WIDE-GAP WELDING TECHNIQUES

David Davis
Semih Kalay
Jian Sun
Transportation Technology Center, Inc. (TTCI)
Pueblo, CO

and

Roger Steele
Metallurgical Consulting Services
Vernon, CT

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WIDE-GAP WELDING TECHNIQUES

SUMMARY

In 2000, the Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), initiated a project to study the current status and possible improvements to in-track rail welding for transit tracks in the United States. The project, supported by the Transit Cooperative Research Program (TCRP) (TCRP Project D-7), includes the following efforts:

- A feasibility study of applying wide-gap thermite weld technology to the transit industry by testing thermite welds in transit tracks,
- A survey of current usage of the wide-gap thermite welds in U.S. and foreign transit and passenger railroads,
- A survey of U.S. transit railways to determine problems experienced in the use of thermite rail welds, and
- A review of current and potential alternative welding processes for field rail welding in transit tracks.

The wide-gap thermite rail welding process was developed to repair rail welds and transverse rail defects. Compared with the current weld or rail defect repair process, wide-gap welding offers reduced cost, lower track occupancy time, and increased safety. In order to test and demonstrate the suitability of wide-gap welding in transit tracks, 10 wide-gap thermite welds were installed for test in the tracks of the Port Authority Transit Corporation (PATCO), New Jersey, April 1–2, 2000. All the test welds were made to replace defective rail welds or to eliminate mechanical rail joints. The welds were made in different locations, thus placing them in different track structures (i.e., ballast tracks and concrete decks) and in different track curvatures. All the test welds were in good service condition as of December 1, 2000.

Two surveys were conducted in 2000. The first survey examined the behavior of conventional thermite welds in North American transit properties. The second survey has sought to determine how frequently and for what purpose(s) wide-gap thermite welds are used in North America and Europe. Survey results show that thermite welds made in recent years have been performing well, while some thermite welds that are 20 to 30 years old are experiencing problems. The surveys also found that welds fail when and where large longitudinal and lateral forces occur. For the wide-gap weld usage survey, limited but positive responses indicate that wide-gap thermite welds were primarily

used for weld or rail defect repair and there had been little problem encountered with wide-gap welds in transit or passenger railways.

Two welding processes—thermite welding and mobile flash welding—account for virtually all in-track rail welds made in North America. Although those current welding processes offer advantages, they also present limitations. In order to find ways to improve in-track rail welding, a review of potential alternative welding processes for in-track rail welding was conducted and a set of criteria was formulated for the selection of an alternative process. The factors considered included cost per weld, total welding time, service performance, requirements for welders' skills, equipment portability, rail consumption and rail/tie movement, flexibility for rail sections and rail head wear, and initial capital investments. Several alternative in-track rail welding processes were presented and discussed in a special workshop where the participants graded the current in-track rail welding processes and potential alternatives. In general, thermite welding was still the favored process for joining rails in track, but improvements in its quality and consistency were needed. To date, no fully developed alternative welding process is available for immediate application. Development of such an alternative welding process, as well as the improvement of the current processes, was encouraged.

This report is presented in four parts: in-track tests of wide-gap thermite welds, a survey of conventional thermite weld performance, a survey of wide-gap thermite welds usage in transit or passenger rails, and alternative welding processes for in-track rail welding.

CHAPTER 1

INTRODUCTION

The Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), initiated a project in 2000 to study the current status and possible improvements to in-track rail welding for transit tracks in the United States. The project, supported by the Transit Cooperative Research Program (TCRP) (TCRP Project D-7) Joint Track-Related Research Program, includes the following efforts:

- A feasibility study of applying wide-gap thermite weld technology to the transit industry by testing thermite welds in transit tracks,
- A survey of current usage of the wide-gap thermite welds in U.S. and foreign transit and passenger railroads,
- A survey of U.S. transit railways to determine problems experienced in the use of thermite rail welds, and
- A review of current and potential alternative welding processes for field rail welding in transit tracks.

CHAPTER 2

IN-TRACK TESTS OF WIDE-GAP THERMITE WELDS

2.1 BACKGROUND

The wide-gap thermite rail welding process was developed for the repairing of weld or rail defects. The initial gap between the rail ends to be welded in a standard thermite rail weld measures 1 in. In the wide-gap thermite rail welding process, the initial gap is larger than 1 in. (2¾ in. for this study). Because of their extra width, wide-gap welds can be used to directly replace most defective field welds, and other types of transverse rail defects, at significant cost savings. Currently, rail defects are repaired using a plug rail and two welds. By reducing the number of welds in track, wide-gap welds offer reduced cost, lower track occupancy time, and increased safety.

TTCI completed a series of laboratory tests for wide-gap thermite welds. The test results showed that the properties of wide-gap welds are very similar to those of conventional thermite welds. Details of the laboratory tests were presented in the AAR *Technology Digest* included in Appendix A to this section (Sun, J. and Sawley K. “Laboratory Evaluation of Wide-Gap Thermite Rail Welds,” *Technology Digest*, TD-98-026, Association of American Railroads, Pueblo, Colorado, October 1998). In-track tests are underway on revenue tracks owned by the AAR member railroads and at the Facility for Accelerated Service Testing (FAST) track located at the Federal Railroad Administration’s (FRA) Transportation Technology Center near Pueblo, Colorado. All of the in-track tests are continuing, with a positive initial performance by the wide-gap welds. It is logical to extend the tests to the transit tracks because transit railroads, like freight railroads, are likely to benefit from this technology. The tracks of the Port Authority Transit Corporation (PATCO) were selected as test sites because of the availability of the wide-gap welding kits for PATCO’s rail section (132 RE) at the time and because of PATCO’s willingness to support a field test. Most other transit systems used 115 RE, 119 RE, or lighter rails. Railtech Boutet, Inc., indicated they could produce wide-gap thermite welding kits for the rail sections if transit systems are interested in the process.

The test welds were installed in the New Jersey side of PATCO’s electrified (third rail) track, which runs from Lindenwold, New Jersey, to downtown Philadelphia (Figure 1). The maximum train speed in the area is 65 mph. There are 1,581 train trips each week and each train consists of two to six cars. Empty car weight is 34 tons while a car at full capacity weighs 55 tons. The annual traffic on each track is estimated in the range of 10 to15 million gross tons (MGT). The traffic during the test period from April 2 to December 1, 2000, was estimated to be 6.5 to 10 MGT. Wheel load and annual traffic is low compared with those in mainlines of freight railroads. The train speed is comparable to that of freight railroads. Most of the rail in the test sections consists of original rails installed in the 1970s.

2.2 APPROACHES

To evaluate the suitability of wide-gap thermite welds for transit revenue tracks, PATCO and TTCI installed 10 wide-gap thermite welds in PATCO’s tracks with Railtech Boutet QP CJ “one-shot” wide-gap thermite welding kits. The welds were monitored for their integrity and their suitability for transit rail traffic.

In addition to the weld integrity, the wear of the welds and their heat-affected zones were measured. The differential in wear resistance is inevitable because of the existence of the thermal cycles in thermite welding. One of the concerns for the application of wide-gap welds is that the differential wear could be excessive due to the extra width of wide-gap welds. Differential wear is more critical in transit or passenger rails because it directly affects ride quality. TTCI’s laboratory tests have shown that the heat-affected zones (usually softer and less wear resistant) in wide-gap welds are not wider than those of standard thermite welds and there has been no indication of excess wear in the ongoing TTCI in-track tests of wide-gap welds. Differential wear will also lead to higher levels of interior and wayside noise and vibration and vehicle wear. In order to address the concern of differential wear, TTCI fabricated an easy-to-operate device (Figure 2) for measuring differential wear on the running surface. The device was used to measure each of the installed wide-gap welds after they were surface finished and cooled to ambient temperature. The device measures the relative heights of the concerned area and the differential wear is presented by the

Figure 1. Test site—PATCO tracks in New Jersey.

height differences between the weld (weld fusion zone and heat-affected zones) and the surrounding rail. The center of the weld and the outer edges of the heat-affected zones are often the softest spots of welds and are most prone to excessive wear. Therefore, those possible soft spots were selected for monitoring of the differential wear of the test welds.

TTCI engineers performed a field inspection of the test wide-gap welds on December 1, 2000. The running surface of each wide-gap test weld was measured to examine the differential wear in the weld and its heat-affected zones.

2.3 RESULTS AND DISCUSSIONS

All 10 of the test wide-gap thermite welds installed April 1–2, 2000, were made to replace defective rail welds or to eliminate mechanical rail joints. The welds were located in different track structures (ballast tracks and concrete decks) and in different track curvatures. Engineers from Railtech Boutet, the supplier of the wide-gap welding kits, assisted in the installation and trained the PATCO welders for the wide-gap process (see Figure 3). The installation operations were successful, and the installed welds appeared to be of good quality. Subsequent ultrasonic tests confirmed the integrity of the welds—no defects were found. PATCO decided to use bulldog bars for all test wide-gap welds. The bulldog bars were used as safety devices, rather than as a means of reducing stress or prolonging the service life of the welds. PATCO will not use bulldog bars in future wide-gap weld installations if PATCO is completely confident of the weld performance. Actually, bulldog bars on 3 of the 10 test welds were taken off later for reasons not related to the welds themselves. Further, the bars were not reinstalled on the welds and there was no intention to do so as of December 2000.

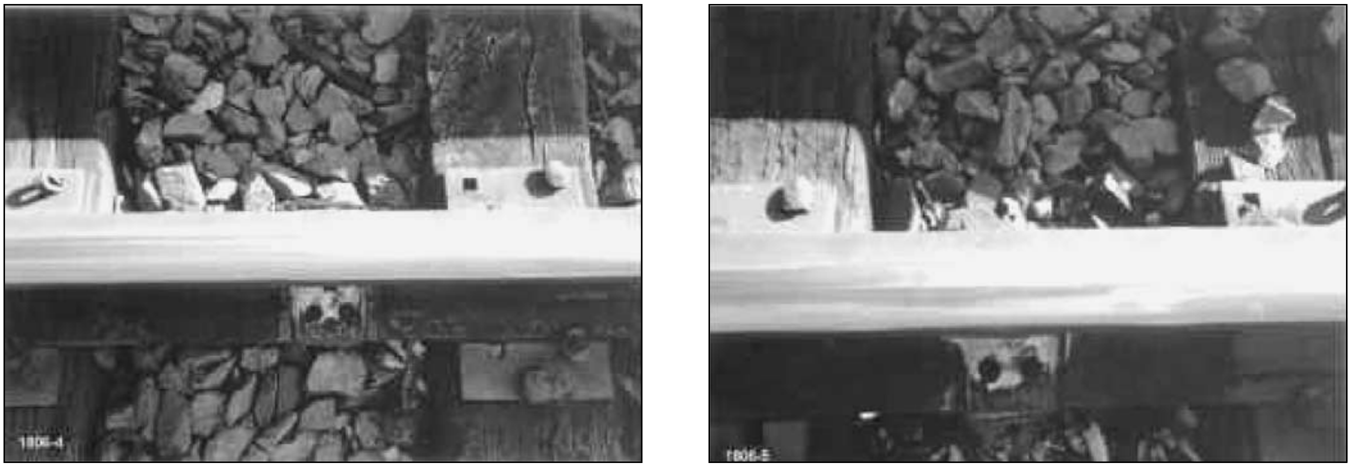
Figure 2. TTCI device used for measuring differential wear of rail welds.

