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Thermite Maintenance Weld Performance at FAST

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SUMMARY

Failures of thermite welds continue to be a major concern for the railroads, costing the industry millions per year.

Many weld failures are experienced each year while in test in the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST), Transportation Technology Center, Pueblo, Colorado. Because the Transportation Technology Center, Inc. (TTCI) maintains detailed logs of thermite welds installed and removed at FAST, trends in thermite field weld performance can be monitored and analyzed. Information is recorded for each thermite weld to better understand the performance of welds under heavy axle load conditions.

This current analysis is directed toward field weld performance during ongoing Phase 5 operations at FAST. Phase 5 began September 23, 1999, and is characterized by the use of cars with 39-ton axle loads and standard trucks and by the use of lubrication on curves, with the exception of Section 7 on the HTL.

TTCI Phase 5 findings:

- Of all weld failures, 66.4 percent occurred in the high rail of curves; 4.9 percent occurred in the low rail, and the remainder occurred in spiral and tangent track.
- The two suppliers of the thermite welds tested had statistically similar percentages for weld failure types.
- During Phase 5, 70 percent of all failures were of the vertical type. Vertical failures typically originate at the base or flange web radius with crack propagation both vertical and transverse to the rail.
- Vertical failures were decreasing throughout Phase 5 operations.
  - In 2000, nearly 90 percent of thermite weld failures at FAST were due to vertical failure.
  - In 2005, less than 50 percent of thermite weld failures at FAST were due to vertical failure.
  - Decrease is attributed to targeted research and attention to installation practices.

For the purposes of investigation, thermite weld failures during the ongoing Phase 5 operations were analyzed and classified as one of six general failure types: vertical failures, horizontal failures, transverse defects, shelling or chipping, a combination of any of the preceding categories, and others not fitting any of the preceding categories.

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INTRODUCTION

Thermite field weld failures are a major problem costing the railroad industry millions per year. Likewise, field weld failures are a considerable problem at FAST. TTCI maintains weld logs detailing both installation and removal of thermite welds in the HTL at FAST. These records are used to explore and monitor thermite weld performance trends.

This investigation focuses on thermite field weld performance during Phase 5 operations at FAST. Phase 5 began September 23, 1999, and is characterized by the use of cars with 39-ton axle loads and standard trucks and by the use of lubrication on curves, with the exception of Section 7 on the HTL. Reference 1 addresses more information on operating conditions at FAST throughout the various phases.

FAST FIELD WELD FAILURE INVESTIGATION

Thermite weld failure data for the HTL was compiled and plotted to investigate trends related to weld type, location, tonnage, and superelevation. Figure 1 shows the layout of the HTL. Figure 2 shows the distribution of failures in the HTL and the accumulated tonnage of all the welds that failed during Phase 5 operations. This data indicated that 66.4 percent of all weld failures occurred in the high rail of curves, while only 4.9 percent of all weld failures occurred in the low rail of curves. The remaining 28.7 percent of all weld failures occurred in spiral or tangent track.

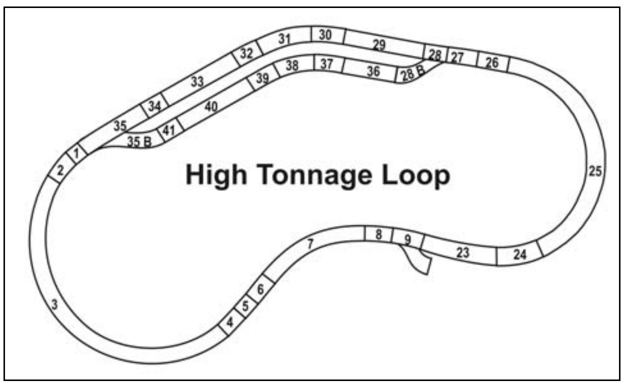


Figure 1. Section Locations on the HTL

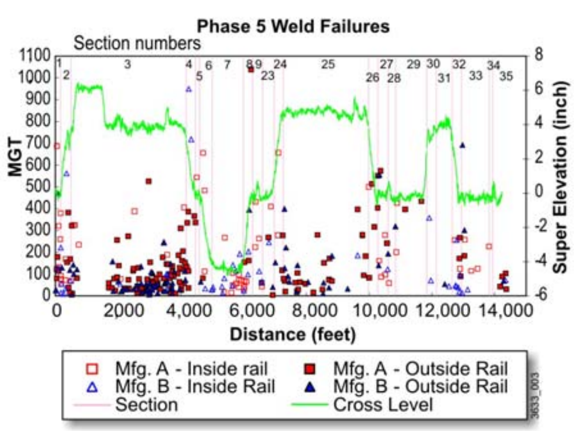


Figure 2. Location and Tonnage of all Field Weld Failures that Occurred during Phase 5

