Appendix I: Metallographic Examination of Samples from GRW Tanker J3910

1 Overview

In order to provide experimental measurements and observations to supplement the analytical calculations and engineering critical assessment of the GRW circumferential seam welds, TWI has undertaken macro- and microscopic examination of several samples taken from GRW tankers.

2 Objectives

- Non-destructively examine sections to determine the presence and extent of lack of fusion indications.
- Destructively examine sections in order to:
  - Characterise the defect morphology (eg volumetric or crack-like) at the locations of lack of fusion indications;
  - Measure the defect lengths and depths;
  - Measure the local joint geometry to provide additional measurements for the ECA calculations;
  - Observe and measure any evidence of fatigue crack growth or ductile tearing;
  - Provide comprehensive post-mortem examination of sections from tankers subjected to topple testing by HSL.

3 Scope of Work

TWI received weld samples from various tankers: J3910, J258, J3564 and J3217. The location where each sample was extracted from (and the associated TWI ID) is shown in Table I1.

All samples were photographed on arrival and subjected to radiography. When appropriate, dye penetrant examination was also undertaken. Metallographic examination was performed for each sample and the exact actions performed are listed in the sections below.

This appendix specifically addresses the examination of the J3910 section.

4 Section from J3910

4.1 Description of section

The as-received section from J3910 is shown in Figure I1. This sample was taken from the offside of band A/8 (ie the front-most band of the eight-banded tanker J3910) and the approximate weld length was 1450mm.

Tanker J3910 was topple tested by HSL, and this sample was from an impacted area of the tanker, with the area of impact making up approximately 800mm of the weld. Visual inspection resulted in the observation of two ruptures in the end dish at the toe of the fillet weld joining the end dish to the extrusion band.

4.2 Radiographic examination

After photography in the as-received condition, the weld was radiographed. The weld was marked up alphabetically with equally spaced letters A to H for datum positions. The radiography report is attached. Lack of fusion was prevalent along the weld and some isolated pores were also noted.

4.3 Dye penetrant inspection

A dye penetrant inspection was performed on the weld and the report is attached. Porosity was found at various locations on the weld. No evidence of through-wall cracking in the weld was observed for the circumferential welds.

4.4 Metallographic examination

Six 10mm thick sections were removed from the weld and macro sections were prepared for inspection. The locations that the sections were removed from are listed in Table I2 and macro images are presented in Figures I4 to I15. For each macro section, the weld cap height, weld cap width and axial misalignment were measured. To check the variability of the axial misalignment measurements, two different methods were tried. A diagram of the measured variables is shown in Figure I16, and Table I3 tabulates these values. Of note is Figure I13, a macro section that contains an example of the internal fillet weld between the extrusion band toe and the inner surface of the tanker shell (a tack weld produced during manufacture). This fillet weld ruptured during the topple testing, most likely due to the narrow throat exhibited by the fillet weld and the extensive root gap arising from the existing shell misalignment.

Micrographs were taking of each sample to measure the size of the lack of fusion defect. For all samples, the lack of fusion defect has the morphology of a small, volumetric defect with some crack-like extension at the ends of the volumetric flaw. A typical example is shown in Figure I17. In Figure I18, a micrograph of the rupture of the fillet weld throat from Figure I13 is shown.

For all macro sections prepared, the lack of fusion defects appear as embedded flaws; that is, a small volumetric defect surrounded by fully-fused material. The maximum defect height measured was less than 1.0mm.

4.5 Conclusions from examination

The conclusions from the post-mortem examination of the section of band A/8 from tanker J3910 are as follows:

1 Radiography revealed extensive lack of fusion indications.
2 Two ruptures of the end dish (parent metal) were observed.
3 Destructive examination along six slices of the joint revealed that the defect morphology is that of an embedded flaw. The maximum height is less than 1.0mm and the length was nearly continuous along the entire section of weld.

Assessment of such a defect treating the flaw as an embedded defect and following the procedures in BS 7910 have indicated that such a defect, even under rollover load conditions would be sub-critical.

Correspondence with GRW has indicated that tanker J3910 is a so-called ‘Period C’ tanker with manufacture between the middle of 2010 to 2012. For a Period C tanker, the welding used a twin wire semi-automated process with manual removal of the locating lip prior to welding. If the welding procedure and method of manufacture are controlled and consistent, then it may be expected that similar defects would be found in other Period C tankers. However, the section described above is from one side of one band from one Period C tanker and therefore there is presently insufficient evidence to extrapolate and conclude that all Period C tankers have embedded defects as opposed to surface defects.

Table I1 Samples received

TWI Sample ID	Tanker	Position	Weld length (mm)
W02	J3910	Band A O/S (impacted)	1450
W03	J3564	Band C O/S front weld	745
W04	J3564	Band C O/S rear weld	745
W05	J3564	Band D N/S front weld	840
W06	J3564	Band D N/S rear weld	840
W07	J3564	Band G O/S front weld	820
W08	J3564	Band G O/S rear weld	820
W09	J2580	Band H O/S (impacted)	1650
W10	J2580	Band H N/S	1660

Table I2 J3910 macro locations

Macro ID	Location (approx. distance from letter in mm)*
W02-01	Unimpacted area (100 from B, 100 from C)
W02-02	Impacted area (90 from C, 110 from D)
W02-03	Impacted area (90 from D, 100 from E)
W02-04	Impacted area (100 from E, 110 from F)
W02-05	Impacted area (100 from F, 90 from G)
W02-06	Unimpacted area (100 from G, 110 from H)

* letters refer to location marked during radiography.

Table I3 J3910 macro measurements (dimensions in mm)

	W02-01	W02-02	W02-03	W02-04	W02-05	W02-06
w	17.22	16.69	17.07	17.14	16.85	16.46
h	2.31	2.67	2.70	2.32	2.77	2.65
m1	0.72	1.70	1.14	0.50	1.49	0.66
m2	0.57	0.90	0.66	0.48	0.61	0.36
a	0.77	0.43	0.78	0.73	0.37	0.26

Figure I1 Section from the impacted side of J3910, band A/8 (as-received).

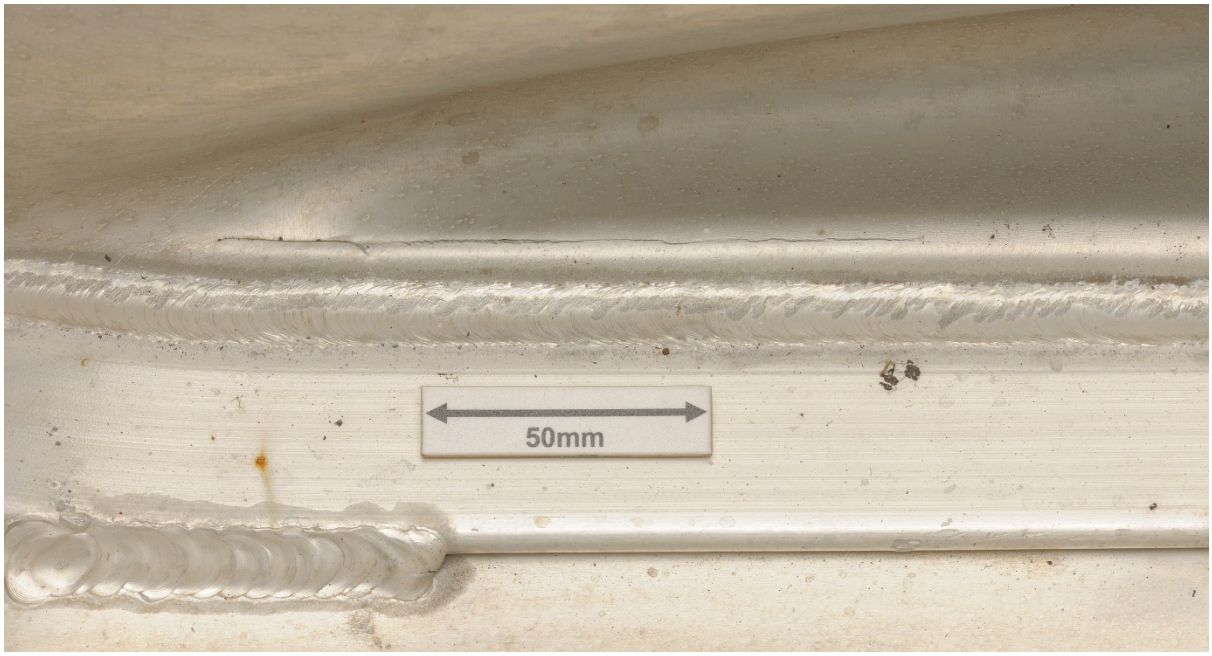

Figure I2 Rupture of the parent metal (end dish) at the toe of the fillet weld joining the end dish to the extrusion band. Rupture located at the left end of the buckled portion of the bulkhead as shown in Figure I1.

