METALLURGICAL REPORT

January 29, 2020

EXAMINATION OF MAIN STEAM SUPPORTNIG LUG

[redacted]

CES PROJECT-17J197
PO-TBD

PREPARED FOR:

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Examination of Main Steam Supporting Lug
[redacted]

1.0 INTRODUCTION

A portion of a support lug ([redacted]) that had been welded to main steamline piping for [redacted] was removed from service and submitted to CES-Engineering Solutions for metallurgical analysis. It was reported that the sample had been removed because a 7” long indication had been detected along the attachment weld in the east lug, as shown by the area marked in white in Figure 1. No information was provided regarding the non-destructive test method used to find the indication.

According to the background information furnished with the sample, the lug was specified to have been fabricated from ASME SA-387, Grade 91 plate material. At the time the sample was removed, [redacted] had been in service for 51,450 hours. The operating temperature and pressure for the main steamline piping was reported as 1064°F and 2201 psi, respectively. Figure 2 shows the lug sample as it appeared when received by CES-Engineering Solutions. The purpose of the examination was to determine the source of the indication in the lug weld.

2.0 CONCLUSIONS

The destructive examination of the lug sample revealed that a crack had initiated from the root of the attachment weld and was propagating through the weld. The crack was approximately 2.4 mm (0.94”) deep within a weld deposit that was approximately 5.2 mm (0.20”) thick at the crack location. The crack was located near the bottom end of the lug and extended upwards approximately 18 mm (0.71”). The majority of the fracture surface was covered by a layer of high temperature oxide, so that the original features of the fracture could not be examined in sufficient detail to determine the cause of the initial cracking. The remaining features at the crack tip were indicative of a single transgranular crack that had propagated by fatigue. Shallow oxide-fatigue notches with a depth not exceeding 0.15 mm (0.006”) were observed on the weld face along the entire length of the marked area.

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Although there was not sufficient evidence to state with certainty why the crack at the root of the attachment weld first developed, it is likely that the cracking initiated during the original welding of the lug, possibly as a "cold" crack, and that the subsequent fatigue propagation occurred in response to the presence of that crack.

Examination of the weld metal in front of the crack tip uncovered highly localized early-stage creep cavitation (stage 2 – isolated cavities) due to the stress-concentration effect at the crack tip. Examination of the remainder of the sample showed that the metallurgical condition of the lug and the weld were normal, with no signs of additional cracking or any significant service-induced distress.

3.0 SUPPORTING DOCUMENTATION

3.1 Visual Examination

The sample was examined with the aid of a low magnification stereomicroscope in order to characterize the general features of the lug and the weld area, and to identify any visible damage or structural anomalies that might have been related to the indication. Of particular interest was the area at the bottom half of the North side of the lug where a portion of the weld had been circled in white to designate the suspected location of the indication (see Figures 1 and 2).

As shown in Figure 3, evidence of oxide-fatigue notching was observed on the weld face along the entire length of the marked area. On the root side of the weld, a crack was observed at the bottom end of the lug on the same side of the lug where the indication was reported to have been detected (North side); the visible crack extended approximately 18 mm (0.71") from the bottom end of the lug.

3.2 Chemistry Results

A material specimen was removed from the lug and chemically analyzed to verify that the correct material had been installed. The results of the analysis are recorded in Table 1, where it can be seen, the composition of the lug was consistent with the requirements established by ASME for SA-387, Grade 91 plate material.

3.3 Metallography

Three metallographic specimens were removed transverse to the North side attachment weld, one from near the top of the marked area on the weld, a second from the approximate mid-point of the marked area and a third from the bottom of the marked area, as indicated in the top photograph in Figure 2. These specimens were polished and etched so that the macrostructural and microstructural features of the weld deposit, the weld Heat-Affected Zone (HAZ) and the lug, itself, could be evaluated in detail using light microscopy.

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Examination of the specimen taken from the bottom end of the marked area revealed a crack that extended 2.4 mm (0.94”) into the 5.2 mm (0.20”) thick weld deposit, as shown in Figure 4. The majority of the crack length was covered by a relatively thick layer of high temperature scale, which obscured the original microstructural features of the crack. Near the crack tip, the visible features of the fracture were consistent with a single transgranular crack that had propagated by fatigue. In front of the crack tip, highly localized early-stage creep damage – i.e., cavitation - was found in the weld metal, as documented in Figure 5. In addition, a few shallow oxide-fatigue notches were observed on the weld face, as shown in Figure 6.

Examination of the specimens from the middle and top of the marked area at the weld revealed no signs of cracking from either the root or the face of the weld, as documented in Figures 7 and 9. On the weld face, a few shallow oxide-fatigue notches were observed, as shown in Figure 8 and 10.

Examination of the lug body and the weld, itself, uncovered no evidence of any discontinuities or other structural anomalies that could have contributed to the onset of the cracking. The typical metallurgical condition of the lug and the weld were found to be normal, with no signs of any significant service-induced distress. The typical microstructural condition of the lug base metal and the weld metal are documented in Figure 11.

3.4 Hardness Testing

Hardness tests were performed on the metallographic sections using a Vickers Hardness Tester with a 500 grams test load. The results of the hardness testing are presented in Table 2. As shown, the hardness of the lug material was consistent with Grade 91 that had been properly Normalized & Tempered and subsequently Post-Weld Heat Treated (PWHT’d) at a moderate temperature for a suitable amount of time; the hardness of the weld metal was consistent with Grade 91 filler metal in a properly PWHT’d condition.

If you have any questions pertaining to the information presented in this report, or if I can be of any further assistance in this matter, please feel free to call me at 423-267-0647.

Author ______________________________
Gang (Joe) Zhou

Reviewer ___________________________
Jeff Henry

Table 1. Chemistry Results

Chemical Composition (Weight Percent)		
ELEMENT	**Lug Base Metal**	**ASME Specification SA-387 Grade 91**
CARBON	0.09	0.06 - 0.15
MANGANESE	0.49	0.25 - 0.66
PHOSPHORUS	0.008	0.025 (max)
SULFUR	0.005	0.012 (max)
SILICON	0.28	0.18 – 0.56
NICKEL	0.16	0.43 (max)
CHROMIUM	8.27	7.90 – 9.60
MOLYBDENUM	0.87	0.80 – 1.10
VANADIUM	0.21	0.16 – 0.27
COLUMBIUM	0.07	0.05 – 0.11
TITANIUM	0.003	0.01 (max)
COBALT	0.018	***
COPPER	0.12	***
ALUMINUM	0.01	0.02 (max)
BORON	0.0005	***
TUNGSTEN	0.009	***
TIN	0.006	***
ZIRCONIUM	ND	0.01 (max)
NITROGEN	ND	0.025–0.080

2010 Section II, Part A

ND – Not Determined

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Table 2. Hardness Measurements

VICKERS HARDNESS VALUES-HV (HRB/HRC)* Vickers hardness tester with a 500-g test load				
Sample	***Location***	***Average***	***Range***	
			Min.	***Max.***
Micro A (SA-387 Grade 91)	Base Metal	229 (97 HRB)	228	231
	Weld Metal	256 (23 HRC)	255	257

* The HRB/HRC numbers are approximate values converted from Vickers Hardness readings using the conversion tables in the ASM Metals Handbook, Desk Edition - 1985.

