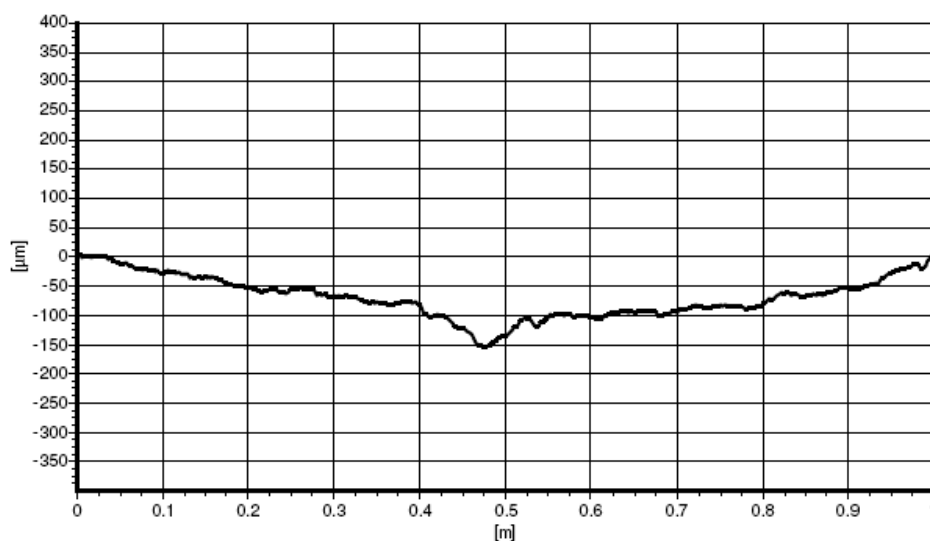
MESSPROTOKOLL

Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 132

Streckennummer :	Messdatum : 22/05/2005
Streckenname : Ulm-Stuttgart	Stoßnummer : 18-1 HPW5
Bahnhof : Geislingen Talgleis	Kilometer : 62.665
Niederlassung : bleibt frei	Schweißstoß : Verbindung Thermit
Prüfer : Schyra/Wegner	Profil : UIC60
Bemerkung :	Gleis : Links
	Strang : Links

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.16 mm
Differenz : 0.16 mm

Prüfer

Bemerkung

30/08/2006 09:36:59

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\CAL03 b Messungen2005Geislingen.r2s

Figure 14 weld 18-1 HPW5, measurement May 2005

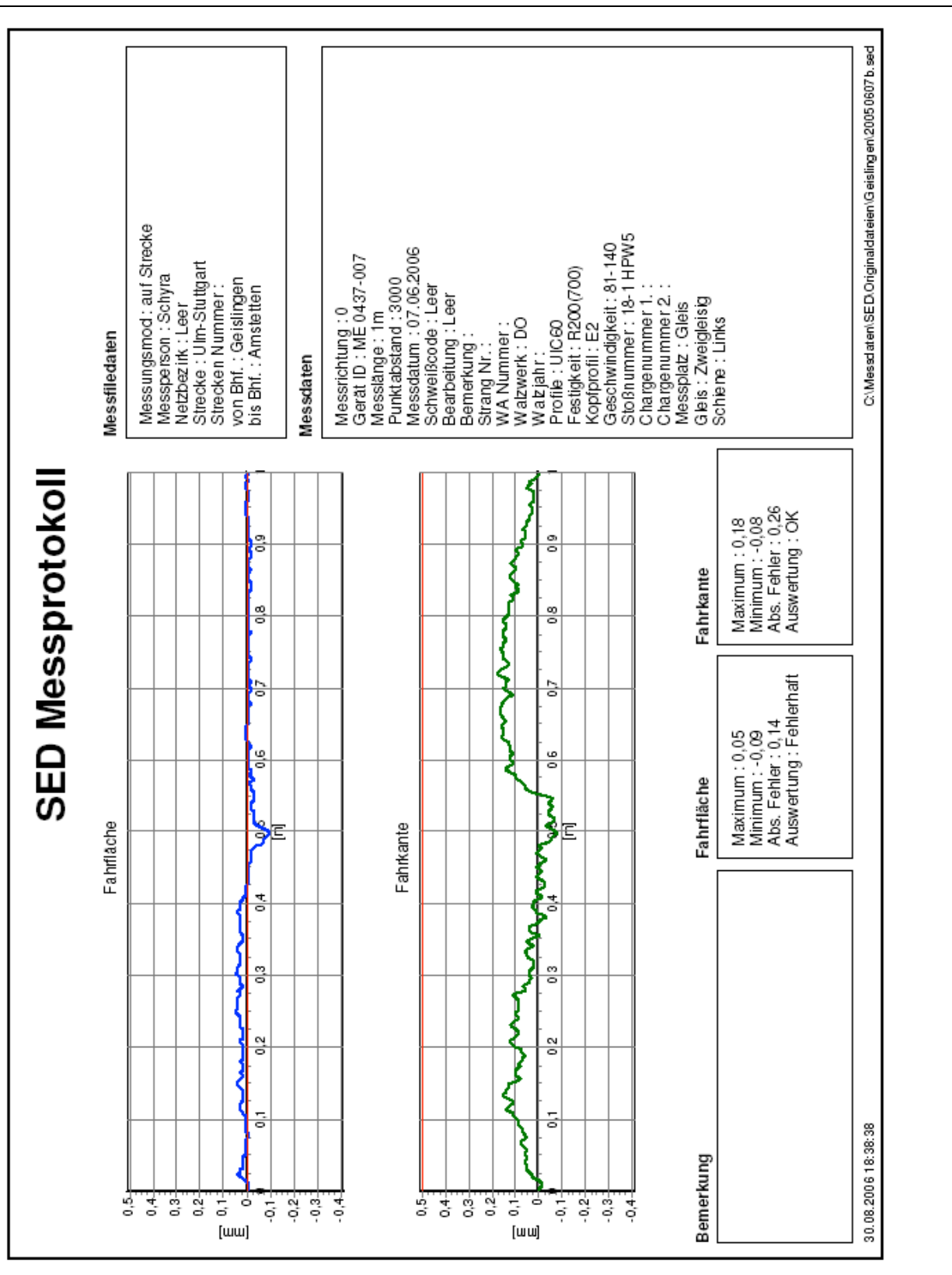


Figure 15 weld 18-1 HPW5, measurement June 2006



SEC

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

Die Messung wurde mit dem SEC Compact Balken durchgeführt.

Balken-Identifikationsnummer : 74

Streckennummer :

Streckenname : Ulm-Stuttgart

Bahnhof : Geislingen Talgleis

Niederlassung : bleibt frei

Prüfer : Schyra

Bemerkung : Z120 Portion

Messdatum : 17/08/1997

Schweissperson :

Stoßnummer : 17-1 HPW7

Kilometer : 62.665

Schweißstoß : VerbindungThermit

Profil : UIC60

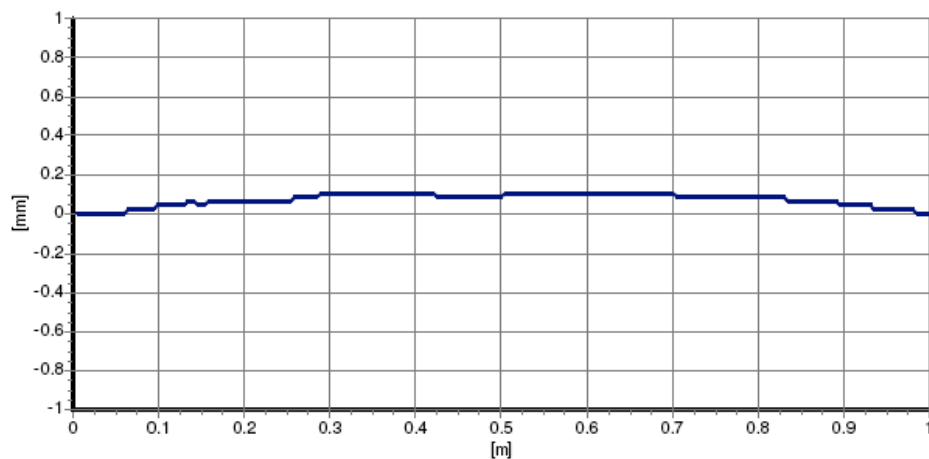
Bemerkung :

: ?

