Improvement in Mechanical Behavior of Expulsion with Heat treated Thermite Welded Rail Steel

S.Rajanna, H.K.Shivanand, Akash Deep B.N

Abstract**—**Thermite welding is mainly used in world. The reasons why the thermite welding method is widely used are that the equipment has good mobility and total working time of that is shorter than that of the enclosed arc welding method on site. Moreover, the operating skill, which required for thermite welding, is less than that of for enclosed arc welding. In the present research work, heat treatment and combined 'expulsion and heat treatment' techniques were used improve the mechanical properties and weldment structure. The specimens were cut in the transverse direction from expulsion with Heat treated and heat treated Thermite Welded rails. Specimens were prepared according to AWS standard and 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 treated and 'expulsion with heat treated' with the properties of their thermite welded rails. Compare the mechanical and microstructural properties of thermite welded rails between heat expulsion with heat treated and heat treated. Mechanical and microstructural response expulsion with heat treated thermite welded rail is higher value as compared to heat treatment.

Keywords**—**Expulsion, Heat treatment, Mechanical, Weldment.

I. INTRODUCTION

CONTINUOUSLY welded rails have been increasingly laid to simplify track maintenance and inspection, control noise and vibration and to ensure travel safety. Rail welded techniques are of the utmost importance for the laying of continuous welded rails. The studies were carried out at different regions of the weldment such as base material, weld metal and heat affected zone. To characterize the properties of the weldment and for identification of various phases, hardness studies were also carried out in detail. Microstructural analysis was also carried out to characterize the various regions of the weldment. Welded Joints are critical spots in rails because by their structural and mechanical characteristics they represent discontinuities in rails. Welded Joints are exposed to longitudinal forces and stresses. Because Thermite welded joints have microstructure of a cast metal. Heat treatment could improve ductility and toughness which are typically low in cast structures. In Indian Railways, Carbon steel rails graded according to their UTS values. Rails failure may occur due to various reasons. It may occur due to the presence of rolling defects like scabs, piping, flaking etc. It may also originate due to poor welding of two rails or improper placement. Since it is safety items and its failure may cause disaster, stringent inspection in predetermined intervals of time and testing are in vogue. Online ultrasonic testing is one of the important tests, which is adopted in specified interval of time. This rail is designed to bear axle load of 22.MT and speed of 120 kmph[2]. There was a curvature on the track where there was thermite welded joint at the failure zone. The fracture was brittle end crystalline in nature. Pinhole porosity was observed at the fracture[3]. Contour of the welding was not properly finished at the web as well as foot of the rail. Deep corrosion pits[4][5] were observed on the foot of the rail. A modified thermite rail welding procedure was developed in which thermite steel that normally comprises the filler metal of a full fusion thermite rail weld was expelled from between the rail ends while in a liquid or partially solidified state. This expulsion was caused by applying an axial force to the rails to move their ends together. It was believed that the expulsion would alter the solidification microstructure and decrease the number and size of metallurgical discontinuities in the fusion zone by decreasing the volume of filler metal, thus improving the joint's fatigue properties. Modified and standard thermite welds were fabricated and compared using the results of hardness tests, and tension tests. Rail steel is subjected to severe service conditions. These material experiences complex loading which are generated by the weight of goods, impact of trains, curves of track, friction and wave actions of locomotive wheels as well as thermal stresses in changing climatic conditions and other critical factors. This rail fatigue research will examine the properties of steel in the modern rails. This research will assist in improving rail road safety by expanding knowledge of rail durability. Research on Rail is important because premature rail fatigue failure has been the cause of derailments and other severe accidents. An improved understanding of this failure mechanism is essential to address related issues of railroad safety, reliability[1] and operational efficiency; head hardening of the rails increases the service life considerably. The higher UTS of rail steel is necessary

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because of the heavier loads and also, to minimize wear from the harder steel used for the cast wheels. The Mechanical properties of metal determine the range of usefulness of the metal and establish the service that can be expected. Mechanical properties are also used to specify and identify metals. The most common properties considered are the strength, hardness, ductility and impact resistance. Experimentation and testing play an important role in suitability of rail steel for railway application. This calls for certain mechanical property requirements and acceptance of the materials under these specifications, which involves thorough understanding of the methods of testing and the significance of testing, can be appreciated with the knowledge of Material science and Metallurgy.

II. EXPERIMENTAL DETAILS

The chemical composition was ascertained with the help of baird emission spectrometer. The rails were cut square and the gap to be welded. (If the rail ends are cut skewed, the gap will be non-uniform and the fusion of the rails will be asymmetric.) .The cut faces were cleaned with kerosene oil and a wire brush to remove rust, dust, or greasy material, etc. (Otherwise, this material may get fused with the weld material and this may render the weld defective.) long steel straightedge was used to align the running edge of the rail head. Stands for crucible and torch were fixed on the railhead. A set of prefabricated moulds of the appropriate rail section was selected and examined for suitability. The rail profile of the mould was checked by placing the mould against the side of the rail to be welded. Commonly utilizing the composition of 5 parts iron oxide powder and 3 parts aluminum powder ignited at high temperature in crucible and reaction between fine aluminum and iron oxide powders and produce a red hot iron and aluminium oxide. After completion of exothermic reaction aluminium oxide floated on top surface of the crucible, about 20 to 25 seconds required for separation of slag from molten steel. If required, small adjustments to the mould profile are made by rubbing the mould gently against the sides of the rail. Then the moulds were placed in the mould shoe. The placement of the mould should be central over the gap as otherwise while pouring the molten metal, one rail end will get more heat than the other and the fusion of the metal at the other rail end may not be complete. A slag bowl was attached to the mould shoe to collect the overflowing slag and molten metal during the pouring. The crucible housed at the correct height and alignment on the swiveling crucible stand. A closing pin placed at the bottom over the opening. The crucible was swung away from the rail and the 'portion' (self-igniting mixture which yields the molten metal) is poured into the crucible, heaped in a conical shape. Welding torch lit and the flame was tuned. This torch was placed in its stand which is fixed over the gap, and the flame directed into the mould through the central opening. The flame heats the rail ends and this is done for each rail section Pre-heating the rail ends (to about 1000°C) is required to help the poured molten metal in washing away the surface oxidation on the rail ends, as otherwise, the molten metal may chill and solidify immediately on coming in contact with cold rail ends, without washing off the surface oxidation. As the preheating is completed, the Thermite reaction initiated by igniting a sparkler and putting it into the crucible, the reaction is allowed and the slag is allowed to be separated from the molten metal. Thereafter, the closing pin is tapped from the outside, thus discharging the metal into the top central cavity of the mould. Thereafter, the crucible and torch stands were removed. Here two techniques were used to improve the quality of weldment. Initially heat treatment technique was adopted

A. Heat treatment:

After solidification, the thermite welded rail was subjected to ultrasonic test to ensure the quality of weld. The heat treatment involved annealing[7] was carried out at 820^0C for 45 min and air cooling to room temperature (normalized condition). In order to know the mechanical properties like tensile, Charpy impact and Hardness, specimens were prepared as per AWS. Standard and subjected to tensile test, Impact test and hardness test.

Secondly expulsion with heat treatment technique was adapted here

B. Expulsion with heat treatment

It is a combined technique of expulsion and heat treatment. First expulsion was carried out ie this expulsion was caused by applying an axial force to the rails to move their ends together. In which thermite steel that normally comprises the filler metal of a full fusion thermite rail weld was expelled from between the rail ends while in a liquid or partially solidified state. The excess Thermite steel over the head of the rail (head riser) removed after solidification (but when the metal is still red hot) by either manual chiseling or using hydraulic weld trimmers and the railhead ground using grinding machines. The thermite welded rail was subjected to ultrasonic test to ensure the quality of weld. The heat treatment involved annealing was carried out at 820^0C for 45 min and air cooling to room temperature (normalized condition). In order to know the mechanical properties like tensile, Charpy impact and Hardness, specimens were prepared as per AWS. Standard and subjected to tensile test, Impact test and hardness test.

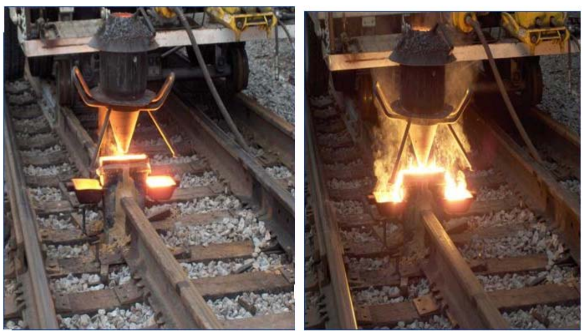

Fig.1 Thermite welding

C. Thermite reaction detail

Aluminium reacts with iron oxides, particularly ferric oxide, in highly exothermic reactions, reducing the iron oxides to free iron, and forming a slag of aluminium oxide.

$$3Fe_3O_4 + 8Al = 4Al_2O_3 + 9Fe \ (3088°C, 719.3kCal\uparrow)$$
$$3FeO + 2Al \square \ Al_2O_3 + 3Fe \ (2500°C, 187.1kCal\uparrow)$$
$$Fe_2O_3 + 2Al \square \ Al_2O_3 + 2Fe \ (2960°C, 181.5kCal\uparrow)$$

The various iron oxides are used in appropriate proportions so as to get the correct resultant quantity and temperature of molten steel. The iron obtained from such a reaction is soft and unusable as a weld metal for joining rails. To produce an alloy of the correct composition, alloys like ferro-manganese are added to the mixture along with pieces of mild steel, both as small particles, to allow rapid dissolution in the molten iron, to control the temperature and to increase the 'metal recovery'. Complete slag separation in a short time and better fluidity of the molten metal is achieved by adding compounds like calcium carbonate and fluorspar.

D Tensile test

The universal testing machine essentially consists of two parts, the strainer or pulling device and arrangement to measure and register the load on a dial. A gradually increasing tensile load applied on specimen and the resulting extension of the specimen observed. The percentage Elongation is a measure of a ductility of the metal percentage to reduction in area is another measure of ductility that can be measured in tensile test.

E Impact test

This test analysis the response of the material for resistance offered by the material to rapid build of stresses. . The equipment could deliver maximum Impact energy of 30 Kg/mm^2 and striking velocity was 5m/sec. The angle of drop was 140 degree. The specimen was placed in the anvil. Energy consumed in breaking was indicated on the dial of the testing machine. A charpy specimen of cross section[9] of 10x10 mm and contains 45-degree notch, 2mm deep with a 25mm root radius as per AWS standard.

III. RESULT AND DISCUSION

Mechanical properties of rail steel

The mechanical properties of rail steel determine the range of usefulness of the metal and establish the service that can be expected. Mechanical testing and experimentation play an important role in suitability of the rail steel for railway application this cause for certain mechanical property requirements and acceptance of the materials under these specifications, which involves thorough understanding the methods of testing and the significance of testing, can be essential with the knowledge of material science and metallurgy and also microstructural analysis were correlated with its mechanical properties like ultimate tensile strength, yield strength, and hardness are very much essential to find suitability for railway application . This basic information on rail steel is very much essential for further studies on fatigue and wears properties of the welded rail steel.

The mechanical properties in thermite welded rails have been improved by adapting two techniques in process as mentioned below.

Condition 1: Heat treatment.

Condition 2: Expulsion with heat treatment

A. Tensile test

As mentioned above two techniques conditions tests were conducted at ambient temperature. The room temperature mechanical properties of yield strength, Ultimate tensile strength and ductility mentioned in Table 1and 2 for above mentioned two different techniques condition of thermite welded rail. The stress is calculated based on the original cross sectional area before testing. The summary of these mechanical properties for two different techniques conditions of thermite welded rails are also given in Fig 2 to 3.. Expulsion and heat treated rail exhibits increase in ultimate tensile strength, yield strength and elongation as compared to heat treated thermite welded rail. The result of present work shows the significant improvement in mechanical properties. In heat treatment causes the replacement of very coarse ferritic-pearlitic structure[6] by much finer structure very thin cementite lamellae appears in the pearlite were as the fine ferrite network on the grain boundaries indicates the size of the prior austenite grains from which the fine ferritic pearlitic structure has evolved. And also changes from brittle to ductile nature.In expulsion process comprises the filler metal in weldment. Thermite welded rail was expelled from between the rail ends helps in fill the cavity formation during welding due to aluminium oxide in partially solid state. This expulsion would alter the solidification microstructure and decrease the number and size of the metallurgical discontinuity in the fusion zone by decreasing the volume of metal thus improving the mechanical properties.

The guage length of tensile specimen encomposes the weld metal and heat affected zone gives noticeable heterogenetic[8] of plastic deformation. The most pronounced deformation was observed in the heat affected zone and the point of minimum hardness however failure occurred in the center of the weldment with a local minimum of hardness. And also rupture occurred after large plastic deformation it means ductile fracture was the operating fracture mechanism. The mechanism of creation of ductile dimples on the fracture surface in characteristics future of expulsion and heat treatment condition.Heat treated Thermite welded rail steel contains inclusions,it contains besides of aluminium, Oxygen and iron, small amount of phosphorous, sulphur and magnesium. All specimen exhibited low value of percentage of elongation and yield strength it means ductility of welded joints of rail very poor due micro porosity and also reaction between the weldmetal and the magnesite reduces the quality of welded joint.

B. Impact Test

The Impact test results of three different conditions of thermite welded rail is mentioned in Table 3.and shows the comparison of Impact Energy of As Thermite weld, Heat treated and Expulsion with Heat treated thermite welded rail..Impact results of expulsion with heat treated thermite welded rail shows improvement in toughness value as compared to other two technique conditions because of ductility improvement in weldment by using heat treatment and minimize the voids, macro porosity and stress concentration using expulsion technique. Residual stresses are minimized by using combined effect of expulsion and heat treatment and gives better impact strength.

TABLE .I
TENSILE TEST RESULTS OF HEAT TREATED THERMITE WELDED RAIL STEEL

S. No.	Young's modulus (GPa)	Yield strength (MPa)	UTS (MPa)	Percentage of elongation
1	211.23	510	694	12
2	214.97	512	699	10.2
3	217.11	516	711	12.1
Average	214.44	512.67	701.33	11.43

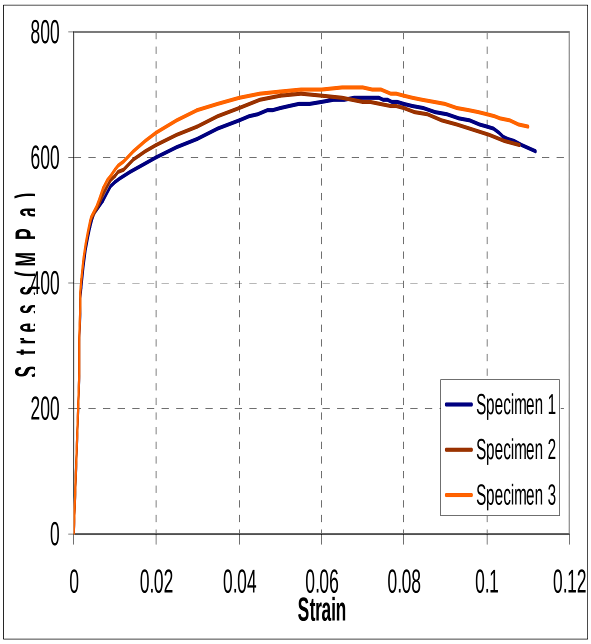

Fig. 2 Stress v/s Strain Curve of Heat treated Thermite welded rail

TABLE II
TENSILE TEST RESULTS OF EXPULSION WITH HEAT TREATED THERMITE WELDED RAIL

S. No.	Young's modulus (GPa)	Yield strength (MPa)	UTS MPa)	Percentage of elongation
1	214.54	535	738	12.6
2	213.42	528	728	12
3	214.01	534	745	12.9
Average	213.99	532.33	737	12.50

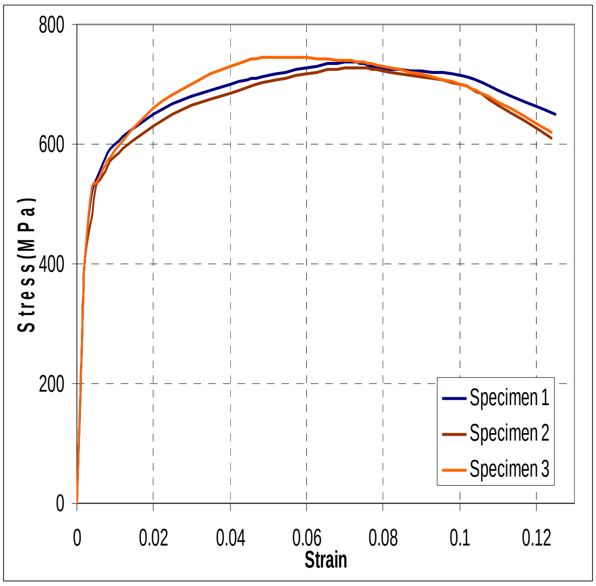

Fig. 3 Stress v/s Strain Curve of Expulsion with heat treated Thermite welded rail

TABLE III
IMPACT ENERGY OF THERMITE WELDED RAIL STEEL

Different techniques of thermite welded rail	1	2	3	Average Impact energy, J
Heat treated	12	11	11	11.33
Expulsion with heat treated	13	13	11	12.33

C Brineel Hardness number

Wear resistance is strongly dependent on the microstructure of metals. In case of rail steels, wear resistance is advanced through the pearlite microstructure. From the above hardness profile of the thermite welded rail steel after heat treatment shows that their significant difference in hardness of thermite welded rail steel and exhibits same hardness profile of Expulsion and heat treated thermite welded rail.. Nonsymmetrical hardness traversing along the longitudinal direction has been observed in this work as shown in the fig 4. After heat treatment, minimum hardness in the weld metal and on the boundary between the heat affected zone and the base metal was observed this could indicate that faster wear will occur on the weld metal softening of heat affected zones of welded rails may deteriorate their fatigue and wear behaviour.This can lead to depressions on the running surface of the rail, disturbing the train passenger comfort.. Minimum hardness existence at heat affected zone nearer to the base metal finer ferritic pearlitic structure existence in post weld treated thermite welded rail. In Expulsion with heat treated techniques normally comprises the filler metal of a full fusion thermite rail weld was expelled from between the rail ends while in a liquid or partially solidified state. This expulsion was caused by applying an axial force to the rails to move their ends together. It was believed that the expulsion would alter the solidification microstructure and decrease the number and size of metallurgical discontinuities in the fusion zone by decreasing the volume of filler metal, thus improving the joint's strength with out changing the hardness.

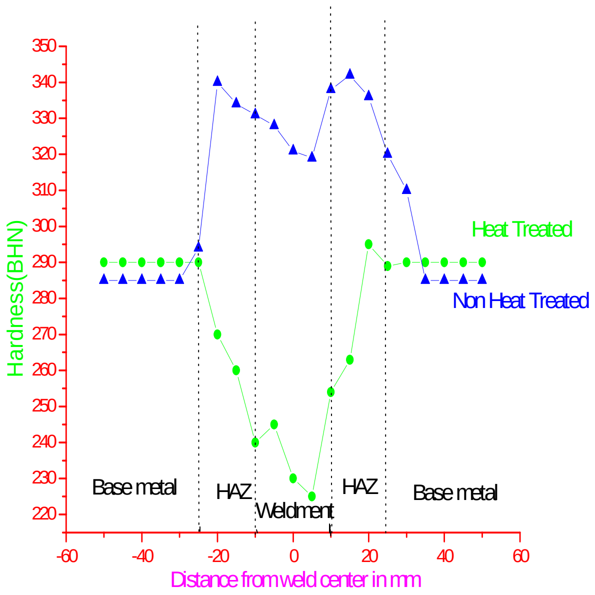

Fig. 4. Brineel Hardness number of thermite welded rail steel

IV. CONCLUSION

All welded tensile specimen of thermite welded rail have failed in weldment region with significant variation in strength due to residual stresses developed due to high temperature ingredient. In case of thermite welded SEM shows that Ferritic-Pearlitic structure and consists of aluminium oxide inclusions formed in the interdendritic space. Thermite welded rails exhibits low ductility and toughness due to the presence of carbide precipitate along the ferrite boundary. All mechanical properties of thermite welded rails is lower due to reaction between the welded metal and magnasite reduces the quality of the welded joints.

- Hardness profile of both expulsion with heat treated heat treated thermite welded rails exhibits almost same profile.
- Failure of thermite welded rail at weldment in both due to lower hardness at weldment after heat treatment expulsion with heat treated heat treated.
- Microstructures exhibits more porosity and inclusion in heat treated as compared to expulsion with heat treatment.
- Heat treatment changes the property of weldment from Brittle to ductile in both. Ie Changes in Microstructure from coarse grain to fine grain structure.manganese sulphide precipate on grain boundary of ferrite and cementite in heat treated thermite welded rail.
- Improves the properties like ultimate tensile strength and % Elongation (ductility), yield strength in expulsion with heat treatment as compared to heat treatment after heat treated welded rails.
- Fracture surface expulsion with heat treatment thermite welded rail joint exhibits gray with fine grained.
- Expulsion with heat treatment thermite welded rail, ductile fracture occurred after a larger plastic deformation proceeding the rupture as compared to thermite welded rail.
- It has been found that Expulsion with heat treatment thermite welded rail joint improves mechanical properties.

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