Appendix L: Metallographic Examination of Samples from GRW Tanker J3217

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 L1.

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 two sections from J3217.

4 Undamaged Sample from J3217

4.1 Description of sample

The undamaged sample from J3217 was removed from the rear dish near side. This section was not involved in the collision that resulted in damage to the off side. Visual examination of the as-received condition showed no ruptures of evidence of damage/cracking to the rim joint weld or the circumferential weld. The sample is shown in Figure L1.

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

Five samples were prepared comprising transverse cross-sections to the circumferential weld and rim joint weld. The locations of the samples are shown in Figure L1. Descriptions of these samples are as follows:

- Sample J3217-01 (Figure L2)
  The macro section revealed no defects in the vicinity of the rim joint weld due to lack of penetration, lack of root fusion or poor fit up. A micrograph of feature A, the extrusion profile positioner lip is shown. An approximately 1.0mm surface-breaking defect is shown with the cause of the defect being lack of fusion between the positioner lip that has not been properly removed and the circumferential weld metal. The etching reveals that potentially the lack of fusion is due to the presence of an external tack weld.

- Sample J3217-02 (Figure L3)
  This figure highlights two features of the J3217-02 sample. At position A, the circumferential weld is shown where, although the positioner lip has been almost entirely removed, there is no fusion between the surface of the extrusion band and the circumferential weld. However, this lack of fusion is orientated parallel (or in-plane) to the primary loading and therefore not be considered as severe as flaws normal to the applied loading such as the surface defect shown in Figure L2. At position B, small micro-cracking can be seen at the toe of the rim joint weld on the inner surface of the end dish.

- Sample J3217-03 (Figure L4)
  Micrographs of the circumferential weld in the vicinity of the positioner lip (location A) and the root of the internal rim joint weld (location B) are shown in this figure. At the positioner lip, there is clear lack of fusion due to the non-removal of the lip. Whilst, the lack of fusion comprising both sides of the positioner lip, such a defect would be treated in an engineering critical assessment by projecting the entire flaw onto a plane normal to the applied load. In this case, it is likely that the defect shown at location A would be considered as an almost 2.0mm deep surface defect. At position B, the root of the rim joint weld has penetrated into the slot of the extrusion band. This has resulted in an approximately 1.0mm lack of fusion defect at the root of the weld and a non-uniform, reduced throat thickness compared to the external rim joint weld. The macrograph shows significant misalignment between the plate and the extrusion band.

- Sample J3217-04 (Figure L5)
  Micrographs of the internal rim joint weld (position B) and the circumferential weld in the vicinity of the positioner lip (position A) are shown for Sample J3217-04 in this figure. Again, there is an excessive gap between the slot between the extrusion band and end dish that has resulted in weld metal flowing into the slot. This has caused a lack of fusion defect about 1.0mm deep at the root of the weld and a slightly reduce through thickness compared to the outer surface/external rim joint weld. At the positioner lip, whilst most of it was removed prior to welding, a small amount remained and there is evidence of a crack-like, 1.0mm deep surface-breaking defect in the circumferential weld. The macrograph shows significant misalignment between the plate and the extrusion band.

- Sample J3217-05 (Figure L6)
  Similar to above, micrographs of the internal rim joint weld and the circumferential weld have been provided (denoted by positions B and A, respectively.) The poor fit-up between the end dish and the extrusion band slot is most evident in this Figure, as excessive weld metal has flowed into the gap between the two. The positioner lip has been almost fully removed, but again there is poor fusion between the surface of the extrusion profile and the corresponding parallel surface of the weld bead.

5 Damaged Sample from J3217

5.1 Description of sample

The undamaged sample from J3217 was removed from the rear dish off side. Visual examination of the as-received condition showed no ruptures of evidence of damage/cracking to the rim joint weld or the circumferential weld; however, visibility was impaired due to the deformed shape of the section. The sample is shown in Figure L7.

5.2 Radiographic examination

Unlike other sections provided to TWI, it was not possible to radiograph this section due to its highly deformed nature.

5.3 Metallographic examination

Five samples were prepared comprising transverse cross-sections to the circumferential weld and rim joint weld. The locations of the samples are shown in Figure L7. Descriptions of these samples are as follows:

- Sample J3217-06 (Figure L8)

In this sample, the deformation experienced by the cross-section is clearly visible. Whilst the tanker shell has experienced extensive bending strains, the orientation of the bending is opposite to what occurs during topple testing. The result is that even if there was a significant surface-breaking lack of fusion defect at the positioner lip (which there is not), the defect would be primarily under compressive loading which would not lead to a fracture failure. The end dish also exhibits some bending, though not as extreme as the tanker shell. The tensile side of the bend is located on the inner surface of the end dish. Whilst there is some excessive weld metal at the root of the inner surface rim joint weld between the extrusion profile and the end dish, there is no significant defect present and no evidence of crack initiation or tearing.

- Sample J3217-07 (Figure L9)

In this sample, the deformation of the tanker shell is similar to that of J3217-06, but the bending is not as extreme. There are no defects at the positioner lip as the lip has been wholly removed before welding, but even if there was one present, it would have experienced compressive stresses, causing the crack to close and not extend. The end dish for this sample exhibits bending but with the tensile side on the external surface, highlighting the complexities of the deformation experienced by the overall section during impact. Both rim joint welds appear to have sufficient throat thickness to have withstood the applied loads and no evidence of cracking was observed

- Sample J3217-08, 09 and 10 (Figure L10-L12)

The features of the remaining samples from the damaged section of J3217 exhibit the same characteristics of samples -06 and -07. Specifically: the tanker shell exhibits bending orientated in way such that any lack of fusion defects located at the positioner lip would experience compressive strains and crack closure (eg samples 09 and 10). The end dish exhibits permanent plastic bending but the rim joints show sufficient throat thickness to resist rupture through the weld throat. No significant manufacturing defects are observable at either the circumferential weld or the rim joint welds.

