THERMITE RAIL WELDING: HISTORY, PROCESS DEVELOPMENTS, CURRENT PRACTICES AND OUTLOOK FOR THE 21st CENTURY

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ABSTRACT

This paper provides a broad overview of thermite rail welding as information for those who use thermite welding or those who have an interest in the process. A short history of thermite welding is included and the process itself is described with emphasis on practical and technical advantages and disadvantages. Some of the numerous efforts performed by manufacturers and other researchers to improve thermite welding are reviewed and the results are discussed with respect to final weld properties. Throughout the paper emphasis is placed upon the improvements in thermite weld quality that have been achieved over the years. Finally, current railroad industry practices for use of the thermite weld are described along with an outlook for the process in the 21st Century. The author provides a list of challenges for railroads and thermite weld manufacturers to consider in order to help insure that thermite weld performance will remain strong in the coming years.

INTRODUCTION AND HISTORICAL BACKGROUND

Although today considered to be "standard operating practice", the development of thermite welding technology to successfully join railroad rails in the field can, if the proper definition is chosen, be considered a miracle for the railroad industry. The authors of Webster's Ninth Collegiate Dictionary (Ref. 1) provide one definition of a miracle as, "An extremely outstanding or unusual event, thing, or accomplishment", and certainly the development of rail welding fits this definition. A less enthusiastic observer might classify thermite rail welding as an innovation, or perhaps as only significant, incremental technological improvement, but rail welding clearly has been and is very important for railroads around the world. Thermite welding made possible the installation of continuous welded rail and with this came many well established associated benefits. Reduced bolt hole rail failures and bolted joint maintenance, increased rail life, better track circuit reliability, reduced equipment wear, a better ride quality and reduced track maintenance costs (Ref. 2) are among the benefits that can be directly attributed to thermite welding.

In 1893 Hans Goldschmidt of Germany began to experiment with aluminothermic reactions (highly exothermic processes involving reactions of metallic oxides with aluminum powders) for the production of high purity chromium and manganese (Ref. 3). This work led to a patent application for the "Thermit" process in 1895

and sales of chromium quickly increased. Due to the large amount of heat released by exothermic chemical reactions and the versatility of the thermit process, other applications were quickly found and Goldschmidt started a corporation in 1897. By the end of the 19th Century, the thermit process had been successfully used to make repairs to large cast and forged steel parts, compression welding using the heat of reaction products had been performed and the first rails were joined.
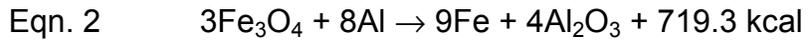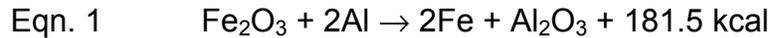
When the change was made from horse power to electric power for European street railways in the 1890's, the higher speeds and loads of the new equipment resulted in unsatisfactory rail joint performance (Ref. 3). In 1899, the first rail weld was installed in Essen, Germany, where the Goldschmidt Corporation had its headquarters. Railways quickly saw the advantages of using a fast, relatively simple, field repair method and usage of the process spread throughout Germany. In 1904 the Goldschmidt Thermit Company was founded in New York and extensive use on street railways in the United States followed.

As is the case today, railway engineers in the early part of the 20th Century tried to find the best methods and practices for various processes, including the welding of rails. A detailed investigation was carried out in the United States by the Committee On Welded Rail Joints which was composed of members from the American Bureau of Welding and the American Electric Railway Engineering Association (Ref. 4). This group had the cooperation of the National Bureau of Standards. The goals of the work were to improve and standardize the making of welded rail joints. The committee's final report, published in 1932, contains voluminous results from tensile, impact, drop, and bend tests along with results of various weld process parameter tests for rail weld joints produced over the course of a decade. A substantial amount of baseline data was created and knowledge on the subject of rail welding was vastly expanded and improved.

Steam railroads around the world began to see the benefits of rail welding. From 1924 to 1930 the German State Railway tested thermite welded rail sections of various lengths and the Krefeld Railway in Germany made 7,000 meters of continuously welded rail (Ref. 3). Thermite welding also played an important role in the reconstruction of the German railway network after World War II. In the United States, the Central of Georgia Railroad used welded rail for tunnel trackage in 1930 and the Delaware and Hudson Railroad is credited with the first open-track installation of thermite rail welds in 1933 (Ref. 3, 5). By 1980, it was estimated that continuous welded rail installations represented more than 80,000 miles of main track in the United States (Ref. 5). Although not all of these welds were made with the thermite process, the aluminothermic method certainly "paved the way" for rail welding. Today there are three major thermite weld manufacturers active in North America.