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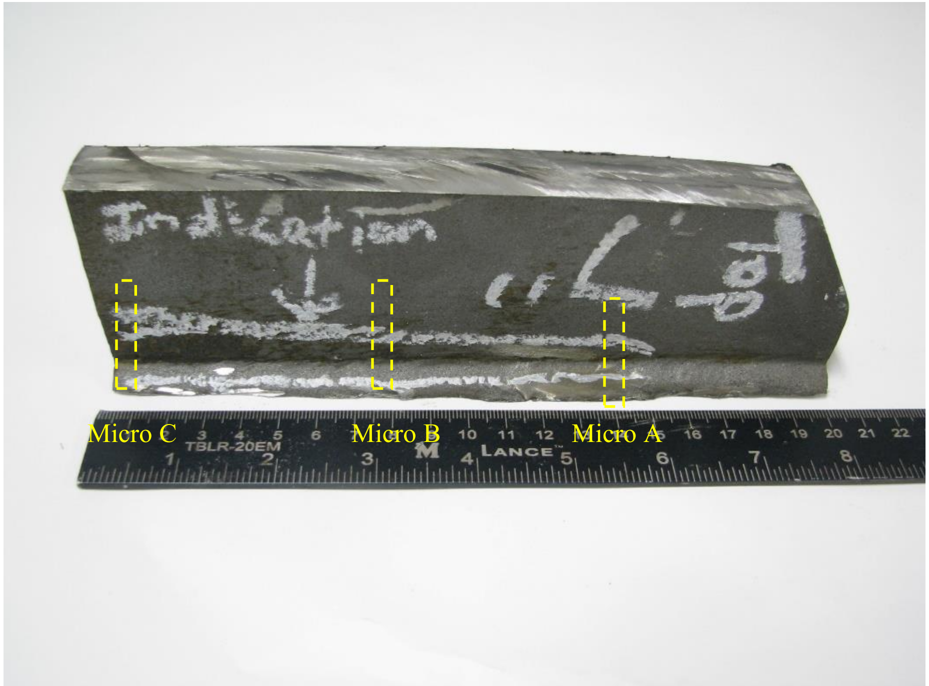
Figure 1. Shown is the north side of the east support lug [redacted], with the approximate location of the indication detected during a non-destructive inspection outlined in white.



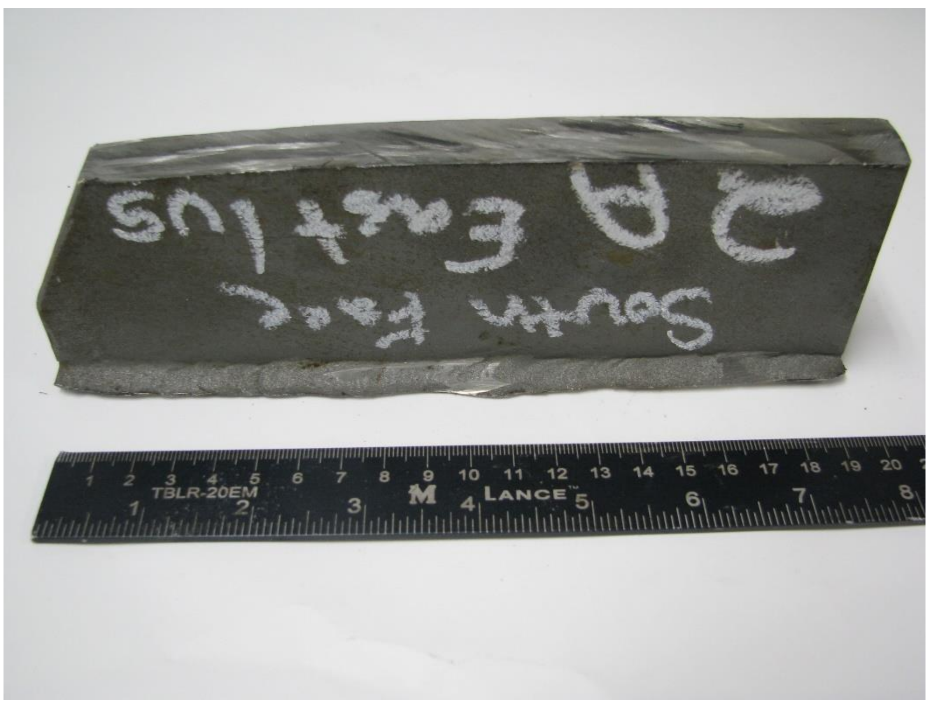


Figure 2. Shown are the general features of the lug sample in the as-received condition; the approximate locations from which the metallographic specimens were removed also is indicated in the top photo.

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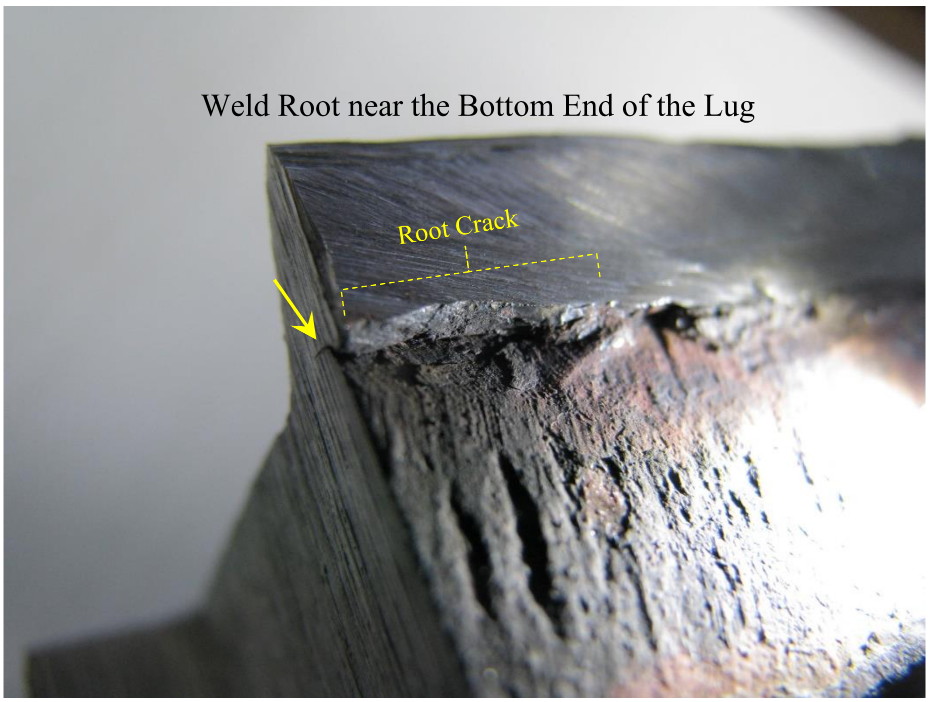

