TECHNOLOGY DIGEST

Timely Technology Transfer — 02-006

Thermite Weld Evaluations at FAST

by Joseph Kristan

Summary

Thermite weld testing at the Facility for Accelerated Service Testing (FAST) in 2001 concentrated on vertical base offset and flashing (run-out) influences on 1-inch premium welds, cracking and metal flow in wide-gap welds, and laboratory evaluation of a new head hardened thermite weld.

A vertical offset base thermite weld test was installed in 2001 at the recommendation of the Heavy Axle Load Research Committee (HALRC) to address a premature (less than 30 MGT) failure percentage increase that occurred in 2000. This test currently has accumulated 14.5 million gross tons (MGT) with no test weld fractures to date. Based on the tonnage accumulation of the premature weld failures, conclusive offset test results will likely be obtained by 50 to 60 MGT.

Seven Railtech Boutet wide-gap thermite test welds had cracked previously at FAST, and the cause was determined to be a reduced hardness in comparison to previously laboratory tested wide-gap welds (approximately 30 Bhn less for new welds). Thus, a new set of wide-gap test welds will be installed in 2002 with mechanical properties similar to those of the previous laboratory tested welds.

A new head hardened thermite weld was evaluated by laboratory testing, at the recommendation of the HALRC. This type of product is not available from any of the current weld producers. This head hardened thermite weld (average deflection of 0.40 inch and modulus of rupture of 91.7 ksi) did not meet the proposed AREMA minimum mechanical properties for slow bend or rolling load testing with rolling load results of 285,800 cycles to fracture at 59,400 pound load. However, engineers are aggressively working on modifications to their welds to improve performance. Subsequent to independent laboratory results showing improved head hardened weld performance, Transportation Technology Center, Inc. will resume testing of this new product.

Future thermite weld testing at FAST will consist of monitoring the performance of the vertically offset base weld test and/or performing failure analysis on any weld fractures. The analysis of any test weld fractures will be critical to the success of the offset test, as the cause of the fractures will need to be determined and documented.

The hardness and surface deformation of any future wide-gap welds will be documented as they are installed and tested. Additional revenue service monitoring of wide-gap welds is being performed in a cooperative effort between TTCI, and the Union Pacific Railroad, and BNSF Railway. The data will be used to supplement the results of the FAST tests.

Suggested Distribution:
- ☐ Maintenance of Way
- ☐ Track Maintenance
- ☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads

INTRODUCTION

Performance and durability of thermite welds have improved greatly over the last decade. At the beginning of the heavy axle load operations at FAST in 1988 with 315 kip cars, the thermite weld failure rate was 89 percent (this failure rate is for service failures only—through weld fractures), because the welds were not optimized to perform in the more demanding environment. As a result of the early thermite weld performance observed under HAL, the weld manufacturers recognized that product improvements were required to obtain acceptable performance under heavier axle loads. Through the efforts of weld manufacturers, the AAR, the railroads, and other research institutions, weld improvements at FAST have reduced the current thermite weld failure rate to 16 percent. Modifications to the alloying, risers, molds, and crucibles have produced a stronger, cleaner, and more consistent thermite weld. Railroads agree, however, that the current thermite weld failure rate of 38 percent (38 percent of 136 RE thermite welds were removed due to fracture or detector car indication during 1998-1999) of 136 RE rail failures reported for 1998-1999 by a major railroad is not acceptable. Consequently, the desire is for thermite weld performance to be comparable to that of flash-butt welding. The utility and applicability of the thermite weld ensures its use on a widespread basis both in North America and elsewhere.

Thermite welds will continue to improve even though adverse conditions under which they are utilized may inherently prohibit performance improvements to match that of flash-butt welds. The flash-butt welds are normally made on new or good condition rail with limitations to the amount of curvature in which the welds can be made. Conversely, the thermite welds are often utilized in less than optimum repair conditions; e.g. mismatched rail ends in rail repair plugs, worn rail, joining rails of different section, and special track work. Laboratory testing of both optimally produced flash-butt and thermite welds has shown the current thermite welds do not achieve the performance of flash-butt welds. Thus, under similar installation and operating conditions, thermite weld improvement is possible.

Another factor in the performance of thermite welds is the required skill and experience of the welder. The alignment, mold installation, preheating, pouring, breakdown, and finishing of the weld are all the responsibility of the welder. Conversely, the flash-butt equipment is more automated with the alignment, making and finishing (with the exception of touch up grinding) of the weld either automated or computer controlled. Thus, both the installation environment and the manufacture of the thermite weld are at a disadvantage in comparison to the flash-butt weld.

Further research is being performed at FAST to improve the performance of the thermite weld. Current research efforts at FAST have concentrated on improving the premium 1-inch gap weld, evaluating the wide gap weld, and evaluating the performance of new and possibly beneficial thermite welding products.

