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# Second-Generation Head Defect Repair Weld Testing at FAST

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## Summary

In March 2014, Holland Company (Holland) and EWI (formerly Edison Welding Institute), with assistance from Transportation Technology Center, Inc., installed 10 second-generation head defect repair (HDR) welds in track for testing on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado.

The first-generation HDR welds tested on the HTL developed vertical fractures.<sup>1</sup> The second-generation HDR design was manufactured to eliminate the stress concentrators that caused the fractures and to reduce batter of the insert. The transformers were modified to reduce heat input into the insert. The insert was modified and improved shear and post-grind methods were applied by the manufacturer.

The second-generation HDR welds tested with the above modification are reported here with the following results:

- One of the 10 second-generation HDR welds was removed because of a weld break at 86 MGT. An apparent lip or lap of weld material on the web of the weld acted as a stress concentrator and likely caused the weld break.
  - After the weld break, the remaining nine test welds were hand scanned. The welds contained transverse defects ranging from 2.5 percent to 30 percent of the cross-sectional head area of the weld.
  - Welds containing smaller defects were either left in track to monitor crack growth or removed for residual stress testing. The ones left in track to monitor crack growth showed small amount of growth intermittent through the weld.
  - The welds containing the larger defects were removed immediately and were opened up to investigate the cause of fatigue and are still under investigation. The remaining welds including the welds with smaller defects were removed at the end of November 2014 with an accumulated tonnage of 149 MGT.
- All welds removed are being analyzed by Holland and EWI.

The first two phases of testing of HDR welds have shown the importance of minimizing stress concentrators under the head of the rail (also important for thermite, head-repair welds) and matching the as-welded hardness of the insert to that of the parent rail).

Another test is scheduled at FAST on a third-generation HDR weld designed by Holland and EWI. Those results will be published in a future *Technology Digest*.



**INTRODUCTION**

Holland and EWI have developed three separate electric flash butt head defect repair weld types (laboratory produced, first generation, and second generation) that have been tested at FAST within the past four years. Testing information and results of the laboratory-produced welds and first-generation HDR welds are reported in TD-14-002 titled “Testing of Electric Flash Railhead Repair Welds at FAST.”<sup>1</sup>

Two laboratory welds with over 500 MGT are still in track at FAST. All first-generation HDR welds were removed in October 2010, because of vertical fractures or transverse defects caused by stress concentrators within the geometry of the head repair inserts in relation to the adjacent railhead.

This TD reports the test findings of the second-generation welds. These tests are being performed to obtain an effective process to repair defects located in the head area of a rail or weld.

**SECOND-GENERATION HDR WELDS**

In March 2014, 10 HDR welds were installed on a 5-degree curve with 4 inches of superelevation on the HTL at FAST. These welds were installed using one of Holland’s mobile welding units (see Figure 1).

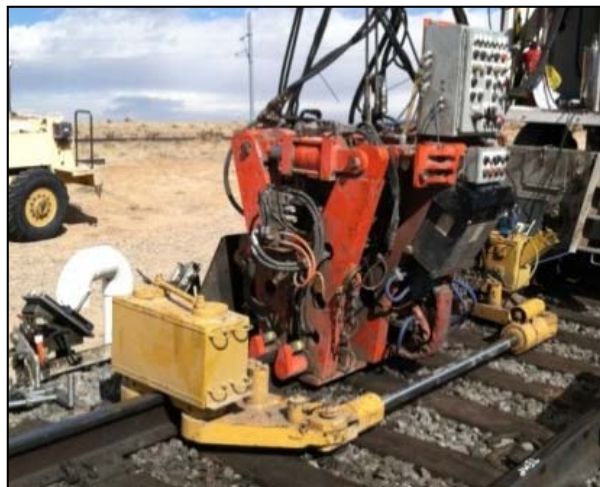


Figure 1. Holland’s HDR Weld Truck used for Production of Second-Generation HDR Welds

No chemistry alterations within the HDR inserts were made; however, the supplier of the material used for the inserts and the method of manufacturing changed between the first and second generation. First-generation inserts were made by partially rolling a rail bloom that was then machined into the insert. Second-generation inserts were manufactured from a billet and then forged into the insert.