THE THERMITE PROCESS - GENERAL DESCRIPTION

The chemical reactions associated with the thermite process are highly exothermic and therefore release tremendous amounts of heat which can be used for welding. The reactions used for today's rail welding processes are between fine aluminum and iron oxide powders which are ignited in a crucible. The most commonly used reactions are as follows (Ref. 6):

Eqn. 1 $Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3 + 181.5$ kcal

Eqn. 2 $3Fe_3O_4 + 8Al \rightarrow 9Fe + 4Al_2O_3 + 719.3$ kcal

The theoretical temperature created by the second reaction is about 5,600°F (Ref. 7), but heat losses due to nonreacting alloy additions, radiation from the crucible, etc., bring the melt temperature down to 3,500°F (Ref. 6). When the exothermic reaction in the crucible is completed, about 20 to 25 seconds is required for separation of the slag from the molten steel. After the slag (mostly aluminum oxide) has floated to the top of the crucible, molten steel is released from the bottom of the crucible. Liquid steel pours down into the hardened sand mold which has been packed with luting sand and special paste around the two rail ends to be joined. The rail ends, which have been preheated with gas torches, are partially melted by the liquid steel as the mold fills and the weld then is allowed to cool and solidify. When the weld is solid the molds, head riser and base risers are removed and the rail head is finish ground to the proper contour for train traffic.

The thermite rail welding process is therefore essentially a "portable foundry" which can be brought to almost any location in the field. Process advantages include portability, relative ease and speed of installation, the flexibility of the process to weld almost any rail sections together, and cost effectiveness. The main process disadvantages are the many process steps that can be altered by the welder and/or the environmental conditions and can result in poorer weld performance. These variables include such things as rail end alignment, rail section size mismatch, the rail end gap, quality of the mold packing job, duration of preheat, preheat of the crucible and diverting plug, moisture in the air, time duration until molds are removed, excessive rail motion during weld solidification, etc. Publications produced by thermite weld manufacturers far more completely describe the detailed steps that are necessary to create a "proper" thermite weld that will survive in track (Ref. 8, 9).

Historically it is known that thermite welds contain substantial microporosity and inclusions and this is a contributing cause of their poor ductility and impact toughness (Ref. 10). Myers et al. (Ref. 10) published values for thermite weld sample tensile test percent elongation (1% to 5.6%), tensile test percent reduction in area (1.8% to 3.5%) and charpy impact toughness (2 ft-lb at room temperature). Since the weld is actually a casting, large columnar grains are found in the microstructure and this is also a major cause of thermite welds being so brittle and tending to fracture in a cleavage mode (Ref. 11). Hauser

(Ref. 2) stated that the most common reasons for thermite weld failure in service are due to porosity, voids and inclusions in the weld metal, or gouges and local areas transformed to martensite during post weld finish grinding.

PROCESS IMPROVEMENTS AND RESULTS

The increasing axle loads and tonnages experienced by North American railroads have increased the demands placed upon all track components, including thermite welds. Thermite rail welds have historically been a weak link in continuous welded rail due to their cast microstructure. However, manufacturers have not been idle and many process improvements have been made over the years and during the last decade in particular. The next section of this paper provides an overview of some of those improvements.

Weld Hardness and Grain Size Improvements

In order to reduce the amount of rail fatigue and wear, rail steels have become significantly cleaner and harder in recent years, particularly with the introduction of new head hardened rail. Fully pearlitic head hardened rail can be in the 360 BHN to 380 BHN range (Ref. 12), and another rail manufacturer reports hardness values over 400 BHN. Wear rates for head hardened rail were seen to be far superior to wear rates for standard rail in tests at the Association of American Railroads (AAR) Facility for Accelerated Service Testing (FAST) (Ref. 13). Although there was little correlation between thermite weld batter rate and hardness in the same recent FAST work, higher thermite weld hardness should intuitively perform better. As a result of customer requests for higher hardness welds to match harder rails, thermite weld manufacturers have produced charges with different chemistries which resulted in harder welds. In the 1980's, the hardness of most weld charges matched that of standard rail at 285 BHN. Today several thermite weld charge hardnesses (fully pearlitic) are available in the marketplace as follows:

- Standard Hardness (305 BHN ± 20)
- High Strength Weld - hardness level 1 (340 BHN ± 20)
- High Strength Weld - hardness level 2 (370 BHN ± 20)

Manufacturers have also refined the grain size of their welds. In general, smaller grains possess better strength, ductility and fracture toughness properties and are preferred over large, cast columnar grains. Data for older thermite welds reveals an ASTM grain size (weld zone) of approximately 1.5 (Ref. 14). Data for newer thermite welds (weld zone) show that this grain size has been substantially improved to greater than ASTM 4 (Ref. 15). This has been largely achieved with improvements in charge chemistry through the addition of alloying elements.

