Welding Techniques

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FOREWORD

The book on ' Welding Techniques' was originally published in 1988 covering different methods for welding of rails, details of specific techniques and quality control aspects. The book was very popular amongst field engineers.

During this intervening period, some of the rail welding methods and specific techniques have undergone major changes. A number of new techniques have also been developed to meet the requirements of the field. It was, therefore, imperative to revise the book thoroughly so that it contains the updated information on the subject matter.

The book covers Flash Butt Welding, Alumino-Thermic Welding and Gas Pressure Welding with emphasis on the first two. Apart from dealing with the basics of these methods, it covers process details, quality control and new developments.

It is hoped that the book will enable Railway Engineers to improve their understanding of rail welding. At the same time, those who are not well conversant with rail welding, can also familiarize themselves with all facets of rail welding with the help of this book.

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Director
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ACKNOWLEDGEMENT

The book on ‘ Welding Techniques’ was first brought out by IRICEN in 1988 to acquaint the field engineers with various welding techniques available for welding of rails. Since then the welding techniques have undergone major changes and several new development have taken place in this area. The authors, therefore, undertook the task of revising the book duly incorporating the latest information on the subject.

The authors are indebted to the faculty members & staff of IRICEN for the support and assistance received from them in the course of bringing out the book. Our thanks are also due to Mrs Vidya Jamma, who did the word processing of the manuscript.

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CHAPTER I

DIFFERENT TYPES OF WELDING

1.1 Definition of welding

According to American Society of Welding, welding is a localized coalescence of metal where coalescence is produced by heating to suitable temperature, with or without the use of filler metal. The filler metal either has a melting point approximately the same as the base metal or below that of the metal. Heating to suitable temperature is compulsory; in addition either pressure or filler metal is required for welding to take place.

1.2 Physical nature of metal

Below their melting point, all metals are crystalline solids made up of grains, i.e., the grains are crystalline. In a typical fine-grain metal, the individual grains are about 0.003 cm in diameter. The grains in turn are made up of atoms. A typical grain would, thus, have about 10^{15} atoms, the diameter of a typical atom being about $3x10^{-18}$ cm.

Metal are made up of grains separated by grain boundaries. In a homogenous single phase alloy, all grains are identical in composition, differing only in size, shape and orientation. The individual grains are crystalline. If we were to draw an imaginary three dimensional network of lines, properly spaced within the grain, nearly all the atoms of the grain could be centred at or very near one of the intersections of these lines and nearly every intersection would be occupied by an atom. The network is called lattice and intersections are lattice points.

1.3 Grain boundaries

When two identical lattices of different orientation, (orientation is a direction of such lines of lattices with respect to arbitrary co-ordinates in space) intersect, there is necessarily a mismatch. At least one layer of atoms must take up position intermediate between two ideal sets of lattice points. This zone or at the most of a few atoms thickness is what we call the grain boundary. It is interesting and extremely important that the attractive forces between these out of position atoms and their nearest neighbours are at best as strong as the attractive forces between atoms located within the grains.

1.4 Physical nature of joining

Theoretically, to produce a weld all that is necessary is that the atoms on the opposite metallic regions should be brought close enough to establish the spontaneous attractive forces. Ideally two perfectly plane surfaces, if treated in this fashion, would be drawn together spontaneously until the distance between them corresponds to the equilibrium inter-atomic spacing. At this point, perfect coalescence would occur and two objects would merge to comprise a single solid body.

The surface of a perfectly clean metal can be visualized as one half of a grain boundary. The lattice is perfect right up to or nearly up to the free surface. The surface atoms are probably in their lattice position. However, they are not completely surrounded by other atoms as are the interior atoms. They are, thus, capable of bonding to another piece of metal i.e, another aggregate of atoms. The energy of these unsatisfied bonds is the source of the surface tension of the metal. It is quite evident then that if we were to bring into contact two perfectly clean, atomically smooth surfaces of a metal, the resulting joint would be as strong as at a grain boundary.

1.5 Processes

From a metallurgical point of view, there are seven processes available for dissipating non-metallic films as explained below:

1) *Fragmentation and mechanical dispersion*

i.e. grinding, filing and sand papering etc., common to all welding processes.

2) *Dissolution and solid state diffusion away from the weld interface in the parent metal.*

i.e., the non-metallic layer at the welding interface gets melted and by application of pressure goes into the parent metal on either side. Flash-butt and gas pressure welding come in this category.

3) *Dissolution by volatilisation*

i.e. the non-metallic layers are sparked off as in the case of flash-butt welding.

4) *Melting followed by mechanical extrusion as a liquid phase*

The metal at the joint in the flash-butt welding process gets squeezed out. Along with this, the non-metallic layer also gets squeezed out.

5) *Fluxing followed by gravity separation of the melting slag*

This takes place in electric arc welding and alumino thermic welding. The non-metallic layer at the faces gets melted and comes up with the lighter slag.

6) *Liquid metal fluxing*

As in alumino thermic welding.

7) *Dissolution and redistribution in the liquid metal*

This happens in alumino thermic welding and electric arc welding. Most of the oxides are removed by fluxing followed by gravity separation of the melting slag. Whatever is left behind gets mixed in the molten metal poured and gets distributed in the new steel with consequent less effect.

It will be seen from the above, that all the above items, except item (1) require heating. Hence, in the process of welding, heating is compulsory, whereas use of pressure and filler metal are optional.

The opposing surfaces can be brought within equilibrium inter-atomic distance by

i) Pressure or autogenous process as in the case of flash-butt or gas pressure welding, or

ii) Fusion or homogenous process as in the case of alumino thermic or electric arc welding. In fusion welding , melting is followed by cooling and while cooling, the atoms always arrange themselves into equilibrium inter atomic distance.

1.6 A rational classification of the numerous welding processes (there are 35 of them) can be made on any of the several bases. If we were to classify on heat source, the main classifications are :

1) electric arc
2) electric resistance, and
3) organic fuel

To establish the metallurgical atom-to-atom bond for welding, we must remove intervening non-metallic layers and this can be done by floating them away or by mechanically destroying them. On the basis of this, the two main classifications are pressure welding and fusion welding.

Pressure Welding or Autogenous Welding is welding together of the parts of the same chemical composition without addition of metal to accomplish the joint.

Fusion Welding or Homogenous Welding is done by adding metal of the same composition as the parts being jointed.

Heterogenous Welding is done using an alloy quite different from the metal parts being jointed, or alternatively the parts themselves may differ significantly in composition.

There are 35 different methods of welding, and basically they can be classified in two main categories, viz. Pressure Welding and Fusion Welding. However all these methods are not suitable for rail welding.

We expect the following properties from a rail weld :

1) Static Strength
2) Fatigue Strength
3) Impact resistance
4) Ductility

5) Toughness or resilience
6) Hardness.

The process of welding should be such that it should not change the metallurgy of rail steel to a large extent. It should be economical and should not require too much time, skill or capital investment.

Based on these considerations, there are only four suitable methods of welding for rails :

1) Flash butt welding
2) Alumino thermic welding
3) Gas pressure welding
4) Metal arc welding

Out of the four methods as mentioned above, only first three methods have been discussed in this book with the emphasis on the first two as these are the most widely used methods for welding of the rails amongst various countries of the world. The Alumino-thermic welding is also referred to as Thermit welding.

CHAPTER II

FLASH BUTT WELDING OF RAILS

2.1 Introduction

Except perhaps in the Japanese National Railways, flash butt welding of rails has been the most popular methods of welding of rails in stationary depots all over the world. The strength of the welded joint made by this process is more compared to any other welding process.

2.2 Principle

The flash-butt welding process is a method of joining metals in which the heat necessary to forge the joint is generated by the resistance of the rails being welded to the passage of an electrical current. Unlike the Thermit and Arc welding processes, no additional chemicals or metals are required to make the weld and in fact the reverse is the case. In Flash butt welding, the parent metal is consumed during the welding cycle and this action creates the necessary heat in the rail ends in order to accomplish the forging action and consolidate the joint. A total length of approximately 25mm to 35mm depending on rail section is consumed per weld.

In the actual welding process, the two rail ends to be welded are firmly held by the clamps of the machine. One rail end is stationary while the other end can move. The rail ends are brought close to each other till they almost touch. Then the electricity is switched on and made to pass through the interface of the two rails. In the process heat is generated and flashing takes place. The moving end is then moved away but brought back after some time. This process continues for specified number of cycles as per pre-determined sequence and rate. When the temperature rises to fusion limit, the rail ends are pressed together with application of force which leads to the welding of the rail ends.

2.3 Basic components of the machine

The basic components in the make up of a flash butt welding machine are, in very simple terms, as follows :

(1) A clamping mechanism to hold the rail being welded firmly in position.

(2) A forging mechanism which has a dual function to:

  a) bring the rails into contact under low force during the initial heating stages of the weld cycle and

  b) apply a high force to the rail interfaces on completion of the welding cycle to extrude all contaminations and consolidate the weld joint.

(3) A transformer which will reduce the mains supply voltage from 400/500 Volts to a suitable welding voltage between 4 and 12 Volts and make available sufficient current to heat the components being welded. The welding current required varies between 30,000 amps to 80,000 amps depending on cross sectional area of the rail being welded.

2.4 Brief history of the process

Flash butt welding technique spread to many countries during the 1930s but much of this development work came to a standstill during the war years particularly in the U.K. and on the Continent. However, by 1950 the flash butt welding of rails was common place in all major railroads throughout the world.

The basic principles of the flash butt welding techniques have not altered since the pre-war days but considerable improvements have been made in the method of controlling the welding parameters and also to the machine design in order to meet the present day rail requirements with emphasis on weld joint alignment and the facility to handle the variety of rail steels currently being produced including the wear resistant grades.

The method employed for removing the weld upset has also changed considerably over the years. Initially, the upset was removed by manual chipping followed by hand grinding operations. The efficiency of this technique left much to be desired and was entirely dependent on the skill of the operator. History shows that hand chipped and ground welds gave rise to fatigue failures after the rails had been in service for several years.

The current design of rail stripping equipment whether incorporated within the welding machine or of free-standing design is capable of removing the weld upset to close tolerances. With such stripping equipment, very little grinding is required to achieve the desired finish standards.

