Appendix J: Metallographic Examination of Samples from GRW Tanker J2580

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, J2580, J3564 and J3217. The location where each sample was extracted from (and the associated TWI ID) is shown in Table J1.

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 J2580 section.

4 Samples from J2580

4.1 Description of sample

The received samples from J2580 are shown in Figures J1-J3. These samples were taken from band H/8 offside and nearside and the approximate weld lengths were 1650mm and 1660mm, respectively. The offside sample was from an impacted area of the tanker, with the area of impact making up approximately 1150mm of the weld. From visual inspection of the impacted sample, a longitudinal crack in the circumferential weld was observed, with a length of over 300mm (Figure J3). Additionally, rupture of the weld joining the end dish to the extrusion band was observed.

4.2 Radiographic examination

After photography in the as-received condition, both welds were radiographed. The radiography reports are attached. Lack of fusion and isolated pores and cavities were found throughout the weld along with the longitudinal crack previously noted. The radiographic inspection interpretation report is attached.

4.3 Metallographic examination

A small amount of dye penetrant was used to pinpoint the ends of the longitudinal crack before a sample was removed incorporating this crack. The total length of the through-thickness flaw was 320mm. This sample was cut into two pieces as shown in Figure J4.

Sample W09-01 was then mechanically broken open to reveal the fracture faces (Figures J5 to J8). The lack of fusion defect was measured on the broken-open section and the total, continuous length was 230mm with very nearly a constant defect height of 1.0mm. It was not possible to measure the length of the initial lack of fusion defect from the section that was not broken open. However, the defect that led to the through-thickness rupture shows up on the radiographic inspection report and therefore the surface length of the initial flaw would have also been in excess of 100mm. However, without accurate measurement it is only possible to say conclusively that the initial lack of fusion defect that led to rupture was 1.0mm deep and at least 230mm long.

A 10mm section was removed from W09-02, near the centre of the crack and a macro section was produced (Figure J9).

This macro clearly reveals the following features:

- There is an initial lack of fusion defect located at the positioning lip (vertical up-stand located near the fusion line of the weld). The height of this lack of fusion is 1.0mm. The length of the lack of fusion defect is in excess of 100mm.
- The lack of fusion defect has the morphology of a surface-breaking flaw, because the material is unfused to the left of the defect (as oriented in Figure J9). See also Figure J10.
- As a result of the overload conditions (ie the topple test) the lack of fusion defect has ruptured through the circumferential seam weld.
- Measurements reveal that the misalignment in this macro section is approximately 0.5mm and the local weld cap height is approximately 1.0mm (see Figure J11).

4.4 Conclusions from examination

The conclusions from the post-mortem examination of the impacted section of band H/8 from tanker J2580 are as follows:

1 As with J3910, rupture of the fillet weld joining the end dish to the extrusion band was observed.
2 Additionally, a through-wall rupture of the circumferential seam weld arising from an initial manufacturing lack of fusion defect has been observed.
3 The length of the through-wall flaw was 320mm. The length of the initial defect that led to rupture was in excess of 230mm.

In the context of the ECA and FEA calculations of the main report, TWI analysed a GRW joint with 'average' joint geometry. For this average geometry, under the fuel oil, higher impact velocity simulation, the critical defect height was 1.1mm. The topple test involving tanker J2580 involved water as the contained fluid and a slightly lower impact velocity. However, correspondence with HSL has indicated that the local bending moment acting on the region in which the through-wall flaw was observed was very similar to the 'topple test' roll over moment that was employed to derive the 1.1mm critical defect height. However, the local joint geometry for J2580 where the rupture was observed contained a smaller weld cap height than the average joint geometry analysed.

Based on the geometry parametric study that was undertaken, this would imply that the critical defect height for J2580 in the proximity of the through-wall rupture would be less than the critical defect height for the average joint geometry. Therefore, based on the results of the detailed FEA undertaken, it is expected that the 1.0mm lack of fusion defect would have led to rupture as it did in the topple test.

Correspondence with GRW has indicated that tanker J2580 is a so-called 'Period A' tanker with manufacture between 2006 and the middle of 2008. For a Period A tanker, the welding used a single wire semi-automated process with no specified (to-date) removal of the positioning lip.

Table J1 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

Figure J1 J2580 Band H O/S sample (as-received).

Figure J2 J2580 Band H N/S sample (as-received).

Figure J3 J2580 Band H O/S sample longitudinal crack.

