

Appendix I: Macro and Microscopic 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, J2580 and J3564. 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.

4 Section from J3910

4.1 Description of sample

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.

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 taken 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

Table I4 J3564 macro slice positions

Macro	Location (approx. distance from top of sample in mm)
W03-01	50
W03-02	160
W03-03	250
W03-04	350
W03-05	450
W03-06	550
W03-07	650
W05-01	50
W05-02	150
W05-03	250
W05-04	350
W05-05	450
W05-06	550
W05-07	650
W05-08	750
W07-01	50
W07-02	150
W07-03	250
W07-04	350
W07-05	450
W07-06	550
W07-07	650
W07-08	750



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

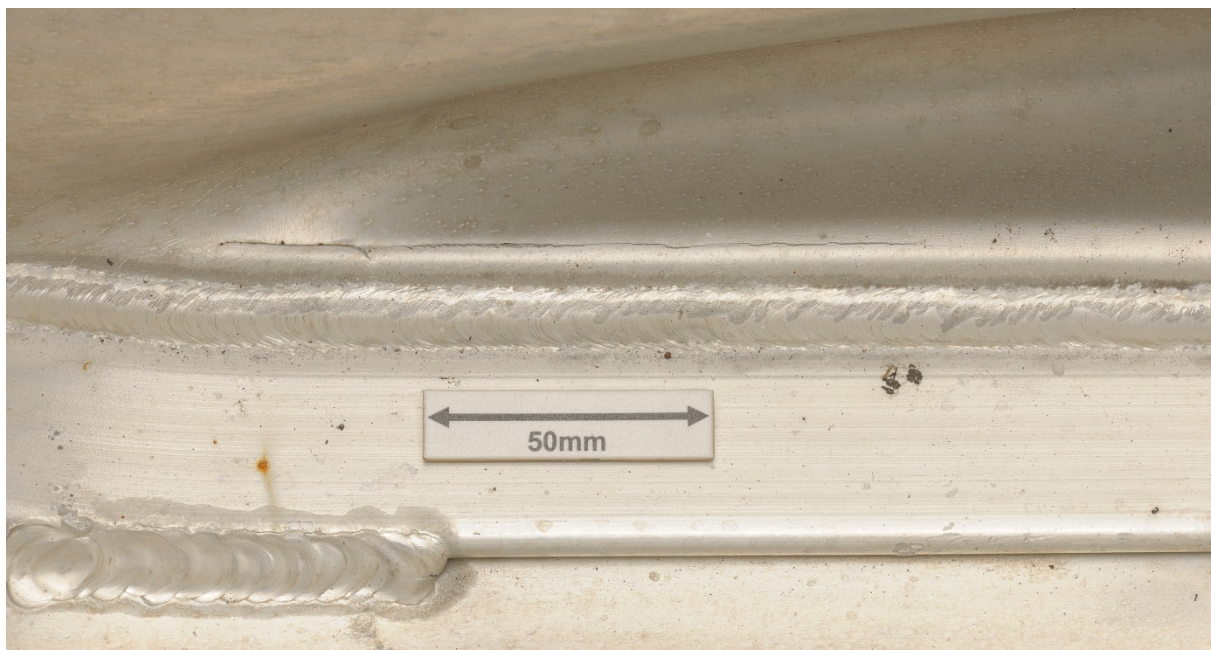


Figure I2 Rupture of the parent metal (end dish) at the toe of the fillet weld joining the end dish to the extrusion band. Rupture located at the left end of the buckled portion of the bulkhead as shown in Figure I1.



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.

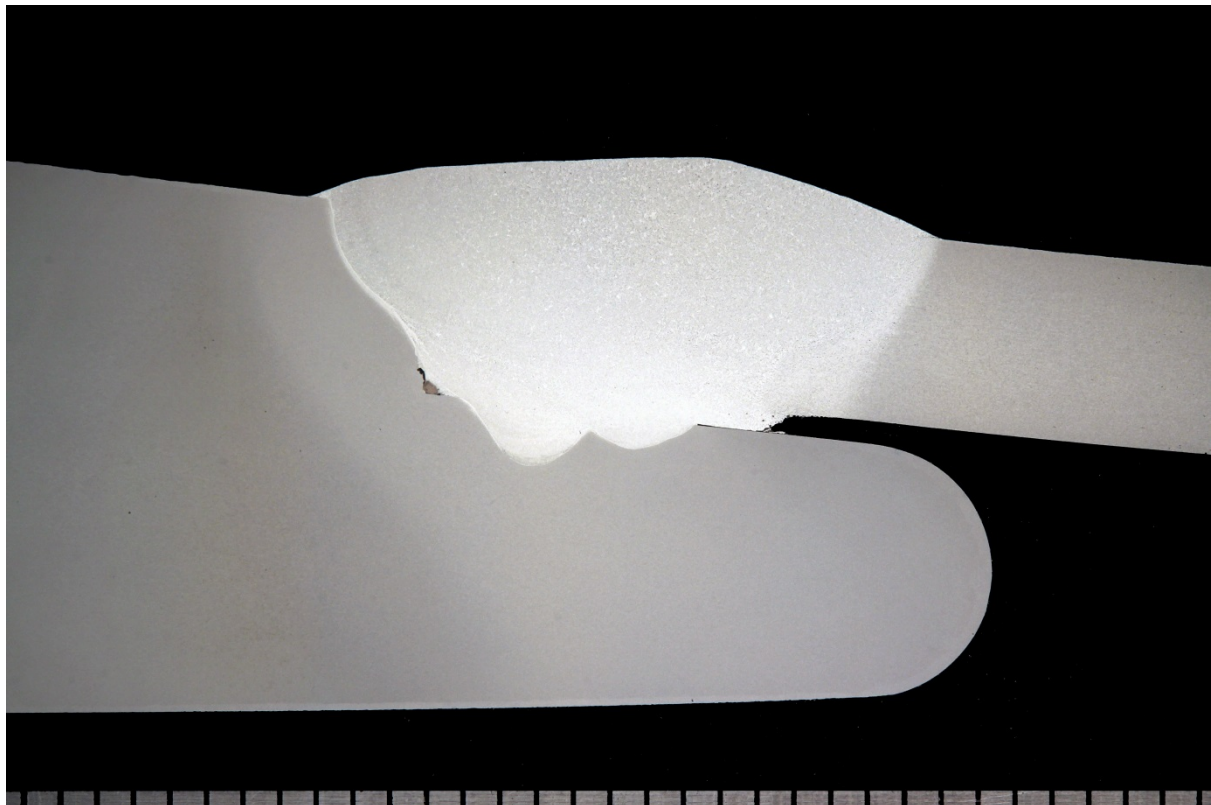


Figure I4 W02-01 macro (J3910 Band A O/S).

