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WRI JOURNAL

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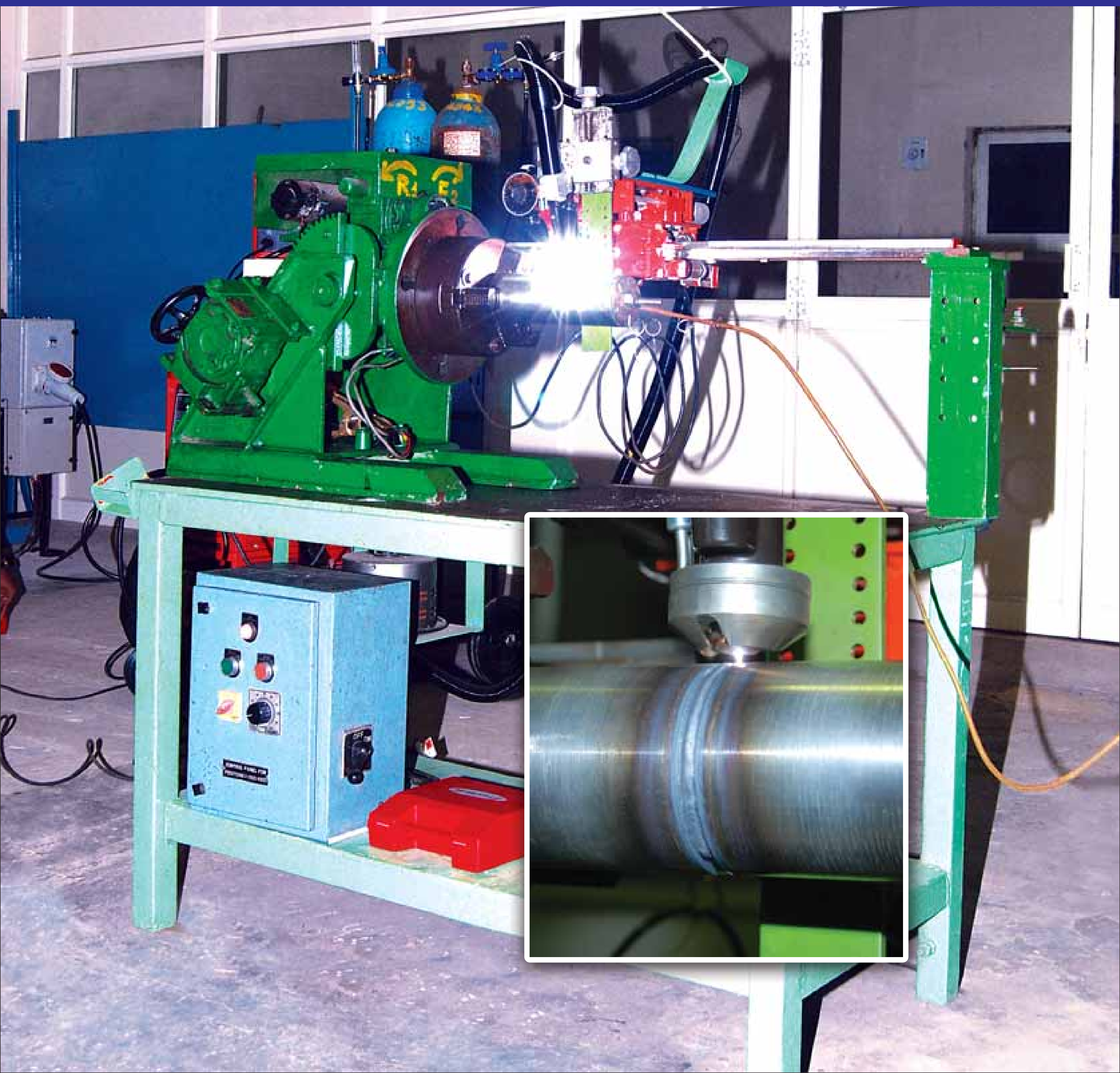
KEYHOLE PLASMA WELDING SYSTEM



CMD, BHEL Visits WRI

Top management officials of BHEL including Mr. Atul Sobti, CMD, Mr. D. Bandopadhyay, Director/HR, Mr. T.Chockalingam, Director/Finance and Mr. S. Gopinath, ED/BHEL, Trichy visited WRI on April 26, 2016. The dignitaries were given a very warm welcome at WRI and were shown the innovations, developments, achievements and recent technological additions at WRI. The entire team was very impressed and CMD desired WRI team to Continue to look at innovations in productive manufacturing. It was a real pleasure to host the senior officials of BHEL at WRI.

In the visitors' book, CMD/BHEL wrote as follows:

"An excellent display of our skills, experience, technology competence in the field of welding technology. This is the best Institute in this field in the country and we need to work towards making it equivalent to world best. Keep it up."

HANDING OVER RECONDITIONED BELL

WRI has restored the reverberation of yet another vintage bell and this time it was for Arulmigu Agasapuriswarar Temple, Kaduveli of Thiruvaiyaru Taluk. The temple bell had developed crack due to long use and had lost it typical sound. The bell was handed over to the temple authorities after performing puja at WRI. In a simple function, Mr. Akhil Joshi, ED, BHEL, (TL & JV and M & A), Corporate Office handed over the bell to the temple authorities, after a puja, in the presence of Mr. S. Gopinath / ED, BHEL, Trichy. Several senior officials of BHEL also graced the occasion. Speaking on the occasion, Mr. Akhil Joshi said that this speaks of the immense potential and skills of the employees of WRI and complimented them. Mr. Gopinath said that WRI has remained innovative in its efforts and has also been able to win the Skoch BSE Order of Merit – 2016, which would be presented later in Mumbai. He appreciated the team work exhibited.

Speaking about the complexity of this bell, even though this weighs only about 35 Kgs and has a height of about 400 mm, Mr. R. Easwaran, General Manager, WRI & Labs said, "The crack was over 120 mm in length and running through the bell thickness. This was a metallurgically challenging job to restore the bell to its original sound. The composition of the bell had significant amount of lead and tin, and this required special consumable to be organised and also the preheating levels for welding had to be reduced, as compared to the conventional bells that WRI has reconditioned in the past. It is heartening that the young generation of welding professionals could be groomed to take up this task."

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COVER PAGES

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Editorial

Dear Reader,

Greetings from Welding Research Institute - India!

April-June 2016 for WRI was marked by the visits of dignitaries. Mr. Atul Sobti, CMD/BHEL, Mr. D. Bandopadhyay, Director/HR, Mr. T. Chockalingam, Director/Finance and Mr. S. Gopinath, ED/BHEL, Trichy visited WRI on April 26, 2016. That they could spend over an hour was a great boon for WRI, as we could explain many of the recent work done. There were also talks by international experts who included: Mr. Manfred Schorghuber from M/s Fronius International GmbH, Austria spoke on Thermo–mechanically Control Processed plates / pipes for high strength applications and Advances in GMAW on Apr 4, 2016; Mr. Neeraj Lohia from Bug-O Systems International, India who talked about Flexible Automation Solution and Spin Arc Technologies on Apr 13, 2016; Mr. Bhavani Shankar from Magpulse Technologies, Bangalore, Overview of Magpulse Technologies on Apr 15, 2016. Mr. Akhil Joshi, Executive Director, BHEL, (TL & JV and M & A), Corporate Office was at WRI on June 4, 2016 and he handed over the vintage bell of Arulmigu Agasapuriswarar Temple, repaired and reconditioned by WRI, to the temple authorities.

WRI organised a one day workshop MIDAS-2k16 (Manufacturing Inroads into Defence, Aerospace and Strategic Sectors) on June 13, 2016, which was well received. WRI was also the technical organising partner along with International Institute Welding and IIW-India in organising the Sixth Welding Research and Collaboration Colloquium at Hyderabad during 7-9 April 2016.

WRI was also among many national awards for its contributions which included Skoch BSE Award 2016, Dr. GV Memorial Award – 2016 and a Best Paper Award.

In this issue, we have put together four articles. Here is a short preview for you:

Magnetically impelled arc butt welding (MIAB) is a solid state welding process with good potential and in the first article, the success story of an application developed for automobile use is shared. Thin tubing (2 mm) could be joined with ease!

The second article is about the flux constituents in Grade 91 submerged arc weldments and their major effect on alloy transfer behaviour across the arc, which varies with elements and also the basicity. So flux planners, be aware of this!

There is a paper on the header to stub welding options in terms of processes and configuration. Full penetration welds give you that extra confidence, as no operating power plants can tolerate a header-stub leakage!

The fourth paper talks of an autogenous keyhole plasma welding process for welding of 8.5 mm thick P91 material pipe. Lower Heat Input helps get reasonable toughness properties, as well. Another productivity option for thin pipe fabricators!

We expect this would be useful and informative to a wide range of our readers. Remember to send your feedback to help improve this Journal further.

With best regards,

R. Easwaran

EXPERIMENTAL STUDIES FOR ESTABLISHING MIAB WELDING TO AUTOMOTIVE COMPONENT APPLICATION

P.R. Venkateswaran, K. Karthick[a], and K. Ganesh Kumar

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a - Department of Mechanical Engineering, SNS College of Technology, Coimbatore

Abstract: *Magnetically impelled arc butt welding (MIAB) is a solid state welding process suitable for butt welding cylindrical sections such as pipes and tubes. MIAB welding needs to be customized for a given application and the customization of operating parameters depends on material type and geometry parameters such as thickness and diameter. In this paper, establishment of MIAB welding procedure for the welding of thin walled low carbon steel tubes of 30 mm outer diameter and 2 mm thickness is discussed. Experimental trials of low carbon steel samples are conducted by varying process parameters of upset pressure, clamp pressure, welding current and welding time. Mechanical and metallurgical studies of the weld joint has been conducted to qualify the welding procedure. The details of the experimental trials and the test results are discussed in this paper.*

Keywords: *MIAB welding, upset stage, arc rotation stage, TMAZ, microstructure, hydrotest*

1.0 Introduction

Magnetically impelled arc butt (MIAB) welding is a solid phase welding process similar to flash-butt welding. In this process, an electric arc is introduced between two closely held circular components and the arc is made to rotate along the circumference by imposing an external magnetic field. The rotating arc causes the temperature at the faying surface to increase. The edges melt due to the distributed heat and are fused by the application of an upset pressure. Similar to flash butt welding process, no filler metal is needed in this process. The uniform heating by the rotating arc provides a more consistent interior and exterior weld flash than typically seen on the flash-butt upset areas. The benefits like short welding time, less internal flash, minimum metal loss, etc. make the process attractive for the high volume production industry like automotive component manufacturing industry.

The principle of working and the construction of the MIAB welding equipment make the process suitable for the welding of thin walled hollow components. MIAB welding is widely used for the automobile component parts such as pneumatic springs, shaft, and vacuum amplifiers of brakes, reactive rod, etc. in the thickness range of 2 to 4 mm. Research studies have also been undertaken [1,2] to explore the possibility of introduction of the process in a pressure vessel manufacturing industry.

In an automobile component welding industry, for the welding of shock absorber component, different welding processes such as seam welding (for upper connection ear to the damper), projection welding (for internal or external braces), MIG welding (for external braces), capacitive discharge welding (for lugs attached to damper), rotary welding (as alternative option for seam welding), etc. are employed. The problems reported with the existing manufacturing practices were leakage of fluid, nugget failing after welding and lug not getting attached properly, lack of penetration in MIG welding. In addition, the cycle time of manufacture is higher as the component had to be moved to different workstations. The introduction of a reliable process with shorter cycle time of manufacture will be very helpful in improving the productivity.

In the present study, the application of MIAB welding for shock absorber component is studied. To simulate the shock absorber component and to establish the optimum welding parameters, study has been conducted on a thin walled carbon steel tube.

2.0 Literature survey

The successful application of MIAB welding process to a specific application involves optimizing the process parameters of current, pressure and time. The knowledge of the electromagnetic force distribution as a result of the externally imposed magnetic field is desirable as this will enable in the understanding of arc rotation process, which in turn will help in the selection of optimum welding parameters. Arungalai Vendan et al. [3] performed a nonlinear electromagnetic analysis to determine the magnetic field and electromagnetic force distribution in MIAB process using finite element package ANSYS. Results of this analysis pertaining to magnetic field show a good comparison with the experimental data for steel tubes.

Arungalai Vendan et.al. [1] have studied the establishment of welding process involving tubes of ASTM A 213 Gr T11 material (47.6 mm diameter, 6.6 mm thick) used for economizer coils in a thermal power plant. Good material properties could be obtained for an arc rotation current of around 200 A with 2 mm gap between tubes. In order to get a quality weld joint, a high current of 1100 A has to be maintained during the last few milliseconds just before forging. Authors [4, 5] further studied the effect of different current levels on final weld quality and the welding procedure establishment in carbon steel tubes.

The above literature show the importance in the establishment of optimum welding parameters and in this paper, an attempt has been made to study the effect of various welding process parameters viz., selection of pressure, current and duration for the various stages of welding like starting, welding and upset.

3.0 Experiment procedure

Fig. 1 shows the overall view of the welding equipment which is employed for the present study. The MIAB welding machine consists of power converter, pump station, control box, welder unit and the remote control as major blocks. The welding trials are performed on a low carbon steel tube conforming to SA210 Gr. A1 material. The chemical composition of the tube material is shown in Table 1. The tubes to be welded are clamped with a gap of 2 mm. The ranges of welding parameters of current, time and pressure for the present application were selected based on the guidelines provided in the literature survey and are shown in Table 2. The welding current and the welding time are divided into three and four stages respectively.