Strang : Rechts

Gleis

Fahrfläche



Maximum : 0.11 mm

Minimum : 0.00 mm

Differenz : 0.11 mm

30/08/2006 08:18:17

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\Geislingen Daten SEC\G.SE

Figure 16 weld 17-1 HPW7, measurement May 2005

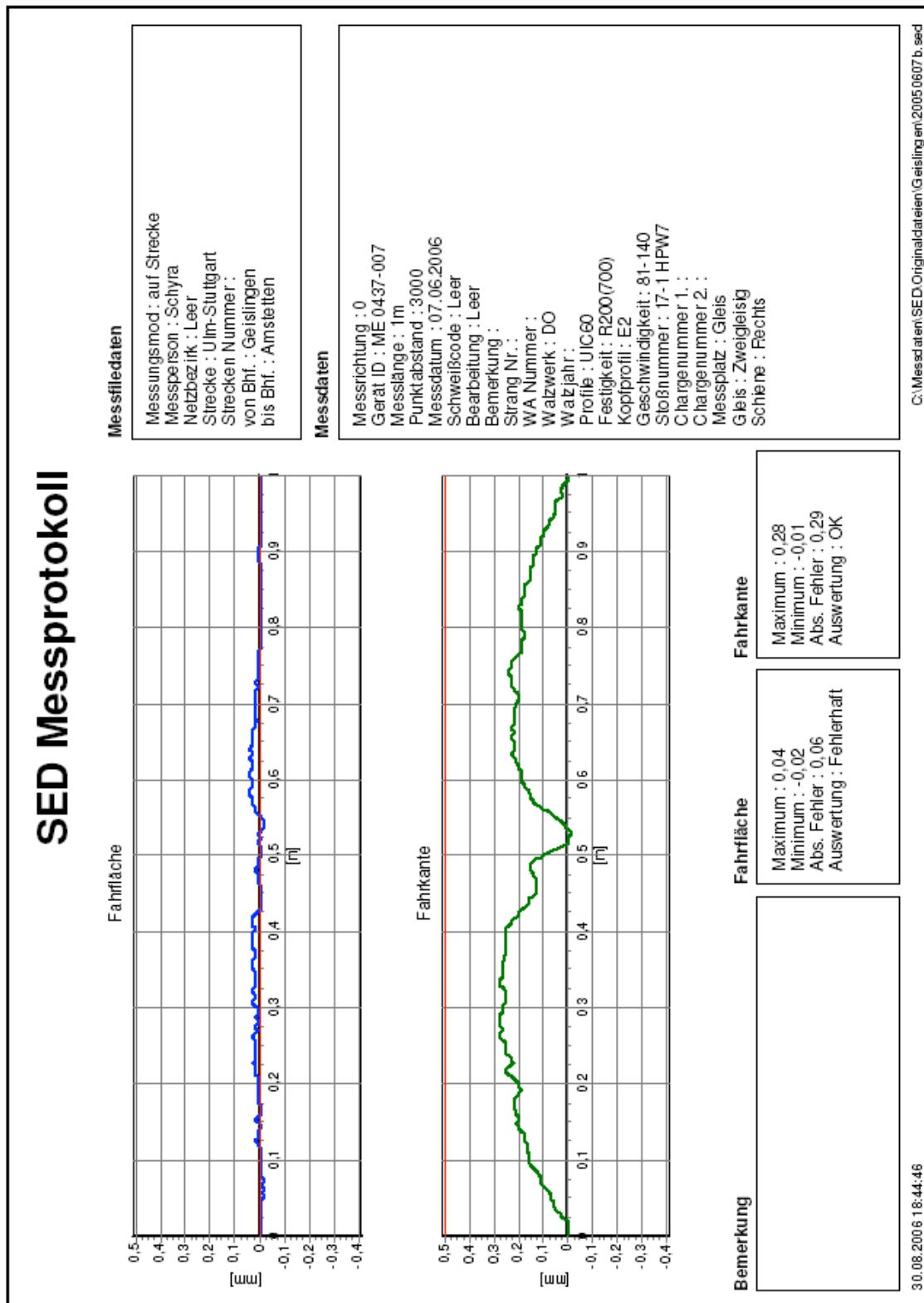


Figure 17 weld 17-1 HPW7, measurement June 2006



R2S

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co. KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

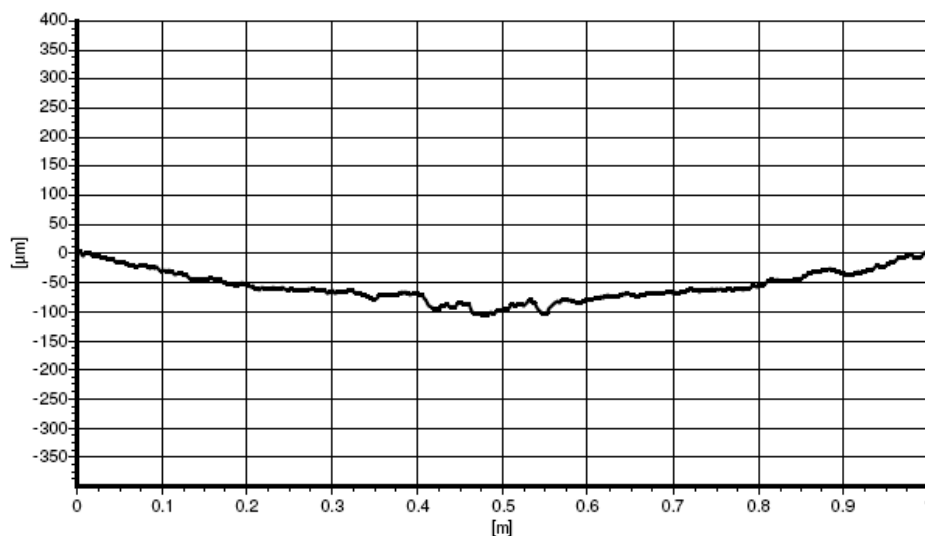
Die Messung wurde mit dem R2S Compact Balken durchgeführt.
Balken-Identifikationsnummer : 132

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen Talgleis
Niederlassung : bleibt frei
Prüfer : Schyra/Wegner
Bemerkung :

Messdatum : 22/05/2005
Stoßnummer : 18-2 HPW6
Kilometer : 62.677
Schweißstoß : Verbindung Thermit
Profil : UIC60
Gleis : Links
Strang : Links

Gleis

Fahrfläche



Maximum : 0.00 mm
Minimum : -0.11 mm
Differenz : 0.11 mm

Prüfer

Bemerkung

30/08/2006 09:38:52

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\CAL03 b Messungen2005 Geislingen.r2s