Crucible Improvements

The crucible is the component in which the initial chemical reaction, melting of the charge and slag separation takes place. As such it must be able to withstand very high temperatures over a number of welds. A major improvement in the not too distant past was the development of the self tapping crucible thimble. The thimble automatically releases the molten steel when the proper temperature is reached (Ref. 16). Before the automatic thimble, the molten steel release was a manual effort and thus consistency of slag separation time, hence final weld product, was less than perfect. Another important development in crucibles came when the "one-shot" crucible entered the marketplace. This process variation reduced the necessary pieces of hardware from 13 to 6 and uses a new crucible for each weld. Advantages of this process include less equipment weight, no need to preheat the crucible and theoretically should reduce the number and/or size of inclusions from the crucible in the weld since the crucible is not used again (Ref. 17). Development of lighter weight crucibles and associated equipment continues to be important as railroads strive to make equipment safer and more ergonomically friendly for employees.

Mold Improvements

Since the thermite weld is a casting the weld surface is not expected to be perfect. However, a smoother surface has fewer and less severe discontinuities which will act as stress concentrations in service. Such discontinuities can include sand, hot tears, porosity, etc. Molds produced today for thermite welding are lightweight and made of hardened sand to uniform dimensions. This is an improvement over early thermite welding molds which were heavy, cumbersome and required more extensive labor efforts such as sand banking (Ref. 4). Today's thermite weld molds are composed of improved refractory materials and have better resistance to heat. Some molds are coated with a zircon wash. Both of these improvements lead to a better weld surface finish (Ref. 18) and less final grinding is needed (Ref. 16). Also, a significant amount of research work, including finite element analyses, has been performed to find the weld collar design which has the lowest levels of longitudinal and vertical stress (Ref. 19). Manufacturers now offer a variety of compromise molds in order to reduce the amount of rail base mismatch when rails of different section sizes are joined. Minimization of the stress concentration at the base can reduce the chance for base initiated fatigue failures.

Improvements In Manufacturing Practices

The major thermite weld manufacturers have parent firms with a headquarters in Europe which means that the ISO 9000 quality process has been a part of their corporate culture for some time. This focus has clearly helped to improve their

operations in the United States. Manufacturing standards have been tightened and equipment has been modernized at plants that produce weld charges. Charge components are now carefully measured to insure that the proper mixture is obtained and all manufacturing information is fully traceable from identification tags on the charge portion bags. Quality efforts have included standardization of manufacturing practices along with routine slow bend tests of welds made with each production run of a weld charge.

Improvements In Training

Thermite weld manufacturers are well aware of the fact that their products are normally viewed in the light of how many failures occur in service on the railroad. They are also aware that the railroad thermite welder determines the ultimate fate of the weld when it is installed. If the weld is installed properly, it stands a much better chance of performing well in service. However, improper installation will lead to premature sudden failure or longer term fatigue cracking. In order to combat weld failures due to improper practices, weld charge manufacturers have produced significantly better training publications in recent years (Ref. 8, 9). They also have stepped up their field "hands on" training efforts in order to insure that railroad welders are aware of best practices. Representatives of manufacturers work with railroad welding gangs in the field across North America and provide important instruction and advice on thermite welding.

RESEARCH REVIEW-RESULTS AND DISCUSSION

As mentioned before, much has been written about the poor ductility and toughness properties of thermite welds relative to the rails they join (Ref. 2, 10, 11, 20). A variety of methods to improve properties have therefore been studied by manufacturers and other researchers over the years. These methods generally seek to reduce porosity and inclusions and/or reduce the final as cast grain size of the weld metal. If a cost effective method can be found to produce a fine equiaxed grain structure with a minimum of internal discontinuities, properties will improve and service life will likely increase. Other research work, including efforts to detect defects as the weld is produced, mathematical fatigue modeling and variations of the thermite weld process are also discussed. Although not every bit of past thermite weld research work is covered, the reader is provided with a working knowledge of what has been done in the field of thermite welding as an overview.

Fracture Toughness Testing

Recent testing of one manufacturer's currently produced product shows that the fracture toughness of thermite weld steel is quite close to that of rail steels (Ref. 21). The reported toughness values are quite similar to results previously published by Australian researchers (Ref. 18). Earlier test data provided by a

researcher in Canada showed that the fracture toughness of a thermite weld was substantially lower (Ref. 22). This highlights the thermite weld charge improvements that have been made by manufacturers in recent years.

Squeeze Welding

One method that has been attempted in order to improve properties by reducing the number of discontinuities present in the final weld is the squeeze welding process (Ref. 23, 24). This process uses the normal thermite welding procedure but adds a mechanical forging step while the weld is still liquid. Much of the liquid steel is expelled and a narrower weld joint with fewer inclusions and areas of porosity remains. Tensile tests showed that the ductility (% elongation, % reduction in area) of the weld metal in the base was substantially improved over a thermite weld made with the normal procedure (Ref. 24). Rotating beam fatigue tests showed that squeeze weld samples had better properties than conventional thermite welds. However, problems with the method include maintaining rail alignment during the forging sequence, removal of excess metal with the shear after welding and poor slow bend test results. More extensive testing will be necessary in order to develop parameters for creation of consistent welds and to develop equipment that is practical and useable for railroad field welders.