The various options to carry out flash butt welding of rails are at:

i) Fixed site depot
ii) Mobile depots
iii) In situ

2.5 Flash butt welding of rails at fixed site depots

At fixed site depots, the rail welding machine, together with ancillary equipment, is housed in permanent or semi-permanent buildings with motorized conveyors transferring the rail from the incoming rail storage tables to the welding, stripping, grinding, pressing and inspection stations. A welding production line consists of a number of operational stations :

1) Rail Storage and transfer table
2) Rail straightening
3) Rail end cleaning
4) Welding
5) Stripping
6) Post weld treatment
7) Rail joint straightening
8) Rail head profiling
9) Inspection
10) Outgoing conveyor system.

2.6 Preparation of rails to be welded

It is essential that the overall rail and particularly the rail ends are presented for welding within the tolerances specified. The criteria for suitability of rails for welding have been laid down in 'Manual for Flash Butt Welding of Rails'.

Rails which do not meet geometrical standards, have to be straightened before welding using a pre-straightening machine.

To ensure proper electrical contact between electrodes of the welding machine and the rail section, the rail end should be thoroughly cleaned to remove all loose scales, paint and rust. This is achieved in practice by brushing and shot blasting/grinding. Cleaning of rail bottom should be ensured by placing a mirror and watching the cleaned surface. Oil and grease, if present, should be removed by Carbon Tetrachloride or Benzene.

2.7 Sequence in the process of flash butt welding

Following sequence is adopted in stationary flash butt welding plants :

1) Aligning
2) Initial burn off
3) Pre-heating
4) Flashing
5) Forging (upsetting)
6) Stripping
7) Post straightening
8) Water cooling

The mobile flash butt welding gives continuous flashing instead of initial burn off, preheating and flashing cycles separately.

2.7.1 Aligning

The running surfaces of rails at interface should be aligned carefully to avoid any 'step' defect on one side of the rail. The fully aligned side of welded panels should be distinctly marked.

2.7.2 Initial burn off

During the initial part of the welding cycle, irregularities of the component interfaces are burnt off to make the end surfaces smooth and parallel so that when pre-heating takes place, the weld current can flow over the complete weld interface.

2.7.3 Pre-heating

The rail ends are brought into contact to allow a low voltage high amperage current to flow which pre-heats the rail ends. The moveable rail is alternatively moved backward and forward producing a series of electrical contacts with the fixed rail end. Thus the rail surfaces are heated upto the red hot stage. The pre-heating cycle is executed in a fully controlled automatic mode, once the parameters are selected.

2.7.4 Flashing

Flashing involves moving the rail in continuous manner initially at a uniform speed but during the last few seconds, at an accelerated rate. The flashing speed is so arranged that the rail ends burn-off without short circuiting or giving rise to an open circuit condition.

2.7.5 Forging (upsetting)

The movement is accelerated and rail ends are butted together to a stage of fusion under a heavy butting force. The welding current is cut off during the later stage. The joint should be kept undisturbed in clamped position for ten seconds after the welding cycle. The following butting pressure is recommended for different types of rails:

- 72 UTS Rails – 5 kg/mm^2
- 90 UTS and Head Hardened Rails – 6 kg/mm^2
- 110 UTS Rails – 7 kg/mm^2

2.7.6 Stripping

The stripping is done either manually using pneumatic chisel or by automatic stripper. The automatic stripper may be integral with the welding plant or installed separately. The automatic strippers strip the hot upset metal all round the rail section.

In case of manual stripping, the recommended width of flat chisel is 50 mm for removal of upset metal from junction of head and web. For removal of upset metal from web and foot junction, half round chisel should be used. Care should be taken to ensure that chipping does not create any notches or under cutting. The automatic stripper can be integral with welding plant or installed just adjacent to welding machine or at 13/26 m distance from it.

2.7.7 Post straightening

A post straightening machine is installed at suitable distance from the welding machine for straightening the joint, if required.

2.7.8 Water cooling

It is desirable to do post straightening after the weld has cooled down to ambient temperature. For cooling the weld, water spray cooling should be adopted. It should be done at suitable distance from the welding plant where the temperature of the weld is not more than 350 degrees Celsius which is normally achieved after 7-8 rail lengths.

2.8 Finishing and Marking

2.8.1 Finishing

The top, side and bottom surfaces of the rail head are ground smooth so that the weld surface is flush with parent rail surfaces. Care should be taken to ensure that the grinding does not burn or notch the rail surfaces. Grinding should be done preferably using a profile grinding trolley. After grinding the top table and sides of the rail head should comply with the laid down geometric tolerances.

2.8.2 Marking

Every joint should have distinctive mark indicating the weld number, month and year of welding and the code of the welding plant. The joint is given a alpha-numeric marking XXXX MM YY AAA where first four digits indicate the weld number starting from 0001 for first weld of every month, the next two digits indicate month of welding followed by last two digits of the year & the three letters at the end being the code of the welding plant.

2.9 Testing

Each weld is required to undergo acceptance tests namely visual inspection, dimensional tolerance check and ultrasonic test. In addition, samples are subjected to transverse bending test and metallurgical tests. The tests are to be carried out as per the procedure given in the 'Manual for Flash Butt Welding of Rails'.

- The weld should be visually inspected for possible cracks, lack of fusion, surface defects like notching and damage in heat affected zone. Welds with visible defects should be rejected.
- Dimensional check should be carried out as per the provisions of 'Manual for Flash Butt Welding of Rails.'
- The entire cross section of the weld should be subjected to ultrasonic testing either by on-line testing equipment or by portable machines. The testing and subsequent action should be carried out as per 'Manual for Ultrasonic Testing of Rails and Welds.'

Sample tests are to be made on pieces of rail of similar section and specification as per laid down frequency. These sample are then subjected to following tests:

- **Hardness Test** – Brinnel hardness test should be conducted before conducting transverse load test. The hardness value should not vary from the hardness of parent rail by more than 20 BHN.

- **Transverse Load Test** – The weld samples should be subjected to transverse load test as per the provisions of 'Manual for Flash

Butt Welding of Rail.' The breaking load and minimum deflection at center have been specified for different rail type and rail section.

- **Macro examination** – One test joint for every 5000 joint is subjected to macro examination. The examination aims at detecting cracks, lack of fusion, oxide inclusion and extent of heat affected zone.

2.10 Post weld controlled cooling treatment for 110 UTS alloy steel rails

110 UTS Cr-Mn alloy rails are required to be subjected to controlled post weld cooling treatment so as to avoid formation of undesirable micro-structure and cracks in weld and heat affected zone.

2.11 Post weld air quenching treatment for flash butt welding of head hardened rails

During welding of head hardened rails the average hardness of the heat affected zone of the rails becomes considerably less than that of parent rail. This low hardness is due to transformation of rail steel occurring at cooling rate much lower than that achieved during the original head hardening operation. Such hardness difference can lead to differential plastic deformation which may cause localized cupping on the welds. Head hardened rails must, therefore, be subjected to controlled cooling treatment to improve the hardness in heat affected zone.

2.12 Manual for flash butt welding of rails

In order to regulate the method of flash butt welding of rails on Indian Railways a Code was brought out by RDSO in 1972 for practice of flash butt welding of rails. It was subsequently revised and brought out as 'Manual for Flash Butt Welding of Rails, 1996.' The Manual has been reprinted in 2004 after incorporating Addendum and Corrigendum Slips. The Manual covers interalia the following :

1) Selection of rails to be welded
2) Suitability of rails for welding
3) Preparation of rails to be welded
4) Procedure of welding of rails :

- Execution of welding
- Post weld heat treatment
- Records of welds
- Post weld straightening
- Finishing of weld
- Marking of joints

5) Inspection and testing of each weld

- Visual Inspection
- Dimensional check
- Ultrasonic Test

6) Sample testing

- Hardness test
- Transverse test
- Metallurgical test

The Manual also contains following annexures:

- Post weld controlled cooling treatment for 110 UTS Alloy Steel Rails.
- Post weld air quenching treatment for flash butt welding of 60 Kg Head Hardened Rails.
- Record of welds.
- Finishing tolerances for welds.
- Precautions to avoid defects in flash butt welded joints.
- Proforma for record of Dimensional check, Ultrasonic testing, Hardness tests and macro examination of welded joints.
- Handling instructions for 90 UTS and Head Hardened Rails
- Check list for Flash Butt Welding Plants.
- List of minimum equipment & machines required for Flash Butt Welding Plants.

For details, the Manual may be referred to.

2.13 Stationary flash butt welding units

The latest stationary flash butt welding machines have a number of advanced features (Fig.1).

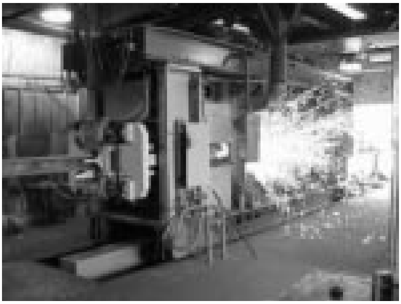

Fig. 1 : Welding by stationary flash butt welding plant

These include :

1) High strength clamping units
2) Capability for welding rails upto 70 kg/m
3) Provision of aligning (anti–twist) devices
4) Post-heat treatment facility
5) Automatic stripping devices
6) Automatic alignment sensor.

2.14 Mobile Flash butt welding units

Mobile flash butt welding of rails was introduced in 1973. Since then it has been widely accepted as a process for field welding of rail joints (Fig.2).

Fig. 2 : Flash butt welding by mobile unit

The mobile flash butt welding machines are either built in standard railway vehicle or as containerized units. In case of machines built on standard railway vehicles, the welding head is positioned between the bogies and can be lowered for welding in running track. In other machines a standard 20 foot intermodal container contains the welding system. The container is set on self-propelled rail bound car or rail-cum-road vehicle.

The containerized units can be used for welding in track or on cess. On the other hand, the standard vehicle machines can be used only for welding in running track. The new machines are fully computerized. Once the welding head is in position, the entire process is carried out automatically at the push of a button. The quality of weld is same as in the case of stationary flash butt welding. The main components of a mobile flash butt welding machine are welding head, control system, diesel engine, generator and rail tensioning unit.