Figure 3. Shown are close-up views of the lug sample on the face-side (top photo) and root-side (bottom photo) of the weld.

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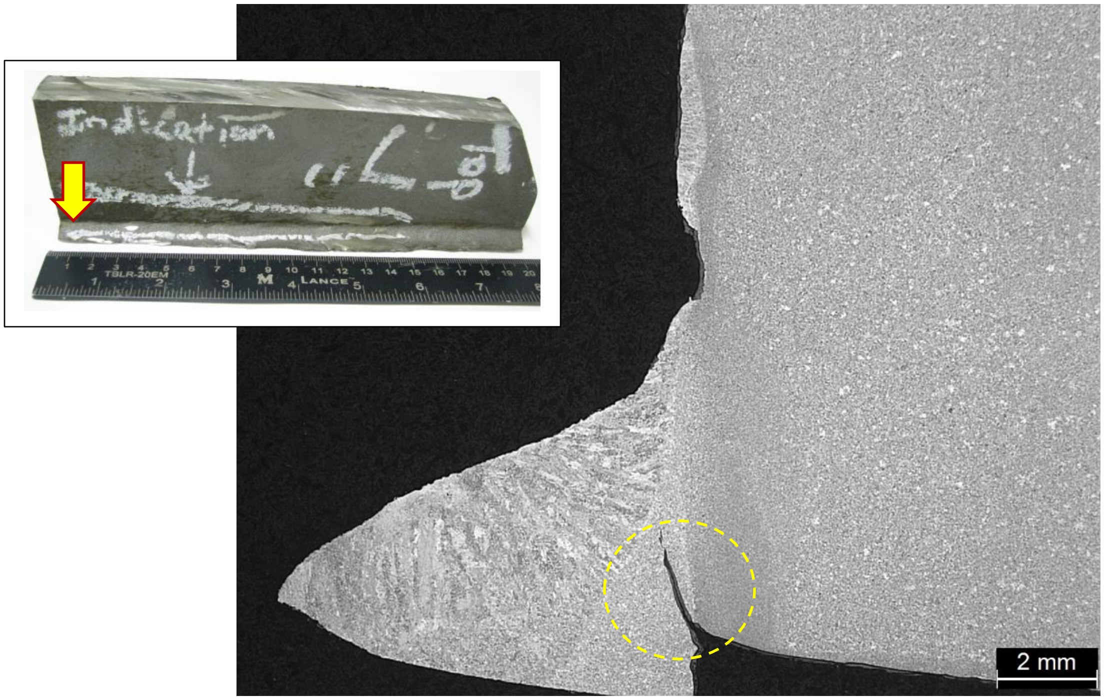
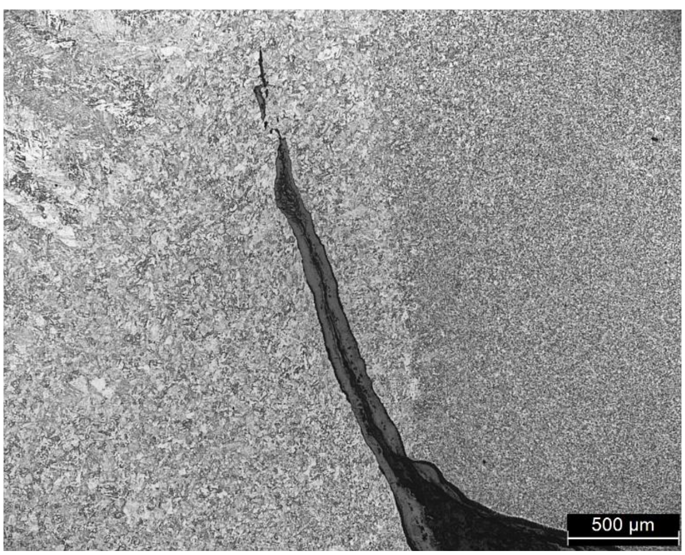
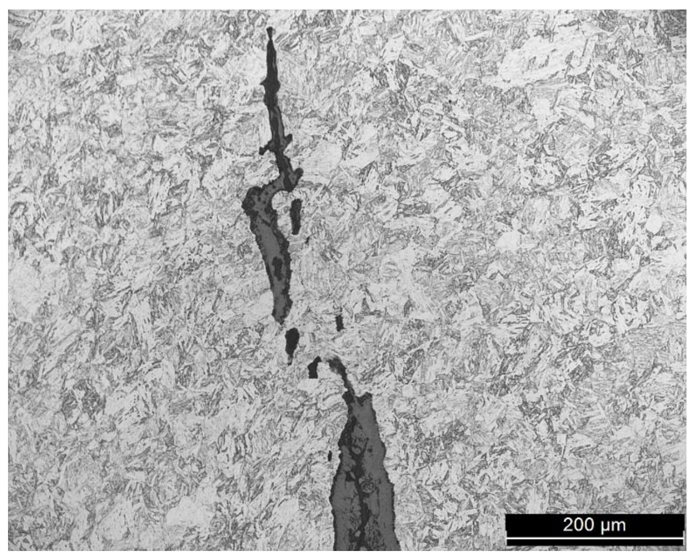


