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Case study

Investigation of a Columbus, Ohio train derailment caused by fractured rail

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ABSTRACT

On July 11, 2012 an eastbound Norfolk Southern train derailed 17 cars within the city limits of Columbus, OH. Three of the cars that derailed were carrying over 86,000 gallons of denatured ethanol. Once breached, the ethanol in the tank cars ignited, fueling a large fire. The derailment led to the evacuation of over 100 people and cost over $1.2 million. This paper will detail the on-scene response and failure analysis performed by the NTSB Materials Laboratory, focusing on the recovered rail that contained 25 transverse detail fractures.

1. Introduction

The National Transportation Safety Board (NTSB) is an independent United States federal government agency charged with determining the probable cause of transportation accidents, promoting transportation safety, and assisting victims of transportation accidents and their families. On July 11, 2012 at 2:03 a.m., eastern standard time, an eastbound Norfolk Southern Railway Company (NS) train derailed 17 cars within the city limits of Columbus, OH at a curve in the track. No train crewmembers sustained injuries. However, two citizens in the area sustained minor burn injuries. Approximately 100 people were evacuated from an area of 1 mile surrounding the derailment.

The train consisted of 2 locomotives, 97 loaded cars, and 1 empty car. The 3rd through the 19th cars derailed. Of the cars that derailed, three (positions 12 through 14) containing denatured ethanol breached, released product, and caught fire. The derailment and ensuing fire destroyed both main tracks of the line. The railroad estimated the damage at over $1.2 million [1].

During the on-scene investigation, multiple fractured rail segments were transported from the derailment site to a separate location within the Ohio State Fairgrounds for preliminary examination. Thirty-five rail pieces were recovered from the derailment area, several of which were attached to each other by joint bars. Of the pieces recovered, 24 of the exposed fracture faces exhibited transverse detail fractures, progressive fractures that originate at or near the surface of the rail head. Three of these rail fragments were transported to the NTSB Materials Laboratory in Washington, DC for additional examination.

Fractured rail has been studied extensively, with many fractures due to contact fatigue from rolling wheels of passing trains [2,3]. Besides the primary loading on the rail, secondary loading from thermal and residual stresses [4], as well as

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environmental changes such as temperature, strongly influence the likelihood of track failures [5]. Wheel-rail contact is only one of a variety of loading conditions requiring complicated long-term studies to determine appropriate life and inspection limits of rail under service [6].

The rail industry has classified rail defects and failures with nomenclature unique to the business [7]. Progressive fractures initiating at or near the rail surface, called detail fractures in North America, are denoted by the orientation relative to the rail rolling direction. Transverse detail fractures can initiate due to rolling contact fatigue failure modes such as shelling (a longitudinal separation of the rail head near the wheel running surface) and head checking (transverse cracking on the gage corner from excessive surface cold working). These failure modes are typical when shear stresses at the wheel-rail contact region exceed the limits for the rail steel. Detail fractures also initiate at internal defects in the rail from manufacturing flaws [8]. Understanding and detecting these and other failure mechanisms is important in preventing catastrophic derailments due to rail failure.

2. Investigation methods

The rail fragments were inspected using destructive and non-destructive methods by the NTSB Materials Laboratory. The on-scene parts were photographed using a Canon EOS Rebel T3i digital camera. This same digital camera was used in conjunction with a Keyence VHX-1000 digital microscope for laboratory documentation. The digital microscope was capable of producing high-dynamic range and composite high depth-of-field images.

Specimens excised from the rail fragments were examined using a Zeiss Auriga 40 field emission scanning electron microscope (SEM). This microscope was equipped with a Thermo Scientific UltraDry NORAN System 7 energy-dispersive X-ray spectroscopy (EDS) for inspection of chemical composition.

Several metallographic cross sections of the rail fragments were prepared. The cross sections were polished and etched with 4% Nital. These metallographic specimens were evaluated using a Zeiss Axio Observer Z1m inverted microscope.

Hardness testing was performed using a Wilson Rockwell hardness tester per ASTM E18 using a diamond indenter and 150 kg load to obtain Rockwell C (HRC) values [9]. The HRC hardness values were converted to Brinell (HB) values [10]. Specimens from the rail fragments were submitted to Lehigh Testing Laboratories in New Castle, DE for chemical analysis. The chemical compositions were inspected using inductively coupled plasma mass spectroscopy (ICP) as well as a combustion infrared detection of carbon and sulfur.

3. Results of the investigation

3.1. Columbus, OH on-scene investigation

Each rail piece was arbitrarily labeled with an identification number between "0" and "200" with each end marked "A" or "B." The ends of each recovered rail piece were documented as being joined to another rail with a joint bar, torch-cut in the field, or fractured. The total length of recovered pieces was approximately 272 ft.

The web portion of the rail pieces contained raised characters that identified the size, date, and manufacturer of the rail. The markings on the rail fragments were consistent with manufacture by three different steel mills:

- US Steel in February 1979 and September 1981.
- Bethlehem Steelton in September 1981.
- Colorado Fuel and Iron in December 1988.

According to the American Railway Engineering Association (AREA) specifications applicable at time of manufacture of the above rail segment, the markings identified the rail to be 132 pound-per-yard rolled steel [11]. The American Railway Engineering and Maintenance-of-Way Association (AREMA) was formed from the merger of the American Railway Bridge and Building Association, Communications and Signal Division of the Association of American Railroads, and the Roadmasters and Maintenance of Way Association with AREA in 1997, which now administers the specifications for rail manufacture. The rail pieces from the three mills contained the "CC" mark indicating that the steel was control cooled, a practice used to reduce hydrogen accumulation in the rail and to prevent internal flake formation [12]. The development of hydrogen flakes during steel manufacture has been shown to cause premature fracture [13].

By visual inspection, many of the running surfaces of the head portions for the rail pieces showed evidence of shelling and severe rolling-contact fatigue cracks, consistent with head checking [14]. Many of the fracture surfaces contained transverse detail fractures that extended from the gage side (inward surface facing the wheel flange) of the rail head in areas that coincided with observed head checking, as shown in Fig. 1.

Transverse detail fractures typically exhibit a smooth texture and dark tinted region relative to other areas on the fracture surface, consistent with fatigue cracking in the rail head [7,14]. In this case, the dark tinted portions of the fracture surfaces appeared black or dark brown, consistent with iron oxide on the surface of steel. The area within the detail fracture portions exhibited crack arrest marks consistent with progressive cracking, later determined to be fatigue [15]. The areas located outside of the transverse detail fracture showed light gray coarse granular features consistent with overstress fracture