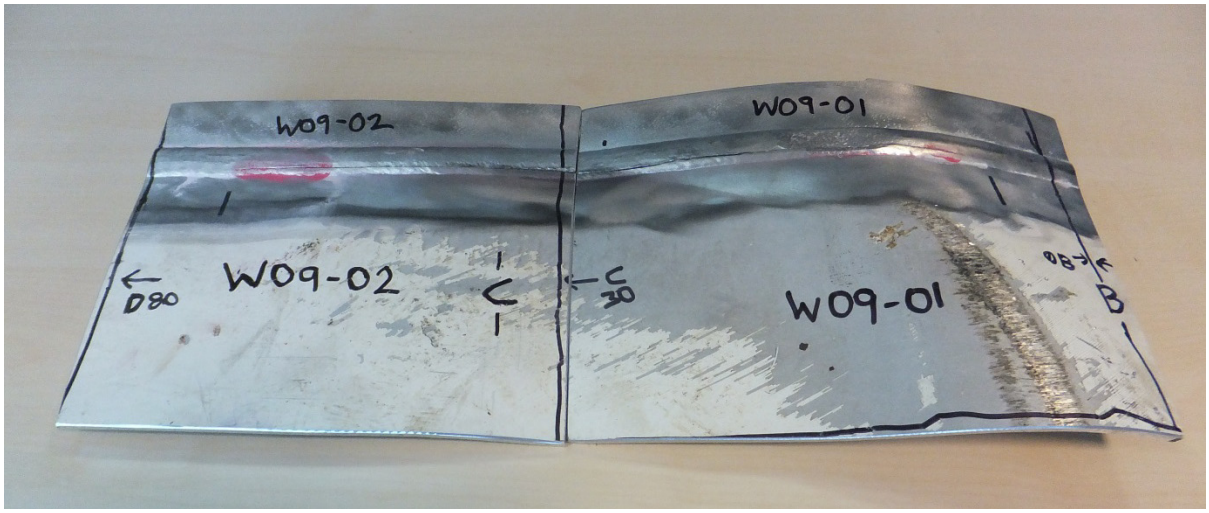

Figure J4 J2580 samples W09-01 and W09-02 (incorporating longitudinal crack).

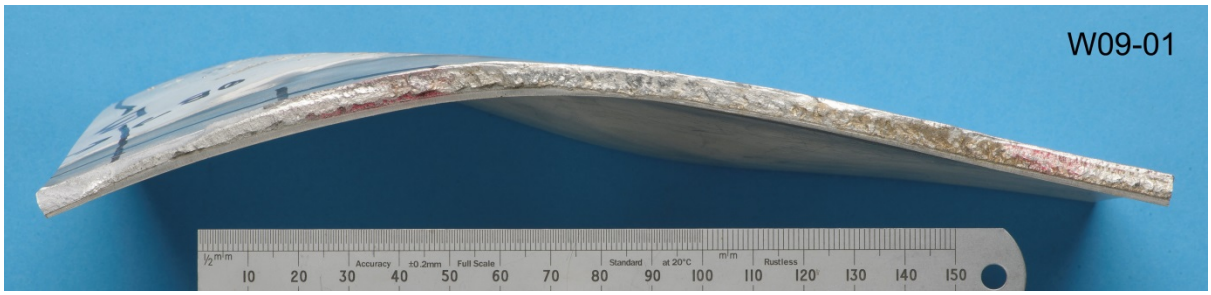

Figure J5 J2580 sample W09-01 fracture surface.