Table 1 - Base metal (SA 210 Gr A1) composition

Elements	C	Si	Mn	S	P	Fe
Composition %	0.23	0.22	0.92	0.009	0.008	96.26

Table 2 - MIAB welding parameters

Stage	Current (A)	Duration (s)	Pressure (MPa)
Arc Initiation	-	1.0	2.25 – 2.75
Arc Stabilization	180 -220	1.8 - 2.2	2.25 – 2.75
Arc rotation	180 -220	1.8 - 2.2	2.25 – 2.75
Upset	360 – 440	0.3	1.8 – 2.2

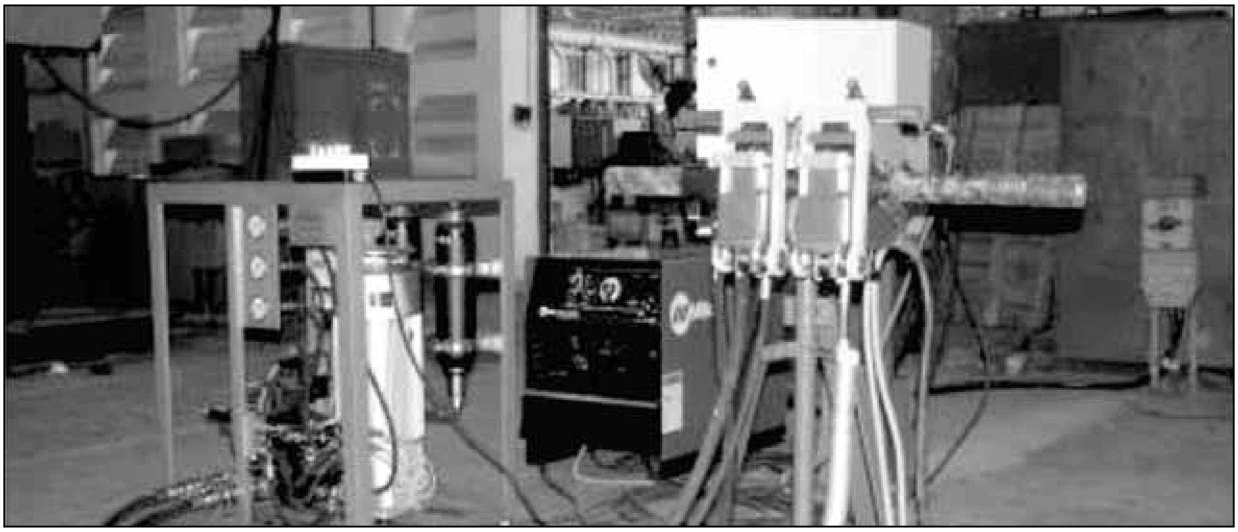


Figure 1 - MIAB welding work station at WRI

The welding process involves four stages as given in Table 2. The arc is initiated and stabilized within a short time and then the stable arc is made to rotate along the circumference of the tube. During this stage, the tubes are held tightly with a clamping pressure. Towards the end of welding, the magnitude of the current is increased significantly for a very short time interval of about 0.3 s. This is then followed by the application of upset pressure butting the fused tubes together. The critical parameters in welding viz. Starting current (I_1), Arc rotation current (I_2), upset current (I_3), Arc stabilization time (T_2), Arc rotation Time (T_3), Upset pressure (P_1) and Clamping pressure (P_2) are varied as shown in Table 3. The other parameters like Arc initiation time (T_1) and Upset time (T_4) are kept constant at 1 s and 0.3 s respectively.

After welding, the weld joint was visually inspected for fusion, bonding, and uniformity of bead profile for acceptance, before subjecting to metallurgical investigations. A set of welded specimen are shown in Fig. 2 for illustration. The specimen were then subjected to tensile, hardness, macro and microstructural examination to assess the strength of the weld joint.

Table 3 - Parameter values for experimentation

Sample No.	Upset pressure (MPa)	Clamping pressure (MPa)	Starting current (I_1) (Ampere)	Arc rotation current (I_2) (Ampere)	rotation current (I_3) (Ampere)	Arc stabilization time (T_2)(s)	Arc rotation time (T_3) (s)
1	1.8	2.25	180	180	360	1.8	1.8
2	1.8	2.25	180	200	360	2	2
3	1.8	2.25	180	220	360	2.2	2.2
4	1.8	2.5	200	180	400	1.8	1.8
5	1.8	2.5	200	200	400	2	2
6	1.8	2.5	200	220	400	2.2	2.2
7	1.8	2.75	220	180	440	1.8	1.8
8	1.8	2.75	220	200	440	2	2
9	1.8	2.75	220	220	440	2.2	2.2
10	2.0	2.25	200	180	440	2	2.2
11	2.0	2.25	200	200	440	2.2	1.8
12	2.0	2.25	200	220	440	1.8	2
13	2.0	2.5	220	180	360	2	2.2
14	2.0	2.5	220	200	360	2.2	1.8
15	2.0	2.5	220	220	360	1.8	2
16	2.0	2.75	180	180	400	2	2.2
17	2.0	2.75	180	200	400	2.2	1.8
18	2.0	2.75	180	220	400	1.8	2
19	2.2	2.25	220	180	400	2.2	2
20	2.2	2.25	220	200	400	1.8	2.2
21	2.2	2.25	220	220	400	2	1.8
22	2.2	2.5	180	180	440	2.2	2
23	2.2	2.5	180	200	440	1.8	2.2
24	2.2	2.5	180	220	440	2	1.8
25	2.2	2.75	200	180	360	2.2	2
26	2.2	2.75	200	200	360	1.8	2.2
27	2.2	2.75	200	220	360	2	1.8
28	2.0	2.25	200	180	440	2	2.2

Figure 2 - MIAB welded samples

5.0 Results and discussions:

a. Tensile test:

The visual inspection of the welded tubes showed that all the tubes have good bonding with no macro defect. Tension Test was carried out as per AWS B4.0 standard and the results are reported in Table 4. All samples fractured at base metal with the UTS values of 420 to 540 MPa. The average value of the UTS is 491.7 MPa. There are only three values which are less than 450 MPa which shows that the parameters have given consistently good result. The view of the tested tensile specimens is given in Fig. 3. (Specification requirement for base metal is 415 MPa minimum)

Table 4 - Tensile test results

Sample No.	UTS (MPa)	Failure location	Sample No.	UTS (MPa)	Failure location
1	529.6	Base Metal	15	474.3	Base Metal
2	527.0	Base Metal	16	450.5	Base Metal
3	540.2	Base Metal	17	464.5	Base Metal
4	440.7	Base Metal	18	493.5	Base Metal
5	459.5	Base Metal	19	438.7	Base Metal
6	500.0	Base Metal	20	451.0	Base Metal
7	495.0	Base Metal	21	510.6	Base Metal
8	453.5	Base Metal	22	469.3	Base Metal
9	531.3	Base Metal	23	490.3	Base Metal
10	506.8	Base Metal	24	477.4	Base Metal
11	420.0	Base Metal	25	510.3	Base Metal
12	527.7	Base Metal	26	541.0	Base Metal
13	519.4	Base Metal	27	496.1	Base Metal
14	531.3	Base Metal	28	520.0	Base Metal

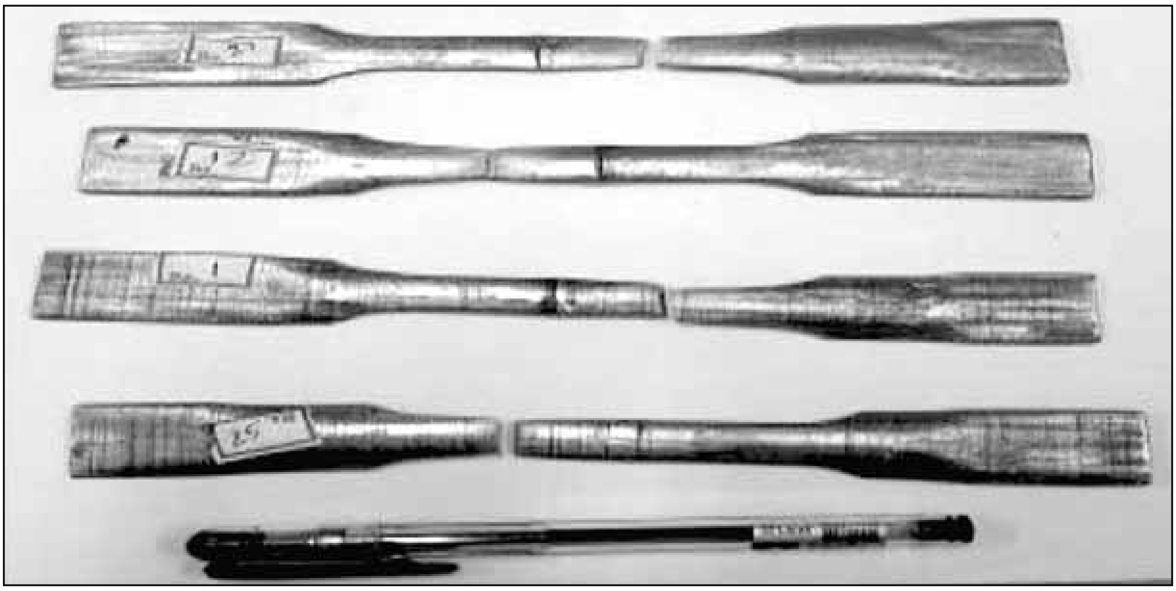


Figure 3 - Tensile test specimen – Failure location at base metal

b. Microstructure analysis:

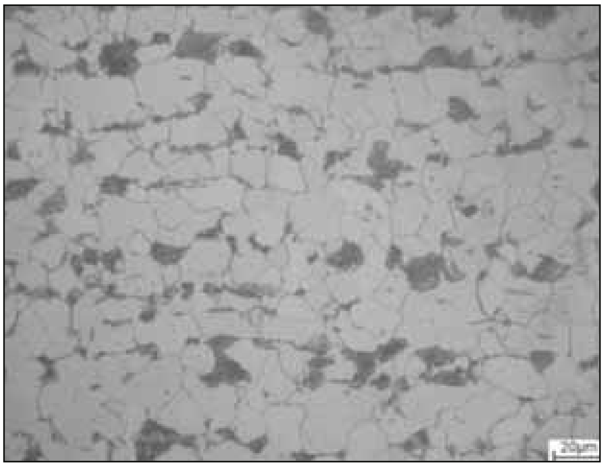


Figure 4 - Optical micrograph of base metal

The optical micrograph (Fig. 4) shows the base metal microstructure of SA210 Gr A1 steel. The microstructure consists of predominantly ferrite with small amount of pearlite formation. The weld metal macrograph, which is presented in Figure 5 shows the visible bond line at the centre of the weld region. Fig. 6a to 6c show the microstructure at various locations adjacent to the weld. There are four distinct thermo mechanically affected zones (TMAZ) next to the fusion line. The zone closest to the weld experiences higher temperature during welding, faster cooling rates and higher extent of plastic deformation. This layer is found to contain finely nucleated acicular ferrite from austenite by displace mechanism. There is some extent of decarburization in this zone, which depends on the high temperature reached at this location which in turn depends on the upset current. Thus higher upset currents of 440 A shows a clear zone of TMAZ I, while for lower currents the zone is not very clearly seen.

TMAZ II is the zone adjacent to TMAZ I. This zone is also heated to slightly lower extent compared to TMAZ I and experiences less extent of plastic deformation. This zone is found to contain a mixture of acicular ferrite and pearlite. TMAZ III is heated to higher temperatures and contains coarse ferrite and pearlite grains and TMAZ IV is found to contain fine ferrite and pearlite grains.

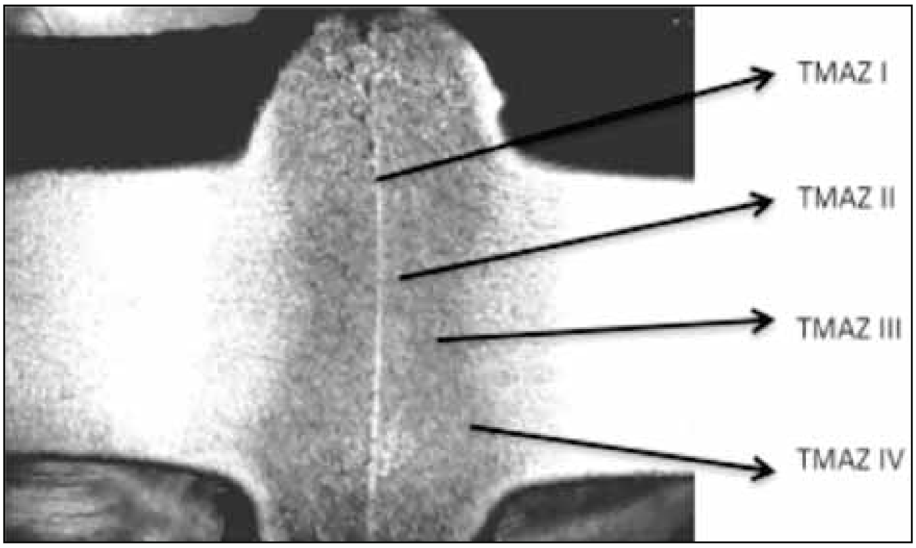
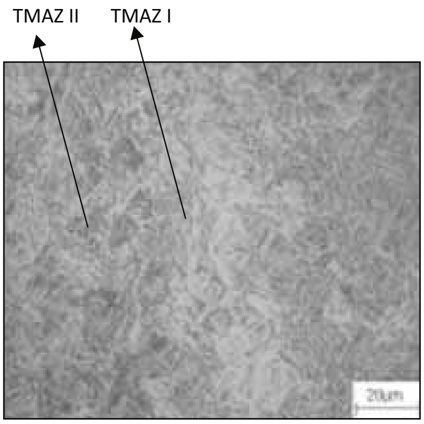
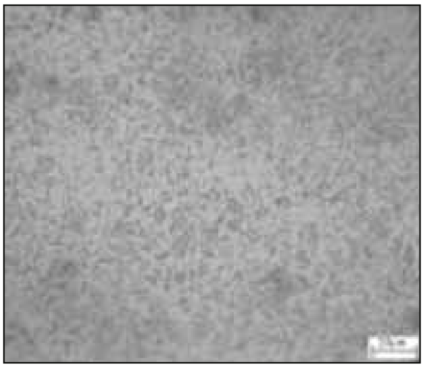


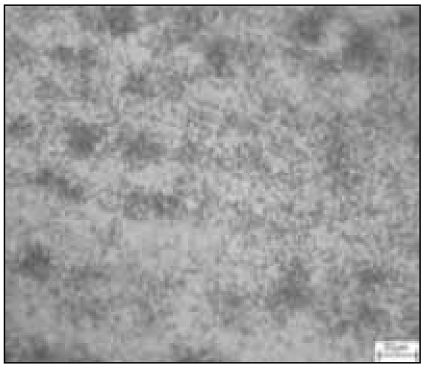
Figure 5 - Macrostructure of Specimen 1 at 15X



(a) TMAZ I and TMAZ II



(b) TMAZ III



(c) TMAZ IV

Figure 6 - TMAZ microstructure of MIAB welded Specimen 1

a. Hardness analysis:

The Vickers's micro hardness profiling of the welded samples has been carried out with 100 g load. The measurement has been taken along the transverse direction from the weld interface at a spacing of 0.5 mm. The hardness result is as given in Fig. 8 and it is found to correlate with the microstructure observations. The hardness results have been given for two typical samples corresponding to the lowest and highest weld metal hardness. The peak hardness is observed in the weld zone and TMAZ I zone, which contain the fine acicular ferrite [6]. The measured hardness is in line with the values reported in literature. Table 5 lists the hardness values of all MIAB weld specimen in TMAZ. The high hardness in the weld and TMAZ I zones also correlate well with the results of the tensile test. In the other TMAZ zones, the hardness shows a gradual decrease and reaches a value of 190 HV in the base metal.

