International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 07 | July 2020 www.irjet.net p-ISSN: 2395-0072

# IMPROVEMENT OF THE MECHANICAL PROPERTIES OF RAIL THERMIT WELDS BY HEAT TREATMENT

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**Abstract-** *The focus of the present study is directed towards improving the mechanical properties and microstructure of the rail thermite welds using heat treatment techniques so that better load bearing capacity and service life is achieved. Thermite welding and Flash Butt welding are the two most commonly used methods for welding of rail tracks throughout the world. The Thermite welding process enjoys the advantages of relative simplicity, portability and low cost. With the advent of high speed rails and increased load demands, many researchers have focused on improving the quality of rail welds. Since Thermite welding is basically a casting process, it suffers from the major casting challenge i.e. unrefined microstructure. This can be considerably eliminated by post weld heat treatment. In the present work, 60 kg section of IRS-T-19-1994 rail track weld samples are heat treated by Normalizing. Then the normal samples and heat treated samples are undergone through Tensile test, Bending test and Brinell Hardness Test. The reports of the two weld samples are then compared to analyze the effects of Normalizing on Thermite weld specimen.*

***Keywords:*** Thermite welding, mechanical properties, microstructure, Heat treatment, Normalizing

## 1. INTRODUCTION

### 1.1 Rail Tracks

Rail tracks, also known as the permanent way (P way), is the structure consisting of the rails, fasteners, sleepers, and ballast plus the underlying subgrade. It enables trains to move. Modern track typically uses hot-rolled steel with a profile of an asymmetrical rounded I-beam. The rails are subject to very high stresses and have to be made of very high-quality steel alloy. The stronger the rails and the rest of the trackwork, the heavier and faster the trains the track can carry.
A typical rail track crossection consists of 3 parts- Head, Web and Foot.

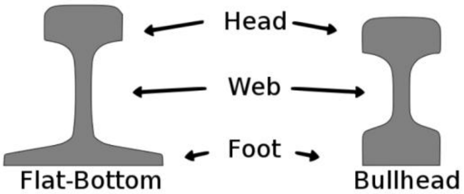


**Fig 1:** Parts of a rail track section (Reference [1])

The rail tracks crossection are classified on the basis of **Weight per meter** like 60kg, 52 kg etc. For the current study, 60kg crossection flat bottom rail track samples are taken for analysis.

Following are the specification of the various section of rail tracks according to the Indian Railway Manual for fusion welding, 1994.

**Table 1:** Specifications of various rail sections (Reference [1])

| Rail Section | Normal Height (mm) | Normal width (mm) |
|---|---|---|
| 60 kg | 172 | 72 |

| | | |
|---|---|---|
| 52 kg | 156 | 67 |
| 90 R | 143 | 67 |
| 75 R | 129 | 62 |
| 60 R | 114 | 57 |

Following is the detailed geometrical specification of a 60kg section rail track.

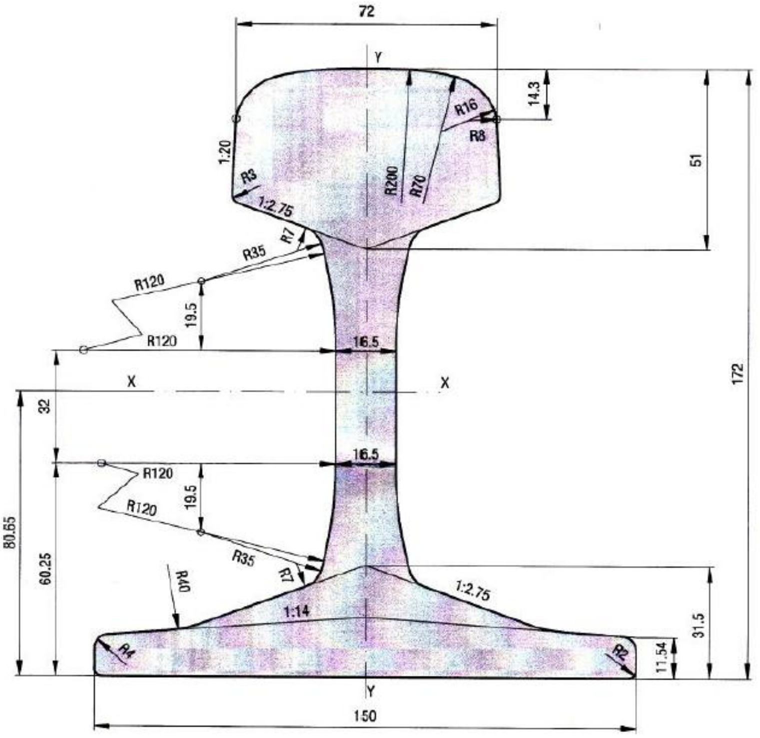


**Fig 2:** Geometrical specification of 60kg rail section (Reference [1])

The rail tracks are made of hot rolled alloy steel. Two **grades** of steels are used**- 880 and 1000**. In our study, the specimens were of the 880 grade steel. 880 represent the Ultimate tensile strength, which is 880 MPa. It bears the IR specification no IRS-T-19-1994. The chemical composition of the rail steel is mentioned below :

**Table 2:** Composition of Rail steel (Reference [1])

| **Constituents** | Carbon | Silicon | Manganese | Sulphur |
|---|---|---|---|---|
| **Percentage by weight** | 0.729 | 0.339 | 1.055 | <0.005 |