6 Conclusions from examination

The conclusions from the post-mortem examination of undamaged and damaged sections from J3217 are:

1 Multiple surface-breaking defects have been observed, arising from lack of fusion along the positioner lip.
2 Multiple lack of root fusion flaws have been observed in the rim joint welds. In most cases, the defect was more severe for the inner surface rim joint weld.
3 Samples machined from the damaged section of J3217 revealed the overall deformation characteristics of the impact: bending of the tanker shell resulting in compressive strains acting on any flaws at the positioner lip and bending of the end dish. In these samples no significant defects, crack initiation or crack tearing was observed

Correspondence with GRW has indicated that tanker J3217 is a so-called 'Period B' tanker.

Table L1 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
W11	J3217	Undamaged	-
W12	J3217	Damaged	-

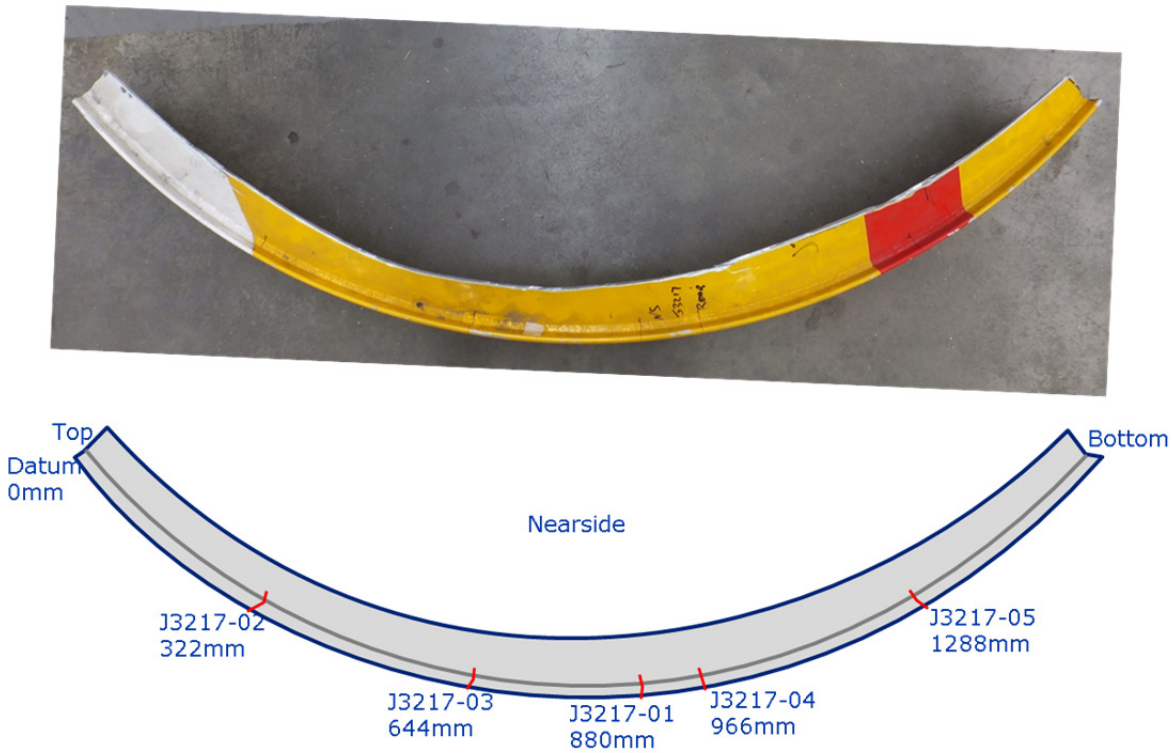


Figure L1 Diagram of samples taken from the undamaged nearside of J3217.