Vibration Of Liquid Weld Steel

It is a well known fact that grain refinements are possible by applying vibrations to solidifying castings. A cast structure with many more smaller, equiaxed grains will have better properties than one with larger columnar grains. One study was conducted to investigate the effect of sonic power on the solidification structure of thermite welds joining construction reinforcing bar sections (Ref. 25). This work showed that sonic power has a strong effect and that the grain size in the thermite weld metal is generally refined by such vibrations and becomes equiaxed. However, vibrations imparted during the last stages of solidification can cause hot tears in the weld center. Later work involved mechanical vibration applied to a still liquid, solidifying thermite rail weld (Ref. 26). The tests were conducted in the field out of track and an air wrench applied to a tightened track bolt provided the vibration. Some improvement in the amount of tensile test elongation was noted for the vibrated welds over a control weld.

In addition to the previously mentioned thermite weld squeeze welding tests, some welds were vibrated while some were squeezed and vibrated (Ref. 24). The vibration frequency was between 20 Hz and 100 Hz. Vibrations alone did not provide a reduction in porosity size over the standard, non vibrated weld. However the squeezed and vibrated welds were clearly better than the standard welds or welds that received only vibration. Although there is limited data, fatigue tests showed that squeezed and vibrated welds were best, squeezed alone second best, followed by vibrated alone and the standard weld. However,

tensile test results for this study did not match earlier work and thus some questions remain. In order to validate this process, further research work needs to be performed. Field practicality also remains an important issue.

The Association of American Railroads recently completed an investigation into the feasibility of using subharmonic weld treatment processes to improve the resistance of thermite welds to premature cracking and fatigue (Ref. 27). The vibrations were intended to reduce the amount of residual stresses present in the weld and to create a finer, more uniform grain size. Treated and untreated welds had very similar final hardnesses and no macrostructural or microstructural difference in the welds was noted. Both types of welds successfully completed 1,000,000 cycles of rolling load testing.

Filtration Of Liquid Weld Steel

If the number and size of inclusions in the thermite weld can be reduced, service life will likely be improved since there are fewer sites for the initiation of fatigue defects. Work with welds joining AISI 1080 steel plates investigated the premise that filters could remove inclusions from liquid thermite steel (Ref. 11, 28). The molten steel was poured from the crucible through zirconia-24 weight percent mullite filters. Although the filters partially dissolved, filtration was partially successful since the volume percent inclusions in the final weld steel was reduced. Development of robust filters that do not dissolve and are easy to use in the field may have the potential to improve the quality and service life of thermite welds.

Electromagnetic Stirring Of Liquid Weld Steel

Electromagnetic stirring (EMS) of steel during continuous casting operations is now routinely used in steel mills. This process stirs the steel, as its name implies, in a generally circular motion while helping to create an equiaxed grain structure with less internal porosity. Ongoing work by researchers in Canada is studying the use of EMS to improve thermite welds (Ref. 29). An electrical coil is placed around the weld and electromagnetic force is imparted to the melt. Researchers found that an equiaxed weld structure can indeed be achieved and that there was no significant change in weld hardness, yield strength or tensile strength with the application of EMS. If excessive voids or inclusion groupings are created as a result of the stirring, strength and ductility will drop. Future work will focus on optimizing EMS voltage and current and will involve slow bend and fatigue tests on full size thermite rail welds. Practical considerations for field railroad use of the process are again important, along with process costs. Electrical power will be needed for the electromagnetic coils and the size/weight of the final assembly will also be an issue.

Acoustic Emission Monitoring

This nondestructive testing technique is a passive monitoring method that "listens" to the sounds emitted by a cooling thermite weld after solidification is complete and determines whether the weld is good or bad. A small transducer is placed upon the rail and the resultant electrical impulses from the weld sounds are evaluated by a software algorithm A weld that is bad emits more sound and different sound amplitudes during the monitoring period (10 minutes) than a weld that is good. These sounds are emitted due to cracks forming at inclusions, porosity, etc., as the weld cools. The algorithm then calculates a numerical "Figure Of Merit" (FOM) which is the measure of weld goodness. Researchers demonstrated that the method can identify defective thermite rail welds during a series of out of track blind tests (Ref. 30). After monitoring, welds were broken in slow bend tests to confirm or deny the presence of significant defects.