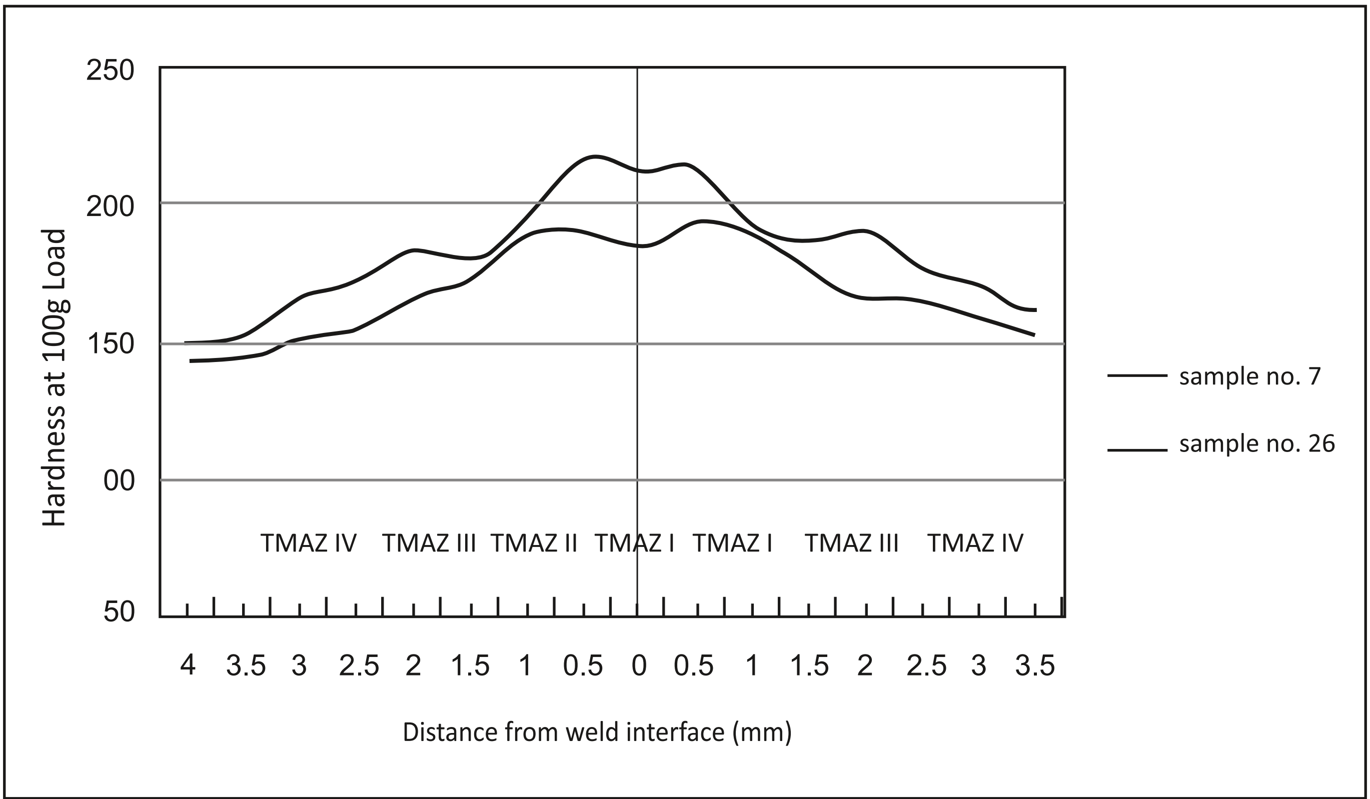


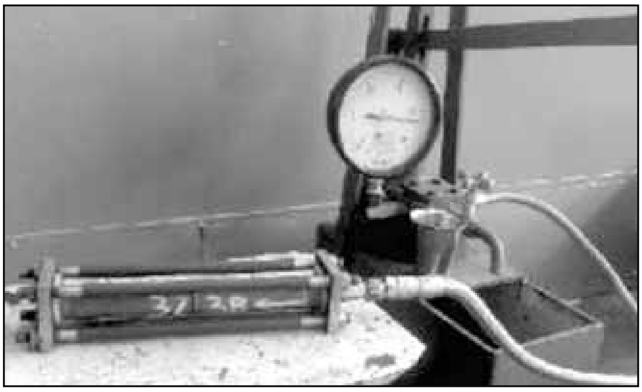
Figure 7 - Range of hardness profile of MIAB welded specimens

Table 5 - Hardness of the samples at the weld interface

Sample No.	Hardness at the weld interface (HV0.1)	Sample No.	Hardness at the weld interface (HV0.1)
1	209	15	207
2	200	16	209
3	196	17	194
4	209	18	210
5	210	19	201
6	210	20	192
7	217	21	201
8	209	22	211
9	198	23	197
10	199	24	192
11	203	25	190
12	210	26	191
13	194	27	193
14	192	28	190

d. Hydro test

One of the requirements of the automotive component is that it has to withstand 8 bar pressure for at least 15 s. In order to evaluate the MIAB weld joint for this requirement, a hydrotest was performed as per ASTM E1003 standard. A separate fixture was made for this purpose and testing was conducted using this custom made arrangement. The hydrotest arrangement is as shown in Fig. 8. It was found that the MIAB weld joint was able to withstand a higher pressure of 20 bar.



6.0 Conclusion

The MIAB welding process has been satisfactorily established for the welding of a 2 mm thick carbon steel tube. The tensile results of all the joints have been good with failure in the base metal region. The microstructure of the MIAB weld joint shows four clear thermo mechanically affected zones, which correlate well with the hardness results. The welded samples are found to withstand a hydro test pressure of 20 bar, which clearly brings out the integrity of the weld joint.

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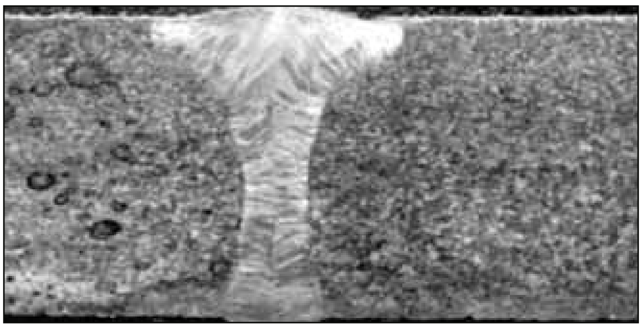
LASER & LASER HYBRID WELDING OF SUPERALLOYS

Research to increase the efficiency of fossil power plants by increasing the steam temperature and pressure has been pursued worldwide. The need to reduce CO_2 emission has recently provided an additional incentive to increase efficiency. This has led to the development of supercritical and ultra-supercritical boiler technologies, which operating at steam conditions in the range of 600°C & 26 MPa. However, to further increase the operating efficiency upto the range of 46%, it is envisaged to increase the operating conditions in excess of 700°C and 35 MPa, which is termed Advanced Ultra Supercritical (AUSC) boiler technologies. Operating at such conditions will warrant the use of strong high temperature materials, usually nickel based superalloys.

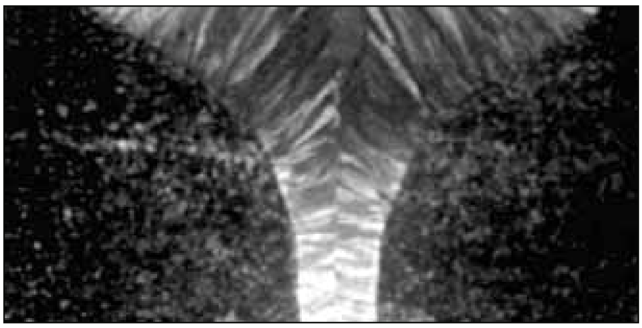
Joining of nickel based alloys is a different ball game and will call for stringent control of welding process parameters because of the inherent issues like susceptibility to hot cracking, liquation cracking, crater cracking, etc. Using low heat input processes will definitely give an edge for joining exotic materials in terms of low heat input, narrow heat affected zone (HAZ), reduced distortion, etc. To confirm the hypothesis, as a forerunner to the main AUSC project, WRI has recently carried out laser and laser hybrid welding studies on nickel alloy 230, which is nickel based super alloy with Cr, W & Mo as major alloying elements.

Laser welding, a non-conventional welding process classified under power beam welding processes has the potential to penetrate into any manufacturing operations. It is a non-contact fusion welding process that produces coalescence of materials with the heat from a laser beam focused on the weld joint. Laser-GMAW hybrid welding is a process, where the laser beam is augmented with a MIG arc and is directed to the same weld pool. The process combines the advantages of both laser and GMAW.

The project has been carried out in collaboration with M/s ARCI, Hyderabad. This investigation determined optimum shielding gas, joint design and welding parameters for laser welding of 6 mm thick plates and tubes and laser hybrid welding of 10 mm thick plates and tubes using filler wires of matching composition to plates and tubes. Susceptibility to HAZ liquation cracking in laser and laser hybrid welds were also evaluated. A 3.5 kW CO_2 slab laser was used for laser welding of 6 mm thick plates and tubes in straight butt joint configuration. The 3.5 kW laser in combination with a MIG welding system was used for laser hybrid welding of 10 mm thick plates and tubes in full “V' groove and “Y” groove configuration by varying joint angle and root height in single pass as well as double pass. The process was optimised on plates and subsequently, optimised for successful welding of tubes without any start/stop defects. Both the laser and laser-MIG hybrid welds were characterized micro structurally and subjected to mechanical tests. Both autogenous and laser hybrid welds have exhibited excellent mechanical and metallurgical properties at both room temperature and elevated temperatures. The tensile strength, impact strength, etc. were found to be matching with that of the base material. Fractography has shown that all welds have undergone ductile fracture in both tensile and impact testing. The welds also had good bend ductility. It could be concluded that nickel alloy 230 is laser and laser-MIG hybrid weldable.



Autogenous laser weld



Laser hybrid weld

WELD EVENTS

WELD EVENTS TAKE A PEEK AT THE MAJOR WELDING EVENTS BEING ORGANISED ACROSS THE GLOBE

FABTECH 2016

Dates : November 16-18, 2016

Venue : Las Vegas Convention Center, 3150 Paradise Road, Las Vegas, NV 89109.

Organised by :

Fabricators and Manufacturers Association (FMA), International, Rockford, Ill, SME, The American Welding Society (AWS), The Precision Metal-forming Association (PMA), Independence, Ohio and the Chemical Coaters Association, International (CCAI)

Main Topics:

- Additive Manufacturing
- 3D Printing
- Arc Welding
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ANALYSIS OF SLAG-METAL REACTION IN SUBMERGED ARC WELDING OF P91 MATERIAL

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Abstract: *The welding flux used during submerged arc welding takes part in the slag metal reaction in the arc zone and consequently has an influence on the chemistry of the deposited weld metal. The basicity of the welding flux decides the oxygen content of the weld metal, which in turn affects the toughness of the weld metal. The basicity and the welding heat input are two parameters which decide the alloy transfer from the wire to the weld metal through the arc. In this paper, the transfer of elements such as chromium, manganese and silicon during submerged arc welding of grade 91 material is discussed. The welding trials were conducted with three different fluxes and two different heat inputs. The composition of the weld metal is found to be affected by the basicity and the heat input. The results are correlated by the study of the different constituents in the welding flux and slag.*

Keywords: *Submerged arc welding, acidic flux, basic flux, slag, alloy element transfer.*

1.0 Introduction

For welding positions and components where mechanised welding is appropriate, submerged arc welding (SAW) is undoubtedly the preferred and most productive process. Although trials have also been carried out with metal cored wire, the preferred option for SAW is solid wire with a flux in the form of granular powder. The flux melts under the arc heat and participates in the chemical reaction. After the reaction is over, the slag floats to the top of the metal and covers the metal during cooling.

The word "slag" may not have a pleasant connotation with the man in the street but they are very important to welding and metal production. They protect the metal and remove undesirable impurities during welding and metal extraction in to the weld metal. Usually, a liquid slag layer covers the molten metal and carries out the following functions

(i) It seals off the metal from oxygen and prevents oxidation

(ii) It removes undesirable elements (e.g., P) from the metal

(iii) It helps to remove non-metallic inclusions (e.g. by flotation, etc.)

(iv) It reduces the heat losses from the metal surface and prevents the "skull formation"

(v) In the continuous welding of steel, liquid slag infiltrates continuously between the molten metal and parent metal, controlling the rate of heat extraction.

(vi) It helps alloy transfer in to the weld metal.

In addition, the flux gives electrical stability to the arc and shapes the weld metal.

The flux takes part in the chemical reaction in the arc zone and the slag which is the result of the chemical reaction, finally floats to the top and covers the deposited weld metal. Slags are very important to the production of clean metals. The old adage "Look after the slag and the metal will look after itself" is very appropriate.

The performance of the flux under the arc heat depends on many physical and chemical properties of the flux. The slag metal reaction, which takes place under the arc has a major influence on the properties of the weld metal. It also influences the transfer of alloying elements such as chromium, which gets oxidised easily.

The objective of the present study is to determine the interaction between slags and weld metal containing chromium and molybdenum in addition to carbon, silicon, manganese, sulphur, phosphorus and oxygen especially, for the welding of grade 91 material. In addition, three case studies have also been presented in the end, which bring out the characteristics of the fluxes for the welding of P91 material.

2.0 SAW Fluxes

Fluxes for submerged arc welding can be classified according to the method of manufacture and chemical composition. Based on the choice of several manufacturing methods, the different types of fluxes available are fused fluxes, bonded or agglomerated fluxes, mechanically mixed fluxes and sintered fluxes.

Fluxes are also identified as chemically basic, acidic, or neutral. The basicity or acidity of a flux is related to the ease with which the component oxides of the flux ingredients dissociate into cation and an oxygen anion. Chemically, basic fluxes are normally high in MgO or CaO and acidic fluxes are high in SiO_2.

In order to describe the compositions and properties of high carbon ferromanganese slags, the term 'basicity' is often applied. It is defined as the mass ratio of 'basic' to 'acid' oxides in the slag phase

$$B = \frac{CaO + MgO + BaO + Na_2O + K_2O + CaF_2 + LIO_2 + \frac{1}{2}(MnO + FeO)}{SiO_2 + \frac{1}{2}(Al_2O_3 + TiO_2 + ZrO_2)}$$

Fluxes having basicity more than one are called chemically basic, ratios near unity are called chemically neutral and those less than one are chemically acidic. It has been stated that the basicity depends on the applied raw materials and will not change in the course of reduction.

Generally, the chemically basic flux is manufactured by agglomeration technique and has lower weld metal oxygen content, which contributes to better mechanical properties due to less density of inclusions and gases. The flux has lower density and viscosity, which contribute to lower current carrying capacity rate and penetration as compared to acidic flux[1, 2]. The flux is hygroscopic and therefore, less tolerant to rust and scaling. Basic fluxes have recently become the prime fluxes for welding in critical applications where close control on weld deposit and chemistry are required. Basic fluxes are available to suit any weldable material by submerged arc welding. These basic fluxes are rich in CaO, MgO, BaO, CaF_2, Na_2O, K_2O with MnO as the basic constituent.

