WELDING FOR THE RAILROAD INDUSTRY

By Brian Meade
Manager of Railroad Technical Services
The Lincoln Electric Company
Cleveland, Ohio

To meet their demanding service conditions, railroads continue to advance welding technology.

There are several distinct differences between railroad welding and that of other industries. The bulk of all railroad welding is performed by either the engineering (track) department or the mechanical (car) department. Welding in the car and locomotive department generally uses the common arc welding processes to join materials such as mild steel, stainless, cast iron, and some manganese. The track department, however, is far more unusual and uses fewer, more specialized types of welding.

The most common track welding functions are electric arc, thermite, and flash butt. Standard arc welding processes such as SMAW, GMAW, and FCAW are used to weld manganese and carbon steel track components. However, thermite and flash butt are used for joining continuous welded rail. The flash butt method is used in the plant to create quarter-mile ribbon rails, which are then transported by a rail train to the location where they will be installed. Both flash butt and thermite (sometimes known as aluminothermic) are then used in the field, to join the larger lengths of rail together into continuous welded rail. They are also used in maintenance welding for replacing defective rail and for light construction.

Following are some of the considerations that separate railroad welding from other fields. Most of the differences occur in the welding of rails and other track components, such as frogs
(the parts of switches where the two tracks join) and crossing diamonds. Therefore, this article will focus most heavily on this area.

Classes of Rail Welding

**Thermite Welding** is a process that joins rail ends by melting them with superheated liquid metal from a chemical reaction between finely divided aluminum and iron oxide. (Fig. A5—from AWS D15.2). Filler metal is obtained from a combination of the liquid metal produced by the reaction and pre-alloyed shot in the mixture.

**Flash Butt Welding** is a resistance welding process that produces a weld at the closely-fit surfaces of a butt joint, by a flashing action followed by the application of pressure after heating is substantially completed. Very high current densities at small contact points between the rail ends causes the flashing action, which forcibly expels the material from the joint as the rail ends are moved together slowly. A rapid upsetting of the two workpieces completes the weld.

**Electric Welding** refers to the standard arc welding processes used elsewhere, particularly shielded metal arc welding (SMAW) or “stick welding (Fig. A1-- from AWS D15.2); gas metal arc welding (GMAW) (Fig. A2 --from AWS D15.2); and flux-cored arc welding (FCAW), with or without additional gas shielding (Fig. A3-- from AWS D15.2.) These processes are used on frogs and crossing diamonds (both manganese and carbon steel); for carbon steel rail ends, switch points, and wheel burns; and for joining carbon steel rails.
Rail Service and Chemical Composition

Part of what makes rail welding different from other welding is the composition of the rail. Carbon content limits are 0.72% to 0.82%, while manganese can range between 0.80% and 1.10%. Rail is subjected to continually varying loads, forces and stresses, in all kinds of temperatures and environments, and must carry out its task without failure for many years. Service demands on modern rail continue to become more severe, with loaded freight cars approaching 286,000 pounds. Wheel loads may reach 36,000 pounds, applied to a contact patch approximately the size of a dime. The resulting contact and shear stresses are severe, both in and on the railhead.

While the first cast iron rail was produced in England in 1776, modern steel rail incorporates steelmaking techniques such as vacuum degassing and multiple-station argon gas stirring. Continuously cast, fully pearlitic, in-line head hardened rail is now being produced with head hardness values exceeding 380 Brinell.

The result of these improvements is rail with better static and dynamic properties, in addition to more metallurgical cleanliness. The chemical composition limits for standard steel rail are shown in the AREA (American Railway Engineering Association) Manual for Railway Engineering (Table 2-1, Chapter 4, AREA Manual).

Related mechanical properties are also spelled out in the AREA manual (Table 2-2, Chapter 4). These include a surface hardness of at least 300 Brinell for standard rail and between 341 and 388 Brinell for high-strength rail (alloy and heat-treated). The 388 Brinell upper limit may be exceeded, providing a fully pearlitic microstructure is maintained. Tensile properties required include a minimum yield strength of 70 ksi for standard rail and 110 ksi for high-
strength rail; tensile strength minimums of 140 ksi and 170 ksi respectively; and minimum elongation in 2 inches of 9 percent for standard and 10 percent for high-strength.

