Principles

of

Thermite Rail Welding

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History of Thermite Welding

First patented by Prof. Hans Goldschmidt in 1898.

Since - applied to welding, foundry and smelting industries.

Thermite welding adopted by railroads in 1916.

First thermite closure welds made in US 1937.

Primary application – railroad industry- join and repair rails in the field.

Application widespread since large scale adoption of continuous welded rail.

A German professor in chemistry, Hans Goldschmidt, developed the thermite reaction process on a commercial scale and incorporated the important development of starting the reaction with a fuse instead of heating the whole reaction charge.

By the early 1900's the Thermite Welding Process was already firmly established in Germany, Great Britain and France for smelting, tramway rail welding, and the welding of heavy machine parts.

Many welding processes have been used for joining rails:

1. Arc Welding.
2. Friction Welding.
3. Electron Beam.
4. Laser Beam Welding.

Today – most common rail welding techniques:

1. Thermite Welding.
2. Flash butt welding.
3. Oxyacetylene gas pressure welding.
4. Enclosed arc welding.

Electric flash butt welding and oxyacetylene gas pressure welding are often employed in fabrication shops and in the field.

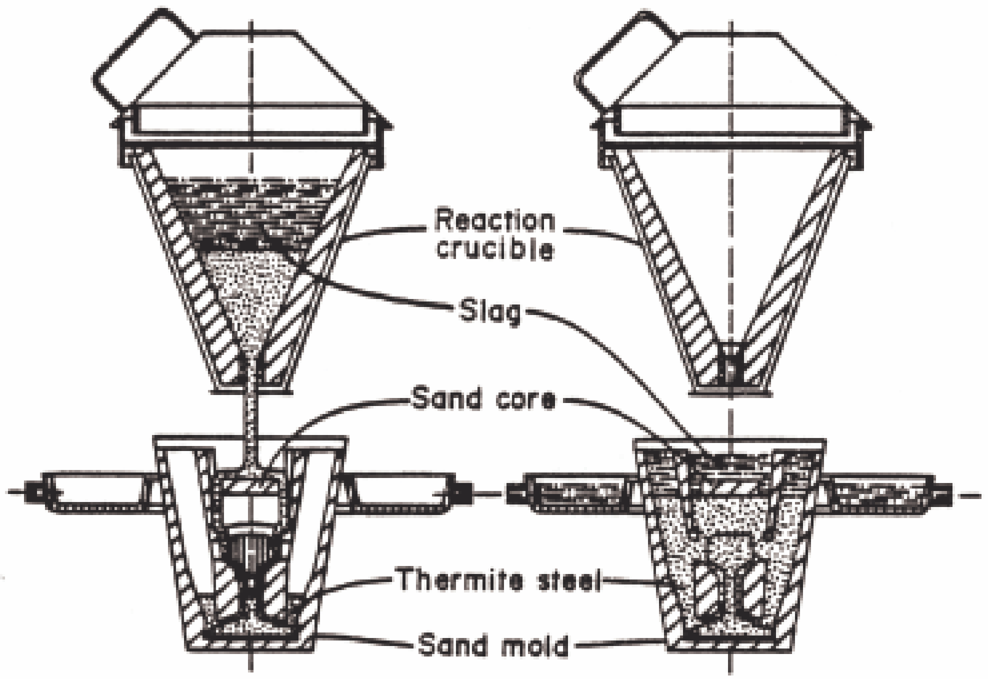
Thermite welding is most common method used in the field.

- **Thermite Welding is a process that produces fusion of steels by heating them with superheated molten metal, obtained from the Alumino-thermic (Thermite) reaction between a Metal Oxide and Aluminum.**

- **Filler material is obtained from the liquid steel.**

- **The work pieces are preheated to provide conditions for full fusion welds between the molten metal and the base metal.**

- **Schematic of a Thermite Rail weld**



Characteristics of Thermite Welding

1. **Similar to a casting process- two rail ends form part of mold wall.**
2. **Coarse grained dendritic microstructure are present in all Thermite welds.**
3. **As a result of this microstructure -**
   - **Fracture toughness and fatigue resistance lower than other types of rail welds.**
   - **Portability and simplicity lead to continued importance in the railway industry.**

Wide application has led to:

1. Active research area in railway industry.
2. Increases in train speed and axle load- stronger demand for railway industry to improve quality and reliability of thermite welds.