Figure I3 Rupture of the parent metal (end dish) at the toe of the fillet weld joining the end dish to the extrusion band. Rupture located at the right end of the buckled portion of the bulkhead as shown in Figure I1.

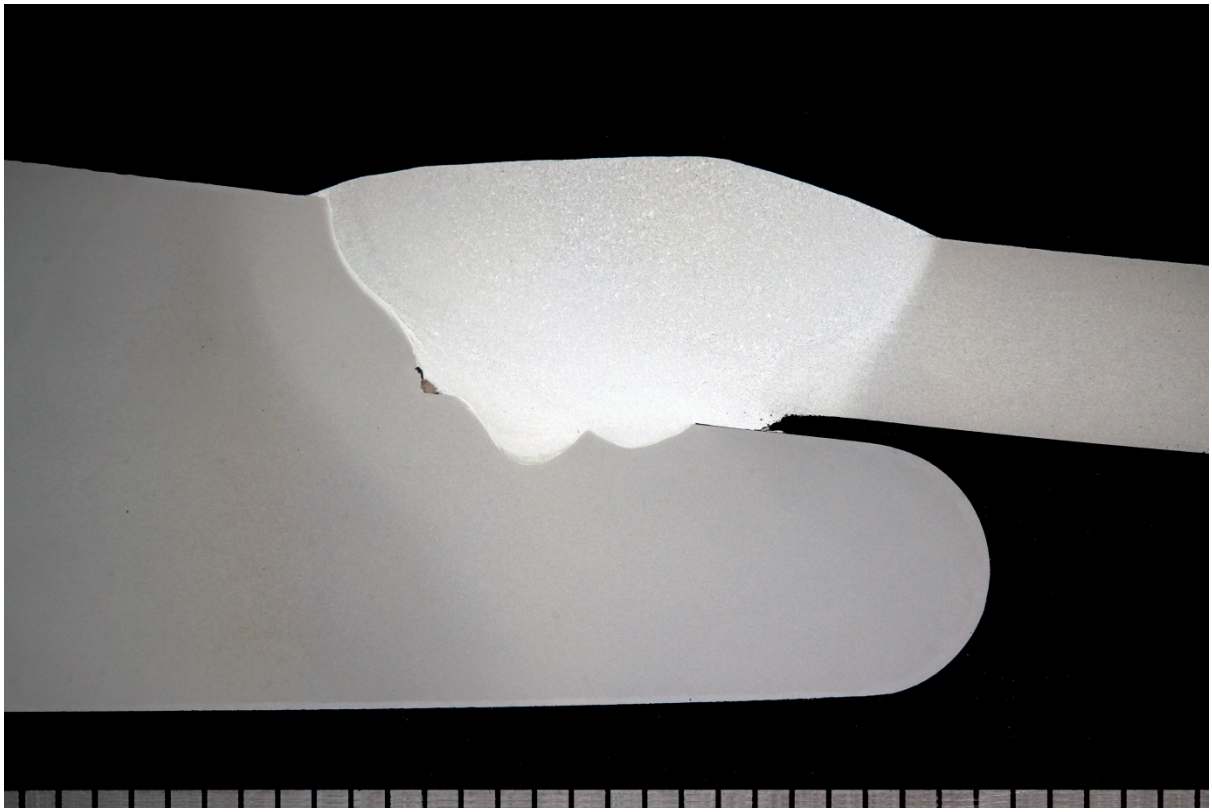

Figure I4 W02-01 macro (J3910 Band A O/S).

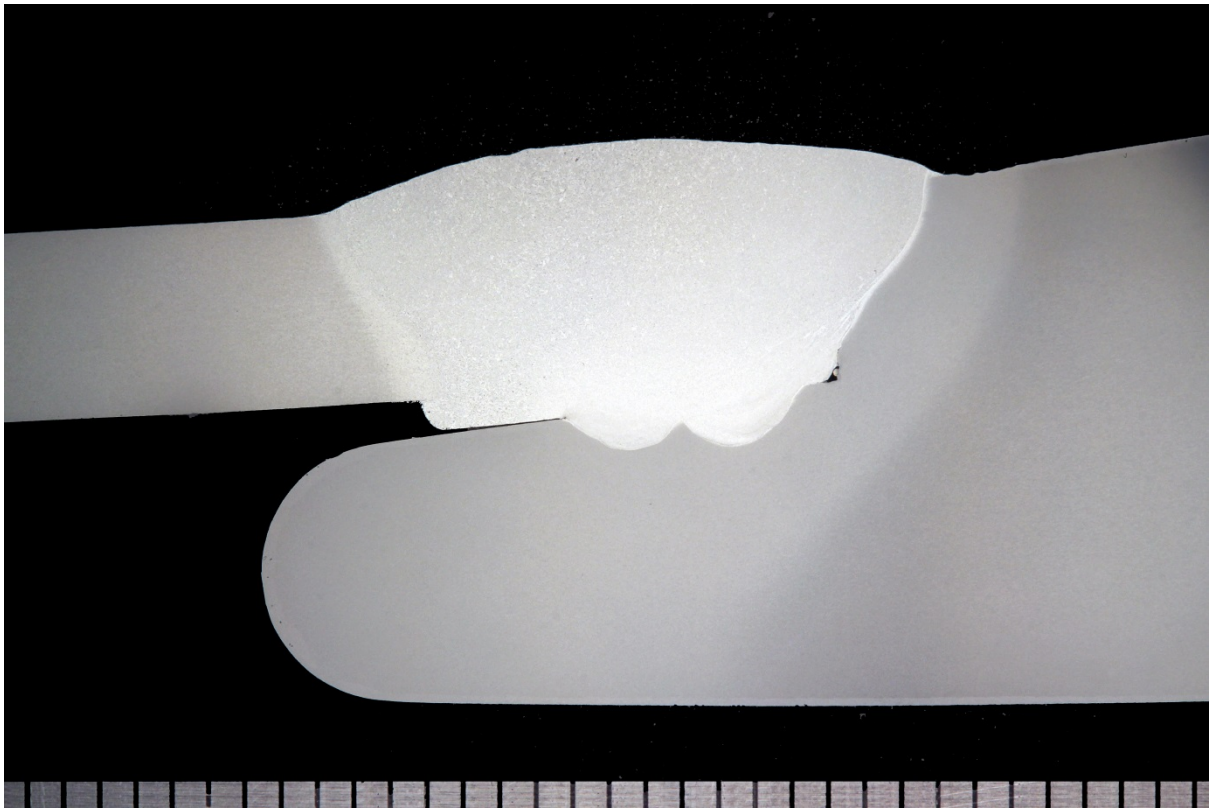

Figure I5 W02-02 macro (J3910 Band A O/S).