Figure 18 weld 18-2 HPW6, measurement May 2005

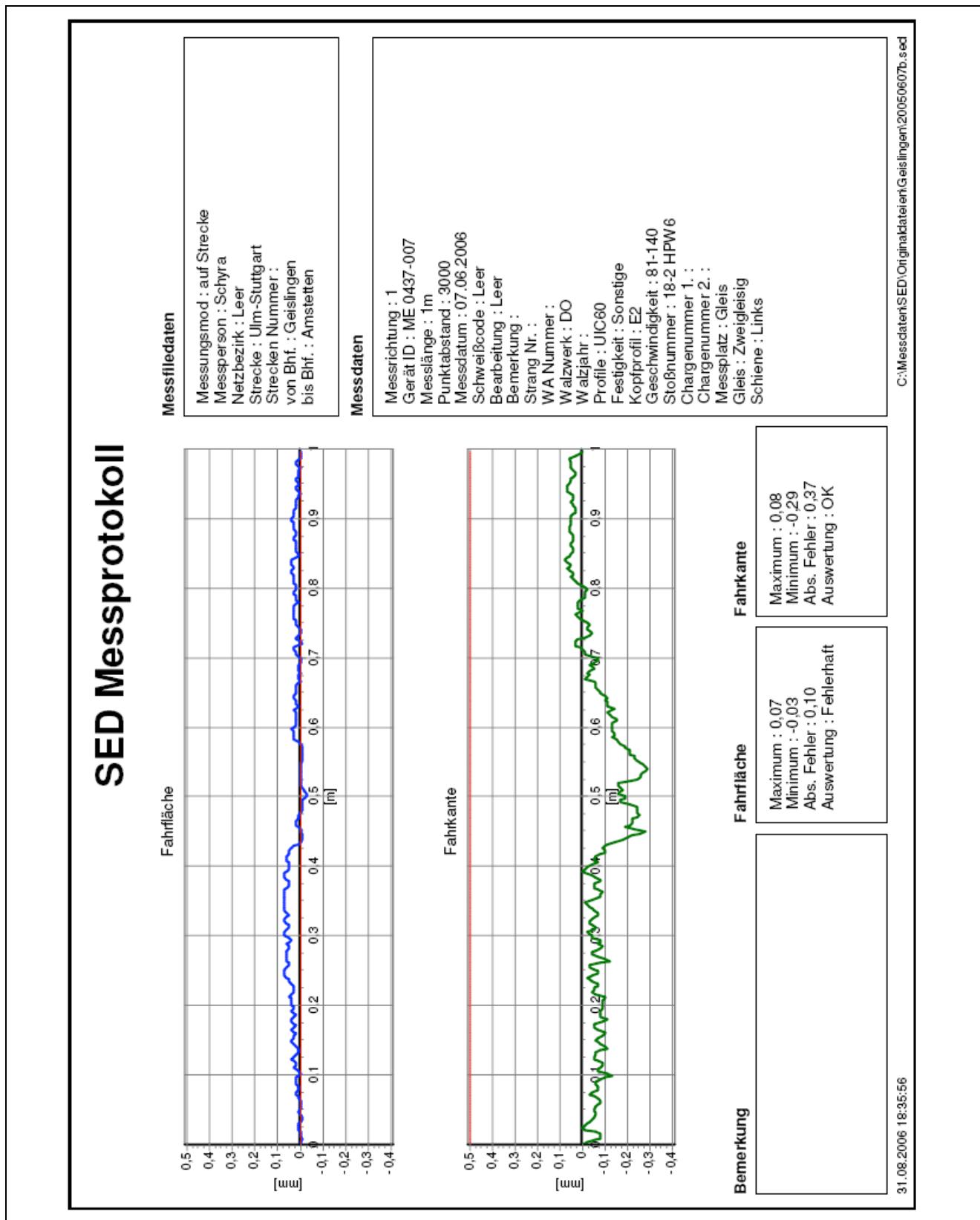


Figure 19 weld 18-2 HPW6, measurement June 2006



SEC

Goldschmidt-Thermit-Group

Elektro-Thermit GmbH & Co.KG
Chemiestrasse 24
06132 Halle (Saale)

MESSPROTOKOLL

Die Messung wurde mit dem SEC Compact Balken durchgeführt.

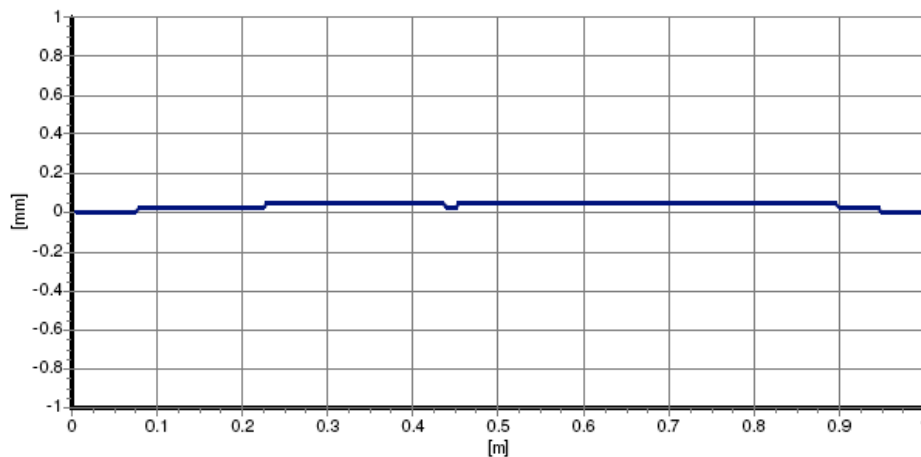
Balken-Identifikationsnummer : 74

Streckennummer :
Streckenname : Ulm-Stuttgart
Bahnhof : Geislingen Talgleis
Niederlassung : bleibt frei
Prüfer : Schyra
Bemerkung : Z120 Portion

Messdatum : 17/08/1997
Schweissperson :
Stoßnummer : 17-2 HPW8
Kilometer : 62.677
Schweißstoß : VerbindungThermit
Profil : UIC60
Bemerkung :
: ?
Strang : Rechts

Gleis

Fahrfläche



Maximum : 0.05 mm
Minimum : 0.00 mm
Differenz : 0.05 mm

30/08/2006 08:20:24

P:\Messtechnik\Gleisversuche\Geislinger Steige\2005052223\Geislingen Daten SEC\G.SE

Figure 20 weld 17-2 HPW8, measurement May 2005

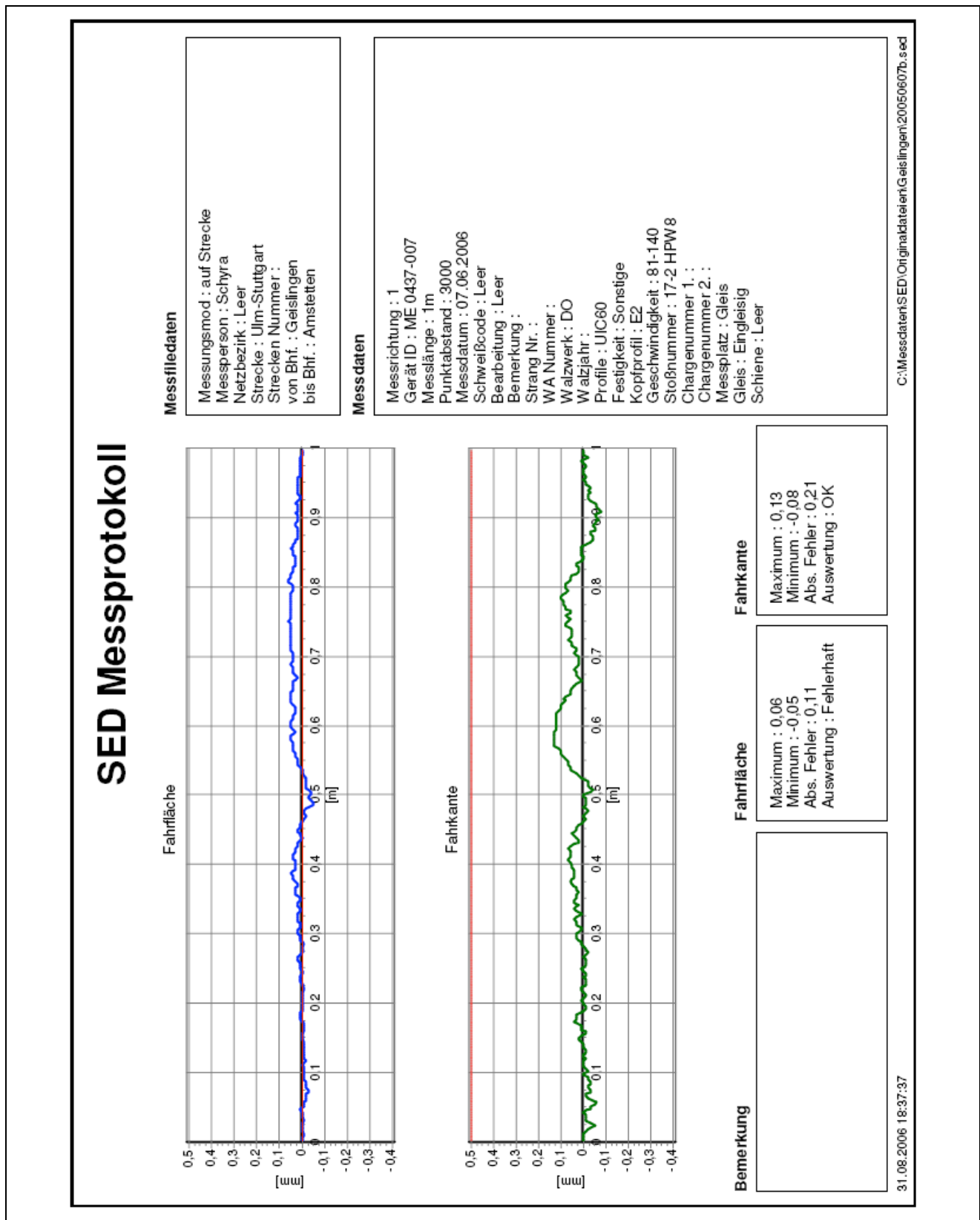


Figure 21 weld 17-2 HPW8, measurement June 2006

3.2 Ofot Line, Norway

- execution of 10 HPW welds in August 2002
- track: Ofot Line
- rail grade 370LHT
- profile 54 E 3
- radius of the track: 300 m
- slope of the track: 13 ‰
- distance of sleepers: 52 cm
- axle load: 25 – 30 to
- annual traffic load: 22 MGT

3.2.1 Hardness Profile

The hardness profile has been measured for four welds (1, 2, 3 and 7) in the initial condition after welding and after 10 months (Figure 22). The hardness measurements have been executed with a mobile hardness tester "EQUOTIP".

Compared to the initial condition hardness increases by about 40 HB after 10 months in track. This is a natural behaviour of the material due to the work hardening caused by the applied load. In general, the hardness measured shows the typical profile for an aluminothermic weld. The observed scattering of the values is mainly caused by the measurement inaccuracy linked to the mobile hardness measurement and the demand for a well prepared surface which is difficult to attain in track.

3.2.2 Cross Profile Measurements

Cross profiles have been measured for two welds (km 7,5 and km 7,54) in the initial condition after the welding and after 22 months (Figure 23) exposed to traffic (39 MGT). The cross profile measurements have been executed with "MINIPROF". For each weld the cross profile was measured at a distance of 0 mm, ± 4 mm, ± 10 mm and ± 15 mm from the weld centre (brown lines). For reference the cross profile at km 7,515 is given (red line). The blue line indicates the cross profile of the weld (0 mm, weld centre) in the initial condition.