Since the beginning of Phase 5, over 1,750 welds have been installed. Approximately 1,050 of which have been removed for maintenance and 300 removed due to failure. Figure 3 shows the cumulative number of weld installations, weld failures, and welds that were removed for other causes for each quarter year of operation throughout Phase 5. Both the weld installation and the weld failure rates remained essentially constant throughout Phase 5, whereas the rate of welds removal for reasons other than failure tended to increase.

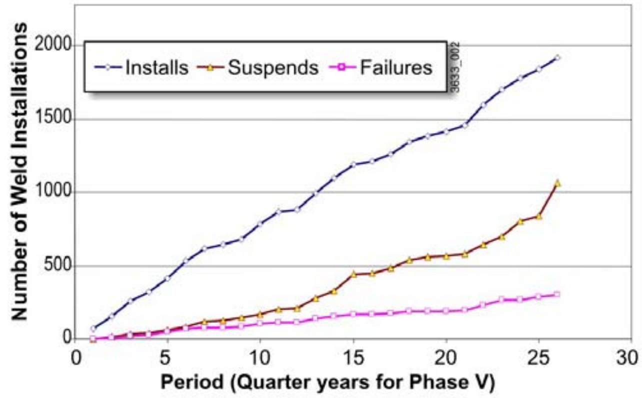


Figure 3. Cumulative Number of Weld Installations, Non-Failure Removal, and Failures for Phase 5 Thermite Field Welds

Due to the high concentration of welds in the HTL and installation of various track-work tests, the rate of weld installations exceeded the failure removal rate by greater than two-to-one, as would be expected in the typical scenario, where two welds are required to replace one failed weld. As welds failed, rail plugs were situated to replace the failed weld and as many adjacent welds as possible to control the proliferation of welds in track.

FAILURE MODE INVESTIGATION

Because of the nature of thermite weld failures, no two fractures are exactly the same. However, strong similarities do exist that allow for categorizing thermite weld failures into several general failure types. For convenience and analysis purposes, thermite weld failures in this examination were divided into six primary categories:

1. VF – Vertical failure
2. HF – Horizontal failure
3. TD – Transverse defect
4. SC – Shelling or chipping
5. C – Combination of more than one of the above
6. O – Other failures that did not clearly fit any of the above categories

Figure 4 illustrates several thermite weld failure types. The distinction between vertical and horizontal failures is discussed in the following paragraphs.