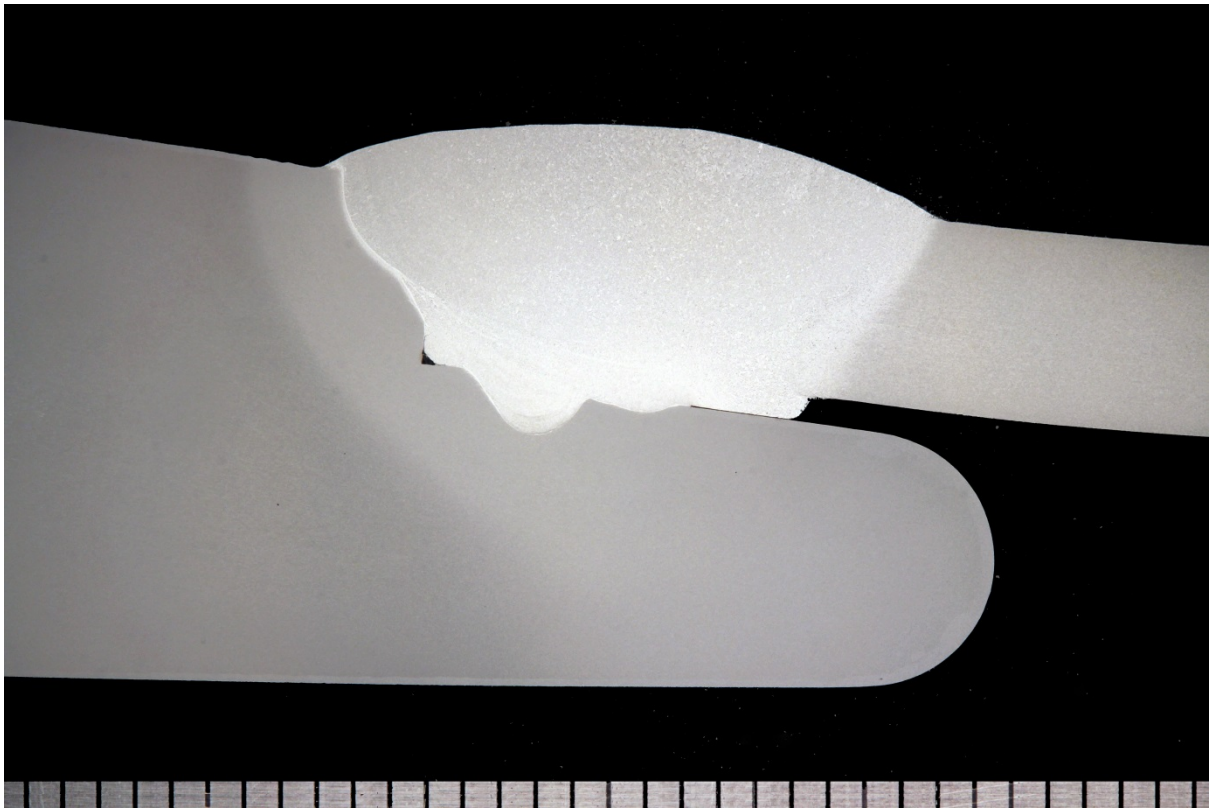

Figure I6 W02-03 macro (J3910 Band A O/S).

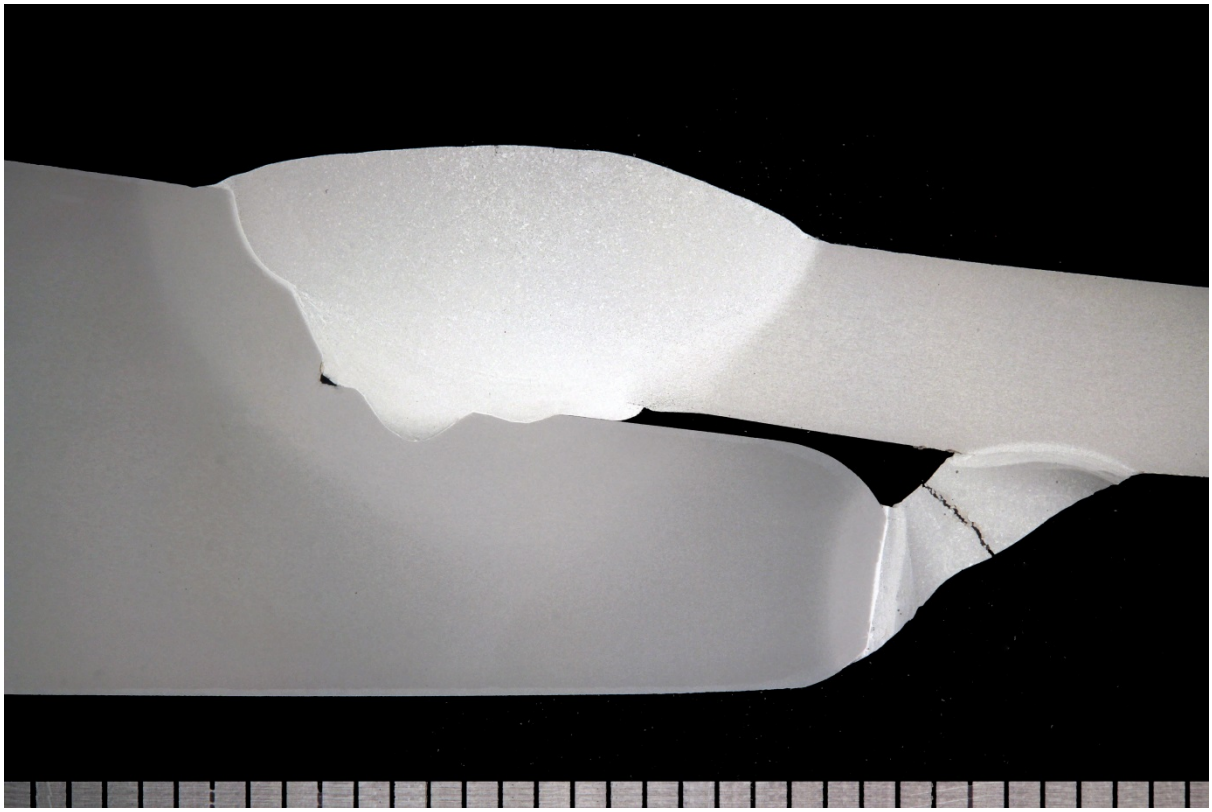

Figure I7 W02-04 macro (J3910 Band A O/S).