FAST VERTICAL OFFSET THERMITE WELD TEST

The continual monitoring of repair welds at FAST allows thermite weld problems to be identified on an ongoing basis. As a method of evaluating the current major thermite weld manufacturer’s products, the FAST maintenance practices are to install each rail plug with one weld manufacturers product at either end. This allows a direct comparison to the relative performance of the weld types. As a result, an infant mortality (less than 30 MGT) increase in one type, Type A, of thermite weld was identified during 2000 (Exhibit 1). Failure analysis was performed on 10 of the premature failures by both TTCI and the weld manufacturer’s engineers. The following consistencies were identified:

- Twelve of the 15 premature fractures were Type A welds with 10 of 12 of Type A occurring in the high rail.
- Nine of the 10 investigated Type A premature weld fractures were due to fatigue that initiated at the center third of the rail base. The other was due to fatigue at the web to base fillet.
- Each of the base fractures occurred between 1/8 and 1/2 inch away from the weld collar back into the parent rail.
- All of Type A high-rail premature fractures had substantial flashing at the fatigue initiation site due to vertical offset at the base of the opposing rails of between 1/16 to 1/4 inch to allow the use of rail repair plugs.

The analysis of the premature thermite weld fractures (premature fractures were service fractures that occured with less than 30 MGT of accumulated tonnage on the weld) by both TTCI and the manufacturer of Type A weld showed that the offset of the rail bases contributed to the fracture and was not caused specifically by the Type A weld. Because each of the fractures initiated a distance away from the weld collar in the flashing area, TTCI concludes that the resultant excessive flashing from the offset of the bases was a major contributing factor to the premature fractures. But the manufacturer of Type A weld contends that flashing has no influence on weld performance and did not contribute to the premature fractures of the FAST welds. Therefore, they attribute failure specifically to the vertical geometry mismatch of the rails.

TTCI = Transportation Technology Center, Inc.; AAR = Association of American Railroads

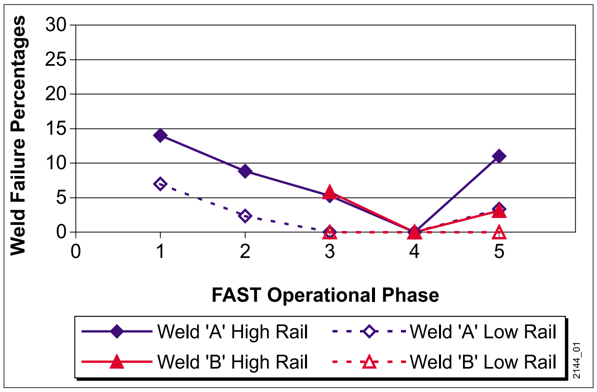

Exhibit 1. FAST Premature (<30MGT) Thermite Weld Failures per Operational Phase

Note: The duration of Phase 4 operations was extremely short and very few welds were installed. Thus, this data is not representative of the actual weld performance during that period.

Additionally, for safety reasons, a competitor's refractory was used to plug the large gap between the bottom of the rail and the mold to prevent any metal from running out. The weld manufacturer contends that this also could have contributed to the premature failures, though no refractory was observed at the fracture initiation sites of any of the analyzed premature failures.

To determine the influence of excessive flashing due to imperfect geometrical alignment of the weld, the Heavy Axle Load Research Committee (HALRC) recommended a vertically offset thermite weld test. The test, which was installed in October, was intended to evaluate the influence of both offset and flashing conditions at the rail base. The thermite weld offset base test consisted of 24 welds installed in rail with an intentional 0.188-inch vertical offset. The flashing at the base of 12 of the welds was reduced by placing a refractory paste on the edge of the mold to fill the opening. This method was used as a result of research performed at the University of Illinois at Urbana-Champaign. The flashing present on 12 of the test welds was unmodified for which a significant amount of flashing is evident at the rail base on the 0.188-inch uplifted rail. Ten of each type were placed in the high rail and two of each type in the low rail in Section 03 at FAST, a 5-degree curve with 4-inch superelevation for a cant deficiency of 1.6 inches at 40 mph typical train operating speed.

The setup of the test welds is intended to incorporate the two common factors between each of the premature maintenance weld fractures. The 0.188-inch offset of the bases correlates directly with the geometry of the premature fractures investigated. The resultant flashing from the offset of the rail bases (without reduced flashing) will theoretically produce a stress concentration site initiating fracture at the rail base a distance away from the weld collar.

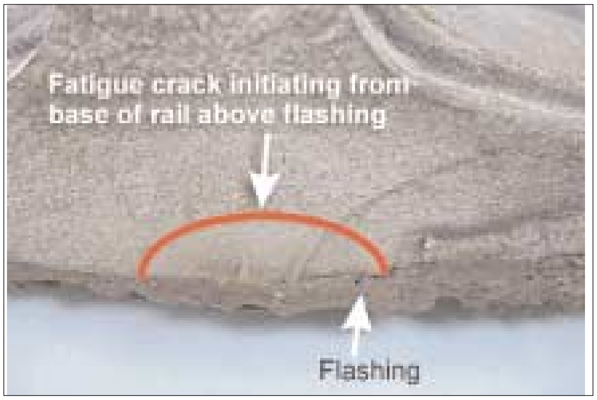

Exhibit 2. Offset Thermite Weld

The vertical offset test welds had received 14.5 MGT through 2001 with no fractures to date. The test welds will likely require an additional 10 MGT before any fractures occur; the average Type A premature weld fracture occurred at 22.4 MGT. Definitive results will likely be attained after 50 to 60 MGT, which will occur approximately mid-year in 2002.