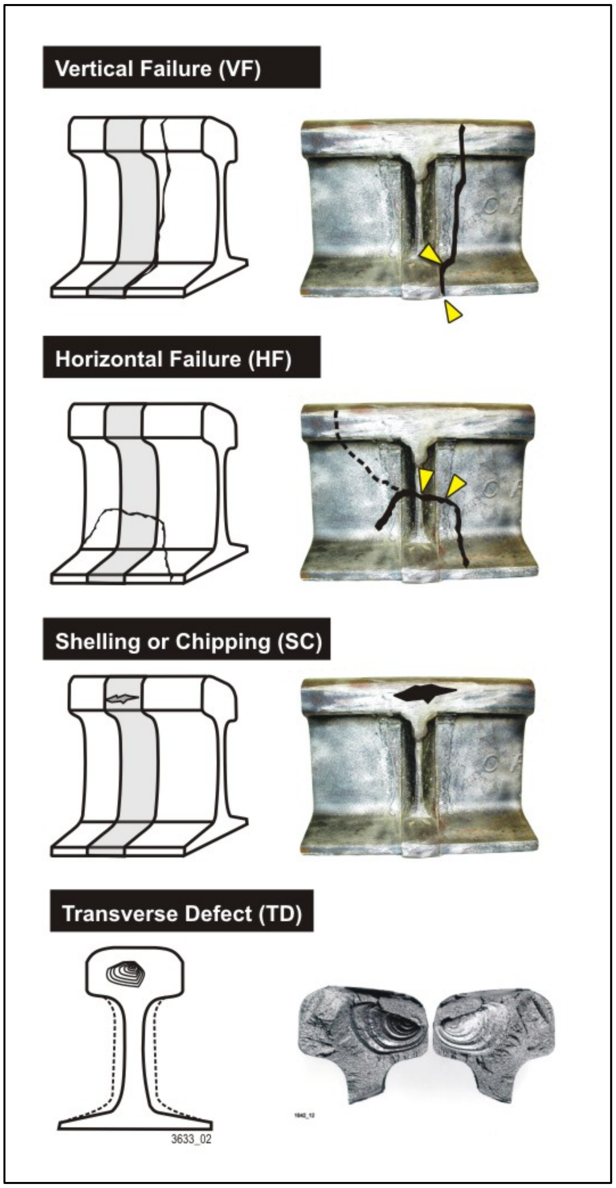


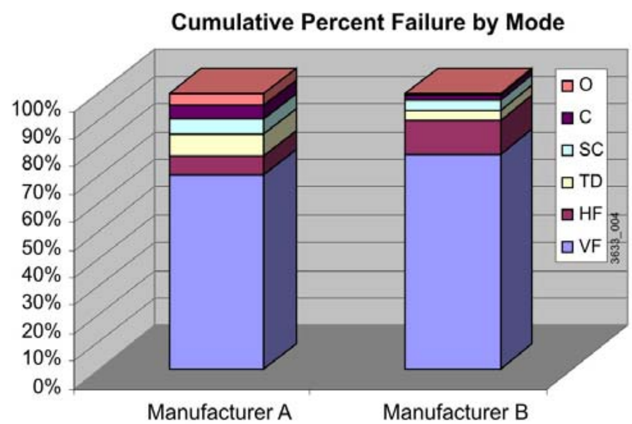
Figure 4. Examples of Thermite Weld Failure Types (yellow markers show typical locations of failure initiation)

VFs typically originate at or near the fusion line of a thermite weld either along the base or at the flange web radius. The failure then progresses under fatigue (oriented vertical transverse to the weld) until the remaining cross-section is unable to support the load, at which point, the weldment then fractures. VFs often originate at or are associated with stress risers caused by flashing remnants from improper weld mold fit-up or with porosity at or near the weld fusion line.

HFs typically initiate at or near the web portion of the weldment and progress horizontally under fatigue through the weldment. The resulting fractures can then turn up, down, or both as they progress into the rail body. HFs often start at inclusions, porosity, surface defects, or surface damage such as grinding marks.

The leading failure type has changed since beginning 39-ton axle load testing at FAST in 1988. Both Phase 1 (July 1988 to June 1990) and Phase 2 (December 1990 to May 1995) failures for standard strength field welds were primarily due to shelling. During Phase 2 operations, premium thermite welds were introduced that had increased hardness and the predominant failure type shifted to horizontal web cracking.[2]

The predominant field weld failure type in Phase 5 has been VFs typically originating at the base or flange web radius. Over 70 percent of all field weld failures during Phase 5 were VF. Figure 5 shows the Phase 5 overall thermite weld failure type, percentage breakdown for the two major thermite weld manufacturer welds used at FAST.



Manufacturer	VF	HF	TD	SC	C	O
A	70.6	6.6	8.1	5.1	5.1	4.4
B	77.8	12.0	3.7	3.7	1.9	0.9

Figure 5. Phase 5 Average Failure Type Percentages for each Manufacturer Welds

Close examination of weld failures during Phase 5 operations reveals that the failure type percentages have been changing. Figure 6 shows the weld failure type percentages from 2000 through 2005 at FAST. At the beginning of Phase 5, VFs constituted 88.9 percent of all thermite weld failures. By 2005, this percentage had dropped to 45.5 percent. Simultaneously, the percentages of all the other weld failure types have increased, HFs with the largest weld failure increase (approximately 20 percent). This shift away from VF is likely due to a strong emphasis in recent research and testing efforts by TTCI, the University of Illinois at Urbana Champaign, and Orgo-Thermit, Inc.[3,4,5,6] These efforts focused on issues such as weld procedures as well as the effects of weld profile, flashing, and alignment on weld performance, all of which may contribute to VFs. The greatest contributing factor is likely due to procedural changes implemented at FAST, since both manufacturers' welds showed a similar and simultaneous shift away from VFs.