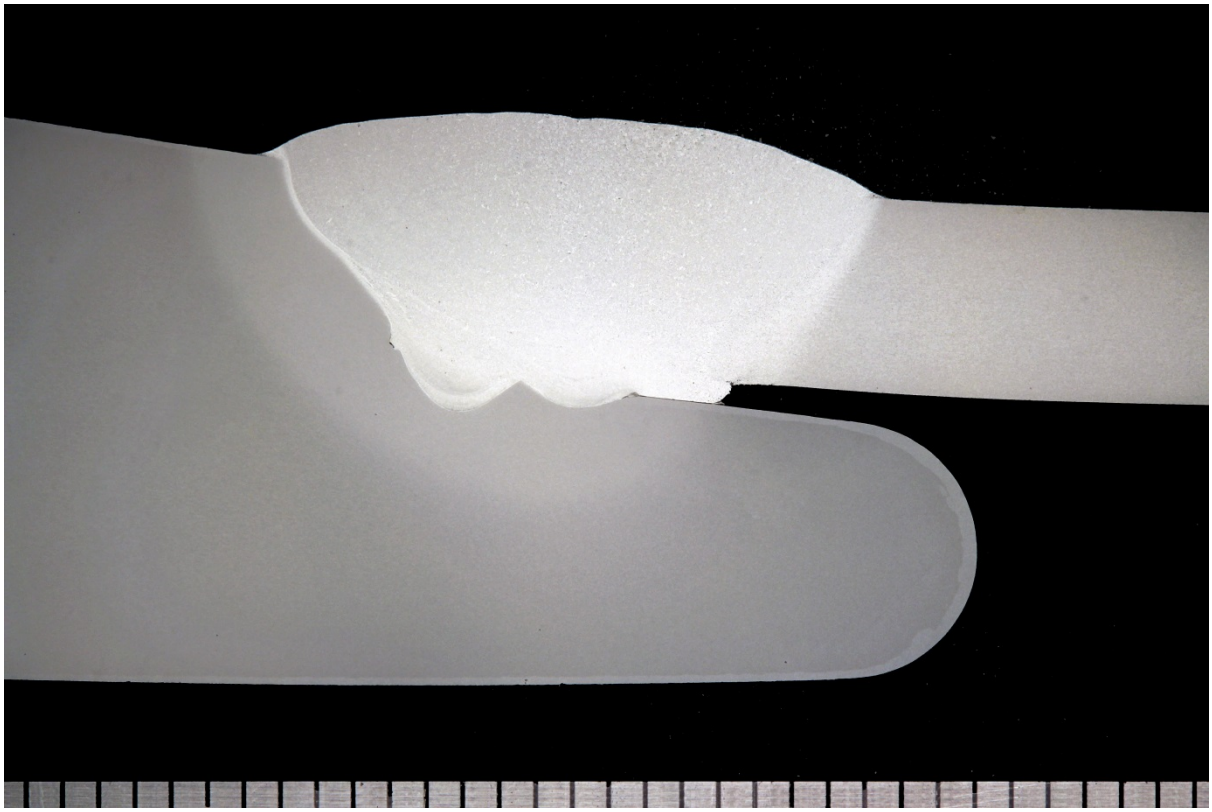

Figure I8 W02-05 macro (J3910 Band A O/S).

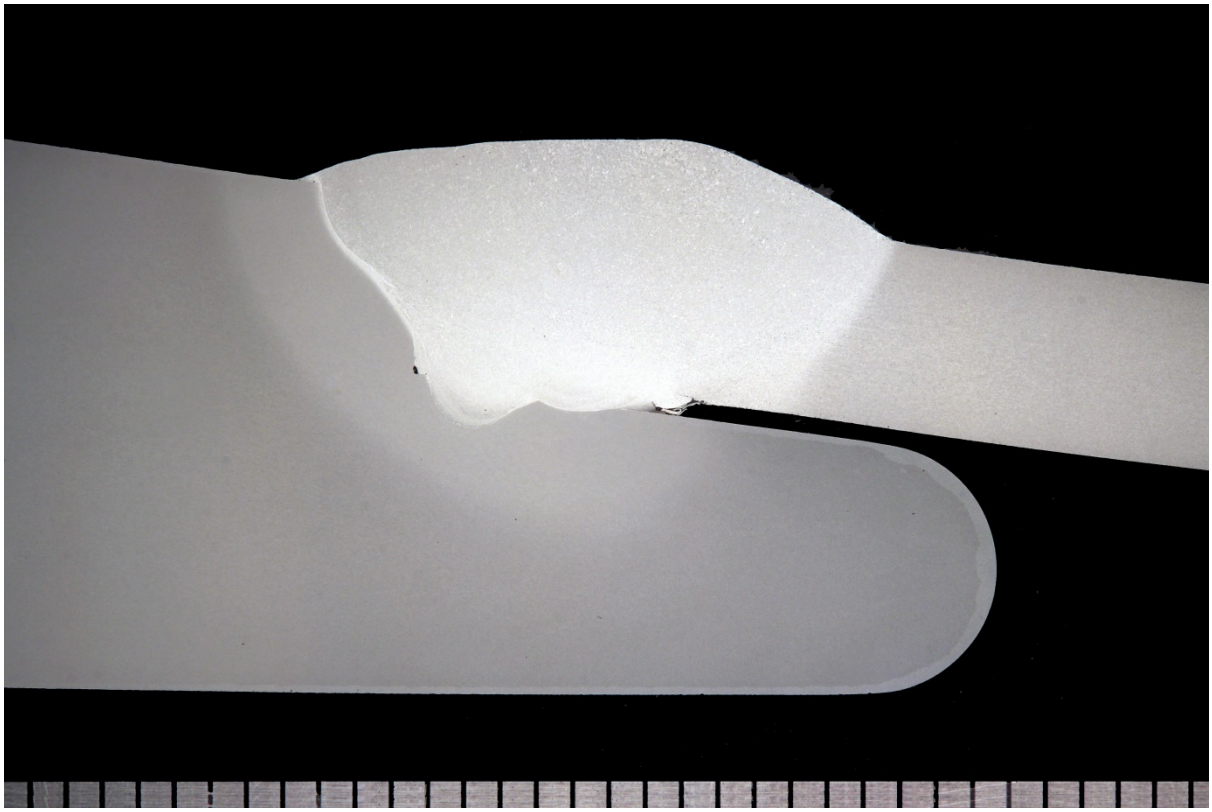

Figure I9 W02-06 macro (J3910 Band A O/S).

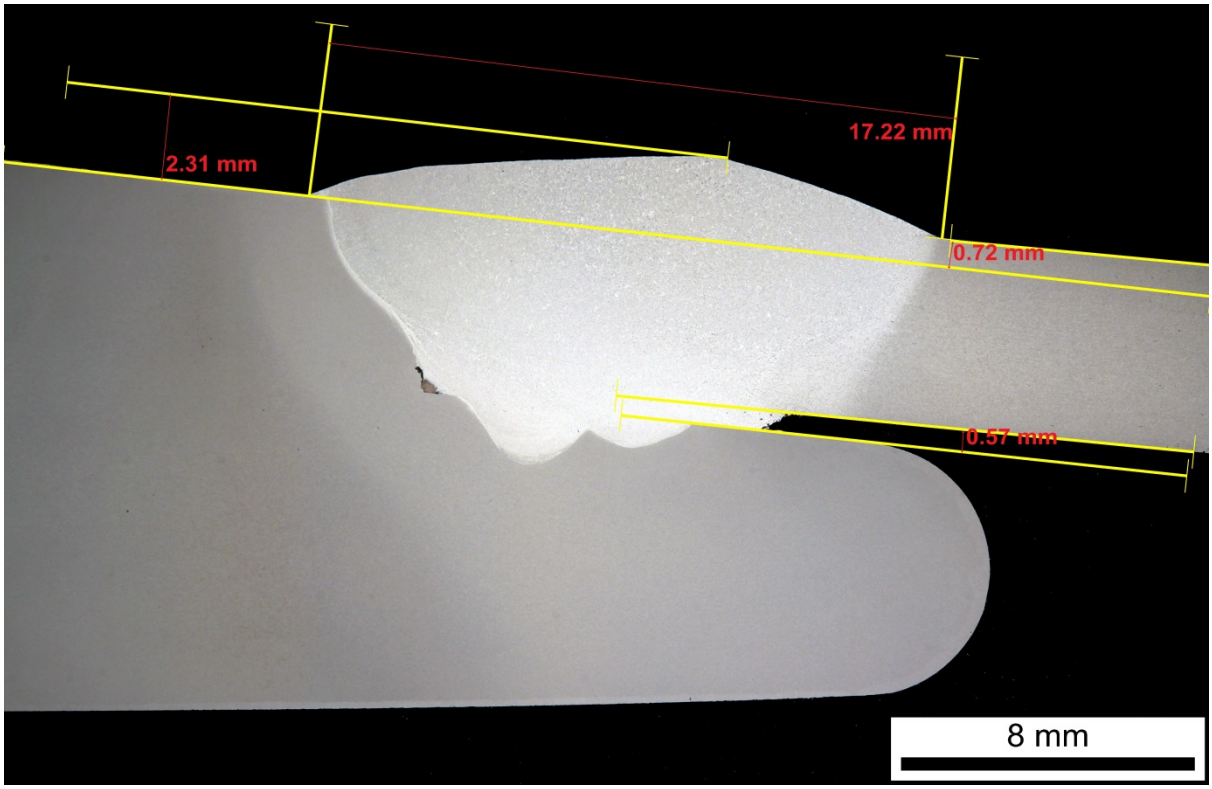

Figure I10 W02-01 macro (J3910 Band A O/S) measurements.