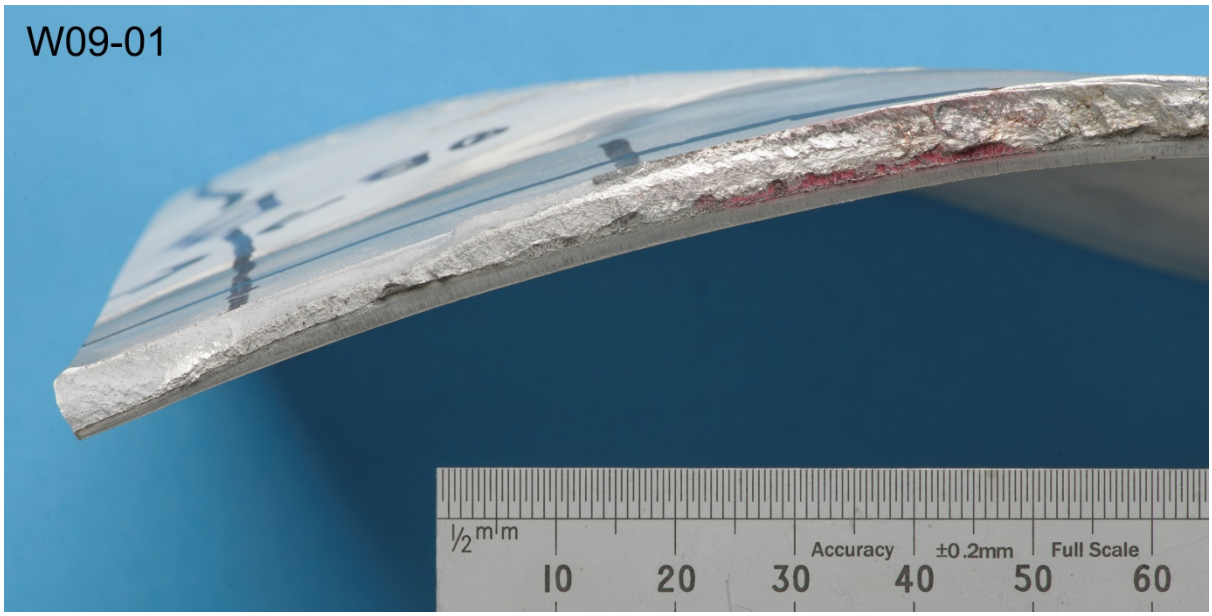

Figure J6 J2580 sample W09-01 fracture surface (left).

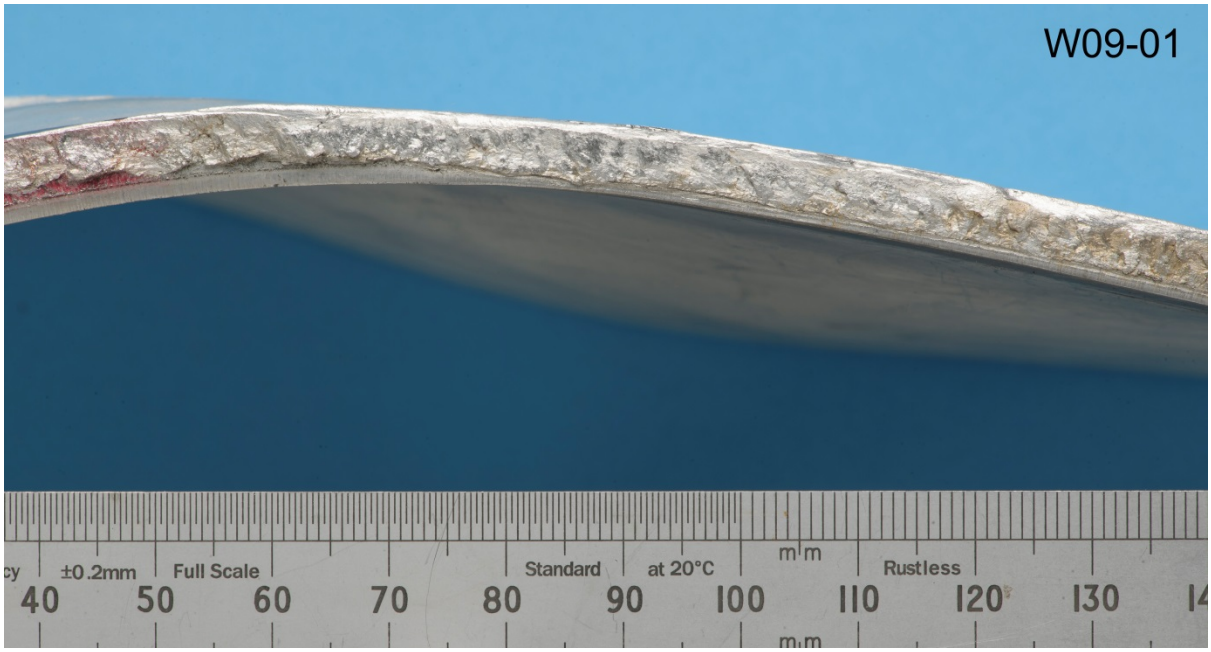

Figure J7 J2580 sample W09-01 fracture surface (centre).

Figure J8 J2580 sample W09-01 fracture surface (right).