### 1.2 Alumino-Thermic Welding (Thermite Welding)

The Thermite welding is based on an exothermic chemical reaction called Alumino-Thermic reaction (Thermite Reaction). This Thermite reaction was discovered and later patented, by German chemist **Dr. Hans Goldschmidt.** It involves an Exothermic reaction of Iron oxide and Aluminum which yields molten iron and aluminum oxide. The Thermite reaction may have following two variations :-

$$\mathbf{Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3 + 759.39\ kJ}$$

$$\mathbf{3Fe_3O_4 + 8Al \rightarrow 9Fe + 4Al_2O_3 + 3009.55\ kJ}$$

(Reference [1])

For welding, the reaction is conducted in a container which is mounted on the top of a mould. The mould is the shape of the desired weldment. In case of rail weld, the mould is of the shape of rail track profile. The reaction is conducted in the container. The heat from the reaction is enough to make the reaction products melt. The molten iron being heavier is collected below and the molten aluminum oxide separates and floats on the top. This molten aluminum oxide acts as slag and prevents molten iron from oxidation. The molten iron is then poured into the mould and the weld is prepared. In this way Thermite welding actually acts like a portable foundry.

### 1.3 Post Weld Heat Treatment

Since Thermite weld is basically a casting process, the microstructure of the weld is similar to cast metal. It has large columnar **Pearlite** grains. This can be improved by heat treatment, such as we do in casting. So we propose to perform post weld **normalizing** on weld samples which can reduce and refine the grain size and improve the mechanical properties like toughness, ductility and tensile strength. Normalizing is done at a temperature of 825°C well into the **Austenite** range for 50 minutes and then the samples is allowed to cool in still air. The properties of the normal and heat treated weld will be then compared by various tests.

## 2. LITERATURE REVIEW

I. **Abdul Zehra Jilabi**, Reference [3], University of Manchester in his thesis *Welding of Rail steels, 2015,* analyzed various Rail welding method including Thermite welding. He conducted Post weld heat treatment on the final joint prepared. Including joint testing, he also did the residual stress analysis, Hardness test and Microscopy. The study concluded that the microstructure improved after heat treatment. Mechanical properties like ductility, toughness, tensile strength increased.

II. **Nikolay A Kozyrev**, Reference [4], Siberian Industrial State University Russia, in his article *Modern Methods of Rail welding, 2017* published in IOP Conf. Series: Materials Science and Engineering, analyzed the Thermite weld which are subjected to induction heating. He suggests problems in Thermite welding can be solved by the fabrication of continuous rail track by compulsory heat treatment of welding joint. Heat treatment is done with induction-heating installation which increases costs. This problem in practice is advised to be solved by combining continuous and pulse flash welding methods, changing the heating rate during welding process and regulating the cooling speed. At that, while partly using continuous flash method, there is a possibility of welding defects.

III. **Besch et al**, Reference [5], filed a US Patent (Patent no. 5306361) titled *Method for improving service life of Rail weld by Aluminothremic Heat treatment*, dated Apr 26, 1994. In this patent, he claimed to have invented a system which can use AT reaction to perform Normalizing on thermite weld on the track itself. He suggests that Normalizing can have positive impact on the grain refinement of the weld microstructure.

IV. **Frederik Hefer**, Reference [6], USA in his article *Rail joining under heavy haul conditions*, published in IHHA 2015, talks about improvement of weld performance by post weld heat treatment. He suggests Heat treatment should be done on both Thermite welds and Flash butt welds. He concludes that Heat treatment can reduce the thickness of HAZ and lower the hardness of HAZ and the weld region.

V. **Dr Ranjanna S,** Reference [7], in her paper *Evaluation of microstructure and mechanical response of thermite welded rail*, IJIRSET, 2013 state heat treatment technique was used improve the mechanical properties and weldment structure. Specimens were subjected to tensile test, Impact test and hardness and their results were tabulated. Microstructural analysis was carried out with the help of SEM. Then analyze to effect of heat treatment on Mechanical properties of their thermite welded rails. Mechanical and microstructural response of heat treated thermite welded rail is higher value as compared to As thermite welded rail.

VI. **Carpenter G. F**, Reference [8], in his paper *Improvement of Rail Thermite Weld Properties by Oxy-acetylene Gas Normalization*, Association of American Railroads Report No. R-821, Chicago, IL, 1992. He took the as produced solidified thermite weld and sought to alter the cast columnar microstructure through heat treatment. The goal was to reduce final 2000 grain size and thereby improve mechanical properties. The solidified weld was heated to about 1450°F 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.

## 3. EXPERIMENTAL DETAILS

### 3.1 Thermite Welding Of Rail Tracks

In standard Rail Thermite welding, the welding procedure includes following steps :-

**i) Joint preparation**

The two rail ends being welded are cut square and carefully aligned and fixed with a gap of about 25 mm between them. This gap is given for contraction allowance. The track faces are cleaned by kerosene using wire brush.

**ii) Mould mounting**

A prefabricated rail section shaped sand mould is then placed around the gap. The mould should be centrally symmetrical to the two tracks. Any gaps sealed luting sand. A slag collector is attached to the mould to collect overflowing slag and molten metal.

**iii) Preheating of mould**

The mould is preheated using a welding torch. Preheating is done to dry the mould thoroughly and to bring the parts to be welded at desired temperature 900$^{o}$C.

