TECHOLOGY DIGEST

Timely Technology Transfer — 00-013

Thermite Weld Failure Survey

by Joseph Kristan

Summary

A survey of revenue service thermite weld failures has indicated that the most common defect is slag inclusions and/or gas entrapment (porosity) often forming at the web/base fillet. The most significant defect in thermite welds found by detector cars was fatigue fractures in the head (detail fractures) initiating at micro-defects in the weld. This thermite weld data is likely skewed as the ultrasonic rail flaw detection process only scans the head and web of the rail, and not the majority of the base. It must also be noted that the overall performance of thermite welds from revenue service was not addressed by this survey. For each of the thermite welds included in this survey as containing a substantial defect, there are currently thousands of welds in revenue service of which the vast majority are sound welds and do not contain defects.

The survey was a part of an overall Association of American Railroads' Strategic Research project to improve the life of thermite welds. Service failures containing major thermite weld defects were analyzed and submitted by participating railroads. From these it was determined that:

- The most common defect (40 percent of total reported failures) was slag inclusions and/or gas entrapment (porosity) forming mainly at the web/base fillet (56 percent of slag inclusion/gas entrapment occurrences).
- Other defects include fatigue initiated due to weld metal run-out between the rail and mold at the web/base fillet region and/or the base of the rail (32 percent), hot tears (15 percent), columnar grain formations (5 percent), pull-aparts (hot) (3 percent), grinding burns (3 percent), and sand inclusions (2 percent).

The survey also included examination of major thermite weld defects found by detector cars. This analysis determined:

- The most prevalent defect observed in the examined welds was fatigue fractures in the head (detail fractures) initiating at micro-defects (non-metallic and metallic inclusions, micro-voids, pores, etc.) in the weld (44 percent of total observed defects).
- Other defects documented from examination of defective thermite welds as indicated by detector car examination include shrinkage (12 percent), slag inclusions and porosity (12 percent), and columnar grain formations (7 percent).

A significant finding was that 24.4 percent of the detector car finds did not contain an observable defect. From the 41 detector car finds examined by TTCI engineers, nearly 25 percent are apparently good welds that were removed.

Suggested Distribution:

- ❑ Maintenance of Way
- ❑ Planning & Analysis
- ❑ Track Maintenance
- ❑ Safety

Work performed by TTCI Transportation Technology Center, Inc.

a subsidiary of the Association of American Railroads

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INTRODUCTION

As an improvement to the bolting of rail joints, thermite welding has become a widely used welding process which utilizes the highly exothermic aluminothermic reaction. This reaction between iron oxide (Fe_3O_4) and aluminum produces the heat required to melt filler metal which flows from a crucible into the opening between the rails and provides a suitable joint. Because of the popularity and widespread use of the thermite welding process, improvements in weld performance could reduce track maintenance and operational costs while at the same time improving safety. Thus, this investigation was conducted to identify the most prolific thermite weld defects in order to direct future research by TTCI to reduce or eliminate defects, thereby improving weld life.

The weld survey consisted of soliciting AAR member railroads for statistical information as well as visual examination of revenue service weld failures and detector car finds for analysis and classification. The statistical information supplied by several railroads in combination with the visual examination of service failures and detector car finds was intended to provide as diverse a weld sample population as possible in order to produce results that are statistically significant.

SURVEY PARTICIPATION

The railroads which contributed information and/or data for this project include Norfolk Southern, Burlington Northern & Santa Fe, Conrail, CSXT, Amtrak, and Union Pacific. The weld manufacturers included Orgo-Thermit, Inc. and Railtech Boutet.

The railroad representatives also provided expert opinions as to what the major thermite weld defects were (prior to data acquisition and analysis) and what the causes could be. The two consistent defects noted were inclusions forming in conjunction with pores and grinding burns. They indicated that modifying the grinding practices eliminated the latter defect. However, there was not a consensus opinion for eliminating the inclusions/porosity formations.

THERMITE WELD REVENUE SERVICE DATA

The thermite weld data was provided in two forms: weld defect data from analysis performed by the participating railroads, and thermite weld samples with detected defects found by detector car analysis. The data and weld specimens provided by participating railroads are summarized in exhibits 1 and 2 with photos of representative defects shown in exhibits 3 through 5. The data is not broken down in more detail, as several factors must be considered when interpreting this information:

- The majority of data submitted did not provide additional detail beyond that shown herein.
- The statistical data provided by the railroads was not proprotionate to each railroad's size. Thus the data may be skewed by unique operating characteristics or failure analysis methods of each railroad.
- Each railroad has its unique and specific installation practices as well as varying climatic and geographical conditions which could influence weld defect formation.

	Slag/ Porosity @edge of Collar	Slag/ Porosity Throughout Weld	Weld Run-out	Hot Tears	Columnar Grain Structures	Pull-Apart (Hot)	Grinding Burns	Sand Inclusions	Totals
Weld Defect Frequency	60	47	85	39	12	9	7	6	265
Weld Defect Percentage	22.6%	17.7%	32.1%	14.7%	4.5%	3.4%	2.6%	2.3%	100%

Exhibit 1. Thermite Weld Defect Data Submitted by Participating Railroads

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

	Fatigue Fractures from Micro-Defects	No Defect Observed	Shrinkage	Slag/Porosity	Columnar Grain Structures	Totals
Weld Defect Frequency	18	10	5	5	3	41
Weld Defect Percentage	43.9%	24.4%	12.2%	12.2%	7.3%	100%

Exhibit 2. Thermite Weld Defects from Examined Welds Removed from Track as Detector Car Finds

In addition, several of the railroads use thermite welds from only one thermite weld manufacturer. These circumstances preclude specifying additional detail such as the weld manufacturer or type of weld as a large and/or diverse enough sample population was not accumulated to discern this form of statistical information.