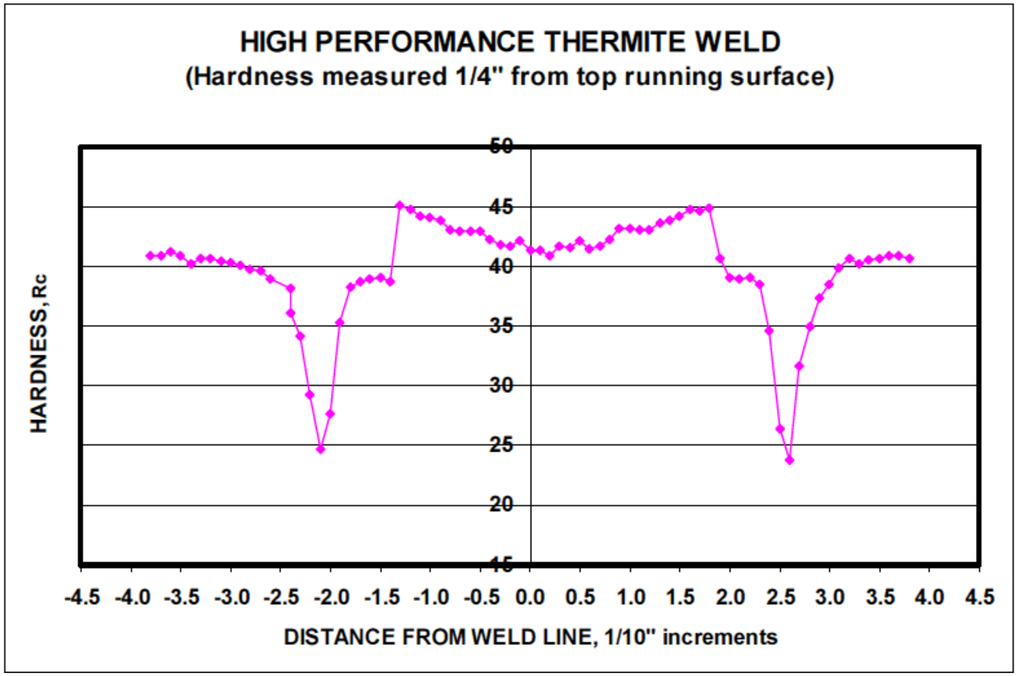
Tensile properties and Impact toughness.

1. **Yield Strength- Comparable or slightly lower than rail.**
2. **UTS- normally lower than rail.**
3. **Most noticeable difference between rail and weld is ductility, both % elongation and % reduction in area is lower in the weld.**
4. **Impact toughness of the weld about half the value of parent rail.**

Hardness.

1. **Compared to base metal the hardness of a weld is normally higher.**
2. **Peak hardness found inside the H.A.Z.**
3. **Region next to the peak hardness is softer than both base and weld metal.**
4. **Standard Rail: Max HAZ = 32 HRC Min HAZ = 20 HRC**
5. **Alloy HH rail: Max HAZ = 45 HRC Min HAZ = 23 HRC**

Typical hardness profile across a head alloyed Thermite weld



Chemical Composition:

Typical chemical composition of parent rail and thermite weld.

- No significant difference in chemical composition except Al content in weld is higher, and Si content is higher when employing Silica base crucibles.

	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Al
Rail	0.8	0.8	0.02	0.02	0.16	0.01	0.05	0.01	0.02	0.006
Weld	0.7	0.8	0.024	0.006	0.23	0.02	0.04	0.01	0.04	0.3

Fatigue performance.

1. **Cyclic loads under train traffic makes fatigue performance most critical issue for railway industry.**
2. **Fatigue strength 180 – 210 MPa**
3. **Different rail qualities can lead to different fatigue responses.**
4. **External geometry of the weld an important factor for fatigue performance.**
5. **External weld geometry and internal microstructural imperfections cause stress concentrations.**

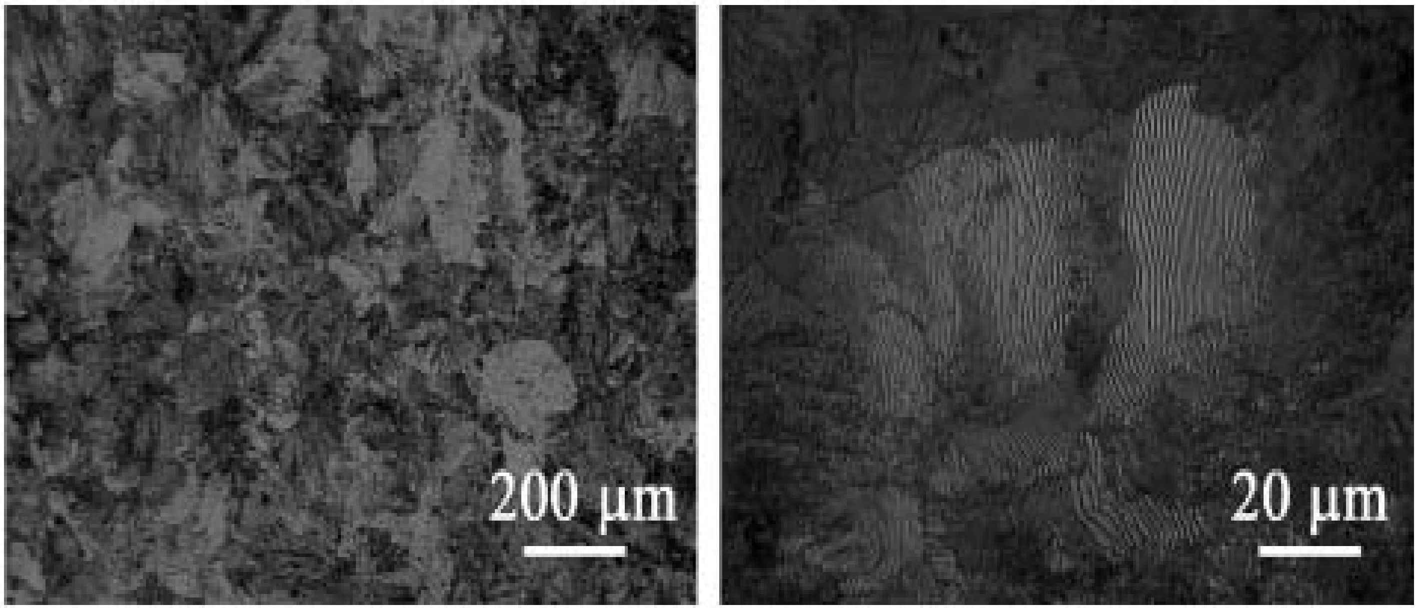
Microstructure of the weld metal:

Typical casting microstructure- large grain size, coarse dendrite branches, inter-dendritic segregations and micro-porosity is responsible for weaker mechanical properties.

3.14.3.6 Weld Microstructure

The presence of martensite is not acceptable at any location in the weldment.

Typical micro-structure of Thermite weld metal.

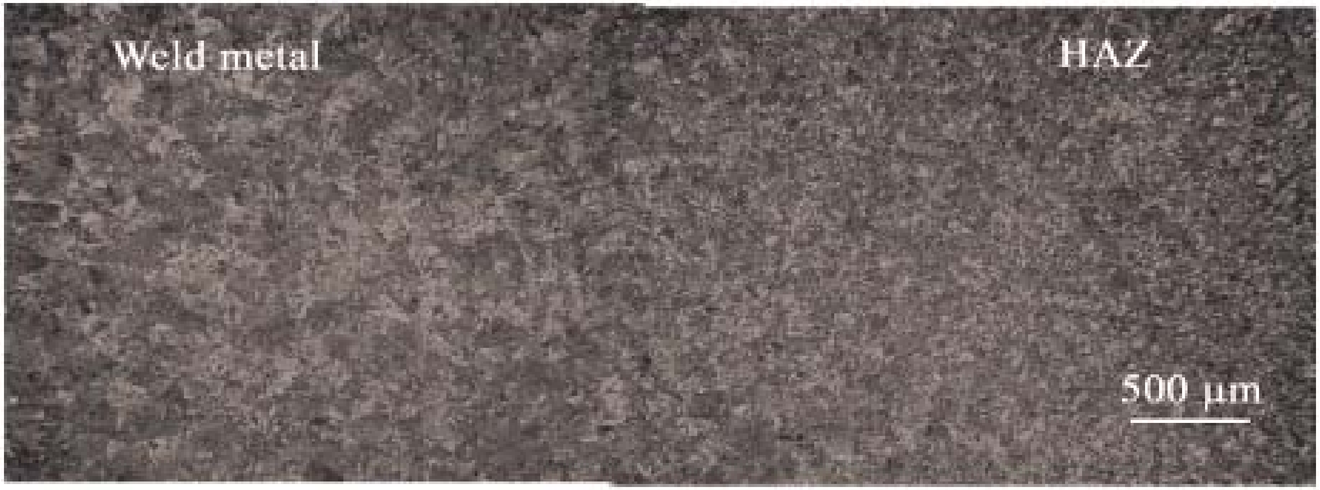


Thermite weld metal has a predominantly pearlitic microstructure.

3.14.4.6 Weld Microstructure Testing

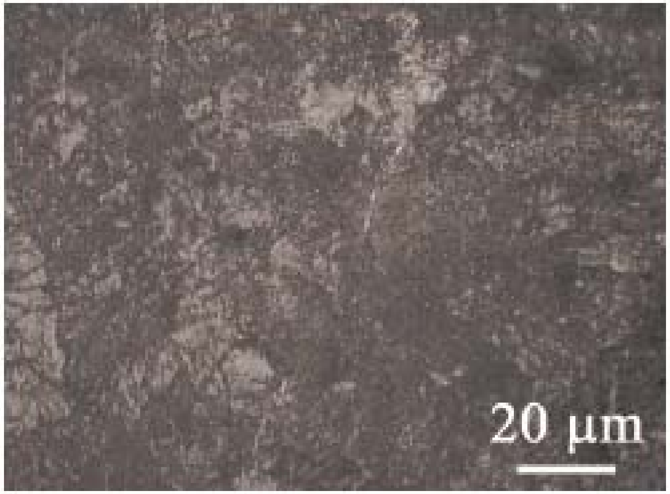
If weld metal hardness exceeds 410 BHN, the weld shall be examined at 100X or higher for confirmation of a fully pearlitic microstructure.

Microstructure of the HAZ

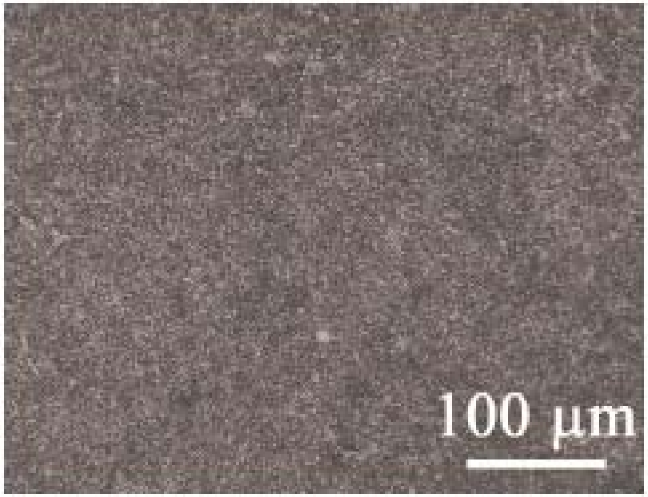


Interface between weld metal and the HAZ

Grain coarsening and a fine pearlite structure exist in the HAZ area.