**iv) Crucible charging**

Crucible is basically a container in which the exothermic reaction takes place. Then a crucible is placed on the top of the mould. Then thermite mixture is charged into the crucible. The thermite mixture is a combination of **finely powdered aluminum** and **iron (III) oxide** (also called ferric oxide) in a mass ratio of 3:5 respectively. The mixture is poured into a crucible that is placed over the mould.

**v) Igniting of Thermite mixture**

A sparkler is ignited and put into the crucible which starts the reaction. The maximum temperature can reach up to 3500$^{o}$C. This is enough to make the charge melt.

**vi) Pouring**

The tapping pin at the bottom of crucible is removed and the molten steel pours into the mould into the gap to form the weld. The slag which is mostly aluminum oxide requires about 25 seconds after completing the reaction to separate from the molten steel and float to the upper part of the crucible. It prevents the molten metal for atmospheric contamination.

**vii) Opening of mould**

After about 15 minutes the crucible is removed and the mould is opened.

**viii) Finishing of weld**

As the weld cools down to normal temperature in about an hour, a weld is grinded and finished in required shape using a profile grinder.

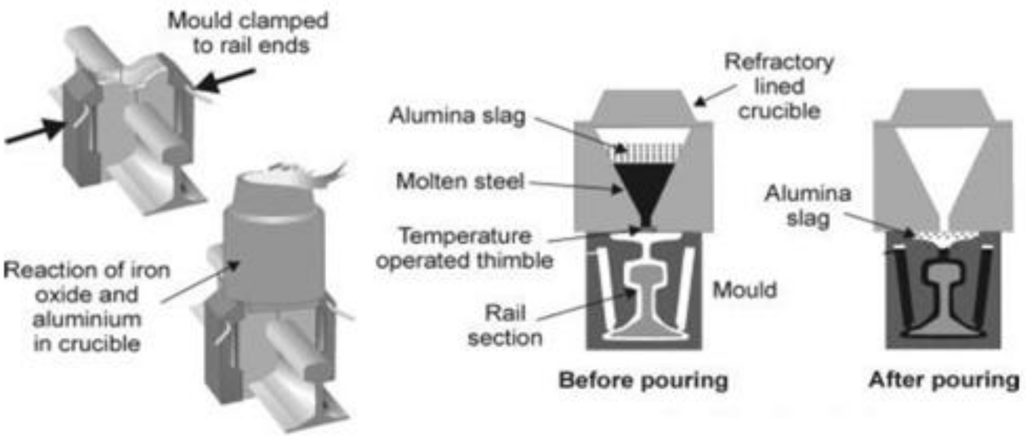


**Fig 3:** Illustrative view of Thermite welding (Reference [2])

**Fig 4:** Installation of mould and crucible

**Fig 5:** Thermite reaction in Crucible

**Fig 6:** Post-weld finishing

**Fig 7:** Final Weld

### 3.2 Sample Preparation

Since we have to conduct heat treatment in a furnace, we had to cut the rail track weld into specimen. The cutting was done using Power Saw. The samples were prepared according to the AWS (American Welding Society) Standard. Each specimen was having a length of **36 inches**. In total, eight specimen were prepared. Four for non heat treated welds and other four for heat treated welds.

**Fig 8:** Specimen cutting

**Fig 9:** Final specimens

### 3.3 Heat Treatment Of Test Samples

A Therelek Sealed Quenched Furnace (SQF) was used to perform normalizing on the rail weld samples. It was a gas fired furnace having maximum temperature range of 1150°C. The hydraulic operated furnace doors were opened. The four weld samples were put into the furnace at once using the cold chain drive. The temperature was set to **825°C** and when the furnace temperature reached the desired temperature, it was maintained at the same temperature for 50 minutes. The auto oil quenching operation of the furnace was turned off. After **50 minutes**, furnace doors were opened and the specimens were brought out. The specimens were allowed to **air cooled** till the temperature reached the room temperature.

**Fig 10:** Sealed Quench furnace (SQF)

**Fig 11:** Specimen coming out of SQF after HT

## 4. TESTING AND RESULTS

### 4.1 Tensile Test

The tensile test was conducted on two non heat treated weld samples and two heat treated weld samples. A Bairoe Universal Testing machine was used for the test. The UTM basically has a puller and a hydraulic strainer. It also has a dial to measure the load. The tensile load is gradually applied on the specimen. The specimen elongates. The load increases till the specimen fails. Two important reading are noted down for every test. The Ultimate Tensile stress (UTS) which represent the strength of weld specimen and Percentage elongation which represents ductility.

**Fig 12:** Universal testing machine used for Tensile test

### 4.1.1 Tensile Test Result For *Non Heat Treated* Weld Specimen

Following are the result of Tensile test conducted on two Non heat treated weld specimen.