The latest mobile flash butt welding units are being provided with computer based data recording system to maintain quality control. Weld data can be displayed on the monitor or printed. Weld records are also stored in the computer and are available for analysis.

2.15 Precautions to avoid defects in flash butt welded rail joints

1) *Oxide inclusion*: The rail end faces and the adjoining surface of the rail profile upto a width of about 25 mm all round should be cleaned properly by portable grinders or brushing machine or shot blasting before welding to remove loose scale, rust, scabs, dust, paint etc.. Oil and grease, if present should be removed by Carbon Tetra Chloride or Benzene.

2) *Lack of fusion*: Preheating cycle, flashing time and butting stroke as standardized for the respective sections should be strictly maintained during welding to avoid this defect. Attempt should not be made to weld higher section rails with welding plant of less butting force. Welding of higher UTS and higher section rails on low butting load plant by

increasing number of pre-heats causes very pronounced heat affected zone and is detrimental to the service life of the weld. Therefore, butting pressure recommended in the Manual For Flash Butt Welding of Rails (5 kg/mm^2 for 72 UTS, 6kg/mm^2 for 90 UTS and head–hardened; and 7 kg/mm^2 for 110 UTS) should be strictly adhered to.

3) *Poor joint due to defects in rails*: Rail ends having cracks, hit marks and other visible rolling defects should be cropped before welding.

4) *Notches and chisel marks adjacent to the weld joint*: During stripping by chiselling and finishing by grinding care should be taken so that notches, dents or chisel marks are not formed on the rail surface as these flaws may act as stress raisers in service, leading to premature failure.

5) *Copper penetration/arcing on rail foot bottom surface*: During flash butt welding, the two copper blocks (electrodes) below the rails get worn out and grooved / dented due to rail movement. Besides, after the flashing / burning off operations, lot of metal oxides are deposited on the copper blocks. Due to this current flow between the rail foot surface and copper block is not continuous. This results in arcing and local melting/ denting and even copper penetration at the rail foot surface. Therefore, after each operation loose oxide/metal should be cleaned by brushing the copper block (electrode) surfaces and the copper blocks should be periodically reconditioned or replaced with new ones.

6) *Use of treated water for cooling system*: The pipes for circulation of water for cooling are, generally, of small size. Due to presence of impurities in water, scaling takes place on inside of the pipes resulting in inadequate circulation of water. Therefore, suitably treated water should be used for cooling system. The welding plant should not be operated if the cooling system is non-functional.

7) The air pressure and voltage/current recommended by the manufacturers must be ensured.

8) The quality of flash butt weld is also dependent on rail end geometry. Excessive bend in rail ends adversely affect the quality of welds. It is possible to rectify bends in the rail ends by pre-straightening. However in case of severe bend, on straightening the bend gets transposed towards the middle of the rails. Therefore, it must be ensured that the rails being welded satisfy the laid-down geometric tolerances,

2.16 Comparison of flash butt welding with thermit welding

The flash butt welding of rails is considered superior to thermit welding on various grounds. These include :

1) The flash butt welding of rails is a forging process and , as such, the strength of joint is almost as much as the strength of the parent metal. Deficiencies such as porosity, inclusions and lack of fusion are avoided. On the other hand thermit welding is a casting process and, therefore, susceptible to deficiencies like porosity, inclusions and lack of fusion.

2) Flash butt welding of rails is an automated process and, hence, less dependent on operator skill. This also results in consistent quality.

3) In case of flash butt welding of rails Heat-Affected Zone is less as compared to thermit welding.

4) Flash butt welding of rails causes less environmental pollution as emission of toxic gases is relatively less as compared to thermit welding.

5) Flash butt welding of rails is safer from personal health considerations as there is no molten metal mass.

2.17 Handling of rails in flash butt welding plants

(As per RDSO's Manual of Instructions on Handling of Rails, 2000)

1) Single Rails should be unloaded from BFR's with the help of specified magnetic lifting devices. In case magnetic lifting devices for rails cannot be provided in Flash Butt Welding Plants, all

handling of single rails should be done with electric hoists and spreader beams.

2) 39 m long rails should be unloaded from BFR's with help of specified magnetic lifting devices. In case magnetic lifting devices for rails cannot be provided in Flash Butt Welding Plants, all handling of 39m rails should be done with synchronized electric hoists and spreader beams.

3) 10/20 rail panels rails should be handled with help of specified magnetic lifting devices. In case magnetic lifting devices for rails cannot be provided in Flash Butt Welding Plants, all handling of 10/20 rail panels should be done with synchronized electric hoists and spreader beams.

CHAPTER III

ALUMINO THERMIC WELDING OF RAILS

3.1 Introduction

Alumino thermic welding is a process that produces coalescence of metals by heating them with superheated molen metal from an alumino thermic reaction between a metal oxide and aluminium. The alumino thermic process is extensively being used world over for joining the ends of the rail. Alumino thermic process, known as Gold Schmidt process was developed in 1896 by a German chemist, Professor Hans Gold Schmidt. Alumino thermic process is based on the chemical reaction of iron oxide with aluminium. The reaction, being ‘exothermic’ is associated with heat generation. Depending upon the particular oxide of iron used as shown below, the reaction can liberate heat energy sufficiently high to even vaporize the resultant iron. However, heat losses, which invariably occur, ensure that iron in molten state is available. The reaction process can be described by the following equations:

$$3Fe_3O_4 + 8Al = 4Al_20_3 + 9Fe \ (3088^0C, 719.3 \text{ kcal})$$

$$3FeO + 2Al = Al_20_3 + 3 Fe \ (2500^0C, 187.1 \text{ kcal})$$

$$Fe_2O_3 + 2Al = Al_20_3 + 2Fe \ (2960^0C, 181.5 \text{ kcal})$$

Different thermit welding processes may use any combination of iron oxide and aluminium as shown above, in different proportions, to achieve the objective of correct resultant temperature of molten metal of required quantity. After the exothermic reaction lasting a few seconds, approximately equal volumes of molten steel and liquid Al_20_3 are separated at a temperature of about 2400^0C. Al_20_3 (slag), being lighter, floats on top of the molten metal. The iron obtained from such a reaction is soft and is unusable as a weld metal for joining rails.

To produce an alloy of correct composition, ferro-manganese is added to the mixture together with pieces of mild steel to control the exothermic reaction and increase the recovery. Also by adding appropriate alloying elements and varying their quantities, the wear resistance of thermit steel can be largely matched to that of the various grades of rail steel to be welded. Thermit rail welding process being essentially similar to a foundry process, certain properties like complete slag exclusion within short time, better fluidity of molten metal etc. are also necessary which are achieved by further addition of certain compounds like calcium carbonate, fluorspar etc.

Precise weights of the constituents are necessary such that after reaction, there remains a small excess of aluminium in the weld metal (say 0.4% by weight). Too little aluminium in the mixture will result in oxidation and loss of carbon and manganese from the weld steel giving a weld-metal with poor wearing characteristics, and possibly a dangerously violent reaction due to the evolution of carbon monoxide. Excessive aluminium may lead to hardening and brittleness of the weld metal.

Such a ready made mixture of appropriate constituents in correct proportion and particle size is termed as 'Portion' and is specific to rail section, metallurgy of rails to be joined and the particular patented process adopted. Indian Railway Standard Specification of Fusion Welding of Rails by Alumino Thermic Process (IRS-T-19-1994) deals with technical requirements for Thermit welding like supply of the 'Portions', Acceptance tests, approval of 'Portion Manufacturers', disposal of rejected portions, procedure for approval of A.T. Welding supervisors and welders, acceptance test of joints welded at site etc.

3.2 Principle of alumino thermic welding of rails

The objective of the alumino thermic process is to apply it for joining two pieces of rail, end to end, by casting molten 'steel' into a refractory mould that has been placed around the spacing between the two rails. The ends of the rail must be straight and the correct welding gap established. The rails must be properly aligned with the faces free of rust, dirt & grease. The rails must then be preheated sufficiently to provide conditions for complete fusion between the molten steel and the base metal of rails to be welded.

Even though it is called a welding process, thermit welding resembles a metal casting where proper gates and risers are needed to :

- Compensate for volume shrinkage during solidification
- Eliminate typical defects that appear in castings
- Provide proper flow of the molten steel and
- Avoid turbulence as the metal flows into the joint.

The thermit reaction is carried out in a conical metallic shell lined with magnesite, called 'crucible', prior to tapping into the moulds. Although thermit reaction is non-explosive, the presence of any moisture is not only detrimental to the success of the weldment, but also potentially dangerous to the welders. During the solidification process of the molten steel, it is critical that no movement, shock or vibration occurs in the rail. The weld must be cooled prior to allowing any traffic to cross the completed weld or to release a hydraulic rail tensor if used during the welding process. For manufacturing good quality alumino thermit welds, RDSO has issued a 'Manual for Fusion Welding of Rails by the Alumino-Thermic Process', which should strictly be followed.

3.3 Rail welding by alumino thermic process

The general principle of thermit welding process as explained earlier is used by several agencies with specific details and specifications for the various stages viz ;

(i) Rail end preparation
(ii) Rail end alignment
(iii) Moulds preparation
  a) Mould selection
  b) Mould installation
  c) Mould packing
(iv) Choice of portion as per rail type and section
(v) Crucible assembly preparation
(vi) Preheating of rail ends
(vii) Ignition of welding portion in the crucible & Tapping
(viii) Mould waiting and stripping
(ix) Finishing of welded joint

Indian Railways used conventional thermit welding process for more than 20 years, before switching over to quick thermit welding with short preheat/SKV process as a standard welding process in the field.

3.4 Quick thermit welding with short pre-heat (SKV process)

The quick thermit welding with short pre-heat (SKV), despite all the improvements, still requires great care by the welders and supervisors during execution. For executing good quality welds, following documents should be referred to;

i) Indian Railway Standard Specification for fusion welding of rails by Alumino-thermic process (IRS-T-19-1994)

ii) Manual for fusion welding of rail joints by the alumino-thermic process (Printed in Sept.1998).

iii) Instructions issued from time to time for improving the quality of welds and to contain weld fracture.