Basically it can be shown that wear of the rail and of the weld show a similar behaviour.

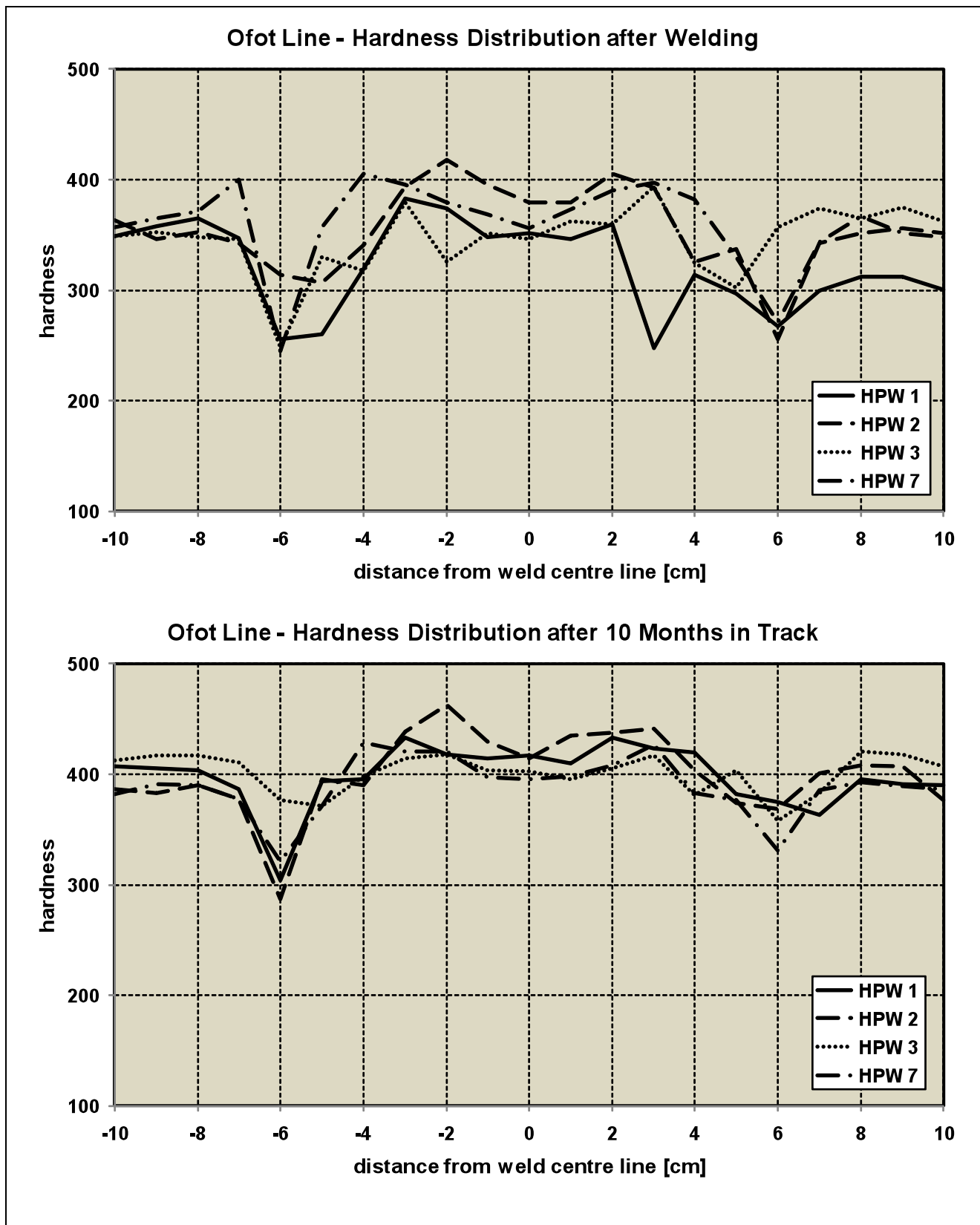


Figure 22 Hardness distribution of HPW welds after welding and after 10 months in track

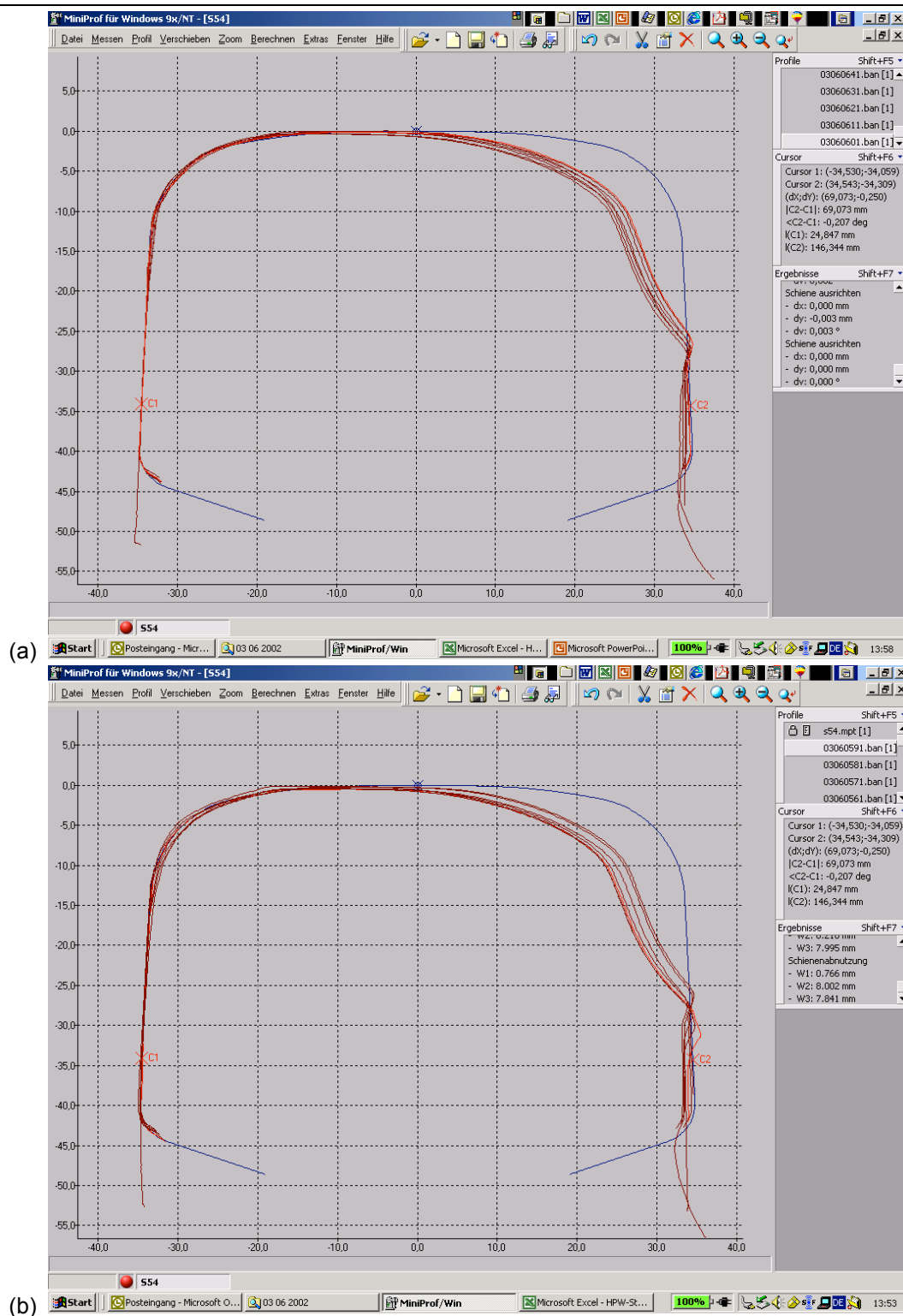


Figure 23 (a) Cross profile measurement after 22 months; km 7,5
(b) Cross profile measurement after 22 months; km 7,54

3.3 Sterbfritz, Germany

The track test "Sterbfritz" will start in December 2009 and will be monitored for a period of at least two years. For this track test head hardened rails of grade R350HT, 370LHT and 400UHC (provided by voestalpine Schienen) will be used. For the track test the following information is given.

- track: Flieden - Gemünden (Elm-Sterbfritz)
- rail grades 350HT, 370LHT, 400UHC
- profile 60 E 2
- load: 100000 to/day
- traffic speed: 100 km/h
- superelevation: 150 mm
- radius 550 m

The test scheme is given in Table 2. It can be seen that not only HPW will be used but also the welding process SkV-Elite. SkV-Elite is a welding process – provided by Elektro-Thermit GmbH – that gives the smallest width of the HAZ (approx. 12 mm) if comparing the different aluminothermic welding processes. Thus, a direct comparison between HPW and SkV-Elite will be possible. Both welding processes are approved welding processes by Deutsch Bahn.