**Thermite Welding**

Although widely used in the railroad industry, thermite welding is probably one of the least understood processes in the balance of industry. Developed as an improvement to the earlier practice of bolting rail joints together, thermite welding still produces some closures with impact and fatigue properties that may be less than desirable. A 1996 Conrail¹ study showed that, in 1994, 26.5 percent of total rail defects were attributable to weld failures, 18.3 percent were due to defective thermite welds and 8.2 percent were due to defective flash butt welds. However, the portability, cost-effectiveness, and convenience of thermite welding results in its continued extensive use.

Thermite welds are actually as much a casting as they are a weld, and consistency may be difficult to achieve. Weld charge manufacturers have made significant improvements to thermite weld quality and hardness in recent years. Comparisons of welds made using thermite charges from two suppliers showed that the premium charges of one firm were typically harder and stronger than the standard charges produced by the other, although there was a substantially greater spread in the strength values obtained with the first firm’s welds. Thermite weld charge manufacturers can provide a variety of weld hardnesses, depending on customer needs. Higher hardness is deemed to be better, considering the desire of the railroads to have the rail last longer under increasingly severe axle loadings and tonnages. The higher hardness also improves fatigue and deformation resistance and more closely matches the hardness of new head-hardened rail,

---
which approaches 400 Brinell. Harder welds also stand up better to heavy traffic and help prevent localized railhead depressions and deformation at the weld.

   Aluminum plays a key role in thermite welding, where it not only reacts with iron oxide to provide the original heat for welding but also serves as a deoxidizer in the weld charge. Here, it tends to react with oxygen in the still-liquid casting as it solidifies, reducing weld porosity and increasing tensile strength. However, too much aluminum will embrittle the steel. To ensure weld quality and consistency, it is important to control all weld charge alloying elements and residuals to keep them within specifications.

   Many variables can affect the properties of welds produced by thermite field welding. Among them are welding procedures, including the amount of gap, preheat, rail movement, rail end cleanliness, weather during welding, crucible cleanliness, and welder skill.

   **Flash Butt Welding**

   Because aluminothermic rail weld failure rates tend to increase with higher axle loads, railroads are looking for viable alternative rail welds. In-track flash butt rail welding has gained great acceptance as an alternative. The process has proven to make strong, reliable welds in field conditions. However, because rail steel is consumed during the course of the process, in-track flash butt welding cannot presently be used as an alternative for all in-track applications.

   The flash butt welding process originally was developed in the former Soviet Union. However, it was improved and perfected in the U.S. by the Holland Company, a major flash butt welding contractor and builder of flash butt welding equipment. Large fixed plant flash butt rail welding plants are commonly used on major railroads units, but mobile truck-mounted units (Fig. 6) can also take the equipment directly to the weld site. A typical unit aligns the rail ends, charges them electrically, and hydraulically forges the ends, melting the two ends together. The
welderhead automatically shears upset metal to within 1/8" of rail profile. A base grinder then removes the 1/8" flashing material, leaving a smooth base and reducing the likelihood of stress risers that could shorten the life of the rail. A magnetic particle inspection, in addition to visual inspections, verifies the quality of the final weld.

The flash butt welding process tends to produce a weld with a heat-affected zone that is much narrower than that of a typical thermite weld (Fig.7). This also results in a more consistent Brinell hardness profile across the finished weld, which signifies a lack of hard or soft spots that can cause welds to deform and ultimately fail.

**Electric Arc Welding of Frogs and Crossing Diamonds**

The extra stresses incurred by frogs and crossing diamonds require a material with high strength and durability, and one that will resist failure under impact and heavy loading. To achieve these properties, they are typically cast from austenitic manganese steel, an extremely tough, nonmagnetic alloy with unique properties that differ from common structural and wear-resistant steels. One of these properties is its capacity for work hardening at the surface under impact while the underlying body retains its original toughness. Metal-to metal wear resistance is excellent, which is essential in rail applications.

For trackwork castings, AREA requires conformance with ASTM A128, *Standard Specification for Steel Castings, Austenitic Manganese*, except for slightly modified chemical requirements that include:

<table>
<thead>
<tr>
<th>Element</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>1.00/1.30%</td>
</tr>
<tr>
<td>Manganese</td>
<td>12.00% minimum</td>
</tr>
<tr>
<td>Silicon</td>
<td>1.00% maximum</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.07% maximum</td>
</tr>
</tbody>
</table>
The high manganese content stabilizes the austenite by retarding its transformation to other structures. Silicon acts mainly as a deoxidizer, while phosphorus is limited because it tends to promote hot cracking, during casting as well as in subsequent welding operations.