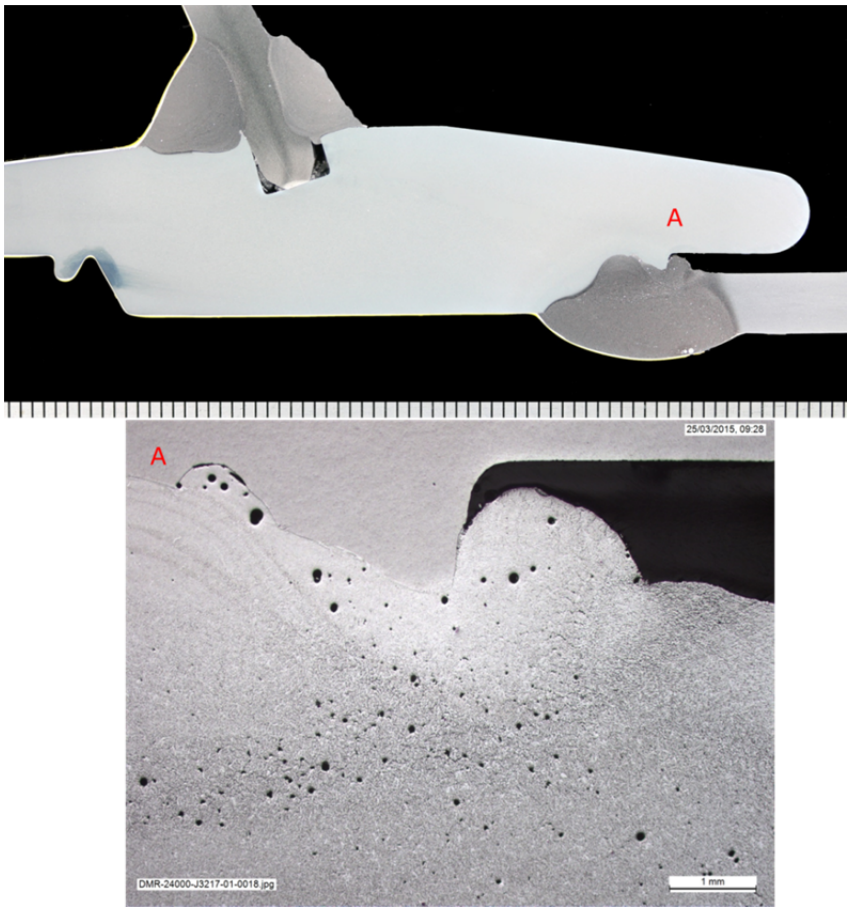


Figure L2 Sample J3217-01 from the undamaged near side of the J3217 section.

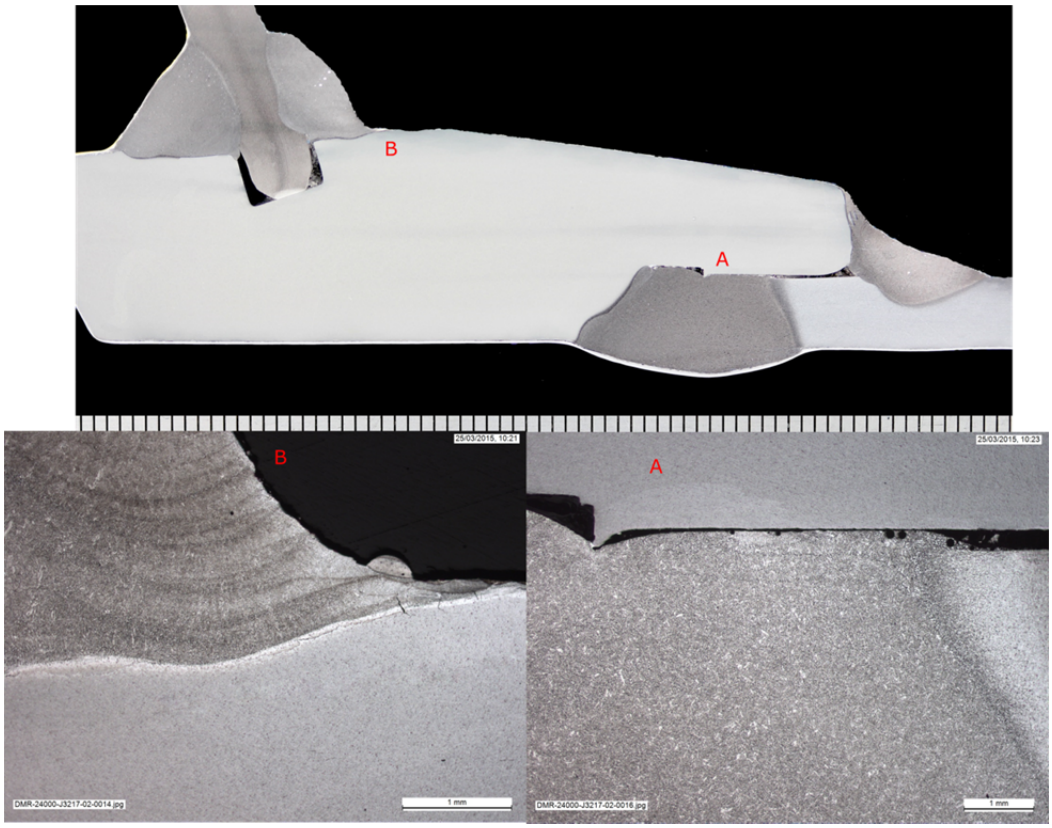


Figure L3 Sample J3217-02 from the undamaged near side of the J3217 section. Scale bars on the bottom to images indicate 1.0mm. Ticks on the top frame indicate 1.0mm.