Special attention was given to the rough and finish grinding of the second-generation HDR insert in relation to the rest of the rail in order to address one of the failure modes of the first-generation HDR welds. With the first-generation welds, although the welds were ground by the supplier to meet their requirements, finish grinding did not completely smooth out the corners of the insert that were located at the point where

the lowest corner of the insert meets the bottom of the railhead. This created stress concentrators at these locations (see Figure 2).

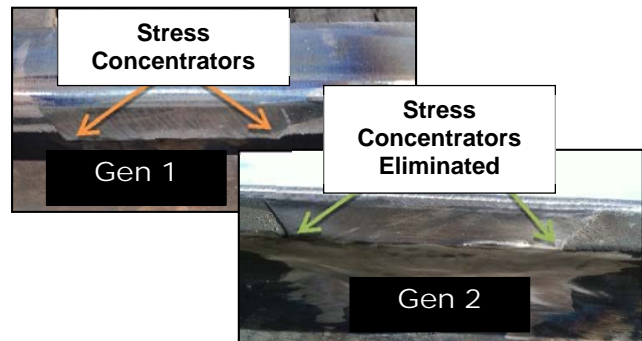


Figure 2. Generation 1 vs. Generation 2 Welds after rough and finish grinding

**FAST TESTING RESULTS**

As with the previous HDR weld tests at FAST, longitudinal profile and hardness tests were periodically recorded for each second-generation HDR weld. Profiles taken at various million gross tons were overlaid to show the wear over time for the second-generation HDR welds. As Figure 3 shows, the amount of wear and deformation of the (b) second-generation testing is about 44 percent less than that of the (a) first-generation welds.

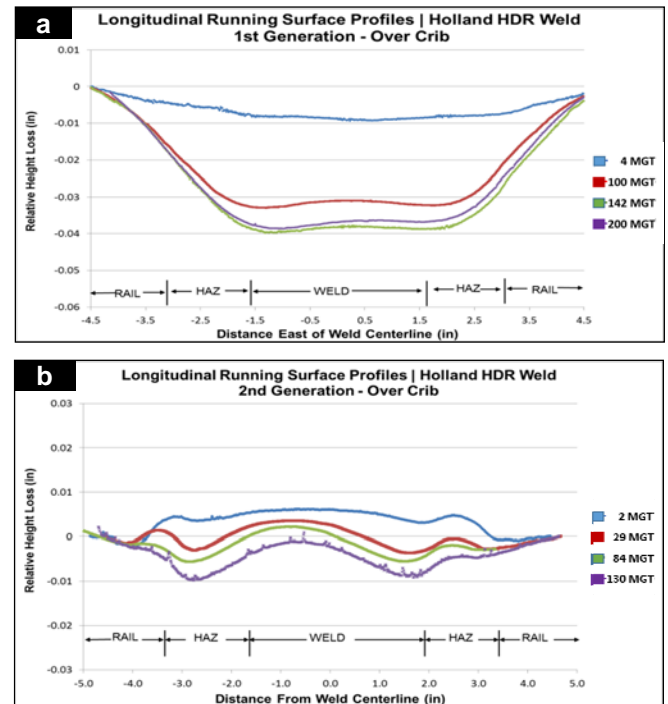


Figure 3. Longitudinal Profiles showing the Difference between the (a) Wear of the First-Generation HDR Welds and the (b) Wear of the Second-Generation HDR Welds

Even with the modifications implemented for the second-generation HDR welds, a weld break nevertheless occurred in August 2014 after only 86 MGT. The weld broke vertically near the center of the HDR insert location. Figure 4 shows different views of the rail break.



**Figure 4. Weld Break, August 2014**  
(The yellow arrow points to the center of the HDR insert)

Holland in collaboration with EWI examined this weld optically to find the initiation and cause of the break. Both sides of the fractured area were mounted and polished and the fatigue striations were carefully examined to find the crack initiation site. An apparent lip or lap was found to coincide with this initiation site. This lip was likely material that was not removed by the grinding process after the welding. This small lip remained even though the weld was carefully ground by the supplier, and the surface appeared to be smooth. A narrow layer of metal was not fully connected to the web of the rail, and this acted as a stress concentrator for fatigue crack initiation. The findings noted that the likely cause of this break was a lip or lap of weld material that was unground and acted as a stress concentrator.<sup>2</sup>

After the break that occurred at the end of August 2014, Transportation Technology Center, Inc. (TTCI) performed nondestructive testing (NDT) ultrasonic scans on the remaining welds. Indications were found at the fusion line in the railhead of most of the welds. TTCI removed one weld containing a 9-percent cross-sectional head area (CSHA) defect and opened it up in the laboratory to determine the cause of the indication (Figure 5).