Since the April 2000 installation, the welds have been monitored for their integrity through frequent visual track inspections and periodical non-destructive test (NDT) inspections. All 10 test welds were in good service condition as of December 1, 2000. No defects were observed in the welds except for a small (~1.5 mm) slag found on the railhead surface of Weld Number 3. Slag inclusions of that size in

Figure 3. Test welds installation and welder training.

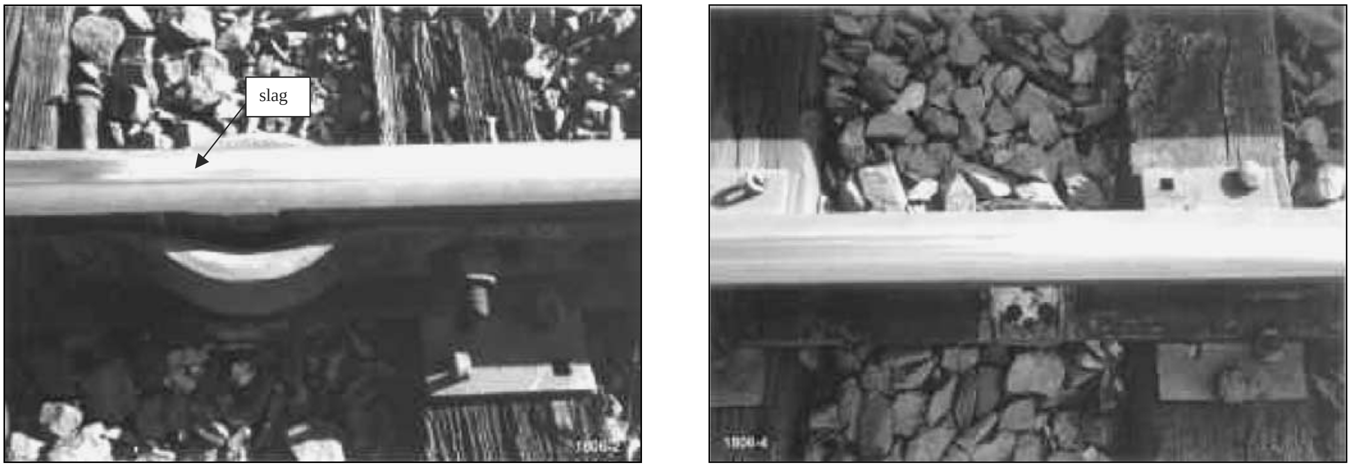
thermite welds are usually not regarded as defects for rejection. Small slag inclusions are often found in thermite welds and can cause failure if located in a critical area (e.g., an area where significant tensile stress occurs). The slag inclusion in Weld Number 3 is located at the running surface. Experience has shown that an inclusion of that size, at such a location, is more likely to wear away than to develop into a sizeable defect. Visual observations did not find any indication of excessive differential wear. The PATCO track supervisor involved in the field inspection believed that the wear of the wide-gap welds was actually somewhat less severe than those of standard thermite welds in PATCO's tracks. Figure 4 shows photographs of all the test welds as of December 1, 2000. Measurements of running surface wear are presented in Table 1 and the results indicate that the differential wear was minimal. Most of the measured differentials were on par with the height variations in other parts of the rail. The comparatively low axle loads of transit traffic and the low accumulated traffic during the test period (6.5 to 10 MGT) did not produce significant wear differences between the weld zones and the rest of the rails. It might take many times more accumulated traffic for a more valid assessment of the differential wear properties of wide-gap welds. This can be achieved if PATCO continues to monitor the test welds.

During the field inspection tour on December 1, 2000, PATCO personnel expressed their satisfaction with wide-gap welding as a repair welding process and said that they would consider adapting the process for their future rail repairs.



Weld Number 1

Weld Number 2

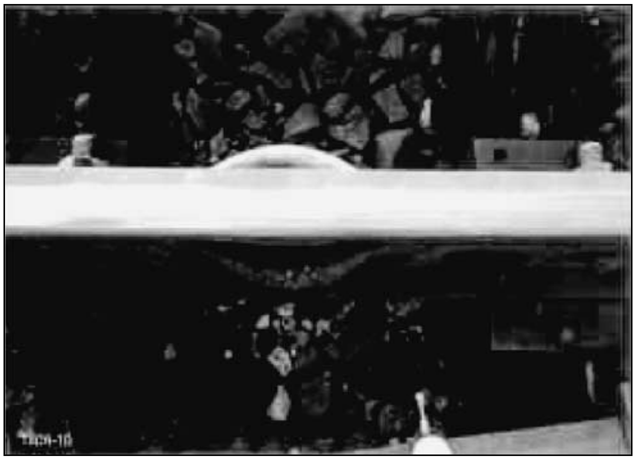


Weld Number 3

Weld Number 4

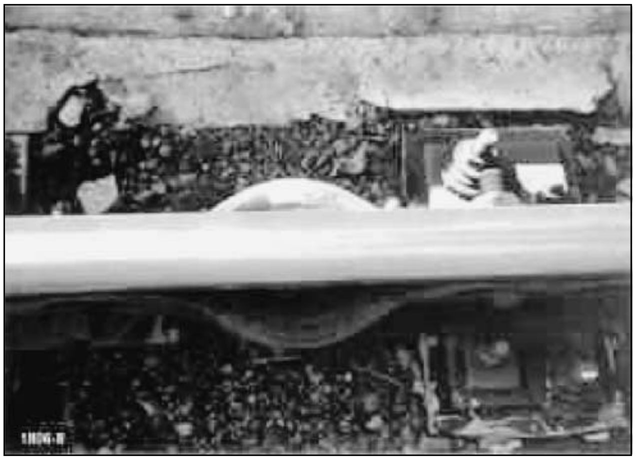
Figure 4. Test wide-gap thermite welds as of December 1, 2000.

Weld Number 5



Weld Number 6

Weld Number 7



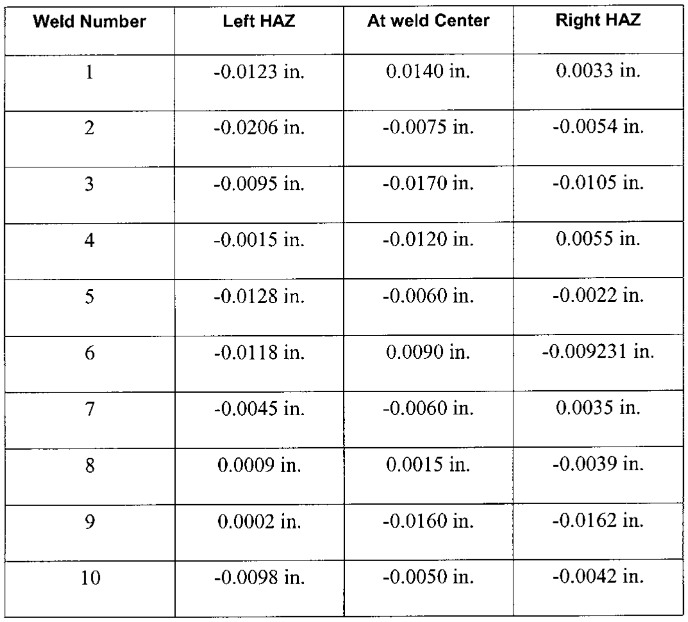
Weld Number 8

Weld Number 9

Weld Number 10

Figure 4. (Continued)

TABLE 1 Amounts of excessive wear* at the weld center and heat affected zones of the wide-gap welds installed at PATCO



Weld Number	Left HAZ	At weld Center	Right HAZ
1	-0.0123 in.	0.0140 in.	0.0033 in.
2	-0.0206 in.	-0.0075 in.	-0.0054 in.
3	-0.0095 in.	-0.0170 in.	-0.0105 in.
4	-0.0015 in.	-0.0120 in.	0.0055 in.
5	-0.0128 in.	-0.0060 in.	-0.0022 in.
6	-0.0118 in.	0.0090 in.	-0.009231 in.
7	-0.0045 in.	-0.0060 in.	0.0035 in.
8	0.0009 in.	0.0015 in.	-0.0039 in.
9	0.0002 in.	-0.0160 in.	-0.0162 in.
10	-0.0098 in.	-0.0050 in.	-0.0042 in.

**Heights relative to a smooth rail running surface (in.).*

A negative value represents excessive wear. Measured on December 1, 2000. (after ~2MGT)

2.4 CONCLUSIONS

- Ten wide-gap thermite welds were successfully installed in transit tracks of PATCO.
- The performance of the test welds was satisfactory.
- Wide-gap welds appear suitable for transit track applications and transit rails may benefit from the potential cost and time savings by adapting the process in rail repairs.
- More traffic accumulation is needed for a complete assessment of the performance of wide-gap thermite welds in transit tracks.

CHAPTER 3

SURVEY OF CONVENTIONAL THERMITE WELD PERFORMANCE

3.1 BACKGROUND

Thermite welds are widely used in both railroad and transit applications for joining rails together. Indeed, the early development of rail thermite welding was primarily in the field of electric street railways at the turn of the 19th century. The joint configuration was very different from that used today in that the cast thermite weld metal served as a filler between the rail ends and a surrounding steel "mold" to which the rail ends became welded. Liquid thermite weld metal was dispensed from a cupola car that serviced many joints in succession. Today, thermite welds for transit applications are identical to those used in general freight railroad applications.

Thermite welding is a process that leaves the volume between the joined rail ends with a cast structure that is similar in composition to that of the rail ends. This cast structure can have mechanical strength comparable to that of the rails themselves. However, the cast metal has a much lower ductility and toughness than the rails and the rail weldments made by the electric flash butt process.

Historically, the poorer ductility and toughness of thermite welds has been accompanied by higher weld replacement (i.e., detected defects and service failures) rates compared with electric flash butt welds in freight railroad service. At the end of 1970, the ratio of thermite weld failure to electric flash butt weld failure was 48:1 in North American freight railroad service based on accumulated failures divided by the number of welds of each type in service. A rough estimate of the ratio of thermite failure rate to electric flash butt failure rate made in October 2000 suggested that today, the value could be closer to 10:1. If this is true, relative thermite weld performance appears to have improved despite substantial increases in the freight wheel loads and tonnage rates.

What has happened in the transit railway field with regard to thermite weld behavior is not clear. Wheel load is an important difference between transit operations and North American freight railroads with wheel loads varying from just under 10,000 lbs. to around 20,000 lbs. These are respectively about 30 percent and 60 percent of the typical loaded 100-ton capacity freight car wheel load. It is not clear whether dynamic augment (due to flat wheels) is significantly different from one type of operation to the other. However, fatigue life under rolling contact conditions (the most damaging case) is inversely related to load raised to approximately the third power. Therefore, at a minimum, transit fatigue lives (in years of service) should be at least 5 times greater than those typical of North American freight railroad operations.

3.2 APPROACH

In order to learn about the behavior of thermite welds in transit applications, TTCI sent a short survey to 27 transit properties in North America. The questions are listed in Table 2. The survey netted 22 responses.

The primary failure mode of thermite welds is fracture, but the wide weldment width (weld metal and heat affected zones) of thermite welds has sometimes promoted corrugation in contiguous rails. This can be considered a secondary deterioration mode. The six questions in the survey were divided into four categories:

- An assessment of whether the respondent's property had had weld failures or corrugation/batter problems,
- An estimate of the number of thermite welds made annually,
- Information on the causes and characteristics of any failures, and
- Information on locations where thermite weld failures had occurred.

The intent of the questionnaire was not to require the respondents to develop failure statistics, but to gain educated impressions of in-transit thermite weld behavior from knowledgeable sources.