Further testing correlated the FOM with slow bend test modulus of rupture and deflection for a group of thermite rail welds (Ref. 31). The correlation coefficient for FOM and deflection was 0.81 while for FOM and modulus of rupture was 0.67. This is a strong indication that thermite welds may be successfully evaluated in track using acoustic emission methods. Problems with the method include a need to avoid grinding and pounding on the rail during the monitoring period and the need for a more sophisticated software algorithm. A larger library of data collected from thermite rail welds, both good and made deliberately defective, will allow for refinements to the FOM criteria.

Mathematical Fatigue Modeling

While a detailed discussion of fatigue in rails and/or thermite welds is clearly well beyond the scope of this paper, a few comments will be made. Researchers at the University of Illinois recently used a rail head local stress fatigue model (RAHELS) to predict the type of thermite weld rail head defect that will form and predict the nucleation life (Ref. 32). Two types of discontinuities, alumina inclusions and pores, were considered in the study. As a result of computer calculations, the authors suggest that rail head fatigue defects in thermite welds will form at pores rather than inclusions. They further suggest that pore shape, orientation and size are key factors in determining the fatigue nucleation life. The model predicts that pores are most damaging where tensile stresses are greatest in the rail head, whether such stresses are residual tensile stresses or are caused by rail contraction in winter. Due to the limited data available from in-service testing, validation of the model as a thermite weld life predictor is not possible at this time.

Post-Weld Normalizing

Research work performed by the Association of American Railroads took the as produced solidified thermite weld and sought to alter the cast columnar microstructure through heat treatment (Ref. 33). The goal was to reduce final

grain size and thereby improve mechanical properties   The solidified weld was heated to about 1450 °F (well into the austenitic range) and then allowed to cool in still air. Trials using gas burners as heat for the process resulted in improved tensile strength, percent reduction in area, and percent elongation for tensile test samples removed from the head area of the thermite weld. However, it was difficult to obtain consistent, uniform values from one test to another and different parts of the weld received different amounts of heat. Field practicality of the system is again an issue.

A thermite weld manufacturer developed an alternative method for post weld, in track heat treating of thermite welds using aluminothermics called the STTW process (Ref. 34). This method uses a graphite box to surround the thermite weld thereby containing the heat produced by a mixture of thermite material, sand and additives inside the box. Heat from the reaction inside the box austenitizes the steel and allows for a refinement in grain size. Drop tests using a 2,000 pound weight were conducted on four feet long rail sections containing different welds in order to determine the relative resistance of the welds to fracture (Ref. 34). Traditional thermite welds, STTW thermite welds and electric flash butt welds were evaluated. STTW welds showed breakage with a drop from 9 to 11 feet while traditional thermite welds broke with a drop of only 2 to 4 feet. The flash welds showed breakage with a drop of 10 to 14 feet. A final weld zone grain size improvement from ASTM grain size number 1.5 to 4 (larger number=smaller grains) was noted for the normalized weld (Ref. 14). If an air blast is used to cool the head faster, the ASTM grain size number increased to 5 (Ref. 14). The STTW welds have been tested successfully in track on a major western U. S. railroad and at AAR FAST. Additionally, Mutton and Moller (Ref. 18) reported significant reductions in the amount of vertical residual stress present in thermite welds that had been heat treated.

Other Thermite Rail Welding Processes

The head repair weld is a variation of the thermite welding process that is available to railroads (Ref. 35). This process uses molten thermite steel to "wash out" defects such as engine burns on the running surface of the rail head. Tensile test and hardness results were similar to results for traditional thermite welds and no defects were found in the sample tested. Two head repair welds were successfully tested for 45 MGT at the AAR FAST track until they were removed for reasons not related to weld performance. One practical problem with the process is that defects extending more than 8 mm below the surface should not repaired with the head repair process since the weld will only wash out a limited depth of rail steel. How to determine depth of surface cracking in the field remains a practical and managerial problem.

Another thermite welding process that shows great promise with respect to improving the rail defect repair process is the wide gap weld (Ref. 36). This weld uses a 68 mm (about 2 3/4 inches) gap between the rail ends instead of the one

inch gap used by the traditional thermite welding process. It is therefore possible to "slice out" selected types of rail defects such as transverse defects, defective flash butt welds and defective thermite welds with a saw and fill the gap with a single wide gap weld. Slow bend tests conducted by a railroad and weld manufacturer show similar modulus of rupture and deflection values to those for normal gap welds. The wide gap weld process can provide a substantial savings over the current method of installing a new plug rail and two traditional thermite welds. An extensive technical evaluation of the wide gap weld including slow bend, fatigue, hardness and tensile tests has been conducted by the AAR and the results will be published this year. Preliminary reports indicate that the properties of normal gap welds and wide gap welds are very similar.