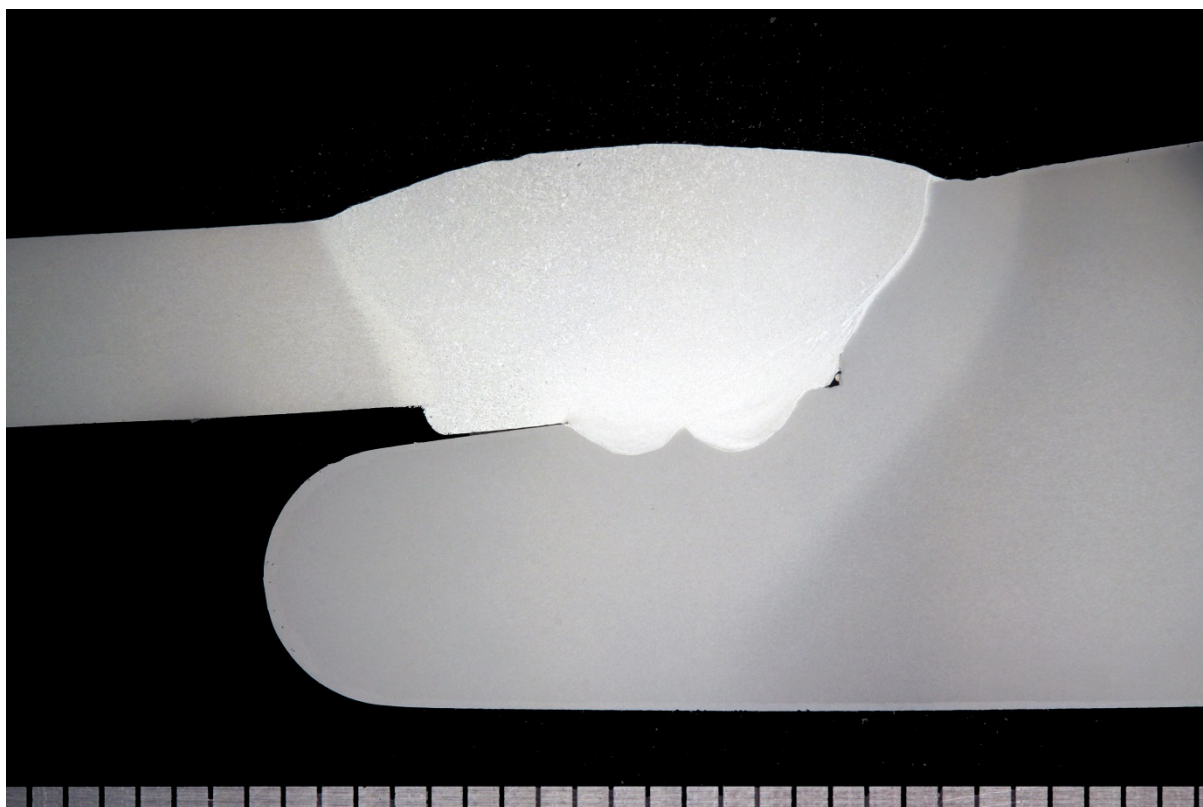


Figure I5 W02-02 macro (J3910 Band A O/S).

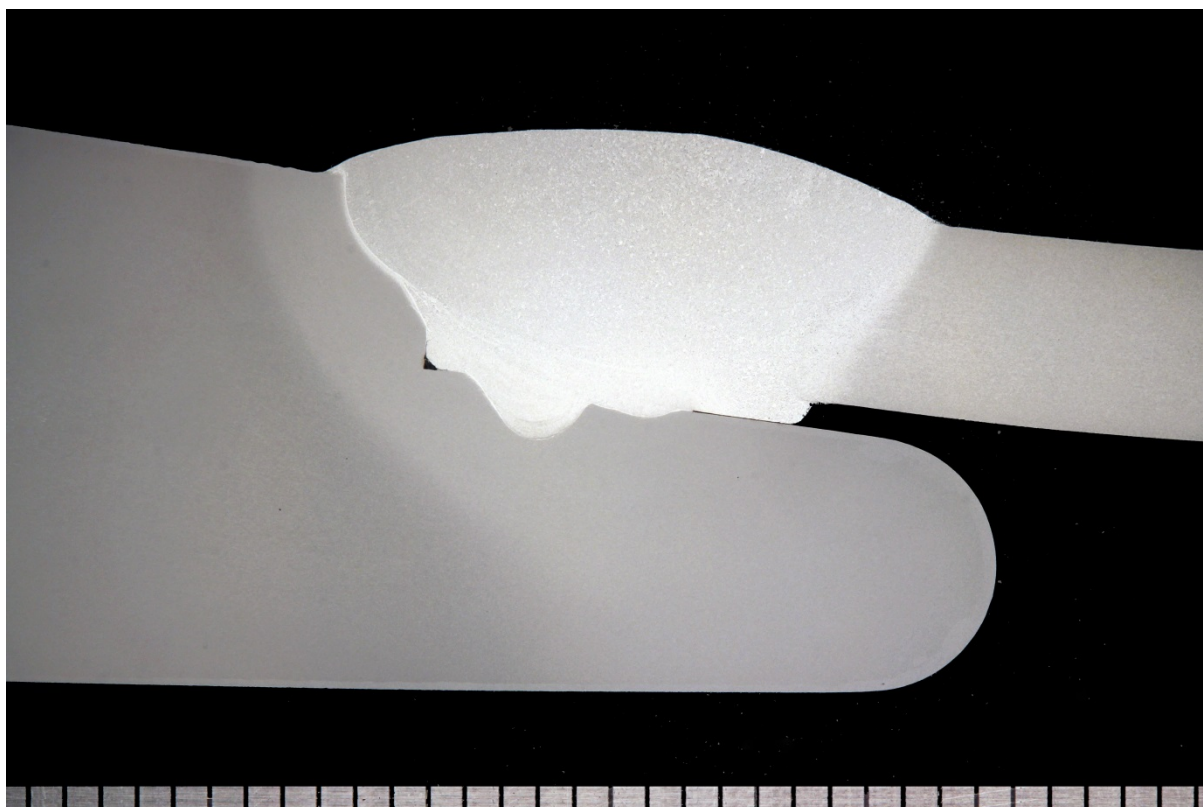


Figure I6 W02-03 macro (J3910 Band A O/S).

