ATTACHMENTS

KASGRO REPORT 1
METALLURGICAL REPORT

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Metallurgical Evaluation of a Welded Steel Plate

Kasgro Rail Corp
121 Rundle Rd
New Castle, PA 16102

Attention: Rick Ford

Confidential and Privileged Information

REPORT No. 202201788

August 22, 2022

Report By:

Brett A. Miller, P.E., FASM

Nadcap Administered by PRI ACCREDITED Materials Testing Laboratories

A2LA ACCREDITED Testing Cert # 1140.03 & 1140.04

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SUMMARY

Metallurgical evaluation of the submitted center plate confirmed that the composition satisfied the requirements for AAR specification M-201-00 for Grade C steel. There were no compositional anomalies that would have contributed to the welding issues. The tensile mechanical properties were in general conformance with the specification, however, the elongation and reduction of area, measures of ductility, were both below the specification requirements. These departures from the specification were not considered to be a cause of the cracking. The hardness measured within the core of the cast plate was satisfactory.

Visual and cross-section microscopic evaluation of the transverse cracks on the welded edge of the plate revealed that they were welding hot cracks. The cracks were jagged and generally followed the columnar solidification grains evident within the weld. Most of the cracks were within the weld, however, one unusually long crack continued through the weld, the heat affected zone (HAZ), and terminated in the base metal. This crack was approximately 7.9 mm (0.311") deep. No gross fusion flaws were identified in the regions that were studied.

Hot cracking of weld metal is caused by a wide variety of potential synergistic factors. Low welding currents, excessive travel speed, small electrodes, insufficient preheat, poor joint preparation, and many other interrelated factors can lead to hot cracking. One substantial concern identified during review of the material specification was regarding the specified composition. Hardenability of a steel is primarily a function of the alloy content, although grain size and other factors also contribute. The AAR specification does not contain upper limits on many of the alloying elements that can contribute to greater hardenability during the welding process. This could result in an enhanced cracking propensity in subsequent lots of the same material resulting from permissible compositional variation. The relatively low welding preheat should be reviewed due to the hardenability of this steel.

DESCRIPTION AND PURPOSE

A railcar center plate that exhibited cracks was submitted for metallurgical failure analysis. It was stated that the cast steel plate had been fillet welded around its entire periphery but that transverse cracks were later identified after a short duration in service. The material of construction was identified as a normalized and tempered cast alloy steel per AAR Specification M-201-00 Grade C. The welding filler metal was identified as an 80 ksi alloy, with a prescribed welding preheat of 225 °F. No further information concerning the welding process was presented. It was requested that the chemical composition and mechanical properties of the plate be determined for specification comparison. It was further requested that cross-section evaluation of the cracking be performed in order to determine the likely cause of the cracking.

ANALYTICAL PROCEDURES

I. Visual Examination and Optical Microscopic Examination
- A. Visual Observations
- B. Photography (digital)
- C. Optical Stereomicroscopy, magnifications up to 120X

II. Chemical Analysis: Base Metal
- A. Optical Emission Spectroscopy, ASTM E415-17

III. Scanning Electron Microscopic Examination
- A. Scanning Electron Microscopy (SEM), permits examination at high magnification and with great depth of field

IV. Mechanical Testing
- A. Tensile Testing, ASTM A370-21
- B. Brinell Hardness, ASTM E10-18
- C. Microindentation Hardness Testing, ASTM E384-17
- D. Approximate Hardness to Tensile Strength Conversion for Steel, ASTM A370-21

V. Metallography
- A. Microstructural Analysis using a Light Metallurgical Microscope, specimen preparation in accordance with ASTM E3-11 (17)
- B. Coating Thickness Determination per ASTM B487-85(13)

RESULTS

VISUAL EXAMINATION

The submitted plate is shown in the as-received condition in Figure 1. The rectangular plate was relatively flat and did not exhibit any gross mechanical damage. One edge of the plate was cut and ground and this is oriented toward the bottom in Figure 1. This edge exhibited the presence of cracks that were the concern of this investigation. A number of visible crack -like features were apparent along this cut edge and two prominent areas were selected for laboratory analysis. These regions were arbitrarily identified as Regions A and B, as shown in Figures 2 and 3, respectively. These regions contained small clusters of cracks that were primarily through the thickness of the cast plate. The top and bottom surfaces of the plate were relatively rough and rusted, so it was not possible to determine how far the cracking continued into the plate. Similarly, it was not possible to determine how deep the weld continued into the base metal due to prior grinding that had been performed. Inspection of the other three edges of the plate did not exhibit analogous cracking, however, those edges were not prepared to the same finish as the edge identified for analysis.

Photographs of representative cracking are shown as Figures 4 and 5. Cracking was irregular and contained some reddish rust. Some features such as porosity in the material surrounding the cracks confirmed that the cracking at the surface was within weld metal. The areas of interest were then examined using optical stereomicroscopy at magnifications up to 100X. Representative images of cracks are included as Figures 6 and 7. The nature of the cracks could not be determined visually, but they were relatively jagged rather than curved, which can be suggestive of incomplete fusion during the welding process.

CHEMICAL ANALYSIS

Chemical analysis was performed on a sample that was removed from the plate and the results are summarized in Table 1. The requirements for AAR Specification M-201-004 Grade C steel castings are included in Table 1 for reference. The composition of the plate satisfied the requirements for this alloy. It was noted that substantial alloying to increase the hardenability and strength of the casting were quantified. The specification permits the steel mill wide alloying discretion in order to satisfy the mechanical property requirements.

MECHANICAL TESTING

Tension testing was performed on a specimen that was removed from the center of the plate thickness parallel to the edge of the rectangular plate. The location of the specimen was approximately 1 ½" from the edge, in an area that would not be affected by the heat of the welding process. The mechanical properties that were obtained on the 0.5" diameter specimen are summarized in Table 2. The tensile strength and yield strength of the plate satisfied the minimum requirements for the specification. Both the elongation and reduction in area values were below the minimum requirements.