**Table 3:** Tensile test result for Non heat treated weld

| Sample No. | UTS (MPa) | Yield Strength (MPa) | Percent elongation |
|---|---|---|---|
| 1 | 632 | 494 | 9.2 |
| 2 | 624 | 492 | 9 |
| Average | 628 | 493 | 9.1 |

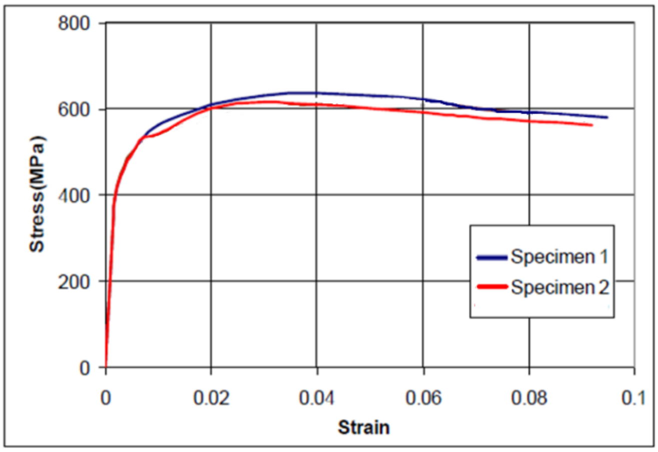


**Chart 1:** Stress vs Strain (Non heat treated weld)

### 4.1.2 Tensile Test Result For *Heat Treated Weld* Specimen

Following are the result of Tensile test conducted on two Non heat treated weld specimen.

**Table 4:** Tensile test results for Heat treated weld

| Sample No. | UTS (MPa) | Yield Strength (MPa) | Percent elongation |
|---|---|---|---|
| 1 | 698 | 512 | 12.2 |
| 2 | 694 | 508 | 10.8 |
| Average | 696 | 510 | 11.5 |

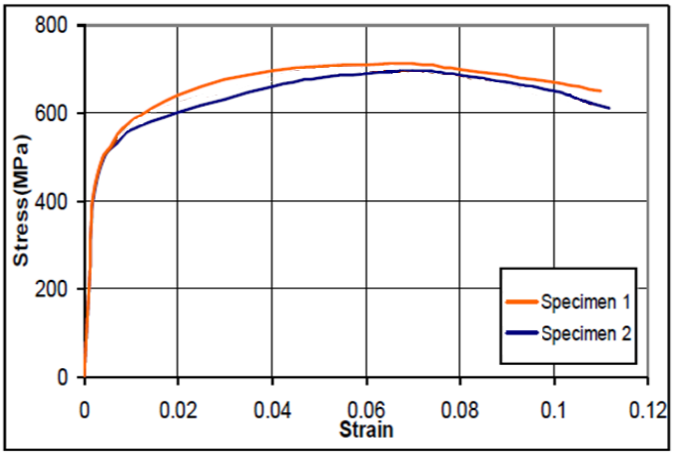


**Chart 2:** Stress vs strain (Heat treated weld)

## 4.2 Bending Test

The Bending test was conducted on one Non heat treated weld sample and one Heat treated weld sample. It was a three point load bending test conducted in accordance to the Indian Railway manual. Two loads were on the extreme acting upwards and one load at the center acting down. The loads were variable increasing gradually till the weld fails.

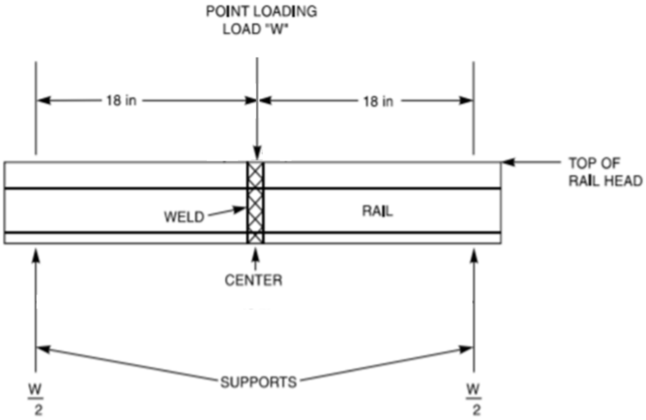


**Fig 13:** Illustration of Bending Test

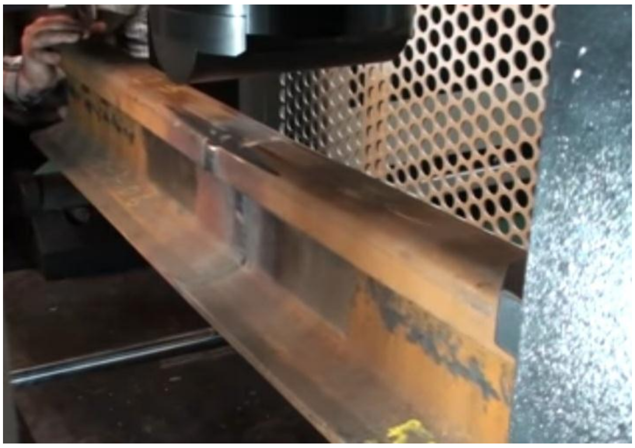
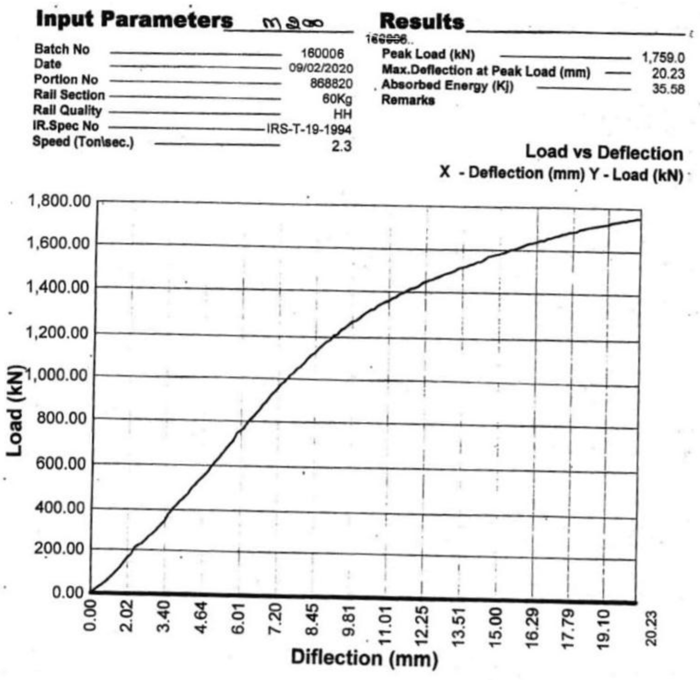