As mentioned above, for the INNOTRACK project a supervision of the track will be made for a period of at least two years. The following inspections are planned to be executed:

- | | |
|---|--------------------------|
| → visual inspection (photographs) | → high rail + low rail |
| → hardness (hardness profile using "EQUOTIP") | → high rail (+ low rail) |
| → cross profile | → high rail (+ low rail) |
| → straightness (SEC or SED) | → high rail (+ low rail) |
| → neutral temperature | → high rail + low rail |

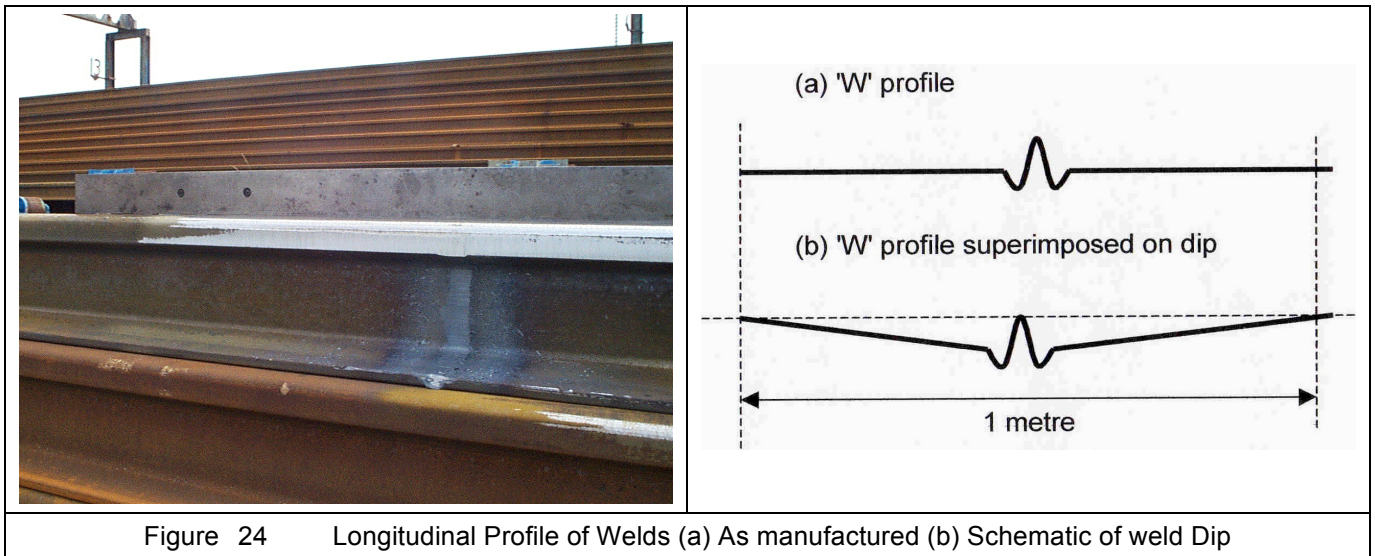
Table 2 Test scheme for track test "Sterbfritz"

km			weld no.	high rail	weld no.	low rail
19,108	R260	350HT	1	SkV-Elite (Z90)	2	SkV-Elite (Z90)
19,228	350HT	400UHC	3	SkV-Elite (Z120)	4	SkV-Elite (Z120)
19,348	400UHC	370LHT	5	SkV-Elite (Z120)	6	SkV-Elite (Z120)
19,468	370LHT	350HT	7	SkV-Elite (Z120)	8	SkV-Elite (Z120)
19,588	350HT	400UHC	9	HPW (350HB)	10	HPW (350HB)
19,708	400UHC	370LHT	11	HPW (370HB)	12	HPW (370HB)
19,828	370LHT	350HT	13	HPW (350HB)	14	HPW (350HB)
19,948	350HT	R260	15	HPW (260HB)	16	HPW (260HB)

4. Flash Butt Welding

There are two key degradation mechanisms that have been observed in relation to welds in rail:

1. Weld "Dip": The loss of vertical alignment is lost over a much greater span than "cupping" as shown in Figure 24. Although all railway networks acknowledge the occurrence of such dips, there is no universal agreement on the factors that contribute to this observed phenomenon.
2. Weld "Cupping": caused by differential wear across the width of the Heat Affected Zone (HAZ) that leads to increased track forces beyond the weld and the associated increase in the rates of rail and track degradation.
3. Rolling Contact Fatigue (RCF) defects on the weld: Head checks or squat type defects have been observed on top of both FB and AT welds.



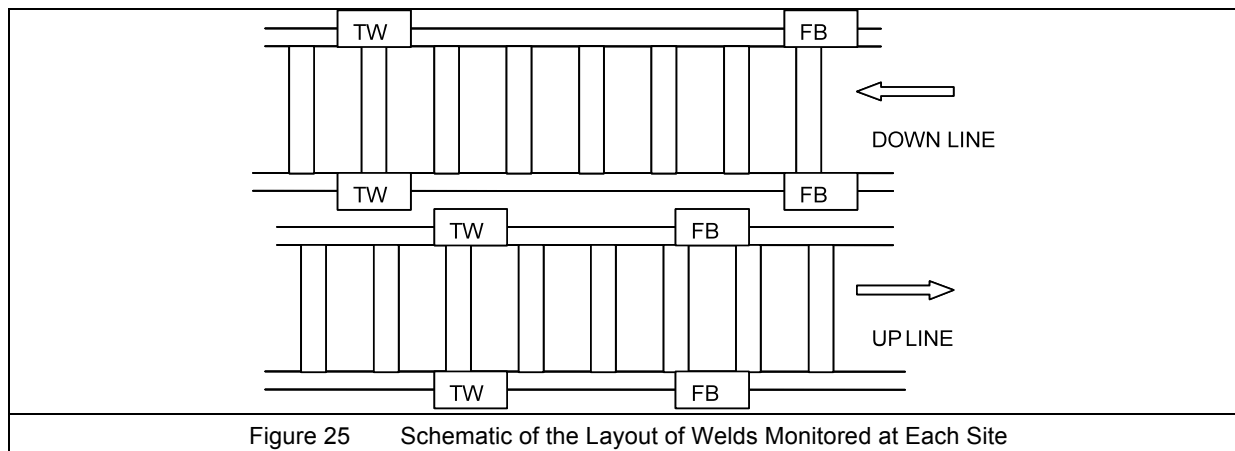
Furthermore the authors are not aware of any systematic study on pedigreed welds to fully characterise the above degradation mechanisms. However, limited monitoring of flash butt and aluminothermic welds already in track has been undertaken by Corus on selected sites on NR network in the UK. Results from one of the sites (1200m radius monitored are presented in the following section.

4.1 Details of Site and Monitoring Methodology

The details of the site are:

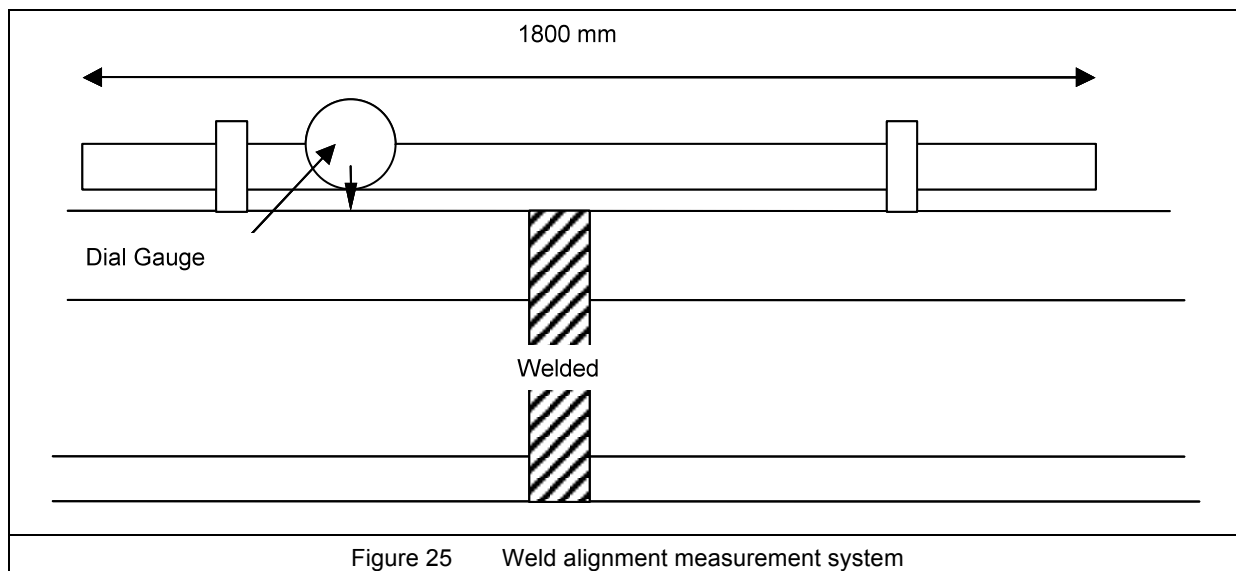
		Site A	
		Up line	Down line
Radius (m)		1200	1200
Rail grade	High	Grade 220	Grade 220
	Low	Grade 220	Grade 220
Rail age	High	2000	2001
	Low	2000	2000
MGT (million gross tonnes per year)		19.73	19.73
Gauge (mm)		1436	1434
Cant (mm)		72	101

A total eight welds were monitored at each site as represented by the schematic in Figure 24. The welds are located at various positions on each line, but wherever possible welds in close proximity to each other have been selected.