Fine pearlite structure in the HAZ



Spheroidized pearlite at the outside boundary of the HAZ

Thermite Welding – Valuable technique for railway industry.

Main advantages:

1. Low capital investment in equipment and materials.
2. In situ welding – no electrical power source required.
3. Relatively robust unsophisticated equipment.
4. All rail steels can be welded.
5. Different rail profiles and rail steel chemistries can be welded to each other.
6. Good portability and simplicity.

Rail Thermite Welding

Basic requirements of Thermite reaction for rail welding:

1. **Produce filler material – match composition of rail steel.**
2. **Energy released from the reaction – bring products to liquid state for slag separation.**

Exothermic chemical reactions to form iron (Fe):

$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3 + 200\ kcal$

$3FeO + 2Al \rightarrow 3Fe + Al_2O_3 + 210\ kcal$

$3Fe_3O_4 + 8Al \rightarrow 9Fe + 4Al_2O_3 + 800\ kcal$

Theoretical maximum temperatures (Degree C)

Table 1. Aluminothermic reactions in rail thermite welding.

Reaction	Heat generation (kJ / mole of Alumina) [Messler 1999]	Theoretical max temp. (°C) [Welding Handbook 1976]
$3/4Fe_3O_4 + 2Al \rightarrow 9/4Fe + Al_2O_3$	838	3,088
$3FeO + 2Al \rightarrow 3Fe + Al_2O_3$	880	2,500
$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$	860	2,960

Iron and fluid slag production by the Alumino-Thermic reaction

$$Fe_2O_3 + 2\,Al \longrightarrow Al_2O_3 + 2Fe + \text{Heat (200 kcal)}$$

Final steel production by Ferro alloying additions

Add to the Fe, alloys, master alloys and/or micro-alloys as required to produce a specific steel chemistry.

Various steel grades (Ferritic, pearlitic, cementitic, bainitic, or austenitic manganese steels) can be produced.

Final pouring temperature around 3800 degrees F.

Steel yield around 52%, balance is Alumina slag.

- **The metallurgy of the Thermite reaction must be considered, and this may be divided into two aspects:**

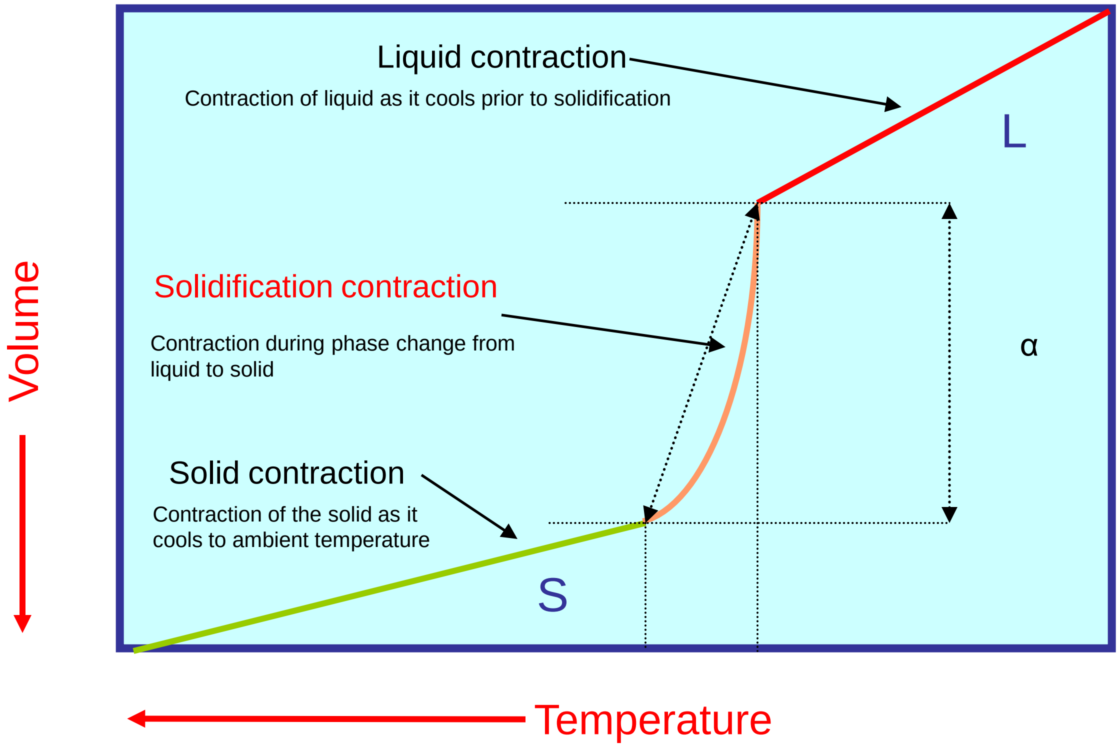
- The proper **de-oxidation** of the Fe producing process is a very important quality requirement.
- **Addition of various different alloying and micro alloying elements**, to improve the physical properties of the final steel producing process, and the final steel quality that must be compatible with the base metal metallurgy to be welded.