3.4.1 Process Specification

3.4.1.1 Suitability of rails for thermit welding

To ensure longevity of thermit weld, it is essential that only good quality rails are used for thermit welding. Good quality rails means fulfillment of the following requirements:

- Rail wear (head & side) should be within permissible limits.
- Rail should be ultrasonically tested.
- Rail should not be twisted or warped.
- Rail ends should not be hogged or battered.
- Rail should not be corroded.
- Rail ends should not be flame cut.
- Rail ends should not have bolt holes within 40mm from the rail ends. If bolt holes are existing within this limits, then microcracks on periphery of the hole will propagate in the weld metal and cause weld fracture.

- In case of second hand rail, rail ends may be cropped to suitable distance to eliminate bolt holes and heat affected zone if any.
- The process has been approved for different rail ‘sections’ i.e. 90R, 52kg., 60 kg etc. and ‘type’ i.e. MM, 90UTS, CrMn & Chrome-Radium alloy steel (110 UTS) & head hardened rails. The process can, therefore, be used only for those rails for which the process has been approved as per section and type of rails.
- Rails should be free from excessive corrosion, reams, laps in flange, excessive wear at rail seat, scabs or wheel burns and corrugations.
- For both new as well as second hand rails, before welding, it should be ensured that the end bends of the rails are within +0.5mm, -0mm in vertical and $\pm$0.5mm in lateral direction, when checked with one metre straight edge.
- While using second hand rail panels for secondary renewals, released from LWR/CWR sections, the ends should be cropped to eliminate fish bolt holes. If rail ends do not have bolt holes, the ends may be cropped to a distance of 150mm for AT welds and 85mm for flash butt welds from the center of welded joint to eliminate HAZ. End cropping may be suitably increased so as to ensure end bends within the permissible tolerances.
- No alumino-thermic welded joint shall be located closer than 4m from any other welded or fishplated joint.
- An abrasive disc cutter should preferably be used for cutting the rails (Fig. 3.1).

Fig. 3.1: Abrasive disc cutter

Many weld failures show evidence of badly cut rail ends. The squareness, evenness & verticality of rail cut depends solely upon the skill of the welder. With portable disc cutters, very little skill is required to produce a perfect cut. For achieving good quality weld such equipment is desirable.

3.4.1.2 Preparation of rail ends for welding

a) Rail fastening should be loosened/removed for at least five sleepers on either side of the joint.

b) The sleepers should also be shifted so as to have a clear working space of 250mm on either side of the joint.

c) Burrs/metal flow at rail ends, if any, should be removed by chiseling/grinding.

d) The rail end faces and the adjacent sides upto 50mm i.e. foot, top & bottom should be cleaned with wire brush or any suitable material to remove all dirt, grease and rust and wiped clean with kerosene.

e) Stipulated gap, as specified for a particular welding technique, must be ensured (Fig. 3.2).

Fig. 3.2: Adjusting the initial gap

With a smaller or wider initial gap (caused either due to poorly cut rail ends or poor positioning of rail ends or because contraction/ expansion in LWR/CWR sections), a weld failure may occur if

i) the gap is narrow, the flow of the flame, for preheating the rail ends, will not be proper and may cause local melting. The observation of a melting rail head may even prompt executing the weld, even though the base of the web may not have been sufficiently pre-heated. Narrow or uneven gaps may reduce the flow of molten steel to the rail ends, thereby reducing the possibilities of achieving proper fusion.
ii) the gap is too wide, the rail ends come in contact with only the outer envelop of the pre-heating flame, thus leading to less pre-heating. Also, there may be a possibility of dipped weld because of shortage of metal.

f) The underside of rail foot of both the rail ends must be inspected for any crack. Sometimes rather than cutting the rail completely through its section, the welders use sledge hammer to separate the rail ends even when the rail foot has not been completely cut. This is a wrong practice which may damage the rail and finally the weld. If any defect is found on the underside of rail, the damaged portion of rail should be removed.

g) In case of 'cess welding' full rail length should be supported level on at least 10 wooden blocks on either side.

h) The rail ends to be welded should be aligned both in horizontal and vertical planes with great care, using wooden wedges applied firmly on both sides of each rail so as to obtain a dimensional accuracy as given in the Manual for fusion welding of rails by Alumino-Thermic process (Fig. 3.3).

Fig. 3.3: Alignment of the rails

The purpose of the alignment of the rail ends is to properly position the rail ends such that, after the weld has been completely cooled to ambient temperature, the welded joint is perfectly flat and straight, with no twist between the vertical axes of the rail ends. On completion of alignment, datum marks should be given on the foot of both rails and the sleepers to detect any longitudinal movement of rails. If the gap is found beyond the prescribed limits, welding shall not be done.

3.4.1.3 Fixing moulds & other assemblies

a) Proper mould should be selected for the rail ends to be welded.

b) Each section of the pair of moulds or base plate in case of three piece mould must be inspected so as to ensure that:

- Moulds are of correct size.
- Moulds that are wet or have evidence, as having been wet should not be used. These moulds should be disposed off properly.
- Broken moulds should not be used.
- Pouring channels and riser holes should be cleared of any obstruction or fins.

Dampness in moulds can lead to porosity and early fatigue failure of welds. As prefabricated moulds have a tendency to absorb moisture from the atmosphere. Therefore, moulds they should be packed in moisture proof polythene bags.

c) Mould shoe fixed with moulds should be of correct size and free from geometric distortions (Fig. 3.4).

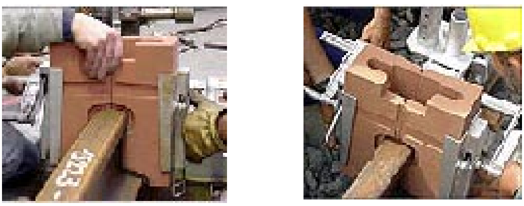

Fig. 3.4: Fixing of moulds and mould shoes

d) Mould shoe fixed in with moulds should then be placed central to the joint gap and fixed in position by tightening the swivel arms designed for the purpose. It is essential that two halves of the moulds fit flush to each other all around, especially at the bottom of rail flange which can be checked by feeling with fingers across the junctions of the two halves and also by looking through the riser aperture.

e) After fixing of the mould shoes, luting of the junction of the mould should be done, starting from the underside of the rail foot and continuing on both sides towards the head of the rail, and using only luting sand with minimum moisture content (6%) supplied for this purpose. To avoid any sand particle dropping into the mould, a luting cover may be placed over mould aperture (Fig. 3.5).

Fig. 3.5: Luting

Improper luting may result in leakage of weld metal. It may lead to formation of a 'fin' at the underside of flange which may lead to development of half moon crack under repetitive loading and may cause the failure of weld.

f) To protect the adjacent rail table from metal splashes during reaction, the rail surface adjacent to the mould on either side should be covered with clay, or preferably with prefabricated sheet cover plates.

g) Slag bowls should then be fitted to the lugs on the outside of the mould shoes.

h) The sand core (fitted with a metal ring) should then be placed in pouring aperture of the mould to ensure correct seating and then removed.

3.4.1.4 Crucible

a) The crucible lines with refractory material should be preheated from inside to remove moisture with the pre-heating torch before making the first weld. It is not necessary to redo this heating for subsequent welds unless the crucible gets damp. Preheating should be done from top to bottom.

Failure to properly dry the crucible may cause the following:

- A defective AT weld that is full of porosity
- Very high steam vapor pressure, created instantaneously by the reaction of the hot steel and moisture in the refractory material. This causes a rupture of the bond of the refractory material in the crucible.
- Danger of hot steel splashing forcefully out of the crucible causing serious personal injury.

b) Slag should be cleared from the crucible side walls after each weld.

- The pouring gate with thimble is designed to have a precise diameter, specific for the process. While cleansing it with a thimble drift, care should be taken not to damage the orifice of the thimble. Thimbles with enlarged orifice should be replaced. Proper seating of the thimble is very important.

Improper seating of the thimble or application of the plugging material may :

- cause premature tapping of the molten weld metal, due to a bypass of the thimble or in the event the thimble being cracked.
- prevent the molten weld metal from tapping into the moulds if any of the plugging material falls on or into the center of the self tapping thimble.

c) The crucible should be placed on the crucible fork fixed to swivel stand on a universal mounting. The crucible should be located in a proper position such that the tapping hole is central to the pouring gate of the mould and at a height of 50mm from the top of the pouring gate. Inaccuracies in these are likely to result in turbulent flow of molten metal.

d) The tap hole in the crucible should then be covered with a closing pin, the head of which should be covered with asbestos pulp and alumina slag. This heat seal enables the welder to tap the molten metal at the precise time he desires.

e) After adjustment of the crucible to obtain correct pouring position, the crucible should be swung clear of the moulds for charging.

In case self tapping thimble is being used for an approved welding technique, self tapping thimble shall be inspected to ensure that it is not wet or cracked.

3.4.1.5 Portion

a) The portion being hydroscopic in nature, should have double packing, first in a polythene bag and then in a cloth bag. Damaged/torn polythene bag may result in moist/damp portion and should not be used.

b) The 'acceptance slip' for the portion given by the RDSO shall be found inside the bag. RDSO's seal should be available on top of the bag. The portion should conform to IRS-T-19-1994.

c) The portion to be used must match the rail section, grade of rail and the welding technique. The portion should be poured into the crucible through fingers with a spraying action and striking the crucible wall so that the bottom plugging remains undisturbed. After filling the portion should be heaped at the center of crucible and a small recess made at the top into which the igniter can be placed.

d) One portion should not be mixed with any foreign material or any amount of additional portion.

f) The crucible cap should then be placed in position and an igniter (sparkler) hooked on to the crucible cap ready for use.

g) Particulars of portion contained in the acceptance slip such as Batch No., Portion No., Date of Manufacture, etc. should be recorded in a register kept for this purpose.

h) Portions should be absolutely dry. As the use of moist portions is prohibited, they should be discarded.

Note : The presence of moisture in the portion, in the crucible or on the work pieces can lead to the rapid formation of steam when the reaction takes place. This may cause ejection of the molten metal from the crucible and may be fatal in addition to lowering the quality of weld. Therefore portion, crucible and moulds must be stored in dry places.

3.4.1.6 Pre-heating

a) The rail ends should then be uniformally preheated with a specially designed torch appropriate to the fuel mixture used. Presently, on Indian Railways air-petrol mixture, compressed air petrol mixture and Oxy-LPG are being used requiring about 10-12min, 4-6 min & 2-3 min respectively to raise the rail end temperature to about 600^0 C (Fig. 3.6).

Fig. 3.6: Pre-heating of the rail ends

b) The pre-heating torches should not be bent or damaged or their holes blocked.

c) Positioning of the pre-heating torch in the mould box must be carefully adjusted because it affects the quality of pre-heating.

d) Recommended pressure should be ensured while pre-heating.

e) The ‘sand-core’ must be held using tongs over the pre-heating flame above the moulds for 30 second to remove any mixture.

Proper pre-heating of the rail ends consists of fulfilling three requirements namely;

i) Minimum pre-heat time
ii) Achieving proper and uniform colour of the rail ends.
iii) Observation of the entire preheating process to ensure that rail end(s) is not melted and there is no breakage of the mould.

f) The welder performing the pre-heat must watch the entire pre-heating of the rail ends from start to completion.

g) Rail ends and moulds must heat evenly. Uneven heat can cause internal cracking of the weld due to uneven cooling.

h) In the event a portion of the rail head or rail face of either rail end is melted, the weld must not be executed.

i) During the pre-heating process, a fairly usual occurrence may be the breakage of the mould. This is where a piece of the mould may break off and fall into the weld cavity. In the event this happens, welding should be stopped, the mould should be removed and disposed off properly and new mould installed.

j) In no event should the diverting plug or anything else cover or prevent the uninterrupted escape of the gases from the riser holes of the moulds during the entire preheating operation.

3.4.1.7 Execution of welding

a) After the pre-heating, the preheating torch is removed and the dried sand core placed in the central pouring apparatus of the mould.

b) The crucible is then swung into position centrally above the sand core, care being taken not to disturb the tapping pin.

c) The crucible cap is removed. The portion in the crucible is then ignited using sparkler by placing the igniter slowly and firmly into the center of portion and crucible cap is replaced.

d) After the reaction subsides, about 5 seconds should be allowed for separation of the slag from the metal. The molten metal is then tapped into the mould by pushing up the closing pin's shank with the tool provided for the purpose. The crucible should not move during tapping and no turbulence should occur while pouring.

In case of occurrence of boiling or vigorous reaction, because of moisture content in the portion or crucible or any other reason, the metal should be tapped outside and not in the mould.

i) Tapping time is very important for the final weld quality. Tapping time is defined as the total time, from the time the portion is ignited, till the molten weld metal begins to pour into the mould cavity.

ii) Premature tapping can cause high aluminium content in the weld metal with possibility of slag inclusion. Delayed tapping, on the other hand, causes loss of heat from the molten metal with the risk of lack of fusion.

iii) Off center pours will cause defective welds due to slag inclusion.

iv) Welding crew members shall be protected during the ignition of the thermit portion and pouring of the molten steel by wearing welding gloves and welding goggles.

v) During the initial violent phase of the reaction, all welding crew members must stand clear.

3.4.1.8 Stripping and trimming

a) On completion of pouring, the crucible is lifted off and slag bowls removed from the mould shoes.

b) The molten metal in the mould should be allowed to cool for a period as specified for that welding technique.

c) After the mould waiting time, the mould shoes should be taken off carefully.

d) Now with the use of hydraulic weld trimmer, mould from the top and sides is removed leaving atleast 1mm excess metal on the rail table for removal during final grinding. During trimming, it should be ensured that the wedges used for aligning are in their position without loosening and are not removed for at least 20 minutes after stripping or until removal of the insulation hood for controlled cooled joint (Fig. 3.7).

Fig. 3.7: Trimming operation by hydraulic weld trimmer

e) The risers should not be removed until cold, when they should be knocked off in direction of rail with a hammer (Fig. 3.8).

Fig. 3.8: Knocking of the riser

Prior to beginning of the mould stripping process, the welder incharge and the crew member, shall plan for the following:

i) After removal the hot crucible must be placed after removal on level & dry area.
ii) The slag pan must be placed at dry location.
iii) The used mould, slag & risers shall be buried after the weld has been completed.

3.4.1.9 Grinding

a) Finish grinding of rail top and sides should be carried out by power grinders (Fig. 3.9).

Fig. 3.9: Grinding operation

b) Grinding should commence only after removing the wedge kept for joint alignment and putting back the fastenings.

c) Final grinding should be done to the original profile of the rail as per the dimensional tolerances prescribed in the Manual on Fusion Welding of Rails. The best finish grinding results on the running surface of the rail head are achieved when the weld has completely cooled to ambient temperature.

3.4.1.10 Post welding work

a) Special alloy steel rail joints (Cr-Mn and Cr-Vanadium type) are required to be slowly cooled and hence immediately after trimming, specially designed insulation hood should be fixed around the joint for the time as prescribed for that particular welding technique.

b) As per Manual for fusion welding of Rails, the first train on a welded joint should be allowed after at least 30 minutes have passed after pouring the molten metal but at restricted speed.

c) Sleepers on either side of the welded joint, which were earlier shifted to make working space, should be repositioned to the desired spacing and packed.

d) All weld joints, till they are ultrasonically tested and found acceptable, should be kept joggle fish plated.

3.4.1.11 Marking

Each joint shall have a distinctive mark indicating month, year of welding, agency, welder's code and weld number on the web of the rail in the vicinity of the welded joint. The details for the same has been given in the Indian Railway Standard Specification for Fusion Welding of rails by Alumino-thermic process. Superviser in charge of the welding crew shall be responsible to ensure the correct marking and identification of completed thermit weld.

3.4.1.12 Record

A record of all thermit welding done should be maintained by the SE (P.Way) as per the instructions contained in Manual for fusion welding of rails by the Alumino-Thermic Process.

3.4.1.13 Inspection & acceptance tests

Details of inspection and acceptance testing have been contained in Indian Railway Standard Specification for Fusion Welding of rails by Alumino thermic process.

3.5 Quality control during execution of welds

3.5.1 Verticality of rail cuts

Rail ends are to be cut vertically, providing a gap of 24-26mm between rail ends. This can be achieved by using abrasive rail cutting discs with cutting guide. Use of abrasive rail cutting discs with cutting guide should be made mandatory so that dependence on the skill of the operator for production of vertical rail cuts is eliminated.

3.5.2 Maintenance of gap between rail ends

Maintenance of correct gap and verticality of cut are important for quality of welds. If the gap is inadequate, the flow of pre-heating gases over the rail ends will be reduced. This may cause local melting where the flame impinges and relatively cold condition at the base of the web. Inadequate gaps or non-verticality may reduce the flow of molten steel to the rail ends, inhibiting fusion. If the gap is too wide, the rail ends contact only the outer periphery of the pre-heating flame. This would mean increased preheating time and longer line occupation time for welding. Variation in rail end gaps may also occur as a result of temperature variations in long unrestrained rails and also in in-situ welding in long welded rails if tensors are not used.

3.5.3 Positioning of moulds

Positioning of the moulds central to the rail gap is very important for uniform pre-heating and proper fusion of rails & weld. Many weld failures when investigated show that the moulds had not been placed central to the gap, as a result of which, the rail end farthest from the flame tip did not get preheated adequately and the fusion had not taken place at this end. The weld metal in this case gets poured off-centre of the rail end gap.

3.5.4 Pre-heating time

Preheating is used to :

- Reduce shrinkage stresses in the weld and adjacent base metal
- Provide a slower rate of cooling through the critical temperature range

For satisfactory fusion of the rail ends, the weld metal should be poured over the rail ends so as to penetrate them, washing away the surface oxidation thereby achieving fusion. For this, the rail ends have to be preheated. Preheating also eliminates all traces of moisture. The rail ends are enclosed in CO_2 hardened silicon moulds with casting and preheating cavities. Preheating is carried out from above the rail. Preheating temperature specified is 600^0 C with tolerance of $\pm$ 20^0C.

The gas pressures and flow rates have to be controlled to avoid overheating of the rail head, at the same time giving a reasonably short preheating time. The height and position of the burner above the rail ends also have to be correct.

3.5.5 Reaction time and tapping time

The welding portion is heated in a separate magnesite lined crucible. The reaction is initiated using igniters inserted centrally in the thermit portion. The portion melts and the slag separates at the top, enabling tapping of the crucible to pour the molten metal into the mould.

It is important to select the correct tapping time as, both undertiming and overtiming of this operation affect the quality of weld. The tapping is to be done after the reaction s completed and the slag rises to the top. The reaction takes about 20 seconds. If tapping is done prematurely, slag separation will not be completed. Therefore slag may get entrapped within the weld metal. Aluminium content also will be high in such cases. If the tapping is delayed after the reaction time is over, loss of superheat takes place. Delayed tapping may thus result in lack of fusion.

3.5.6 Pouring of metal from crucible

The pouring of the molten metal has to be smooth and continuous. A bad tapping action or self tapping of the crucible, caused by inadequate insulation of the head of the mild steel tapping pen, may cause a turbulent intermittent pour, leading to oxidation of the weld metal. These oxides may form into “beads” or “plates”, both of which may cause weld failures in service.

3.5.7 Post cooling time

After pouring, molten metal is allowed to cool and solidify with mould intact for a period of 4 to 6 minutes. It is seen that the temperature of metal in the head of the rail after the mould intact period is over is about 1000^0C, which is much above the range of temperature of 500^0C to 800^0C critical for controlled cooling. Controlled cooling is necessary to produce the desired microstructure in the weld metal.

3.5.8 Surface finishing of welds

Geometry of the running surface of welded joints is very important as any imperfection gives rise to the following bad effects :

- Higher stresses in rails and welds making them fracture prone
- Damage to vehicle suspension
- Pulverising of ballast
- Damage to rubber pads/concrete sleepers
- Passenger discomfort

The defectively finished welds may be dipped, humped, or locally worn. These irregularities are either due to post grinding imperfections or due to use of weld metal of incorrect composition. These surface defects become more critical for higher speeds which call for higher standards of track surface. Track with poor rail geometry deteriorates faster than track with good rail geometry. This necessitates increased track maintenance frequency. Hence the solution to this problem lies in –

- Improved weld quality and geometry of rail welds
- Straightening of dipped welds.

Important measures to improve geometry of rail welds are:

- Correct initial alignment of rails
- Accurate measurement using straight edges and feeler gauges and adjustment of the rail ends such that they are set high at the time of welding to allow for differential shrinkage.

- Correct preparation of rail ends to get square ends and correct gaps and maintaining the gap during welding by the use of tensors.
- Grinding the weld when it is cool, to avoid dips during subsequent thermal contraction.

The operation of straightening of dipped welds consists of three stages :

- Controlled three-point vertical bending of the rail

- A machining process to smoothen the running surface across the weld.
- Effective packing of the ballast to support the weld.

This is a once-only operation. After this attention, the finished welds should require no attention to their geometry during the life of the rail (Fig. 3.10).

Fig. 3.10: Finished weld

3.6 Corrosion of welds

The presence of a weld reduces the corrosion resistance of welded joint for the following reasons :

- Compositional variation in the base metal, Heat Affected Zone (HAZ) and weld metal result in a condition favouring galvanic corrosion.
- Residual stresses due to welding induce stress induced corrosion.
- Weld discontinuities such as surface flaws and junction of rail and weld collar act as preferential sites for local corrosion attack.

For rail welds, by far the most important stress inducing factor is the collection of corrosive agents, especially discharge from toilets of coaches, at the junction of rail and weld collar. A thin collar weld or a collarless weld, apart from considerably improving the fatigue strength of welds, reduces the risk of corrosion induced failures. Hardened steel gets corroded more rapidly in acidic conditions. Treatments inducing alkaline conditions are expected to reduce corrosion of HAZ.The pH values substantially above 8 would be needed to suppress the corrosion effect completely. Coating or painting the welds and base metal to prevent corrosion in the region of stress concentration helps to enhance the fatigue strength of the welded joint.

3.7 Fatigue strength of welded joint

Fatigue cracks in welded joint tend to develop at regions of stress concentration due to weld shape, joint geometry, weld imperfections and welding residual stresses. It is, therefore, necessary to reduce the stress concentration to improve the fatigue strength of welded joints. This can be achieved by the following measures:

- Removing the weld re-inforcement on both sides of the joint by machining the weld to the level of the base metal or by designing collarless welds.

- Surface coating and painting the welds and base metal to prevent corrosion in the region of stress concentration.

- Smoothening the surface by removing dip in welds and smooth grinding the surface irregularities (most fatigue cracks originate at the surface.)

3.8 Genesis of common weld defects

3.8.1 Weld imperfections

Weld imperfections fall in three categories:

- Lack of fusion and solidification cracks. These features can substantially reduce the fatigue strength of a welded joint or cause initiation of brittle fracture.
- Volumetric imperfections such as porosity and slag inclusions. These reduce the load-bearing area of the weld and hence reduce the static strength of a joint.
- Geometric imperfections such as misalignment.

All the above weld imperfections have the effect of locally elevating the stress levels.

3.8.2 Weld defects

- Solidification behaviour in the fusion zone controls the size and shape of the grains, the extent of segregation, and the distribution of inclusions and defects such as porosity and hot cracks. It also controls weld metal microstructure, grain structure, and finally the weld metal properties.

- In solidification mechanics, the important parameters that influence microstructure are temperature gradient and alloy composition. In the final weld-metal grain structure, a coarse structure is susceptible to hot cracking whereas a finer grain structure is more resistant to hot cracking. It is therefore important to concentrate efforts on refining the fusion zone grain structure.

- Weld cooling rate substantially affects the volume of porosity in a gas contaminated weld. At fast cooling rates, the level of porosity is low, as the nucleation and growth of bubbles in the liquid are severely suppressed. Similarly, at very slow cooling rates, porosity is minimal because bubbles have ample time to coalesce, float and escape. At intermediate cooling rates the greatest volume of porosity in weld is observed.

- The sources of porosity are contaminants including moisture, oils, paints, rust mill scale and oxygen & nitrogen in the air. The rail ends to be welded and the consumables used for welding including the welding portions and the mould are to be cleaned and dried. Filler metal containing Aluminium, Titanium and Zirconium are known to act as deoxydizers in reducing porosity to acceptable limits.

- Hot cracking occurs during weld solidification. This can occur in the weld metal or in the HAZ, and is caused by low melting temperature constituents, apart from tensile stress induced in the weld during solidification shrinkage.

Cold cracks can occur in the weld fusion zone or in the HAZ and is due to tensile stresses (from external loading or residual stress from welding), martensite microstructure of steel or the presence of hydrogen.

3.9 Irregularities observed during field execution of welding

- Welding registers are the basic records which give data regarding execution of welds which have bearing on the weld performance. It is vital to have integrity of welding data. The welding registers maintained at site lack this integrity which makes it difficult to assess the performance of welding operations.

- For uniform preheating of the rail ends, the nozzle of the burner should have the correct geometry and alignment. Bend in the nozzle is not being checked at many sites. This aspect needs to be emphasized in the Manual for Fusion Welding of Rails by the Alumino-Thermic Process.

- Quality of moulds supplied by certain suppliers are, in some cases, inferior, resulting in contamination of the molten weld metal. The design of the mould has also not been laid down in the Manual resulting in variations in certain designs which are not acceptable.

- In concrete sleeper track, movement of sleepers to provide space for central placing of moulds involves strenuous manual labour. For this reason, cases of welds executed without central placing of moulds with respect to the rail end gaps are more in concrete sleeper track. This results in lack of fusion at one of the two rail ends.

- Welding registers maintained with integrity show many cases of welding done under restricted line occupation time. This seriously cuts into the post weld cooling time and has a great bearing on the life of the weld. The registers also show reaction time far exceeding the permitted time in respect of portions supplied by certain suppliers.

- Use of weld trimmer for removal of excess metal is restricted to very few welding sites. Where manual chipping is done, the tendency for the labour is to chip off the excess metal when it is hot, without allowing for the mould waiting time, as chipping is easy when the metal is hot.

3.10 Measures suggested to reduce weld failures

- A welding mixture which is able to cope up with welding conditions most likely to be achieved in field conditions particularly relating to preheating and chemical composition and microstructure comparable to that of rail steel needs to be designed. IRS-T-19-1994 Specification needs to be revised to include provisions to conform to this design.

- Preheating using oxy-propane instead of vaporized liquid fuel should be adopted to eliminate variation in quality and chances of underheating due to inadequate maintenance of pressure in the tank.

- Design of mould and crucibles supplied by different manufacturers differ. There is no guidance to the field staff as to the standards for moulds and crucibles fit for use in the field. The specifications for the moulds and crucibles with standard arrangement drawing should form part of the 'Manual For Welding of Rails By The Alumino Thermic Process'. The specification should also cover the need for cleaning of the crucible of excess slag before use, the criteria for replacement of crucible, and the height of crucible above the mould when placed on its support for welding operation.

- Use of alignment beam for achieving precise alignment of rail ends should form part of Alumino Thermic Welding operations.

- Residual stresses induced in the weld region due to thermal expansion and contraction experienced by the base metal, heat affected zone and the weld proper should be measured and studies should be conducted with a view to reduce these stresses.

- Technical requirements for controlled cooling should be clearly laid down for 90 and higher value UTS rails.

- Fatigue strength of welded joint can be improved considerably by removing/reducing the weld reinforcement on both sides of the joint. Reliability of ultrasonic testing and corrosion resistance also increases by this.

- The Manual may also contain provision regarding the correct dimensions and alignment of burner nozzles for preheating.

- Strict quality control should be exercised, both during manufacture and packing of weld portions and during field execution of welds.

3.11 Recent development in Alumino-thermic welding technology of rails

Alumino-thermic welding is widely used process for in-situ welding of rails all over the world and the same is the case with Indian Railways. Presently on Indian Railways approximately 5.5 lakh AT welds are being done every year. Welding joints executed by alumino thermic process are the weakest of all the welds and therefore prone for fractures. As per the statistics issued by RDSO, about 60% fractures occurring on Indian Railway are attributed to alumino-thermic joints. To reduce the total number of AT welding fractures quality of AT welding technique needs improvement. Several developments have taken place with a view to improve the quality of alumino-thermic weld such as:

i) AT welding technique with three piece mould.
ii) AT welding technique with compressed air petrol pre-heating.
iii) AT welding technique with Oxy-LPG fuel mixture.
iv) AT welding technique with 60/52 kg combination joint.
v) Wide gap (75 mm) welding technique for fracture repair.

3.11.1 AT welding techniques with three piece mould

At present AT welding of rail is being carried out with two piece mould. The detailed procedure of fixing of mould and its luting has been specified in the Manual. However, sometimes due to improper fixing of mould by untrained welders, the fins are created at the bottom of welds. The presence of fins at the bottom of AT welds acts as stress raiser for initiation of half moon fatigue cracks thereby reducing the life of the welds. To avoid the presence of fins, AT welding technique for 52 kg. 90 UTS rails with three piece moulds has been developed (Fig 3.11). It is expected that three piece moulds welding will be adopted on Indian Railways in a big way.

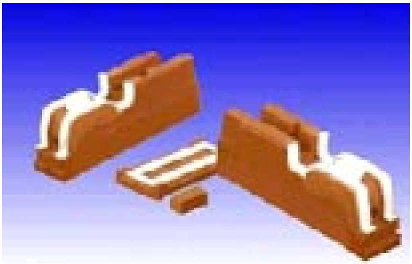

Fig. 3.11: Three piece mould

3.11.2 AT welding with compressed air petrol pre-heating

The compressed air petrol pre-heating technique, with preheating time of 4.0 and 4.5 minutes for 52 kg. (90 UTS) and 60 kg. (90 UTS) rails respectively, has been developed with a view to reduce preheating time and the heat affected zone. At present, the pre-heating time for SKV welding technique is 10 minutes for 52 kg. (90 UTS) rail section and 12 minutes for 60 kg (90 UTS) rail section. Therefore, compressed air-petrol pre-heating technique offers considerable reduction in pre-heating time and thereby saving of precious block time.

The Heat Affected Zone (HAZ) in a weld is the most vulnerable zone of AT weld and most of the AT weld failures take place through HAZ only. It is always desirable to have minimum possible width of HAZ. With the use of compressed air petrol technique, HAZ is reduced considerably because of shorter preheating time, thus increasing the service life of AT welded joint.

3.11.3 AT welding technique with Oxy-LPG fuel mixture

The Oxy-LPG fuel mixture can reduce the pre-heating time to 2-3 minutes because of the intensity of heat application and also resulting in the narrower HAZ. As the pre-heating time is considerably reduced, the requirement of block for executing the welding is also reduced.

3.11.4 AT welding for combination joint

On every railway system, more than one rail section is used depending upon vintage of rails and type of traffic. Moreover, at times, rails of two or more cross sections are laid on the same route. Often, it is required to insert glued joints, points & crossings or SEJs of rails having different cross-section. Earlier combination fish plates were used for joining of rails having different cross-sections. But, the combination fish plates result in battering, hogging of rails ends and also require periodical watch & maintenance.

An ideal answer to this problem is to replace the junction of different cross section of rails with forged junction of combination rails. But, there forged rails are required to be imported from foreign countries and which naturally cost much.

As an alternative, AT Welding technique for welding of 60kg (90 UTS)/52 kg (90UTS) rails joints has been developed. The use of this welding technique has resulted in improved riding comfort and improved maintainability (Fig 3.12).

Fig. 3.12: Combination joint

3.11.5 Wide Gap (75 mm) Welding Technique

AT present, the fractured rail/welds have to be replaced by long rail closure. This rail piece is inserted in the track after creating a gap of about same length and welded with the existing rail on both the ends. Thus, in order to remove one defective/fractured AT weld, two AT welds are created. The whole process of replacing the fractured/defective weld with closure rail piece involves considerable amount of man power and block time as well as wastage of rails. With the development of 75mm wide gap welding technique, the defective/fractured weld can be replaced with a single 75mm wide gap AT weld thus resulting in considerable saving of man power and block time required for execution of AT welds (Fig 3.13).

Fig. 3.13: Wide gap weld

The major procedural difference between the standard 25mm gap welding and 75mm wide gap welding arise mainly due to larger quantity of thermit steel in later. Because of increased volume, the heat content of thermit steel is greater which leads to slower solidification. Hence, temperature dependent post welding activities such as demoulding, trimming and grinding are slightly delayed. As a result, time required for execution of wide gap welding joint is slightly longer than one standard 25mm weld, but still lower than the time required for two 25mm standard weld.

Advantages of wide gap welding technique are:

- A single defective/fractured weld/rail can be replaced on one to one basis.
- It will not require insertion of a 6m rail piece.
- Less number of traffic blocks will be required.
- Lesser number of weld failures due to reduced number of welds hence improved safety.
- Saving in requirement of joggled fishplates.
- Lesser number of wooden blocks will be required.
- Substantial saving of manpower, material and increased availability of track for running of trains.

3.12 Project for acquiring state of the art alumino-thermic welding technology

With the objective of improvement in the quality of AT weld, a work to acquire state of the art technology to improve quality of Alumino thermic welds has been sanctioned by Railway Board under SRSF costing Rs. 30 crores.

The objective of the project is to acquire the state of the art technique of alumino thermic welding as a complete package encompassing entire gamut of activities involved in the welding. The package would involve improvement in the consumables and equipment, training of welders and supervisors and the latest technological advances in this field from global leaders. It is expected that the following aspects of alumino thermic welding would get upgraded.

3.12.1 Reduction in element of human error

This is expected through

- Use of One-shot Crucible
- Use of Auto Thimble
- Acquiring Skills

3.12.1.1 One-shot crucible

Used only for one weld, the one shot crucible is made from a refractory compound agglomerated by means of synthetic resin (Fig. 3.14). The thermic factor of this crucible is notably better than the conventional crucible and its use results in cleaner steel and consistent weld quality.

Fig. 3.14: One shot crucible

The need for accurate adjustment of crucible on its frame is eliminated. The one shot crucible comes factory packaged with the portion, crucible and automatic thimble. Various features of one shot crucible are:

- Light weight (14.5 Kg)
- Simple 4 step installation- align rail, install moulds, preheat rail and ignite
- Durability-the crucible is packed in an external protective sand layer.
- Environmentally sealed against outside elements.
- Moulds are available in both 2 or 3 piece type.

By having a constant and reliable crucible to produce the weld metal, quality of the weld is increased substantially mainly because of the fact that the thermal balance of the alumino-thermic reaction always remains the same. This ensures a highly uniform tapping temperature, which is one of the key quality parameter for alumino-thermic welding as for any steel production process.

3.12.1.2 Auto Thimble

The use of auto thimble ensures that the pouring commences at the correct temperature (Fig. 3.15). It allows tapping at pre-determined temperature thereby eliminating errors associated with manual tapping i.e. early or late tapping. In case of early tapping, slag may accompany weld steel. On the other hand, in case of late tapping, weld steel may loose heat which may cause inadequate fusion.

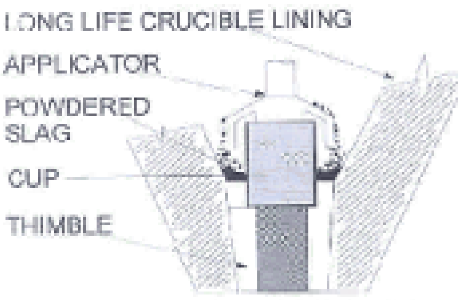

Fig. 3.15: Auto thimble

With use of auto thimble safety of personnel is also ensured as no person is required near the crucible thus eliminating the chances of injury.

3.12.1.3 Acquiring Skills

The execution is to be carried by the trained welders and supervisors of the firms from abroad. The quality control regime followed by them would be accessible and Indian welders/supervisors will be associated with the execution team to imbibe quality control measures.

3.12.2 Improved weld metal chemistry

The portions manufactured in the state of the art plant will be imported. These are expected to give consistent quality.

With above in view, following methodology has been adopted:

- Establishing superiority of technique (laboratory stage) - The firms are required to send internal test results for 5 welds using technique proposed to RDSO for evaluation.
- Establishing superiority of technique in Indian conditions (field stage) - The firms will weld 50 joints with their own welders, portions, consumables, supervisors in open line section. There should not be any defects when tested by USFD and weld should be free from fins, blow holes etc. Weld should survive at least 15GMT traffic without developing any defect/failure. Higher fatigue strength will be specified for these welds as compared to welds executed with existing technology. In addition, 50 welds will be executed by Indian Railway welders using the consumables and technique provided by the firm to provide exposure of the technique to Indian Railway welders. However, the welds executed by Indian Railway welders will not be used for various tests for evaluation of the technique.
- Extensive field trials - If the results during field stage are found satisfactory, Railway Board will place trial order on two firms for execution of 1000 welds in open line track with 30-40 GMT traffic density. This work is expected to be completed in a time frame of 6 to 8 months and the welds so executed will be monitored by

RDSO for a period of 1 year. Defective welds percentage of less than 0.2% when tested by USFD at the end of evaluation period will be the evaluation criteria for in-service trials.

3.13 Guidelines for safe welding

Safety of men and material is one of the important aspects during execution of Alumino-thermic welding. Here are some of the guidelines for ensuring safety during welding. It is assumed that the welding is being undertaken by fully trained welding operators and supervisors and that appropriate Thermit Welding techniques are being followed using approved equipment. These guidelines are for reference only and should not be taken as complete.

Hazards associated with the Alumino-thermic process can be minimized by appropriate welder training supported by correct welding technique, local safety instructions, use of safety protection, and correct maintenance and use of thermit welding equipment.

3.13.1 Specific hazard

Burns

There are a number of activities during the welding operations where burns of varying severity might be sustained:

- Cutting of rail ends (Flame or Abrasive disc)
- Hot rails (Following rail end preparation, after welding and final grinding)
- Thermit crucible drying, preparation for use (especially for manually tapped crucibles), during removal after tapping, or removal after failure to tap.
- From hot equipments such as preheat torches, weld trimmer, mould shoes(during removal), and crucible.
- From splashes of molten or hot metal- which may arise during manual tapping, or from abnormal conditions such as a run out or violent ejections from the crucible if water is present (wet portions, incorrectly dried crucible), slag pouring into damp slag bowls etc.

- From sparks from rail cutting, the alumino-thermic reactions, rail grinding
- Burns from fires and explosions.

Fire

Fires may occur as a result of bad practices or an accident and may involve bankside vegetation, rubbish, flammable gasses, petrol or petrol driven equipments.

Associated cause are:

- Sparks from rail cutting, alumino-thermic reaction, rail grinding
- Splashes of molten or hot metal
- Explosion
- Incorrect disposal of hot slag, or excess thermit steel
- Welding close to wooden sleepers

Explosion

May occur because of bad practices like:

- Incorrect use of flammable gases (acetylene or propane)
- Molten metal and / or slag coming in contact with water as a result of run out from moulds or crucible, or incorrect disposal of molten or hot solid slag.

Damage to eyes

Injury to eyes may arise from a number of causes during the welding process:

- Splintering of ballast or concrete sleepers resulting from shock heating from hot metal/slag splatter, carelessly directed cutting or preheating equipment, or during crucible drying.
- Fragments of flying slag during crucible cleaning and tapping thimble removal
- Glare from burning igniters, Alumino-Thermic reaction and molten metal/slag steam.

Flying objects

Risks may arise from flying components, such as:

- Rail fastenings during removal, and replacement
- Cold weld risers, lumps of mould during removal
- Loose chisels during manual trimming
- Broken cutting discs or grinding stones

Noise

The risk of hearing impediment can occur during disc cutting, chisel trimming, and profile grinding.

Risk may be eliminated or limited by sensible working practices and reference to welding documentation.

- Only trained welding staff, duly accompanying the competency certificate issued by RDSO or Thermit Portion Plant / Lucknow as the case may be, should be authorized to perform the welding. This is the responsibility of the concerned executive to see this aspect.
- Welding procedure must be adhered to as mentioned in that particular welding technique.

3.14 Guidelines for storage and transportation of AT portion

The 76th Track Standards Committee has recommended following guidelines for inclusion in Manual for fusion welding of rails by the Alumino-thermic Process:

- Stores should be dry, well ventilated, and where required lighting, power and running water should be available. In all cases building construction should be in compliance with the FIRE regulations applicable to the substances being stored. Consideration shall also be given to the relevant regulations issued in this respect.

- The appropriate notices should be displayed where materials such as Thermit Portions and Igniters are stored.

- Portions should be stored in a secure, non-combustible building. While it is preferable that they should be stored separately, they may be stored with other non-inflammable materials, such as equipment and small tools, mould, luting sand in sealed bags, etc. in which case ideally they should be segregated. The store should be dry with ventilation to prevent excess humidity or dampness, and should be designated as a non-smoking area, with no naked flames.

- Portion must not be stored in the same building as explosive or flammable items (e.g. fuel, fuel gases, igniters).

- The sealed boxes must not be opened until immediately prior to use. Any spillage should be immediately swept up and the material disposed in accordance with safety data sheets. Steel shovels should not be used on concrete floors, which might create a spark.

- Portions should be used in rotation i.e. first in - first out.

- Proper notices should be displayed inside and outside the building together with the standard warning sign, which should read “Metallic Powder : In case of fire DO NOT USE WATER”.

- The Local Fire Brigade should be informed of exact location of store and nature of contents. Only dry powder extinguishers of appropriate class should be used in the proximity of Thermit powders.

- Tubes of igniters should be stored in a locked steel cupboard, or other secure steel container. On no account must these be stored in the same building as the portions.

- AT portion should not be transported in passenger trains. In exceptional cases, it may be carried in Brake Vans. In such eventuality the thermit portion and igniters should not be kept in same package. The package containing igniters should be kept in tin cases / steel containers.

- Portion manufacturing firm will ensure that necessary precautions are taken during transportation of AT portion by road as applicable for such type of material. For this purpose, suitable symbol / notices etc. will be displayed on the packing of AT portion as well as on vehicle as applicable for such type of material.

- Manufacturer of portion shall provide a sheet containing best safety practices with every package for the guidance of the user covering various aspects in safe handling, storage, transportation and disposal of thermit materials.

CHAPTER – IV

GAS PRESSURE WELDING OF RAILS

4.1 Introduction

Gas pressure welding (GPW) is another commercially adopted processes for welding of rail joints. The welding of rail joints by this process is more or less similar to that of welding by flash butt welding process. In both the methods, the two rail ends are fused together to form a welded joint. No external metal is required to fill in between the two rail ends as being done in alumino-thermic welding or metal arc welding.

Gas pressure welding is extensively used in India for joining the reinforced steel bars for civil construction purposes. This welding process has been widely used in many of the advanced countries for joining rail ends due to various techno-economic considerations. These include reliability, consistency in quality and ease of process. Japanese National Railways have been using this method extensively. Gas pressure welding plants are designed for use in stationary plants, mobile depots or in situ. One gas pressure-welding machine was also imported for the Eastern Railway from Japan and has been in use since 1966. This plant can weld 52kg, 90R & 75R rail sections. Konkan Railway Corporation Ltd (KRCL) adopted the gas pressure welding for joining the rail ends to complete the 760 km project in a shortest possible time to make it a model project with high technical standards & quality in welding. KRCL imported Chinese & Japanese gas pressure welding plant from China & Japan. These plants are capable of gas pressure welding of 52 kg rails (both 72 & 90 UTS).

4.2 Principle of the technique

The term 'Pressure Welding' is often used, as synonym for solid phase bonding since almost all the solid-state processes require pressure. The source of heating may be either gas mixture, electricity or open-hearth fire. GPW is not a fusion process ; it is a solid phase bonding technique. GPW of rail ends utilizes the mixture of oxygen and acetylene gases for heating the rail ends for a short time to attain the temperature of about 1250^0C to 1300^0C and thereupon the application of high pressure causes the bonding of the rail ends.

4.3 Equipments

Gas pressure welding plant mainly consists of:

i) Pressure welding device
ii) Hydraulic control unit
iii) Hydraulic pump
iv) Burner assembly
v) Gas Flow Control box
vi) Automatic trimming device
vi) Rail end surface grinder
vii) Disc & surface grinders
viii) Flange correctors
ix) Hot-rail reform correctors
x) Power generator set
xi) Portal gantries & electric hoists
xii) Rail lifting arrangements
xiii) Winches for pulling welded rail panels
xiv) Rollers
xv) Miscellaneous working tools

4.4 Steps involved in gas pressure welding

4.4.1 Preparation of rail ends

Rail having kinks/bend should not be used for welding without rectifying the same. The rail end surfaces should be ground flat by the end grinders so that they match squarely to each other. The squareness should be checked by the right angle. The end grinding operations shall be done at the stock of rails prior to placing the rails over rollers for welding. The embossed marking on the web of rails under the clamps as also the paint, rust, dust etc. at a distance of about 100mm all around the rail ends shall be removed by grinding.

After the end preparations, the rails should be placed on adjustable rollers for welding. Before the end surfaces are brought against each other, each end face should be checked again for ensuring correct straightness. These should be cleaned by carbon tetrachloride to remove oil, dust etc completely. Then the rail ends should be aligned properly with the help of 1 m long straight edge.

4.4.2 Setting up of gas pressure welding apparatus

The pressure in the gas system is adjusted. The gas pressure welding apparatus is set across the top of each rail. Predetermined pressure to the rail ends is given and upsetting length at a predetermined value is set on the indicator.

4.4.3 Rail heating and upsetting

The burners should be placed in the burner case. The distance between the burner tips and the rail surface should almost be same. The fire proof plates should then be placed at its positions on the main body of the machines i.e. between the burner and the clamp/ trimmer. Fresh water should be poured into the burner for every joint and the water level should be checked every time before the burner is ignited. The burners should be ignited away from the joint and the flame is adjusted so as to have the same flame characteristics at both halves of the burner.

The flame characteristics should be checked daily at least once before the start of heating. When the flame is adjusted and ready, the burners should be moved over the joint line and the time for heating should be noted.

When the heating temperature is about 1050^0C the 'upsetting' starts. As the temperature increases, the rate of upsetting also increases. As soon as required upsetting is achieved, the burners should be set aside and both the flanges should be subjected to correction.

4.5 Post welding activities

4.5.1 Scarfing

Immediately after welding is over, the upset metal around the metal joint is removed by flame scarfing by using two units of rivet cutting blow pipes. At the end of scarfing, the thickness of excess metal left should be as small as possible, say about 1mm. Scarfing of the weld should be done as quickly as possible. The scarfing normally takes up to 2.5 minutes.

4.5.2 Normalising

This is a process by which the internal stresses at the weld joint is removed. After flame scarfing, the joint is once again fed to the pressure welding machine and the burner is ignited. Keeping the weld joint static, the burner is reciprocated to and fro at a rate of 12 reciprocations per minute over a range of about 70mm.

The time required for normalizing different rail sections (i.e. from the time of ignition of gas to the time of putting out the gas flame) is 30 seconds to 1 minute as standard.

4.5.3 Hot correction

This process is done after the normalizing operation. Hot rail corrector corrects the lateral misalignment of the joint which is checked by means of a 1 m long straight edge with a slot at the centre. This slot in the straight edge is necessary to accommodate the upset metal still left after scarfing the joint. Dimensional check for both vertical and horizontal tolerances should be carried out while the joint is still red hot as hot corrections, if required, should be carried out in the hot conditions only.

4.5.4 Grinding and finishing

The joint is then grounded to the specific tolerances using an electric portable hand grinding machine.

4.5.5 Inspection and Testing

The rail joint is inspected to check the dimensional tolerances. It is also required to carry out ultrasonic rail flaw detection and dye penetration test for internal and surface welding defects.

4.5.6 Acceptance tests

One out of 100 joints should be subjected to transverse bend tests for which the minimum breaking load and deflection shall be 100T and 15mm respectively. The brinnel hardness tests should be carried out on the welds, heat affected zones as well as on the parent rails.

4.6 Safety measures

As the operators face the flames as well as grinding sparks regularly, the use of protective gears for eyes, clothes, head and foot for all the operators are recommended. These protective gears should also be the identity of the gas pressure welding team working at the welding site.

4.7 Maintenance activities

For proper functioning of gas pressure welding plants and for safety of the personnels, following maintenance activities are required:

General

- When attaching and detaching chucks, interrupt the power switch of the hydraulic pumps.
- Clean the chuck once a day. Clogging will cause slipping.
- The allen bolts of the chucks shall be tightened daily.
- When detaching the hydraulic hoses, ensure putting a cover on the coupler. If dust accumulates, trouble will occur.
- Be sure of lubricating the sliding parts of the machine.
- Be sure of clamping the coupler manually, and fully tighten the screws.
- The trimming edges should be ground fine after every 100 joints.

Burner

- In gas pressure welding, handling of the burner shall be the most important factor. The burner should be operated with the great care.
- In case dust etc. is sucked into the mixing chamber, resulting in

clogging, clean with special cleaning needle, and remove the monometer cock, and wash the inside of mixing chamber with tap water.

- Cleaning the nozzle holes and the face of the burner should be ensured to avoid back fire.

Gas volume control device

- Before using, ensure proper connections of hose pipes and check all joints against leakage by applying soap water on them.
- Ensure periodical replacement of the check valves, packings, etc., of the dry safety device, pressure equalizer and back fire arrester, etc.
- When connecting the pressure regulator and gas volume control device with rubber hoses, ensure connecting correctly oxygen and acetylene gas connectors.

Gas manifold

- Ensure checking all joints against leakage with soap water.
- Handle all the installed valves with care.
- Be careful not to bend the connecting hose pipes of oxygen and acetylene gas to an acute angle.
- Check the gauges to ensure correct pressures.

Housing method

- Remove the hydraulic hoses of the machine proper, hydraulic pump and hydraulic operating box and place caps on the internal and external couplers.
- Wipe wet parts by water with dry cloth.
- Oil the lubricating and sliding parts.
- Arrange and store the wiring cords.
- Thoroughly close the main cock of the gas cylinder.
- Arrange and store the rubber hose for gas piping.

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