NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

December 4, 2014

MATERIALS LABORATORY FACTUAL REPORT Report No. 14-020

1. ACCIDENT

Place : Casselton, North Dakota
Date : December 30, 2013
Vehicle : BNSF Grain Train, G-RYLRGT9-26A
NTSB No. : DCA14MR004
Investigator : Richard Hipskind, RPH-10

2. GROUP MEMBERS

Erik Mueller, NTSB, RE-30
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Steven Dedmon, Standard Steel
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3. DETAILS OF THE EXAMINATION

On March 25, 2014, representatives from the NTSB and BNSF attended a plant tour of Standard Steel, LLC in Burnham, PA. Standard Steel was established in 1795 as Freedom Forge and has been in continuous operation since 1830. While in the past Standard Steel manufactured a variety of alloys and parts for multiple industries, at the time of the visit, the company focused primarily on producing wheel and axles for the railroad industry. Standard Steel, LLC previously manufactured ring products, but due to excess required capital investment needed to maintain the equipment, divested from ring production.

At the time of the visit, the company employed approximately 600 hourly union shop staff and 75 salary staff. The company products conformed to AAR and ISO manufacturing quality standards. However, these were not separate production processes, but rather one process that complied with both standards.

Standard Steel procured all of their incoming material from recycled scrap purchased from seven vendors. The scrap was sampled when received to ensure the material did not exceed residual element limits, rendering the material unusable. This scrap chemistry was verified with a melted and cast "hockey puck" sample analyzed using optical emission spectroscopy by the chemistry lab.[1] The scrap was stored in a yard outside the furnace and casting shop. The material was manipulated using a large electromagnet on an elevated gantry crane. The scrap material was loaded into a series of charging buckets on rail carriers. These containers were transported into the facility by rail. Typically, three charging buckets would be used to fill an arc furnace during production of one heat.

The melting and casting floor consisted of three consumable-electrode electric arc furnaces: one with a 75-ton capacity and the other two with 45-ton capacities.[2] The company was planning on procuring a fourth furnace (64 ton) as well as modifying the larger 75-ton furnace to a smaller 65-ton size with higher productivity. The furnaces employed an acid refractory lining.[3] Each furnace required at least 3 hours before the heat could be tapped and transferred to the ladles, used in teeming the ingots. The heat chemistry was verified using samples withdrawn by pneumatic tubes handled by operators. Once these samples cooled, they would be transported to the chemistry laboratory via a vacuum tube system. The melt temperature was controlled using electromotive force feedback.

The electric arc furnaces used a triple electrode configuration to reduce hot spots in the melt (Figure 1). The electrodes were consumable graphite segments, connected by tapered threaded nipples to the sockets of the adjacent segment. Furnace tapping was performed in three stages. A large water-cooled vacuum hood air filter adjacent to the top of the furnace was used to remove ejecta and fumes emitted by the furnace.

Once the melting process was complete, the molten steel heat from the electric arc furnaces was tapped into the ladle through the furnace-tapping spout. These ladles were positioned so that the opening was below the tapping spout of the arc furnaces. During the pouring process, the ladle chemistry was monitored by a series of samples taken by operators. This chemistry was sent back to the furnace and ladle operators in real time from the laboratory. This quality process allowed the operators to adjust the ladle chemistry by adding the proper quantity of alloying elements, determined from information provided by the laboratory. Neutral gas, typically argon or nitrogen, was bubbled through the molten steel to remove slag impurities and gases such as oxygen and hydrogen. The ladle temperature was checked during the stirring process that also cooled the molten steel. The stirring process continued until the molten steel in the ladle cooled to a temperature specific to the heat composition. The molten steel in the ladles were then probed for hydrogen before teeming.

[1] *Optical emission spectroscopy* is a method of measuring concentrations of elements in samples by sampling characteristic light wavelengths produced when a sample is vaporized by an electric arc.

[2] An *electric arc furnace* is a furnace in which metal is melted by an electric arc between adjacent electrodes and the work metal.

[3] The refractory linings of electric arc furnaces are chosen to impart acidic or basic quality to the melt slag to control processing properties such as impurity content, process time, and slag formation. *Slag* is the nonmetallic byproduct resulting from mutual dissolution of flux and nonmetallic impurities in the steelmelting process, which serves to protect the molten metal from the air and extracts certain impurities.