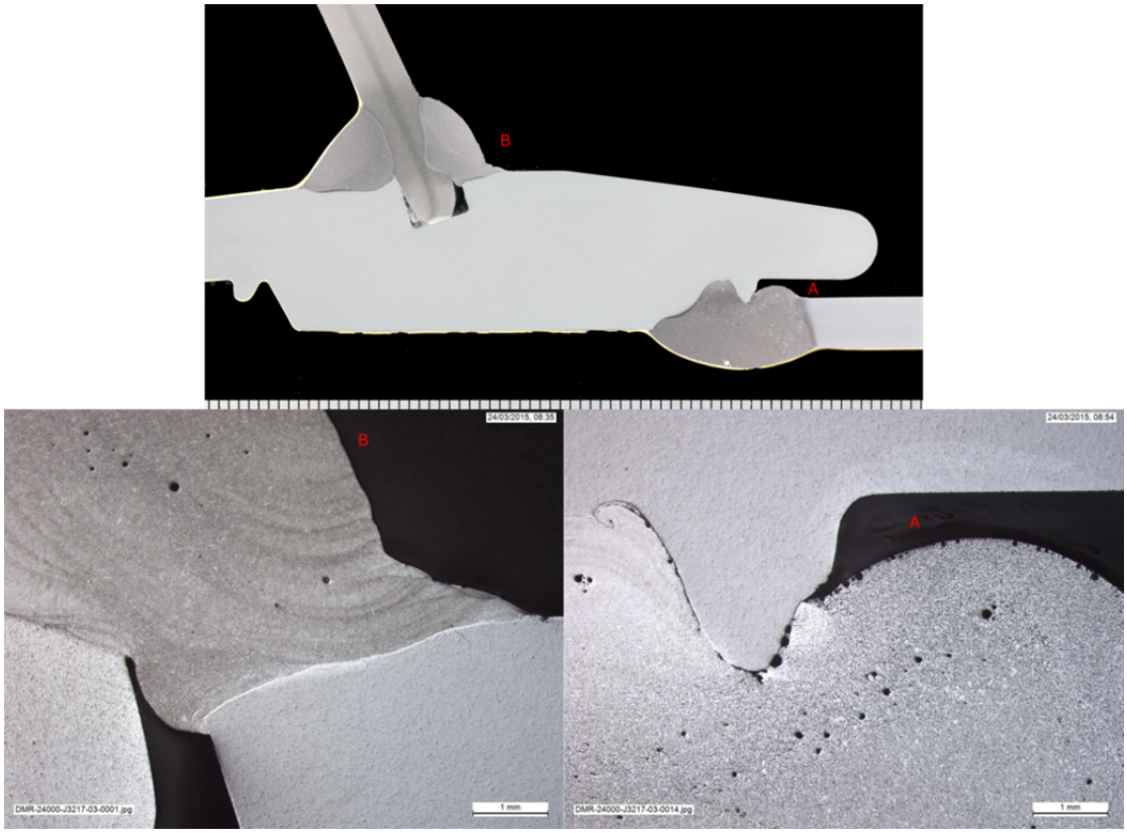


Figure L4 Sample J3217-03 from the undamaged near side of the J3217 section. Scale bars on the bottom two frames indicate 1.0mm. Ticks on the top frame indicate 1.0mm.

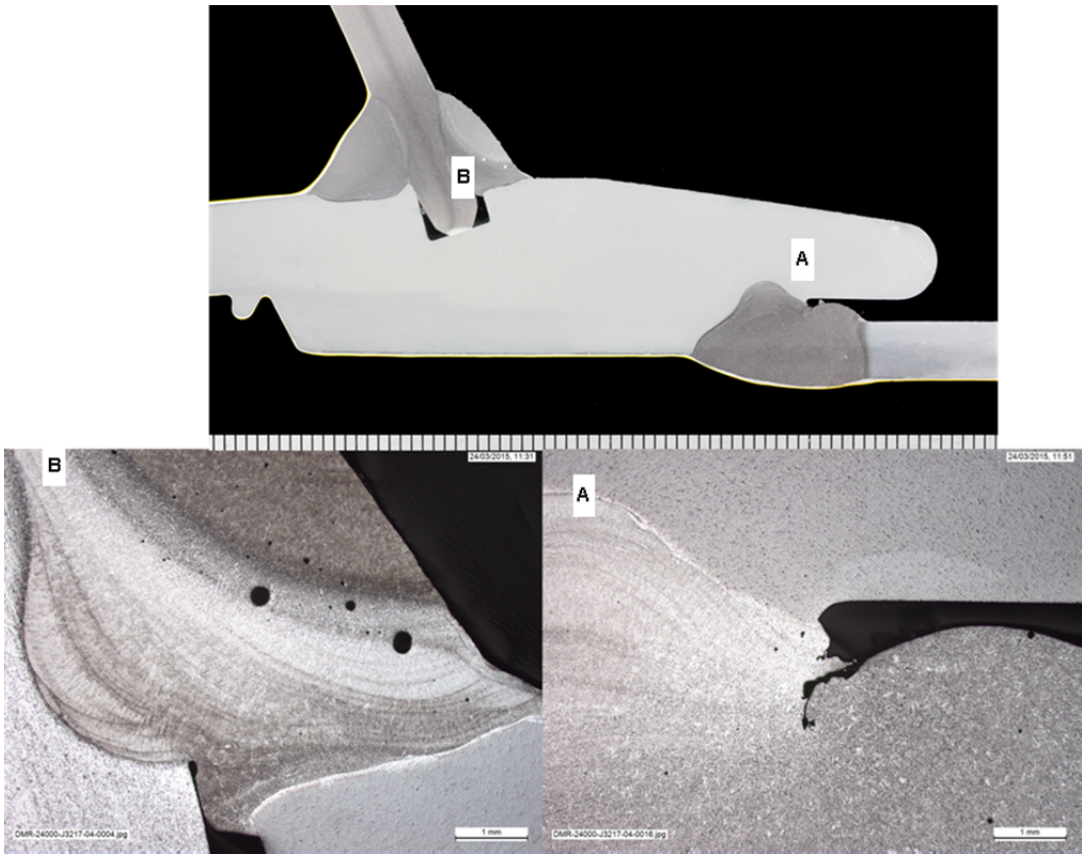


Figure L5 Samples J3217-04 from the undamaged near side of the J3217 section. Scale bars on the bottom two frames indicate 1.0mm. Ticks on the top frame indicate 1.0mm