Properties ranged from smaller, new transit systems to large, older systems. Systems that carried appreciable freight traffic on passenger lines, such as Metra Passenger Services, were not included in the survey in the belief that the heavier wheel loads of the freight traffic would influence the results. The transit wheel loads ranged from 10,000 lbs. (i.e., trolley/light rail operations) to almost 20,000 lbs. (i.e., heavy commuter rail operations).

3.3 RESULTS AND DISCUSSIONS

The results of the survey are presented in Tables 3 through 5. The properties are arranged in alphabetical order. A summary of the full answers from each responding property is

TABLE 2 Questionnaire for thermite welds survey

1.	How are the conventional thermite welds that have been installed in your tracks been performing? Have some failed? Are any exhibiting batter that is of concern (leading perhaps to corrugation of adjacent rails)?
2.	If failures have occurred, have they tended to be early in the life of the welds (say failure just after installation) or after extended periods of service?
3.	Have any broken welds been examined visually (on the fracture faces) to determine where the origin of failure might have been? If so, what are the findings?
4.	If failures have occurred, are most (a) in curves or tangent track? (b) in standard or premium rail? (c) at locations in track where strong longitudinal forces develop? (d) failing when the ambient temperatures are low or have been falling (cold snap)? and/or (e) failing in tunnels or near turnouts (stiff track conditions)?
5.	Are your thermite welds all of the same manufacture and, if so, which one? If not, what manufacturers have you used and why?
6.	Do your crews do the thermite weld installation? Do they use any special fixturing (say for alignment control)? Approximately how many thermite welds does your property install in a year? And are they mostly for plug rail installation or for new construction?

given in Appendix B to this subreport. Several of the smaller, newer systems such as the Delaware Administration for Regional Transit (DART), MetroRail of the Miami-Dade Transit Agency, the Sacramento Regional Transit District, and Metrolink (southern California's commuter rail system) have had no failures to date. But even older systems, such as Edmonton Light Rail Transit (LRT), the Greater Cleveland Regional Transit Authority, and the Washington Metropolitan Area Transit Authority (WMATA), have not reported failures. The Bay Area Rapid Transit (BART) reports only a 5 percent cumulative thermite weld failure over 30 years. San Francisco Municipal Railway (SF Muni) reports some failures. Metropolitan Atlanta Rapid Transit Authority (MARTA) reports only two or three failures in 20 years. Tri-County Metropolitan District of Oregon (Tri-Met) has experienced only two pull-aparts. Metro-North Railroad reports only occasional failures, while New Jersey Transit indicates only some failures. Commuter rail Massachusetts Bay Transit Authority (MBTA) reports only one or two service failures per year with about 12 Sperry indications per year. Long Island Railroad (LIRR) indicates some failures but reports that the thermite welds are "performing very well." MBTA (Subways) and TTC note that welds that are properly installed and that pass inspection tend not to fail. PATCO reports very few failures with new welds; in most cases, the welds are over 20 years old. Metropolitan Transportation Authority New York City Transit (MTA-NYCT) has experienced some failures, but describes the performance as good.

In that this was not a rigorous statistical survey, it may be that the reliability of recollection is less for older systems. But what is clear is that there is no perception of a significant thermite weld failure problem . Only the Southeastern Pennsylvania Transportation Authority (SEPTA) describes 1970s welds as failing at an alarming rate. This suggests that newer welds are performing better than those over 20 years old, the thermite failure problem manifests itself mostly after very long service life, or both.

The TTCI test team performed a visual and ultrasonic inspection on welds within 2 weeks after the welds were made. With few exceptions, welds that passed inspection did not experience failures. A two-step ultrasonic testing process was used for approving new welds. The process used 0- and 70-deg probes as well as 45-deg probes in pulse-echo, through transmission, and pitch catch modes. MARTA also uses ultrasonic inspection, while Edmonton uses magnetic particle inspection, in addition to ultrasonic testing before the weldments have gone into service. BART performs acceptance tests on welds in new track construction.

TABLE 3 Thermite weld performance survey results

PROPERTY	QUESTION	
	Regular Thermite Welds Fail? Batter?	**~ Welds per Year?**
BART	Less than 5% over 30 years Limited batter only on ballasted track	30 (maintenance)
Calgary Transit	Very small % in street track No batter	20 (both plug & special work installation)
DART	No failures or batter	1 plug in 4 years
Edmonton LRT	No failures on in-service track or batter	50 (30 for plug installation)
Greater Cleveland RTA	No failures or batter	80
LIRR	Some failures ("performing very well") No batter as yet	800-1000
MARTA	Two or three failures in 20 years Minor batter, no corrugation	*No answer*
MBTA (Subways)	No problems with properly made welds No batter, no corrugation	20-40 (3/4 for new construction)
MBTA (Commuter Rail)	One or two service failures/year No batter Maybe a dozen Sperry indications/year	500
Metro link (Bi-State Development)	No failures Some small amount of batter	20
Metro North	Only occasional failures No evidence of batter	1200
Metro Rail	No failures yet No batter	15-20 (rail replacement)
MTA-NYCT	Nine failures this year in rails from 1980 to 1995	Avg. 160/yr.
NJT	Some failures No batter indicated	1000-1200 (75% for new work)
Northern Indiana	A small % of failures	100 (mostly new construction)
PATCO	Very few failures with new kits; most failures in welds 20+ years old Welds +12 years old have some batter with adjacent corrugation	80 (both plug and new rail installation)

TABLE 3 (Continued)

Sacramento Regional Transit	No failures thus far No batter	6-8 (mostly plug installation)
SEPTA	1970s welds failing at an alarming rate No batter indicated	100 to several hundred
SF Muni	Some have failed Some have batter	50-500
Tri Met	Two pull aparts so far No batter reported	Only 2 in 14 years
Toronto Transit Commission	Welds which pass inspection haven't failed No batter if weld hardness comparable with that of rails	700-1500 (mostly for small project closures/plugs, STW, etc.
WMATA	No failures in last 5 years No batter	*No answer*

	QUESTION		
PROPERTY	**Thermite Weld Manufacturer?**	**Installation Contractor or Property Crews?**	**Special Fixturing?**
BART	Boutet and Orgothermit for 6 years Now using Railtech (one-shot)	New construction is done by Contractors Maintenance is done by BART crews	Yes, alignment jigs
Calgary Transit	Railwel	Calgary crews	Yes, alignment beams
DART	Orgothermit (construction); Calorite (maintenance)	*No answer*	*No answer*
Edmonton LRT	Alfex, Boutet	Contractor	Some contractors, yes others wedges
Greater Cleveland RTA	Railtech, Boutet	RTA crews	No
LIRR	Boutet	LIRR crews	Wedges on timber ties Fixture on concrete ties
MARTA	Calorite	MARTA crews	Alignment fixture
MBTA (Subways)	Boutet in past; Calorite for last 10 years/Both approved	MBTA crews limited most by construction contractor	No
MBTA (Commuter Rail)	Calorite	MBTA crews	No

TABLE 3 (Continued)

Metro link (Bi-State Development)	Orgothermit, Railtech, Boutet	Contractor	*No answer*
Metro North	Railtech, Boutet, Orgothermit	Metro North crews	No
Metro Rail	Calorite	Metro Rail crews	No
MTA-NYCT	Railtech (one-shot)	MTA-NYCT crews	No
NJT	Currently Orgothermit Some Calorite in past	NJT crews	No
Northern Indiana	Railwel but Boutet to be tried	NICTD crews	No
PATCO	Boutet and Calorite	PATCO crews	Yes, alignment fixture
Sacramento Regional Transit	Railwel, Calorite, Railtech (one-shot)	SRT crews	Yes
SEPTA	Calorite, US Thermit, Orgothermit	Typically SEPTA crews but some contractor installation	*No answer*
SF Muni	Calorite & US Thermit	Contractor	Yes, alignment fixture
Tri Met	Orgothermit Calorite	Contractor	Yes, alignment fixture
Toronto Transit Commission	Railwel (long preheat)	Toronto Transit Commission crews	*No answer*
WMATA	Orgothermit	WMATA crews	Yes, alignment fixture

PROPERTY	**QUESTION**		
	Occurrence in Life or N/A?	**Cause/Where Initiated?**	**Curve/Tangent?**
BART	Generally late	Slag inclusions in head	45% curve, 55% tangent
Calgary Transit	Late	Uncertain	Stiff, in-street track
DART	*No answer*	*No answer*	*No answer*
Edmonton LRT	Early (before track went into service)	Insufficient preheat	*No answer*
Greater Cleveland RTA	*No answer*	*No answer*	*No answer*
LIRR	Late	*No answer*	Tangent

TABLE 3 (Continued)

MARTA	Early	Poor welding technique	*No answer*
MBTA (Subways)	Most early; very occasionally late	Poor welding technique Occlusion in head	Late "bloomers" in tangent track
MBTA (Commuter Rail)	Mostly early; now and then an old one	*No answer*	No difference
Metro link (Bi-State Development)	*No answer*	*No answer*	*No answer*
Metro North	Late (8-10 years)	Slag inclusions, improper preheat	Not determined
Metro Rail	*No answer*	*No answer*	*No answer*
MTA-NYCT	Late in life	*No answer*	Tangent
NJT	Late	Slag inclusions	*No answer*
Northern Indiana	*No answer*	Improper rail handling or inadequate tamping at compromise joints	Tangent mostly where longitudinal forces develop
PATCO	Tested welds have not failed for at least 10 years	Slag inclusions in head/web or base/web interface	Some in sharp curves
Sacramento Regional Transit	*No answer*	*No answer*	*No answer*
SEPTA	Some early, most late	Lack of fusion, inclusion or porosity	Tangent track
SF Muni	Both early and late	*No answer*	*No answer*
Tri Met	Early within first year	*No answer*	Tangent
Toronto Transit Commission	Generally early	Lack of fusion porosity, base contamination (old arc weld repairs on thermite welds)	*No answer*
WMATA	*No answer*	*No answer*	*No answer*

TABLE 3 (Continued)

	QUESTION			
PROPERTY	**Standard or Premium?**	**Strong Longitudinal Forces?**	**Low Temps/Cold Snaps?**	**Tunnels/Turnouts?**
BART	89% Standard, 11% Premium (62% end hardened)	62%	Yes	24% interlocking, 37% aerial structures, 2% subway
Calgary Transit	*No answer*	*No answer*	Yes	*No answer*
DART	None Failed	*No answer*	*No answer*	*No answer*
Edmonton LRT	*No answer*	*No answer*	*No answer*	*No answer*
Greater Cleveland RTA	None Failed	*No answer*	*No answer*	*No answer*
LIRR	*No answer*	*No answer*	Very cold weather	*No answer*
MARTA	*No answer*	*No answer*	No	*No answer*
MBTA (Subways)	Uncertain	"Stiffness plays a roll"	Uncertain	About same in each
MBTA (Commuter Rail)	None in premium	*No answer*	Mostly in fall	*No answer*
Metro link (Bi-State Development)	None Failed	*No answer*	*No answer*	*No answer*
Metro North	Standard rail (which is most of rail in track)	Uncertain	No	No
Metro Rail	None Failed	*No answer*	*No answer*	*No answer*
MTA-NYCT	About the same	Insufficient data	Cold weather/late night or early morning	All this year in tunnels
NJT	*No answer*	No pattern	*No answer*	*No answer*
Northern Indiana	*No answer*	Yes (where neutral temp is out of adjustment)	Sometimes but usually after 3 or 4 cold snaps	*No answer*
PATCO	*No answer*	*No answer*	Yes	*No answer*

TABLE 3 (Continued)

Sacramento Regional Transit	None Failed	*No answer*	*No answer*	*No answer*
SEPTA	Standard rail	Minimal to moderate	Fail in cold weather	Stiff track
SF Muni	*No answer*	*No answer*	*No answer*	*No answer*
Tri Met	Standard	No	Yes	No
Toronto Transit Commission	*No answer*	*No answer*	Yes	*No answer*
WMATA	None Failed	*No answer*	*No answer*	*No answer*

The tests include alignment checks, dip/peak checks, visual surface inspection, magnetic particle testing, ultrasonic testing and radiographic testing. PATCO inspects new welds ultrasonically and notes that if a weld has passed, it is not likely to fail for at least 10 years. It may well be that other transit companies perform pre-service non-destructive acceptance testing as well, but the questionnaire was not designed to examine that issue.