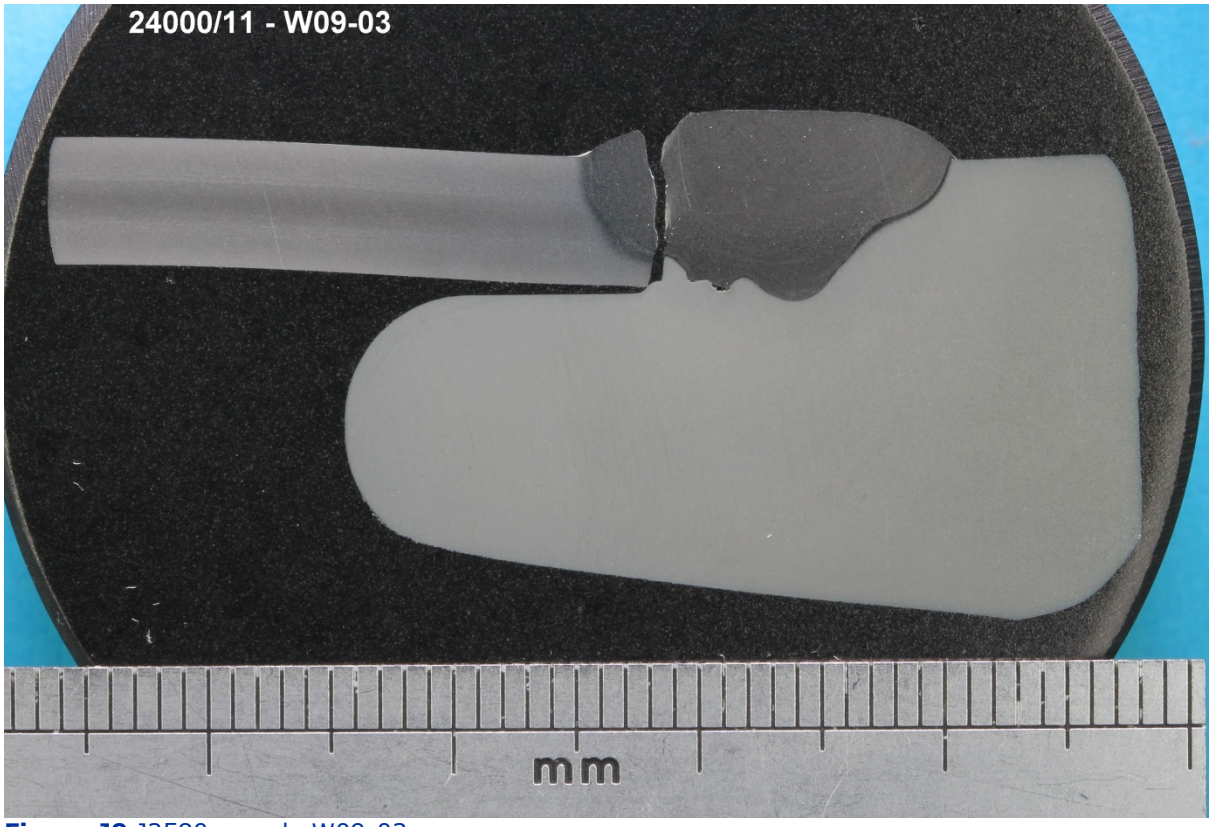

Figure J9 J2580 sample W09-03 macro.