Micro-C
HCl Picric

Bottom End of Lug Indication-Side of the Weld

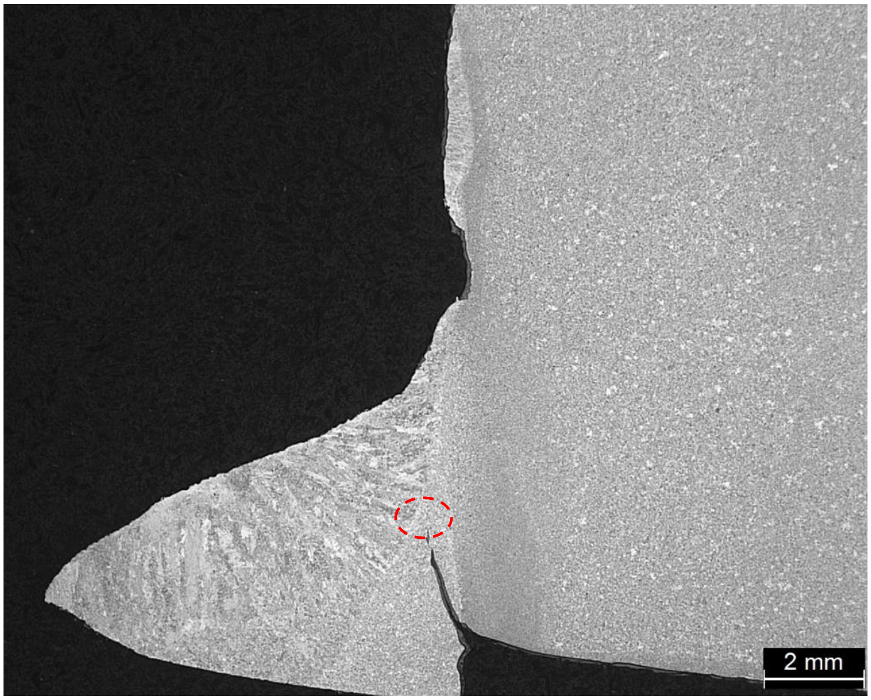




Micro-C

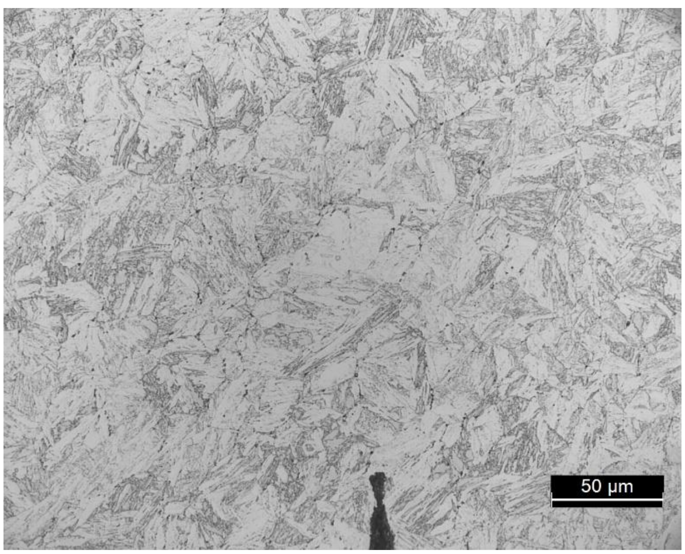
HCl Picric

Figure 4. Shown are the features of the crack that was found to have initiated from the root of the weld. The crack depth is approximately 2.4 mm, while the total thickness of the weld metal at this location is approximately 5mm.



Micro-C
HCl Picric

Bottom End of Lug Indication-Side of the Weld



Micro-C

HCl Picric

Figure 5. Shown are the features of the weld metal near the crack tip, with evidence of early-stage creep cavitation (Stage 2 – isolated cavities) visible near the crack tip.

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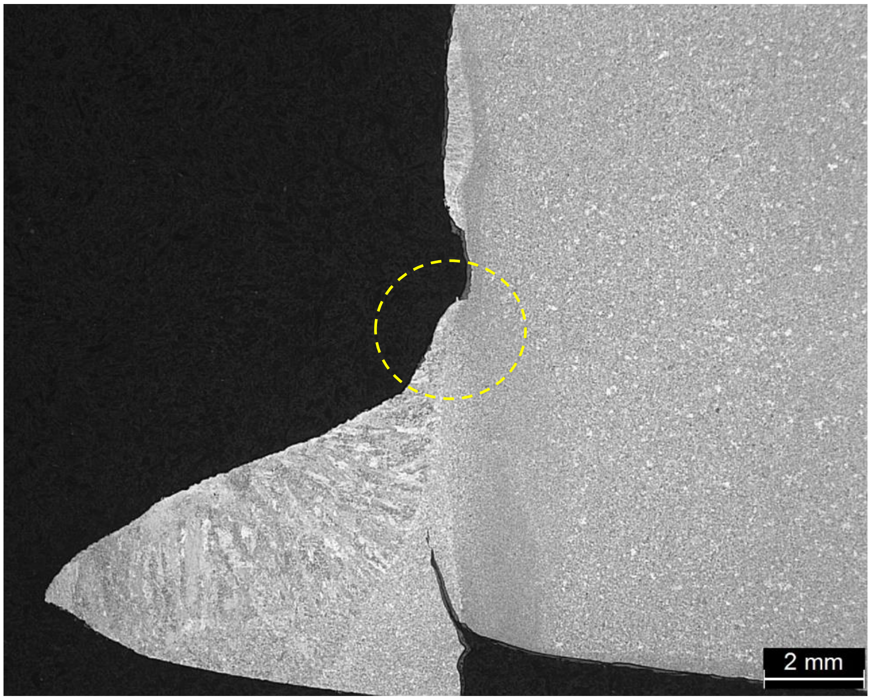
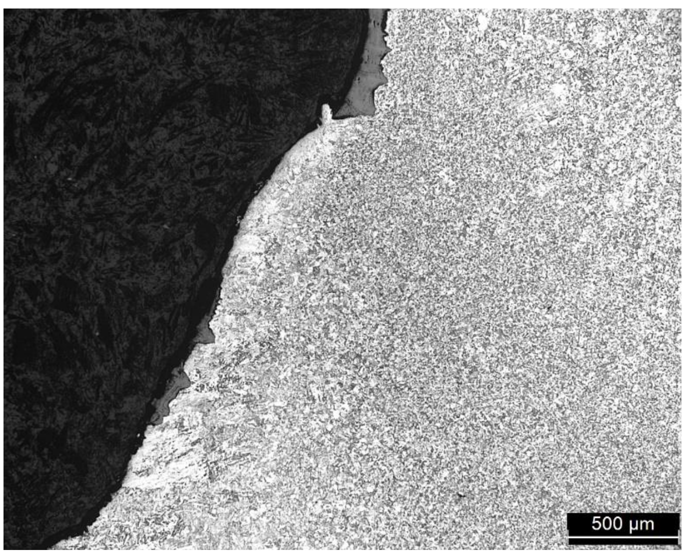
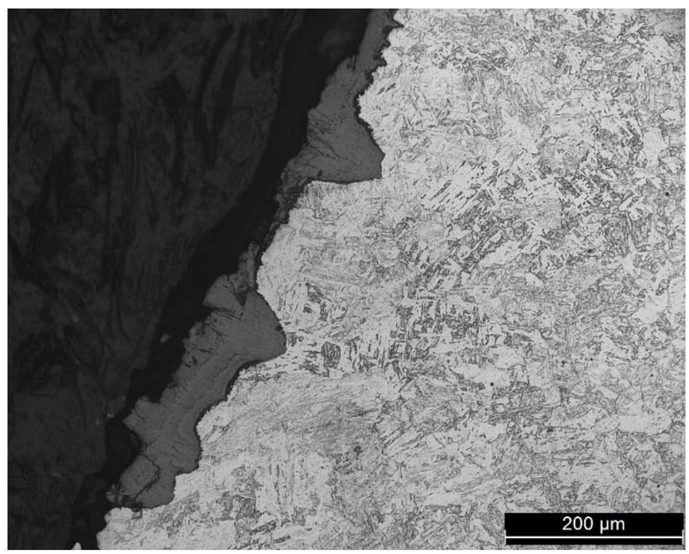