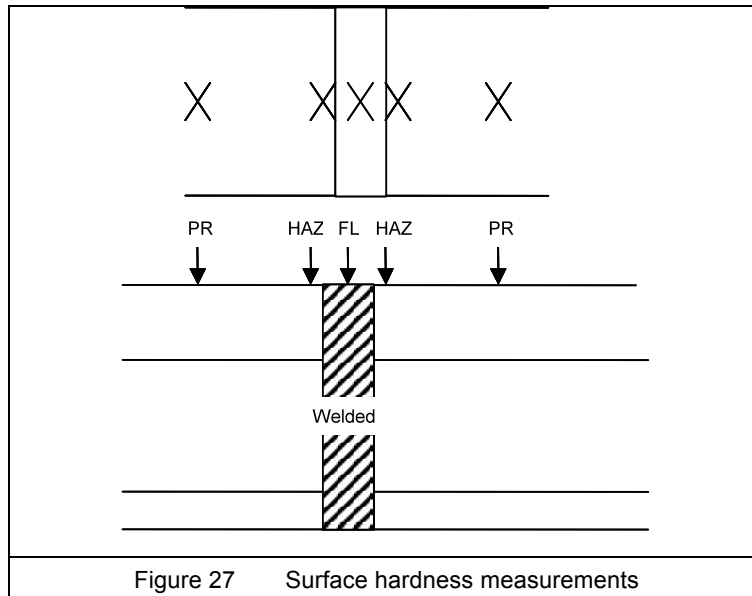


The welds were monitored at 3-6 monthly intervals and the following assessments were carried out:

1. **Longitudinal Alignment:** This assessment was undertaken to determine the magnitude of dipped joints. The weld alignment assessment system comprised a straight edge and displacement dial gauge as shown in Figure 25. Measurements were made at 50 mm intervals. The central position is taken as the centre of the weld and is indicated on the weld profile plots with a bold vertical line.
2. **Railhead Profiles:** Rail profile was measured using the Miniprof equipment at a prescribed location, 50 mm before the weld relative to the direction of traffic. The influence of the weld profile on vehicle behaviour was also assessed through examination of the visible running band.



3. **Running Surface Hardness:** Hardness measurements were made across the railhead and weld using the equotip portable hardness testing equipment to establish the degree of work hardening. Surface hardness profiles are taken at five positions (Parent rail – Within HAZ – Weld Centre Line – Within HAZ – Parent rail) as shown in Figure 27.



4. **Rolling Contact Fatigue Defects:** Although a statistically significant number of welds would need to be monitored to assess the contribution of weld metallurgy or profile, presence and the characteristics of any RCF defects was also recorded.

The results, covering a 21 month monitoring period, and their discussion are presented in the following section.

4.2 Results and Discussion

4.2.1 Assessment of Weld “Dipping”

The weld alignment measurements for the site (Site A) are presented in Figure 28. In all cases the direction of traffic is from left to right.

It is apparent that even in such a small sample size of 8 welds (4 FB and 4 AT) there are some that depict a “hog” while some show a clear “dip”. However, since these welds were not monitored from the installation date, it is not possible to separate the influence of the service conditions from the original as manufactured geometry of the welds.

A further important factor that influences the geometry of the welds is revealed by a closer examination of the changes in the magnitude of “hog” or “dip” from one monitoring visit to the next. The Up Line appears to have been tamped since the previous inspection as all the welds are now slightly hogged with the level of both TWUL and FBUL having been raised by ~0.2 and 0.3mm, respectively. In contrast, the welds in the Down Line are virtually unaltered with the TWDH and TWDL still hogging at 0.2mm and 0.4mm and the FBDH and FBDL dipping ~0.3mm.

Consequently, the two important requirements for the determination of the comparative rates of degradation of longitudinal alignments of welds are:

1. The manufactured and as installed geometry and alignment of the welds, which should provide the benchmark against which the degradation resulting from passage of traffic can be measured. It should also be emphasized that the manufacturing process parameters including the rail end conditions need to be recorded if the cause of weld dips is to be identified.
2. The maintenance history of the monitoring site with particular reference to tamping and grinding. Knowledge of the location of the previous welds is also required so as to eliminate the influence of “ballast memory”.

It is intended to satisfy these requirements in the planned installation of the monitoring site.

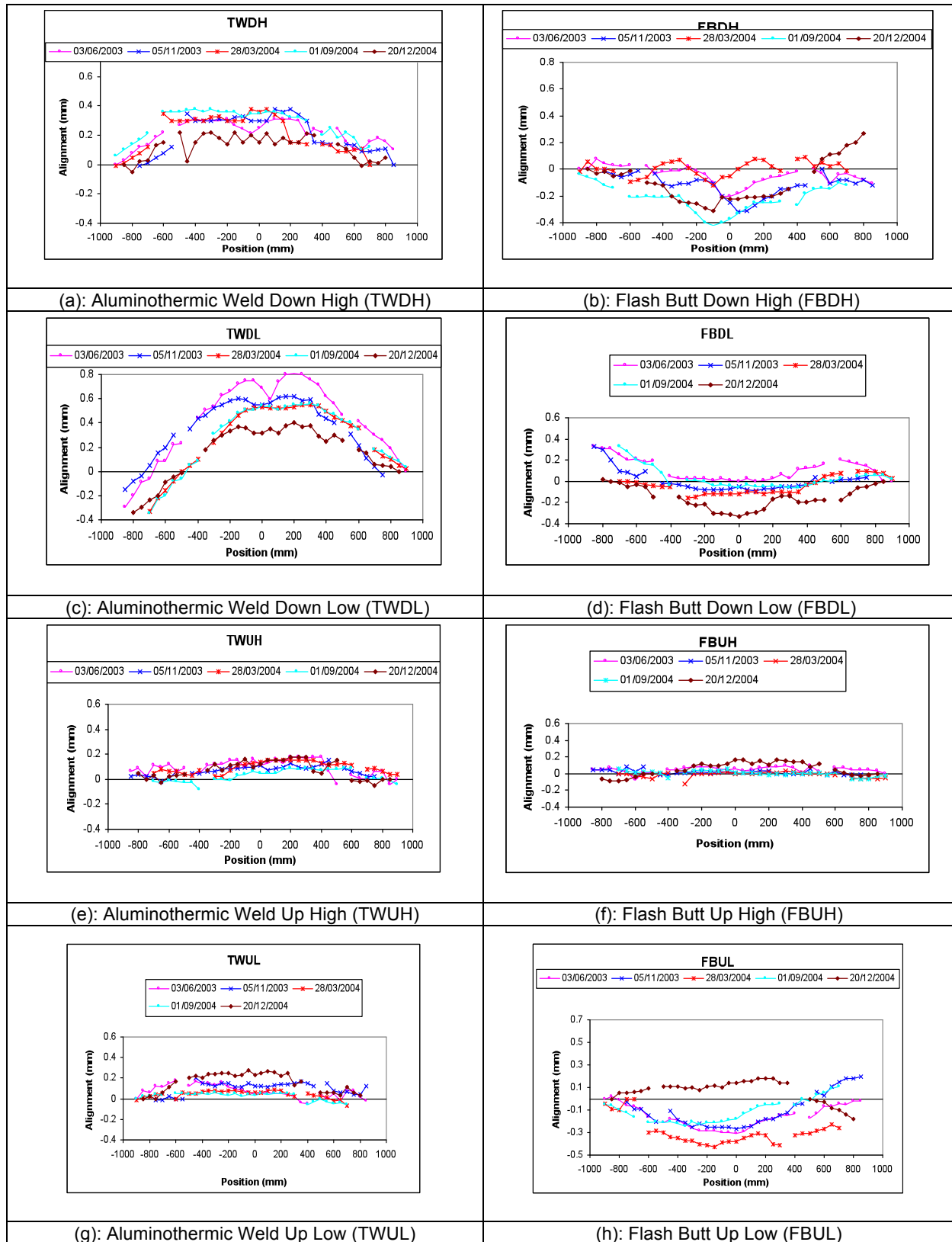


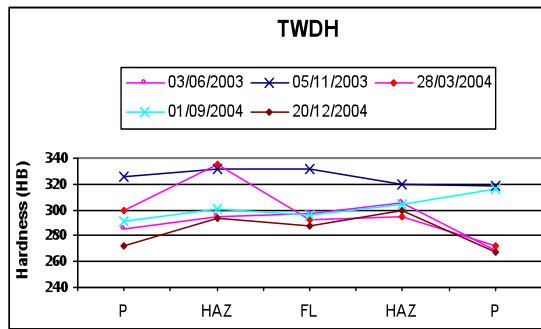
Figure 29 Weld Alignment Degradation at Site A