The chemically acidic flux has higher density and viscosity, which contribute to higher current carrying capacity rate and penetration. It is non-hygroscopic and therefore can tolerate higher degree of rust and scale. Generally, the flux is manufactured by fusion technique and has higher weld metal oxygen content, which contributes to inferior mechanical properties due to higher density of inclusions and gases[1]. The characteristics of chemically neutral flux are between the characteristics of acidic and basic fluxes. This acidic fluxes are rich in acidic constituents like SiO_2, TiO_2, and Al_2O_3.

A neutral flux adds little or no alloying elements to the deposited weld metal. The main ingredients of the flux are Al_2O_3, TiO_2, MnO, etc. Notch toughness is higher due to the presence of Al and Ti, which promote the formation of acicular ferrite in the weld metal.

3.0 Welding slags

Welding Slags have similarities to glasses. Glasses tend to have high SiO_2 contents, enamels contain appreciable amounts of B_2O_3 whereas, and welding slags are usually based on the CaO-Al_2O_3-SiO_2 system. The slags for nonferrous welding are frequently based on fayalite- e.g. FeO.SiO_2. Coal slags/ fly ashes are basically CaO+Al_2O_3 + SiO_2 with relatively low CaO levels (<10%) and tend to be very viscous [3].

Liquid slags are made up of ions which are involved in reactions between metal and slag such as those given below

$$2Al + 1.5\, SiO_2\,(slag) = 3Si + Al_2O_3\,(slag)$$

$$2Al + 1.5Si^{4+} = 1.5\, Si + 2\, Al^{3+}$$

The unofficial first law of high temperatures states:

"At high temperatures everything reacts with everything else" and the second law states

"They react bloody quickly and it gets exponentially - worse as the temperature increases".

Slags react with the metal and with the atmosphere. Their reactivity varies between the viscously aggressive to benign (glasses) and is very dependent upon the slag composition[4].

Some slags are basically unstable at high temperatures, since two or more components in the slag will react and the composition will change continuously e.g. P92 flux slag, where fluorides and oxides react as follows.

$$3CaF_2 + Al_2O_3 = 2AlF_3\,(g) + 3CaO$$

And the slag composition shows a steady increase in CaO concentration and a decrease in Al_2O_3.

The properties of the slag are important, since they have a decisive effect on both process control and on the quality of the product and good quality property data are needed to develop reliable mathematical models of the process and to optimise the efficiency of the process and quality control. An example of process control is that the slag compositions should have a high sulphur removal-capacity to maximise transfer of S from the metal to slag; this is usually achieved by using a liquid, high-basicity flux. If desulphurisation is below requirement, more CaO is added to increase the basicity, but it could also increase the liquidus temperature (T_{liq}) of the slag and thereby reduce the amount of liquid slag formed, which, in turn, results in less de-sulphurisation [4].

An example of the effect on product quality occurs in continuous welding. Longitudinal cracks occur on the surface of the weld metal and have to be repaired, thereby increasing expenditure and energy. It is known that flux viscosity and break temperature of fluxes used in welding must be optimised to eliminate longitudinal cracking.

Slag/metal reactions are very important in the production of clean metals (eg. desulphurisation and dephosphorization) but they can sometimes produce unwanted reactions. Slag/metal reactions involve ions and involve charge exchange resulting in the changes.

The slag is used in welding processes to shield the metal from oxidation; oxygen can have a significant effect on transition-metal, multi-valent oxides (eg: Fe^{2+}/ Fe^{3+}, Cr^{2+}/ Cr^{3+}, Ti- Nb- oxides). In the case of Fe^{2+}/ Fe^{3+}, the Fe_2O_3concentration has a significant effect on the properties (eg. viscosity, electrical resistivity). Thus, it is important that the partial pressure of oxygen, in a welding process be selected to reflect the conditions of the industrial process being studied. Nitrogen tends to be inert to most slags but those containing Ti and Nb will react with N_2 to form TiN and NbN inclusions, which can have significant effects on the process.

Reactions of slags with moisture can have important effects. In oxide slags with the H_2O being both chemically-bonded to the slag and adsorbed on the slag; this can affect the performance of the slags. However, the effects of moisture are more severe when dealing with slags containing fluorides, (or chlorides) such as P92 agglomerated fluxes, and Alumina rich fluxes because of the reaction:

$$CaF_{2\,slag} + H_2O\,(g) = CaO_{slag} + 2HF\,(g)$$

The hydrogen fluoride (HF (g)) emitted can cause plant corrosion and pose a threat to health of the plant personnel. This will increase the notch toughness of the weld metal as the weld will contain less oxygen.

4.0 Slag metal reaction in P91 material

Much work has been done on slag-metal reaction of submerged arc welding process involving Si, Mn, Cr & O transfer [4]. During welding of alloys containing elements such as Cr, any loss of the alloying elements across the arc may lead to poor mechanical properties of the weld metal. It is also known that any addition of oxygen in the weld metal will have a tendency to lower the impact strength of the weld metal. Thus the study of loss / gain of elements during submerged arc welding of a high alloy steel is desirable.

The transfer of chromium during submerged arc welding with basic fluxes may be represented by the equation

$$2Cr + 3O = (Cr_2O_3)$$

The loss of elements like Cr to the slag depends on the basicity index of the flux and the choice of welding parameters. The loss of Cr to the slag as a function of the flux basicity index is shown in Fig. 1[5]. It is seen from the relationship that the basicity index of the flux should be minimum 1.7 for the avoidance of any chromium loss to the slag. Among the welding parameters, the current is found to have more influence as compared to the voltage [5].

The transfer of oxygen during welding is independent of the transfer of other alloying elements. Mitra et al.[4] ha ve suggested that high

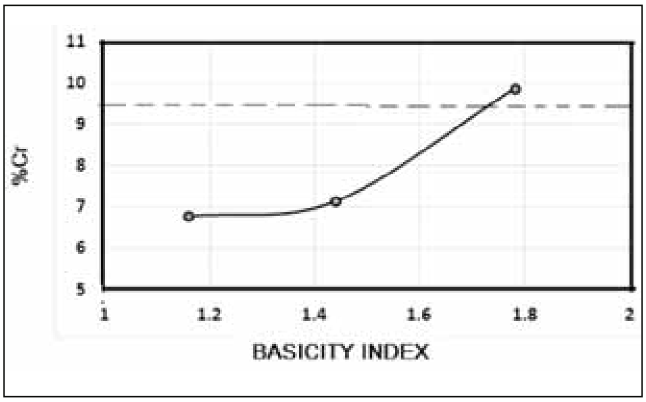

Figure 1

amount of oxygen is present in the arc plasma due to the decomposition of the oxides present in the slag to sub-oxides and oxygen. For most welding fluxes, this oxygen potential is controlled by the silica content of the flux. The activity of the silica will control the oxygen content in the weldment, which depends on the basicity index of the flux used for SAW welding. The relation between oxygen content in weld metal and basicity index is shown in Fig. 2 [1].

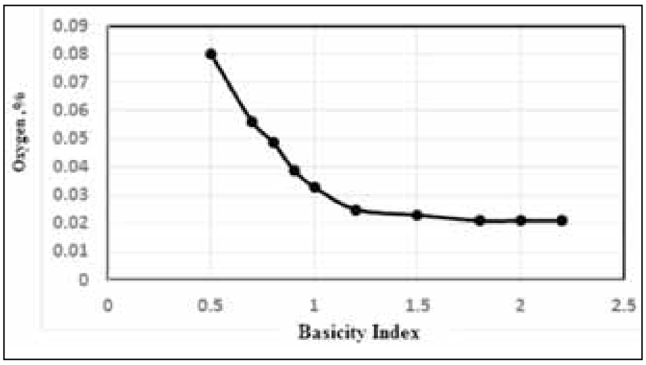

Figure 2 - The empirical relationship between Basicity Index of the welding Flux and weld metal oxygen content.

The present work is on the chromium transfer to the weldment of P91 material with three different basic SAW fluxes. The interaction between slags and weld metal containing chromium as major element in addition to other elements like Mn and Si has been studied in detail. The effect of flux composition and the welding heat input on the final weld metal chemical composition and the corresponding mechanical properties are presented in the paper.

5.0 Case studies on effect of welding parameter on weld metal composition

P91 material is a creep strength enhanced ferritic steel which finds wide usage in power plants for the manufacture of components operating in the temperature range of 540 to 590°C. The improvement in properties of modified 9Cr-1Mo is achieved by controlled additions of vanadium, niobium and nitrogen combined with a normalised and tempered heat treatment. The chemical composition of modified 9Cr-1Mo is indicated in table 1. This steel is incorporated into ASME as SA-213-T91 for tubing, SA-387-Grade 91 for plates, SA-335-P91 and SA-369-P91 for pipe and SA-182-F91 and SA-336-F91 for forgings.

Table 1 - Chemical composition (%) of 9Cr-1Mo steel employed in the study

C	Mn	Si	P	S	Cr
0.08 0.12	0.03 0.60	0.20 0.50	0.015 - max	0.010 -max	8.0 9.5

Ni	Mo	V	Al	Nb	Cu	N
0.40 - max	0.85 1.05	0.18 0.25	0.04 - max	0.06 0.10	0.10 -max	0.03 0.07

In the present study, three commercial SAW agglomerated fluxes for the welding of P91 material have been employed under two different welding conditions. Table 2 gives the chemical composition of the three fluxes used in the trial and Table 3 gives the welding conditions employed in the study. In all the cases, the chemical composition of the weld metal has been analysed as shown in Table 4.

Table 2 - Chemical composition of the commercial welding fluxes for P91 material

Constituents	Flux –I (%) Composition	Flux –II (%) Composition	Flux –III (%) Composition
SiO_2	23.86	24.86	34.59
MnO	1.74	1.83	0.56
$CaO+CaF_2$	28.99	18.21	43.56
MgO	24.88	31.37	2.56
Al_2O_3	13.76	19.81	4.56
Fe_2O_3	0.75	0.12	0.12
TiO_2	0.32	0.35	0.35
V_2O_5	1.40	0.80	0.8
Cr2O3	5.56	6.42	10.22
BI	1.78	1.44	1.16

Flux particle sizes and their uniform distribution within the bulk flux are important because that influences feeding, recovery, amperage level, and weld bead smoothness and shape. A general rule of thumb requires, as amperage increases, the average particle size for fused fluxes should be decreased when the mesh fraction 18x24 was singled out as that minimizing the number of defects, grain size according to ISO 14174: 2 - 20.

Fig. 3 shows a typical agglomerated flux which was used for the study. Fig. 4 and 5 show the weld bead deposited using the flux and the corresponding slag.

The chemistry of weld metal welded using the three fluxes and using two different welding conditions are presented in Table 4. Similarly, the chemistry of the welding slag under the different conditions are presented in Table 5.

Table 3 - SAW process parameters employed in the study

Parameter	I	II
Current(A)	400	500
Voltage(V)	28	30
Polarity	DCEP	DCEP
Electrode	E-9018-B9	E-9018-B9
Electrode diameter (mm)	4.0	4.0
Electrode stickout(mm)	30	35
Welding speed (mm/min)	300	450
Inter pass temperature °C	230-250	230-250
Heat input (J/mm)	2240	2000

Table 4 - Chemical composition of weld metal using different fluxes and different welding conditions

Flux	Weld para meter	C	Mn	Si	P	S	Cr	Ni	Mo	V	Al	Nb	N
1	1	0.084	0.82	0.260	0.010	0.010	7.59	0.62	0.92	0.16	0.020	0.06	0.04
1	2	0.106	0.96	0.430	0.010	0.010	9.87	0.73	0.99	0.23	0.022	0.07	0.06
2	1	0.086	0.86	0.284	0.0116	0.012	7.09	0.68	0.94	0.16	0.020	0.07	0.05
2	2	0.104	0.88	0.432	0.011	0.011	7.61	0.74	0.98	0.21	0.022	0.07	0.06
3	1	0.074	0.57	0.374	0.0116	0.012	6.78	0.53	0.85	0.16	0.020	0.05	0.05
3	2	0.100	0.64	0.524	0.036	0.012	7.14	0.52	0.84	0.18	0.018	0.07	0.07

Table 5 - Weld Slag chemistry for different welding fluxes and welding parameter

Flux	Weld para meter	SiO_2	MnO_2	CaO_2	MgO_2	Al_2O_2	Fe_2O_3	TiO_2	V_2O_5	Cr_2O_3
1	2	24.726	1.408	29.544	24.794	12.412	2.226	0.328	0.162	0.550
1	2	27.008	0.888	27.44	22.248	10.174	3.444	3.328	0.162	0.236
2	1	25.270	1.584	18.864	28.754	15.016	4.382	0.342	0.060	0.344
2	2	27.942	1.060	16.55	25.890	15.016	8.950	0.292	0.060	0.148
3	1	35.250	0.476	38.586	1.396	3.180	3.306	0.356	0.050	9.256

38.586

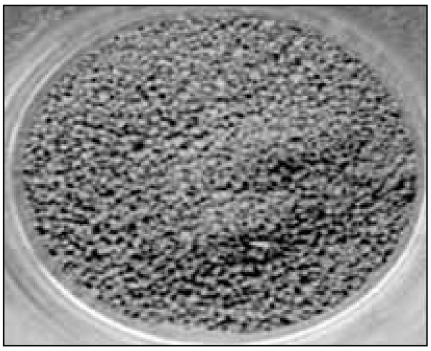

Figure 3 -Agglomerated high basic flux

Figure 4 - Weld metal deposit using high basic fluxes

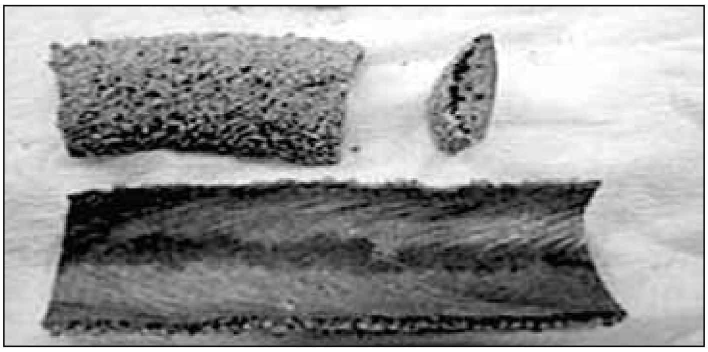

Figure 5 - Welding slag formed with high basic fluxes

6.0 Results and discussion

The weld metal chemical composition was found to depend on the basicity index of the flux and the welding parameters employed for the welding trial. It was seen that the Cr transfer is linked to the basicity index of the flux which was used. The Cr content was highest in the case of flux 1, which has a basicity index of 1.78 and lowest in the case of flux 3 with a basicity index of 1.14. This is in agreement with the literatures as shown in Fig.1. The Cr content is also dependent on the welding parameters. Lower welding heat input resulted in higher transfer of Cr as could be seen in Table 4.