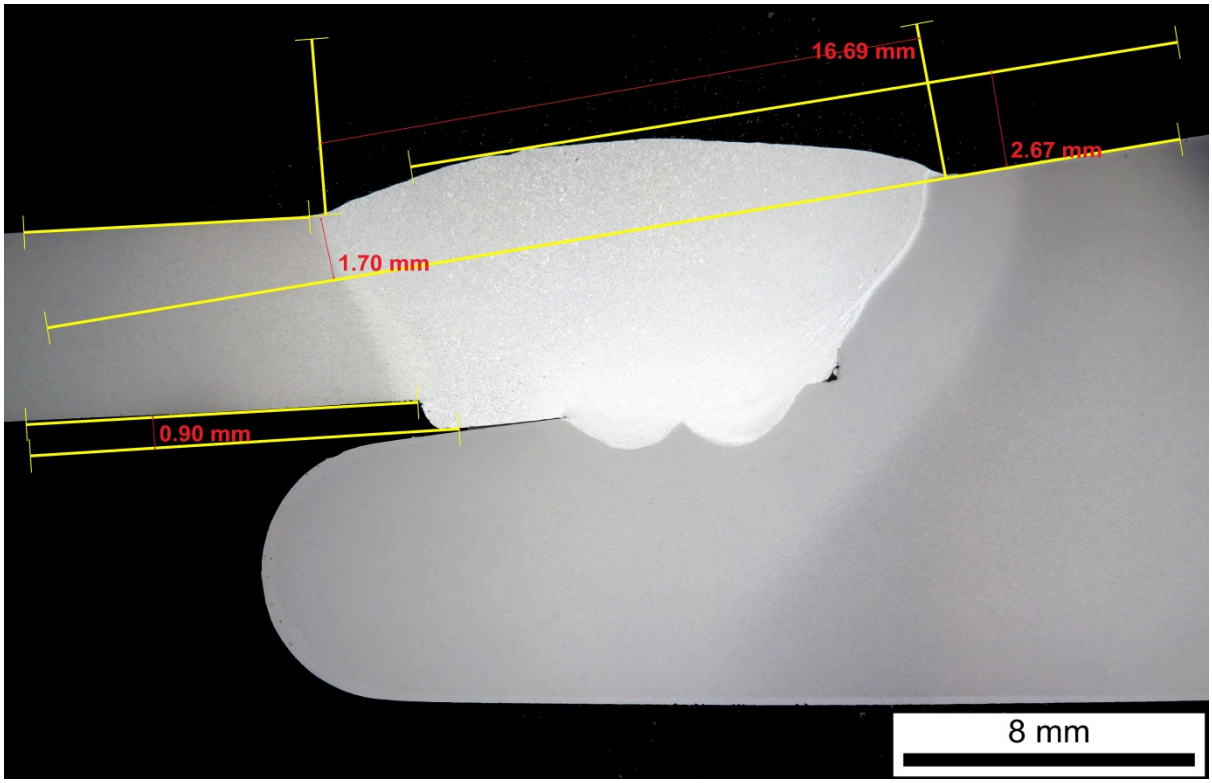

Figure I11 W02-02 macro (J3910 Band A O/S) measurements.

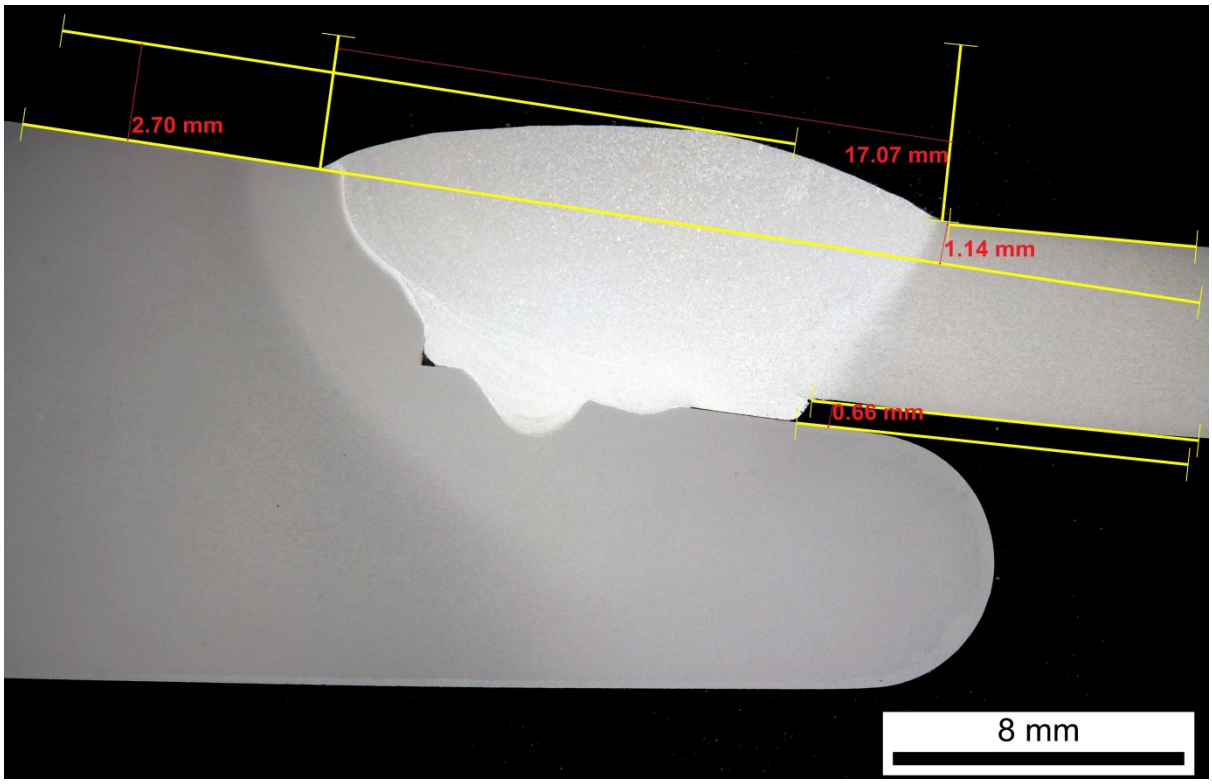

Figure I12 W02-03 macro (J3910 Band A O/S) measurements.