Micro-C
HCl Picric

Bottom End of Lug Indication-Side of the Weld





Micro-C

HCl Picric

Figure 6. Showing the features of the oxide-fatigue notches on the face of the weld.

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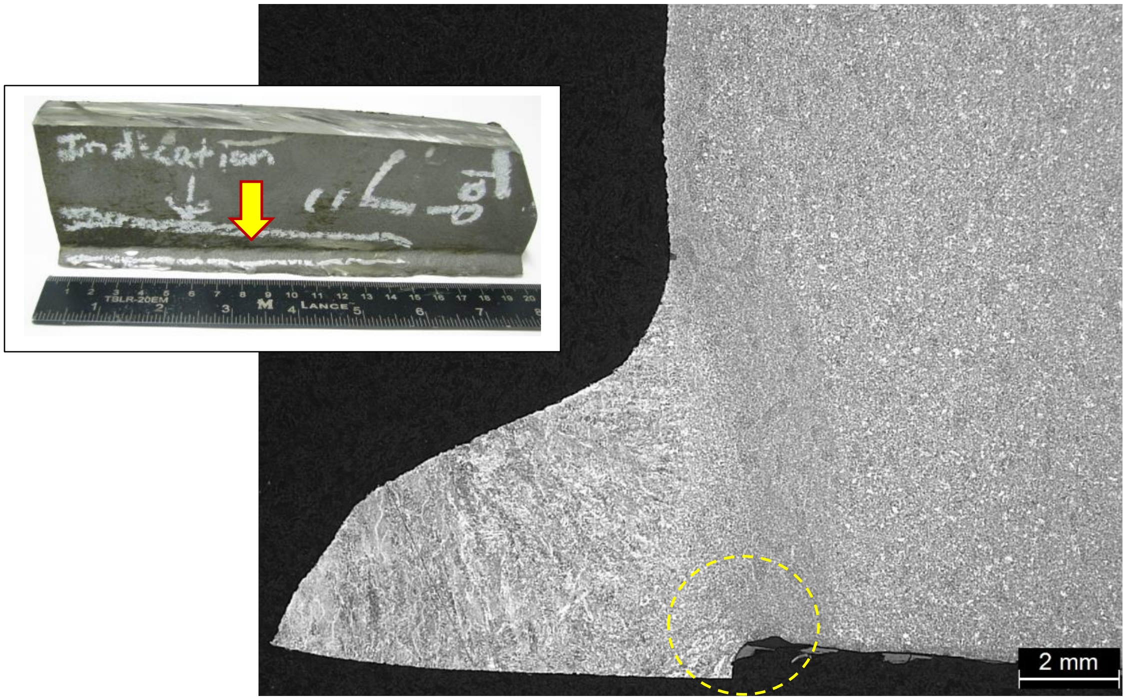
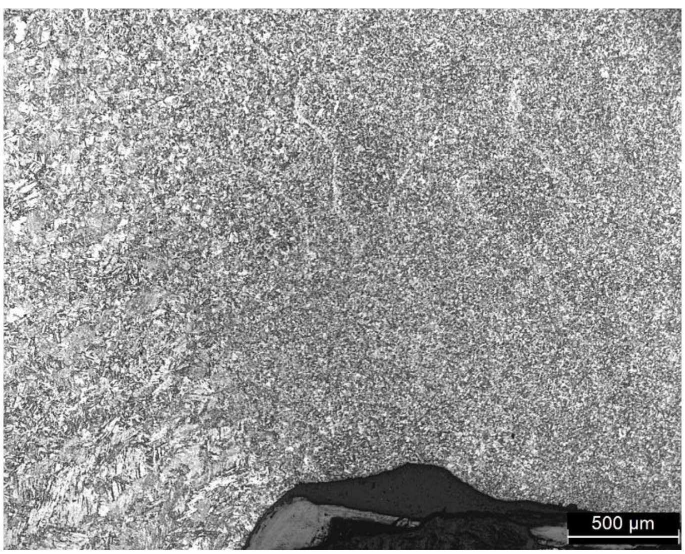
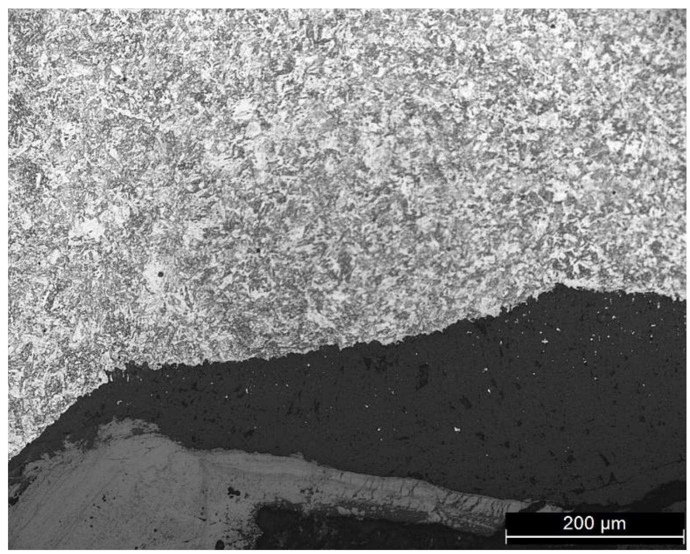


Micro-B
HCl Picric

Mid-Length of Marked Area Indication-Side of the Weld





Micro-B

HCl Picric

Figure 7. Shown are the features of the root of the weld at the mid-length of the marked area, with no sign of any crackling.