**Figure 5. Weld Removed after Hand Scanning found a 9-percent CSHA NDT Indication within Weld**

EWI subsequently examined the weld that was removed using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometer (EDS) chemical analyses. A “shiny spot” was located and SEM images indicated globular-shaped particles that melted and resolidified without any bonding. The EDS data suggested manganese-sulfur-silicate inclusions that were smashed flat during the welding process and created a “flat spot” in the joint. The flat spot acted as a stress concentrator allowing progressive crack growth with continuous fatigue of the rail.<sup>3</sup>

Table 1 contains the removal information gathered by engineers and NDT technicians for all 10 welds in test at FAST.

**Table 1. Removal Information of Second-Generation HDR Welds at FAST**

Holland 2nd Generation HDR Test Welds - Installed March 2014						
TTCI ID	Holland ID	Rail Location	Removal Date	CONDITION/REASON FOR REMOVAL	TOTAL MGT	Comments
1	HW564	OSR	10/11/2014	Gage NDT Indication (1% CSHA)	120.28	Over crib
2	HW566	OSR	10/13/2014	Transverse Defect (3% CSHA)	120.09	Over Existing EFB Weld
3	HW567	OSR	8/29/2014	Weld Break	86.00	Over crib
4	HW568	OSR	9/5/2014	Center Positive NDT Indication (9% CSHA)	86.17	Over crib
5	HW569	OSR	10/30/2014	Center - Positive NDT Indication (2.5% CSHA)	143.39	Over crib
6	HW571	ISR	11/10/2014	Center Positive NDT Indication (4% CSHA)	149.17	Over Existing EFB Weld
7	HW572	OSR	10/13/2014	Transverse Defect (3% CSHA)	120.09	Over Existing EFB Weld
8	HW573	ISR	11/10/2014	Center Positive NDT Indication (7% CSHA)	149.17	Over Existing EFB Weld
9	HW574	OSR	10/30/2014	Transverse Defect (30% CSHA)	120.09	Over Tie
10	HW575	ISR	11/10/2014	Transverse Defect (15% CSHA)	149.17	Over Tie

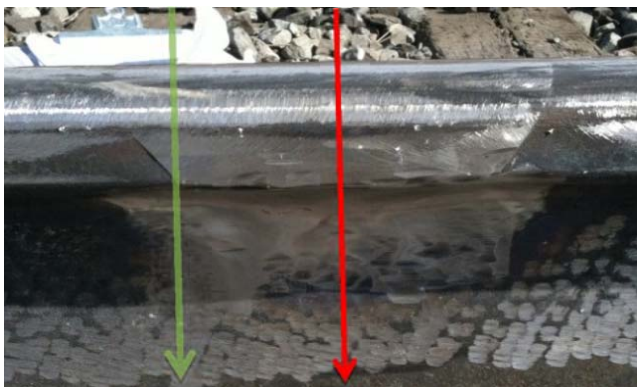
### RESIDUAL STRESS TESTING OF SECOND-GENERATION HDR WELDS

TTCI engineers conducted residual stress testing on three of the head defect repair welds containing smaller NDT indications of 1- to 3-percent CSHA to try to determine whether residual stresses could have contributed to the weld failure. For all of the three welds, the rail cuts were made transverse to the rail at 0.25 inch from the strain gages (Figure 6).

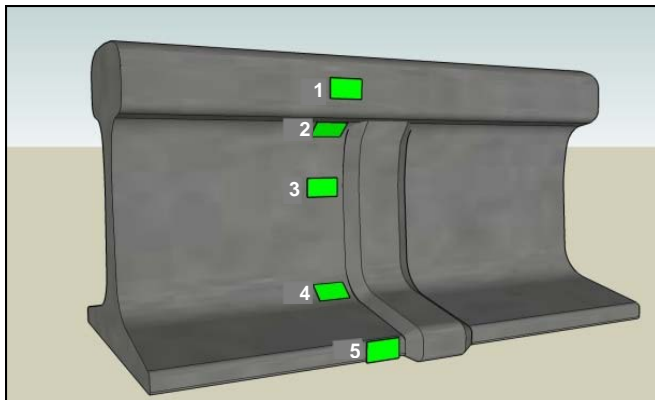
Each residual stress test weld was equipped with seven strain gages placed next to the weld as Figure 7 shows. At these seven locations, the pre- and post-cut micro-strain was recorded by the train gages and converted to residual stresses.