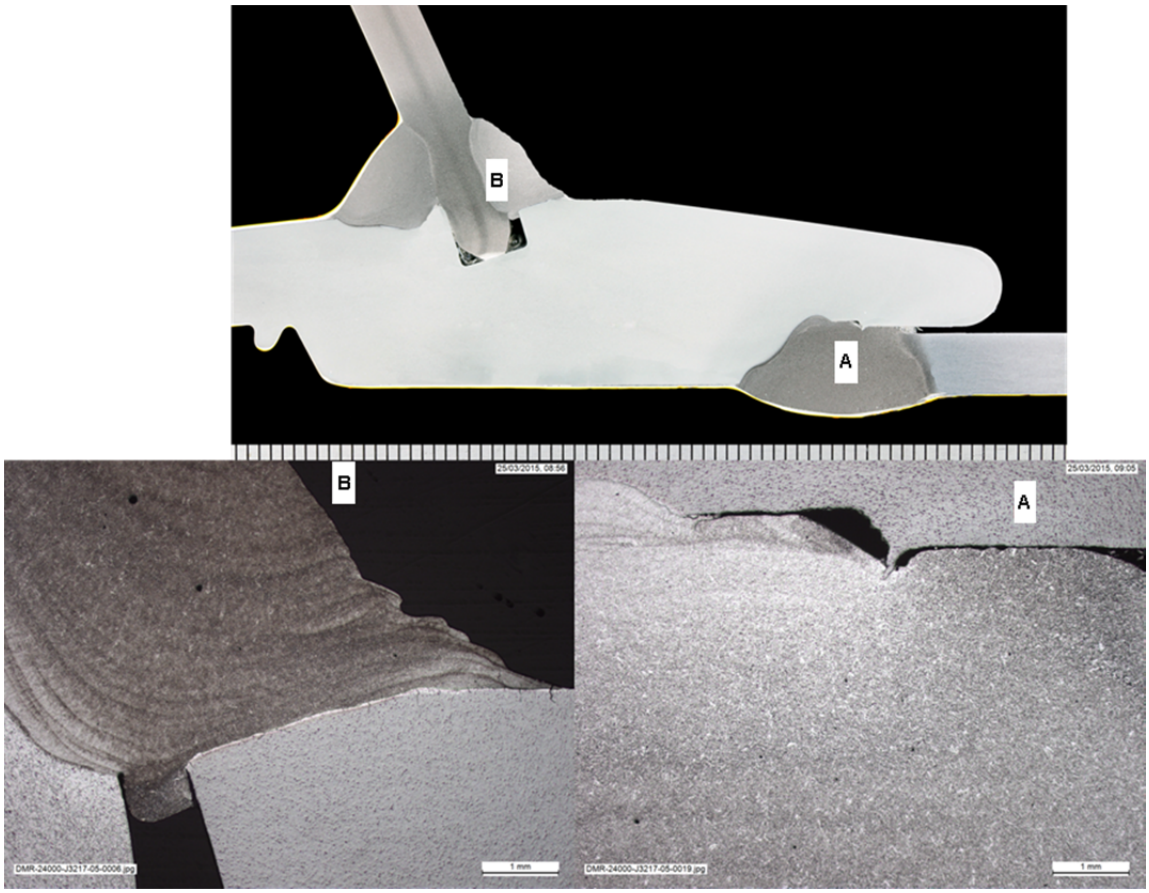
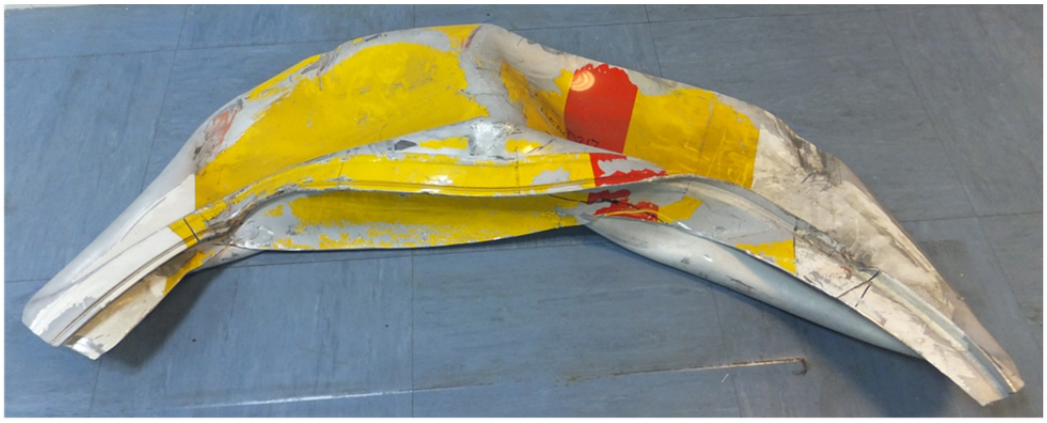


Figure L6 Sample J3217-05 taken from the undamaged nearside of J3217. Scale bars on bottom two frames indicate 1.0mm and ticks on the top frame indicate 1.0mm.