Some transit properties (i.e., BART, MARTA, Metrolink, PATCO, and SF Muni) did indicate that minor batter, sometimes accompanied by corrugation, occurred after extended service. Most transit railways, however, were not aware of batter or corrugation occurring in the vicinity of the thermite welds.

The number of welds made each year varied from less than 1 to nearly 2000 per year. Frequently, contractors make the welds on new construction while transit company forces make repair welds. That appeared to be the case, at least for the larger properties. All of the available thermite kits appear to work in transit applications. Perhaps one-third of the transit companies or contractors working for them used alignment fixtures in making the thermite welds.

Survey question Number 2 sought to determine if the transit properties were experiencing problems with infant mortality (i.e., failures of the weld just after installation), wear out, or both. Generally, early failures (i.e., infant mortality failures) are the result of loss of manufacturing control, and the rate at which they occur diminishes with service exposure. For a thermite rail weld, fatigue is the most likely mechanism of failure if it is exposed to service loadings. For a fixed thermite process, infant mortality failures have the best chance of being minimized if pre-service visual and non-destructive inspection are used. Of the four transit systems that reported the use of early or pre-service non-destructive inspection (BART, Edmonton LRT, TTC, and PATCO), Edmonton LRT and TTC cite the occurrence of early fail-

TABLE 4 Results of wide-gap thermite weld usage survey of U.S. transits

1. Do you install wide gap welds, and if so, how long have you been doing so?
2. To what purpose do you apply wide gap welds and what are the criteria that you use in deciding whether to install a wide gap weld?
3. How extensively have you used the wide gap welds? Typically how many do you install in a year?
4. Have there been any difficulties in the use and performance of these welds - as for instance with fracture and/or batter development?
5. Are any special maintenance procedures required to assure their continuing satisfactory performance?
6. Are you aware of other properties that have been using wide gap welds, and if so, might I prevail upon you for the name and address of person(s) to contact?

TABLE 5 Questionnaire for wide-gap thermite weld usage in Europe

PROPERTY	QUESTION Use Wide Gap Welds? Application?
BART	Yes/Replace defective in-service weld and out-of-specification new welds
Calgary Transit	Yes/Replace thermite weld (pull apart or detected defect)
DART	No
Edmonton LRT	No
Greater Cleveland RTA	No
LIRR	Not as yet/Plan to use them for re-welding joints, elimination of batter
MARTA	No
MBTA (Subways)	No
MBTA (Commuter Rail)	No
Metro link (Bi-State Development)	Yes/Four installed thus far
Metro North	No
Metro Rail	No
NJT	On order/Replace defective welds
Northern Indiana	No
PATCO	Yes/Replace defective field welds
Sacramento Regional Transit	No
SEPTA	Has considered using them
SF Muni	No
Tri Met	No
Toronto Transit Commission	No
WMATA	No

ures, while BART and PATCO cite late failures. It is not clear from the information gathered in the informal survey whether the early failures cited by Edmonton LRT and TTC occurred prior to an early or pre-service inspection. The BART and PATCO experiences (mostly likely the TTC and Edmonton LRT experiences as well) suggest that careful pre-service visual and non-destructive testing may be effective in minimizing the occurrence of early life failures.

The dominant weldment features associated with weld failure are slag inclusions/occlusions, porosity, and less frequently, lack of fusion. These are features characteristic of a casting type welding process, but the severity of these can be related to such factors as dwell time before pouring and preheating characteristics (time and torch orientation)—the latter being a reflection of crew practice. Poor welding technique was mentioned several times in the survey and can indicate human error. Generally, the solution is more rigorous training of the crew and more exacting quality assurance. Rail handling, another crew practice issue, was mentioned in the survey.

Survey question Number 4 asked where and when thermite weld failures occurred. The most consistent correlation was with low temperatures and cold snaps. The Northern Indiana Commuter Transportation District noted that the worst condition did not always occur during the first cold snap but rather after three or four of them. This may be the result of some cumulative effect, such as a gradual increase in track stiffness. Cold snaps tend to increase tensile longitudinal forces; thus, failures may occur more readily in the area where strong longitudinal forces already exist. Not surprisingly, MARTA's southern location reports no effect of cold snaps. This suggests that cold snaps are contributory but not essential in causing thermite weld failures.

Less apparent was the effect of longitudinal (tension) forces. There was a greater tendency for thermite weld failure in locations with higher longitudinal forces (e.g., where neutral temperature was out of adjustment). BART reported that 62 percent of its thermite weld failures occurred where there were strong longitudinal forces. BART also reported that 24 percent of failures occurred at interlockings and 37 percent on aerial structures.

Given that most track will be tangent and most rail in track will be standard, it is not surprising that most thermite weld failures occurred in tangent track and in standard rail. BART reported that 45 percent of its thermite weld failures occurred in curves. In addition, PATCO observed failures in sharp curves. These occurrences suggest that strong lateral loads can contribute to thermite weld failure. MBTA (Commuter Rail) reported no thermite weld failures in premium rail (i.e., high-strength rail), while BART reported that about 11 percent of its thermite weld failures occurred in premium rail—most notably end-hardened rail. MTA-NYCT noted the failure rate to be about the same in both standard and premium rail. According to the American Railway Engineering and Maintenance Association (AREMA) classification, premium rail has a hardness of 341 Brinell Hardness Number (BHN) or higher.

SEPTA and MARTA reported failure occurrences in stiff track regions. This was consistent with BART observations at interlockings and on aerial structures. Interestingly, only 2 percent of BART thermite weld failures occurred in tunnels. Metro-North reported no thermite weld failures in tunnels, while MTA-NYCT noted that all failures occurred in tunnels based on the assessment in 2000. This difference between Metro North and MTA-NYCT, two systems close to each other, may be associated with the relative amount of tunnel trackage on each property.

3.4 CONCLUSIONS

- Thermite welds made in recent years appear to be performing very well with regard to failure and batter.
- Very old welds (20–30 years old) appear to have a much higher failure rate and some batter and corrugation may occur.
- Pre-service visual and non-destructive inspection appear to be helpful in weeding out potential infant mortality weldments.
- Thermite weldments appear most susceptible to failure in regions of stiff track, during cold snaps, and areas where strong longitudinal tension forces exist.
- Track locations that may experience high lateral loads may encounter higher incidences of thermite weld failure.

CHAPTER 4

SURVEY OF WIDE-GAP THERMITE WELD USAGE IN TRANSIT OR PASSENGER RAILS

4.1 BACKGROUND

As described in Chapter 2 of this report, wide-gap welds are made using a wider (2 to 3 in.) prepared gap than that of normal welds (1 in.). The wider gap allows the weld to replace defective welds and many other rail defects, potentially supplanting the normal process of installing a plug rail with two standard thermite welds. Thus, wide-gap welds have the potential to significantly reduce the cost of rail repair and to reduce the total number of field welds in track.

After years of development and tests, certain U.S. freight railroads have started the implementation of the wide-gap welding technology, and the initial results have been positive. It is of interest to understand the feasibility of wide-gap welding in transit track applications. In addition to the in-track tests described in Chapter 2 of this report, TTCI conducted a survey on the current wide-gap usage in transit and passenger tracks. European thermite welding suppliers were included in the survey because it was believed that wide-gap welds had been used in Europe. The objective of the TTCI survey was to determine the scale of wide-gap weld usage and note any problems associated with wide-gap weld application in transit or passenger tracks.

4.2 APPROACH AND RESULTS

A question was included as part of the survey of North American transit properties regarding what properties might have been considered in using wide-gap welds, and if used, for what purposes. The responses are incorporated into Table 5. Four transit companies—BART, Calgary Transit, Metrolink, and PATCO—have used wide-gap welds for replacing defective thermite welds. SEPTA has considered using them. New Jersey Transit has ordered wide-gap weld kits for replacing failed field welds. LIRR has plans to use wide-gap welds.

In Europe, several organizations were initially suggested by Frank Kuster of Elektro-Thermite GmbH & Co. Ultimately, eight European organizations were contacted; of these, four responded to the survey. Three respondents indicated they did use wide-gap welds and their responses are contained in Appendix C to this subreport.

The responses indicate that Germany’s Deutsche Bahn Gruppe (DB Netz) and the Norwegian National Rail Administration (Jernbaneverket) began using wide-gap welds in the early to mid-1980s. The Danish Rail System (Banestyrelsen) and the Swedish National Rail Administration (Banverket) introduced their use in the early 1990s. Jernbaneverket and Banestyrelsen make about 50 and 75 wide-gap welds per year, respectively. Banverket reports that 2.5 to 3 percent of all thermite welds made per year are wide-gap welds. The primary usage has been for repair of defective or fractured thermite weldments, although some mention is made of repair of other rail defects. The European companies surveyed seem to have encountered no special problems in the use of wide-gap welds and no special procedures appear to be needed.

4.3 CONCLUSIONS

- Wide-gap welds are beginning to gain acceptance by North American transit railways for replacing defective or broken thermite welds.
- Wide-gap welds have been successfully used in Europe since the early 1980s, apparently without experiencing problems or requiring any special precautions.

CHAPTER 5

ALTERNATIVE WELDING PROCESSES FOR IN-TRACK RAIL WELDING

5.1 BACKGROUND

In-track rail welding is unique in many aspects from other welding applications and has special requirements for the welding processes. In North America, two welding processes, thermite welding and mobile flash welding, account for virtually all rail welds made in the field.

In thermite welding, the rails are joined by filling the gap between rail ends with super-heated, molten metal from an aluminothermic reaction between iron oxides and aluminum. Thermite welding has many advantages for field applications, including its ease of portability, low capital investment, and suitability for the rough conditions in the field. Thermite welding has no net consumption of rail, and longitudinal rail movement is generally not needed in the welding operation. Thermite welding has been the predominant welding process for joining rails in the field. However, the ductility and fatigue properties of the thermite weld metal have been inferior to those of rail steel. The inferior properties of thermite weld metal are mainly attributed to its dendritic cast structure, porosity, and inclusions. Various attempts, including squeezing the thermite metal out of the weld or stirring the thermite metal during solidification, have been made to improve the properties of thermite weld metal, but success has been limited. To a certain extent, thermite welding is an operator-dependent process; as a consequence, the quality of thermite welds has not been consistent.