Physical properties of thermite steel

Influenced by:

1. **Chemical composition**
2. **Rate of cooling from austenitic range of temperature which affects:**
   - **Metallurgical microstructure**
   - **Grain size**

Mold and riser design considerations

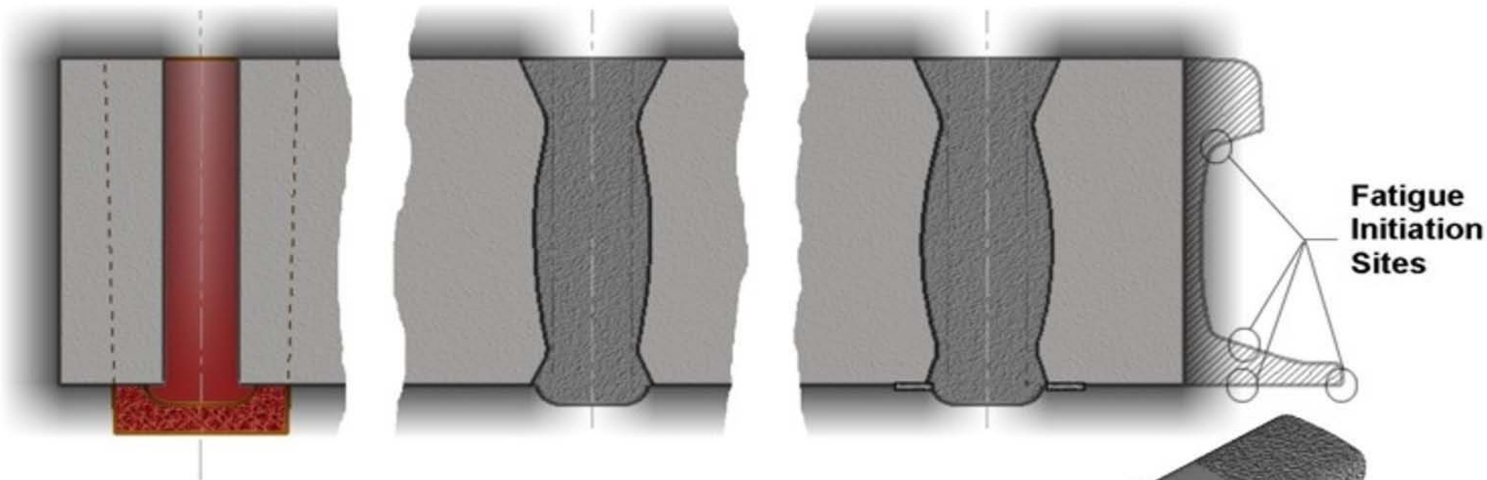


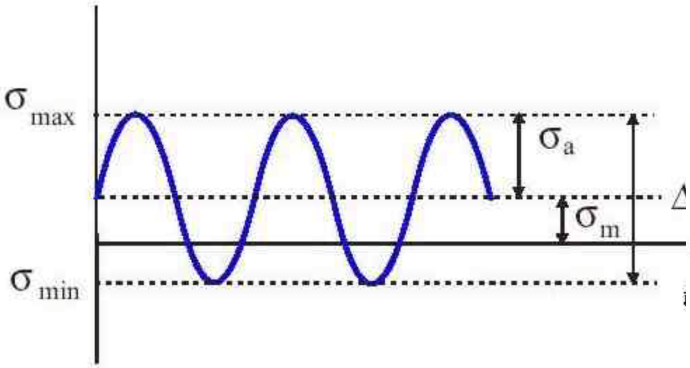
There are three types of shrinkage: *shrinkage of the liquid*, *solidification shrinkage* and *patternmaker's shrinkage*. The shrinkage of the liquid is rarely a problem because more material is flowing into the mold behind it. Solidification shrinkage occurs because metals are less dense as a liquid than a solid, so during solidification the metal density dramatically increases. Patternmaker's shrinkage refers to the shrinkage that occurs when the material is cooled from the solidification temperature to room temperature, which occurs due to thermal contraction

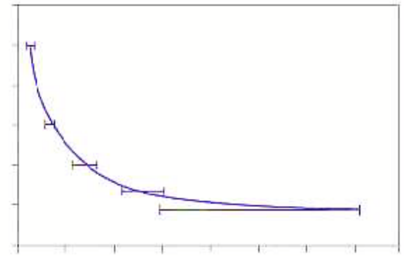
Quality Control

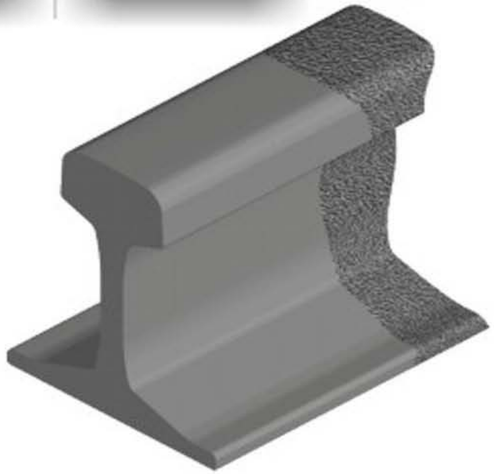
- **The aspect of physical weld properties leads naturally on to the consideration of quality control of Thermite welds which must be divided in 2 categories:**
  - Control of the raw materials and consumables.
  - Establishment and control of a suitable welding procedure for the specific rail steel grade to be welded