The mechanism of transfer of silicon is quite opposite to that of chromium. The weld metal silicon content decreases with increasing basicity index of the flux. As the flux basicity increases, the activity of the SiO_2 decreases, thereby reducing the silicon content in the weld metal. Also, as the chromium content of the electrode increases, the activity of the oxygen decreases rapidly, thereby increasing the silicon content in the weld metal. The reaction may be written as

$$3Si + 2(Cr_2O_3) = 4\,Cr + 3(SiO_2)$$

This will explain the effect of basicity and initial chromium content of the electrode on the silicon content of the weld metal. On increasing the basicity, the activity of the (SiO_2) decreases and the reaction proceeds forward, whereas on increasing the chromium content, the reaction is reversed. As in the case of Cr, lower heat input results in higher transfer of Si in the weld metal.

The transfer of Manganese depends mainly on the initial manganese content of the electrode and flux type. It is not significantly influenced by the presence of other alloying elements. This is in agreement with the other researchers [5]. Manganese may be lost by vaporization while welding with high manganese electrode and flux system.

The metal-slag reaction is dependent on the temperature of welding. For every 100°C increase in temperature, an increase of 0.8–1.2 mass % Si and 1.5 to 2.4 % of chromium in the alloy phase takes place in the higher CaO contents region. The recovery of iron oxide will be more at high welding current, thereby the transfer of alloying elements to the weld metal will be more.

However, temperature has no virtual influence on the equilibrated Si compositions when β-SiC replaces graphite as the stable phase. In contrast, to the relatively small effect on the metal-slag equilibrium, temperature is of great importance for the equilibrium relations when the gaseous species are taken into account. The CaO concentrations of slags shift notably to the lower region with increasing temperatures. Increasing temperature has the advantage of lowering the manganese and chromium losses in the slag phase.

7.0 Conclusion

From the study, it is found that flux constituents has a major effect on alloy transfer behaviour across the arc. The transfer of chromium to the weld metal strongly depends on the type of flux used and the welding parameter chosen. Use of a flux with higher basicity will result in higher transfer of Cr in the weld metal. But the behaviour of elements such as Si are opposite to that of Cr and use of high basic flux results in lower Si content of the weld metal. The element transfer also depends on the heat input and lower heat input results in higher element content in the weld metal.

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WELDING OF TMCP STEEL AND ADVANCES IN GMAW

Mr. Manfred Schorghuber from M/s Fronius International GmbH, Austria spoke on the above topic on Apr 4, 2016. In his talk, he discussed the criticality in welding of Thermo – Mechanically Control Processed plates / pipes for high strength applications.

The materials possess yield strength in the range of 500-600 MPa making them suitable for demanding applications. The welding of such materials to be carried out with care to retain the properties. In the second part, he discussed the emerging applications with the appropriate window for CMT/TPSi power sources.

SPIN ARC TECHNOLOGIES – A TECHNOLOGICAL BREAKTHROUGH IN MIG PROCESS

Mr. Neeraj Lohia from Bug-O Systems International, India gave a talk on the subject on Apr 13, 2016. Initially, he discussed various flexible automation solutions available with them for different applications involving butt, fillet welding, etc. In the later part, he covered the details of Spin Arc Technologies, a development of Bug-O systems, which gives a spin to the arc with a cam arrangement at the tip of the wire. This gives a stirring effect to the arc thereby giving advantages like improved penetration, wider gap bridging, refined microstructures improving the strength and toughness properties, etc. The other advantage is that it comes as a separate attachment and can be used with any type of power sources.

INCREASING APPLICATIONS OF MAGNETIC PULSE WELDING

Magnetic Pulse welding is a solid state joining process suitable for applications involving dissimilar combinations like Al-Cu, Al-steel, etc., which will be a tough combination to join otherwise. The process of joining is achieved by sudden discharge of high current giving a huge push to one of the components to be welded against the other, thereby creating the joint at the interface. Mr. Bhavani Shankar from Magpulse Technologies, Bangalore gave an overview of the process along with the applications they have developed with this technology, at WRI on Apr 15, 2016.

MANUFACTURING INROADS INTO DEFENCE, AEROSPACE AND STRATEGIC SECTORS (MIDAS2k16)

A one day workshop was organized on the above topic in collaboration with IIM, Trichy Chapter at WRI on June 13, 2016. The objective of this event is to give an exposure about the products for the Defence, Aerospace and other Strategic sectors, that can be manufactured in the industrial infrastructure available in Tamil Nadu, which includes BHEL and the 500 odd MSMEs around Trichy, Chennai and Coimbatore, which are actively involved in fabrication and machining. The event had senior level scientists/executives as speakers from leading the institutes/industries in strategic sectors like DRDL, Brahmos, VSSC, NPCIL, HAL, and CVRDE. Dr. S. Sundarrajan, Director, NITT was the Chief Guest and Mr. S. Gopinath, ED/BHEL, Trichy Complex presided over.

Speaking on the occasion, ED/BHEL has highlighted the importance of organizing such events and recalled how strategic sectors have grown, which was possible because of their outsourcing vendors and congratulated the organisers for coming out with such an event. He has also mentioned that Trichy is not only a hub for fabrication but also has good machining facilities. He concluded his address by saying that Trichy hub is looking forward to work together with the strategic sectors to bring laurels to the country as a whole. By inaugurating the event, Dr. S. Sundarrajan, Director, NITT, in his inaugural address mentioned that this event has brought together a group of like minded people. He recalled the vision of Dr. APJ. Abdul Kalam about expanding the wings

of missile project, where BHEL is thought of as a top choice. He also recalled how 26 odd industries were selected for fabrication in defence sectors and among them 5 industries have grown to a very big level. He also mentioned that currently, India is the biggest purchaser of defence equipment. With the “Make in India' campaign gaining prominence, Govt. of India has put an offset policy, in which 20% of any fabrication has to be within the country. He further mentioned that for younger generation it is a fantastic opportunity. Mr. Kumar Sarangarajan, GM/ATP & BDG of BHEL, Trichy proposed the vote of thanks.

Earlier Mr. R. Easwaran, GM/WRI & Labs delivered the welcome address.

Following the inauguration, there were talks by eminent scientists and technocrats from the participating organisations. The talks have covered the opportunities that are available for outsourcing and where the industry belt in this region could actively contribute to meet the ever growing demands.

FEASIBILITY STUDY OF FULL PENETRATION WELDING OF HEADER TO TUBE JOINT USING DIFFERENT COMBINATION OF ARC WELDING PROCESSES

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Abstract: *Headers are integral part of boilers, which collect and distribute the steam (steam / water or water-steam mixture) from the generating tube as part of coal fired power plants and are subjected to high temperature and pressure. Hence, the joints connecting headers to tubes in these components have to cater to stringent requirements such as superior weld quality, corrosion resistance, creep properties, thermal stability during service, etc. To ensure proper welding, utmost care has to be taken for selecting the groove design suiting the welding process. Any leakages in the header to tube weld joint affect the efficiency of boiler and call for repairs & rework at site. The present work was carried out to compare the performance of full penetration header to tube joint carried out using different combinations of welding process for a pilot Heat Recovery Steam Generator (HRSG) module. The weld quality was assessed by visual examination, Magnetic particle Inspection (MPI), macrostructural analysis and finally with the hydro test. Welding was carried out using three different combination of welding process i.e., full Gas Metal Arc Welding (GMAW), Tungsten Inert Gas (TIG) root welding followed by Shielded Metal Arc Welding (SMAW) & root TIG welding followed by GMAW process and out of them, root TIG welding followed by GMAW process gives the better weld quality.*

Keywords: *Gas metal arc welding, tungsten inert gas welding, shielded metal arc welding, header to tube joints, HRSG*

1.0 Introduction

Over the past 20 years, boiler manufacturers have relied on a variety of tube to header joint designs in their heat-recovery steam generators (HRSG). Basically, there are two categories of tube-to-header joints viz. welded only and rolled(including rolled and welded). The welded joints, which were acceptable to the codes of construction may be of partial penetration type or full penetration type. Partial penetration welds are typically characterized by groove weld followed by fillet weld. Mostly, tube-to-header weld joints are designed according to the sketches presented in Fig.1 and Fig.2 and can be of either full penetration welds or partial penetration welds. More precisely, Fig. 1 depicts a standard full penetration joint and Fig. 2 shows the common variation on the partial penetration joint, i.e. Stick-through types of joints and socket-seat type of joint with a through-hole size equal to the outer diameter of the tube, which eliminates the seat.

Recent studies has indicated that header to tube leakage is one of the worrying causes for forced outages in boiler and improvement in weld life of tube to header joint has always been important to designers and welding engineers.

The tube to header weld configuration can be achieved either by full penetration weld by changing the groove design as shown in Fig.1 or by partial penetration weld using set-on-type joint design as shown in Fig.2. In Full Penetration groove, the weld

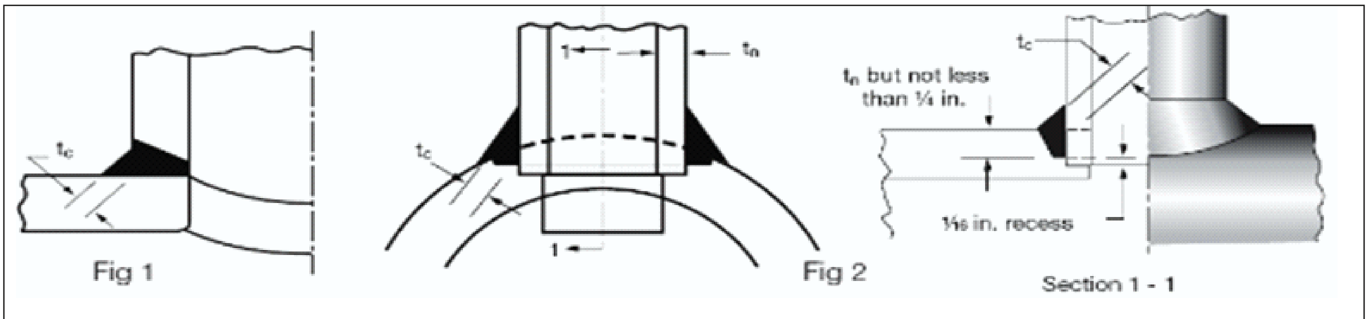


Figure 1&2 - Full Penetration Groove Design and Partial Penetration Groove Design

penetration extends completely through the thickness and delivers more strength & quality, which is not happening in the partial penetration weld joint. Hence, change of partial penetration weld into full penetration weld will improve the weld strength, quality, reliability, eliminate leakages and the spot hydro test can also be eliminated, as the weld quality can be ensured by radiography inspection.

However, the full penetration weld requires a particular edge preparation and special fixture to fit-up the header to tube joints, whereas the partial penetration joint doesn't require any special edge preparation and fit-up is also easy [1]. In full penetration welds, uniform fusion can be achieved between the header and tube and the joint can also be inspected from inside using boroscope, which will not be possible in partial penetration joint.

In the present work, the focus is on joint design & welding process for welding of header to tube joints, which can deliver the weld with higher strength, good quality, complete fusion and finally no leakages at site. Though, previously many attempts had been made theoretically to investigate the weld joint performance using mechanical tools and software, in the present work, three different combination of welding process i.e., full GMAW, root TIG followed by SMAW and finally root TIG followed by GMAW processes were studied to achieve the full penetration header to tube joint using modified groove design and the joint characteristics were evaluated and compared.

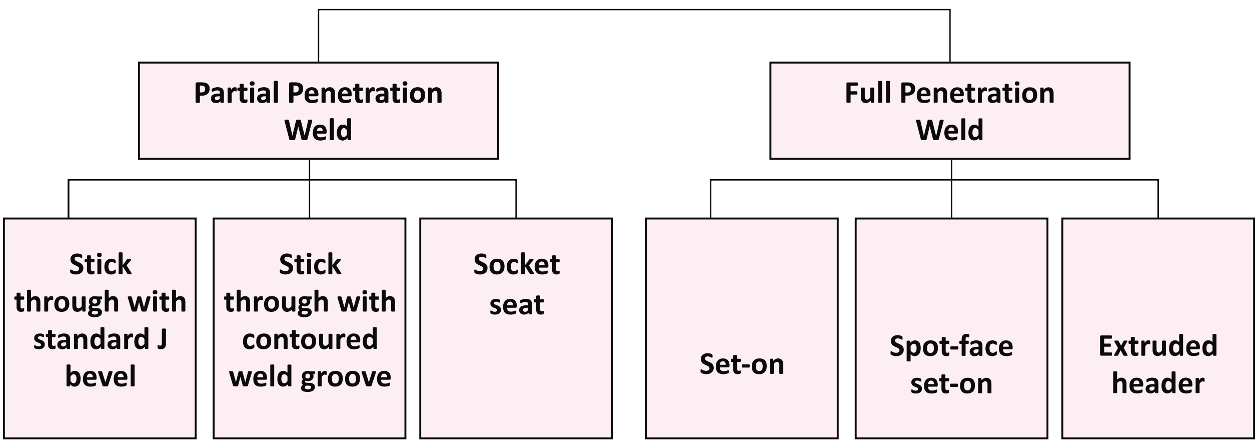
2.0 Types of groove design

The type of groove design followed for different types of welds are given and discussed below:

2.1 Stick-through with standard J bevel

This is the most common tube-to-header joint configuration, as it meets the designer requirement and also the least expensive weld joint. Fig. 3 (a) shows the tube hole with “J” bevel preparation. The resulting weld is shown in Fig. 3 (b) & Fig. 3 (c) after chemical etching. The design is easily absorbed by stick-through joint during fit-up because minor tube length variation are

Figure 3 (a, b, c) - Stick-through with standard J bevel groove design



tolerated and this eliminates the need to trim-to-fit every tube, as is the case with other joint configuration. Finally, the stick-through weld joint is a fillet weld and does not require the higher level of skill compared to that an open-root weld requires [1].

2.2 Stick-through with contoured weld groove

This joint design is very similar to earlier design as shown in Figure 3, but having different depth of deposition on both the high and low sides of the header tube hole. This is more expensive weld preparation compared to standard J groove and is shown in Fig. 4. It also requires more filler metal than the standard J around the low side and the joint [1].

2.3 Socket seat

The socket-seat stick-through configuration is shown in Figure 5. Fabrication of this tube-hole configuration is a two-step process of boring and machining as required. Fit-up and welding must guard against cracking of the weld caused due to shrinkage-induced by mechanical stress inside the joint [1]. The socket seat type groove design is being used in most of the header to tube joint in many thermal power plants. In this joint design, steps are made on the pipe and tube with square (flat face) butt edge preparation. In this type of groove design, root pass welding by GMAW or GTAW will be difficult because of insufficient reach or poor torch accessibility at the root side and hence, mainly SMAW process is being used. This peculiar type of groove design gives difficulty in achieving the complete fusion between pipe and tube and also could result in leakages from joint during operation.