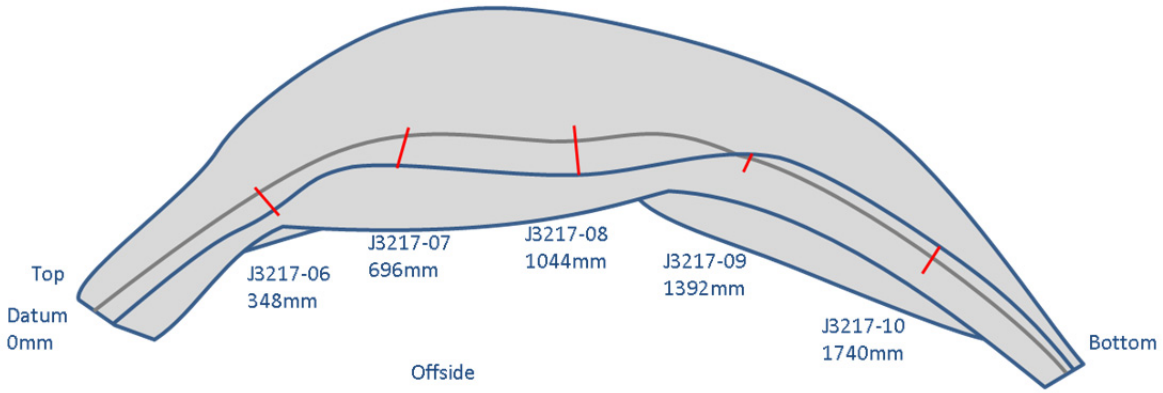


Figure L7 Diagram of the samples taken from the damaged offside of J3217.

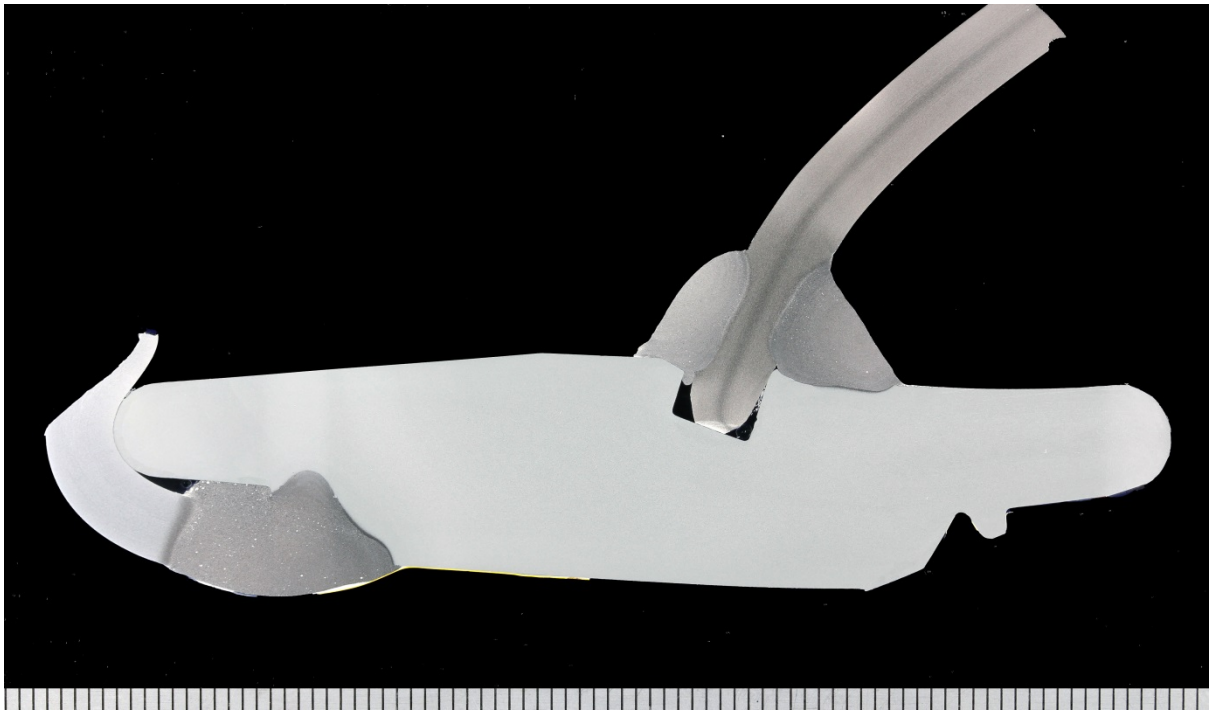


Figure L8 Sample J3217-06 from the damaged offside of J3217. Ticks indicate millimetre scale.