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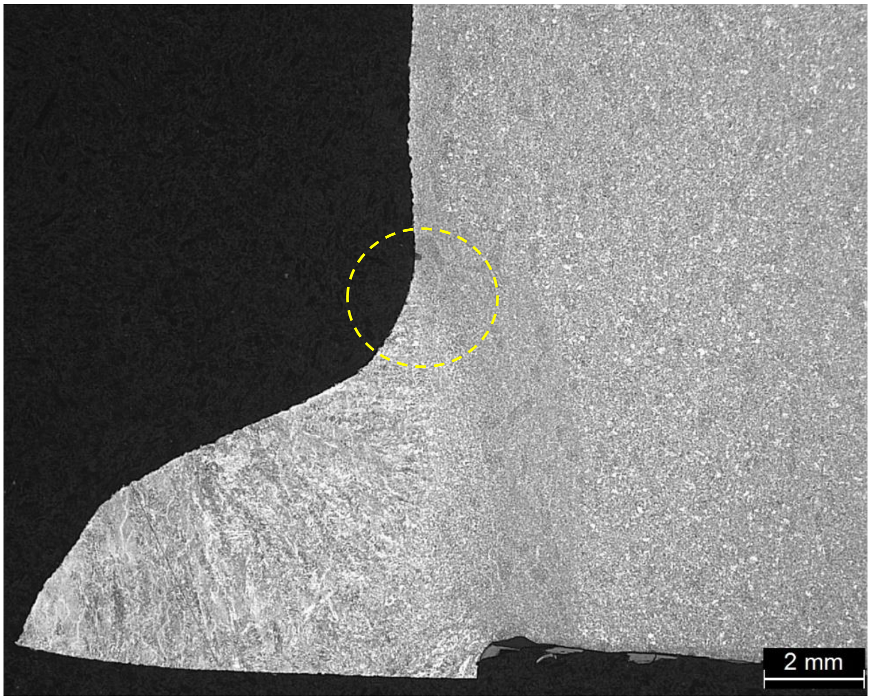
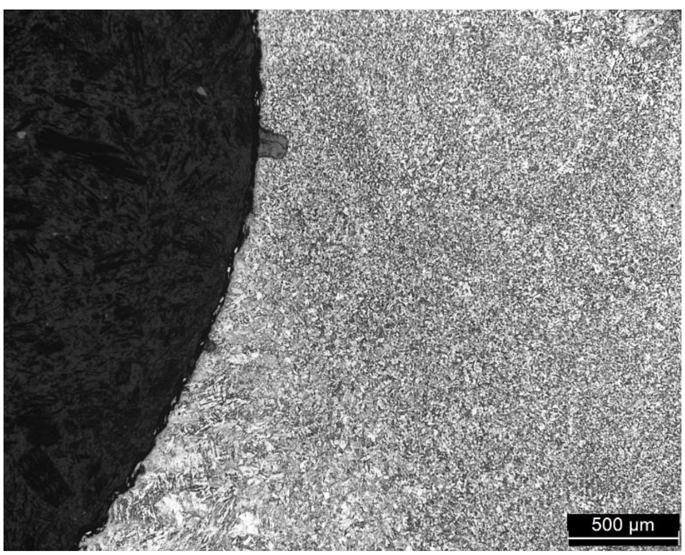
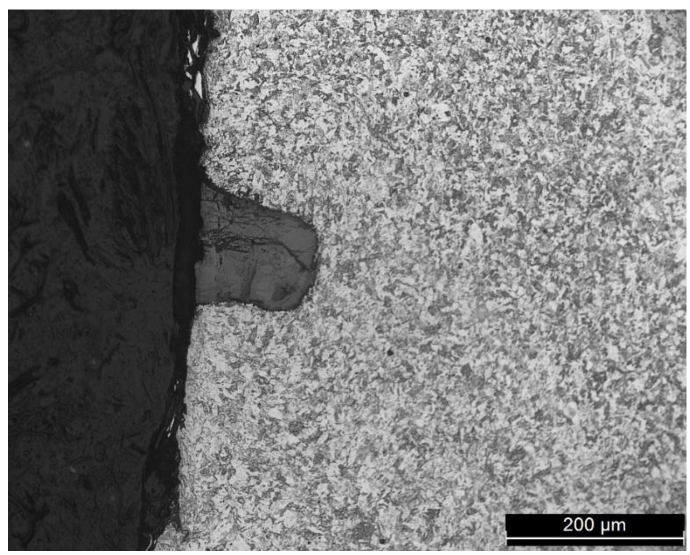


Micro-B
HCl Picric

Mid-Length of Marked Area Indication-Side of the Weld





Micro-B

HCl Picric

Figure 8. Shown are the features of oxide-fatigue notches on the face of the weld at the mid-length of the marked area.