Electric flash butt (EFB) welding has been used in fixed rail welding plants for years, and its failure rate is low compared with that of thermite welds. In fact, it is so successful that it is virtually the only in-plant rail welding process in North America. Mobile flash welding was first developed in Russia to weld rail in the field and it is now used worldwide. The mobile flash welder can be carried on a heavy-duty, rail-highway truck or a rail-bound vehicle. A computer controls rail aligning, welding, and shearing processes to achieve a consistent quality that is near the level of stationary plant flash welds. Mobile flash welding can be cost-effective when numerous welds are to be made in the same area. The process has been used in joint elimination, yard reinstallation, continuous welded rail (CWR) renewal, and other applications. However, flash welding does consume 1 to 2 in. of rail, and longitudinal rail movement is needed for the flashing and forging processes. Those characteristics make the process less suitable for rail and weld defect repair. Its application is also limited by the high equipment cost and less-than-ideal portability.

The major advantages and disadvantages of the current field rail welding processes are illustrated in Table 6.

In addition to thermite and electric flash, gas pressure welding had been used in North America for rail joining—mostly in fixed rail welding plants or portable welding plants. Although flash welding has replaced gas pressure as the main method of in-field welding in North America, gas pressure welding is still widely used in Japan. In gas pressure welding, the rail ends are heated by oxyacetylene torches and upset force is applied when the rail ends' temperature reaches 2,000°F. During the process, each rail moves $^3/_8$ in. to produce an upset region and the upset metal is removed by hydraulic shearing. The process is sensitive to the gas atmosphere. Overall, the service performance of gas pressure welds has been found to be better than thermite welds, but not as good as flash welds.

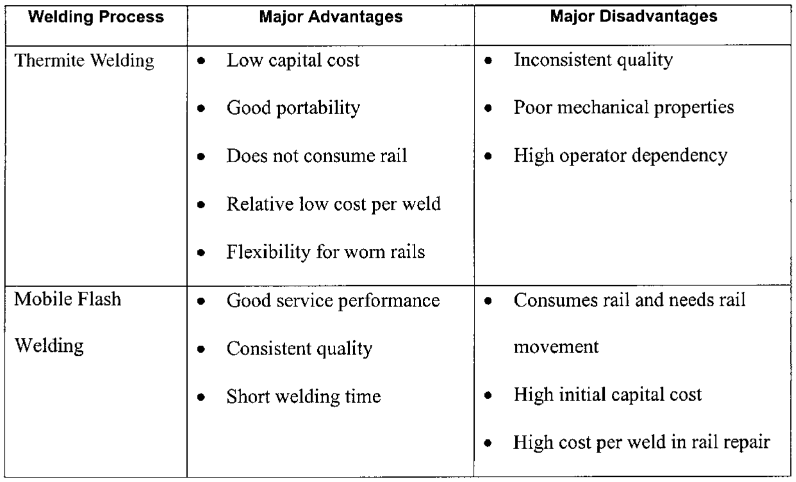
Enclosed arc welding is also used in Japan to join rails in the field. The service performance of enclosed arc welds is considered less reliable than those of flash welds or gas pressure welds. Other attempted rail welding processes include electroslag welding, homopolar welding, induction welding, friction welding, submerged-arc welding, and squeeze welding (i.e., a modified thermite welding).

5.2 APPROACH

Because of the unique requirements of in-track welding, the criteria for selecting welding processes can be significantly different from other applications. TTCI formulated a set of criteria for selecting in-track welding and analyzed the current and potential processes. In addition, an in-track welding workshop involving over 50 international rail welding experts and welding researchers was held in Chicago, Illinois, on May 31, 2000. The objective of the workshop was to examine the current and potential in-track rail welding processes. The workshop exposed railroaders and contractors to some new ideas in rail joining, while exposing researchers to the realities of making welds in-track where trains are always waiting to run.

The workshop began with presentations from railroads, suppliers, and welding research institutions and continued

TABLE 6 Major advantages and disadvantages of current field rail welding processes



Welding Process	Major Advantages	Major Disadvantages
Thermite Welding	• Low capital cost • Good portability • Does not consume rail • Relative low cost per weld • Flexibility for worn rails	• Inconsistent quality • Poor mechanical properties • High operator dependency
Mobile Flash Welding	• Good service performance • Consistent quality • Short welding time	• Consumes rail and needs rail movement • High initial capital cost • High cost per weld in rail repair

with roundtable discussions. Participants graded the current and potential alternative welding processes against the TTCI-formulated criteria.

5.3 RESULTS AND DISCUSSIONS

After analyzing the requirements for in-track rail welding, workshop participants determined the primary factors to be considered when selecting an alternative welding process. These factors are detailed in the following subsections:

- Cost per weld,
- Total welding time,
- Service performance,
- Requirements for welder skills,
- Equipment portability,
- Rail consumption and rail/tie movement,
- Flexibility for rail sections and railhead wear, and
- Initial capital investment.

5.3.1 Cost Per Weld

The cost per weld is an important factor for the railroad industry due to the large number of field rail welds made each year. The total cost of each thermite weld, excluding the cost associated with the possible train delay, can be as low as $200, but can well exceed $300 in certain circumstances. The average cost for a mobile flash rail weld is greater than $500. Any new rail welding process would be competitive if the per weld cost were less than $250. A premium in cost per weld of a new process can be justified, however, if the weld failure rate can be significantly reduced, thereby lowering life cycle cost.

5.3.2 Total Welding Time

When a weld is to be made in track, the track has to be taken out of service and the possible consequence is a train delay. Train delays lead to additional cost for transit operations, and more importantly, affect the industry's ability to meet their customers' expectations. Thus, it is in the industry's best interest to complete the welding work without causing a train delay. That requires welding work to be completed in the shortest time possible. Any new welding process must take less time to perform than it currently takes to produce a thermite weld (about 45 min).

5.3.3 Service Performance

Service performance can be measured by the weld failure rate, the average service life, and the degree of differential wear in the weld and heat-affected zones (corrugation). It would be ideal if the welds made with any new welding process would perform better than or as well as the flash rail welds. The minimum requirement for the new welds is performing better than the current thermite welds.

5.3.4 Requirements for Welder Skills

Consistency in weld quality is paramount to train operation safety; therefore, the quality of the rail welds should have minimum dependency on the skills of the welders and the welding process itself should be easy to perform.

5.3.5 Equipment Portability

One of the merits of thermite welding is its excellent portability. All the equipment and materials needed to perform field rail welding can be easily loaded in a lightweight truck. In most cases, the equipment and materials can be brought to the site without occupying the track. It would be ideal if the new welding process matches the portability of thermite rail welding.

5.3.6 Rail Consumption and Rail/Tie Movement

The ideal rail welding process for in-track welding should not consume rail, otherwise its application in rail defect repairing and closure rail welding will be limited. Consumption of rail during welding usually requires use of rail pulling equipment and unfastening of rail in track. Additionally, it can lead to further maintenance to destress the rail. If rail has to be consumed in the process, it should be less than that consumed in flash welding. Some welding processes would require longitudinal rail movement. This is not desirable as rail movement requires additional equipment and operation time. Also, welding processes that require rail longitudinal movement very often consume rail as well. Tie movement also requires additional time, so it should be avoided as much as possible.

5.3.7 Flexibility for Rail Sections and Railhead Wear

The welding process should be easily adaptable to suit any rail sections used in transit properties. In many cases, the rails to be welded are worn rails. That requires the welding process to tolerate a railhead worn $^1/_4$ in. or more. In some cases, the rails to be welded have different degrees of railhead wear that require the welding process to tolerate the mismatch of the worn rails. The potential welding process should be able to weld rails with a differential wear up to $^1/_8$ in.

5.3.8 Initial Capital Investment

Finally, the initial capital investment for each welding unit should be within a reasonable limit. In addition, the post-welding cooling rate should be appropriate, and no brittle metallurgical structure should exist in the welds.

The criteria for in-track rail welding process selection are summarized in Table 7.

TABLE 7 Criteria for in-track welding process selection

Parameters	Desired	Acceptable
Cost per weld	< $250	<$500
Total time per weld	< 30 minutes	< 45 minutes
Performance	Better than EFB welds	Better than thermite welds
Welder's skill	No need	Minimum
Welders/gang	No more than 2	No more than 3
Rail consumption	No	Less than EFB welds
Rail movement	No	Less than EFB welds
Tie movement	No	Seldom
Rail section	115 – 140 RE	115 – 140 RE
Worn rail mismatch	Up to 1/4 in.	Up to 1/8 in.
Worn rail wear	Up to 1/2 in.	Up to 1/4 in.
Initial capital investment	<$10,000	<$50,000
Portability	Better than thermite welds	Can be loaded in a truck
Post welding cooling rate	Ensure pearlitic structure	Ensure pearlitic structure

5.4 THE IN-TRACK RAIL WELDING WORKSHOP

In addition to the currently used in-track rail welding (i.e., thermite and mobile electric flash) processes, workshop participants presented the following welding processes for consideration: gas pressure welding, arc welding, homopolar welding, induction welding, and magnetic pulse welding. In general, the workshop participants favored improvements to the current welding processes, especially the thermite welding process for its relatively lower cost and easy portability. However, the participants were not satisfied with thermite welding, because the quality of thermite welding depends on welders' skills and thus has a higher failure rate (at least in freight railroads). The participants believed that consistency in weld quality is very important and could be improved by further automation of the welding process. Because of the limitations in current in-track rail welding processes, further development of alternative rail welding processes was encouraged. The workshop participants also evaluated each of the welding processes using the TTCI-developed criteria. Overall, the participants believed that, for the time being, thermite welding meets the criteria better than other welding processes.

CHAPTER **6**

CONCLUSIONS

- The criteria for in-track rail welding process selection were formulated.
- An in-track welding workshop was successfully held.
- Thermite welding is still a preferable process to join rails in track, but needs improvements.
- Development of alternative in-track rail welding processes should be encouraged.

APPENDIX A

AAR *TECHNOLOGY DIGEST* TD-98-026
“LABORATORY EVALUATION OF WIDE-GAP THERMITE RAIL WELDS”

TECHNOLOGY DIGEST
Timely Technology Transfer — 98-026

LABORATORY EVALUATION OF WIDE-GAP THERMITE RAIL WELDS

by Jian Sun and Kevin Sawley

Summary

Laboratory tests undertaken by Transportation Technology Center, Inc., show that wide-gap (68 mm, 2.68 inches) welds have properties very similar to conventional welds and are fit for service trials. The welds, which can be used to directly replace most defective welds (and possibly other types of rail defects), have properties very similar to those found in standard (1-inch gap) welds. Tests show that:

- Wide-gap welds take about 6 minutes longer to make than standard welds, because of extra solidification time needed.
- In metallurgical structure and mechanical properties, wide-gap welds differ little from standard welds.
- As with standard welds, wide-gap welds have beneficial residual stress in the rail foot, which helps protect the weld against fatigue.
- The bend-test properties of wide-gap welds are marginally lower than standard welds, but the measured modulus of rupture exceeds the minimum specified for plant welds.

Both types of welds were made in 136RE standard rail, using the Railtech Boutet QP CJ "one-shot" process. Because of their extra width, wide-gap welds can be used to directly replace most defective field welds, and possibly other types of rail defects, at significant cost savings. At present, rail defects are repaired using two welds and a plug rail. In addition to offering reduced repair cost, wide-gap welds will lower track-occupancy time, and reduce the number of welds in track, thereby increasing the potential for safety. Current studies are examining their performance in track, and in full-scale fatigue loading. Future work will determine how they can be used to best advantage in service.

Suggested Distribution:
☐ Maintenance of Way
☐ Planning & Analysis
☐ Track Maintenance
☐ Safety

TTCI
Transportation Technology Center, Inc.