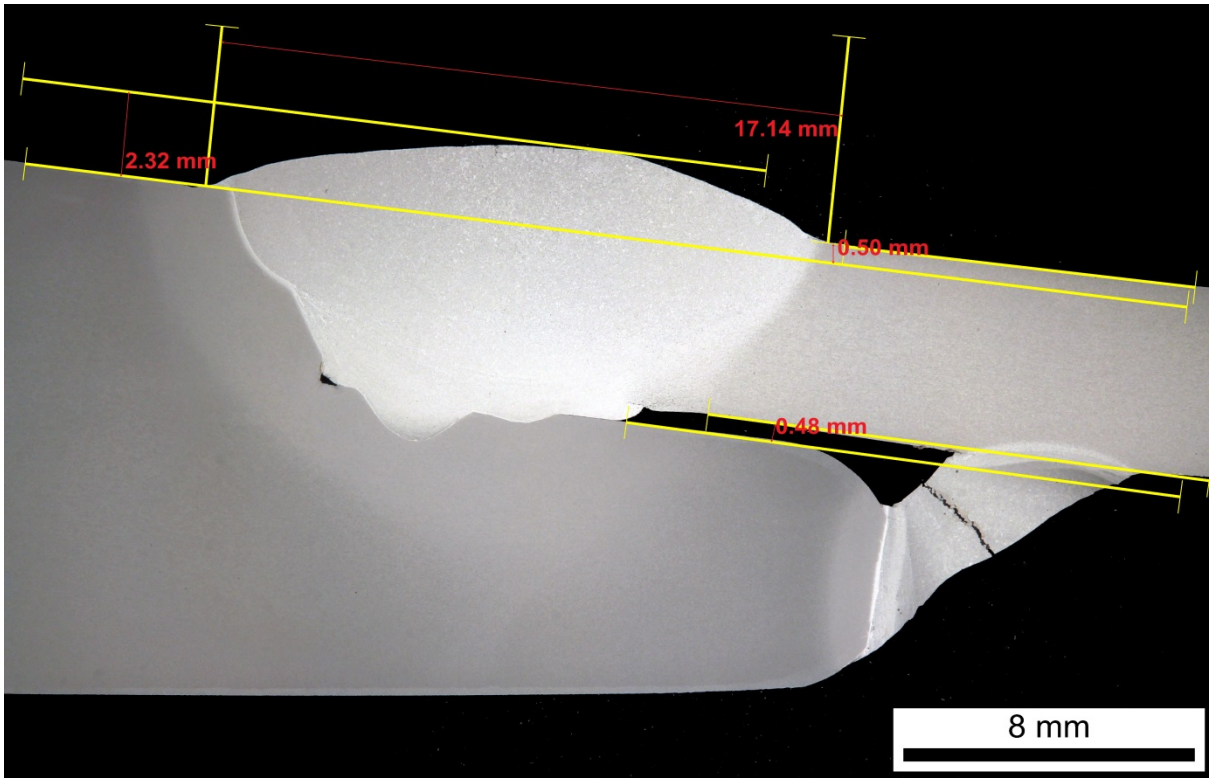

Figure I13 W02-04 macro (J3910 Band A O/S) measurements.

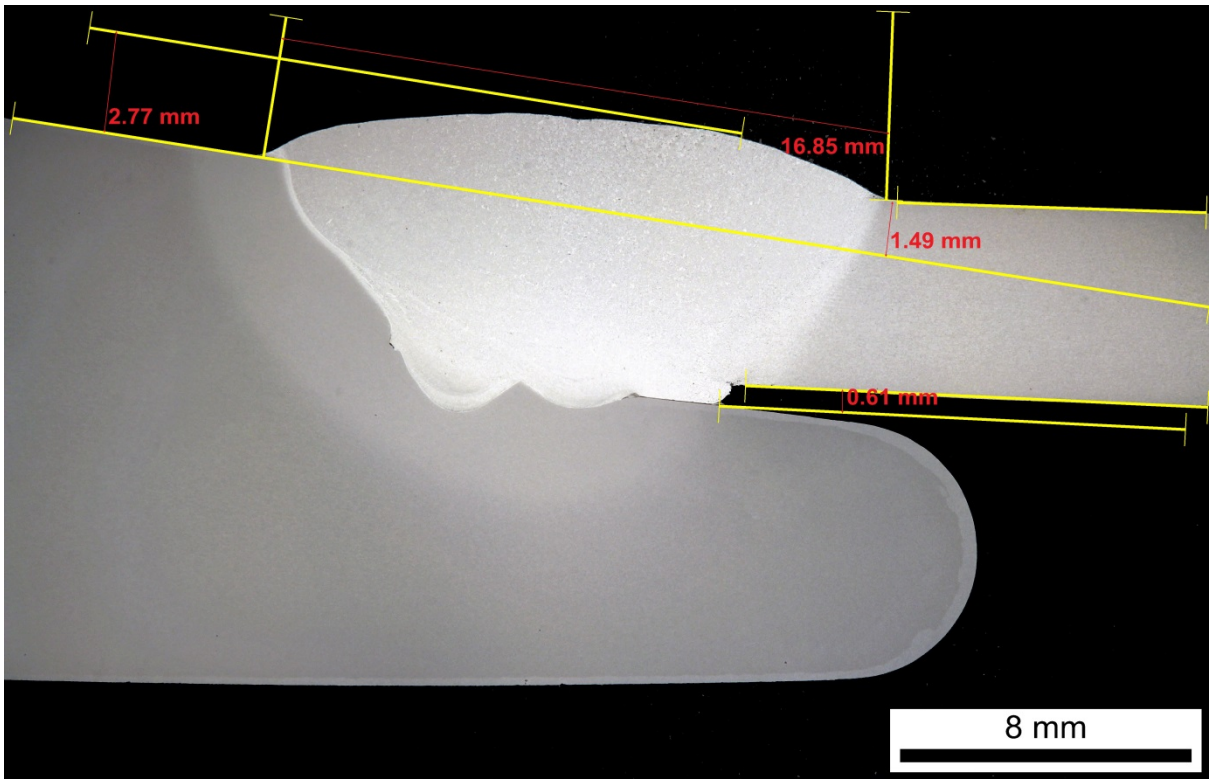

Figure I14 W02-05 macro (J3910 Band A O/S) measurements.

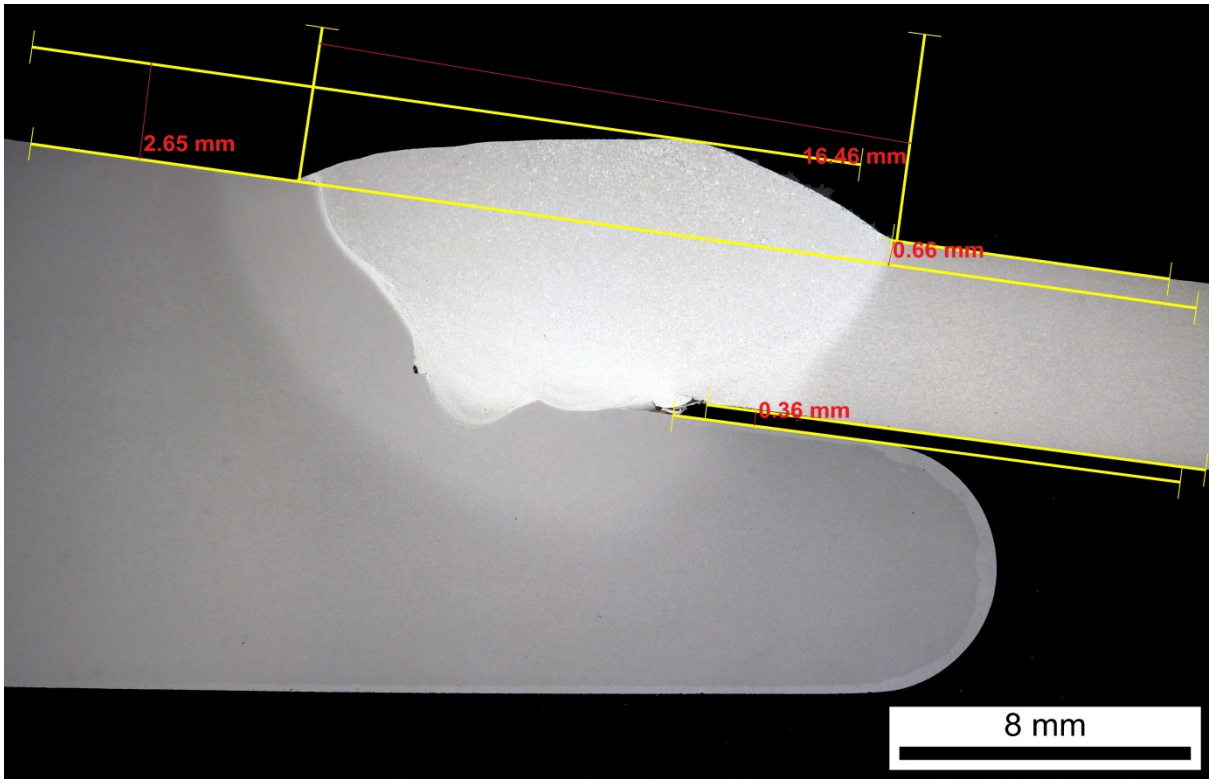

Figure I15 W02-06 macro (J3910 Band A O/S) measurements.