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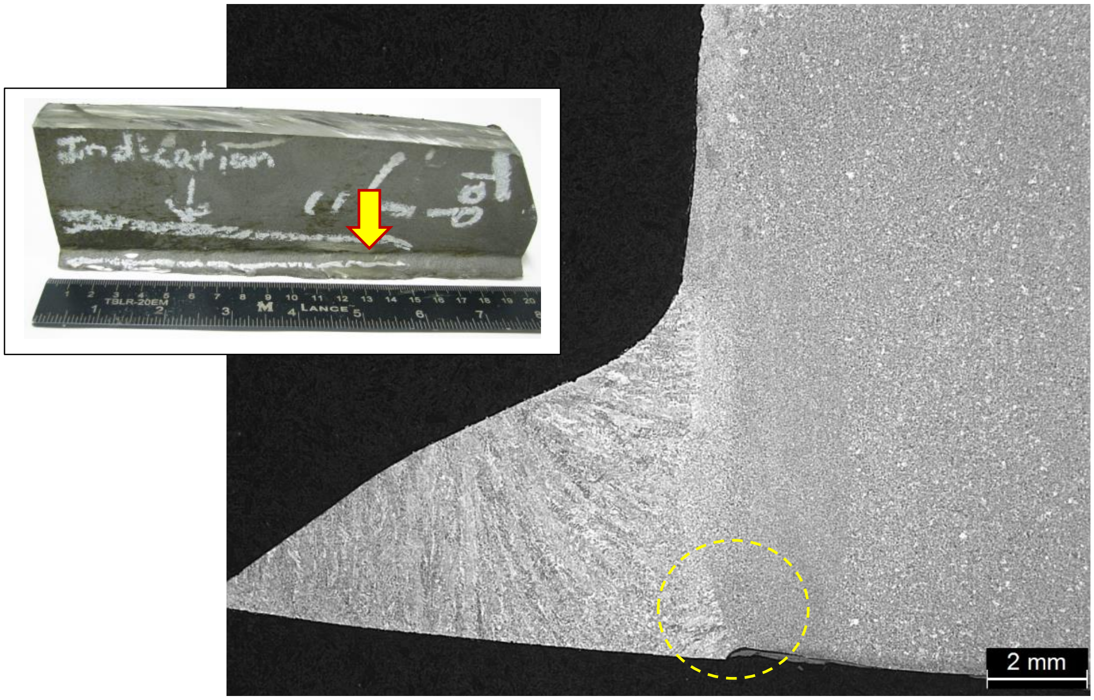
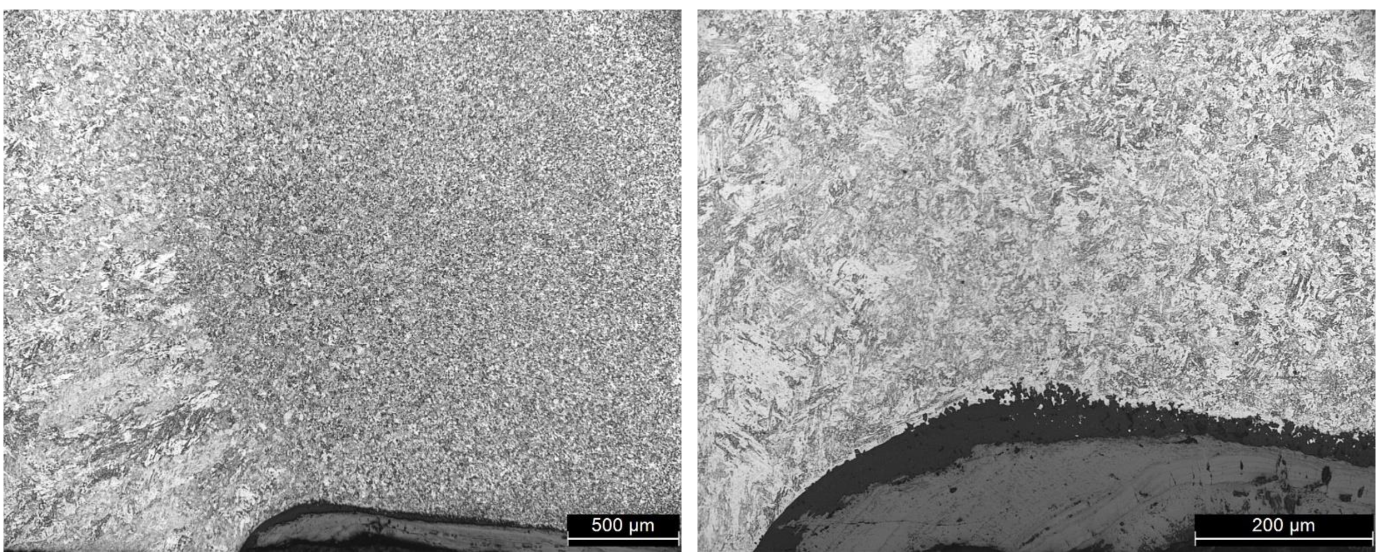


Micro-A
HCl Picric

Top End of Marked Area Indication-Side of the Weld



Micro-A

HCl Picric

Figure 9. Shown are the features of the root of the weld at the top end of the marked area, with no sign of any crackling.

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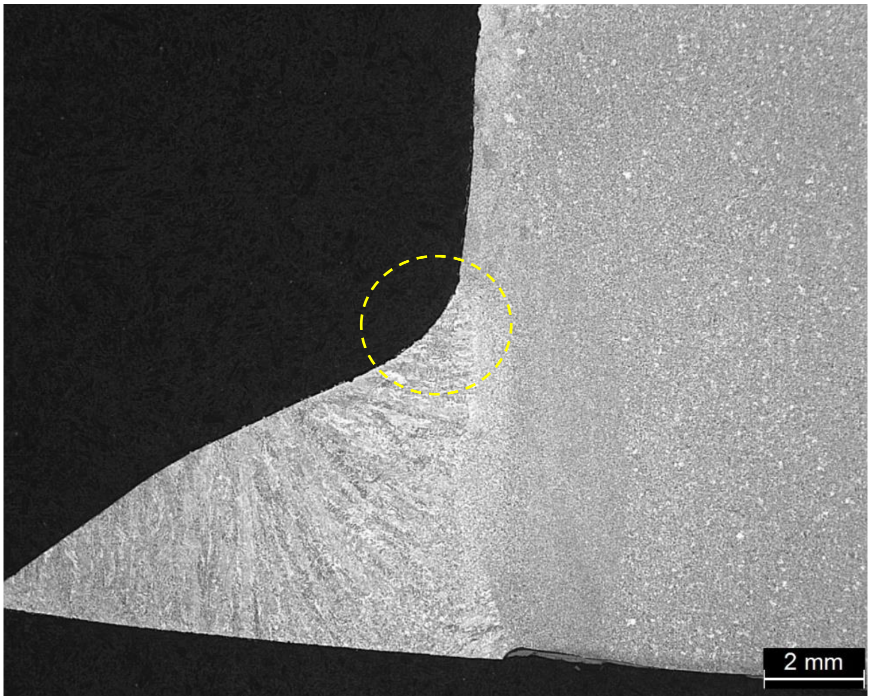
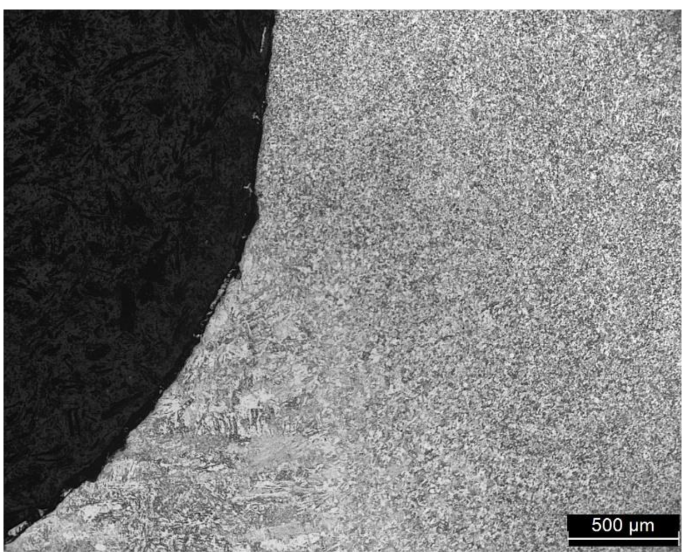
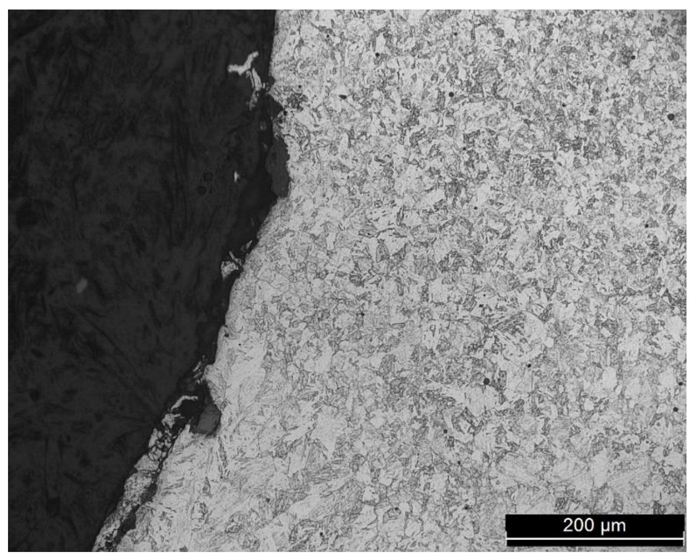