Figure 4 - Contoured weld groove

Figure 5 - Socket seat

2.4 Set-on

The set-on tube-to-header configuration is shown in Fig. 6 and uses a tube-hole diameter equal or smaller than the tube ID. In small-diameter headers, the tube end typically is coped (so called "fish-mouthed") to match pipe contour. This joint requires an open-root weld and the back side is inaccessible; therefore, it demands a higher degree of skill from the welder than is required for most other joint configurations [1].

2.5 Spot-face set-on

This joint similar to the set-on, eliminates the need to fish-mouth the tube end by spot-facing the header. It is also an open root weld, but the recess can make more difficult access to the root. Precise tube trimming to fit with the header is still required for uniform weld preparation. The typical spot face set-on type groove design is shown in Fig. 7 [1].

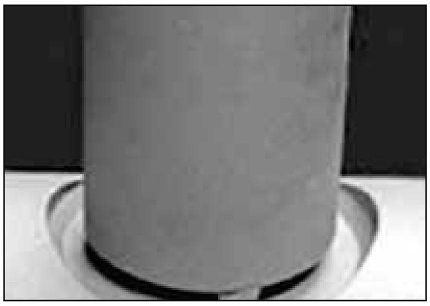


Figure 6 - Set-on

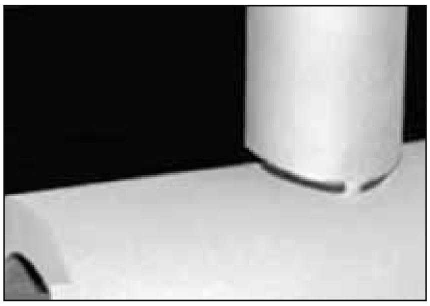


Figure 7 - Spot face set-on

2.6 Extruded header

Extruded tube holes enable butt welding of tube to header (Fig. 8). This joint is marked by a lower-stress connection than the other welded joints, because the transition legs of the extrusion have radius and a butt weld is used in place of fillet weld. The weld can also be easily radiographed. While the extruded header has its advantages, the tube field on an extruded header is significantly more expensive to produce compared to the other joint with machined tube holes. Lastly, this joint uses an open-root butt weld, calling for greater skill on the part of welder than some of the other joint configurations [1].

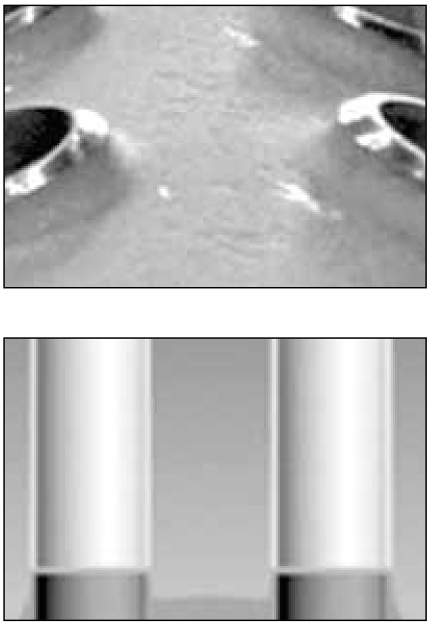


Figure 8 - Extruded header groove design

3.0 Objective

From the above 6 different type of groove design, the spot face set-on-type groove design has been selected and an attempt has been made to study the different welding process and identify the suitable welding process to get the 100% weld quality.

4.0 Experiment Work

4.1 Base & Filler materials

For experimental trials, materials similar to the ones used in thermal power plants were identified, i.e., for header, SA 335 P22 alloy steel and tube of SA 213 T11 alloy steel. The dimensions of the header is 127x20 mm and that of tube is 31.8x3.6 mm. The chemical composition of both the materials as per ASME are given in Table 1. For welding, filler wires and consumables having a minimum tensile strength of 550 MPa has been selected from ASME Sec IIC. Accordingly, filler wire/rod meeting the specification of ER 80S-B2 and electrode meeting the specification of E8018-B2 were used and the chemistry of the consumables are tabulated in Table 2.

4.4 Weld characterisation:

After completion of the welding process, all the welds were sectioned in the transverse direction and polished as per the standard metallographic procedure. The specimens were then etched using 2% Nital solution to study the weld geometry, weld fusion and presence of weld defect, if any in the welded joint. The typical specimen preparation used for macrostructural analysis is shown in Fig.11. Macrostructures were taken using a stereo microscope and a magnification of 100x was used to capture the macrostructure of the welded samples.

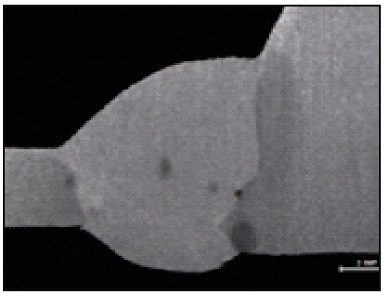
Table 1 - Base material composition of pipe and tube

Material	Composition %						
	C	Mn	P	S	Si	Cr	Mo
SA 335 P22 (Header Pipe)	0.05-0.15	0.3-0.6	0.025	0.025	0.5	1.9-2.6	0.87-1.13
SA 213 T11 (Tube)	0.05-0.15	0.3-0.6	0.025	0.025	0.5-1	1-1.5	0.44-0.65

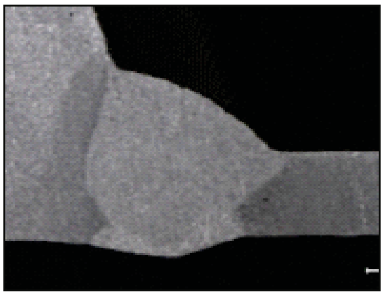
Table 2 - Filler material composition of welding electrode and rod

Electrode	Composition %							
	C	Mn	P	S	Si	Cr	Mo	Ni
E8018-B2	0.05-0.12	0.9	0.03	0.03	0.8	1-1.5	0.4-0.65	-
ER80S-B2	0.07 – 0.12	0.4-0.7	0.025	0.025	0.4-0.7	1.2-1.5	0.4-0.65	0.2

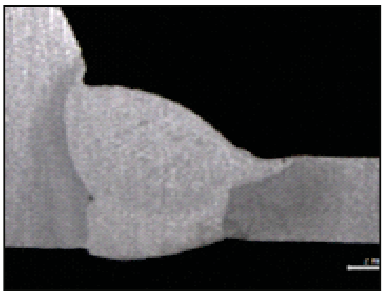
Figure11 - Typical specimen for macro analysis



Option 1
full GMAW



Option 2
TIG + SMAW



Option 3
TIG + GMAW

Figure 12 - Macro analysis of full penetration header to tube welding

Fig. 12 shows the macro structure images of weld samples using three different process combinations. Macrostructures were taken in order to investigate the soundness of weld joint and the Table 4 consolidates the results of weld macrostructural analyses for all the three combination of welding processes. It is clear from Table 4 that Option-3 gives the superior weld quality compared to Option 1 & Option 2.

Based on the macrostructural analysis, it can be concluded that the root TIG followed by GMAW will be the optimum welding process for the full penetration header to tube joint with superior weld quality. To further confirm the quality of Option-3, eight numbers of header to tube joints were welded using root TIG followed by GMAW combination and the results were found to be satisfactory. Fig. 13 shows the repeatability trials on 8 numbers of header to tube joints and also further preparation of sample by cutting for macrostructural analysis.

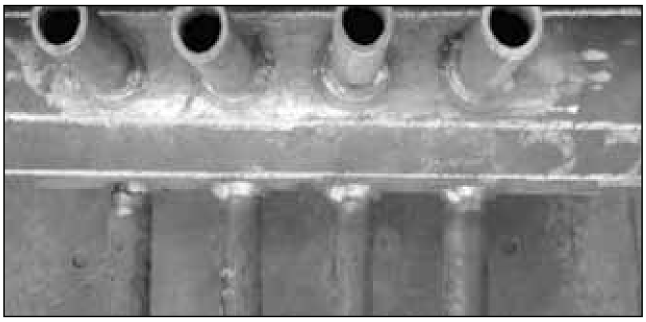


Figure 13 - Repeatability trials for further macro analysis

Figure 14 - Root Penetration

Table 4 - Weld quality comparison of all the three welding process

Weld Defect	Option-1 Full GMAW	Option-2 Root – TIG + SMAW	Option-3 Root - TIG+ GMAW
Lack of fusion	Observed	Not Observed	Not Observed
Slag inclusion	Observed	Observed	Not Observed
Undercut	Not Observed	Observed	Not Observed
Excess penetration	Observed	Observed	Not Observed
Spatter	Observed	Observed	Observed

After sectioning the weld joints, the root fusion & penetration was visually inspected from bottom side and penetration was found to be satisfactory in all the 8 samples with complete penetration throughout the circumference. Fig. 14 shows the root penetration of header to tube welded joint. Once again the samples were taken out from the repeatability trials for macrostructural analysis as shown in Fig. 15 and results were found to be satisfactory. Root TIG followed by GMAW process gives the consistent weld quality. All the 8 joints were free from all the defects listed in Table 4.

After confirming the weld quality, a small HRSG module was fabricated using spot face set-on type full penetration groove design, using root TIG followed by GMAW process. The pilot HRSG module consist of 500 mm length header on either side, welded with 1 m length tubes as shown in Figure 16. A special fixture was also designed for precise fit-up of module and before welding, all the tubes were tack welded by keeping the module in horizontal position.

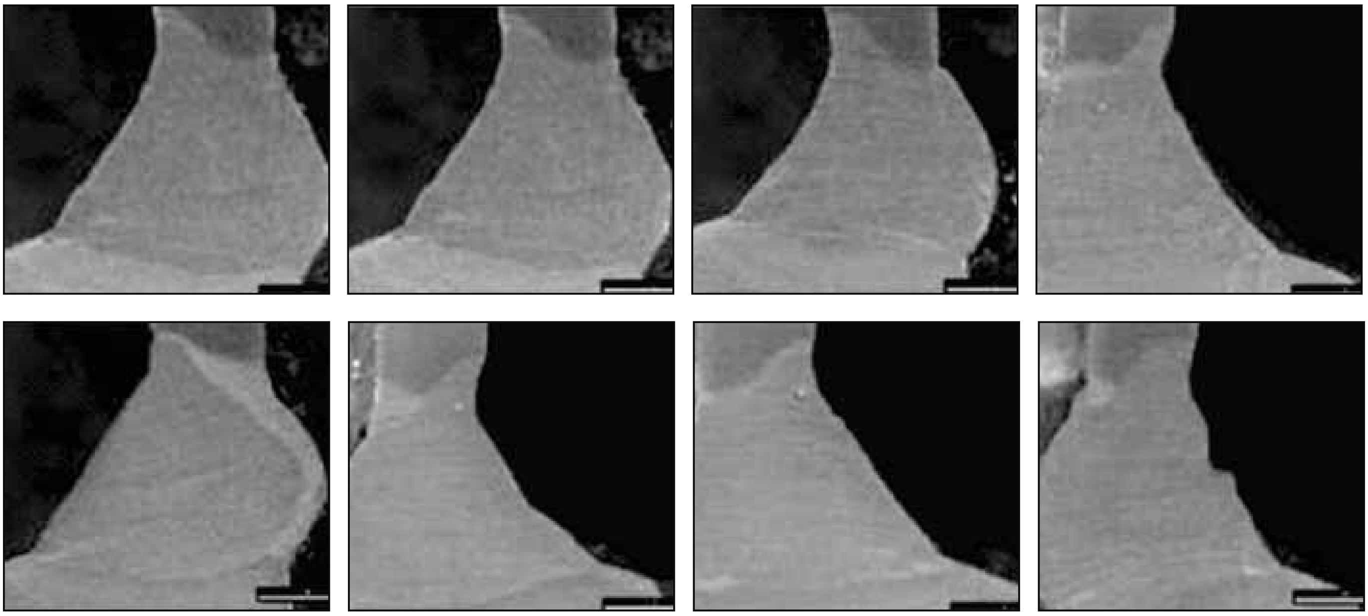


Figure 15 - Macro analysis of full penetration header to tube welding

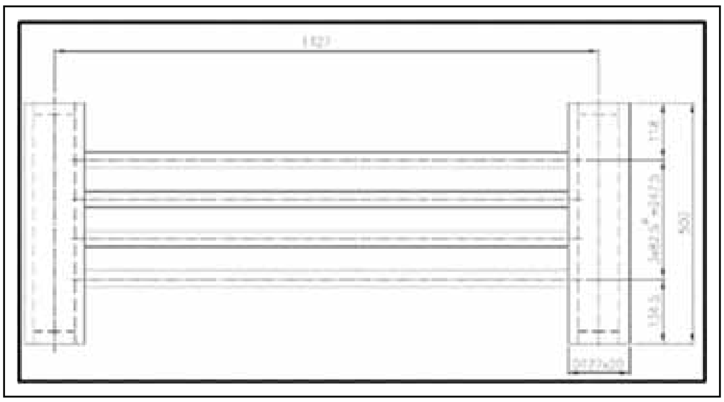


Figure 16 - Fabrication drawing of small HRSG module

Fig. 17 (a, b, c and d) show the welding sequence of pilot HRSG single row module with header pipe of 500 mm length and tube of 1m length, maintaining a pitch distance of 82.5 mm. All the welding trials were carried out by keeping the HRSG module in horizontal position. Fig.17-a shows the root pass welding using TIG welding process and filler passes by using GMAW process as shown in Fig. 17-b. The fabricated HRSG module is shown in Fig. 17-c.

After completion of header to tube welding, the joints were subjected visual examination and MPI. During the above said inspection, there was no major indication and hence, the component has been sent for hydro test. Fig. 18 shows the preparation for hydro test. All the four ends was closed and provided with two opening in either direction for water inlet and pressure gauge fitting. The complete welded assembly was hydraulically tested as shown in Fig. 19, at a pressure of 135 kg/cm^2, which is 1.5 times the design pressure. The result was found to be satisfactory and no leakages were noticed in any of the joints. With this satisfactory result of hydro test the above designed welding process and parameter seems to be optimum to achieve the desired weld quality and reliability for full penetration spot face set-on-type groove design.