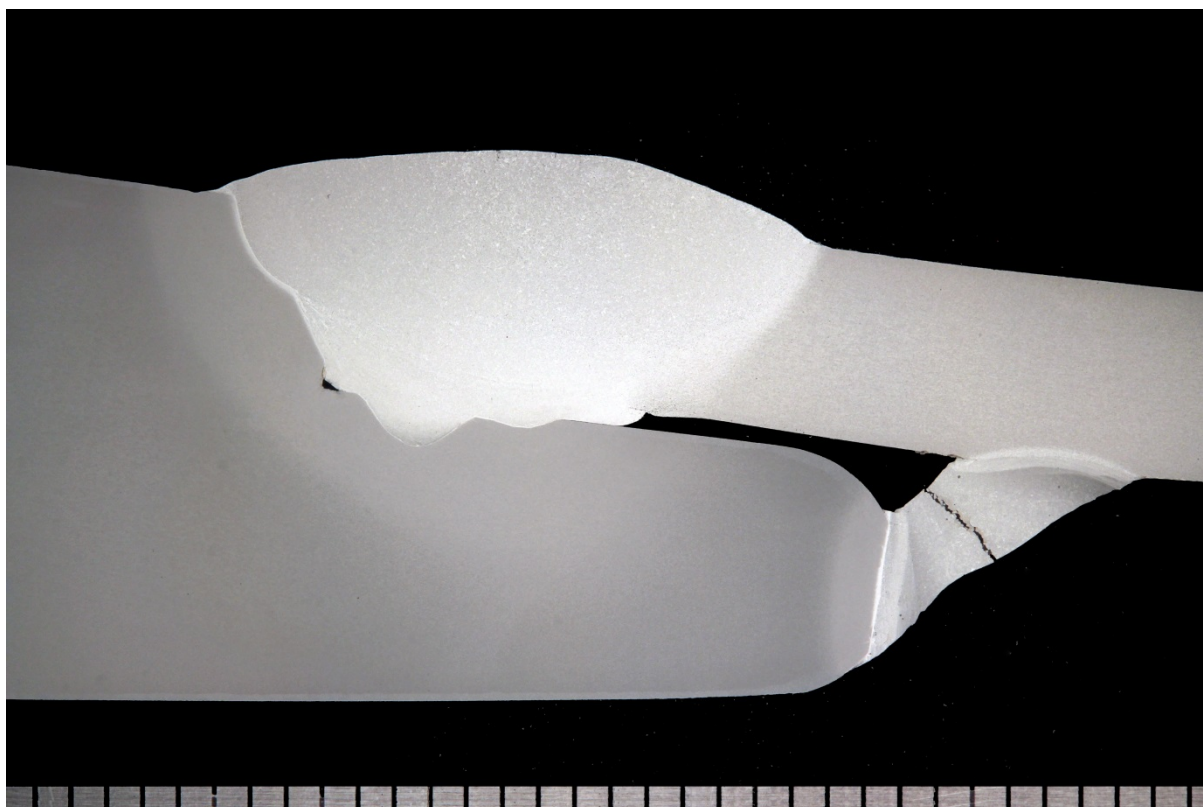


Figure I7 W02-04 macro (J3910 Band A O/S).

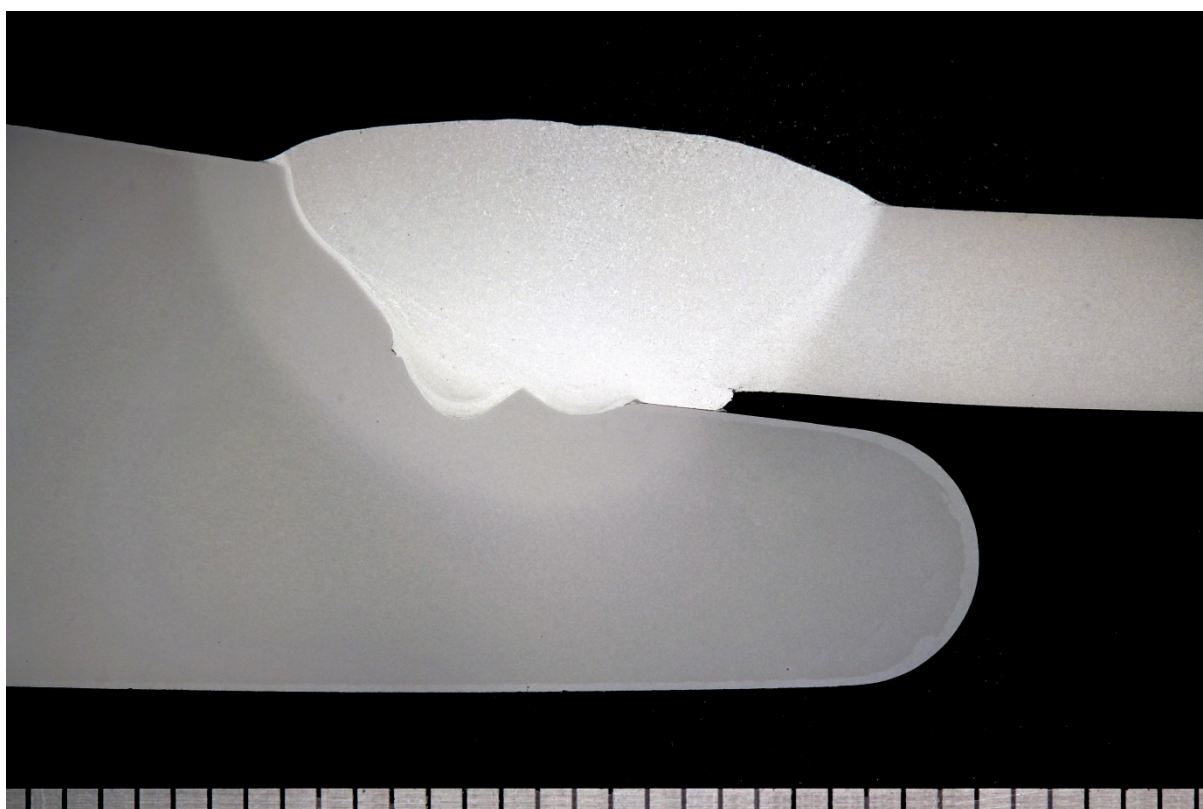


Figure I8 W02-05 macro (J3910 Band A O/S).