**Fig 14:** Bending Test in lab

### 4.2.1 Bendig Test Result for *Non Heat Treated Weld* Specimen

Maximum load- 1759 kN

Maximum deflection- 20.23 mm



**Input Parameters** [illegible]

Batch No — 160006
Date — 09/02/2020
Portion No — 868820
Rail Section — 60Kg
Rail Quality — HH
IR.Spec No — IRS-T-19-1994
Speed (Ton\sec.) — 2.3

**Results**

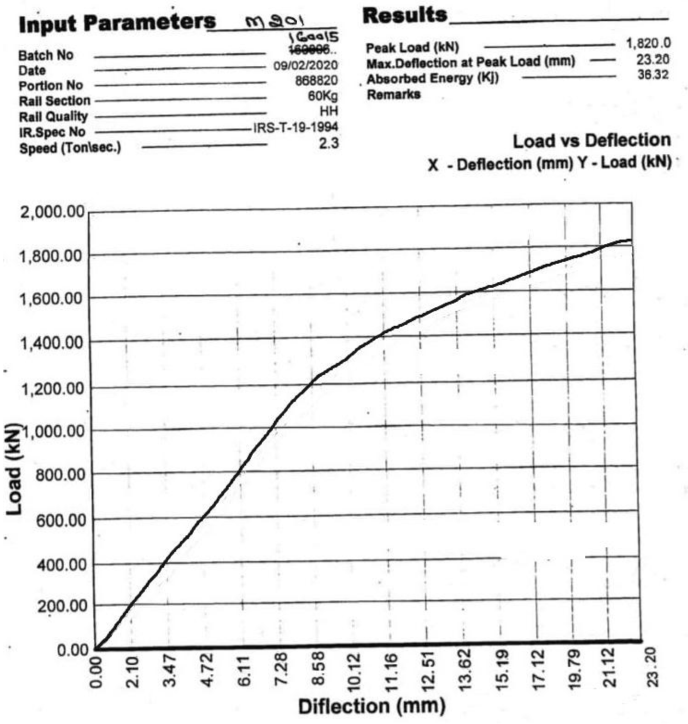
~~160006~~..
Peak Load (kN) — 1,759.0
Max.Deflection at Peak Load (mm) — 20.23
Absorbed Energy (Kj) — 35.58
Remarks

**Fig 15:** Bending test report (Non Heat treated weld)

### 4.2.2 Bendig Test Result for *Heat Treated Weld* Specimen

Maximum load- 1820 kN

Maximum deflection- 23.20 mm



**Input Parameters** [illegible]

Batch No — 160015 ~~160006~~..
Date — 09/02/2020
Portion No — 868820
Rail Section — 60Kg
Rail Quality — HH
IR.Spec No — IRS-T-19-1994
Speed (Ton\sec.) — 2.3

**Results**

Peak Load (kN) — 1,820.0
Max.Deflection at Peak Load (mm) — 23.20
Absorbed Energy (Kj) — 36.32
Remarks

**Fig 16:** Bending test report (Heat treated weld)

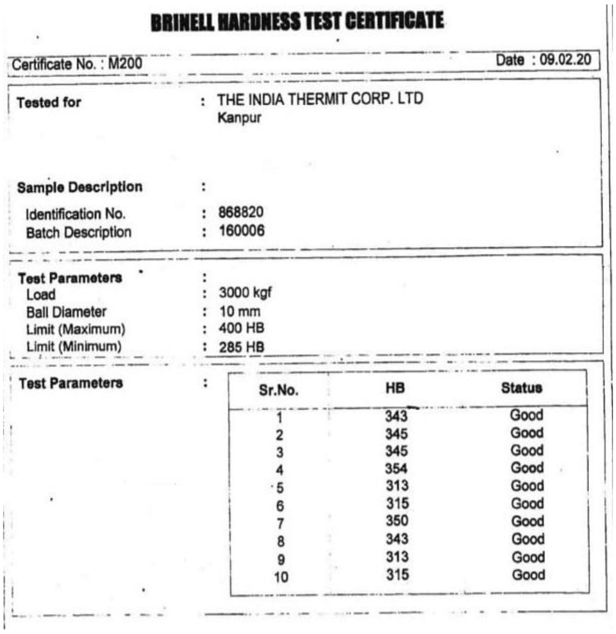
### 4.3 Brinell Hardness Test

The Hardness test were conducted on FIE Brinell Hardness tester. A spherical indenter was used having a dia of 10mm. The load was 3000 kgf. A set of two readings each were taken in each zones. The main zones are mentioned in the table below.