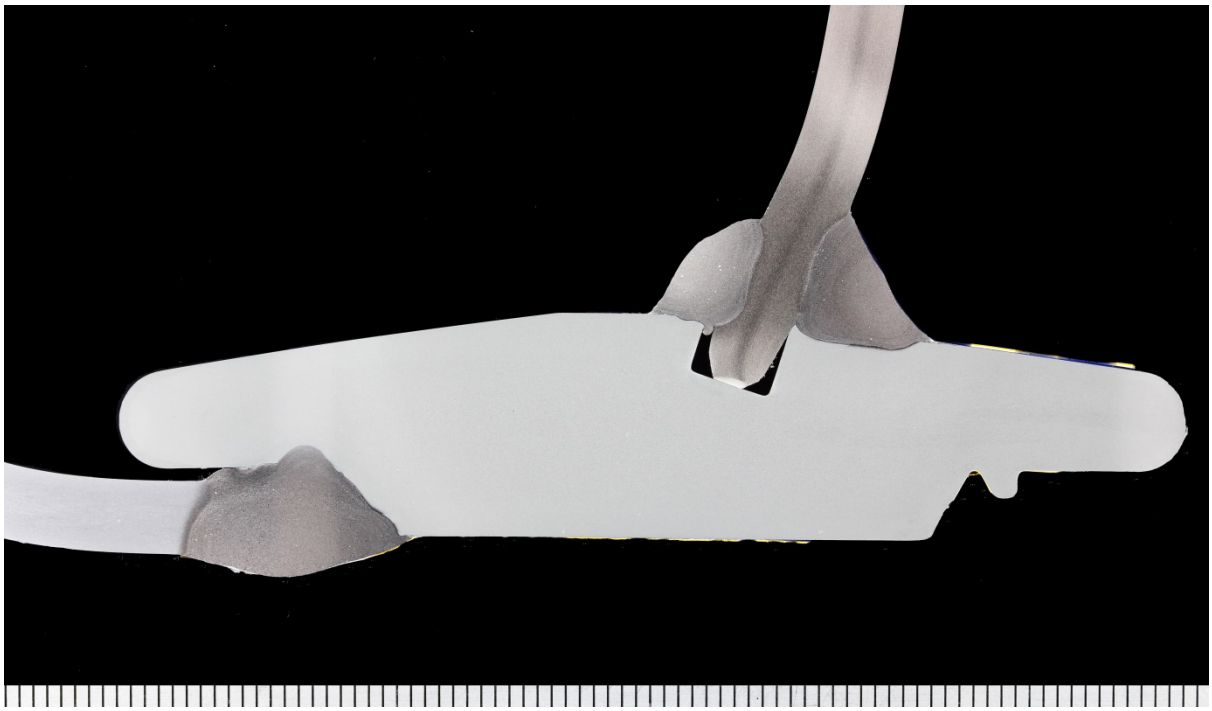


Figure L9 Sample J3217-07 from the damaged offside of J3217. Ticks indicate millimetre scale.

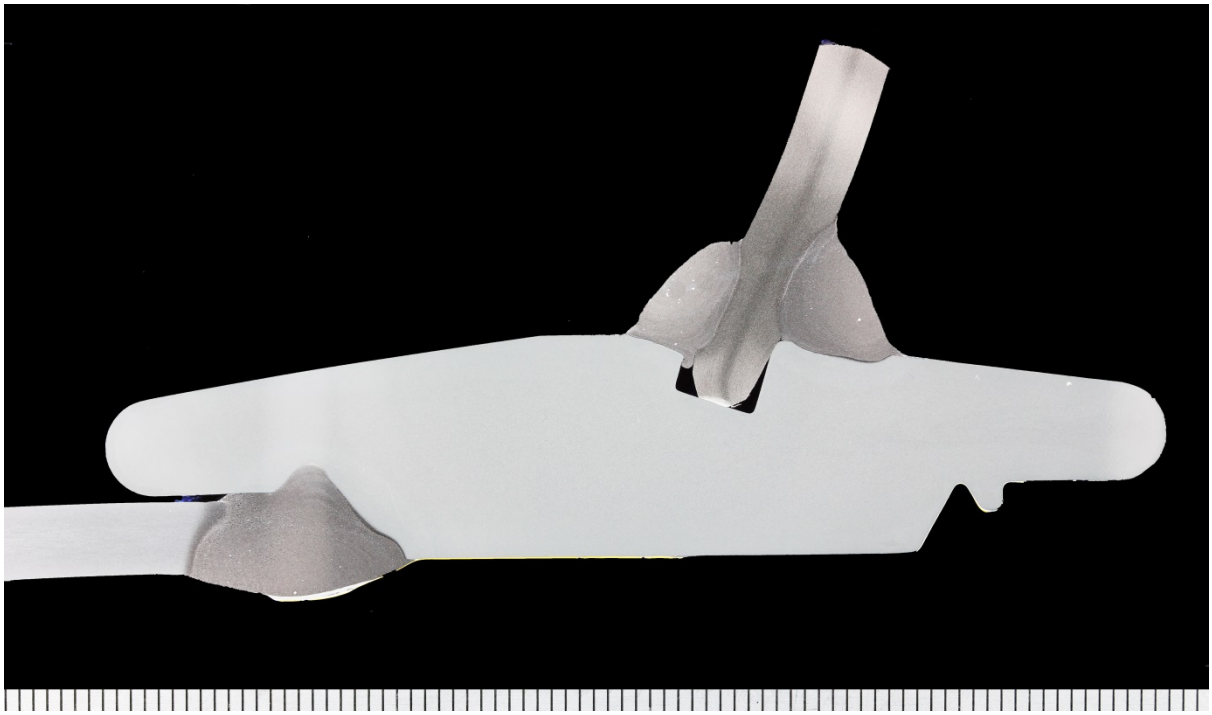


Figure L10 Sample J3217-08 from the damaged offside of J3217. Ticks indicate millimetre scale.

Figure L11 Sample J3217-09 from the damaged offside of J3217. Ticks indicate millimetre scale.