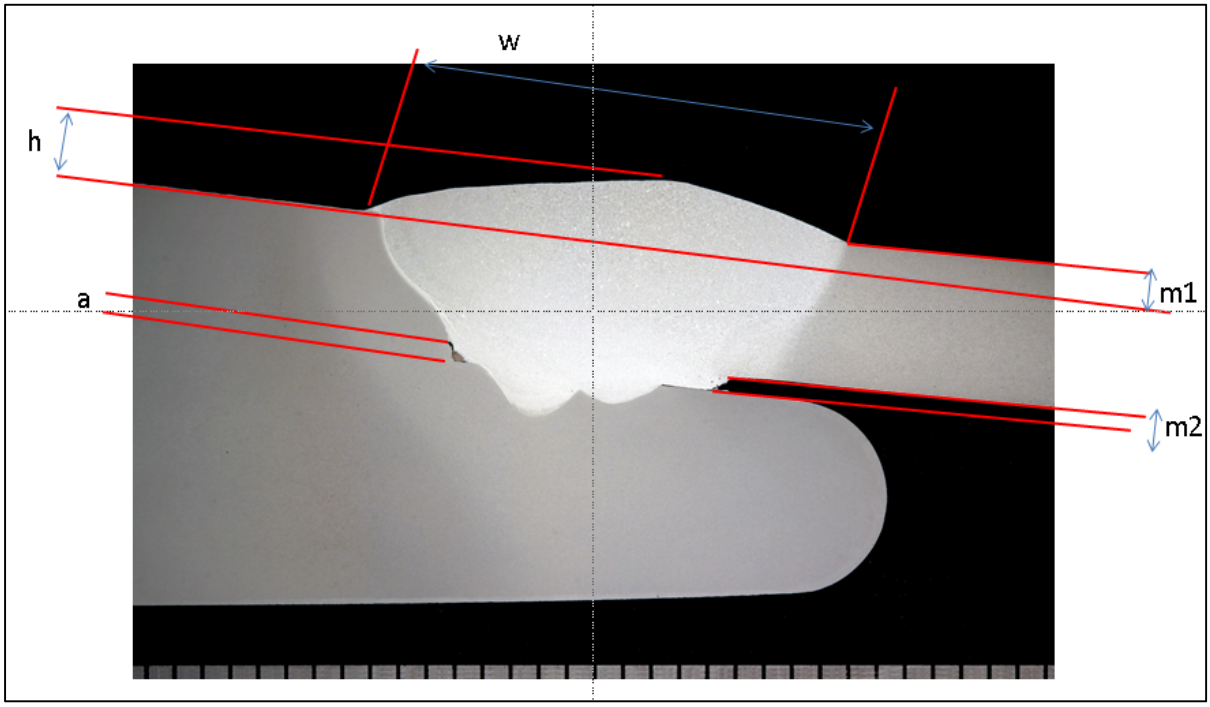

Figure I16 Macro measurements.

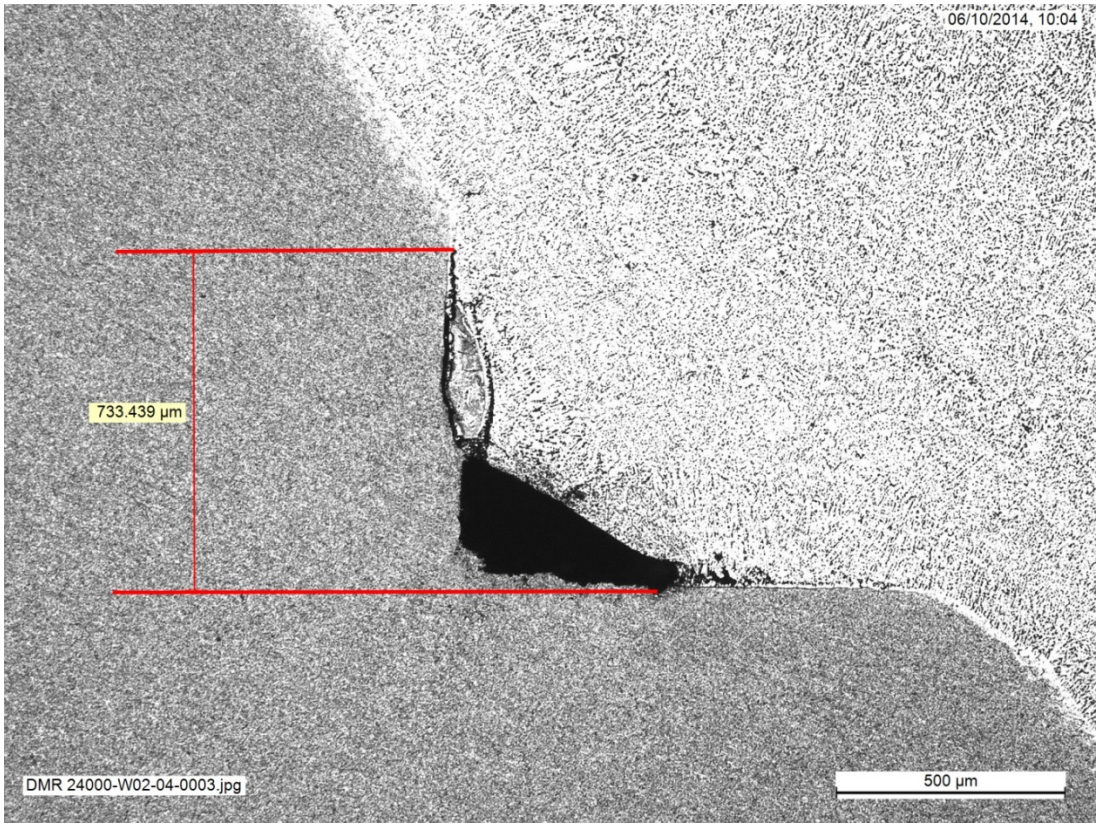

Figure I17 Micrograph from sample W02-04 of the lack of fusion defect. The total height is 733µm (less than 1mm).