CURRENT RAILROAD PRACTICES

Thermite welding gangs on North American railroads produce thermite welds for several different reasons as follows:

- Insulated joints - new and relay
- Welding at start or end of rail laying job
- Relay rail - CWR program
- Road crossing renewal
- Turnouts - new to body of track
- Fill in rails for out of face cropping
- Repair of defects

The most common use of the thermite weld is, at least on Conrail, to repair rail defects. Conrail data shows that of the approximately 27,000 thermite welds made in 1996, an estimated 42% of them were used to repair rail defects found during the course of the year. The next most common application for thermite welds would likely be the installation of continuous welded rail, including the associated insulated joints, followed by road crossing renewals and finally installation of turnouts.

With respect to failures of thermite welds, Conrail finds about 1,000 defective thermite welds through rail testing and service failures each and every year. However, due to a lack of uniformity in weld stamping practices, it is generally not possible to determine the vintage of failed thermite welds. Another major eastern railroad installs about 30,000 welds annually (Ref. 34) and they claim to have a "very small" short term failure rate. A smaller railroad in the midwestern United States indicated that they install about 5,000 thermite welds annually with few defects (Ref. 34). One eastern North American railroad in particular reports a low failure rate for thermite welds and investigates failures in detail with an eye towards corrective action and training. The latter railroad also requires that all thermite welds be stamped with month, year and welding gang number for traceability and remedial training purposes. The field practice of weld stamping is not uniform throughout the railroad industry.

AAR FAST data from 1990 showed that shelling and web cracks were the most common causes of weld failure (Ref. 37). Australian researchers observed that fatigue cracking in the web of the rail weld is the most significant mode of thermite weld failure under heavy axle load conditions (Ref. 19). More recent AAR FAST data reported that weld failures due to spalling and shelling are a potential problem under heavy axle loads (Ref. 13). With respect to detail fractures of thermite rail welds, Oderio provides a metallurgical analysis and valuable information (Ref. 38).

A major advantage of the thermite welding process is that almost any two rails can be joined successfully. However, regardless of the reason for installation, compromise thermite welds can be problematic due to differences in rail section size. This can occur due to installation of a repair plug rail of different profile in existing rail, or at road crossings or other locations. The natural stress concentration at the base joint provides a ready site for fatigue crack initiation. By welding rails with closely matched section profiles, the success rate for thermite welds can be significantly improved. Compromise molds of various sizes are now being used more often by railroads instead of attempting to pack difficult section size differences with sand by hand. The use of the proper welding kit for the rails to be joined is clearly important for successful welding.

Some railroads have standardized purchasing/installation practices and use only one manufacturer's thermite welds. Conrail, however, and other railroads use the weld charges of both firms. Such decisions are sometimes related to historical practices within given territories along with purchasing and vendor competition issues. Other important factors related to such a decision are storage space for welding material which may take up substantial valuable space, and the cost required for additional tooling. Of course, quality issues are key and a railroad may determine that one type of weld is superior to another. One recent evaluation found that two weld types were quite similar (Ref. 15). Contract thermite welding is used by many smaller railroads and transit agencies, and is less common with larger railroads, who tend to use their own welding forces. The provision of welding services by contractors is a growing part of the thermite welding business.

Welder training remains one of the most important parts of any welding program as there is substantial opportunity for human error in the thermite welding process. Such training typically occurs "on the job" under the direction of welding supervisors, as opposed to a rigorous formal school. The number of field welding gangs managed by one supervisor can vary widely between railroads. Annual welding seminars are held by railroads for supervisors, and field training representatives are supplied by thermite weld manufacturers assist with the training process for field welders. Each railroad generally produces its own welding procedures manual for use by welders. A working group in Subcommittee 1 (Welding) of AREMA Committee 4 (Rail) is currently drafting a

specification for thermite rail welding in order that practices become more uniform. One person involved in the thermite welding field stated that the process's assets of flexibility and versatility can also be its greatest "liabilities", because welds can be misapplied causing service performance to suffer.

OUTLOOK FOR THE 21st CENTURY

Railroad engineering personnel clearly have an invaluable (and presently irreplaceable) tool at their disposal with the thermite weld, and this tool allows for joining all shapes, sizes and hardnesses of rail. The thermite weld will therefore remain an important part of railroad construction and repair practices well into the next century. Although mobile electric flash butt welders are more common than in the past, the natural cost and simplicity advantages of thermite welding will insure that the thermite weld will not disappear. However, the 21st century is not without challenges and the following section outlines what the author believes will be important issues for railroads and manufacturers.

Here's what **railroads** need to do to insure that the thermite weld is ready for the 21st Century:

Improve welder training programs - Perhaps rigorous formal instruction is needed to insure that uniformity is achieved across the railroad. AWS or formal in-house certification for railroad welders should be considered.

Adhere to manufacturers' recommended practices - "Shortcuts" cut weld life. If the instructions are followed, a better weld is produced.

Minimize the amount of rail mismatch where possible - Proper planning by maintenance personnel to minimize mismatch will improve thermite weld life. Use of similar rail sections will result in better welds.

Give welders proper time and equipment - Faster is usually not better.