Work performed by
a subsidiary of the Association of American Railroads
October 1998©

INTRODUCTION AND CONCLUSIONS

To gain assurance that they can be used with confidence in North American service, Transportation Technology Center, Inc. (TTCI), has evaluated wide-gap (68 mm, 2.68 inches) thermite welds and compared them with standard (1-inch) gap welds. Both types of test welds were made in 136RE standard rail, using the Boutet QP CJ "one-shot" process. Laboratory tests to evaluate the welds show:

- Wide-gap welds take about 6 minutes longer to make, because of the extra solidification time needed.
- Wide-gap welds exhibited inclusion levels similar to standard welds.
- In structure, residual stress, and mechanical properties (including slow bend), wide-gap welds differ little from standard welds.

Because of their extra width, wide-gap welds can be used to directly replace most defective field welds, and other types of rail defects, at significant cost savings. At present, rail defects are repaired using two welds and a plug rail. Wide-gap welds offer reduced cost, lower track-occupancy time, and increased safety by reducing the number of welds in track. Further studies are under way to examine their performance in track, and in fatigue loading, and will evaluate how they can be used to best advantage in service.

MANUFACTURE OF TEST WELDS

Wide-gap and standard thermite welds were made using new 136RE standard rail. Welds were made by Railtech Contracting Corporation using the Boutet QP CJ "one shot" process in a railroad yard fixture at Cleveland Track Material (Chicago). The fixture was used for good alignment, and to ensure that test welds were produced under reasonably typical railroad conditions. In all, 34 welds were made — 19 wide gap and 15 standard (1-inch gap). A conventional oxygen-propane preheating system was used, with a nominal 6.25 minutes preheating time for both welds. Actual preheating time and tap times for each weld were recorded, as well as time to subsequent actions. These are shown in Exhibit 1.

	Welds	
	Wide-gap	**Standard**
Preheat time (sec)	392±8.5	386±8.6
Tap time (sec)	All within limits	
Actions (minutes after tapping)		
Slag-pan removal	3	3
Crucible removal	3.5	3.25
Clamp/jacket removal	10	4
Shearing	11.5	6

Exhibit 1. Details of Weld Manufacture

There is no difference in time needed to set up wide-gap and standard-weld mold assemblies. Thus, wide-gap welds are likely to increase total welding time by about 5 to 6 minutes. This extra time is needed so that the greater mass of molten metal can solidify before shearing. As is the case with any thermite weld, early use of shears will lead to damaging hot tears in the railhead. (There may be a further small increase in overall weld time because of increased railhead grinding needed for wide-gap welds.)

LABORATORY TESTS AND RESULTS

Rolling-load test

Three wide-gap welds were tested in rolling-load machines according to standard TTCI procedures. In all cases the load applied to the railhead top was 59,400 pounds. Two welds passed the criterion of 2 million cycles without failure. The third weld failed at 1.6 million cycles from small defects at the collar edge at the center of the web.

Slow-Bending Test

Three wide-gap and three standard welds were tested at Miner Enterprises (Chicago) according to American Railway Engineering and Maintenance of Way Association (AREMA) four-point slow-bend test procedures. Exhibit 2 details the results.

Wide-gap welds showed slightly lower strength (by 3 percent) and deflection properties (by 13 percent). Thermite welding standards are being examined by the industry, but there is no current slow-bend test standard. For comparison, for plant welds the AREMA specifies a minimum deflection of 1 inch, and a minimum modulus of

120,000 pounds for standard rail under four-point loading. All the welds in Exhibit 2 exceed the draft European thermite specification, which effectively calls for a minimum modulus of 108,000 pounds and does not require a minimum deflection.

Welds	Maximum load (kips)	Deflection (inch)	Modulus of rupture (ksi)
Wide-gap: 1	407.0	0.712	129.4
2	431.6	0.926	137.3
3	443.3	0.982	141.0
Average	**427.4**	**0.873**	**135.9**
Standard: 1	446.2	1.037	141.9
2	424.4	0.910	135.0
3	448.5	1.049	142.7
Average	**439.7**	**0.999**	**139.8**

Exhibit 2. Results of Slow-Bending Tests

Structure, Shape, and Ultrasonic Testing

Macrostructure specimens were taken to reveal the weld cross-section along the rail longitudinal center line. The wide-gap and standard weld specimens showed complete fusion between the weld metal and the rail ends. However, the amount of rail end melted in the base of the wide-gap weld was barely adequate (0.078 inch). Such minimal melting implies that minor changes in the weld installation may lead to lack of fusion defects. To overcome this, the weld manufacturers suggested modifying the position of the preheating torch. A further weld made with a repositioned torch showed fully acceptable rail-end melting, with a minimum melting of 0.22 inch on both sides of the weld. Railtech Boutet has adopted this torch repositioning in its wide-gap weld procedure.

The width of the heat-affected zone (HAZ) of wide-gap welds was similar to that of standard welds. This is important, since HAZs are softer than parent rail, and wear at a greater rate. Wider zones are thus likely to give greater weld dip, greater dynamic forces, and shorter weld life. HAZs are unlikely to present a special problem with wide-gap welds. The metallurgical structures of the weld metal in wide-gap and standard welds was very similar at both the micro- and macrolevels. There was no significant difference between the welds in terms of size and density of porosity and inclusions. Both types of welds had smooth transitions between the weld collars and the parent rails, and no sharp corners. Neither weld showed evidence of severe stress concentrations that might impair performance.

All welds (standard and wide gap) were examined ultrasonically using 0-, 45-, and 70-degree probes from the rail top. No defects were found. In addition, two wide-gap and two standard weld samples were cut to a length of 12 inches with the weld central. These were examined from the rail ends with a 0-degree probe, and no defect indications were found. The implication is that, when properly made, wide-gap welds should have no greater defect levels than standard welds.

Tensile Properties, Hardness, and Chemical Composition

Tensile specimens were taken longitudinally from the base and head of wide-gap and standard welds. In all cases the specimens were taken with the fusion line at the center of the gage length. All fractures occurred outside the gage length, but results consistently showed that the wide-gap welds had similar strength and ductility to the standard welds.

Internal hardness traverses were made 5/8 inches below the running surface, using a Rockwell C tester. The hardness profiles across the two types of weld were similar (Exhibit 3). Results

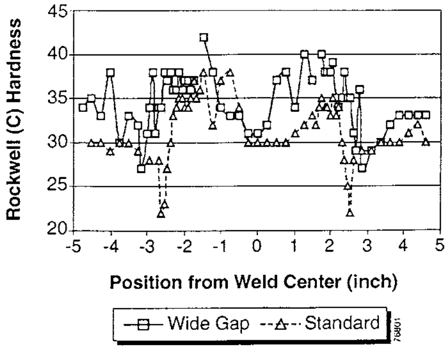


Exhibit 3. Hardness Profiles across Standard and Wide-Gap Welds

confirmed that wide-gap welds do not have extensive HAZs. Measurements of surface hardness, and internal hardness in the rail base, reaffirmed the above finding.

Chemical analysis showed that, with the exception of vanadium (higher in the wide-gap weld), and manganese (lower), the chemistries of both types of welds were similar. Vanadium is likely to increase strength, and may balance the slightly lower manganese content of the wide-gap weld.

Both welds had lower carbon content than the parent rail weld (about 0.64 percent, compared to 0.74 percent). However, they had higher silicon content, which may compensate for the lower carbon content and also may increase strength.

Residual Stress

Residual stresses formed in manufacture have a large effect on the service life of welds. Normal welds have compressive residual stresses at the bottom of the rail foot, which protect against fatigue. Because of this, the strain-gage technique was used to measure residual stress in both types of welds. Gages attached to the surfaces of the welds at the collar-to-rail interface, measured longitudinal stress in the head, web, and base. Two welds of each type were examined. Results in Exhibit 4 show that wide-gap welds have stresses no different from standard welds.

DISCUSSION AND FUTURE TESTS

The properties of wide-gap welds are very similar to those in standard welds. The third wide-gap weld in the rolling-load test did not pass 2 million cycles. However, failure was from a defect which can also occur infrequently in standard welds. Further tests of wide-gap welds are under way. Their long-term performance is being monitored in track at the Facility for Accelerated Service Testing. Also, a full-scale fatigue fixture has been built to test welds in four-point loading. Tests will be completed later this year.

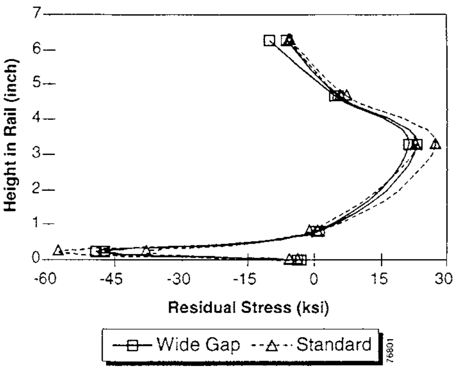


Exhibit 4. Measured Residual Stresses in Thermite Welds

Wide-gap welds take about 6 minutes longer to make, but allow defective field welds and possibly other rail defects to be repaired using one weld, instead of two standard welds and a 20-foot rail plug. Wide-gap welds can also provide additional time-savings since it usually takes less time to align existing rails to make a wide-gap weld than it takes to align a rail plug in the track. The final task of this project will be to define where, and under what conditions, these types of welds can be used to the best advantage.

Note: Contact Jian Sun at (719) 584-0698 or Kevin Sawley at (719) 584-0636, with questions or comments about this document.

E-mail: jian_sun@ttci.aar.com
kevin_sawley@ttci.aar.com
Web site: www.ttci.aar.com

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.

APPENDIX B

QUESTIONNAIRE RESPONSES: THERMITE WELD PERFORMANCE IN TRANSIT TRACK

TRANSIT COMPANIES RESPONDING TO THE SURVEYS

North America:

- Bay Area Rapid Transit (BART)
- Calgary Transit, Canada
- Delaware Administration for Regional Transit (DART)
- Edmonton Light Rail Transit (Edmonton LRT)
- Greater Cleveland Regional Transit Authority (Greater Cleveland RTA)
- Long Island Railroad (LIRR)
- Metropolitan Atlanta Rapid Transit Authority (MARTA)
- Massachusetts Bay Transit Authority (MBTA)
- Metrolink of Southern California (Metrolink)
- Metro-North Railroad
- Metropolitan Transportation Authority New York City Transit (MTA-NYCT)
- MetroRail of Miami-Dade Transit Agency
- New Jersey Transit
- The Northern Indiana Commuter Transportation District (Northern Indiana)
- Port Authority Transit Corporation of New Jersey (PATCO)
- Sacramento Regional Transit District
- San Francisco Municipal Railway (SF Muni)
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Tri-County Metropolitan Transportation District of Oregon (Tri-Met)
- Toronto Transit Commission
- Washington Metropolitan Area Transit Authority (WMATA)

Europe:

- DB Netz—Deutsche Bahn Gruppe, Germany
- Jernbaneverket, Norwegian National Rail Administration, Norway
- Banestyrelsen, Danish Rail System, Denmark
- Banverket, Swedish National Rail Administration, Sweden

QUESTIONNAIRE FOR THERMITE WELDS SURVEY

1. How are the conventional thermite welds that have been installed in your tracks been performing? Have some failed? Are any exhibiting batter that is of concern (leading perhaps to corrugation of adjacent rails)?
2. If failures have occurred, have they tended to be early in the life of the welds (say failure just after installation) or after extended periods of service?
3. Have any broken welds been examined visually (on the fracture faces) to determine where the origin of failure might have been? If so, what are the findings?
4. If failures have occurred, are most (a) in curves or tangent track? (b) in standard or premium rail? (c) at locations in track where strong longitudinal forces develop? (d) failing when the ambient temperatures are low or have been falling (cold snap)? and/or (e) failing in tunnels or near turnouts (stiff track conditions)?
5. Are your thermite welds all of the same manufacture and, if so, which one? If not, what manufacturers have you used and why?
6. Do your crews do the thermite weld installation? Do they use any special fixturing (say for alignment control)? Approximately how many thermite welds does your property install in a year? And are they mostly for plug rail installation or for new construction?