Testing of Thermite welds





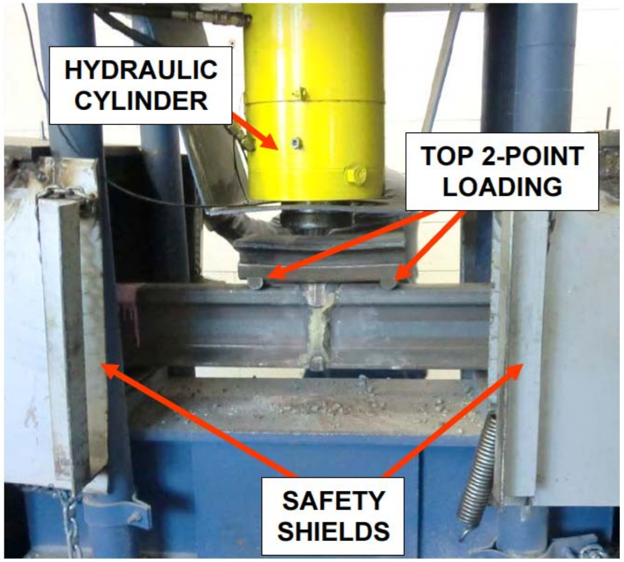




Tests performed on welds for qualification

- **Metallurgical tests** – Macro and micro examinations, cleanliness of steel measurements, phase transformations, microstructure, inclusion counts, grain size measurements, fracture toughness, impact and strength tests.
- **Chemical tests – Wet, OES, AA**
- **Fatigue tests –**Rolling load machine or Repeated loading test
- **Residual Stress Measurements-** strain gauges
- **Hardness tests** – Macro and micro hardness
- **Destructive tests** – slow bend fracture load, drop test and deflection (ductility) test
- **Non destructive testing-** ultrasonic, magnetic particle, X Ray and/or gamma ray.
- **In –track testing** with heavy axle loads (315 000 lbs. cars)

Destructive tests are performed during the manufacturing of the Thermite Welding Powders to assure the quality of the powders.



- Welded rails are fractured in a bending press with the rail supported across a span of 36” or 48”. Rail head in compression and base in tension
- Break loads and deflections are measured and recorded and must meet industry specifications.

4 Point slow bend results.

Rail Grade	Modulus of Rupture	Deflection
Standard Carbon	110,000 psi minimum	0.90 inch minimum
High Strength	120,000 psi minimum	0.60 inch minimum

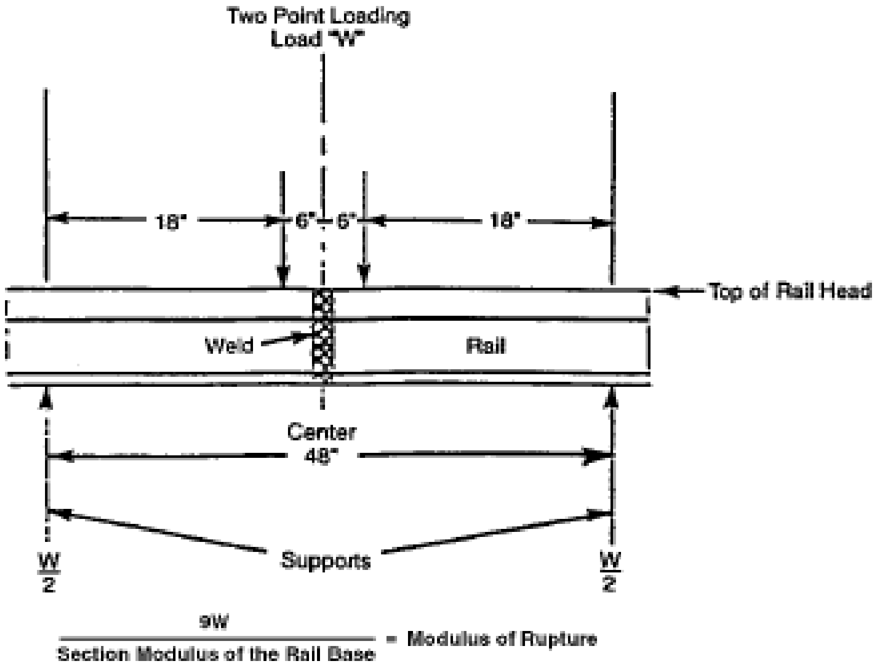
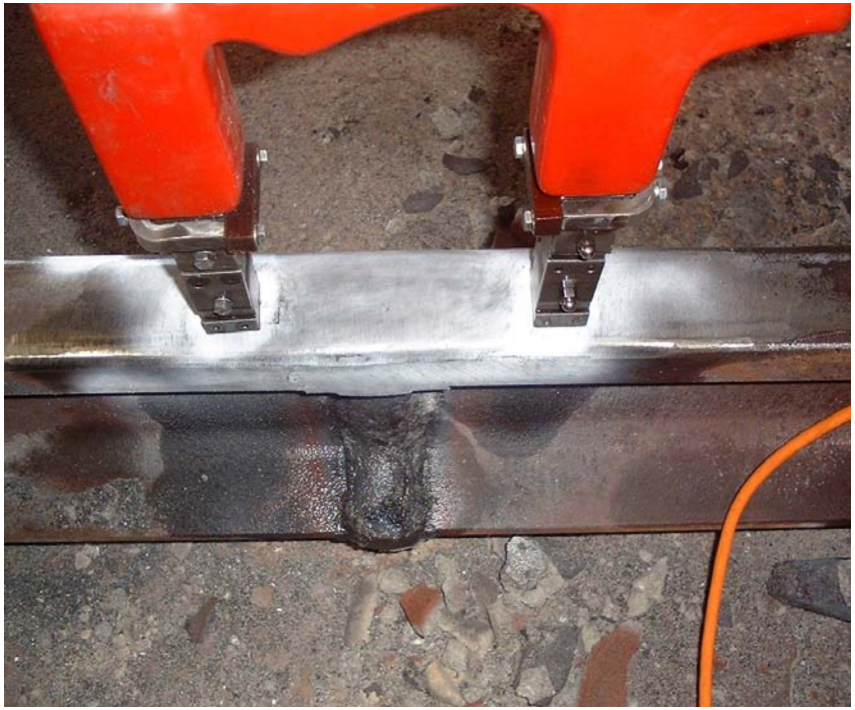