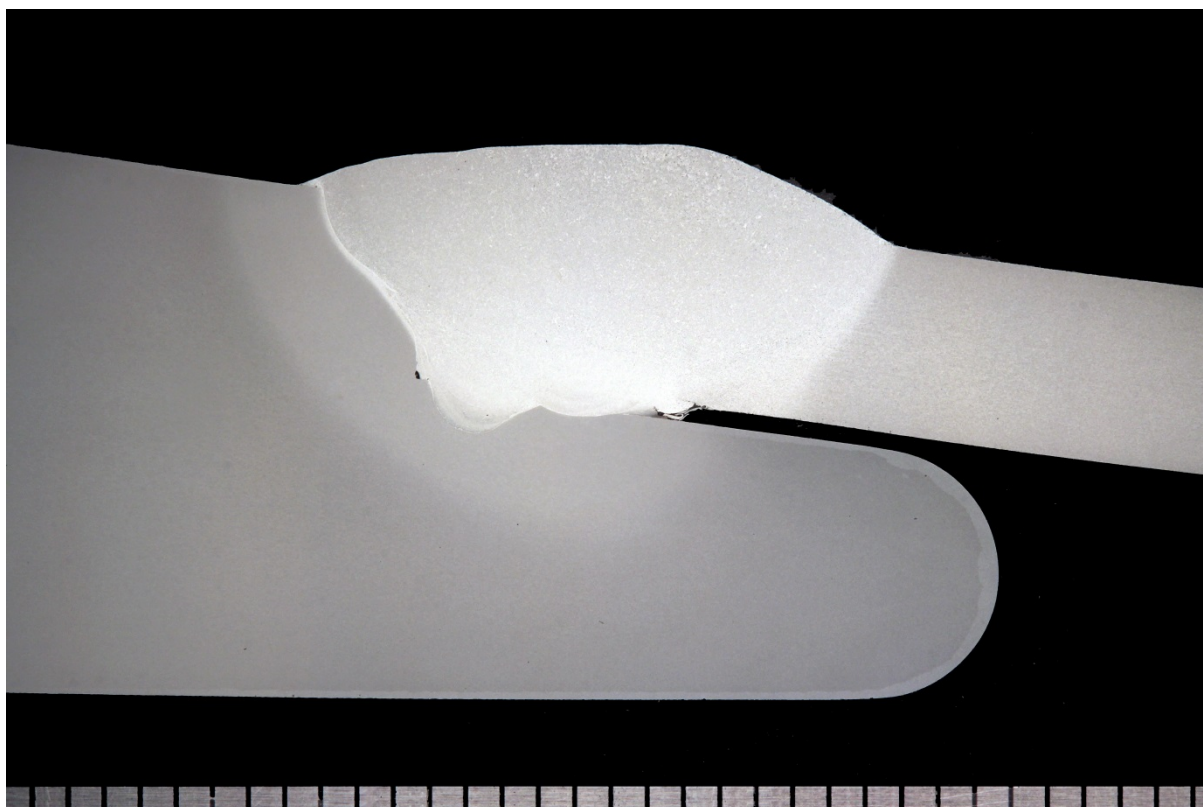


Figure I9 W02-06 macro (J3910 Band A O/S).

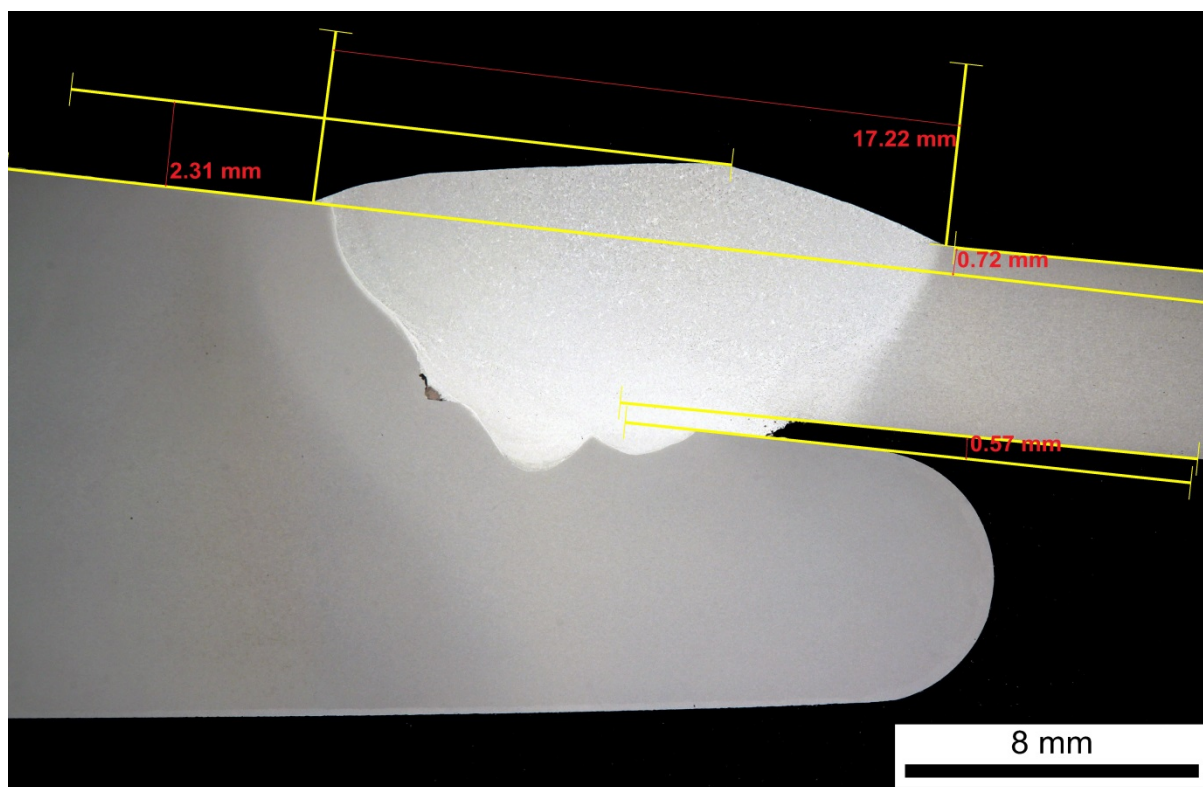


Figure I10 W02-01 macro (J3910 Band A O/S) measurements.