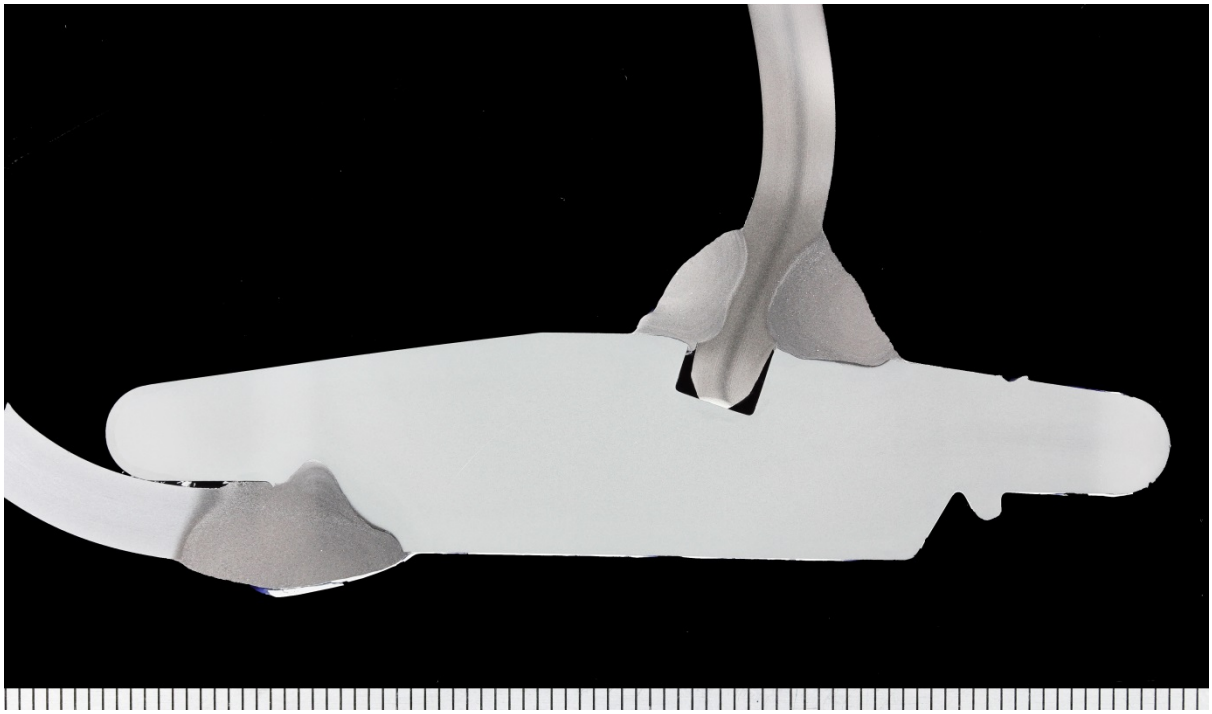


Figure L12 Sample J3217-10 from the damaged offside of J3217. Ticks indicate millimetre scale.

Gammax Independent Inspection Services Ltd
Inspection House, Bury St. Edmunds, Suffolk IP29 4BY *Telephone:01284 850888 Fax:01284 850808*

Radiographic Inspection Report

Client:	**TWI Ltd**	*GIIS No.:*	**150311CR**	*Rev.:*	**0**
Client's P.O. No.:	**P746043**	*S.O. No.:*	**301**	*W.O. No.:*	**485**
Client's Job Ref.:	**J3217**	*Inspection Date:*		**10 March 2015**	
Sheet No.:	**1 of 1**				

Details of Item Tested

Material:	**Aluminium**	*Thickness:*	**15mm**
Diameter:	**-**	*Welding Process:*	**131:MIG**
Type of Joint:	**Butt/Fillet**	*Parent Metal Condition:*	**As rolled**
Surface Weld Condition:	**As welded**		

Radiographic Equipment

Type of Equipment/~~Source~~:	**Andrex 3002**		
Tube Voltage/~~Source Strength~~:	**80Kv**		
Focal Spot/~~Source Dimensions~~:	**3 x 1**		
Film (Make and Type):	**Fuji 50**	*Processing:*	**Automatic**
Screens:	**None**	*Filters:*	**None**
IQI (Type and Size):	**10 AL EN**	*Position:*	**Source Side**

Inspection Details

Test Procedure/Standard:	**RTP-04/BS EN 17636-1**	*Technique:*	**SWSI/Panoramic**
Focus to Film Distance:	**900mm**	*Object to Film Distance:*	**Contact**
Exposure Time (~~CiMins~~/mAmin) :	**Butt: 3 x 30** **Fillet: 3 x 50**	*Film Density:*	**≥2.3**
Sensitivity:	**W13**	*Acceptance Criteria:*	**Advisory**

Inspection Results

Item Tested	*Interpretation*	*Recommendations*
J3217		
Butt Weld	**Lack of side wall fusion, intermittent, length of weld.**	
	Lack of root fusion, intermittent, length of weld.	
	Porosity Ø2mm max, 880mm from datum.	
	Intermittent porosity, length of weld.	
Internal Fillet Weld	**Lack of root fusion, full length of weld.**	
External Fillet Weld	**Lack of root fusion, full length of weld.**	
	Porosity Ø1mm max, 625mm from datum.	
	Porosity intermittent, length of weld.	

Inspection Performed By: **Thomas Donohoe PCN306055**
Verified By: **Jamie Cartwright-Thomas PCN 309169 CSWIP673131**

CSWIP 3.1
RAD PCN II
UT PCN II
MPI PCN II
DPI PCN II

Digitally signed by Jamie Cartwright-Thomas
DN: cn=Jamie Cartwright-Thomas, o=Gammax Independent Inspection Services, ou, email=jamie@gammaxuk.co.uk, c=GB
Date: 2015.03.13 13:44:17 Z

Client	*Inspection Authority*
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