Figure 4-3-18. Loading Arrangement for the Slow Bend Test for Deriving the Modulus of Rupture

After 4 Point slow bend test.

Non Destructive Testing- The welds are tested by means of hand held ultrasonic and or magnetic particle inspection as specified for each job.



Magnetic particle inspection

3.14.3.1 Ultrasonic Acceptance

The weld between the two joining rail ends shall be accepted if it has no reflective surface greater than 1/8 inch.

Ultrasonic testing.

Fatigue Testing

- a Fixture is used to apply cyclic bending loads to the rail with a Thermite weld in the middle. This simulates the weight of a passing train, but not the tractions due to braking and accelerating.
- The results relate to the service life of the welds.

- **Bolted joints leads to in track:**

➢ **Vibration**- rider comfort

➢ **Hammering** (noise) and subsequent deterioration of the rolling stock, rail and sub structures –ballast, ties, fastenings –weld rail continuously.

Benefits of Continuous Welded Rail:

- No wheel battering
- No battered rail ends or bolt holes
- No maintenance of mechanical joints
- Improved road bed
- Improved track circuits
- Better fuel economy
- Quieter train passage
- Smoother ride

Thermite Welding gangs produce thermite welds for several different reasons:

- Repair of rail defects (40 to 50%)
- Insulated joints –new and relay rail
- Relay rail- CWR program
- Road crossing renewal
- Turnouts- new to body of track
- Welding at start or end of rail laying job.

Basic outline of the Thermite rail welding procedure that must be controlled for a particular welding process.

General steps in performing a Thermite Weld:

- Rail end preparation- Cut, clean, gap, alignment
- Fit-up of refractory molds
- Sealing of mold to rail
- Pre-heating
- Ignition and pour of the Thermite steel
- De-molding and shearing
- Surface grinding - finish

Preparation of the rail ends and alignment of the rail:

- Rail ends are cut perpendicular to the rail axis by a rail saw, abrasive disc or torch.
- Important that battered, cracked or worn rail is cut off.
- Cut rail ends should be cleaned by filing or wire brushing to remove surface oxide.
- Rails to be properly aligned with a defined gap width.
- Both rails at the joint should be elevated to compensate for the greater thermal contraction in the rail head than that of the web and base.

Installation of the refractory molds:

- Attach the mold to the rail, and seal the mold to rail with luting sand.

- Ensure the mold interior is clean and free of sand.

Preheating of the rail ends and mold:

- Preheat the rail end and mold sufficiently with an oxygen – propane torch, or a propane/air blower.
- The burner is specially designed to fit in the mold opening.
- The burner height, burner alignment and gas pressures of the preheating gases must be controlled.

Ignite the thermite portion and pour the molten steel:

- **Position the crucible over the mold opening, and then initiate the thermite reaction with an igniter or electronic ignition system.**

- **To ensure a complete reaction and good metal- slag separation, tapping time (time between the ignition and pour) needs to be accurately controlled.**

Strip the weld and finish the running surface:

- Remove the mold after the weld metal is solidified.
- Shear of the excess weld metal using a hydraulic rail shear.
- Grind the running surface to obtain the correct rail head profile.

General Description of the Thermite Welding Process

- **Rail end preparation.**

➢ Fastenings are loosened.

➢ Cleaning of rails ends.