4.2.2 Assessment of Weld “Cupping”

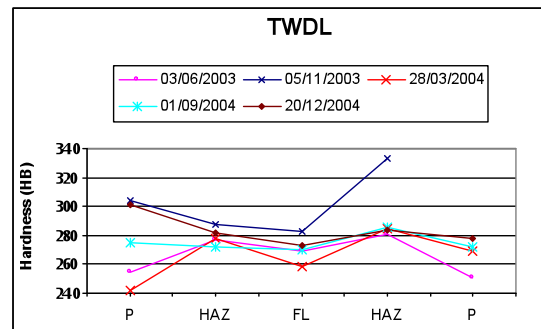
It is apparent from the weld alignment charts shown in Figure 29 that the technique of a straight edge coupled with a dial gauge (Figure 25) is not discriminating enough to measure the width and depth of “cupping”. Similarly, the rail profile was only measured at one location (~50mm prior to the weld) and hence did not reflect the differential wear in the HAZ of the welds.

Hardness measurements across the width of the weld were measured with a view to explaining any observed differences in wear performance. However, the hardness charts shown in Figure 30, reveal a large variation in the measured values which is probably more a reflection of the inherent variability of the measurement technique (Equitip) rather than the material properties.

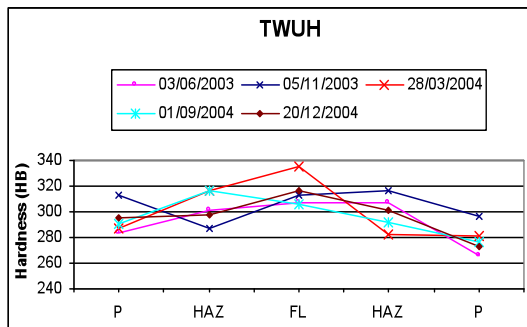
Consequently, modern laser based or corrugation measurement equipment is recommended for the precise measurement of the degradation of weld geometry.



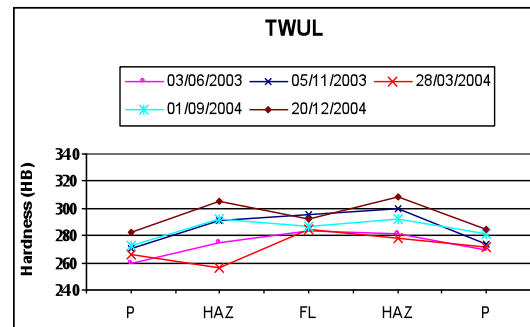
(a): Aluminothermic Weld Down High (TWDH)



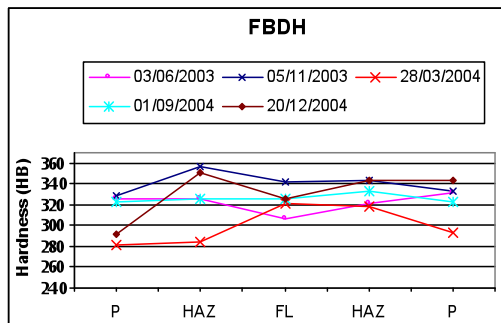
(b): Aluminothermic Weld Down Low (TWDL)



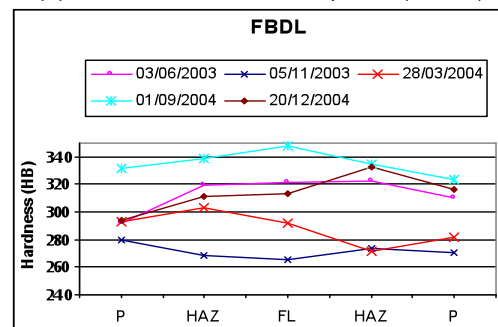
(c): Aluminothermic Weld Up High (TWUH)



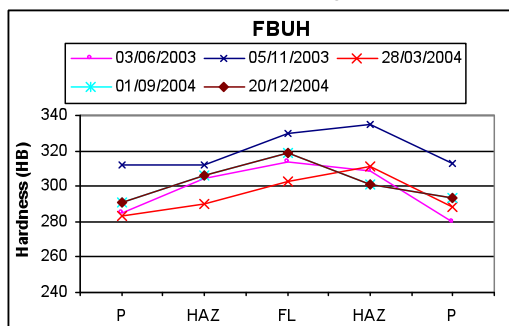
(d): Aluminothermic Weld Up Low (TWUL)



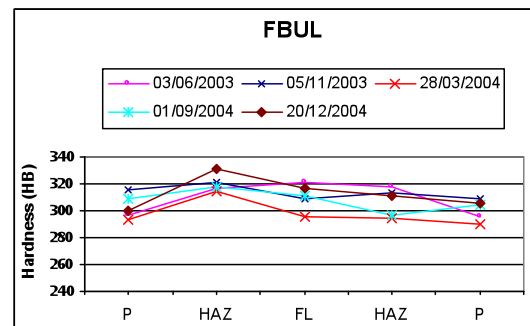
(e): Flash Butt Down High (FBDH)



(f): Flash Butt Down Low (FBDL)



(g): Flash Butt Up High (FBUH)



(h): Flash Butt Up Low (FBUL)

Figure 30 Hardness Measurements Across Welds (Site A)

4.2.3 Rolling Contact Fatigue (RCF) Defects on Welds

Figures 31 and 32 shows examples of RCF cracks observed on both FB and AT welds respectively. However, what is not apparent from such examples is whether it is the metallurgy of the welds or the profile irregularities at the welds or a combination of the two. Furthermore, the monitoring of several track sites in the past has also revealed that a large majority of the welds do not exhibit RCF cracks. Nevertheless, there have been sizeable numbers of both FB and AT welds affected by squat type defects or with RCF cracks.

It is, therefore, evident that the causes of RCF/squat defect formation on welds is not fully understood and a comprehensive programme of research is required to establish the influence of weld geometries and the susceptibility of the metallurgy of AT and FB welds to such defects. Although the track test proposed to evaluate the innovations in FB and AT welding will monitor any development of RCF/squat type defects, the very limited number of welds that will be monitored precludes the comprehensive study that is required.

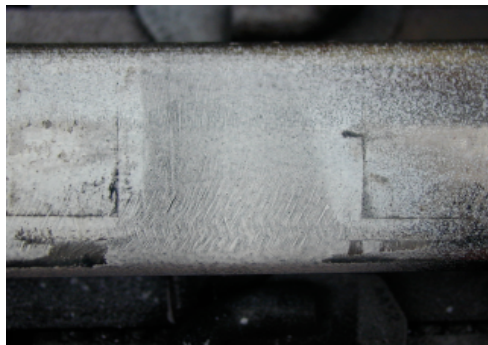


Figure 31 RCF cracks on FBDH

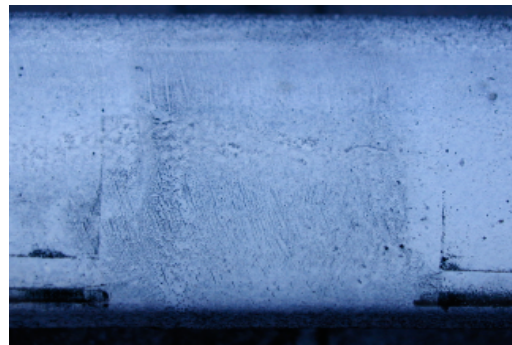


Figure 32 RCF cracks on gauge corner of TWUH

5. Proposed Track Test Trials

5.1 Trial Objectives

There is growing evidence that the use of premium grade (higher hardness) rails provides greater resistance to rolling contact fatigue and wear and hence will provide LCC savings. However, parallel developments in rail welding technologies are essential to ensure that the welded joints between the premium grades and those between standard (Grade R260) and premium grades do not become a “weak link in the chain”. Furthermore, although there are defined standards regarding the geometry and the microstructural characteristics of FB and aluminothermic welds, their rate of degradation with traffic and their maintenance requirements are not fully understood and quantified. The proposed trial has, therefore, been designed with the objective of:

“To undertake assessment of the degradation of two novel welding technologies, one FB and one AT, in comparison with the corresponding current welding procedures and as a function of traffic density and rail grades”.