SURVEY RESPONSES

BART/Michael O. Brown/ Special Projects Manager

1. The thermite welds installed at BART have been performing extremely well. Some field welds have failed; however, the failure rate is estimated to be less than 5% failure rate over an approximately 30-year period. Batter is occurring on a limited basis; a localized rail corrugation pattern will emerge, but the larger concern is damage to ties and fasteners and noise. Weld batter tends to occur only on ballasted track.
2. Defects on field welds, in general, occur after extended periods of service (I would contribute this to the extensive acceptance testing during construction). Field weld service failures (those not located by an ultrasonic rail defect test car) have occurred approximately at a rate of 0.25%.
3. Yes, the failures have originated from slag inclusions within the railhead area of the weld.
4. a. 45% curves, 55% tangent
   b. 11% on premium rail
   89% on standard rail

Note: of these, 62% have been on end hardened rails

c. 62% have been at locations where strong longitudinal forces can develop (ballasted track).

d. Service failures have been associated with sharp temperature drops.

e. 24% within interlocking complexes

37% on aerial structures with direct fixation construction

2% on Subway Structures with Direct Fixation Construction

5. No, all of the major manufacturers of field welds have been used (our construction specifications do not require the use of any specific manufacturer—they only define final quality). For maintenance, we were using “Boutee” brand welds, then moved to Orgo-Thermit brand welds. For the last six years we have been using “one-shot” type field welds manufactured by “Railtech.” In the past the brand that we used was driven by what our welders were experienced with (the majority of our track welders come to us from nearby railroads or track work construction contractors). The move to the “one-shot” type welds was a conscious decision because of the improved quality and reduced cost of using a disposable crucible.
6. Yes, though the vast majority of field welds are installed by contractors during new track construction. Our maintenance crews exclusively install field welds for maintenance. “A-Frame” type alignment gigs are primarily used; on special installations (such as welds at frog legs) large “home made” alignment gigs are used. Maintenance crews install approximately 30 welds per year. Typical uses are for worn rail replacement and rail plugs to remove rail defects.

CALGARY TRANSIT/Bob Charles/
Manager of Engineering and Maintenance

1. Thermite welds have been performing very well. A very small percentage have failed in in-street track. Welds do not exhibit batter.
2. After extended life.
3. Yes, one cannot detect where a defect has originated by visual inspection.
4. Failures have occurred in stiff in-street track. Visually they will be picked up when ambient temp drops.
5. Yes, Railwel
6. Yes, Calgary transit crews do all thermite welds. Yes, we use beams, etc., for alignment control. Both plug installation and special track work. Twenty welds yearly.

DART/Darvin Kelly

1. No failures, no batter, no corrugation
2. No answer
3. No answer
4. No answer
5. We use Calorite. Orgothermit was used during construction.
6. Installed one plug in the last four years. We have a new system.

EDMONTON LRT/Jim Stein

Edmonton operates a light rail system over 12.3 route-km of track (all of which is double track). The track is continuously welded 100 lb. ARA-A rail. Rail for the initial leg (8.9 route km) was butt welded. Subsequent new construction and maintenance has utilized thermite welds exclusively. All thermite welds are ultrasonic and magnetic particle tested before the track goes into service.

We have not considered using wide gap thermite welds. We don’t know enough about them.

1. We are happy with the performance of the conventional thermite welds to date. We have not experienced any failures on in-service track. Batter does not seem to be a problem. Our only problems are related to poor welding (i.e., peaked welds, dished welds form over grinding).
2. All of the failures we’ve had to date have occurred just after installation. In each case the cause has been insufficient pre-heat time. In all cases the failures were detected prior to the track going back into service.
3. We haven’t done an examination of any of the weld fracture faces, as it was evident at the time the failures were the result of insufficient preheat time. I believe in each case the welder mistook standard preheat kits for limited preheat kits.
4. N/A
5. We specify Alfex, Boutet or approved equal.
6. We contract out all thermite weld installation. Our own crews do not have the necessary training to do thermite welding. Some of the contractors use a frame to align the rails and maintain the rail ends in place. Others use wedges. Over the last few years we’ve installed about 50 welds annually. About 30 or so of these each year are associated with rail plug installation. We are gradually replacing all bolted insulated joints with glued insulated joints. Unfortunately, the holes for the bolted ij’s are usually out of alignment and, as a result, we have had to install the glued ij in plug form. The remaining welds have been for track replacement projects.

GREATER CLEVELAND RTA/AlanSoukup/
Supervisor of Track

1. No
2. No answer
3. No answer

4. No answer
5. Yes—Railtech Boutet (CJ Crucible)
6. a. Yes
   b. No
   c. 80
   d. Rail installation 39′ to 950′

LIRR/J. M. Sais/Asst. Chief Engineer-MW

1. Thermite welds have been performing very well in our rail system. We have experienced some failures. Joint batter has not become evident as of yet.
2. The failures that have surfaced were on welds that have been in service for extended periods (five years or longer). Sperry Rail Service picked up the majority of these failures.
3. Over the years we have found failures emanating from various locations of the weld area and for different reasons.
4. We have had only two actual breaks within the weld area. These welds were in service for many years and were Sperry tested at least twice a year. These breaks occurred on tangent track, in very cold weather.
5. We have been using thermite welds on our system for 26 years. To date, all our thermite products have been manufactured by Boutet and supplied by Esco Company. This company has always supplied us with a superior product and has always provided support. They have always been willing to train our crews on site with on-site training.

MARTA/H. R. Jordan

1. Our welds have performed well. We have had two or three failures in twenty years. All of these failures have occurred within the first 24 hours. Two failed immediately and one failed the next day under traffic. We put weld straps on our new welds and perform ultrasonic testing before putting them into service.

   We have had minor problems with "batter" but none of concern and none leading to corrugation.
2. All three failures have been within the first 24 hours.
3. No. The reason for our failures were obvious—poor welding technique.
4. With only three failures to report, I cannot add value to this discussion. Temperature was not a factor.
5. We have always used Calorite.
6. Yes, we do our own. We use an alignment beam on all welds.

MBTA SUBWAYS/Mark O'Hara

1. The MBTA has generally experienced no problems with thermite welds which were properly executed. There has been no real concern with weld batter and no evidence of rail corrugation generated by poorly finished thermite welds.
2. The overwhelming majority of thermite weld failures which the MBTA has experienced have occurred shortly after welding has taken place and have been, upon examination of the weld's interior, attributable to poor welding technique. An occasional thermite weld has failed after years of service. Examination of these welds has, in almost every case, shown a very minor occlusion in the head from which a fault line has propagated. It is suspected that a sudden impact load, such as from a direct hit from a wheel flat, caused an otherwise dormant internal defect to become active.
3. See answer number 2
4. a. Although no specific statistics have been kept, it seems as though the majority of "late blooming" thermite weld failures have occurred in tangent track where typically trains would be travelling the fastest (50 mph on the MBTA).
   b. No data is available to differentiate failures in standard vs. premium rail.
   c. Again, record keeping is somewhat sketchy, but it seems an equal amount of failures have happened in tunnels where ambient temperature swings are moderate and in open right-of-way at the end of CWR strings where high longitudinal forces would be expected to develop.
   d. No temperature data is available.
   e. No specific data is available, but it doesn't seem, at least anecdotally, that differing track stiffness moduli play a significant role in thermite weld failure at the MBTA.
5. Most all thermite welds done at the MBTA in the past 10 years or so have been manufactured by Calorite. Other manufacturers' welds, such as Boutet, have been also used in the past. It seems the choice of weld is a matter of personal preference for the people doing the welding as, in the case of welds done by contractor, the material is specified as "Calorite or Boutet or approved equal."
6. MBTA crews perform a very limited amount of thermite welding; most are done under contract by track construction contractors. No special fixturing is used to align rails for welding, typically a long straight edge and a 6″ level. Thermite welds at the MBTA probably number in the 20 to 40 range annually. Maybe ¾ are done for new construction tie-ins and the rest for plug rail installations.

MBTA (COMMUTER RAIL)/Peter Wright

1. One-two service failures/yr.; a dozen Sperry indications per year; UT hand tests made within one day; no batter.

2. Mostly service failures are right after installation (one every couple of years within 24 hours). Sperry indications mostly older (8–10 years).
3. No answer
4. No difference for different locations; no failures in premium rail; most failures in fall of year.
5. Calorite
6. MBTA crews do welding; no fixtures; about 500/year.

Note: About 10% of old Billerica gas welds have failed since 1987 (potentially good candidates for thermite wide gap welds—RKS).

METROLINK/Paul Genisio/Chief Engineer

1. The conventional welds have been performing. None have failed. Some batter but no concern.
2. None failed.
3. None failed.
4. N/A
5. Orgothermit and Railtech Boutet. Presently use Boutet and have had no problems with them.
6. We have about 20 welds done a year. These consist of Sperry and plug welds. A contractor for heavy maintenance does all the welds. He bids the job for 3–5 years.

METRO NORTH RAILROAD/Richard Krasnow/ Asst. Chief Engineer

1. They have performed well. We do have occasional failures. No evidence of batter.
2. We have found that failures tend to occur after a number of years have passed (8–10 years or more).
3. Yes. Generally these are the result of slag inclusions or improper preheating.
4. a. Undetermined
    b. Standard rail, which is the majority of our rail
    c. Unknown
    d. No
    e. No
5. No. Railtech—Boutet—Orgothermit/Lowest responsive bidders per our specs.
6. Yes/No/1200/New construction

METRORAIL/John White/ Track Maintenance Supervisor

1. Current thermite welds are performing 100%.
2. No answer
3. No answer
4. No answer
5. Calorite
6. Yes, Metro crews install welds. Only metal wedges are used for alignment. Fifteen to 20 welds per year. Almost always changing old rail for new.

MTA-NYCT/Michael S. Dawson

1. a. The conventional thermite welds have been performing well.
    b. Yes, we have experienced weld failures.
    c. Not to our knowledge.
2. Since January of this year there have been 9 failures. The age of the rails varies from 1980 to 1995.
3. No
4. a. Most failures have occurred on tangent track.
    b. According to our records of the failures this year, the number of weld failures between standard and premium rails are approximately the same.
    c. We have insufficient data to come to any such conclusion.
    d. Most of the failures have occurred during cold weather. We don’t have sufficient data to determine if the failures occurred during falling temperatures, but most breaks have been found very late at night or early morning.
    e. All weld failures have occurred in tunnels, based on this year’s assessment.

NJ TRANSIT RAIL OPERATIONS/Bruce Wigod

1. No
2. Extended service
3. Yes—the vast majority contain slag inclusions that are indicative of human error
4. No discernible pattern
5. NJT uses Orgothermit almost exclusively, though there are some Calorite welds on the property. Procurement is through a bid process.
6. NJT does 1000–1200 welds/year—75% for new construction. No special tools are used. NJT employees do the work.