Brinell hardness testing was performed on a specimen that was also removed remote from any welding effects. The obtained result is provided in Table 3. The plate satisfied the hardness range per the material specification.

Vickers microindentation hardness testing was performed on a polished metallographic cross-section specimen. Measurements were made in the weld, heat affected zone, and within the base metal remote from any welding effects. Hardness measurements are summarized in Table 4. The measured base metal hardness equated to an approximate tensile strength very similar to the measured tensile strength of the plate. The weld was slightly higher than the base metal hardness level. The heat affected zone hardness was substantially harder than both the base metal and the weld, indicative of a welding process that resulted in substantial transformation.

METALLOGRAPHY

Metallographic cross-section specimens were prepared at horizontal planes through the center of the plate in both Regions A and B. The specimens were examined in the as-polished condition and after etching to reveal the microstructures. Each specimen was examined at magnifications up to 1,000X. Representative images of the observed diagnostic features are provided as Figures 8 through 22. The cross-section specimens confirmed that the visible cracks on the ground edge surface were deep cracks within the solidified weld metal. The cracks were jagged and many regions were filled with oxide. Additionally, the cracks were oriented at an angle to the edge of the plate. Several cracks that did not intersect the plate edge in the plane examined were identified. All of the cracks on the prepared specimens were measured and some of the measurements are included in the images. The deepest measured crack was at Region B and it was approximately 7.9 mm (0.311") deep. This crack was found to be through the entire weld, heat affected zone, and then terminated within the adjacent base metal. All of the remaining cracks were entirely within the weld except one that was partially into the heat affected zone. Etching revealed that the cracks to a large extent followed the columnar solidification grains within the weld. Some small pores and a small region of minimal incomplete fusion were identified but no gross fusion flaws were identified.

The typical microstructure of the cast plate consisted of ferrite, coarse lath martensite and temper carbides. The observed structure was consistent with the specified normalized and tempered condition. The heat affected zone contained substantial martensite transformation, confirming prior hardness testing results. The weld microstructure also contained ferrite and coarse martensite.

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Materials Testing Laboratories

Respectfully submitted

Brett A. Miller, P.E., FASM
Technical Director

Concurrence

Brian Kelly
Failure Analyst

TABLE 1 – CHEMICAL ANALYSIS TEST RESULTS, WEIGHT PERCENT

Element	Plate	AAR M-201-00 Grade C Specification Requirements
Carbon	0.31	0.32 Maximum
Manganese	0.91	1.85 Maximum
Silicon	0.72	1.50 Maximum
Phosphorus	0.016	0.04 Maximum
Sulfur	0.009	0.04 Maximum
Chromium	0.63	-----
Nickel	0.18	-----
Molybdenum	0.67	-----
Aluminum	0.04	-----
Titanium	<0.01	-----
Cobalt	0.01	-----
Copper	0.10	-----
Niobium	<0.01	-----
Vanadium	0.02	-----
Iron	Remainder	Remainder

Results in weight percent unless otherwise indicated

TABLE 2 – TENSION TEST RESULTS

Property	Plate	AAR M-201-00 Grade C Specification Requirements
Ultimate Tensile Strength, ksi	108	90 Minimum
0.2% Offset Yield Strength, ksi	76	60 Minimum
Elongation, %	19	22 Minimum
Reduction in Area, %	41	45 Minimum

Specimen Dimensions; 0.5” diameter x 2” gage length
Percent elongation was measured using elongation-after-fracture measurements

TABLE 3 – BRINELL HARDNESS TEST RESULTS, HBW, 3,000 KG TEST LOAD

Results	Plate	AAR M-201-00 Grade C Specification Requirements
Specification	229	179 - 241

TABLE 4 – VICKERS MICROINDENTATION HARDNESS TEST RESULTS – HV_{500gf}

Measurement	Base Metal	HAZ	Weld
Reading 1	249	462	293
Reading 2	235	443	280
Reading 3	232	389	305
Reading 4	241	379	287
Reading 5	237	373	315
Average	239	409	296
Approximate Tensile Strength Equivalent ①	110 ksi	192 ksi	136 ksi

①– Conversion per ASTM A370-21

Figure 1. Photograph showing the submitted center plate. The ground weld edge that exhibited cracks is toward the bottom in this image.

Figure 2. Image showing a cluster of cracks identified as Region A. A number of individual vertical cracks were evident on the cut and ground surface.

Figure 3. Image showing a cluster of cracks identified as Region B. A number of individual vertical cracks were evident on the cut and ground surface.

Figure 4. Close-up image of several of the Region A cracks. The top and bottom edges of the cast plate were ground. A cross-section specimen was prepared through the center of these cracks.

Figure 5. Close-up image of several of the cracks at Region B. A cross-section specimen was prepared through the center of these irregular cracks. Several gas pores are also apparent in this image.

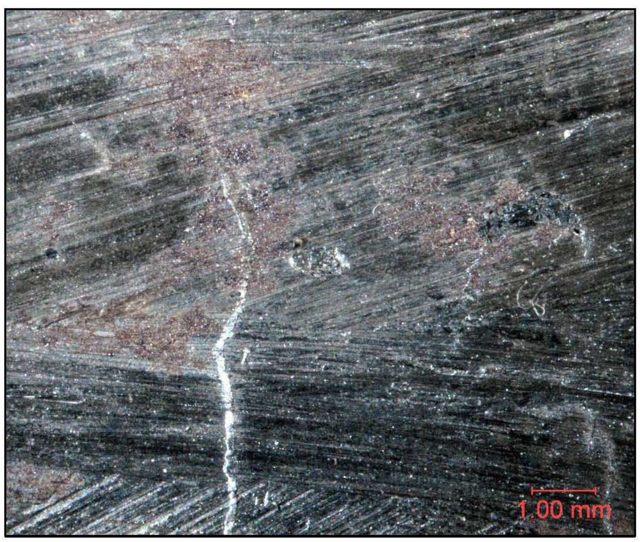

Figure 6. Stereomicroscope image showing some of the fine crack features at Region A. (4.9X)

Figure 7. Stereomicroscope image showing some of the fine crack features at Region B. (4.9X)

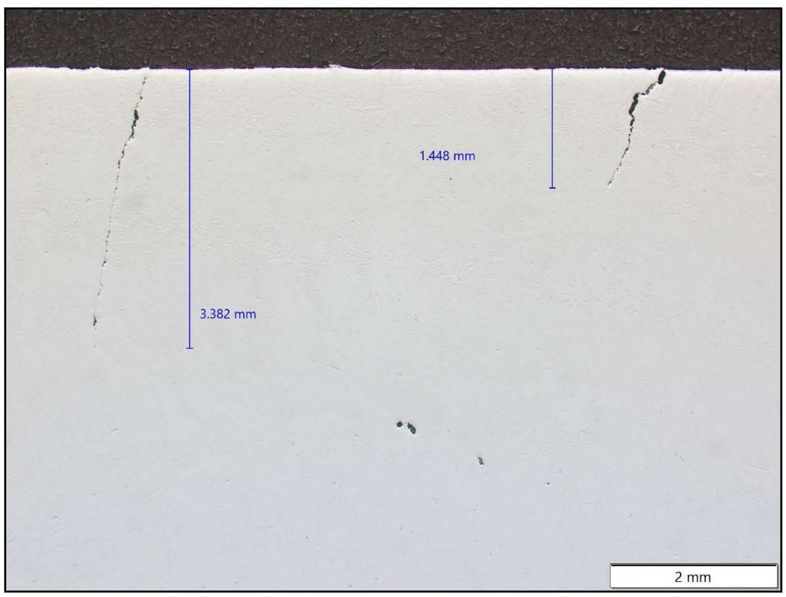

Figure 8. Metallographic cross-section specimen through one part of Region A. Irregular, angled cracks were evident to a maximum depth of 3.4 mm (0.134”). (As-polished, 14.9X)

Figure 9. Photomontage of the crack region in Figure 8 after metallographic etching. The cracks were entirely within the weld (arrows). (2% Nital etch, 8.8X)

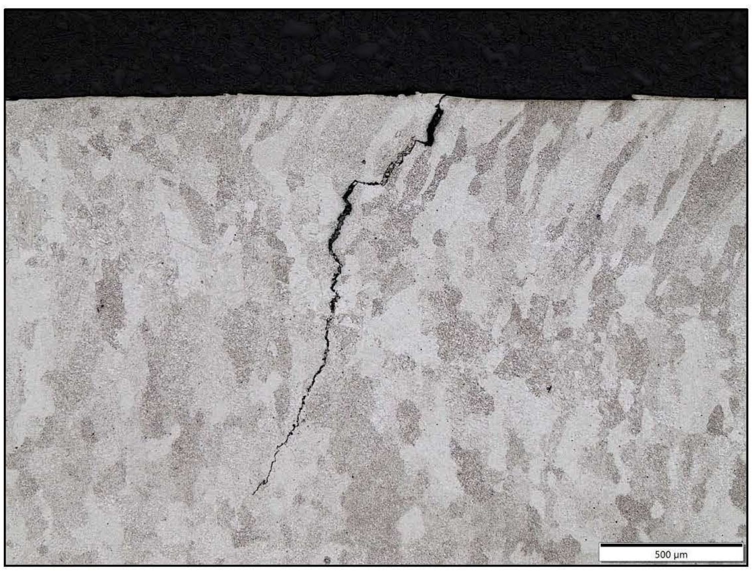

Figure 10. Low magnification image showing the jagged crack toward the right in Figure 9. The cracking followed the columnar solidified grains within the weld. (2% Nital etch, 50X)

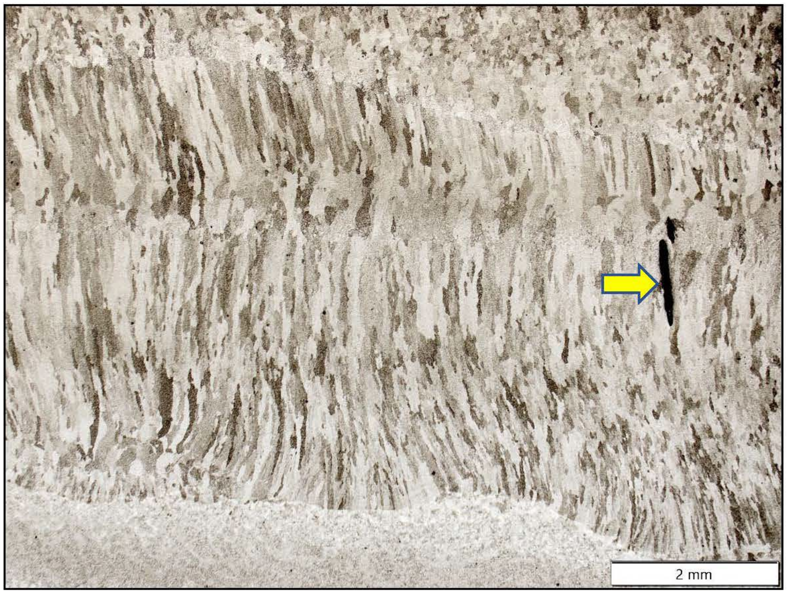

Figure 11. Metallographic cross-section specimen through an additional location of Region A where a subsurface fissure (arrow) was evident. (As-polished, 14.4X)

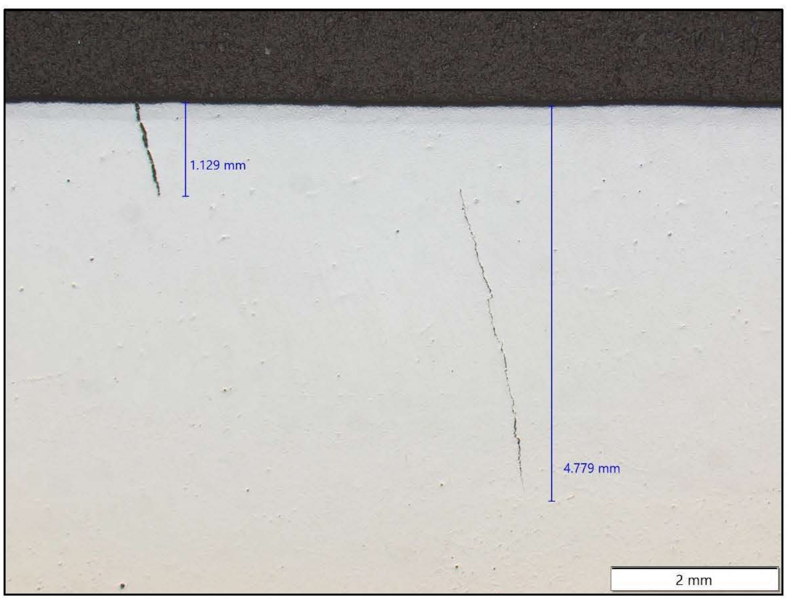

Figure 12. Metallographic cross-section specimen through one part of Region B. Irregular, angled cracks were evident to a maximum depth of 4.8 mm (0.188"). (As-polished, 14.4X)

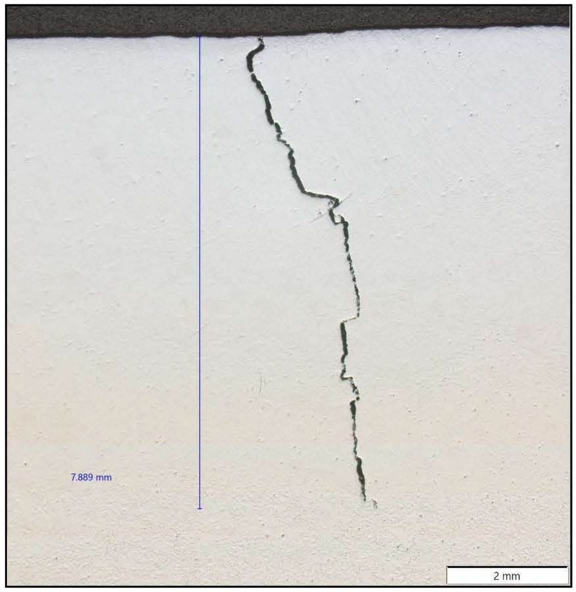

Figure 13. Photomontage of the deepest crack on the specimen from Region B. This jagged crack was approximately 7.9 mm (0.311”). (As-polished, 10.4X)

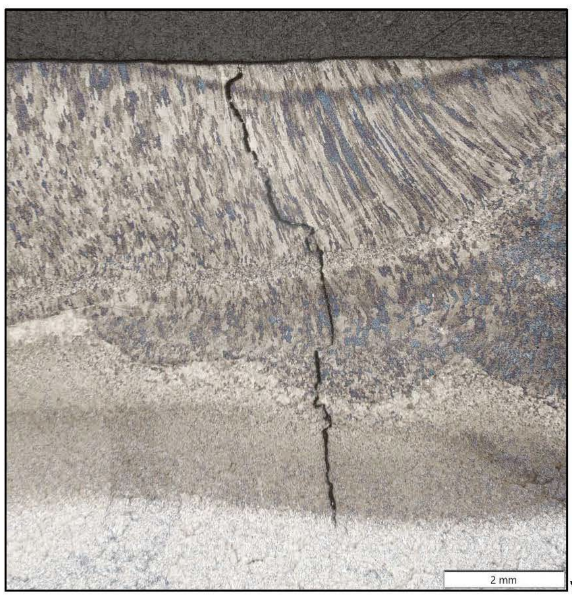

Figure 14. Etched view of the crack in Figure 13 showing that the tip of the crack stopped within the base metal, below the weld heat affected zone. (2% Nital etch, 10.5X)

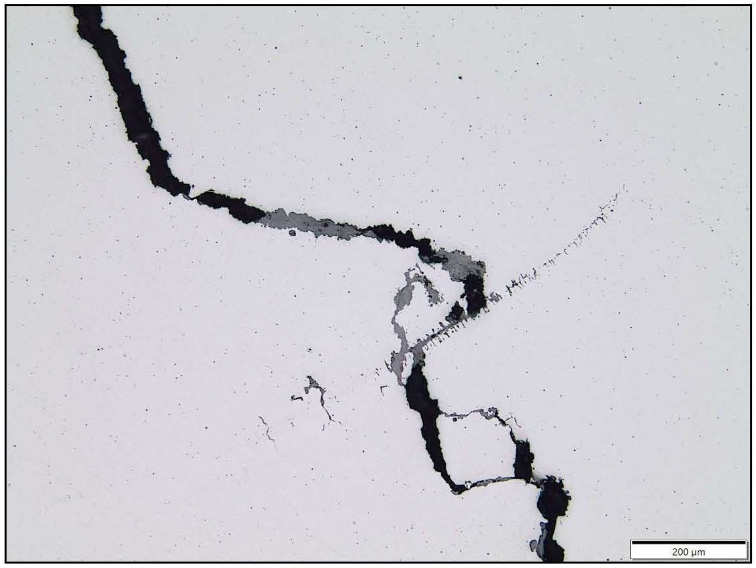

Figure 15. A region within the center of the largest crack is shown. Oxidized incomplete fusion and intergranular cracking were apparent. (As-polished, 100X)

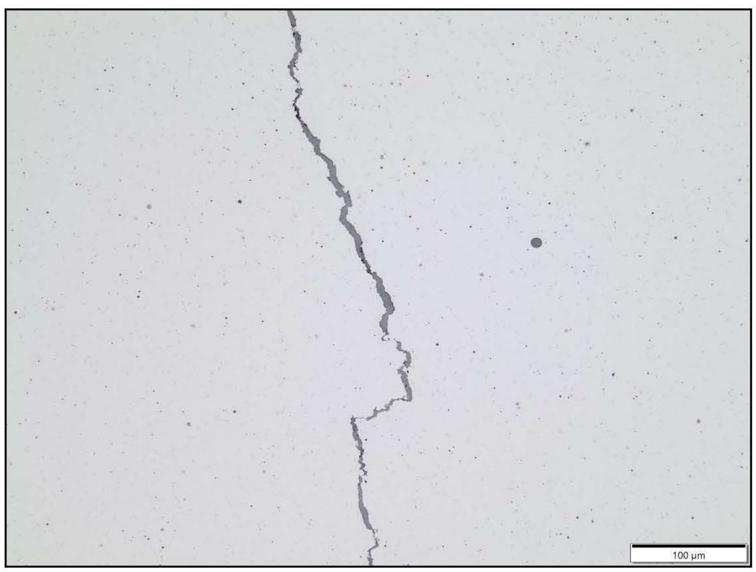

Figure 16. Image of a portion of the crack toward the right in Figure 12 showing that the tight crack was filled with oxide. (As-polished, 200X)

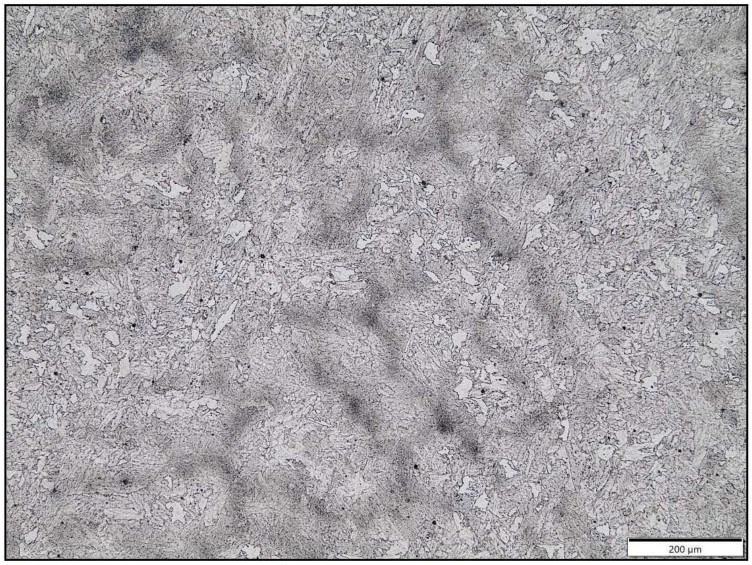

Figure 17. Metallographic image showing the typical core microstructure of the cast steel plate. Dendritic solidification segregation evidence was observed. (2% Nital etch, 100X)

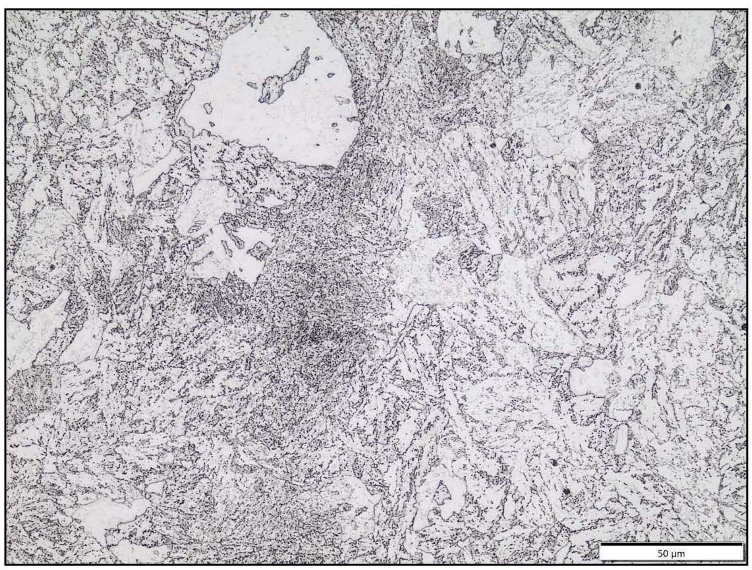

Figure 18. High magnification image of the typical core microstructure of the plate which consisted of a highly tempered lath structure. (2% Nital etch, 500X)

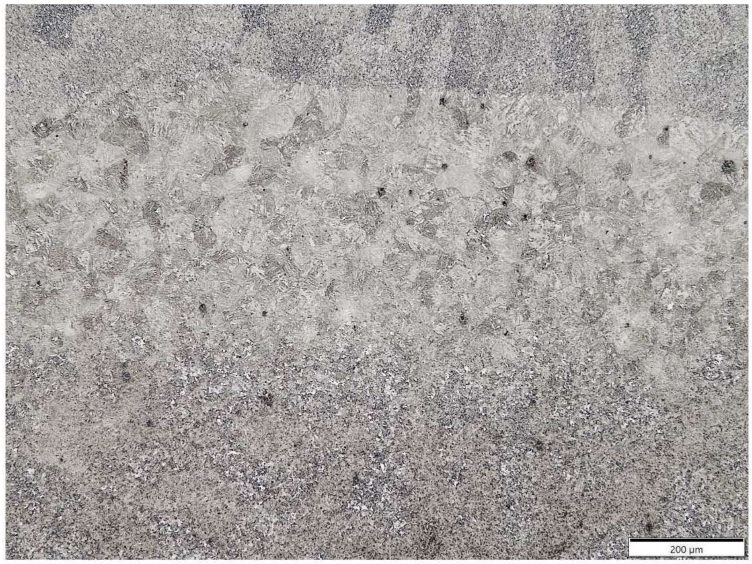

Figure 19. Metallographic image showing the typical heat affected zone microstructure of the cast steel plate adjacent to the weld. (2% Nital etch, 100X)

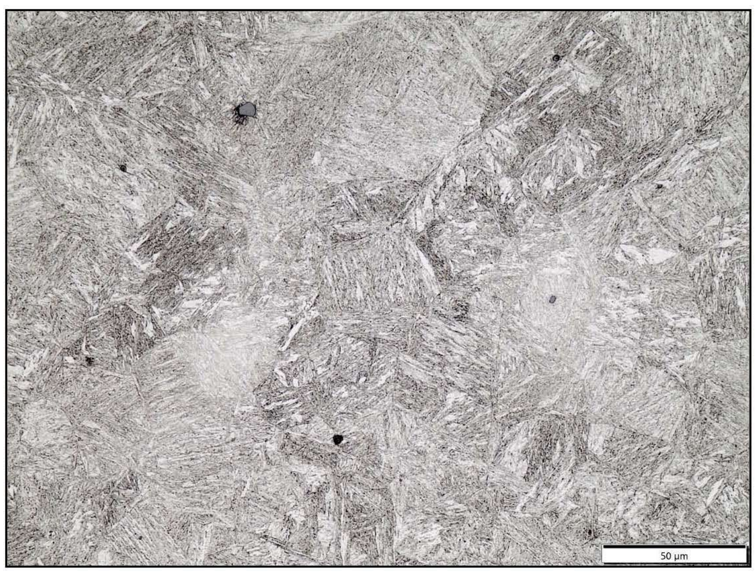

Figure 20. High magnification image showing the fine martensite evident in the heat affected zone of the weld. (2% Nital etch, 500X)

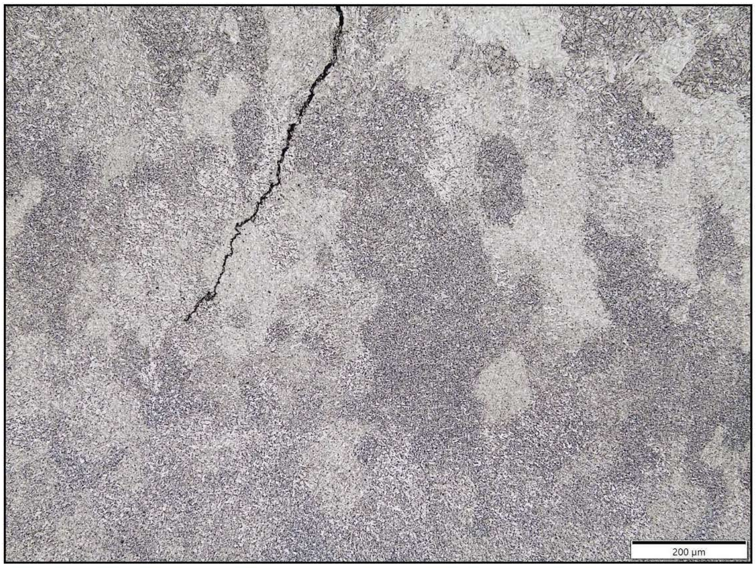

Figure 21. Metallographic image showing the typical weld zone microstructure. (2% Nital etch, 100X)

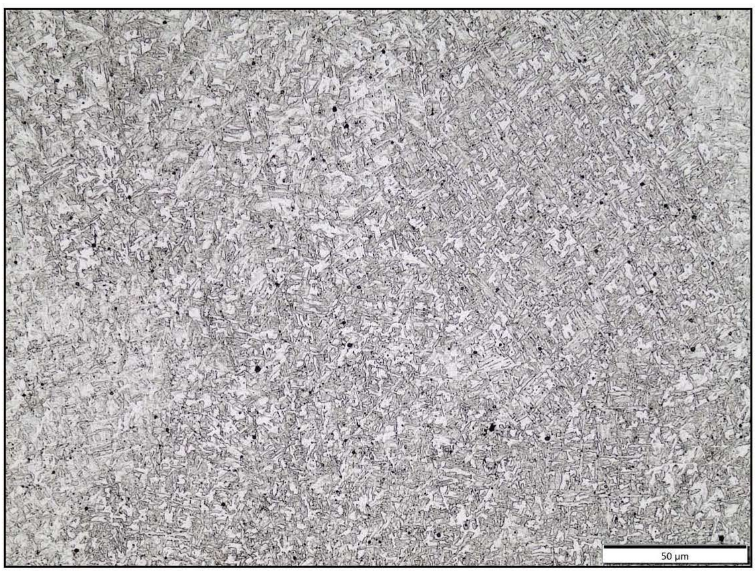

Figure 22. High magnification image of the typical weld microstructure which contained some lower transformation products. (2% Nital etch, 500X)

Atlas Project Trispan Test Piece

Inspectors: Inspection completed by B Wowianko III and J Carrier I

Date: September 2, 2022

Equipment: Epoch 650 7809, 2.25 MHz 1"x0.5" Transducer, with 45 deg Wedge

During the inspection of the sample two (2) cracks indications were found on the BR side of the sample. The two crack indications in question extend 5" and 6" in length. These indications do not appear to encroach to the exterior edges of the test sample.

Figure 1: Image of Trispan Test Piece showing two (2) crack indications on the BR side of the sample

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Figure 1: Image of Trispan Test Piece showing two (2) crack indications on the BR side of the sample

Figure 2: Image showing the crack indication that is 5" in length

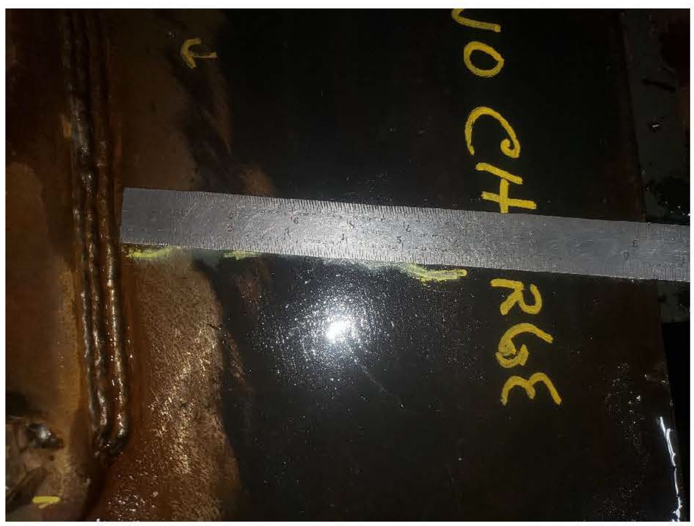

Figure 3: Image showing the crack indication that is 6" in length

Brock Wowianko III

Brock Wowianko Level III, Jason Carrier Level I

CLIFFS

September 15, 2022

To: Eric Beach
General Manager Plate
Triad Metal International
Pittsburgh, PA

From: S. Smith, B. Wowianko and T. Ros
Cleveland-Cliffs
Burns Harbor Plate Quality Assurance

Customer Claim - Triad Metals Investigation

Background

Triad Metals submitted a specimen to the Burns Harbor Plate Mill Metallurgical Laboratory for evaluation due to cracking near the weld of the fabricated sample. The plate grade is ASTM A572-15 GR 60 with two possible serials H023195 or J020022 shown in table 1. Both possible serials were rolled and shipped from Burns Harbor in early 2018.

The provided plate was torch cut in two locations as seen in Figure 1. The specimens extracted from the two locations were given the following I.D.s "BI" (SS00001) and "BR" (SS00002). Samples from both locations were prepared for chemical analysis, tensile and V-Notch Charpy impacts tests. The results of these tests are found in tables 2, 3, and 4.

Dye penetrant and ultrasonic evaluation was conducted on the BR side of the sample to determine the presence of cracks or any other imperfection in the material and the weld.

Table 1. Possible serial numbers of the provided plate.

SM Grade	Serial Number	Heat Number	Ship Manifest	Ship Date
A257	H023195	812z36570	803-29091	01/26/2018
A257	J020022	812z36480	803-29364	02/09/2018

Figure 1. Cut procedure on the provided plate with labeled I.D.s.

Non-Destructive Testing

Dye penetrant testing was performed on the BR side of the sample. Multiple small crack indications were found along the weld in the Heat Affected Zone (HAZ). Refer to the arrows in Figure 2 and Figure 3.

An Ultrasonic evaluation was conducted on the sample, two ultrasonic indications were found on the BR side of the sample. These indications were found roughly one inch into the sample and did not propagate to the surface or edge of the material. These indications lined up with the location of the support beams on the bottom of the part, as shown in Figure 3.

Left

Middle

Right

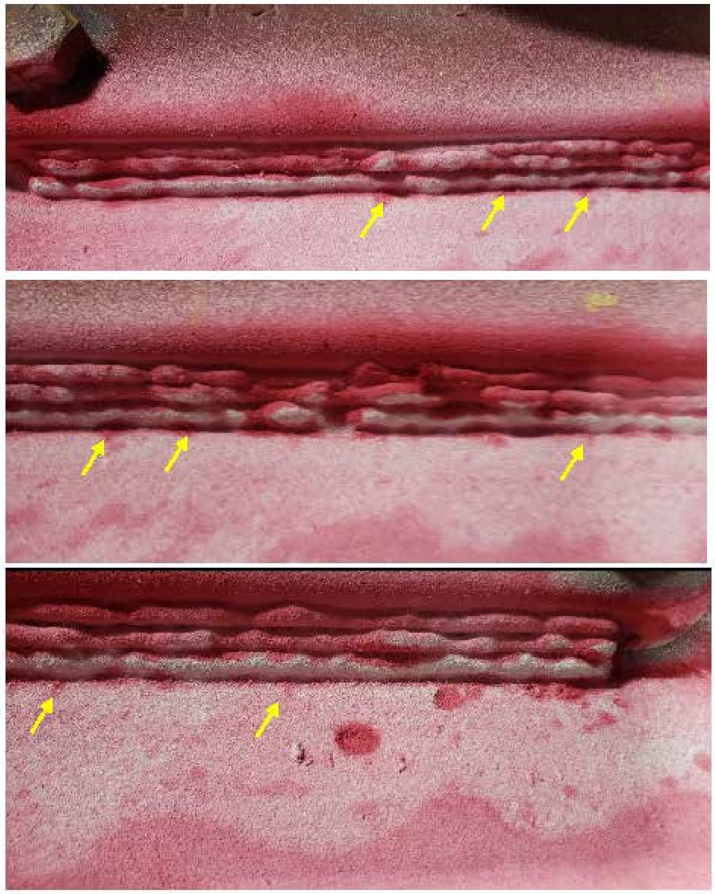

Figure 2. Multiple small cracks in the HAZ detected by Dye Penetrant inspection in the BR side of the sample received for investigation.