Figure 8 shows the results of the residual stresses when compared to each other. A straight rail which was cut longitudinally was also included for reference of the rail that the welds were installed in. This profile was obtained from a previous residual stress test when the rail was cut in April 2009.<sup>4</sup>

The longitudinal residual stress profile for the new rail was primarily in compression with the exception of the top of the head and the base of the rail, which were in tension.<sup>4</sup> This differs from the HDR residual stress profiles, which are in compression at the top of rail and web and in tension under the railhead making this portion of the weld more susceptible to fracture at stress concentrators under the railhead.

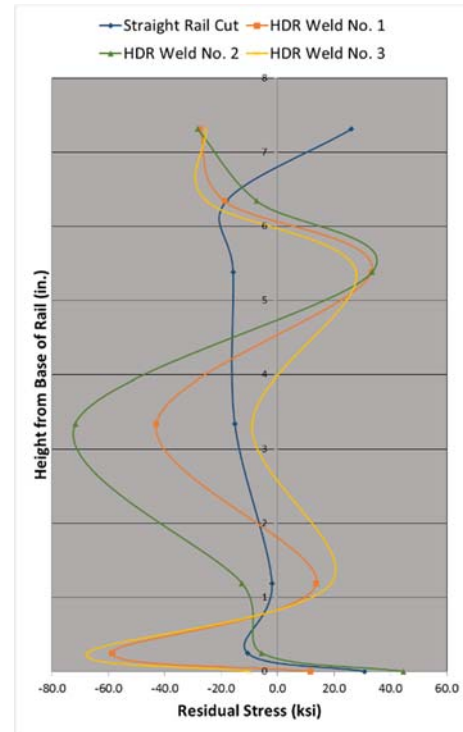


**Figure 6. Second-Generation HDR Weld after Production**  
(Red arrow shows the vertical cut direction down the center of the insert for Weld Nos. 1 and 2; the green arrow shows the cut direction at the point where the left bottom corner of the insert meets the bottom of the railhead for Weld No. 3.)



**Figure 7. Example View showing the Placement of Strain Gages attached to a Thermite Weld**

Strain gages were placed in similar arrangement for the railhead repair welds. 1. Side top center of railhead. 2. Side of the railhead. 3. Rail neutral axis. 4. Center of radius between the rail web and foot. 5. Tip of the base flange. Not shown were strain gages placed at the top of rail and at the bottom center of the rail foot.



**Figure 8. Longitudinal Residual Stress Profiles for all Three Welds Tested and a Straight Rail Cut**

**FUTURE DEVELOPMENT AND TESTING**

Holland and EWI are reviewing the results of the second-generation HDR weld test performed at FAST on the HTL and are making necessary changes to address defect initiations found within the welds. After changes are made, Holland will work with TTCI in establishing a third-generation testing of the EFB HDR welds.

*The evaluation of innovative products and concepts is an important part of the Association of American Railroads' Strategic Research Initiatives Heavy Axle Load Implementation Program at FAST. New and untried products can be evaluated under controlled conditions that would be difficult or impossible to replicate in revenue service. Testing at FAST provides important information on the performance of these types of products to the railroad industry, without exposing railroads to potential risks that could be associated with revenue service testing.*

**REFERENCES**

1. Gutscher, Daniel and Joseph LoPresti. March 2014. "Testing of Electric Flash Railhead Repair Welds at FAST." Technology Digest TD-14-002. AAR/TTCI, Pueblo, CO.
2. Workman, David. October 2014. "Failure Analysis of HW 567: Summary Report." EWI Project No. 14022MYY. EWI, Columbus, OH.
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4. Gutscher, Daniel. March 2010. "Railhead Repair Weld Residual Stress Investigation." Technology Digest TD-10-007. AAR/TTCI, Pueblo, CO.

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