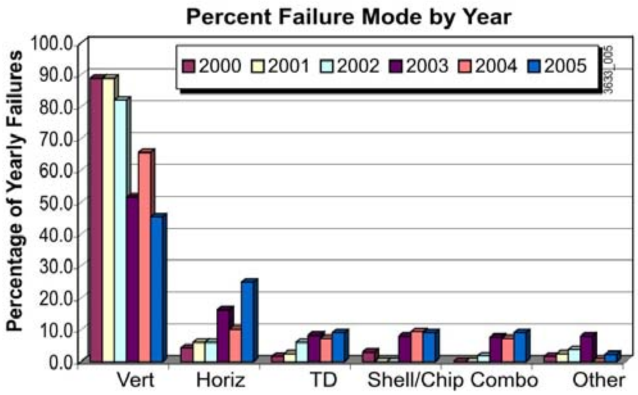


Figure 6. Phase 5 Failure Mode Trends

Anecdotal evidence had suggested that one manufacturer's VFs tended to favor initiation from the flange web radius, whereas the other manufacturer's VFs tended to favor initiation at the base. This investigation, however, was not able to provide sufficient empirical evidence to either confirm or deny this assertion since the records of VF did not always identify the origin.

Weibull analysis was employed in an attempt to determine average weld life. Valid results were not obtained due to the presence of more than one failure mode that could not be taken into account. For example, within the VF type, two different fracture initiation sites are common, the base and the flange web radius. Maintenance practices at FAST also make determination of average weld life difficult in that many welds that have not failed are removed along with failed welds resulting in a large population of data that cannot be used for a valid comparison.

CONCLUSIONS

TTCI maintains detailed logs of thermite welds at FAST to monitor and analyze performance trends. In this investigation, thermite weld failures during the ongoing Phase 5 operations were examined and categorized as one of six general failure types. Data was compiled and plotted in various ways to explore possible trends. Findings are as follows:

- The prevalent failure type during Phase 5 operations has been VFs (70 percent overall average for Phase 5).
- Research and development efforts at TTCI and in the industry during Phase 5 have targeted many of the causes of VFs.
- Both major thermite weld suppliers had similar percentages for failure type.
- The percentages in failure type during Phase 5 have been changing. In the year 2000, approximately 90 percent of failures were VFs, but by 2005 this percentage decreased to 45 percent of failures being vertical in nature.

The implications of these findings are that training and attention to installation practices as well as manufacturer weld improvements can significantly influence thermite weld performance.

FUTURE WORK

TTCI plans to further investigate the effects of the stress state of rail weldments and their relation to rail weld failures.

This year, TTCI plans to install new thermite welds in track at FAST from both of the manufacturers mentioned herein. These thermite welds incorporate design improvements addressing issues related to the initiation of VFs. This will include the installation and testing of advanced geometry welds.

REFERENCES

1. LoPresti, Joseph and Semih Kalay. November 2000. "FAST Heavy Axle Load Testing Update." *Technology Digest*, TD-00-024. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
2. Garcia, Gregory and Jon Hannafious. September 1995. "Thermite Weld Performance under Heavy Axle Load Operations at FAST." *Technology Digest*, TD-95-020. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
3. Kristan, Joseph. February 2002. "Thermite Weld Evaluations at FAST." *Technology Digest*, TD-02-006. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
4. Lawrence, Fredrick V., et al. April 2003. "Increasing Thermite Weld Fatigue Life through Improvements in Weld Profile." *Technology Digest*, TD-03-005. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
5. Kristan, Joseph. December 2003. "Effects of Flashing and Alignment on Thermite Weld Performance." *Technology Digest*, TD-03-026. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
6. Kristan, Joseph, October 2004. "Thermite Weld Progress." *Technology Digest*, TD-04-015. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.

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