Other than these special limits, the metallurgy of cast rail components is similar to other austenitic manganese castings. Understanding the basic metallurgy of this material will make it easier to relate to the special aspects of welding it. At high temperatures, the structure of all types of steel is essentially austenitic. Although most carbon and alloy steels transform to other structures as they cool, the addition of large amounts of manganese combined with sufficiently fast cooling suppresses this transformation. Manganese steel castings may be relatively brittle before heat treatment, as normal cooling rates in the mold are too slow to retain a fully austenitic structure. This is rectified by heating and holding at the appropriate austenitizing temperature (generally 1850 to 1950 F), then quenching in cold, agitated water. Proper procedures are important, since either inadequate austenitizing or too slow cooling can result in excessive carbides that will lower the mechanical properties.

Reheating of manganese steels can also cause carbide precipitation and resulting embrittlement, with the degree depending upon both exposure time and temperature. Thus, it is necessary to use welding procedures that will minimize or avoid prolonged overheating.

This and other considerations make electric arc welding of manganese frogs an area that can sometimes confuse a newcomer to this field. Without the ability to properly focus on all data generated by the manufacturer of welding materials, the weldor can easily be perplexed by the erratic results achieved with different welded track castings. The difficulty can arise from a number of areas.
Lincoln Electric conducted a study of manganese frog welding failures in October, 1996. A team of engineers, assembled to evaluate weld metal fatigue in a #10 rail bound manganese casting, studied these areas:

- Number of times welded
- Gross MGT (million gross tons/year) on track segment
- Age and type of castings
- Welding procedure
- Welding materials composition
- Composition of the base casting

There have been claims of premature cracking in weld deposits made with manual electrode and wire on frog castings for nearly 60 years. Lincoln Electric has recorded data from 1937 that supports the usage of a manganese-based formulation in a product developed to rebuild manganese frog castings. At that time, Lincoln supplied a 12-14% manganese electrode to the railroads along with a stainless electrode to seal cracks that were in the original castings. The stainless steel electrode was used only in the flangeways and deep in the bottom of the casting, prior to buildup with the manganese-based electrode. The 1996 study supported the earlier data and also yielded some interesting conclusions for improvements in the technique used.

The as-received casting is shown in Fig. 1. A closeup view of the cracking area is shown in Fig. 2. Sections AA and BB were made with a carbon arc torch to remove the cracked portion for further study.

Sections CC and EE in Fig. 3a were made to study the region near the point that seemed to be free of cracks on the surface. Cracks were observed in the base metal and in the weld. The morphology of the cracks indicates that the preexisting cracks in the base metal have grown into
the weld during or at the end of welding, and these have subsequently opened up under load in
service (Fig. 3b and 3c). In addition, the presence of a repair weld near the base metal can be
seen in Fig. 3b. This was identified as a 312 stainless weld, which was put down to repair cracks
in the base casting prior to building up with a manganese electrode.

The cracks in the base casting follow the austenite grain boundaries, as shown in the
higher magnification view, Fig. 3d. As they grow into the weld, they continue along the
austenite grain boundaries as seen in Fig. 3e. A full section of the weld with the whole casting
(Section EE) is shown in Fig. 4a. As is evident, there are cracks in the base metal that
subsequently run into the weld metal (Fig. 4b). Based on this evidence, this cracking
phenomenon appears to be a form of hot cracking.

Sections FF, GG, and HH were taken in the cracked region (Fig. 5a). Section GG is
shown in Fig. 5b and indicates that the cracks at the top have opened up under the loading during
service.

**Conclusions for Improving Weld Repair Performance**

In summary, the welding in this example was done in a situation that caused hot cracking.
Chemical analysis reveals that the phosphorus level in the base casting is somewhat on the high
side. The effect of phosphorus in causing hot cracking is well known (See AWS D15.2 Annex B
for discussion of phosphorus under B2 and B6.2).

The evidence of the stainless bead (used to seal a crack prior to buildup with manganese
electrode) shows that the cracks in the base casting grew along the austenite boundary until they
reached the stainless deposit. This deposit retarded the growth of the cracks and protected the
weld deposit. Changing the technique to include a light layer of 308L or 312 stainless steel can
only improve the performance of the weld repair. Lower heat input while welding can help reduce hot cracking. Wirefeed welding processes that favor lower heat input are highly recommended, as opposed to “stick” welding. Lincoln Electric continues to conduct experiments to determine whether manganese electrode deposit chemistry can be further optimized to provide greater resistance to weld cracking growing from preexisting cracks in the base casting.

#     #     #