### 4.3.1 Brinell Hardness Test Result for *Non-Heat Treated Weld* Specimen

**Table 5:** BHN for Non heat treated weld

| S.No. | Zone | BHN |
|---|---|---|
| 1 | Weldment | 343 |
| 2 | | 345 |
| 3 | HAZ Left | 345 |
| 4 | | 354 |
| 5 | PM Left | 313 |
| 6 | | 315 |
| 7 | HAZ Right | 350 |
| 8 | | 343 |
| 9 | PM Right | 313 |
| 10 | | 315 |



**BRINELL HARDNESS TEST CERTIFICATE**

Certificate No. : M200
Date : 09.02.20

Tested for : THE INDIA THERMIT CORP. LTD
Kanpur

Sample Description :
Identification No. : 868820
Batch Description : 160006

Test Parameters :
Load : 3000 kgf
Ball Diameter : 10 mm
Limit (Maximum) : 400 HB
Limit (Minimum) : 285 HB

Test Parameters :

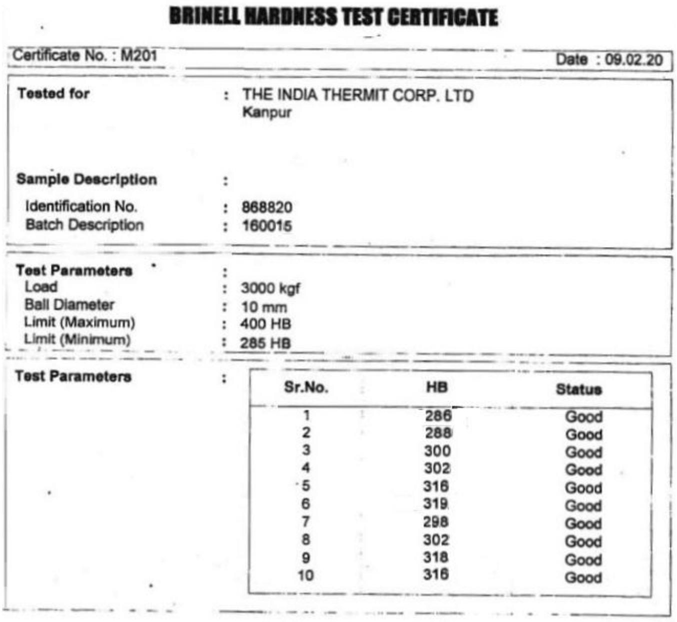
| Sr.No. | HB | Status |
|---|---|---|
| 1 | 343 | Good |
| 2 | 345 | Good |
| 3 | 345 | Good |
| 4 | 354 | Good |
| 5 | 313 | Good |
| 6 | 315 | Good |
| 7 | 350 | Good |
| 8 | 343 | Good |
| 9 | 313 | Good |
| 10 | 315 | Good |

**Fig 17:** Brinell test report (Non heat treated weld)

### 4.3.2 Brinell Hardness Test Result for *Heat Treated Weld* Specimen

**Table 6:** BHN for Heat treated weld

| S.No. | Zone | BHN |
|---|---|---|
| 1 | Weldment | 286 |
| 2 | | 288 |
| 3 | HAZ Left | 300 |
| 4 | | 302 |
| 5 | PM Left | 316 |
| 6 | | 319 |
| 7 | HAZ Right | 298 |
| 8 | | 302 |
| 9 | PM Right | 318 |
| 10 | | 316 |



**BRINELL HARDNESS TEST CERTIFICATE**

Certificate No. : M201
Date : 09.02.20

Tested for : THE INDIA THERMIT CORP. LTD
Kanpur

Sample Description :
Identification No. : 868820
Batch Description : 160015

Test Parameters :
Load : 3000 kgf
Ball Diameter : 10 mm
Limit (Maximum) : 400 HB
Limit (Minimum) : 285 HB

Test Parameters :

| Sr.No. | HB | Status |
|---|---|---|
| 1 | 286 | Good |
| 2 | 288 | Good |
| 3 | 300 | Good |
| 4 | 302 | Good |
| 5 | 316 | Good |
| 6 | 319 | Good |
| 7 | 298 | Good |
| 8 | 302 | Good |
| 9 | 318 | Good |
| 10 | 316 | Good |

**Fig 18:** Brinell test report (Heat treated weld)

## 5. ANALYSIS OF RESULTS

The results of Tensile test, Bending test and Brinell hardness test conducted on the Non heat treated and Heat treated samples are compared thoroughly to understand the effect of heat treatment on the quality and durability of the Thermite weld.

