Analysis Of Boiler Plate from 1880 Historic Train

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Introduction

Since 1957 the 1880 Train has operated three steam locomotives from the 1920s as tourist attractions . Because of the locomotive's age a host of mechanical issues cause significant problems.

- Spare parts for the train are exceptionally difficult find
- 80 plus years of service deteriorate materials and mechanical systems
- The power boiler has the potential to cause serious damage to life and property in the event of an explosion
  - Very little is known about old boiler steels properties.

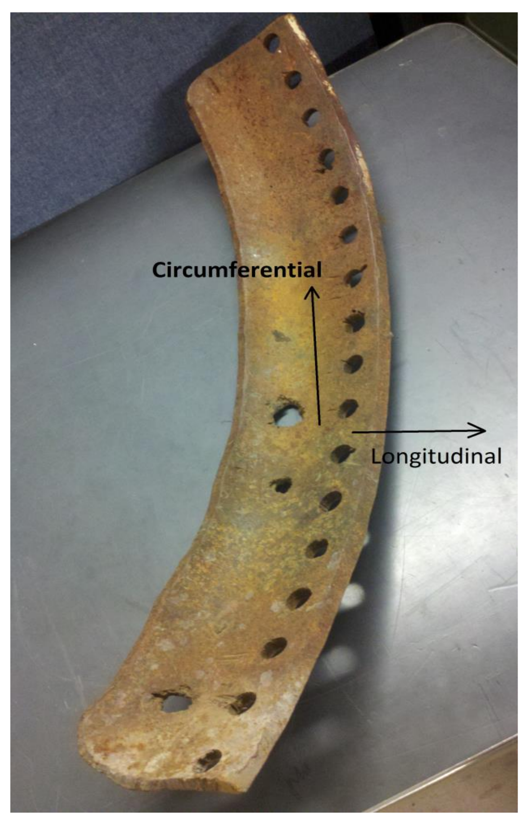

Figure 1: Boiler plate as received

Objectives

- Determine the physical properties of the boiler steel, and compare them to a modern pressure vessel steel
- Characterize the microstructure of the steel
- Evaluate the steel's ability to operate safely

Procedure

Microstructural Analysis

- Metallography of cross sections from all three directions
- All samples etched in 4% nital
- Optical and electron microscopy

Mechanical Analysis

- Sub-sized tensile testing
- Fracture toughness (K_Q)
- Charpy V notch impact
- Four samples for each test were cut; two samples from each direction, circumferential and longitudinal (see Fig. 1)

Figure 2: K_{IC} testing setup

Results

Microstructural Analysis

- Structure consists of ferrite and pearlite
- Relatively clean microstructure with some manganese sulfide and silicon dioxide inclusions
- Average grain size is approximately 30 microns

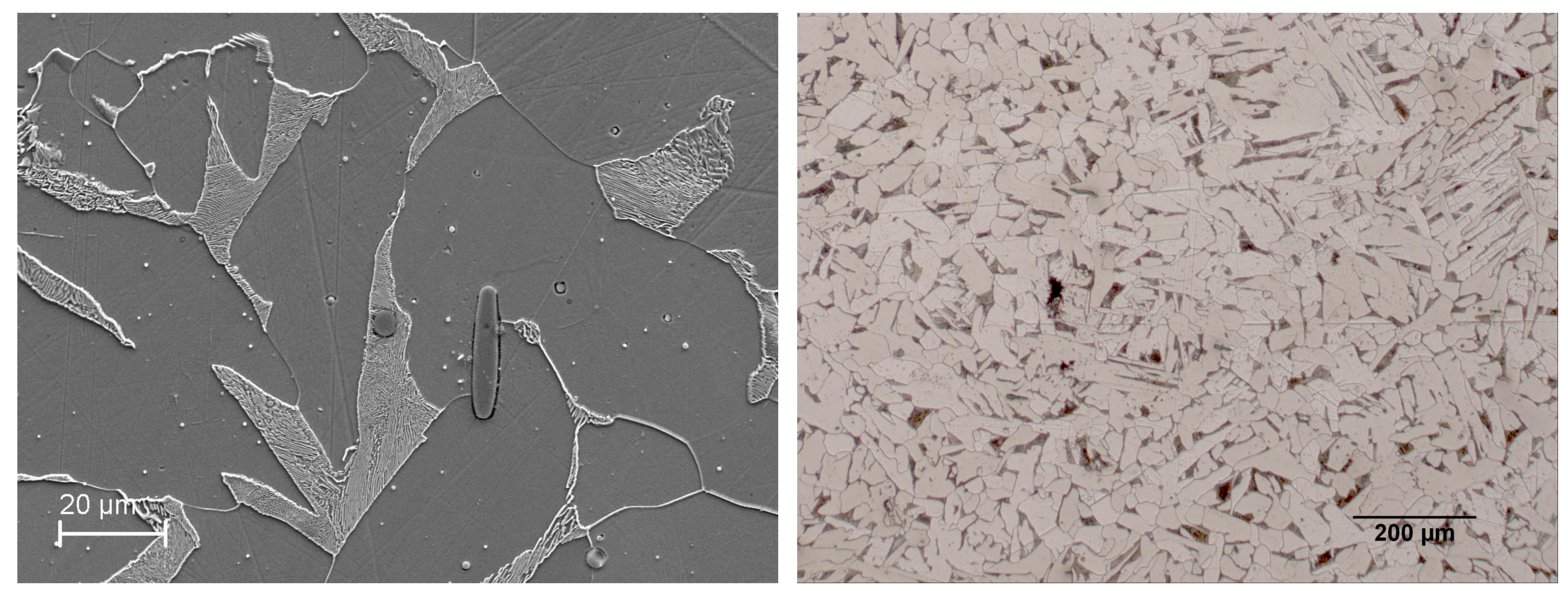

Figure 3: Circumferential cross section (SEM left, OM right)

Mechanical Analysis

- The tensile testing shows that the steel performs at, or slightly above its original specifications
- Charpy impact values for the 1880 Train steel were higher than that of ASTM A516, the modern standard for pressure vessels
- True K_{IC} samples could not be obtained, however K_Q values were found for two samples
  - Since K_Q decreases with increasing sample thickness, the K_{IC} for this steel would be even lower than its K_Q, which is already significantly lower than that of the A516

Table 1: Property Comparison

	Yield Strength (psi)	Ultimate Strength (psi)	Percent Elongation	Charpy V notch (ft-Lbs)	Fracture Toughness (Psi $\sqrt{in}$)
ASTM A516-70	38,000 (min)	70,000 (min)	21%	15	178,000 (K_{IC}) [2]
Original Specifications [1]	27,500 (min)	55,000 (min)	25 %	N/A	N/A
Specimen 1 (Longitudinal)	36,000	60,200	23.5%	25.5	N/A
Specimen 2 (Longitudinal)	36,500	58,800	20%	22.25	40,500 (K_Q)
Specimen 3 (Circumferential)	34,200	56,800	19.7%	45	N/A
Specimen 4 (Circumferential)	33,600	55,100	23.5%	20.25	37,700 (K_Q)

Conclusions

- The material meets its ratings which is significant because all previous engineering analysis had been conducted using these unconfirmed original specifications. This allows us to have much more confidence in the safety of the train
- The fracture toughness values indicate that the material has a low tolerance for surface defects, and thus careful attention should be paid to the size of these flaws

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Future Work

- Comprehensive boiler design analysis
- Weld strength analysis
- Additional mechanical testing from more samples

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