The ingot mold configuration consisted of a series of 8 to 12 vertical cylindrical molds, interconnected via a central spider-gate distribution system (Figure 2). The ingot molds were “big end up,” which is the preferred casting shape for fully killed steel.[4] The bottom pour setup was composed of a slotted cast iron base-plate, cast iron stools that the molds rest on, the ingot molds, and refractory gates for each stool. Horizontal refractory runners connect to the refractory king brick that distributes the molten steel to each of the runners. Above the king brick, there was a cast iron trumpet with a refractory lining and a cast iron base plate cover. Casting sand was placed between the cast iron and refractory components, excluding only the up gates. Steel rigging was used to keep the molds vertical and properly spaced. The top of the trumpet (or funnel) was covered with an aluminum-foil covered cardboard conical cap that prevented sand from entering the trumpet and gates during the start of teeming.

Once the proper temperature and chemistry were achieved, the ladle was positioned by the overhead crane above the center trumpet (Figure 3). A fiber shroud was affixed under the off-center slide gate nozzle of the ladle, and a tube was connected above the shroud to allow the flow of neutral gas into the ladle. The neutral gas stirred the liquid in the ladle, helping to homogenize the temperature and composition. The argon bubbling also prevented entrainment of atmospheric oxygen into the tap stream. Once the nozzle was opened, the molten steel burned away the cap on the top of the center trumpet, and flowed into the spider gate system, filling the ingot molds. The process took approximately 45 minutes to fill the largest ingot molds.

Standard Steel personnel discussed some of the ingot casting parameters and potential issues that were monitored in case of production problems. Typically, the ingots were filled quickly at the start for several minutes. The flow rate was then tapered off to create steady state flow along the ingot centerline until the end of the mold-filling process. If a temporary decrease in the filling rate occurred during teeming due to an obstruction in the runners or up-gates, then solidification within the refractory path could become constricted. The constriction could increase the velocity of the fluid entering the mold, creating turbulence and localized ingot remelting that can lead to casting defects. These defects typically manifested themselves in one of the ingots. Blockage at the king brick would likely create casting issues with the ingot molds fed by the horizontal runners affected. The flow rates from the ladles were measured using load cells on an overhead crane at the time of the visit. At the time of the production of axle S/N 1102 7A1 E0912, the flow rate was measured using a float in one of the molds.[5]

The ingots were torch-cut to the required weight and placed outside the axle forging facility until processed. Each cut ingot was fed into a gas-heated soaking furnace, which had an opening to the outside storage area. Once properly heated, each cut ingot exited the soaking furnace and moved along a roller conveyor system towards the forging dies. A claw grabbed the cut ingot from the conveyor and placed it in the track positioned part-

[4] *Killed steel* is steel treated with a strong deoxidizing agent such as silicon or aluminum to reduce the oxygen content to a level such that no reaction occurs between carbon and oxygen during solidification.
[5] This axle serial number was the axle that fractured during the Casselton, ND derailment on December 30, 2013.

handling manipulator. The ingot section was fed into a four-hammer radial forge, where the part cross-section was reduced and fed towards a second work piece manipulator on the opposite side (Figure 4). The cut ingot was passed back and forth through the radial forge several times, leaving a spiral appearance on the forging surface from to the computer synchronized hammer blows.

The forging was grabbed and moved via an overhead track system towards the torch cutting area. The forging was torch cut on the ends to remove excess material and cut in the middle to separate the forging into two axles. The cut axles were then individually press straightened.

The axles were then fed into a continuous axle heat-treating line comprised of three furnaces, which were used to double normalize and temper the forged axles. These furnaces were gas-fired and temperature-controlled by manned computer stations.

The rough-forged axles were placed on a conveyer system where they were machined using a three-step process. The ends of the axles were trimmed and holes were center-drilled. The holes were used to the center the axle. At this point, the axle serial numbers were etched onto the ends. Next, a lathe using four cutting tools excised the journals, dust collars, and wheel seats. Lastly, a lathe machined the remaining central portion of the axle body to the required shape and diameter.

The axles were examined for internal defects by ultrasonic inspection (UT) after machining.[6] The portable pulse-echo UT detectors settings, such as frequency and amplitude, were setup for either axial or radial inspection direction. The detectors were calibrated to reference standards. The operators were permitted to modify these settings as needed to locate certain defects better. The operators were all at least ASNT Level II certified.[7]

The axles rolled along an inspection and shipping-preparation table for simultaneous access by two UT operators. The operators used portable UT devices and inspected the axle from both ends. During the radial UT inspection, the operators brushed couplant from paint cans along the length of the axle barrel (Figure 5). The operators then probed the length of the axle with a circular transducer, looking for an 80% backwall reflection drop, which would result in rejection of the part.[8] The axle was then inspected again along the barrel length rotated 90° from the original inspection line to probe for oblong and irregular shaped internal defects. The axles were axially UT inspected from each end using UT devices calibrated to axial inspection configurations (Figure 6). Once tested and cleared, each axle was tagged with a bar code traceable to a serial number, heat number, facility, date, and processing label (Figure 7).