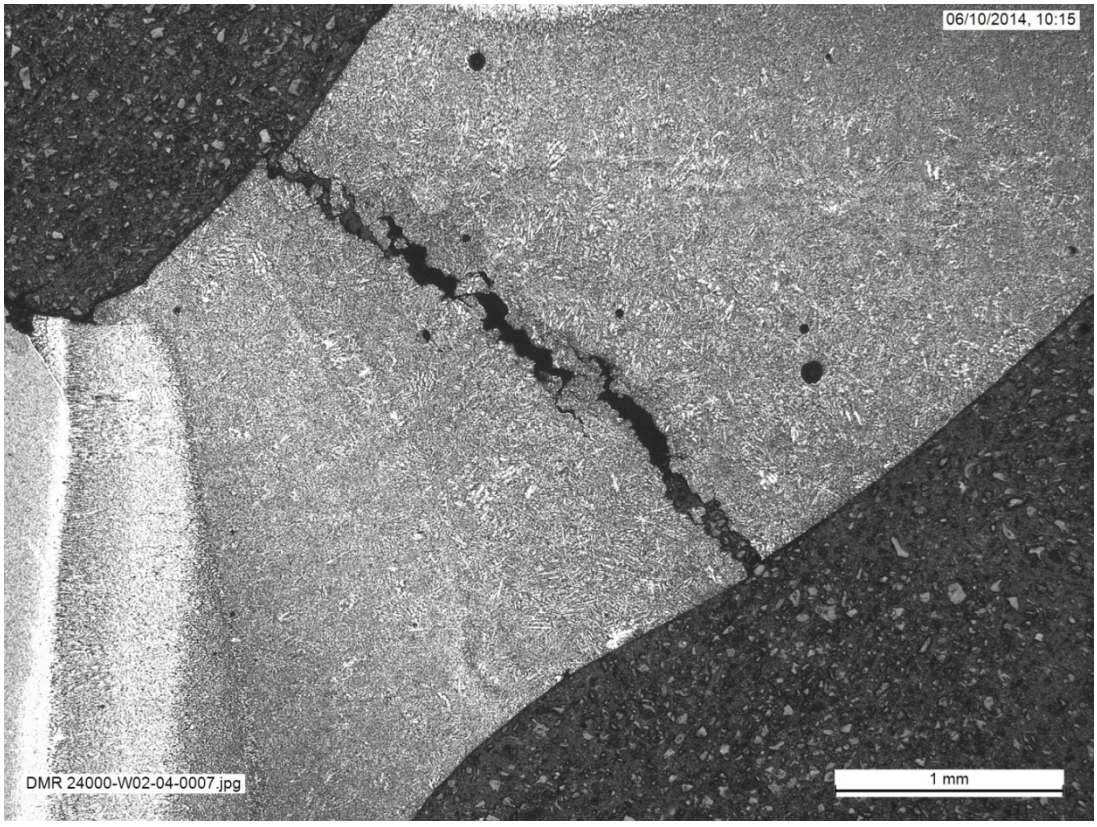

Figure I18 Micrograph from sample J3910 W02-04 showing the ruptured tack weld.

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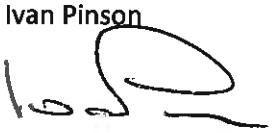
RADIOGRAPHIC INTERPRETATION INSPECTION REPORT

Client	HSL	**Sheet**	1 of 1
Sample identification	J3910, Band A, Weld 02	**Date of inspection**	29-Sep-14
Job No.	24000		

TWI Reference MI 1638
IQI 10ALEN5
Wire Visible 5 wires

Results	
Item Reference	**Comments**
A-B	Lack of Fusion 0 to 190 (Full length)
B-C	Lack of Fusion 0 to 25
	Lack of Fusion 62-205
C-D	Lack of Fusion 0 to 205 (Full length)
	Pore @ 113
D-E	No radiograph
E-F	Lack of Fusion 0 to 205 (Full length)
	Pore @ 180
F-G	Lack of Fusion 0 to 107
	Lack of Fusion 142 to 205
G-H	Lack of Fusion 0 to 55
	Lack of Fusion 76 to 205
	Pore @ 148

Interpreter Ivan Pinson

Signature of operator 

Qualification ASNT Level III

UKAS TESTING 1046

The TEST HOUSE

Certificate of Test

Client: TWI, Granta Park, Great Abington, Cambridge, CB21 6AL
Date of receipt: 17 September 2014 *Date of test:* 18 September 2014
Reference No.: T41333 *MI No.:* 1638
Order No.: To follow *Specification:* N/A

Description: Section of aluminium butt welded fuel tanker reservoir, 16mm thick (in area of interest) x 1450mm long, W02 is the only weld of interest.
Identity: Project No. 24000/11, Project Leader: M Haslett
Test methods: *Procedure:* TP29, BSEN ISO 17636-1:2013
Inspection Authority: N/A

RADIOGRAPHIC INSPECTION REPORT

INSPECTION DETAILS							
Single wall single image	✓	Double wall single image		Double wall double image		Focus film distance (mm): 800	
						Object film distance (mm): 16	
						Exposure time (mA min): 20	Beam angle (°): 90
Type of equipment: Pantak 160kV CP Unit						Screens: Nil	Filters: Nil
Tube voltage (kV): 48						IQI	Type & size: BSEN 462 10 Al EN
Focal spot/source dimensions: 3mm							Source side: ✓
Film - make and type: Fuji 80							Film side:
Film density range: 1.9 – 2.6							Sensitivity: Wire No. 11

RESULTS Acceptance criteria: None specified

Radiograph identity	Weld/Sample identity	Accepted/ Rejected	No space to place the IQI alongside the weld so a specific IQI shot was taken at each end of the weld, before and after the radiography of the weld was completed
P0664	Trial shot	N/A	Settings assessment and adjustment
P0665	A-B IQI shot	N/A	No assessment of weld was made
P0666	A-B	N/A	No assessment of weld was made
P0667	B-C	N/A	No assessment of weld was made
P0668	C-D	N/A	No assessment of weld was made

- End of Test Results -

Note - The test results detailed above apply only to the sample(s) of material submitted to the laboratory.

Tests Performed by: *P R Robinson* *Witnessed by:*

Certificate Approved by: *P Robinson, Section Leader*

Signed ..... *Date* 24/9/2014

Certificate of Test

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Identity: Project No. 24000/11, Project Leader: M Haslett
Test methods: *Procedure:* TP29, BSEN ISO 17636-1:2013
Inspection Authority: N/A

RADIOGRAPHIC INSPECTION REPORT

INSPECTION DETAILS						Focus film distance (mm): 800		
Single wall single image	✓	Double wall single image		Double wall double image		Object film distance (mm): 16		
						Exposure time (mA min): 20	Beam angle (°): 90	
Type of equipment: Pantak 160kV CP Unit						Screens: Nil	Filters: Nil	
Tube voltage (kV): 48						IQI	Type & size: BSEN 462 10 Al EN	
Focal spot/source dimensions: 3mm							Source side: ✓	
Film - make and type: Fuji 80							Film side:	
Film density range: 1.9 – 2.6							Sensitivity: Wire No. 11	

RESULTS Acceptance criteria: None specified

Radiograph identity	Weld/Sample identity	Accepted/ Rejected	No space to place the IQI alongside the weld so a specific IQI shot was taken at each end of the weld, before and after the radiography of the weld was completed
P0669	D-E	N/A	No assessment of weld was made
P0670	E-F	N/A	No assessment of weld was made
P0671	F-G	N/A	No assessment of weld was made
P0672	G-H	N/A	No assessment of weld was made
P0673	G-H IQI Shot	N/A	No assessment of weld was made

- End of Test Results -

Note - The test results detailed above apply only to the sample(s) of material submitted to the laboratory.

Tests Performed by: *P R Robinson* *Witnessed by:*

Certificate Approved by: *P Robinson, Section Leader*

Signed ..... *Date* 24/9/2014

The TEST HOUSE

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Date of receipt: 17 September 2014 *Date of test:* 18 September 2014
Reference No.: T41333 *MI No.:* 1638
Order No.: To follow *Specification:* N/A

Description: Section of aluminium butt welded fuel tanker reservoir, 16mm thick (in area of interest) x 1450mm long, W02 is the only weld of interest.
Identity: Project No. 24000/11, Project Leader: M Haslett
Test methods: *Procedure:* TP28, BSEN ISO 3452-1:2013
Inspection Authority: N/A

LIQUID PENETRANT INSPECTION REPORT	
INSPECTION DETAILS	
System: Colour contrast	Material surface condition: As welded
Cleaning agent: Johnson and Allen JAC-2 Cleaner Batch Number: M302329	Viewing equipment: Portable UVA Lamp Identification number: B438
Penetrant: Johnson and Allen JAP penetrant Batch Number: H1307	Penetration time (minutes): 30
Penetrant remover Johnson and Allen JAC-2 Cleaner Batch Number: M302329	Development time (minutes): 30
Developer: Johnson and Allen JAD Developer Batch Number: D844	Viewing conditions: White Light measured at: 2300 Lux UVA Light measured at: N/A

RESULTS Acceptance criteria: None specified

Surface	MI number	Indications	Comments
100% of weld and 15mm either side	1638	Isolated pore	C+118mm
		Scattered porosity	F+80mm, 84mm long
		Isolated pore	G+154mm

- End of Test Results -

Note - The test results detailed above apply only to the sample(s) of material submitted to the laboratory.

Tests Performed by: *J Fordham* *Witnessed by:*

Certificate Approved by: *P Robinson, Section Leader*

Signed ..... *Date* 24/9/2014