FAST WIDE-GAP WELD TESTING

The Railtech Boutet, Inc. WGW wide-gap weld (2.68 inch, 68 mm) was laboratory tested at TTCI in 1998 (*Technology Digest* 98-026). The wide-gap welds were evaluated using rolling load, slow-bend, tensile, hardness, and residual stress tests as well as macrostructural examination. The average properties of the wide-gap weld all met that of the conventional 1-inch gap welds tested. Subsequent to the initial laboratory test, the wide-gap welds were also tested for fatigue (*Technology Digest* 00-007) and performed better than the standard welds. Thus, the wide-gap welds were deemed appropriate for track testing because of the acceptable laboratory test results.

Twenty-five wide-gap test welds were installed at FAST in Sections 30 (spiral), 31 (5-degree curve, 4-inch superelevation), and 33 (tangent) through 1999 and 2000. Cracks with excessive metal flow were found on the field side of four of the welds after slightly over 84 MGT. These welds were removed from track for investigation. Three more welds sustained cracking and are currently being monitored. There have not been any wide-gap weld service failures at FAST. An investigation of the cracked welds from FAST determined that the hardness was lower than either the laboratory tested wide-gap welds or standard 1-inch gap welds. A laboratory wide-gap weld tested had an average hardness of 302 Bhn as made without any work (strain) hardening from service operation. Conversely, the wide-gaps at FAST had an average running surface hardness of 269 in new and 333 Bhn in work hardened condition. For comparison, the typical running surface hardness of an as-poured standard gap weld is 296 Bhn.

Representatives of the weld manufacturer were informed of the findings and are contributing several wide-gap test welds for an in-depth laboratory evaluation. If the properties of these welds are comparable to the previously laboratory evaluated test welds, a number of wide-gap welds from the same production lot as those tested will be installed in track at FAST for additional evaluation of wide-gap weld performance.

NEW THERMITE RAIL WELD PRODUCT LINE AVAILABLE IN NORTH AMERICA

A thermite weld manufacturer offered a new thermite weld to the North American market in 2001. The weld was chosen by the HALRC for evaluation by TTCI because of several distinct differences between it and other available products. The weld is available in a head hardened type as well as standard 1-inch and wide gap welds. Another distinctive feature of this weld is the light weight of the prepackaged crucible. This alternative prepackaged crucible contains the thimble, weld portion, and cap factory sealed in a plastic film. Thus, the steps of pouring the thermite into the readied crucible and smoothing the top of the portion are not needed. Additionally, the design of the crucible and packaging are also intended to protect the crucible from damage during shipping and handling. The self-contained crucible may be a small step in the evolution of the thermite weld, but theoretically, it could be an advantageous step.

The HALRC was particularly interested in the head hardened weld, and accordingly, several test welds were manufactured of 136-RE rail at FAST, as Exhibit 3 shows, for laboratory evaluation. Each of the test welds poured at FAST was done under the direct supervision of the weld manufacturer. The performance of the welds was to be evaluated through slow bend, rolling load, hardness, and fatigue testing as well as macrostructural and chemical analysis.

The mechanical testing of the head hardened welds began with rolling load and slow bend tests. The criteria for the rolling load test are a 59,400-pound load applied to the railhead through a minimum of 2-million cycles. The head hardened test weld fractured after 285,800 rolling load cycles; and thus, did not meet AREMA's proposed minimum test requirements.

The head hardened thermite welds were also slow bend tested to determine the mechanical strength of the joint. Exhibit 4 shows the slow bend test results for three welds tested. None of the head hardened welds met the proposed AREMA slow bend test criteria for the head hardened rail. As a result of the performance of the head hardened thermite weld in the rolling load and slow bend tests, the evaluation of the test welds was halted.

This weld manufacturer has taken an aggressive engineering approach to improve the performance of their welds. Because of this effort, TTCI will likely resume laboratory testing of the head hardened thermite weld in 2002. If the weld performs acceptably in the TTCI laboratory evaluation, the weld will be considered for track testing at FAST.

Exhibit 3. Test Weld being Poured at FAST for Laboratory Evaluation

Exhibit 4. Results of Head Hardened Thermite Weld Slow-Bend Tests

Weld Number	Deflection (inch)	Modulus of Rupture (ksi)
1	0.50	90.6
2	0.35	93.8
3	0.35	90.6
Average	**0.40**	**91.7**
Proposed AREMA Specification	• *0.60 High Strength Rail* • *0.90 Standard Carbon Rail*	• *120 High Strength Rail* • *110 Standard Carbon Rail*

Note: Please contact Joseph Kristan at (719) 585-1852 with questions or comments about this document.
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