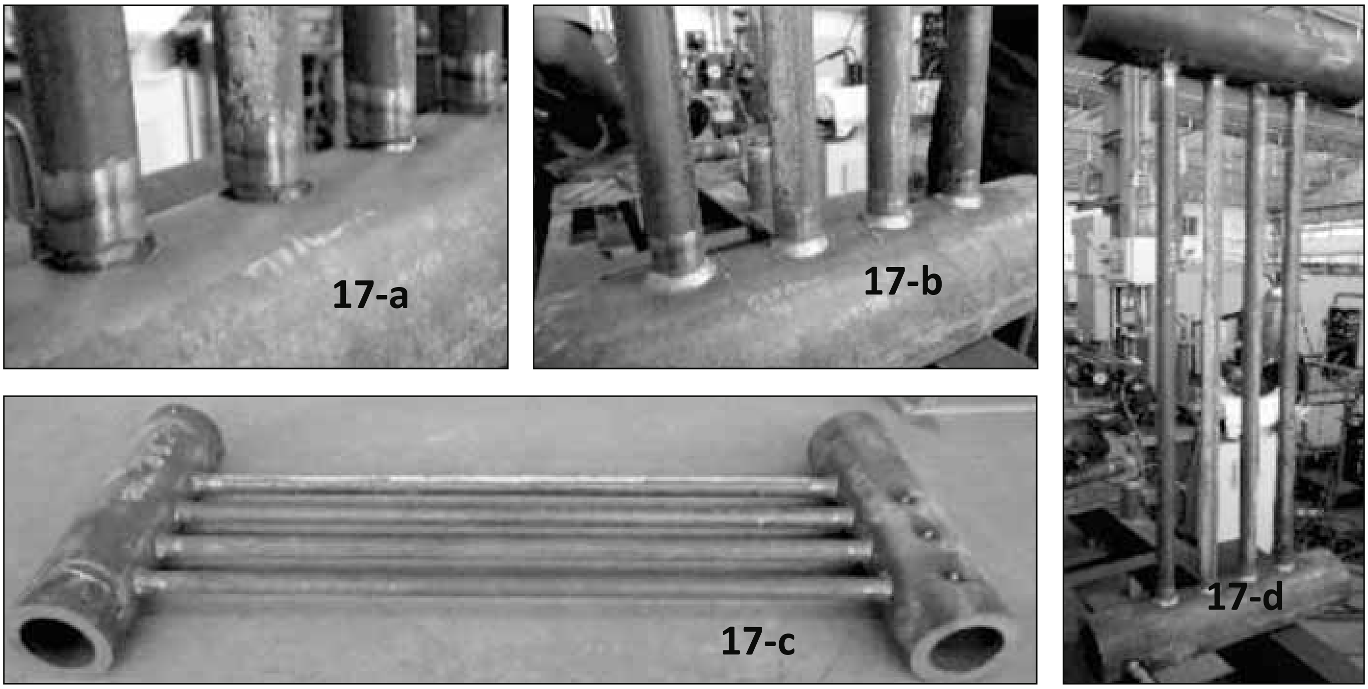


Figure 17 (a, b, c & d) - Welding of header to tube assembly module

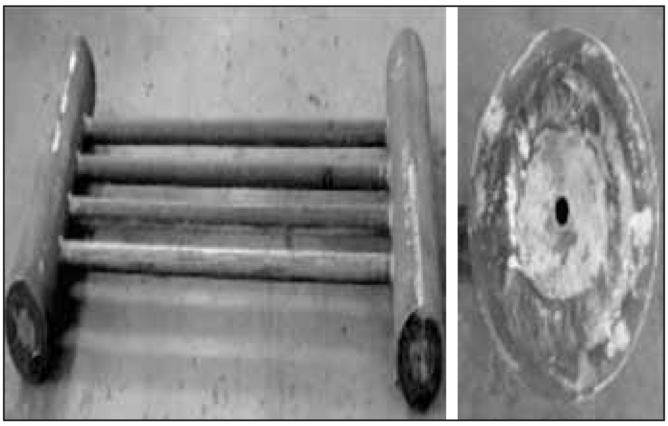


Figure 18 - Preparation for hydro test

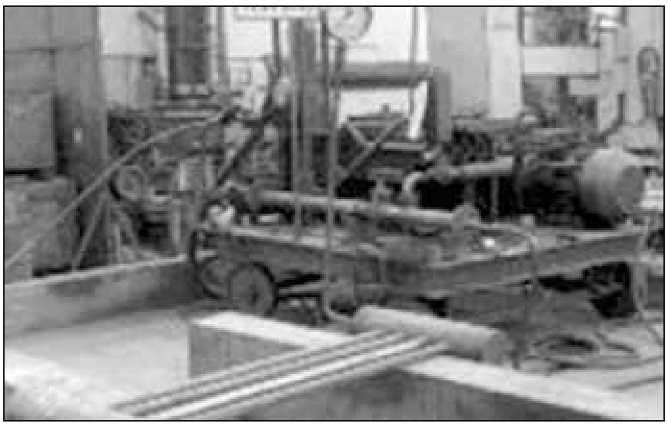


Figure 19 -Hydro test of header assembly

5.0 Conclusions

Based on the above study, following conclusions can be made,

1. Weld joint groove design, welding process and welder all are equally responsible for excellent weld quality and reliability.
2. Weld joint leakages can be eliminated by replacing partial penetration groove design to full penetration groove design.
3. For the full penetration joint design, root TIG followed GMAW process can be the better option for achieving superior weld quality.
4. The full penetration weld quality will depend on the joint fit up and welder skill compared to partial penetration joint.
5. The repeatability trials of TIG root followed by GMAW gives the consistency in weld quality and the same is confirmed by hydro test of the fabricated module.

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Evolution of phases in P91 steel in various heat treatment conditions and their effect on microstructure stability and mechanical properties

To achieve high thermal efficiency, modern day thermal power plants operate at higher operating temperature and pressure which necessitates use of steels with high creep rupture strength such as modified 9Cr-1Mo steels. The study discusses the evolution of phases in modified 9Cr-1Mo (P91) steel and their effects on microstructural stability and mechanical properties have been studied for specimens that were subjected to different thermal heat treatment conditions. The main focus has been to study the effect of heat treatment temperature ranging from 623 K to 1033 K (350–760 °C) on P91 steel. Further, the effect of furnace cooling, water quenching, tempering at 1273 K (1000 °C) and austenitizing on the mechanical properties and microstructure has been studied. The techniques used for material characterization were scanning electron microscopy (SEM), optical microscopy (OM) and X-ray diffraction. For low tempering temperature, i.e. 623 K (350°C), $M_{23}C_6$, M_3C, M_7C_3, and MX precipitates have been observed with high yield strength (YS), tensile strength (UTS), hardness and low toughness. In the high temperature range, 923–1033 K (650–760 °C), fine MX, M_7C_3, $M_{23}C_6$, M_2X, and M_3C precipitates have been observed with low YS, UTS, hardness and high toughness. The steel tempered at 1033 K (760 °C) was observed to be having best combination of YS, UTS, hardness, toughness and ductility.

Materials Science and Engineering A:
Volume 664, 2016, Pages 58–74

Investigation of welding residual stress in flash-butt joint of U71Mn rail steel by numerical simulation and experiment

U71Mn rail steel has been widely used in high speed railway construction, and it is commonly joined by flash welding process. It is inevitable to avoid very high residual stress in the welded joint. In this study, residual stresses in a rail steel flash-butt joints were measured by hole-drilling method. Meanwhile, an in-house finite element programme JWRIAN was developed to simulate welding residual stresses in the flash-butt joint. To effectively and accurately predict welding residual stress, a fast computing algorithm named iterative substructure method and an advanced material model with consideration of the influence of solid-state phase transformation were included in the computational approach. By comparing the calculated results with the experimental data, the validity of the developed computational approach was verified. Both experimental and numerical results suggest that the solid-state phase transformation plays a very important role in the course of formation of welding residual stress. In addition, simulation results indicate that the welding residual stress distribution in the flash-butt joint is very complex, and the peak values of tensile residual stress are relatively high. The residual stress distributions of the rail steel joint obtained by numerical simulation will be helpful in assessing the structural integrity. An advanced FEM was developed to simulate welding residual stress in high carbon joint. Phase transformation significantly affects welding residual stress distribution in U71Mn steel joint. The residual stresses could be accurately predicted by FE model with consideration of phase change.

Materials & Design
Volume 25 December 2015, Pages 1296–1309

Dissimilar ultrasonic spot welding of aerospace aluminum alloy AA2139 to titanium alloy TiAl6V4

The microstructure, hardness, lap shear strength and fracture energy of AA2139–TiAl6V4 spot joints produced by ultrasonic welding were investigated and related to the weld thermal cycle. No obvious inter metallic reaction layer was observed in the AA2139–TiAl6V4 welds, even using transmission electron microscopy. The hardness profile of AA2139 side after welding was studied, demonstrating that the heat introduced by the welding process leads to some softening with partial hardness recovery after natural aging. The effects of welding time on peak load and fracture energy were investigated. The peak load and fracture energy of welds increased with an increase in welding time and then reached a plateau, i.e., maximum peak load 5.3 kN and maximum fracture energy 3.7 kN mm. In all cases, failure occurred by fracture at the weld interface.

Journal of Materials Processing Technology
Volume 213, May 2016, Pages 382–388

WELD SHOP

WELD SHOP FEATURES THE NEW ADDITIONS TO THE EQUIPMENT PORTFOLIO AT WRI

KEYHOLE PLASMA ARC WELDING

SPECIFICATIONS

✓ **Power Source**
- Inverter controlled Transtig 4000 DC power source
- 310 A @ 100 % duty cycle
- Digital process control
- Slope up and slope down of current

✓ **Plasma Module**
- Add on plasma module
- Plasma gas flow – 0.1 – 10 lpm
- Plasma current – 1 – 30 A

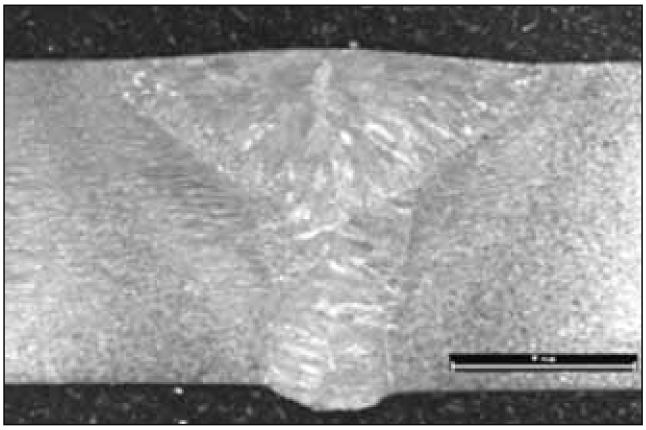
✓ **Gas**
- Plasma gas – Ar
- Shielding gas – Ar, He, N_2

✓ **Gas**
- Plasma gas – Ar
- Shielding gas – Ar, He, N_2

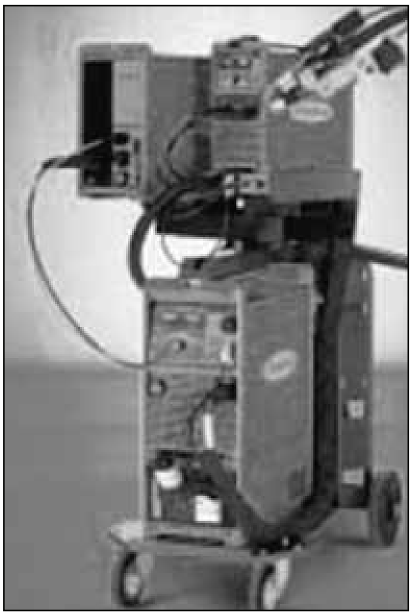
✓ **Welding Torch**
- Robacta 3500 – amenable for automation

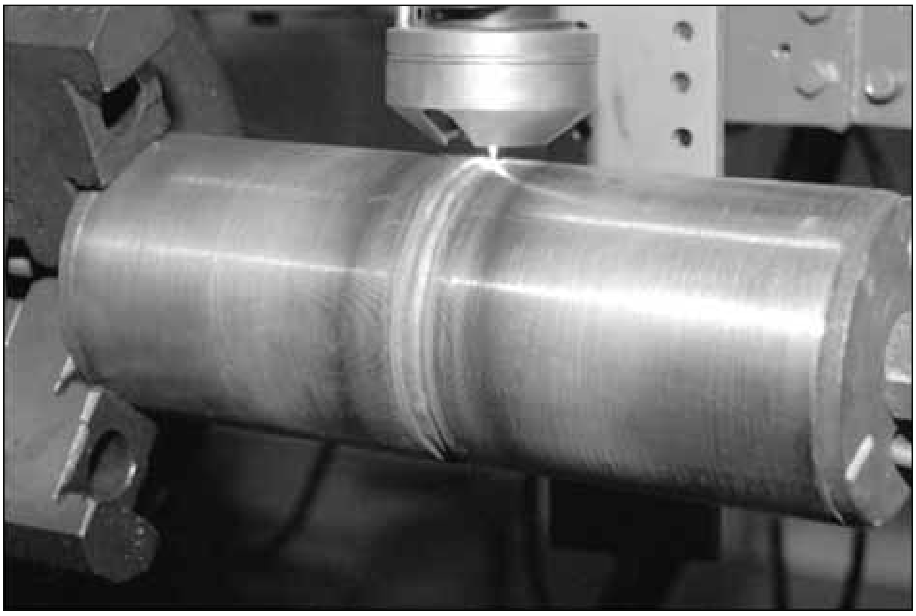
ADVANTAGES
- Deeper penetration
- Better productivity
- Better arc stability
- Less sensitive to stand off distance variations
- Autogenous welding process
- Less heat induced damage

WELDING CAPABILITIES
- Single pass welding upto 10 mm thickness in stainless steel and nickel based superalloys
- Optimized parameters available for carbons steel, Cr-Mo steel, stainless steels (austenitic, ferritic and duplex grades) nickel based superalloys in similar and dissimilar configuration
- Welding of both flat and symmetrical components
- Mechanized welding
- Welding with wire feeding possible



Plasma Welded Nickel Alloy





KEYHOLE PLASMA WELDING STUDIES ON P91 MATERIAL

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Abstract: *High intensity welding processes are always beneficial for welding of heat sensitive materials to reduce the heat induced damage. In the present work, keyhole plasma welding process has been optimized for welding of 8.5 mm thick P91 material in pipe configuration and subsequently, autogenous butt welding has been carried out on P91 pipe using the optimized parameters. The joints were characterized in both as welded and post weld heat treated (PWHT) condition @ 760°C for 2 h. Macrostructures of welds were uniform without any hidden defects. The weldment had three distinct zones fusion zone (FZ), coarse grained heat affected zone (CGHAZ) and fine grained heat affected zone (FGHAZ). PWHT welds had good bend ductility in both face and root whereas, in the as welded condition weld lacked ductility and it was more prominent in the face. Hardness across welds have not indicated the formation of any soft intercritical zone in the weldment. Tensile testing has shown that all welds had 100% joint efficiency. However, the welds had very poor impact properties compared to the base material in both as welded and PWHT conditions. Welds had predominantly tempered martensitic structure in all areas except the fusion boundary, where delta ferrite could be observed.*

Keywords**:** *Keyhole plasma welding, P91, autogenous welding, mechanical properties, delta ferrite*

1.0 Introduction

The advancements in the field of both coal based and nuclear power sectors have increased the use of materials like Creep Strength Enhanced Ferritic steels (CSEF) because of the inherent benefits it offers like good high temperature stability, high thermal conductivity, low coefficient of thermal expansion, better weldability, etc. compared to austenitic stainless steel, which has been the choice for quite some time for such high temperature applications [1]. Most popular in the category of CSEF steels is the 9Cr-1Mo (P91) steel, usually supplied in normalized and tempered condition and has tempered martensitic structure at room temperature. The material has very good strength at both room temperature and elevated temperatures upto 593 °C [2]. P91 finds its use in the advanced boiler technologies like super critical (SC), ultra super critical (USC) and advanced super critical (AUSC) in applications like headers, tubes, panels, etc. [3]

The application areas of these materials will involve welding and hence, weldability is one of the prime requirements. The common welding issues associated with this material are high susceptibility to hydrogen induced cracking due to hard CGHAZ with conducive environments, Type IV cracking in the soft intercritical zone during high temperature service, poor notch toughness in the weld and HAZ, formation of deleterious phases in weld, etc. [4, 5 ,6]. Most of the issues in these materials could be alleviated by welding with as low heat input as possible. The control of heat input is very difficult in conventional welding processes such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) and submerged arc welding (SAW), due to lower power densities, which demands the welding to be carried out in the multipass mode [7, 8, 9]. The use of low heat input processes could be the possible alternative. The advanced and low heat input welding processes like laser beam welding (LBW) and electron beam welding (EBW) have shown to offer some benefits in the limited work carried out so far in P91 and similar materials like P92 and reduced activation ferritic martensitic steel (RAFMS) [10, 11, 12]. Because of low heat input and concentrated nature of the heat source, the benefits were like reduced HAZ, absence of CGHAZ, no delta ferrite and soft intercritical HAZ, etc., which were the key issues with conventional welding processes listed above.