Investigate thermite weld failures - If you don't know why it broke, it may happen again. Stamping welds with date/gang information helps any failure investigation. Consider the establishment of a thermite weld database to track the in service performance of welds. *Do we really know enough about failures?*

Arrange for corrective action after a thermite weld failure - If you don't do this, it will happen again.

Don't expect miracles - Improvements and progress in thermite welding will likely be incremental, not of a dramatic, "breakthrough" nature.

Support manufacturers' innovations - If we as an industry don't, who will?

Clearly communicate needs to manufacturers - "More and more with less and less until everything can be done with nothing" generally does not lead to substantial, positive improvements.

Support adoption of the AREMA thermite welding specification - More uniformity is a positive step towards fewer failures.

What **manufacturers** need to do:

Help railroads with training - Manufacturers are the experts on their process. Their representatives need to be active and in the field.

Keep ergonomics in mind when developing equipment - Fewer injuries and better safety are important.

Find ways to reduce porosity and inclusions - Railroads will need better fatigue life and welds with fewer pores and inclusions. This is a *key* issue.

Continue to develop welds that closely match rail steels - The requirements for improved wear resistance and improved rail head fatigue life will intensify. In order to meet the demands of the next century, this author feels that harder welds are very important.

Improve ductility and impact toughness - Not an easy problem, but keep working on these issues.

Consider alternative weld microstructures - Bainitic rails are being developed. Please start the development of bainitic thermite welds *now*.

Continue to innovate - Look for new, cost effective ways to improve your processes. Don't stand still. Trains will be more frequent, axle loads will increase and 315,000 pound freight car loads are just around the corner.

Maintain and improve product quality - The railroad environment will not get any easier, so this is absolutely essential.

More finite element analysis and analyses in general - Although such analyses can be expensive and time consuming, they will likely pay dividends in terms of service life.

REFERENCES

1. *Webster's Ninth New Collegiate Dictionary*, Merriam-Webster, Inc., Springfield, MA, 1987.

2. Hauser, D., "Welding of Railroad Rails-A Literature and Industry Survey," In *Rail Steels-Developments, Processing and Use, ASTM Special Technical Publication 644*, edited by D. H. Stone and G. G. Knupp, pp. 118-144, American Society for Testing and Materials, Philadelphia, PA., 1978.

3. Kachik, Robert, Personal letter communication, May 29, 1998.

4. American Bureau of Welding and American Electric Railway Engineering Association, "Committee On Welded Rail Joints-Final Report," New York, New York, September, 1932.

5. *The Track Cyclopedia*, Simmons-Boardman Books, Inc., Omaha, NE, 1985, p. 170.

6. Steele, R. K., "Field Welding Of Rails," Association Of American Railroads Report No. R-618, Chicago, IL, December, 1985.

7. O'Brien, R. L., Ed., *Welding Handbook-Volume2, Eighth Edition*, American Welding Society, Miami, FL, 1991, p. 892.

8. Orgo-Thermit, Inc., "Thermit® Welding Rules and Procedures SkV Weld," Orgo-Thermit, Inc., Lakehurst, NJ, revised January, 1998.

9. Railtech Boutet, Inc., "Procedure for Aluminothermic Rail Welding-Boutet Process-QP Process With CJ Crucible (One Shot)," Version 1.05, Railtech Boutet, Inc., Napoleon, OH, February, 1997.

10. Myers, J., Geiger, G. H., and Poirier, D. R., "Structure and Properties of Thermite Welds," *Welding Journal Research Supplement*, Vol. 61, August, 1982, pp. 258s-268s.

11. Schroeder, L. C. and Poirier, D. R., "Thermite Rail Welds; The Process, Mechanical and Metallurgical Properties, and Possible Improvements," *Railroad Rail Welding*, Proceedings of the Rail Welding Symposium, Memphis, TN, November 29-30, 1983, Railway Systems and Management Association, Northfield, NJ, pp. 21-59.

12. Bramfitt, B. L., et al. " A Synopsis of PST's Advanced In-Line Head Hardening Process After Two Years of Production and In-Service Testing," *Proceedings of the 39th Mechanical Working and Steel Processing Conference-International Symposium on Rail Steels*, Indianapolis, IN, October, 1997, pp. 1057-1060.

13. Reiff, R. P. and Garcia, G., "Update on Rail and Field Weld Tests Under Heavy Axle Loads," *Proceedings of the International Symposium on Rail Steels,* Baltimore, MD, October, 1994, pp. 93-103.

14. Kachik, Robert, Personal letter communication, August 23, 1994.

15. Lonsdale, C. P. and Luke, S. T., "An Investigation of Thermite Weld Composition and Properties," *Proceedings of the International Conference on Advances In Welding Technology*, EWI, Columbus, OH, November 6-8, 1996, pp. 447-460.