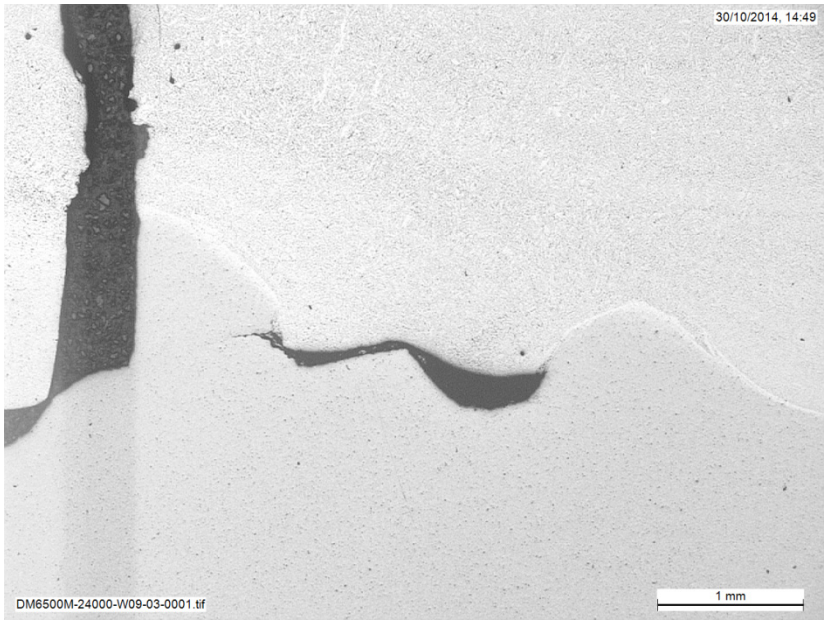

Figure J10 J2580 sample W09-03 macro. Focus on the initial lack of fusion at the positioner lip.

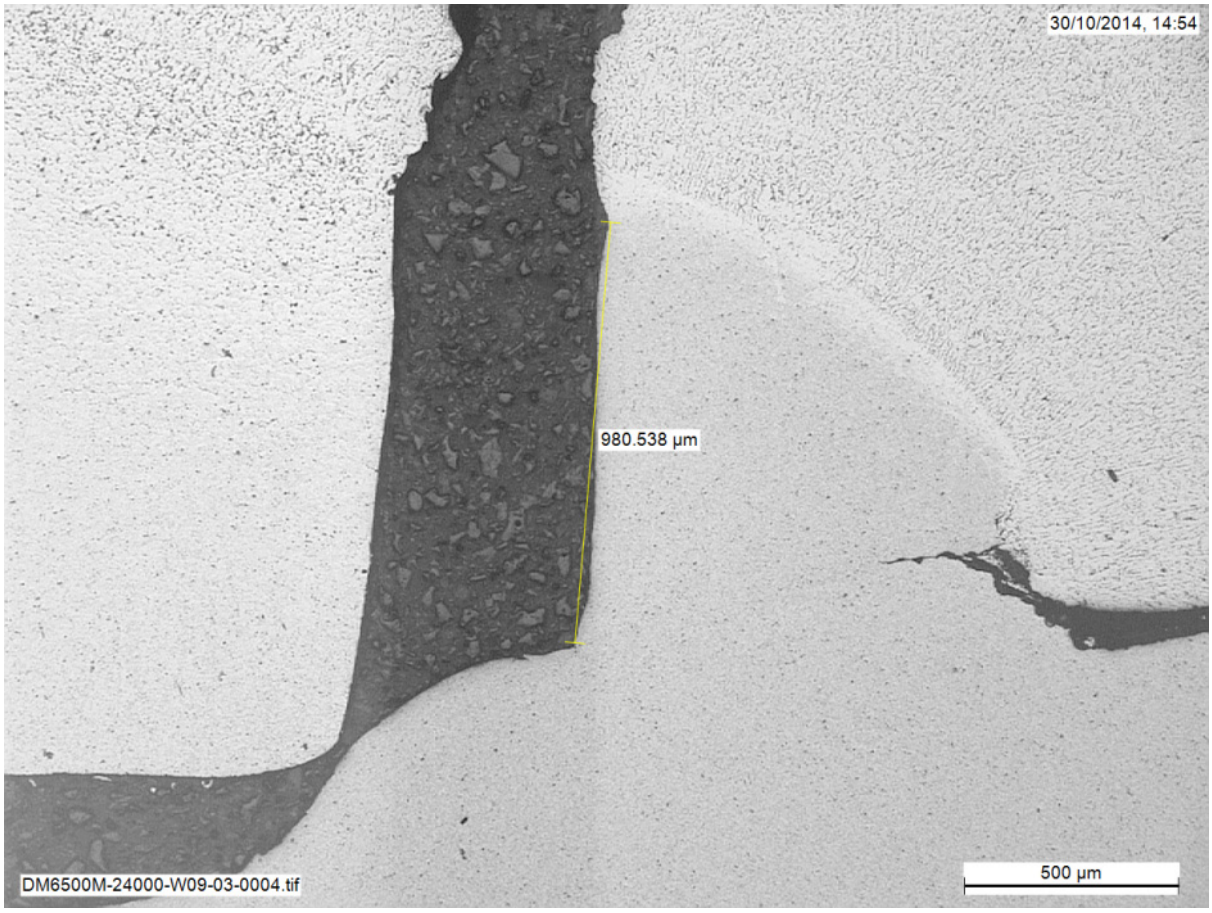

Figure J11 J2580 sample W09-03 macro. Measurement of the lack of fusion defect at the positioner lip. Initial height of the surface flaw is approximately 1.0mm.