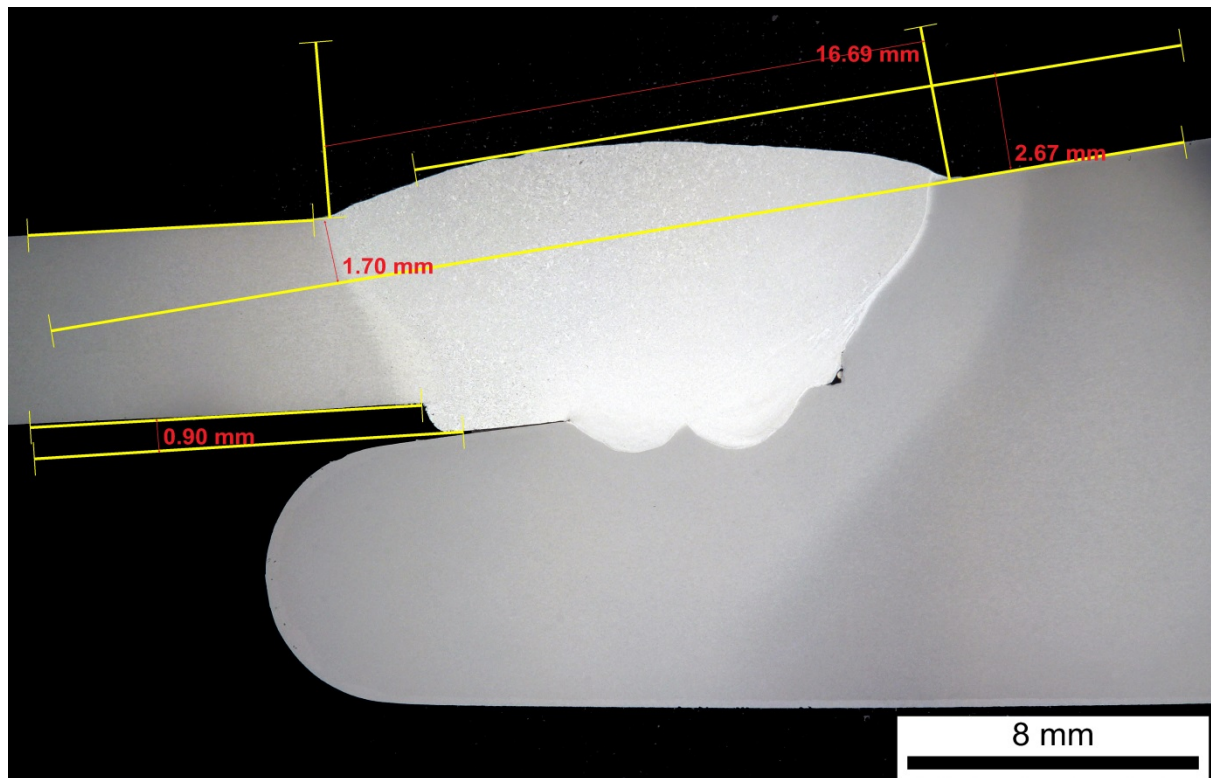


Figure I11 W02-02 macro (J3910 Band A O/S) measurements.

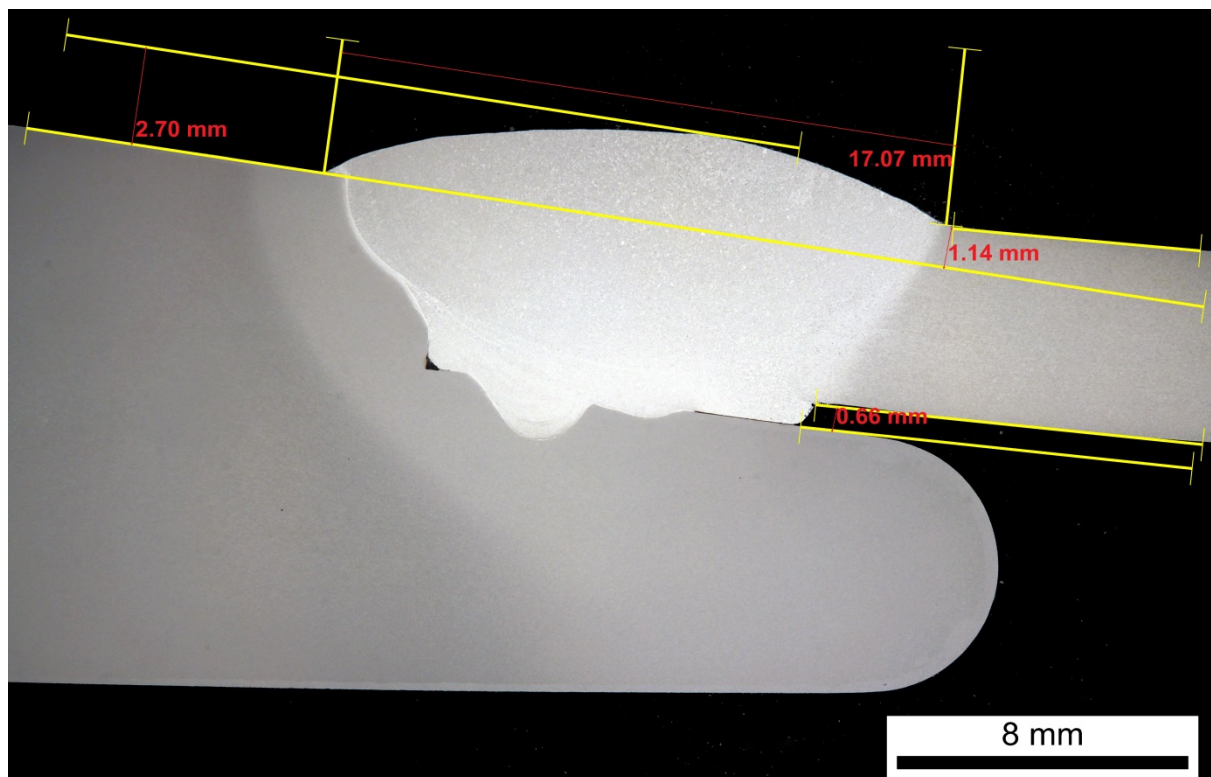


Figure I12 W02-03 macro (J3910 Band A O/S) measurements.

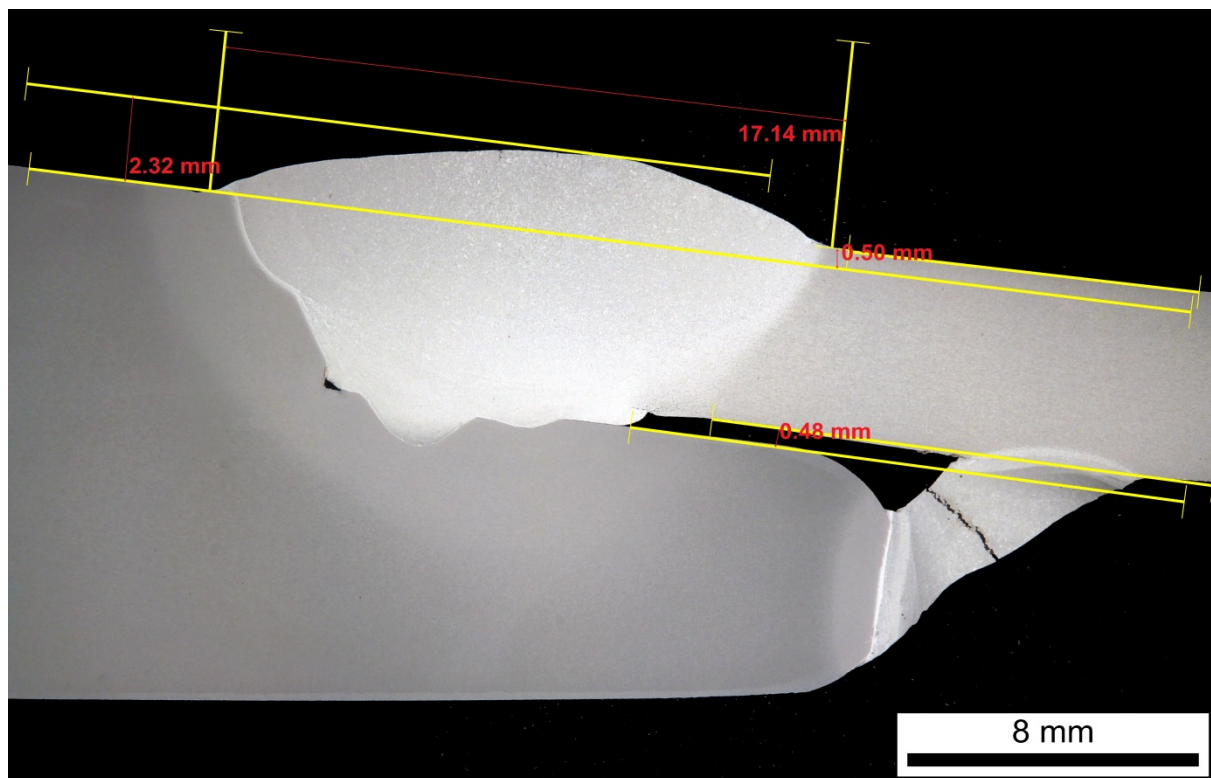


Figure I13 W02-04 macro (J3910 Band A O/S) measurements.

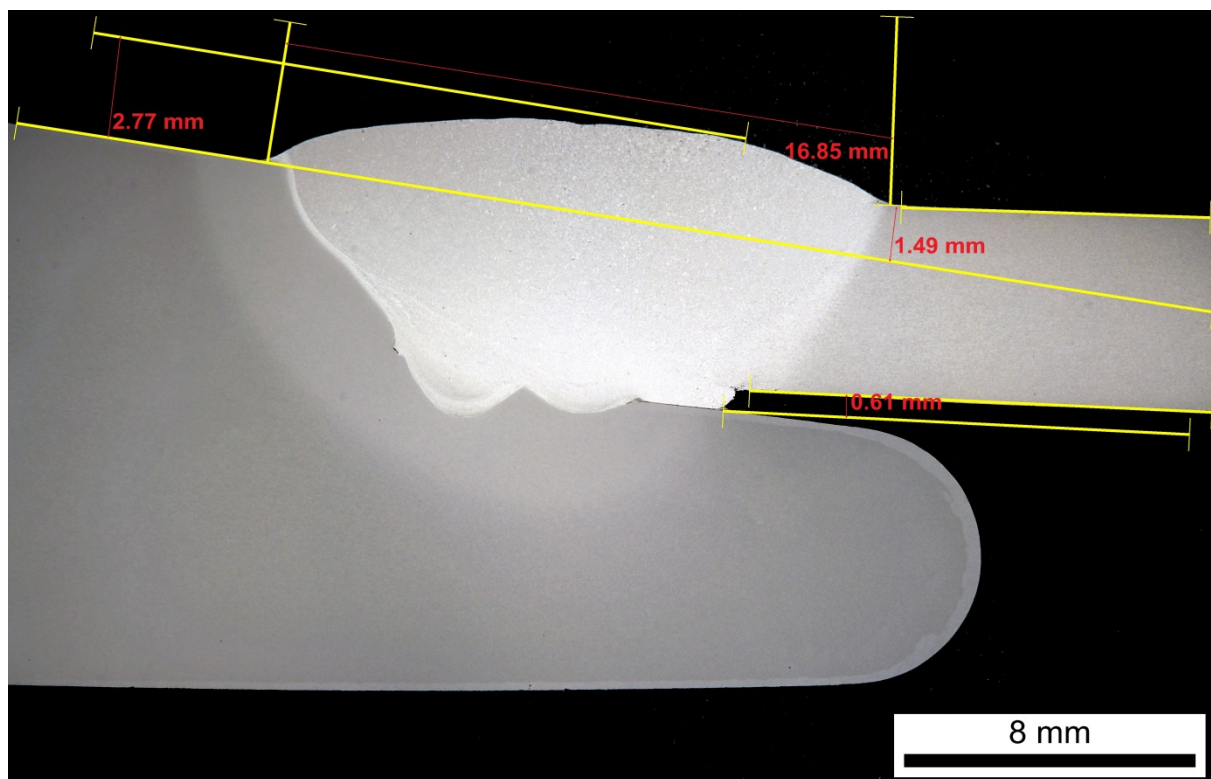


Figure I14 W02-05 macro (J3910 Band A O/S) measurements.

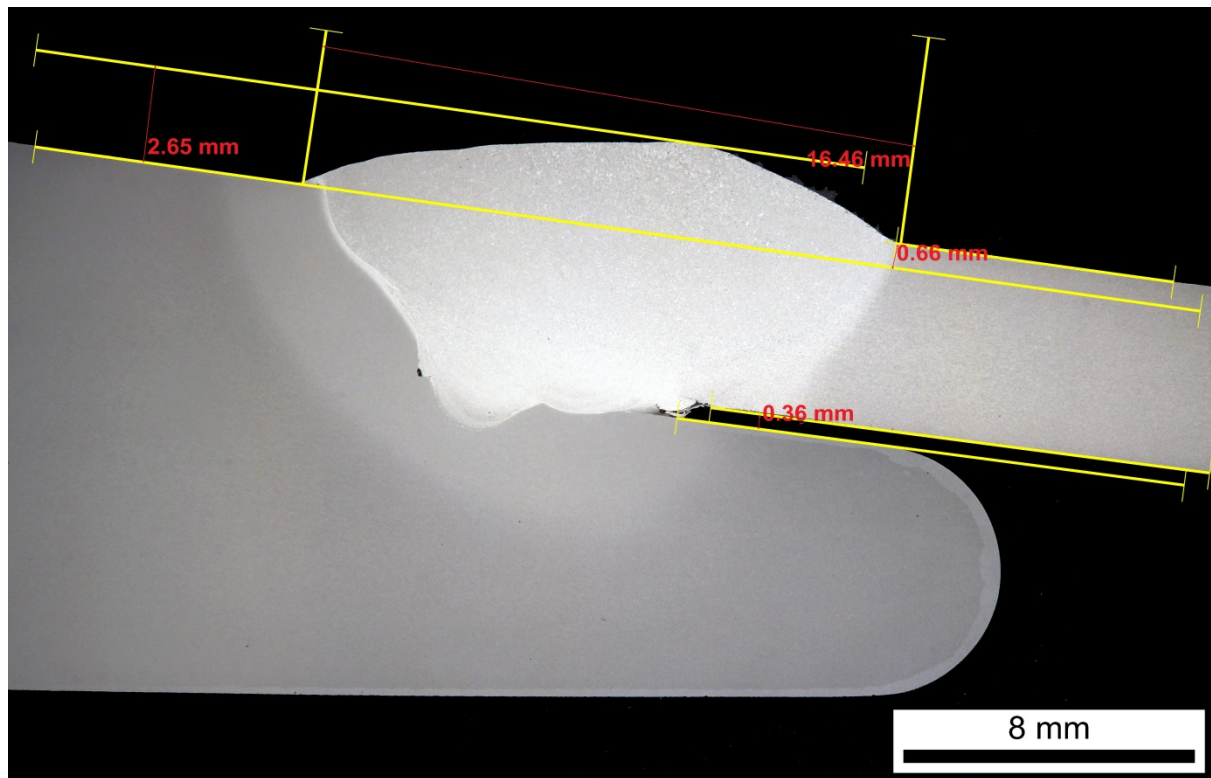


Figure I15 W02-06 macro (J3910 Band A O/S) measurements.

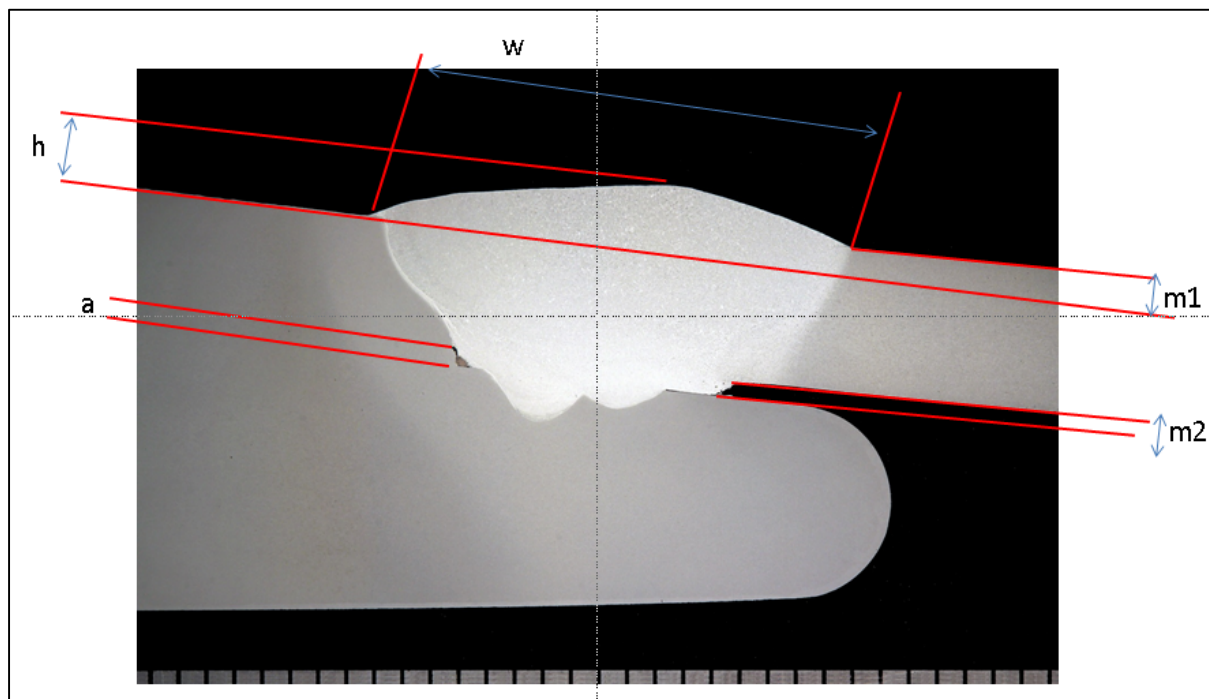


Figure I16 Macro measurements.

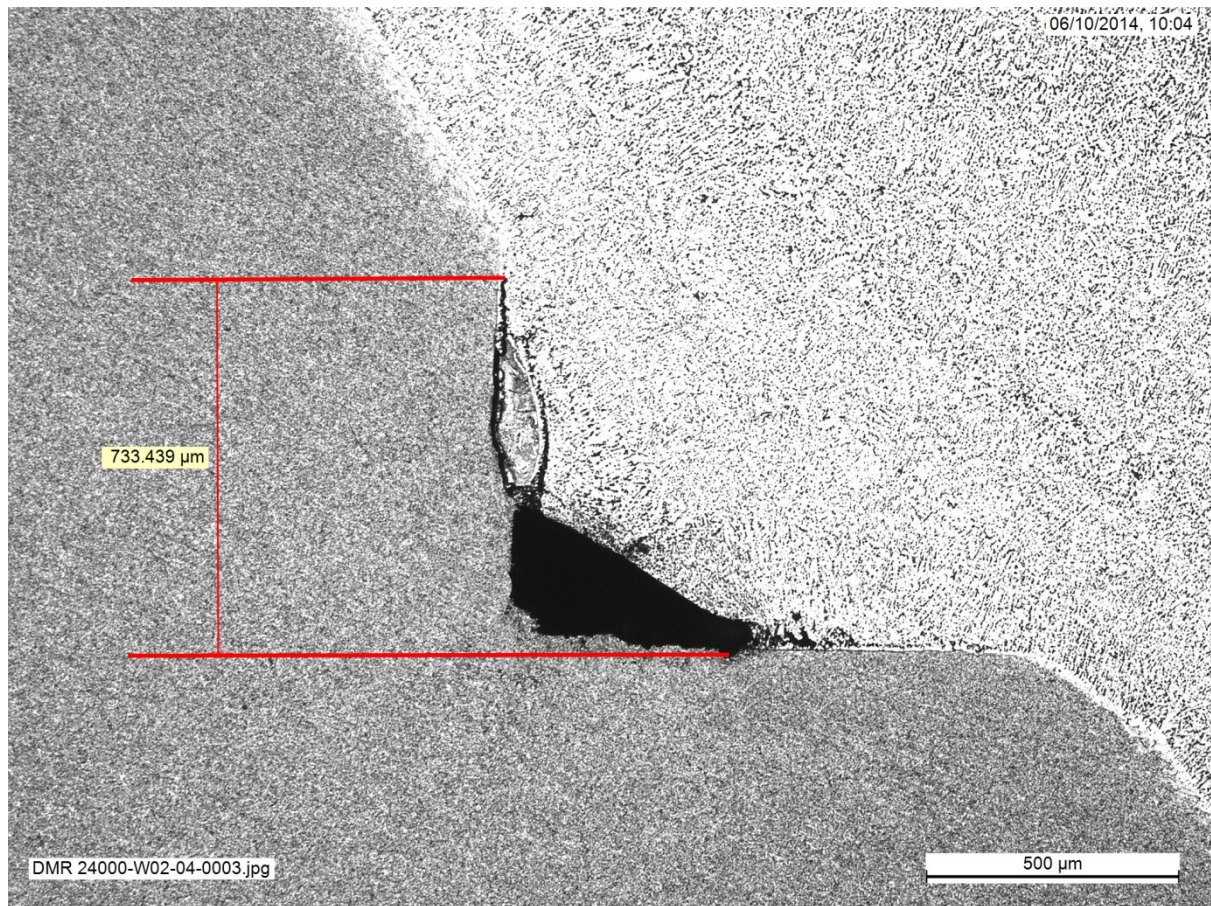


Figure I17 Micrograph from sample W02-04 of the lack of fusion defect. The total height is 733 μm (less than 1mm).

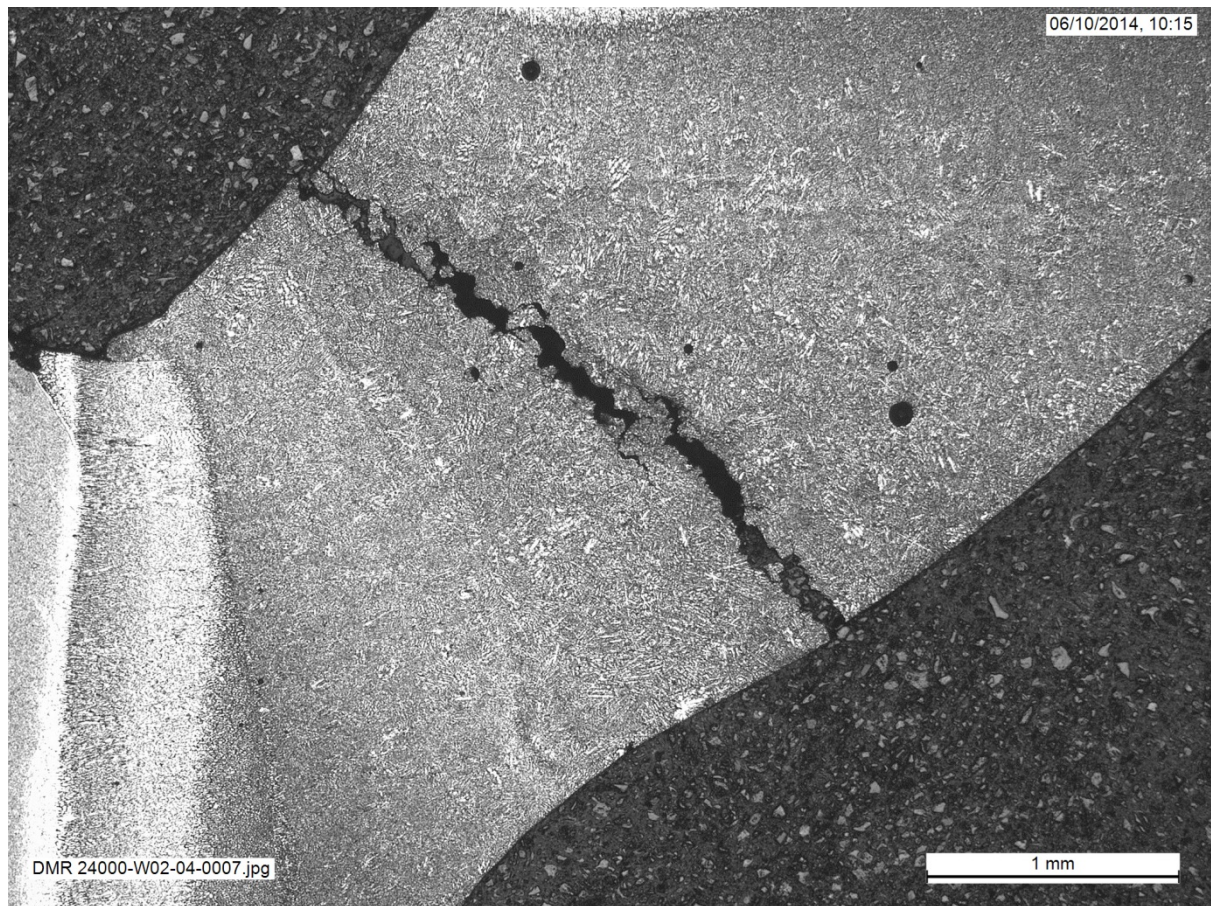


Figure I18 Micrograph from sample W02-04 showing the ruptured tack weld.