### 5.1 Analysis of Tensile Test Results

**Table 7:** Tensile test result comparison

| Parameter | Non Heat treated weld | Heat treated weld | % increase |
|---|---|---|---|
| UTS Avg (MPa) | 628 | 696 | 10.83% |
| Yield Stress Avg (MPa) | 493 | 510 | 3.44% |
| Percent elongation -Avg | 9.1 | 11.5 | 26.37% |

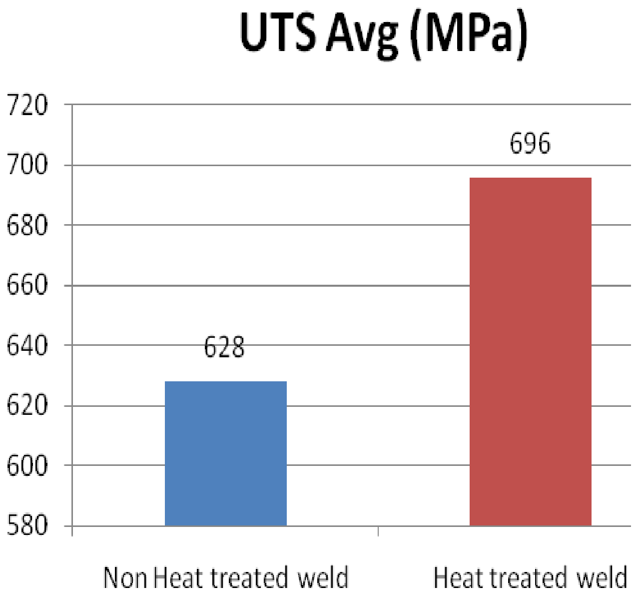


**Chart 3:** Avg UTS comparison

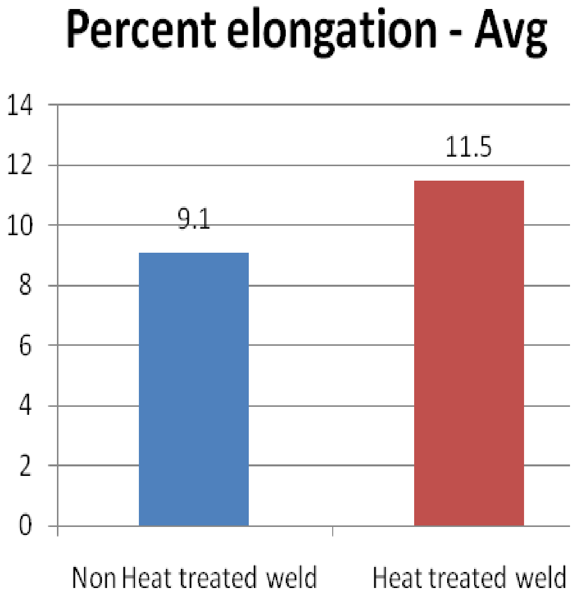


**Chart 4:** Avg perc elongation comparison

It is clear from above results, after heat treatment, the Ultimate tensile strength of the Thermite weld increased by 3.44%. On the other hand the ductility (Percent elongation) increased by 26.37%, which is significant. This has happened due to the refined and finer grain structure in Heat treated weld.

### 5.2 Analysis of Bending Test Results

**Table 8:** Bending test result comparison

| Parameter | Non Heat treated weld | Heat treated weld | % increase |
|---|---|---|---|
| Max load (kN) | 1759 | 1820 | 3.46% |
| Max deflection (mm) | 20.23 | 23.20 | 14.68% |

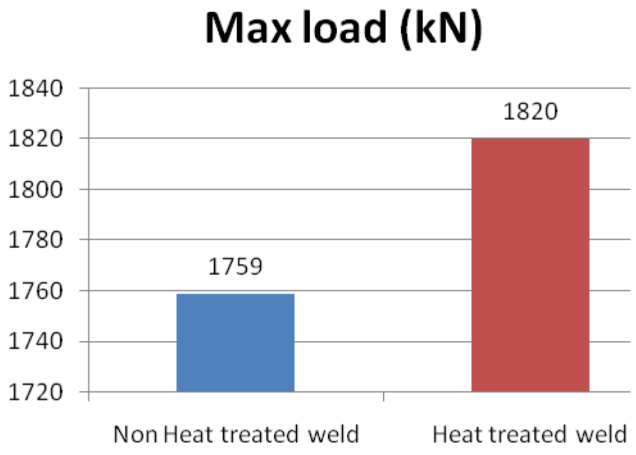


**Chart 5:** Max bending load comparison

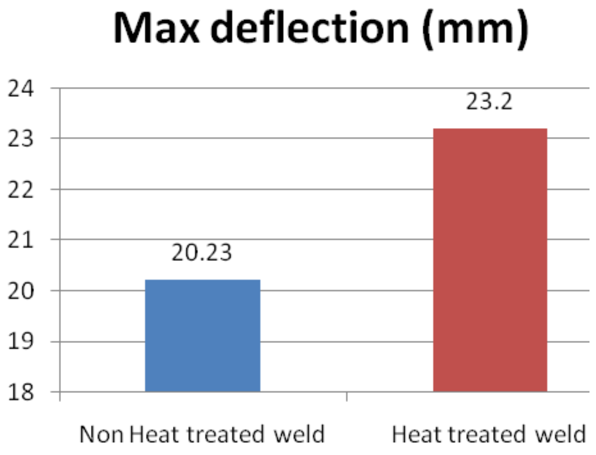


**Chart 6:** Max deflection comparison

As we can see, the load carrying capacity of the weld has increased by 3.46% after Normalizing. Also the maximum deflection it can undergo has also increased considerably by 14.68%. Again this can be attributed to a better grain structure in heat treated weld as compared to large columnar grains in Non heat treated weld.