16. Kramer, J., "Thermite Welds: Getting Ready For Heavier Loads," *Railway Track and Structures*, Vol. 89, No. 12, December, 1993, pp. 16-20.

17. Kramer, J., "Thermite Welding Changes Pay Off,*" Railway Track and Structures*, Vol. 92, No. 1, January, 1996, pp. 21-23.

18. Mutton, P. J. and Moller, R. H., "Improved Aluminothermic Welding Technology," *Proceedings of the Rail Track Australia Conference*, September, 1994.

19. Mutton, P. J. and Soeleiman, S., "Performance of Aluminothermic Welds Under High Axle Loads," *Proceedings of the 4th International Heavy Haul Railway Conference*, Brisbane, Australia, 1989, pp. 180-187.

20. Schroeder, L. C. and Poirier, D. R., "The Mechanical Properties of Thermite Welds in Premium Alloy Rails," *Materials Science and Engineering*, 63 (1984), pp. 1-21.

21. Lonsdale, C. P., and Lewandowski, J. J., "Fracture Toughness of Thermite Rail Weld Steel," *Proceedings of the 39th Mechanical Working and Steel Processing Conference-International Symposium on Rail Steels*, Indianapolis, IN, October 21, 1997, pp. 1083-1090.

22. Bassim, M. N., Personal communication letter to C. P. Lonsdale, 1996.

23. Fry, G. T., "A Modified Thermite Rail Welding Procedure," Association of American Railroads Report No. R-826, Chicago, IL, September 1993.

24. Liu, W., Sun, J., and Markase, M. J., "Progress on the Development of a Squeeze Thermite Process*," Proceedings of the International Symposium on Rail Steels*, Baltimore, MD, October, 1994, pp. 145-153.

25. Siska, P. C., "The Effect of Sonic Power Vibrations on Solidifying Thermit Welds," M. S. Thesis, The Ohio State University, Columbus, OH, 1980.

26. Lonsdale, C. P., "An Evaluation of Grain Refinement Techniques in Thermite Rail Welds," M. S. Project, Case Western Reserve University, Cleveland, OH, 1993.

27. Kristan, J. and Garcia, G., "Evaluation of Thermite Weld Treatments," *Technology Digest TD-97-046*, Association of American Railroads, Pueblo, CO, December, 1997.

28. Schroeder, L. C. and Poirier, D. R., "Improving the Structure and Properties of Thermite Weld Metal," *Materials Science and Engineering*, 63 (1984) pp. 23-33.

29. Gianetto, J. A. et al., "Influence of EMS on Rail Thermite Weld Structure and Properties," *Proceedings of the 39th Mechanical Working and Steel Processing Conference-International Symposium on Rail Steels*, Indianapolis, IN, October 21, 1997, pp. 1091-1099.

30. Lonsdale, C. P. and Bassim, M. N., "Conrail Field Testing of the Acoustic Emission In-Process Weld Monitoring System," *Proceedings of the 11th Annual North American Welding Research Conference*, EWI, Columbus, OH, November 7-9, 1995, pp. 411-427.

31. Lonsdale, C. P. and Jarmasz, M., "Further Studies of Thermite Rail Welds Using Acoustic Emission Monitoring Techniques," Proceedings of the International Conference on Advances in Welding Technology, EWI, Columbus, OH, September 17-19, 1997, pp. 461-468.

32. Fry, G. T. and Lawrence, F. V., "A Fatigue Model for Thermite Rail Welds," *Report No. 170/UILU ENG-95-4005*, University of Illinois at Champaign-Urbana, April, 1995.

33. Carpenter, G. F., Markase, M., Jha, B., "Improvement of Rail Thermite Weld Properties by Oxy-acetylene Gas Normalization," Association of American Railroads Report No. R-821, Chicago, IL, December, 1992.

34. Del Vecchio, Mike, "Apples and Oranges: Advances for both welding methods," *Railway Track and Structures*, Vol. 93, No. 1, January, 1997, pp. 21-27.

35. Lonsdale, C. P., "Evaluation of the Head Repair Weld Thermite Rail Welding Process," *American Railway Engineering Association Bulletin*, Vol. 96, No. 751, May, 1995, pp. 211-225.

36. Lonsdale, C. P., et al., "Use Of the Wide Gap Thermite Weld For Repair of Selected Rail Defects," Submitted to the *American Railway Engineering and Maintenance of Way Association Bulletin*, July, 1998.

37. Brave, G., "FAST/HAL Rail Weld Performance*," Proceedings of the Workshop on Heavy Axle Loads*, Pueblo, CO, 1990, pp. 11(1)-11(11).

38. Oderio, J. A., "A Metallurgical Study of the Detail Fracture in Thermite-Welded Railroad Rails," M. S. Thesis, The University of Illinois at Champaign-Urbana, Urbana, IL, 1992.