The proposed trials also provide an opportunity to assess the performance of premium steel grades compared to the current standard Grade R260/R260Mn with reference to the two key rail degradation mechanisms of wear and rolling contact fatigue (RCF). Since any deterioration in the geometry of the weld is a source of excitation of the vehicle, any development of corrugation will also be monitored.

5.2 Trial Scope

In accordance with the objective of WP4.6, two novel welding procedures have been proposed to counter degradation of weld geometry and integrity. However, the availability of a range of rail steel grades to meet the requirements of different duty conditions makes it necessary to assess the performance of the proposed welding procedures in combination with the rail grades. Thus the matrix of type of weld and steel grade combination comprises 6 combinations of the three available steel grades, two current welding procedures, and two novel welding procedures. A full factorial matrix is shown in Table 5 below but it rules out a number of combinations for pragmatic and obvious technical reasons.

Table 5 Matrix of Rail Steel and Weld Type to be Considered for Track Tests				
Rail A	Rail B	Type of Weld	Weld No.	Comments
Grade 260 Mn	Grade 260 Mn	Standard AT	AT1	Establishing degradation benchmark for current AT welds
Grade 260 Mn	Grade 350HT	Standard AT	AT2	Not required, rail hardness differential suggests preference for HPW
Grade 260 Mn	Grade 400 HB	Standard AT	AT3	Not required, preference for HPW - rail hardness differential.
Grade 350HT	Grade 350HT	Standard AT	AT4	Not required, High rail hardness requires harder welds - preference for HPW
Grade 350HT	Grade 400 HB	Standard AT	AT5	Not required, High rail hardness requires harder welds - preference for HPW
Grade 400 HB	Grade 400 HB	Standard AT	AT6	Not required, High rail hardness requires harder welds - preference for HPW
Grade 260 Mn	Grade 260 Mn	HPW	AT7	Not essential but could be considered for 2nd AT weld with existing weld at the end of the trial site
Grade 260 Mn	Grade 350HT	HPW	AT8	Required to establish degradation benchmark for HPW welds
Grade 260 Mn	Grade 400 HB	HPW	AT9	Required to establish degradation benchmark for HPW welds
Grade 350HT	Grade 350HT	HPW	AT10	Not required, performance estimated through that of AT11
Grade 350HT	Grade 400 HB	HPW	AT11	Required to establish degradation benchmark for HPW welds
Grade 400 HB	Grade 400 HB	HPW	AT12	Required to establish degradation benchmark for HPW welds

Table 5 Matrix of Rail Steel and Weld Type to be Considered for Track Tests				
Rail A	Rail B	Type of Weld	Weld No.	Comments
Grade 260 Mn	Grade 260 Mn	Standard FB	FB1	Establishing degradation benchmark for current FB welds and comparison with N-HAZ (FB7) and AT Welds (AT1 & AT7)
Grade 260 Mn	Grade 350HT	Standard FB	FB2	Performance assessment required as harder grade will be welded to existing Grade 260 Mn at the start/end of the appropriate curve
Grade 260 Mn	Grade 400 HB	Standard FB	FB3	No required, suitability/unsuitability assessed through that of FB2
Grade 350HT	Grade 350HT	Standard FB	FB4	Required for comparative assessment against N-HAZ (FB10)
Grade 350HT	Grade 400 HB	Standard FB	FB5	Not required, suitability/unsuitability can be assessed through that of FB2 and FB11
Grade 400 HB	Grade 400 HB	Standard FB	FB6	Required for comparative assessment against N-HAZ (FB12)
Grade 260 Mn	Grade 260 Mn	N-HAZ FB	FB7	Establishing degradation benchmark for N-HAZ and comparison with current FB welds (FB1) and AT Welds (AT1 & AT7)
Grade 260 Mn	Grade 350HT	N-HAZ FB	FB8	Comparative assessment against that of FB2
Grade 260 Mn	Grade 400 HB	N-HAZ FB	FB9	Establishing performance benchmark for N-HAZ welds under large hardness differential between adjacent rails.
Grade 350HT	Grade 350HT	N-HAZ FB	FB10	Required for comparative assessment against Current FBW (FB4)
Grade 350HT	Grade 400 HB	N-HAZ FB	FB11	Establishing suitability of N-HAZ procedures for two premium grade steels
Grade 400 HB	Grade 400 HB	N-HAZ FB	FB12	Required for comparative assessment against Std FBW (FB6) and for establishing suitability of N-HAZ procedures for two premium grade steels

Based on the above matrix and consideration for selection, the configuration of the welded strings, shown in Table 6, is recommended for installation.

It should be noted that all rails would be supplied to the selected FB welding FB plant in lengths of 36m to be welded into 108m long welded rail strings as per the specification in Table 6. The FB welding of all rails involved in the proposed track test will be monitored by the rail suppliers and the proposed welding technology providers.

6. Conclusions

6.1 Aluminothermic Welding

In the given report results from track tests are presented (Geislinger Steige and Ofot Line). The aluminothermic welding process HPW has been documented in terms of profile and hardness measurements (Ofot Line) and straightness measurements (Geislinger Steige). Nevertheless, none of the track tests offers a complete documentation of the behaviour of the welds throughout a reasonable period of time. Furthermore, a comparison of the achieved results is not possible, because typically only one welding process is used for a track test and not several processes. But only the direct comparison between different welding processes (under the same traffic conditions) would make it possible, to assess the quality of welding process in detail.

However, for both track tests it was reported that the HPW welds showed no irregular behaviour during the time they had been observed. That means that qualitatively good welds were executed. Basically, this gives evidence that the welding process itself is working correctly.

The hardness measurements executed in the Ofot Line show that

- (a) hardness decreases in the HAZ and
- (b) that the overall hardness level increases due the work hardening.

Both effects are generally known and cannot be judged as being “good” or “bad”. Both aspects are attributes that have to be linked to an aluminothermic weld that is exposed to traffic.

With regard to the measurements executed in the Ofot Line it can be seen that the hardness profiles of the welds show no irregularities after 10 months exposed to traffic. Again, this result gives evidence that the welding process worked correctly and that the welds are of good quality.

Regarding the cross profile measurements it hardly possible to draw clear conclusions. The results show that after 22 months in track the wear of the welds and the wear of the rail are similar. This is a good result if assessing the quality of the Thermit portion. Both, hardness of the weld (not including the hardness of the HAZ) and the amount of wear are more or less linked to the microstructure and the chemical composition of the weld metal. However, the welding process and the Thermit portion used have to be regarded as a system that provides a weld with good properties.

Nevertheless, it can be regarded as a good result that wear of the welds is comparable to the wear of the rail material. That means that the amount of wear along the weld and rail are determined by the given track conditions and no increased wear of the welds is observed due to an insufficient weld quality.

For the track test “Geislinger Steige” results of straightness measurements are reported. As shown above, the value for the difference between minimum and maximum value increases slightly. This is an expected behaviour for the welds that can be linked to the increased wear in the HAZ of weld. However, for the given track (track category P230) all straightness measurements are within the tolerance regarding the acceptance criteria for aluminothermic welds. That means that the rate of wear is laying within reasonable limits.

If regarding the planned track test “Sterbfritz” it is expected to gain more valuable results. Here an overall monitoring of HPW welds and SkV-Elite welds is planned. Thus a direct comparison and an assessment of the advantages and disadvantages of the different welding processes will be possible.

However, in the final report the results of this track test will be presented.

6.2 Flash Butt Welding

The key degradation mechanisms encountered on welds has been briefly discussed with reference to limited data available from previous monitoring of track sites. It has been concluded that the causes of weld “dip” and “cupping” cannot be established from the data available from past track test sites. However, the reduction in the width of the HAZ and the greater uniformity of the hardness profile from the newly developed Narrow HAZ FB welding process, suggests that weld “cupping” defects could be eliminated.

The underlying causes of weld “dips” are not universally agreed and there is little validated data to establish the magnitude of impact on track maintenance costs. A comprehensive monitoring programme is recommended and is incorporated into the proposed track test that will enable critical comparison of the standard and the Narrow HAZ FB welds with respect to these two degradation mechanisms.

Another weld degradation mechanism that accounts for the removal of a significant number of welds from track is the occurrence of squat type defects. Again, the cause of RCF/squat defect formation on welds is not fully understood and a comprehensive programme of research is required to establish the influence of weld geometries and the susceptibility of the metallurgy of AT and FB welds to such defects. However, the very limited number of welds that will be monitored in the proposed track test precludes the comprehensive study that is required to identify the causes.

A comprehensive plan for the track test has been proposed and includes the requirements of the monitoring equipment and procedures to ensure that they are sufficiently discriminating to establish the differences in the degradation behaviour of the different welds.