UKAS TESTING 1046

The TEST HOUSE

Certificate of Test

Client: TWI, Granta Park, Great Abington, Cambridge, CB21 6AL
Date of receipt: 10 October 2014 *Date of test:* 11 October 2014
Reference No.: T41352 *MI No.:* 1779
Order No.: To follow *Specification:* N/A

Description: Section of aluminium butt welded fuel tanker reservoir containing 2 longitudinal welds (Only weld 9 is suitable for radiography),16mm thick (in area of interest) x 1520mm long.
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): 57						IQI	Type & size: BSEN 462 10 Al EN
Focal spot/source dimensions: 3mm							Source side: ✓ / Film side:
Film - make and type: Fuji 80							
Film density range: 2.2 to 2.9							Sensitivity: Wire No. 12

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
P0725	A-B, IQI shot	N/A	N/A
P0725	A-B	N/A	See Appendix 1
P0726	B-C	N/A	
P0727	C-D	N/A	
P0728	D-E	N/A	
P0729	E-F	N/A	
P0730	F-G	N/A	
P0731	G-H	N/A	
P0732	G-H, IQI Shot	N/A	

- 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* 21/10/2014

The TEST HOUSE

Certificate of Test

Client: TWI, Granta Park, Great Abington, Cambridge, CB21 6AL
Date of receipt: 10 October 2014 *Date of test:* 13 October 2014
Reference No.: T41352 *MI No.:* 1780
Order No.: To follow *Specification:* N/A

Description: Section of aluminium butt welded fuel tanker reservoir containing 2 longitudinal welds (Only weld 10 is suitable for radiography),16mm thick (in area of interest) x 1470mm long.
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): 57						IQI	Type & size: BSEN 462 10 Al EN	
Focal spot/source dimensions: 3mm							Source side: ✓	Film side:
Film - make and type: Fuji 80							Sensitivity: Wire No. 12	
Film density range: 2.2 to 2.9								

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
P0734	A-B, IQI shot	N/A	N/A
P0734	A-B	N/A	See Appendix 1
P0735	B-C	N/A	
P0736	C-D	N/A	
P0737	D-E	N/A	
P0738	E-F	N/A	
P0739	F-G	N/A	
P0740	G-H	N/A	
P0741	G-H, IQI Shot	N/A	

- 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* 21/10/2014

The TEST HOUSE

TEST REPORT

Client:	TWI	Sample identity:	
Job reference:	T41352		Appendix 1
Date:	13-Oct-14		

Radiographic Interpretation

Weld	Position (mm)	Results
9	A - B	Fine linear indication throughout (Lack of sidewall fusion) Isolated pores and cavities
	A + 265mm to film end	Longitudinal crack
	B - C	Longitudinal crack , Isolated pores and cavities throughout
	C to C + 115mm	Longitudinal crack + Lack of sidewall fusion to film end
	D to E + 110mm	Lack of sidewall fusion, Isolated pores and cavities to 2.5mm diameter
	E+110mm to F+150mm	Longitudinal crack opens up from Lack of sidewall fusion Isolated pores
	F+150mm to G+150mm	Longitudinal crack
	G + 150mm to H	Intermittent lack of sidewall fusion
10	A - B	Lack of sidewall fusion and isolated pores to 2mm diameter
	B to C + 80mm	Lack of sidewall fusion and isolated pores to 2mm diameter
	C+80mm to D +230mm	No significant indications
	D+230mm to E+80mm	Isolated pores and linear porosity indicating lack of fusion
	E + 80mm to F+185mm	Lack of sidewall fusion throughout
	F + 185mm to H	Intermittent lack of sidewall fusion throughout

It should be noted that the 'Lack of sidewall fusion' interpretation is based on fine linear indications that may or may not be as interpreted. Only a metallographic section would accurately identify the defect and it is recommended that this is carried out to confim the interpretation.

There are many isolated pores up to a diameter of 2.5mm and there are also many cavities of various shapes and sizes none of which are longer than 3mm.

The longitudinal cracks are not subject to misinterpretation only the start and finish positions which depend on the measurements of the person viewing the films and his interpretation of where the defects start and end..

Report prepared by: P Robinson Signed.....Date: 13/10/2014	Inspection: