CPKC Test Department

Laboratory Procedures for Analysis on Failed Components

Following are the typical stages of a failure investigation that the Test Department would apply. It should be noted, however, that determination of root cause may or may not require all of the analysis stages below (e.g., failure mode can be determined by visual and non-destructive testing alone).

1. Collection of background information and samples
2. Visual examination including sketches and pictures
3. Non-destructive testing (NDT); dye-penetrant, dimensional, MPI, UT, etc.
4. Conformance to specifications or standards (mechanical properties, chemical composition)
5. Macroscopic examination; internal and external conditions (acid etching to reveal macroscopic features such as, inclusions, discontinuities, or segregation)
6. Microscopic/metallographic examination; origin identification, microstructure, grain size, metallurgical defects, etc.
7. Determination of failure mechanism
8. Comprehensive test report

In the case of involvement of regulatory/government investigative agencies (e.g. TSB, NTSB), confirmation from said agency is highly recommended before applying any of the above procedures. This is especially important if destructive methods of testing are involved, in which evidence would be permanently altered (i.e. cutting/sectioning components to facilitate testing). CPKC Regulatory Affairs will typically facilitate this communication.

TEST DEPARTMENT LABORATORY REPORT

Subject:	Derailment: Bordulac, North Dakota Broken Rail Analysis	**Keywords:**	ES, RAIL, CM, EC, 092
Report Date:	December 31, 2024	**Project No.:**	2024-092

Sample Description:	One 43"section of 115lb rail manufactured by Colorado Fuel & Iron. Based off available stampings the age is unknown.
Standard/Specification:	Visual Inspection Ultrasonic Inspection Magnetic Particle Inspection Hardness Testing (AREMA Chapter 4 Section 2.1.3.3 and Internal Procedures) Macroetch Examination (AREMA Chapter 4 Section 2 Table 4-2-3) Dimensional Analysis (CPKC Red Book of Track Requirements, Section 17, Page 199) Chemical Composition (AREMA Chapter 4 Table 4-2-1-3-1a)

BACKGROUND

On 07/05/2024 at approximately 03:36 GMT, train 242-03 and derailed 29 railcars on the main track of the Carrington Sub (MP 342.5) near Bordulac, North Dakota. (Incident No. 1002130855). The train was proceeding eastbound at 44.57 mph at MP 342.5 where it was below the restriction speed of 50 mph. Of 29 railcars, 17 tank cars were transporting hazardous materials. The National Transportation Safety Board (NTSB) is conducting an ongoing investigation (ID RRD24LR012) to assess various possible factors that may have contributed to the accident. On November 7, 2024, the NTSB requested a piece of 115-lb rail section from the south rail, showing signs of end batter, obtained from the derailment site in Bordulac, ND, be further investigated. This rail sample was received on 12/05/2024 for laboratory analysis.

Figure 1: Location of the Derailment Occurrence in Carrintong Subdivision (MP 342.5)

SUMMARY

In summary, analysis of the rail section submitted could not find evidence that attributes the rail to the point of derailment (POD); the cause of the fracture seen in the rail is determined to be attributed to post-derailment forces. Additionally, the rail was found to be mostly compliant with industry and internal standards for the make and grade of rail and lacking any manufacturing or internal defects that could be causal to the incident.

The above conclusions are supported by the following test results:

Visual Inspection

- Visual inspection of the rail showed that it was subject to minor batter, including what appears to be wheel ride along the head. There was no indication that this section of rail was the point of derailment for the incident.
- Inspection of the fracture face's morphology showed that the rail failed due to a sudden brittle fracture. There was no indication of crack propagation or fatigue.

Ultrasonic Testing

- Ultrasonic inspection of the rail did not yield any indications of internal defects.

Magnetic Particle Inspection

- MPI did not yield any indications of significant defects either along the rail or specifically in the vicinity of the fracture face. Minor gauge corner cracking was witnessed along the length of the head.

Dimensional Analysis

- Wear measurements were taken according to CPKC Engineering Services Red Book of Track Requirements to measure both the head's vertical and horizontal wear. Based on the measurements taken, the rail wear is well within acceptable limits.

Hardness Testing

- The rail was subject to hardness testing according to AREMA Chapter 4 Section 2.1.3.3 for the head, as well as additional testing for the remainder of the web and base. While the head hardness was measured using a Rockwell C hardness test, these were correlated to Brinell hardness using the following correlation:

$$BHN = 165.77 + 2.3597(HRC) + 0.0777(HRC^2)$$ *AREMA Chapter 4 Table 4-2-1-3-3a*

- Hardness gradients within the rail head were found to be typical. Two of three hardness measurements near the running surface fell below the head hardness minimum requirement for intermediate strength rail (350 BHN) but were above the requirement for standard steel rail (310 BHN).

Macroetch Examination

- Examination of the macroetched transverse cross section of the rail revealed minor segregation down the center of and contained within the web. The segregation observed was within the limits set out by AREMA Chapter 4 Table 4-2-3.

Chemical Analysis

- Examination of the rail's chemical composition found it to be in line with AREMA standards contained in Chapter 4 Table 4-2-1-3-1a.

TEST RESULTS

The 43" section of rail was subjected to visual inspection, ultrasonic testing, magnetic particle inspection, and dimensional analysis in its received condition. The rail was then sectioned to obtain samples immediately behind the fracture face to conduct hardness testing, macroetching, and chemical analysis.

It should be noted that due to incomplete markings; the vintage of the rail is unknown. Testing compared the rail to current AREMA and internal specifications.

Please see Appendix A for further details on the sections in question.

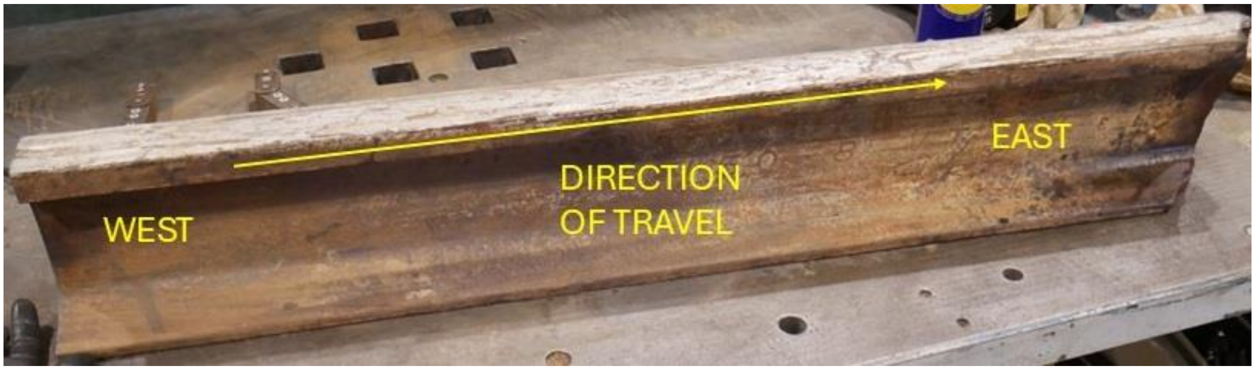

Image 1: The 43" section of rail after being cleaned. The field side is visible.

Image 2: Field side rail brand saying "1150-8 VT CF &" on side of rail.

Image 3: Gauge side rail stamp saying “IH” and “37” on opposite side of rail.

Visual Inspection

Many small batter marks are scattered across the head, lacking a consistent direction. There was a single long mark that ran the length of the rail section, consistent with a wheel flange riding along the rail running surface (Image 4). There were no batter marks on the sides of the rail.

In the received condition, the fracture face of the rail was heavily corroded/rusted. Though some features may be obscured as a result, the fracture face (shown in Image 5) displayed the traits of a sudden and catastrophic brittle fracture throughout its entirety. It was relatively flat with a granular appearance and exhibited chevrons denoting an initiation point at the base corner (gauge side) of the rail (Image 6). No visual evidence was found of any pre-existing defects or fatigue growth.

The location of the initiation point suggests that the rail had been loaded such that the gauge side was under the most stress.

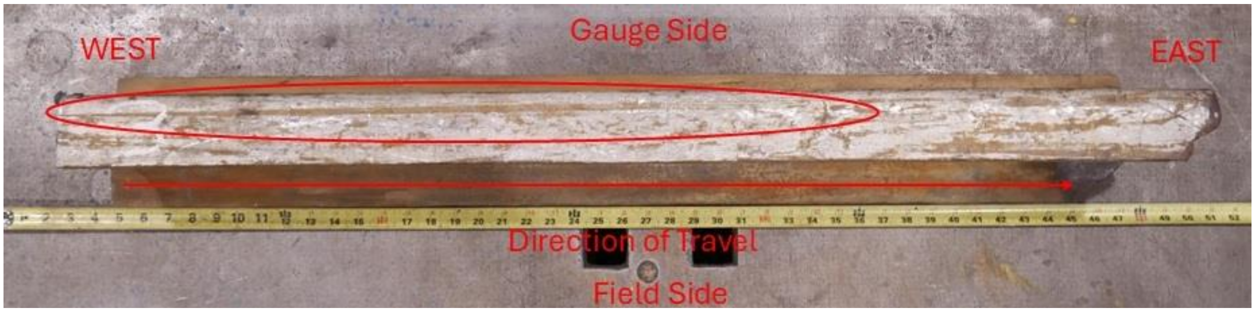

Image 4: A composite image of the railhead showing the batter with the damage caused by wheel ride circled in red.

Image 5: The fracture face showing characteristics of brittle fracture, namely a flat surface and chevrons pointing towards the initiation sites.

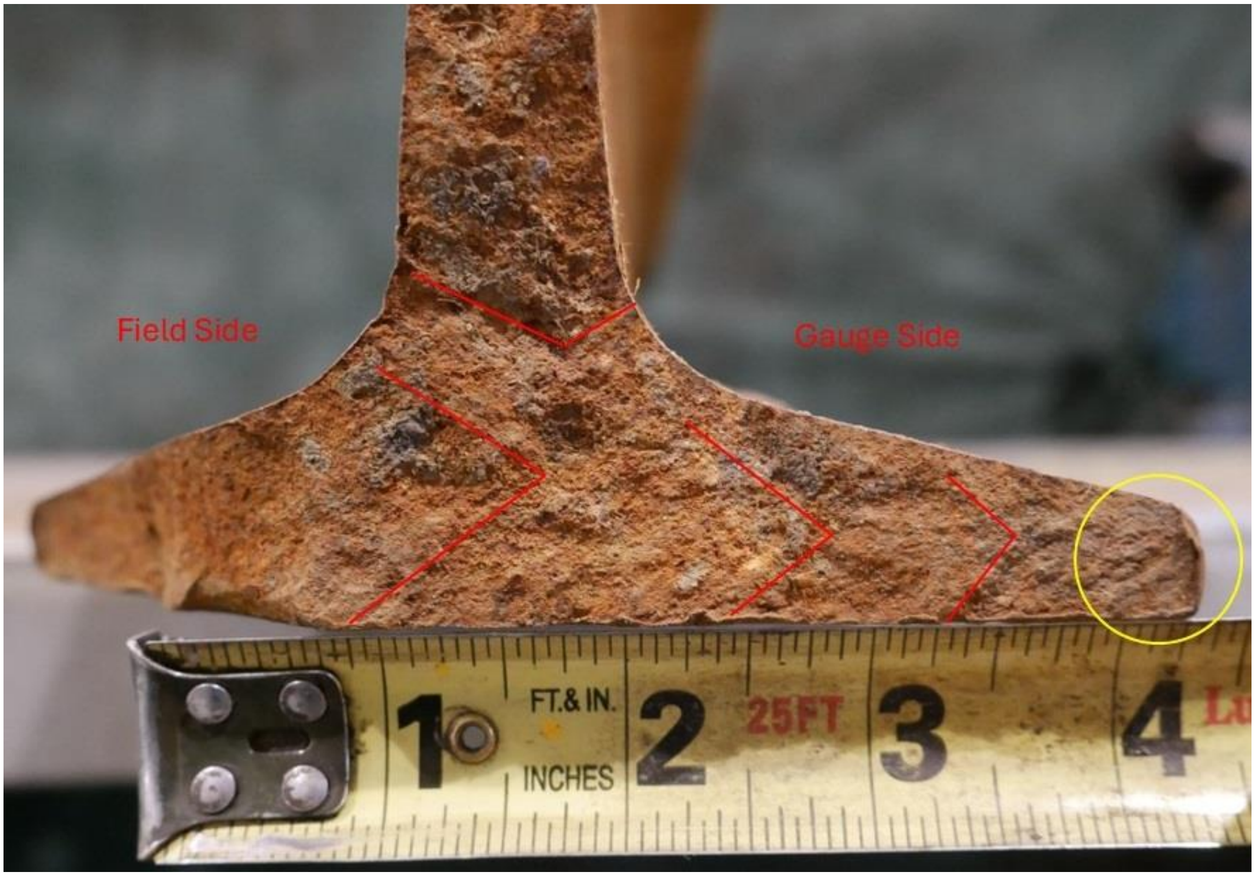

Image 6: A closeup of the bottom half of the fracture face highlighting the chevrons (red) pointing towards fracture initiation location (circled in yellow).

Ultrasonic Testing

The rail was subject to ultrasonic testing across its entire length, beginning at the site of the fracture and terminating at the end of the rail. The probe examined the portion of the head immediately above the web and searched for indications through the height of the rail, all the way to its base. No indications of any defects were detected.

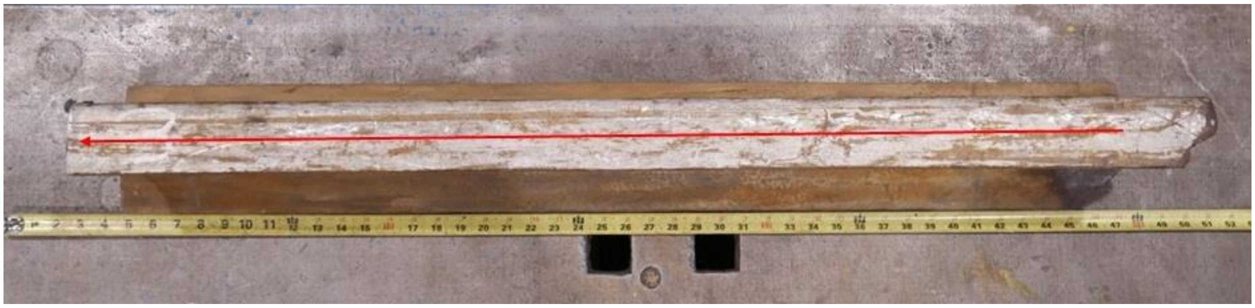
Image 7: The start point and direction of travel of the UT probe.

Magnetic Particle Inspection

All surfaces of the rail were subject to magnetic particle inspection (MPI), including the fracture face. Testing found rolling contact fatigue cracks along the gauge side of the rail running surface, however none appeared causal to the primary fracture. No other indications were found along the rail segment, including secondary fractures along the fracture face.

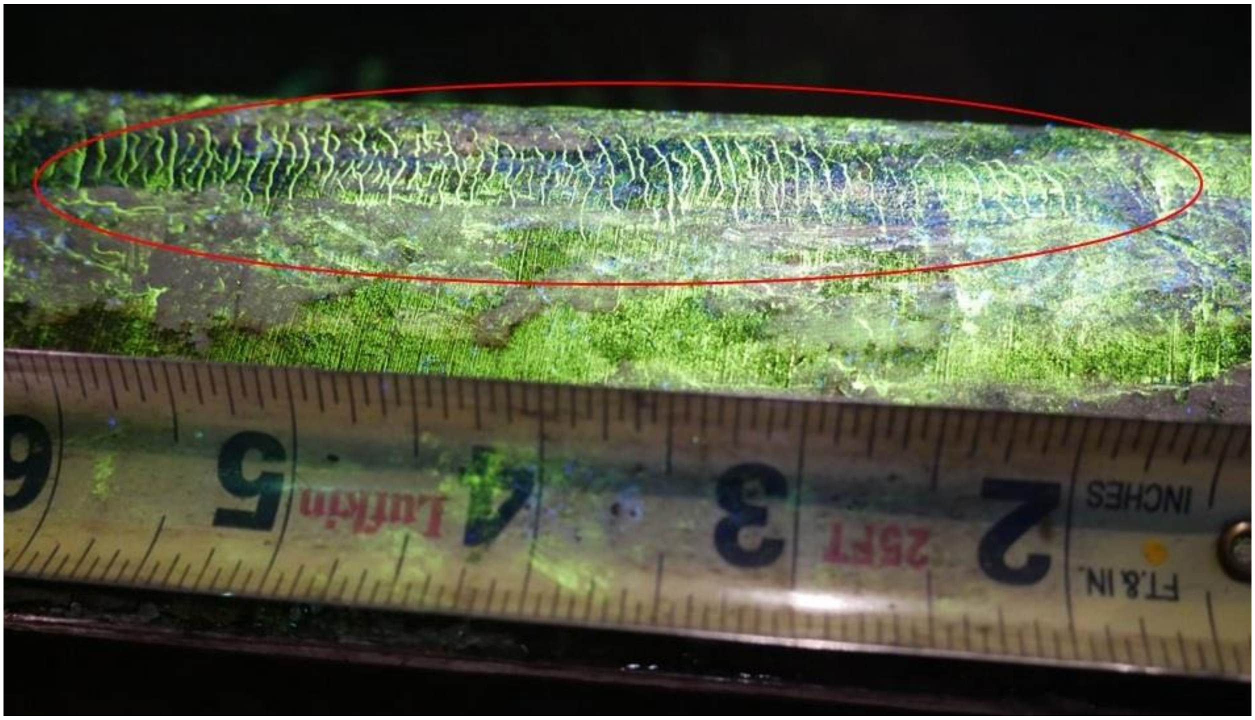

Image 8: The gauge corner cracking revealed by MPI along the gauge side of the rail.

Dimensional Analysis

The wear along the side and top of the rail head was measured to ensure compliance with CPKC Red Book of Track Requirements, Section 17, Page 199. Using a rail wear gauge, readings were taken along the length of the rail and can be found in Table 1 below. Based on the Red Book of Track Requirements, the rail was not worn to the point that it required special maintenance or replacement.

Table 1: Rail Head Wear Measurements

Distance from Fracture*	Top Head Wear	Side Head Wear
1”	9/32”	0”
12”	9/32”	0”
24”	9/32”	0”
36”	¼”	0”
42”	¼”	1/32”

***** The distance from the fracture was measured from the portion of the base that would yield the shortest overall length.

Hardness Testing

The head of the sample was subjected to a hardness testing regime specified by AREMA Chapter 4 Section 2.1.3.3 while the remainder of the web and base were subjected to testing to quantify hardnesses in these regions. All of the hardness measurements taken from the head and upper web region were done using a Rockwell C indenter and then correlated to Brinell hardness using the equation below. See Image 9 for the pattern followed.

$$BHN = 165.77 + 2.3597(HRC) + 0.0777(HRC^2)$$ *AREMA Chapter 4 Table 4-2-1-3-3a*

Meanwhile, the measurements taken from the rest of the web and the base were done using a Brinell hardness tester. See Image 10 for the pattern followed.

Figure 2, illustrates the hardness gradient within the rail head along lines 1, 2, and 3. Point 1 on line 1 hardness was found to be 356 BHN, above the minimum requirement for intermediate strength rail head hardness (350 BHN). However, similar hardness measurements for point 1 on lines 2 and 3 fell below this minimum but were above the minimum for standard rail (310 BHN).

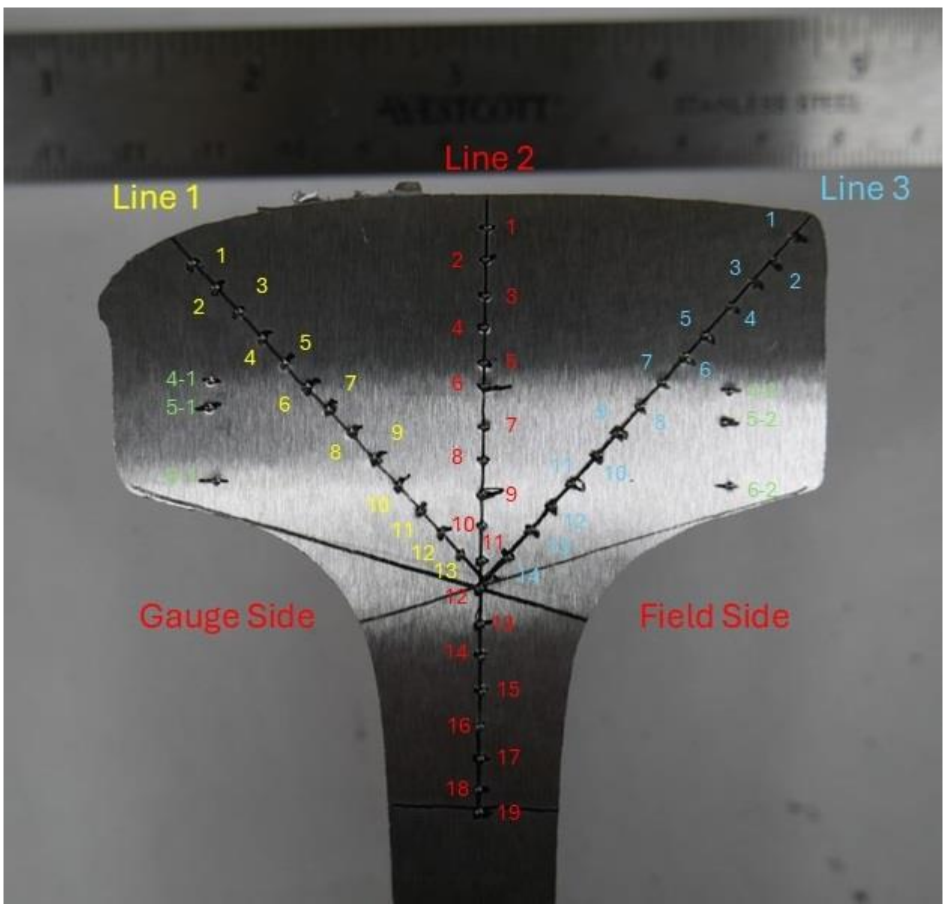

Image 9: Location of hardness measurements in the rail head. Along lines 1,2, and 3 each point is spaced out by 0.125” Furthermore, points 6-1 and 6-2 were added as they were not part of the original specification for the head. This was done as a contingency in case points 4-1/4-2 and 5-1/5-2 were too close together.

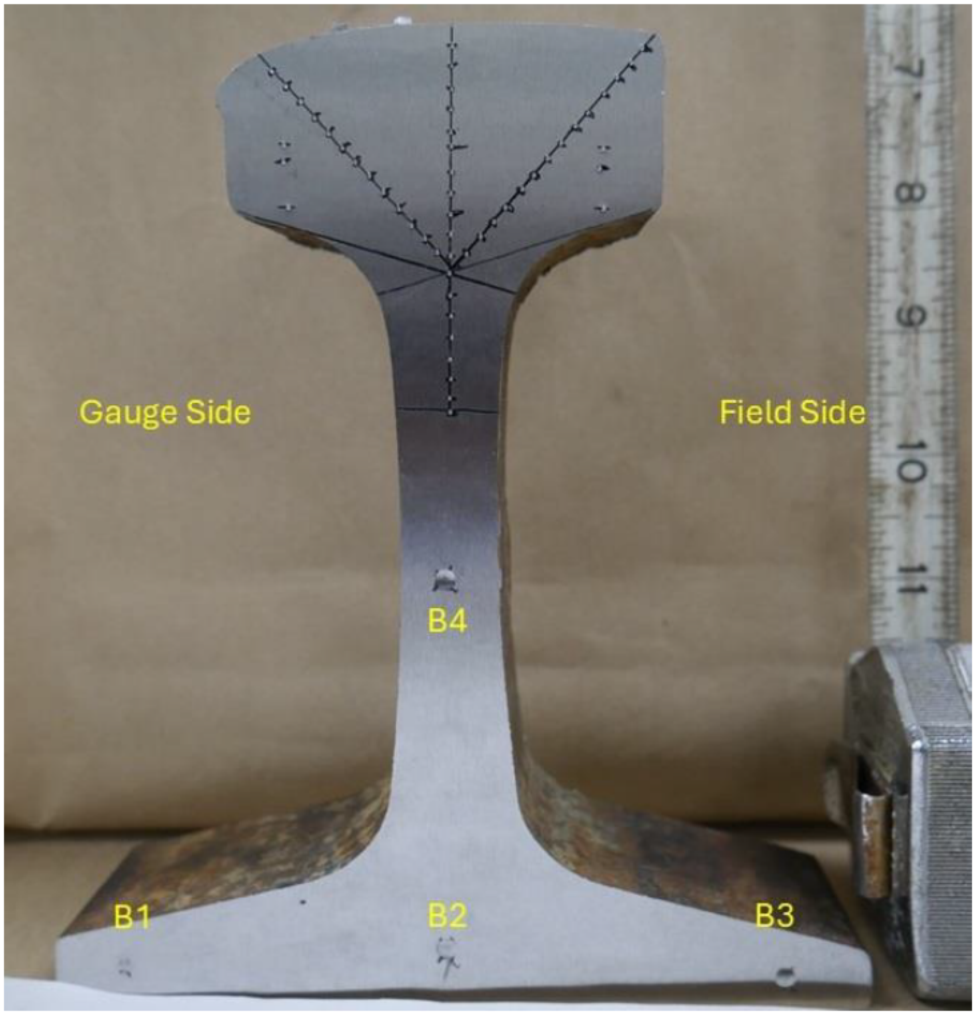

Image 10: The location of the four Brinell hardness tests conducted in addition to the Rockwell C test.

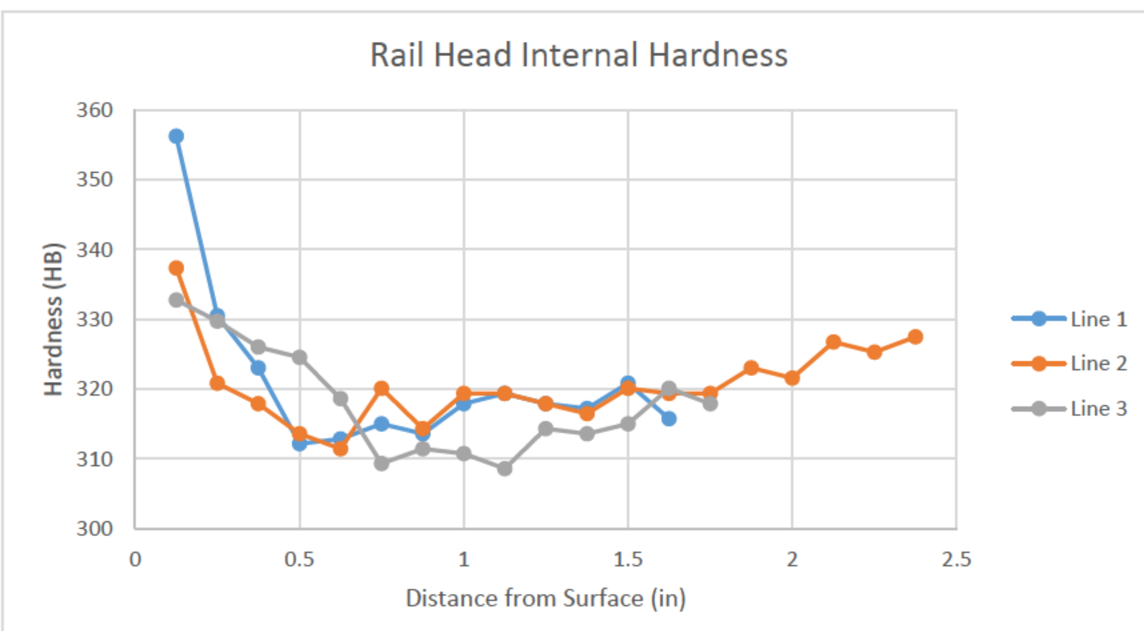

Figure 2: Hardness gradient within rail head cross section.

Table 2: Hardness Measurement Results.

Line 1		
Point	HRC	HB (Correlated)
1	36.6	356
2	33.3	331
3	32.3	323
4	30.8	312
5	30.9	313
6	31.2	315
7	31.0	314
8	31.6	318
9	31.8	319
10	31.6	318
11	31.5	317
12	32.0	321
13	31.3	316

Line 2		
Point	HRC	HB (Correlated)
1	34.2	337
2	32.0	321
3	31.6	318
4	31.0	314
5	30.7	311
6	31.9	320
7	31.1	314
8	31.8	319
9	31.8	319
10	31.6	318
11	31.4	316
12	31.9	320
13	31.8	319
14	31.8	319
15	32.3	323
16	32.1	322
17	32.8	327
18	32.6	325
19	32.9	328

Line 3		
Point	HRC	HB (Correlated)
1	33.6	333
2	33.2	330
3	32.7	326
4	32.5	325
5	31.7	319
6	30.4	309
7	30.7	311
8	30.6	311
9	30.3	309
10	31.1	314
11	31.0	314
12	31.2	315
13	31.9	320
14	31.6	318

Additional Points Hardness		
Point	HRC	HB (Correlated)
4-1	31.0	314
5-1	32.1	322
6-1	32.8	327
4-2	31.8	319
5-2	31.7	319
6-2	31.8	319

Brinell Hardness Points				
Point	D1(mm)	D2(mm)	HB	HRC (Correlated)
B1	3.3	3.4	331	35.5
B2	3.5	3.5	302	32.1
B3	3.4	3.4	321	34.3
B4	3.5	3.5	293	30.9

Table 3: Averages of Hardness Measurements

Average Hardnesses	
Group	Average (HB)
Line 1	321
Line 2	321
Line 3	318
Brinell Hardness Points	311.75
Additional Hardness Points	320
Overall	319

Macroetch Examination

To examine the general structure of the sample, a transverse cross section was macroetched with a 50-50 mixture of hydrochloric acid and water at 200°F for 20 minutes. As can be seen below in Image 11, a 1.5" long segregation line is present in the web. In accordance with AREMA Chapter 4 Section 2 Table 4-2-3, segregation is allowable as long as it is confined entirely to the web. As such, the rail meets the standard. The remainder of the macrostructure appeared homogenous, with no internal defects observed.

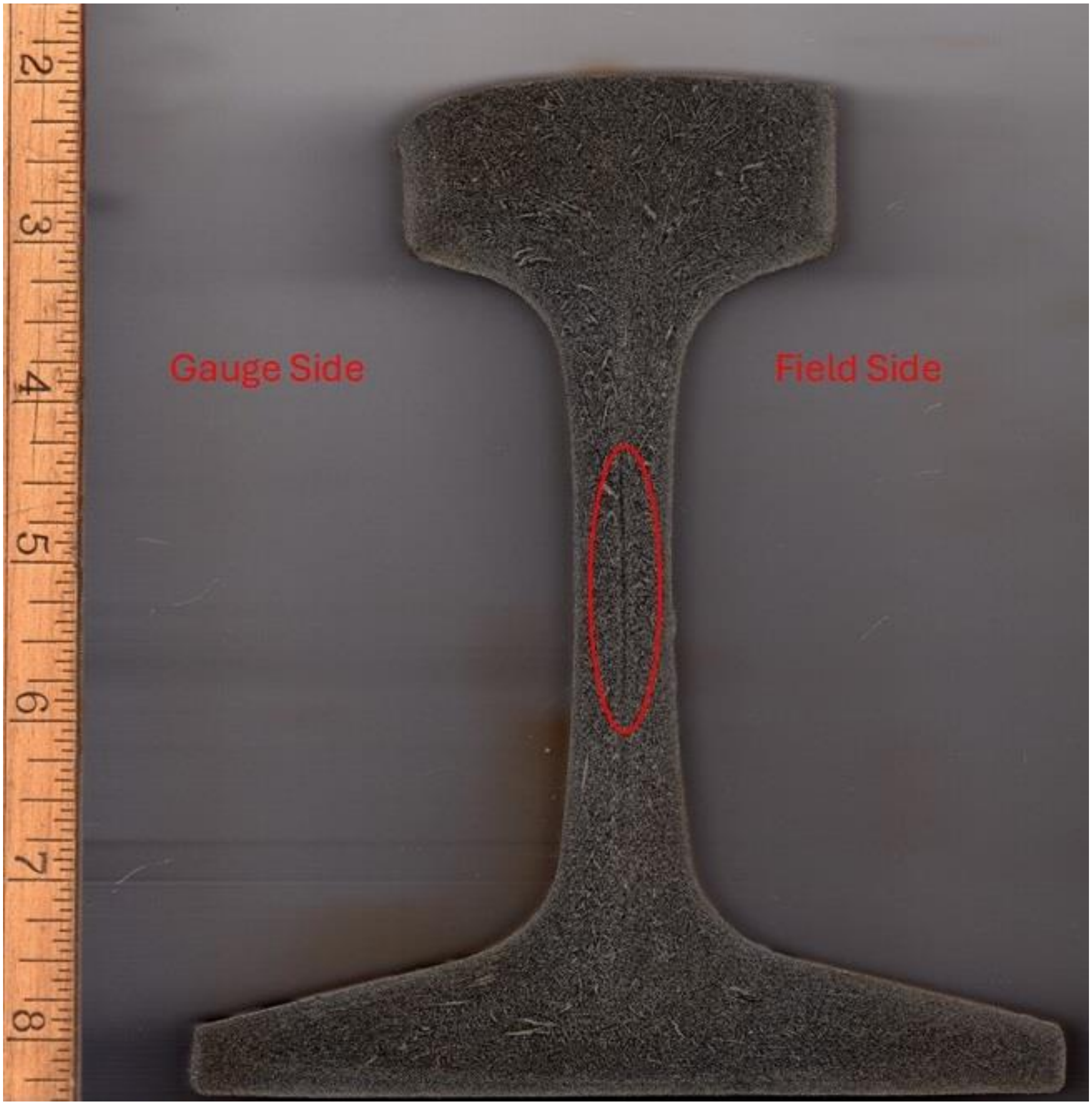

Image 11: The macroetched sample with the segregated area circled in red.

Chemical Analysis

The chemical composition of the rail was determined by sampling the head by spark optical emission spectroscopy (OES). Several samples were taken and then averaged to arrive at the composition found in Table 4. When compared to the standards laid out in AREMA Chapter 4 Table 4-2-1-3-1a, the rail was found to be within specification.

Table 4: Chemical Analysis Results

Element	Measured	AREMA Spec. Carbon Rail Steel
Carbon	0.812	0.74 - 0.86
Manganese	1.004	0.75 - 1.25
Phosphorus	0.015	0.02 (Max)
Sulphur	0.016	0.02 (Max)
Silicon	0.431	0.10 - 0.60

APPENDIX A: Sectioning

Once the non-destructive testing was completed, the rail was cut into four sections in order to get the two samples necessary for the destructive testing. The first section, with a length of 3.5", was the fracture face. It was cut from the rest of the rail in order to preserve it. The second section (1" long) was sample 1, which was macroetched. The third section (1.5" long) was sample 2, which was used for both hardness testing and chemical analysis. Finally, the fourth section was the remainder of the rail; it was not used for any destructive testing.

Image 12: The four sections of rail, the fracture face, sample 1, sample 2, and the remainder.