Micro-A
HCl Picric

Top End of Marked Area Indication-Side of the Weld





Micro-A

HCl Picric

Figure 10. Shown are the features of the oxide notches on the face of the weld at the top end of the marked area.

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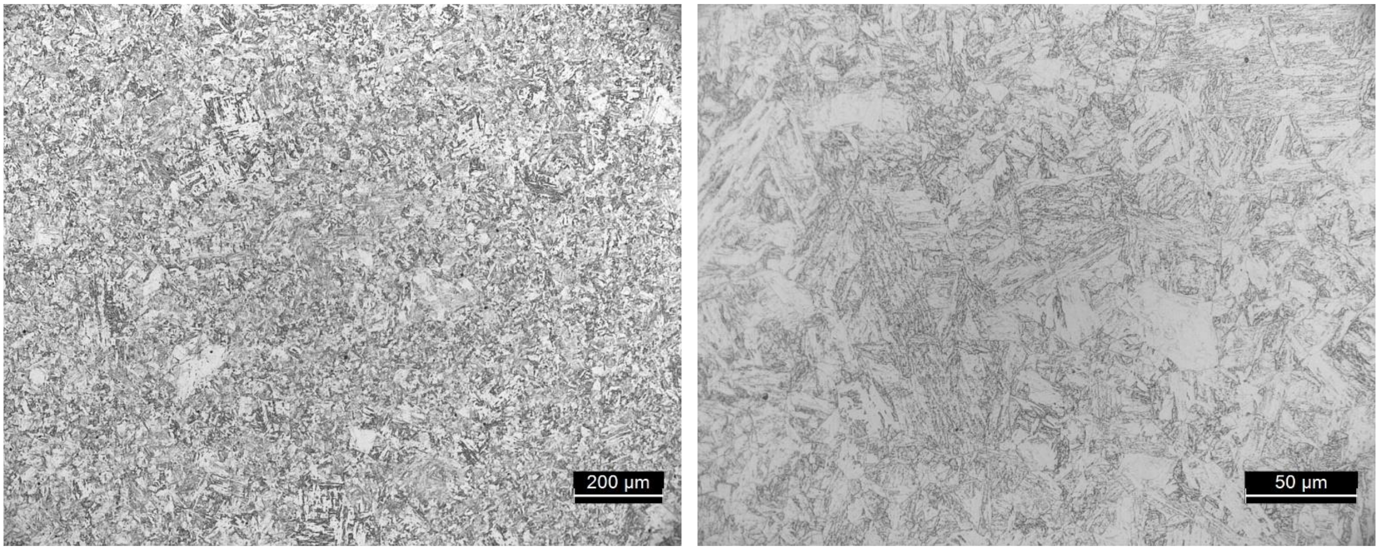
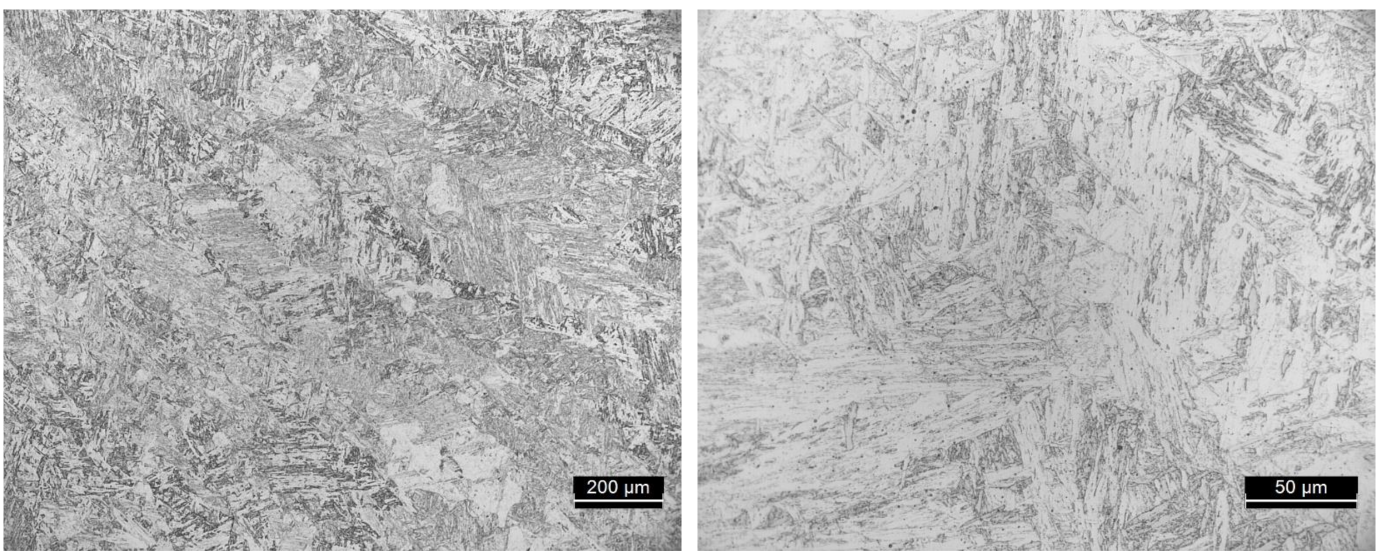


Micro-C *Base Metal* HCl Picric



Micro-C *Weld Metal* HCl Picric

Figure 11. Shown are typical microstructural features of the base metal and the weld metal in the main steam lug sample.

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