### 5.3 Analysis of Brinell Hardness Test Results

**Table 9:** Brinell hardness test result comparison

| **Zone** | **BHN** | |
|---|---|---|
| | **Non Heat treated weld** | **Heat treated weld** |
| PM Left | 313 | 317 |
| | 315 | 319 |
| HAZ Left | 345 | 300 |
| | 354 | 302 |
| Weldment | 343 | 286 |
| | 345 | 288 |
| HAZ Right | 350 | 298 |
| | 343 | 302 |
| PM Right | 313 | 318 |
| | 315 | 316 |

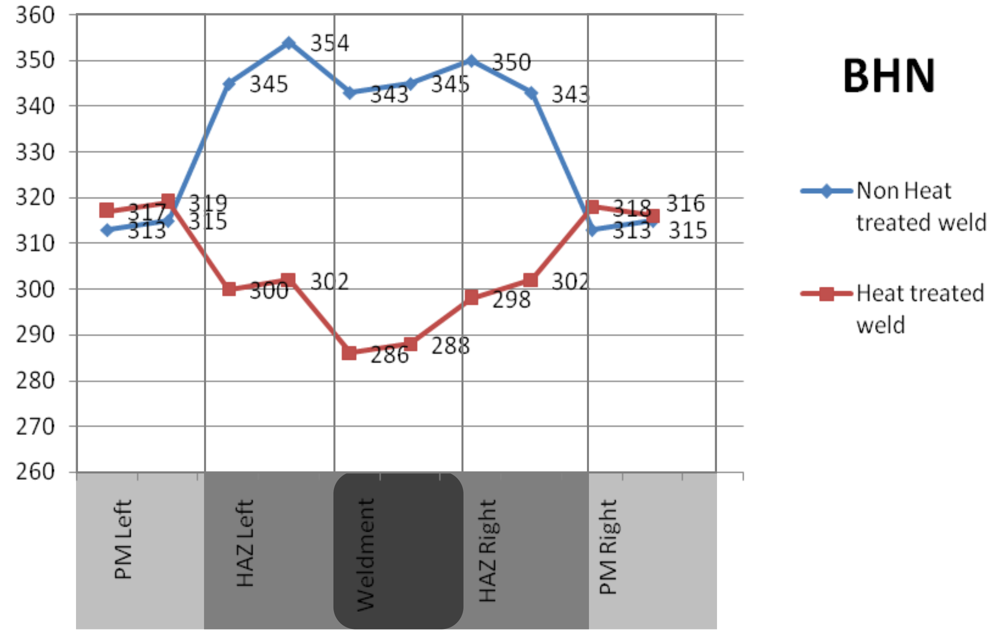
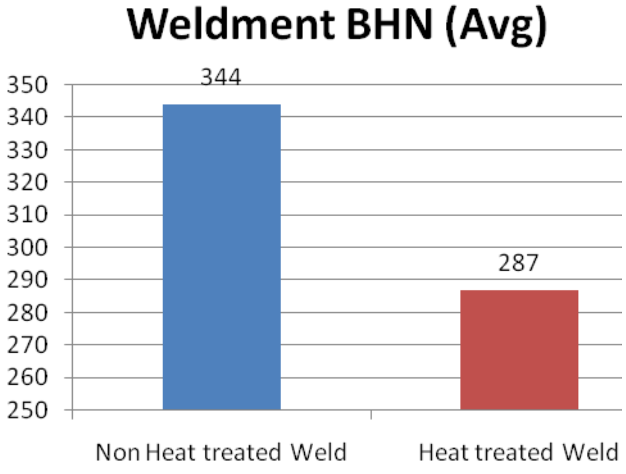


**Chart 7:** BHN comparison in all regions



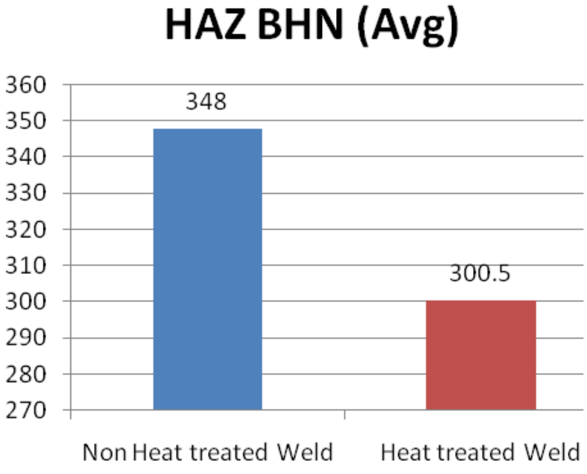


**Chart 8:** BHN comparison in Weld region

**Chart 9:** BHN comparison in HAZ

The hardness in the weld region has decreased by 16.57%, while hardness in the Heat affected zone (HAZ) has decreased by 16.65%. This means that the brittleness of these regions has decreased. It can bear more deflection without cracking or failing.

## 6. CONCLUSIONS

This study gives a clear implication that conducting Normalizing on Thermite weld considerably improves the tensile strength, ductility, load bearing capacity and deflection bearing ability of the weld. Heat treatment also reduces the hardness of the weld which decreases the brittleness of the weld region. All these improvements can be of great advantage for our railway and metro tracks that bear large loads and fatigue. This can improve the quality and serviceability of Thermite welds. Hence we believe this is a way foreword to improve our rail tracks and reduce risk of failure.

Although it is not possible for the rail track welds to be Heat treated in the furnace. We tried to use Gas burner for heating the weld up to desired temperature, but the heat was not uniform and continuously burning the Gas flame for 50 minutes was uneconomical. In our next research we will try to solve this problem. We will focus on making a heat treatment setup that can be installed on the track itself and is simple and economical.

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