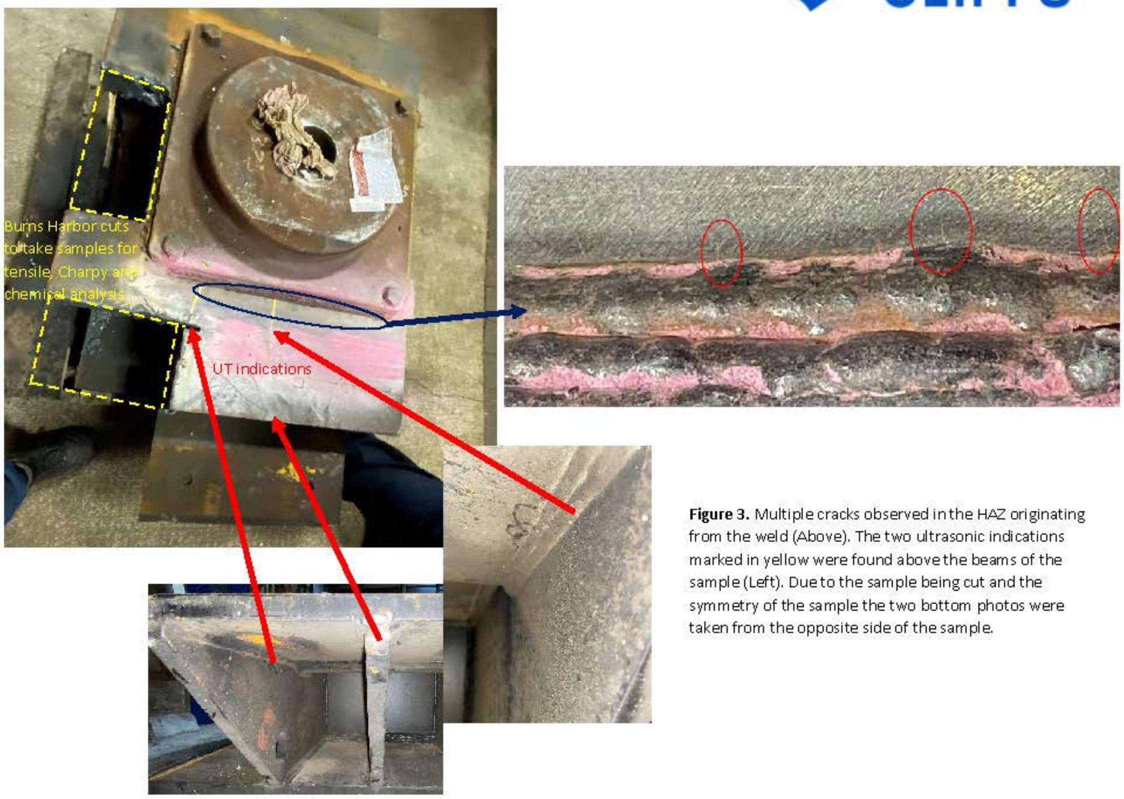

Figure 3. Multiple cracks observed in the HAZ originating from the weld (Above). The two ultrasonic indications marked in yellow were found above the beams of the sample (Left). Due to the sample being cut and the symmetry of the sample the two bottom photos were taken from the opposite side of the sample.

Tensile Tests Results

Tensile properties were found to be acceptable and consistent with the properties reported in the Plate Material Test Results (MTR).

Table 2. Tensile results

I.D. Number	Sample	Location	Yield (ksi)	Tensile (ksi)	Elongation (%)
SS00001	BI	Top	78.3	94.6	25
SS00001	BI	Bottom	78.3	94.6	25
SS00002	BR	Top	78.6	94.4	27
SS00002	BR	Bottom	78.6	94.4	27
H023195^	-	-	76	94.1	28
J020022^	-	-	80.8	96.6	34

^ indicates certified test results from shipped plate

Charpy V-Notch Impact Tests Results

Charpy tests were conducted at 0°F. All impact tests results met specifications and are consistent with the properties reported in the MTR.

Table 3. Impact results

I.D. Number	Sample	Energy (FT.LBS)			Average (FT.LBS)
SS00001	BI	83	107	129	106
SS00002	BR	106	91	106	101
H023195^	-	107	63	87	86
J020022^	-	89	80	74	81

^ indicates certified test results from shipped plate

Chemical Composition Results

The chemical analysis conducted on the sample returned from the customer is consistent with the heat analysis as reported on MTR.

Table 4. Chemical composition results

Element Symbol		**Composition**	
	BR (wt%)	**H023195 (wt%)^**	**J020022 (wt%)^**
C	0.171	0.17	0.18
Mn	1.24	1.18	1.19
P	0.011	0.011	0.012
S	0.003	0.003	0.004
Si	0.281	0.265	0.275
Cu	0.017	0.018	0.021
Ni	0.01	0.01	0.01
Cr	0.03	0.03	0.03
Sn	0.002	0.002	0.002
Mo	0.005	0.003	0.007
V	0.089	0.083	0.088
Al	0.35	0.033	0.03
Cb	0.002	0.002	0.002
B	0.0003	0.0002	0.0002
Ti	0.002	0.002	0.002
Ca	0.0022	0.0024	0.0023

^ indicates certified test results from shipped plate

Conclusions

The chemical composition and mechanical tests results obtained from the sample received for investigation meet the requirements of the ASTM A572-15 GR 60.

These results are consistent with MTR of the possible Plate Serials and match the chemistry of the plates sent to the customer.

Based on the results from the sample received from the investigation there is no evidence that point out issues related to the material. The multiple cracks that were observed are most probably related to the welding practice used during the fabrication of the part.