The data shown in Exhibit 2 was from defective thermite welds found by detector car inspection. After removal from track, these welds were broken open with the head in tension to allow observation of the detected defect (as most defects found by the detector car are in the head of the rail). A small number of welds were fractured with the base in tension to simulate the service stress state of the rail. However, the fracture path often did not intersect with the detected defect and this method of opening was not used further. All of the data shown in Exhibit 2 is for thermite welds which were fractured with the head in tension. Some of the welds were also inspected with handheld nondestructive testing equipment prior to breaking, and all showed some type of indication of porosity and/or voids; however, no defects were visually observed on the fracture surface of several of the welds (Exhibit 2) .

Tonnage accumulation to failure for the submitted weld data was also provided for 144 of the 265 welds. The average tonnage to failure for the revenue service welds was 169 million gross tons.

SIGNIFICANT RESULTS

The accumulated weld data suggests that the significant majority (approximately 91 percent) of thermite weld failures could be preventable by adherence to and/or improvements in current installation practices. Large

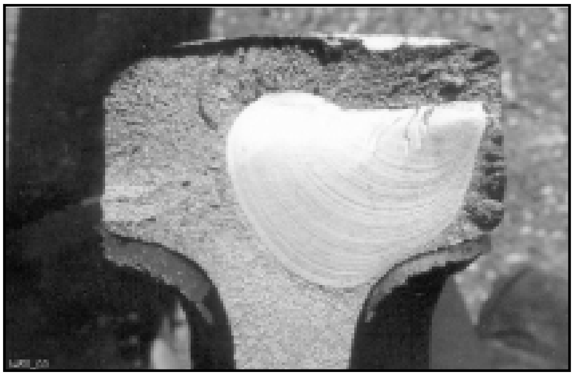

Exhibit 3. Fatigue Fracture (Detail Fracture) Initiating at Micro-Defect in Weld

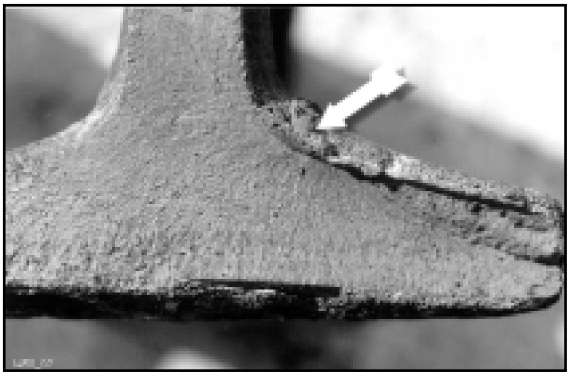

Exhibit 4. Fatigue Defects from Metal Run-Out at Rail Surface

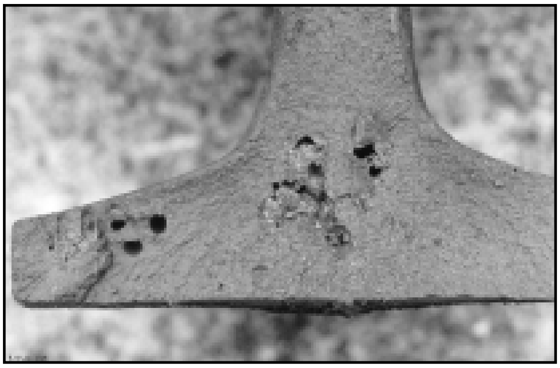

Exhibit 5. Thermite Weld with Slag/Porosity

visible internal defects were found at the fracture initiation sites of most submitted and examined welds. These defects include slag/porosity, weld run-out, hot tears, columnar grain structures, pull-aparts, grinding burns, sand inclusions, and shrinkage. A possible starting point for the elimination of the observed slag/porosity, run-out, hot tears, and grinding burns is through adherence to or possibly slight modifications in current weld manufacturer recommended installation practices as well as improvements in the thermite weld kits and consumables.

Another significant finding is that 24.4 percent of the detector car finds did not contain an observable defect. Of the 41 detector car finds examined, nearly 25 percent were good welds. A possible reason for the false calls can be that the expected response, or lack thereof, from the 45 and 70 degree ultrasonic shear waves is that there should be no signal reflection back to the transducer unless a reflecting surface is introduced. The various surface finishes introduced from thermite welds may introduce reflecting surfaces that generate signal responses similar to those from weld discontinuities such as slag, gas pockets, and cracks. Thus, improvements in NDT techniques could reduce removal of good thermite welds and therefore reduce maintenance costs.

It must also be noted that the overall performance of thermite welds from revenue service was not addressed by this survey. For each of the thermite welds included in this survey as containing a substantial defect, there are currently thousands of welds in revenue service of which the vast majority are sound welds and do not contain defects.

FUTURE WORK

The gathering of the thermite weld failure data from revenue service was intended to direct future research to reduce or eliminate the most prevalent weld defects. Areas to address include the formation of slag inclusions and porosity, weld run-out, hot tears, and grinding burns and possibly the micro-defects from which fatigue cracks initiate. Work plans to address these areas of concern will be considered by the AAR Engineering Research Committee.

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.