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[6] *Ultrasonic testing (UT)* is a commonly used, low-cost, and rapid non-destructive testing method that uses high-frequency acoustic energy to detect internal flaws.

[7] One of three certification levels according to the requirements as defined by the *American Society for Nondestructive Testing Recommended Practices SNT-TC-1A*.

[8] This percentage of signal decrease is indicative of an internal defect interfering with the reflected UT signal as defined in *AAR Specification M-101 (Manual of Standards and Recommended Practices, Wheels and Axles).*

The Standard Steel, LLC Quality and Technical Department used a variety of equipment to inspect the chemical, microstructural, and mechanical properties of the axles and wheels produced. This department works directly with the shops during part production to change processes to monitor compliance to part standards. The laboratory personnel also performed finite element calculations and simulations to understand the manufacturing process better and to reduce defects and residual stresses in parts.

Erik Mueller
Materials Research Engineer

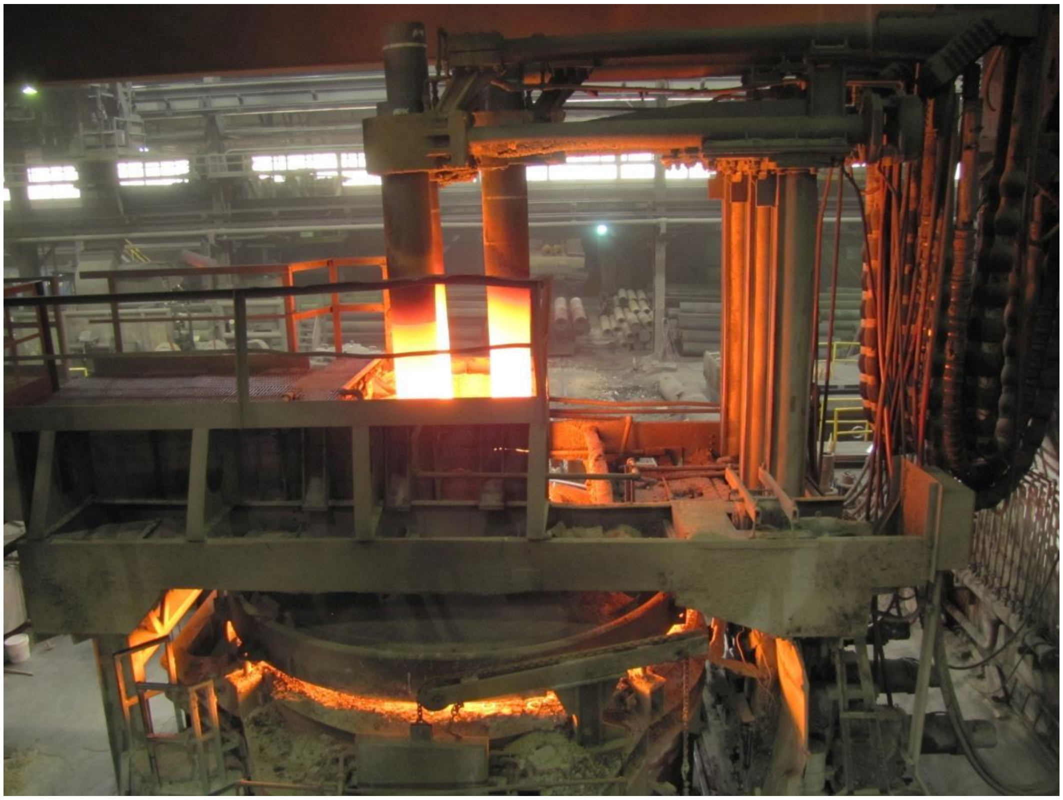

Figure 1 – An electric arc furnace after removal of the three consumable electrodes.

Figure 2 – The bottom of an ingot mold, after teeming and removal of the cylindrical molds.

Figure 3 – A ladle positioned over the center trumpet after ingot teeming.

Figure 4 – Radial forging of a heated cut ingot, held by the “A” manipulator.

Figure 5 – Radial UT inspection of a finished axle.

Figure 6 – Axial UT inspection of a finished axle.

Figure 7 – Finished axles, after inspection identified with bar code labels.