NORTHERN INDIANA/Chris Beck

1. In general we have been very satisfied with the performance of the thermite welds. We are currently looking at buying these welds from Boutet. We will test them and evaluate.
2. We have had a small percentage of welds fail. Failures have been a result of improper rail handling or improper tamping of ties on compromise welds. Some failures have not surfaced until the first cold snap.
3. We visually examine all failed welds. A few failures were a direct result of the railhead being hit with a

sledge hammer or spike maul during the weld set-up process.

4. In general, failures have occurred in tangent track where strong longitudinal forces develop. Some failures have occurred in areas where neutral rail temp. is out of adjustment. We try to use a 95F–105F NRT. It is really odd that we don't see failures at the first cold snap; it is usually after the first three or four cold snaps that the weld experiences failure.
5. To date we have always used Railwel products. We have recently placed an order with Boutet to try their products.
6. NICTD crews perform the thermite welds. We do not use any special fixtures, just the standard jackets and clamps. NICTD installs approximately 100 welds per year. Most welds are for new construction.

PATCO (Pennsylvania and New Jersey)/ Peter S. Gentle/Asst. General Manager, Engineering & Maintenance

1. The vast majority of thermite welds on PATCO perform well. We have had very few failures of the more current weld kits; most failures occur in welds 20 years or older. The older welds (12 years plus) are exhibiting signs of batter with some adjacent corrugation.
2. The weld is ultrasonically tested and usually fails the test. We have not had any failures for at least ten (10) years.
3. Yes. Most of the fractures have been found to have large slag inclusions either at the head/web interface or the base/web interface.
4. The vast majority have occurred due to temperature changes with a few in high degree curves.
5. PATCO has used both Boutet and Calorite weld kits. Initially, it was felt that these manufacturers had a cleaner kit with more quality control. In recent years all manufacturers have been producing consistent kits and choice is simply a matter of convenience and availability.
6. PATCO crews perform their own thermite welds. PATCO uses the facilities maintenance workers to perform the thermite rail welding. These employees represent a class of higher skilled workers than the track forces. PATCO uses an alignment beam for alignment control. PATCO performs approximately 80 welds per year in both plug rails and new rail installation.

SACRAMENTO REGIONAL TRANSIT/ Larry Davis/Wayside Maintenance Supervisor

1. No problems with conventional welds. No welds that failed. No batter.
2. N/A
3. N/A
4. No failures
5. Railwel Calorite/Railtech (one-shot)
6. Yes
   Yes
   6–8
   Plug rail installation

SEPTA/Tony Bohara/ Operations Support—Administration

1. Thermite welds installed in the 1970's have been failing at an alarming rate.
2. Some fail early; majority after extended period.
3. Yes—usually lack of fusion, an inclusion or porosity is at the origin.
4. Tangent track, standard rail, minimal to moderate longitudinal forces. They fail in cold weather and typically stiff track conditions.
5. We have used Calorite, US Thermite and Orgothermit.
6. Typically, SEPTA crews install but contractors install them as well. Numbers vary from 100 per year to several hundred in 1970–1980's.

SF Muni/Robert Ramirez/Track Engineer

1. Some failed, yes. Some batter, yes.
2. Both early and late in life
3. None inspected for failure origin.
4. No pattern
5. Calorite and U.S. Thermite. Less failures with Calorite.
6. No welds made by Muni forces. Contractors do new construction and use alignment fixture. 50–500/year.

Note: Some failures at bond thermite welds. There currently is an ultrasonic test program on rails in tunnels.

TRI MET/Cork Jennings/Manager of Maintenance of Way

1. a. Very well
   b. Two pull aparts.
   c. No batter that has been reported to us.
2. Yes, within first year.
3. No
4. a. Tangent
   b. Standard
   c. No
   d. Yes
   e. No
5. Orgothermit and Calorite
6. a. No—construction contractor
   b. Contractor does beam
   c. Two in 14 years
   d. New most all

TORONTO TRANSIT COMMISSION/ Brian Longson

1. Generally, the Toronto Transit Commission has had a very good history of usage with thermite welds. With only a few exceptions, welds which have passed inspection and installation do not lead to failures. With our highest traffic of 40 MGT and in the worst case 15T axle loading, we do not see a lot of batter or corrugation, provided the weld is compatible in hardness with the rail.
2. Failures which have occurred have been generally early in the life of welds. We have a standard which requires manual ultrasonic and visual inspection of each new thermite weld within two weeks of installation, which follows a strict process of acceptance/rejection by a trained NDT crew. In years past we did encounter some cracked welds/failures related to a change in welders. This caused us to develop a two-step UST process for approving new welds, which utilizes 0 and 70 degree probes, as well as 45 degree probes in pulse-echo, through transmission and pitch-catch modes.
3. The findings related to defective welds are almost all related to lack of fusion, porosity, or contamination in the base. We have experienced few defects in the head and negligible in the web. In-service failures have almost all been a result of old arc weld repair work done to build up thermite welds. This practice has been discontinued.
4. Failures have been related to sudden changes in ambient temperatures (cold snap).
5. The Toronto Transit Commission uses only thermite kits from Railwel (Auto-tapping Delachaux).
6. The Toronto Transit Commission does all its own maintenance and new construction. We follow the recommended practices and use the specific equipment manufactured by the supplier for the welds. We install between 700–1500 welds per year, but are tending to use less with greater use of flash butt welding. The welds are mostly for small project closures, plugs, STW, etc.

WMATA/Donald Painter

1. The regular thermite welds are performing well. There have been no recent failures. At this time, there is no rail batter developing at weld locations.
2. No broken welds have occurred.
3. No broken welds reported.
4. No broken welds have occurred in the past five (5) years. All broken welds are tested.
5. Yes. Orgothermit is the only one that we use, at this time.

26. Yes. The Track & Structures crew install thermite welds. Yes, alignment beams are used during installation.

APPENDIX C

QUESTIONNAIRE RESPONSES: WIDE-GAP WELD USAGE

QUESTIONNAIRE FOR WIDE-GAP WELD SURVEY

1. Do you install wide gap welds, and if so, how long have you been doing so?
2. To what purpose do you apply wide gap welds and what are the criteria that you use in deciding whether to install a wide gap weld?
3. How extensively have you used the wide gap welds? Typically how many do you install in a year?
4. Have there been any difficulties in the use and performance of these welds—as for instance with fracture and/or batter development?
5. Are any special maintenance procedures required to ensure their continuing satisfactory performance?
6. Are you aware of other properties that have been using wide gap welds, and if so, might I prevail upon you for the name and address of person(s) to contact?

RESPONSES FROM EUROPE ON WIDE-GAP WELD USAGE

BANESTYRELSEN/Christian von der Maase

1. Yes, Banestyrelsen have been using SKV-L-75 method the last 10–12 years.
2. We use wide welds mostly as a reparation weld in cases where:
   –UT-control detects a defect in normal welds.
   –Where a turnover has to be taken due to underground problems/renovation and after the old welds are removed, welded back in place.
3. We make about 75 wide welds/year.
4. No, we don’t have more problems with wide welds than with normal ones. The heat input is much greater, and that can (theoretically) give some problems with surface batter.
5. We do not have special maintenance procedures related to wide welds.

BANVERKET/Anders Frick

1. In 1990 BV started to use gap 50 mm from the company Elektro-Thermit. We have so far not been using gap 75 mm. Besides Elektro-Thermit, BV is also buying thermite welding equipment (PLA method) from the company Railtech International in France. They are marketing gap 68 mm. We have since 1998 been using this 68 mm gap.
2. We are using gap SkV/50 mm or PLA/68 mm mainly for the purpose of repairing, i.e. re-welding of existing thermite joinings. The criteria is that if standard gap, 25 mm, can be cut leaving a gap of 50 mm or 68 mm, then the welders are allowed to use wider gap, i.e. gap >25 mm. If, for one or the other reason, a wider cut has to be done (for example a breakage with branching cracks), a rail of minimum length 5 m has to be welded into the track.
3. In percentage 2½–3 of all thermite welds are performed with gaps larger than the standard 25 mm gap.
4. No special problems are reported.
5. No, not any special compared to the standard gap.
6. I don’t know for sure if and in such case how much wide gaps are used in the other Scandinavian countries. The following persons can be contacted for inquiry:
   Norway: Mr. Frode Teigen at Jernbaneverket. Fax No. +47 22 455249
   Denmark: Mr. Christian van der Maase at Banestyrelsen: Fax No. +45 3376 5054
   Finland: Mr. Pekka Rautanen at Oy VR-Rata Ab: Fax No. +358 19 456 4855

DB NETZ/Hartmut Hug

General remark: The wide gap welding is an unconditioned approved aluminothermic welding process. Restrictions set by consumers are based rather on economical than on technical reasons.

1. Yes, first tests were executed in the early 80’s and officially approved roundabout 1987.
2. Repair purposes only. E.g. replacing a defect welding or other rail defects, when renewing (replacing) stock rails, blades, frogs, etc. in turnouts.
3. Unfortunately, I have no statistics on hand to compile the numbers of these welds.
4. No known, so far, There are no indicators that wide gap welds have a higher fracture rate than other aluminothermic welds. Batter development (I understand this as a lack of hardness on the running surface within the heat affected zone) are negligible.
5. No, these welds are inspected by ultrasonic tests under the same conditions as other welds (intervals, procedure). Of course, the quality of the welding compounds

has to be checked with an appropriate quality control system either by the supplier or by the consumer.

6. I am not sure which other companies are using wide gap welds, but I guess most of the non-DB companies (which are a minority) use them as well.

Concerning the addresses of these companies, please contact Mr. Kuster of ET again.

JERNBANEVERKET/Frode Teigen

1. Yes, we do install wide gap welds in track and have been doing so since 1985. The process we have been using since 1985 is ET SkV L75 with 75 mm nominal weld gap.
2. We use wide gap welds for the following purposes:
   –Repair of transverse rail defect instead of using rail plug
   –Repair of transverse rail break instead of using rail plug
   –Repair of unsuccessful rail weldings
3. The amount of wide gap welds is approx. 50 per year.
4. No
5. No

RESPONSES FROM NORTH AMERICAN PROPERTIES USING WIDE-GAP WELDS

Question: Has your system considered using wide gap thermite welds in its tracks and, if so, for what purpose(s)?

BART/Michael O. Brown/
Special Projects Manager

Yes. Wide gap thermite welds are used to remove defective welds found in track (usually by ultrasonic rail defect testing). New track construction contractors are also allowed to use wide gap welds to remove defective welds (field and factory) found during acceptance or pre-revenue weld testing (this testing includes alignment checks, dip/peak checks, visual surface inspection, magnetic particle testing, ultrasonic testing and radiographic testing).

CALGARY TRANSIT/Bob Charles/
Manager of Engineering & Maintenance

Yes. To correct a thermite weld that has pulled apart or fatigued due to internal defect.

LIRR/J. M. Sais/Asst. Chief Engineer—MW

We are planning to implement the wide gap thermite welds. The purpose being is that if we should have a run-through, we would be able to re-weld the joint without changing the rail. The wide gap molds would also enable us to cut out the end batter and weld joints that normally require a rail change.

METROLINK/Paul Genisio/Chief Engineer

Yes, we have used four to date.

NJ TRANSIT/Bruce Wigod

NJ Transit has ordered but not used wide gap welds. It is a maintenance item that will be used to replace failed welds without changing rail.

PATH/Peter S. Gentle/Asst. General Manager,
Engineering & Maintenance

Yes. We used them to assist the TTC and also to test performance and reliability to be able to replace bad field welds without installing plug rails.

SEPTA/Tony Bohara/
Operations Support—Admin.

Yes, we have considered using them to replace defective thermite welds.

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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