➢ The gap is cut

➢ Alignment of running surface and running edge.

• Attaching the preformed molds.

- Molds for the correct rail size must be used and must be a close fit to the rail.

• Luting of the molds

- Lute the outside area between mold and rail to avoid the danger of a run-out (leak of molten steel).

- **Preheating of the rail ends.**

- The rail ends are preheated for a prescribed time period using oxy/propane at prescribed gas pressures in order to remove all moisture and to get the rail ends to a fusion temperature of around 1000º F.

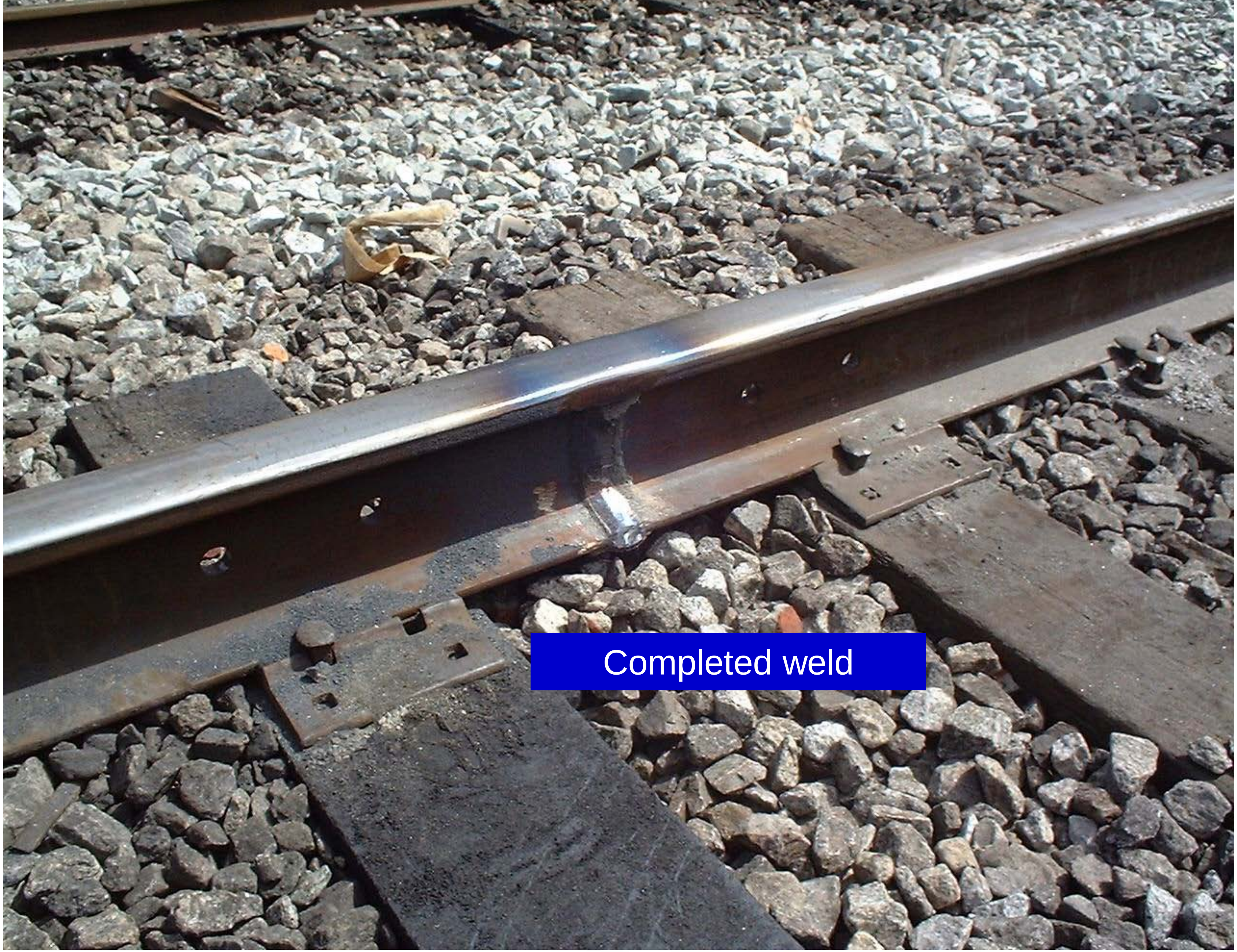
➢Initiation of the chemical reaction with a special igniter after preheating


Thermite reaction initiated
3
3

Casting of the Thermite Steel into the molds between the rail ends

Hydraulic shearing of the excess metal after pouring.


Profile grinding of the weld


Completed weld

Most common
Thermite weld defect types.

Most common defects are:

- **Cold welds** caused by insufficient preheating or welding with small gaps.

- **Porosity** caused by welding in the rain or using wet/damp materials.

- **Pull aparts** caused by high tensile stress in track.

- **Fatigue breaks** poor fit up of molds to rails or poor track sub-surface conditions.

Summary:

- A process typically used to join rails together is the aluminothermic process.
- It is a weld that is very application friendly.
- It is a filler weld metal process that bonds using heat and steel both produced from an exothermic chemical reaction.
- The process has been used to weld rails for about one hundred years.

Thank you