Even though LBW and EBW are highly beneficial because of their technical edge, the technologies are highly capital intensive, making it difficult to be adopted by every fabricator. The other possible alternative in such case could be keyhole plasma arc welding (PAW), which has both power densities and costs between conventional arc welding process and LBW & EBW. Keyhole plasma arc welding, an advanced arc welding process can carry out the welding in autogenous and characteristic keyhole mode and is capable of producing deep penetration welds in single pass welding. The process is also a low heat input welding process and hence, will have benefits similar to other power beam welding processes.

PAW is a modified TIG welding process in which the arc formed plasma will be contained in the copper nozzle and pushed through the small orifice providing a constricted arc. The highly concentrated energy because of the constricted arc is giving the power and energy to produce deeper welds in single pass. Hence, PAW is one of the candidate processes for welding of P91 materials.

PAW has been successfully used for welding of different grades of steels and stainless steels including duplex stainless steel, carbon steel, etc. and have exhibited excellent weld properties [13, 14, 15]. However, information on keyhole plasma welding of P91 material is scarce in the open literature. The present paper discusses the keyhole plasma welding studies on P91 pipe. Initially, the parameters were optimized and subsequently, butt joints were made using optimized parameters. The butt joints were subjected to mechanical and metallurgical testing in both as welded and post weld heat treated (PWHT) condition @ 760 °C for 2 hours. The properties of the weld joints are presented and discussed.

2.0. Experimental Details

The welding experiments were conducted on P91 pipe of dimensions 83.5 mm OD and 8.5 mm thickness. The chemistry and mechanical properties of the base material have been evaluated and the results are presented in Table 1 & 2 respectively. The edges of the pipes were faced and the pipe ends were tightly clamped using a fixture to ensure zero gaps during welding. Prior to fitting, the ends were thoroughly cleaned using acetone to remove any dirt, oil, grease, etc. The tightly fitted pipes were placed in a rotary positioner and the pipe was made to rotate under the arc. The pilot arc produced by low current was used to position the main plasma arc exactly at the centre of the weld joint. Back purging with Ar @ 20 lpm was given to protect the root side of the weld from oxidation and the same was supplied through the hole in the end cap. Totally 3 joints were made using two different welding parameters. The parameters were chosen based on the optimization experiments carried out in bead on pipe mode, which is not discussed in the current paper. Out of the three welds, two were subjected to PWHT @ 760 °C for 2 h and furnace cooled before characterization. The welds were designated as NP, L and H for non-post weld heat treated; low current-high heat input (2989 J/mm) and high current – low heat input (2072 J/mm) parameters with PWHT and the same are shown in Table 3. The welds were subjected to macrostructural analysis, room temperature tensile testing and 180° bend testing, charpy V-notch impact testing, microhardness measurements across the weld and microstructural analysis using optical microscopy.

Table 1 – Chemistry of the base material

Element	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb	Al	N
%Wt	0.08-0.12	0.20 - 0.50	0.30-0.60	Max 0.02	Max 0.01	Max 0.40	8.00–9.50	0.85-1.05	0.18-0.25	0.06-0.10	Max 0.040	0.030-0.070

Table 2 – Mechanical properties of the base material

Material	UTS (MPa)	YS (MPa)	Elongation (%)	Impact Energy @ RT , J
ASTM A335 Gr.P91	694	588	26	205

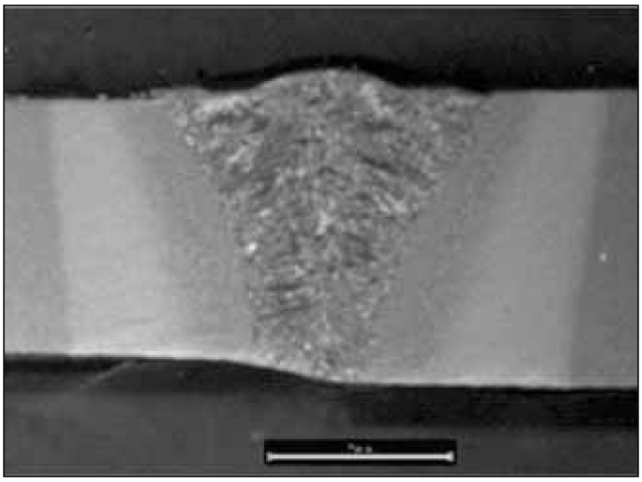
Table 3 – Welding parameters

ID	Current (A)	Voltage (V)	Plasma gas flow rate (lpm)	Speed (mm/min)	Shielding gas (lpm)	Purging gas (lpm)	Heat input, J/mm
NP	135	28.4 -30.1	2.5	111	12	20	2072
L	130	28.3-30.4	1.8	73.83	12	20	2989
H	135	28.3-31.1	2.5	111	12	20	2072

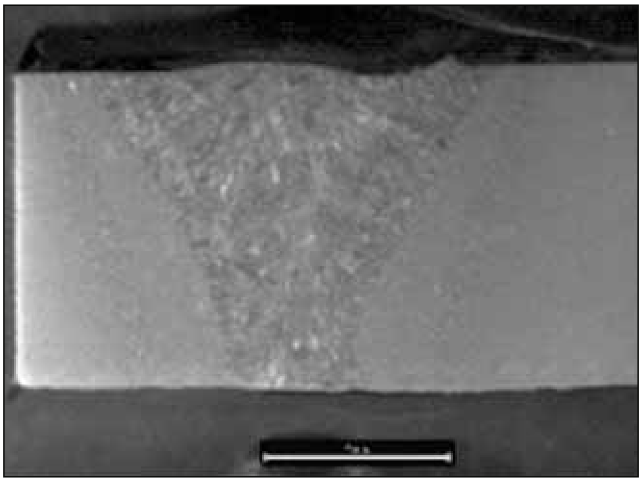
3.0. Results and Discussion

3.1. Macrostructure

Macrostructure of the plasma welded butt joints etched using villela's reagent are shown in Fig.1. Welds were found to be smooth with good bead characteristics. No hidden defects were observed, even in the weld which was characterized without any PWHT. The bead geometry measurements are reported in Table 4.



NP



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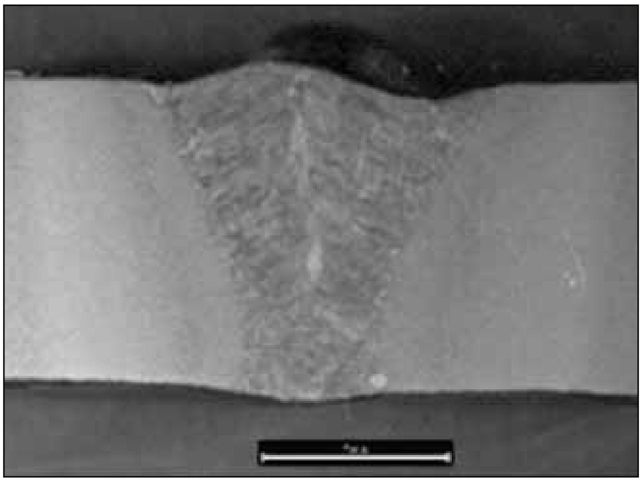

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Figure 1 – Macrostructures of plasma welds

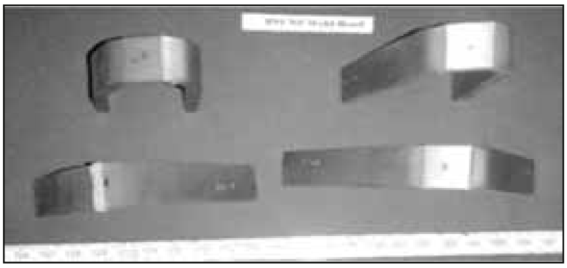
Bead geometry measurements have shown that the weld width was more for the weld made with low current and low speed compared to the other parameter. However, the weld was found to be smoother with flat top bead and without any concavity at the top for the weld made with low current. This is because of the low plasma gas, which has reduced the intensity of the plasma gas. It is because of the same reason, lower speeds were essential to achieve full penetration in this plasma gas condition. In the case of high current parameter, because of comparatively higher speed, the cooling rates would have been fast and has resulted in the hump formation at the centre of the weld bead.

Table 4 - Bead geometry values of plasma welds

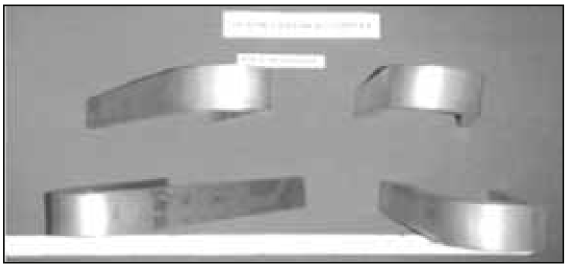
ID	Reinforcement, mm	Top bead width, mm	HAZ width, mm
NP	0.788	9.435	1.524
L	0.237	11.063	2.704
H	0.540	9.952	1.505

3.2. Bend testing

Bend test results are shown in Fig.2.



NP



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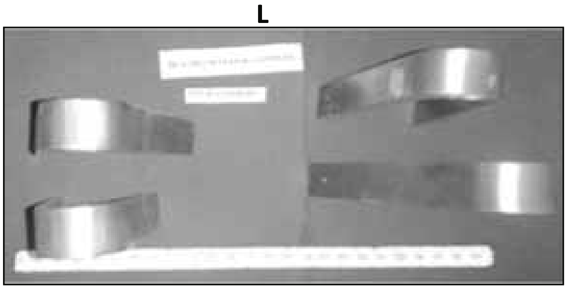

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Figure 2 – Bend test results

Root and face bend ductility of the PWHT welds with both the parameters (L,H) are excellent and has cleared the bend tests as per AWS B4.0 standard, as can be seen in the Fig.2. In case of weld NP, it is interesting to note that it has cleared the root bend test and out of two, one of the specimens has cleared the face bend test. In case of plasma welds, the weld is narrow with low width to depth ratio. In the present case, the width to depth ratio is around 1.2 only. Since the weld is narrow, the amount of weld metal in the tension side will be less and this would have reduced the interference of the hard weld metal in the bend forming, which could be the reason for good bend ductility in the as welded condition itself. This reiterates the hypothesis that high intensity processes with narrow fusion zone will be beneficial for welding of such heat sensitive and exotic materials. However, it could be noted that there is a shift in weld line, which is a typical characteristic of a hard weld metal in the bend forming.

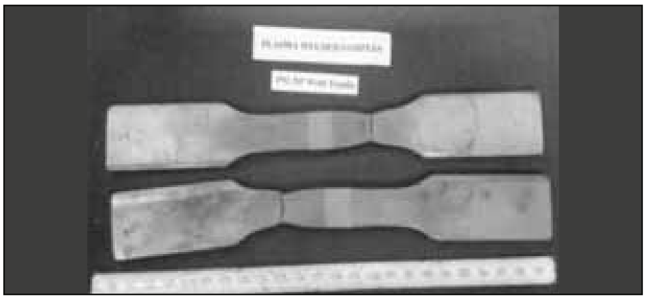
3.3. Tensile testing

The transverse tensile test results are given in Table 5 and the tensile tested specimens are shown in Fig.3. Two specimens were tested per parameter and the average is only presented in the table

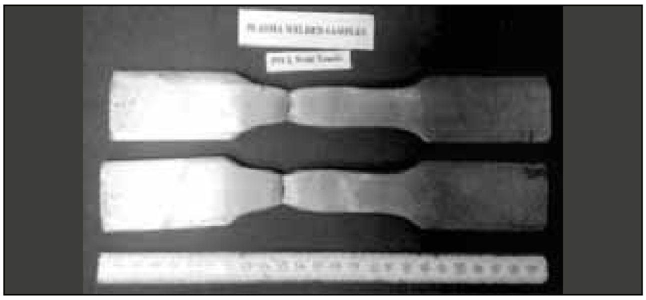
Table 5 - Tensile test results

Specimen	YS, MPa	UTS, MPa	% Elongation	Position of Fracture
NP	539.5	650.5	16	Base metal
L	583	697.5	19	Base metal
H	572	699	18	Base metal

As can be seen from the results, the failure has always been located in the base material irrespective of the parameters and weldment condition. However, without heat treatment, the failure has happened at lower strength values comparatively. In the PWHT condition, the strength values obtained were almost the same. The lower strength value in the as welded



NP



L

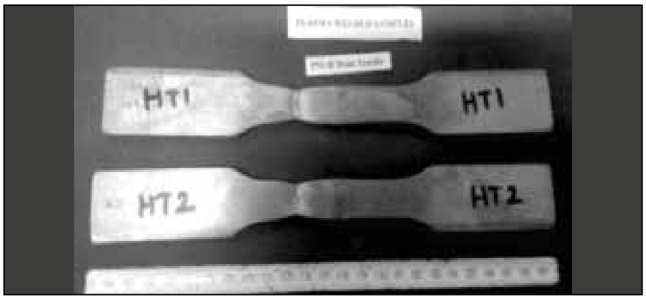


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Figure 3 – Tensile Tested Specimens

condition is because of very hard and high strength in the weld, which gives a restraint effect during pulling in tension and concentrates all the elongation in the base material. Hence, the failure happens in the strain controlled mode and occurs in the base material at a lower strength level in spite of high hardness/strength of the weld. Even though the % elongation is not a critical parameter in the transverse tensile test, this can be indication of ductility. Comparatively more % elongation in the weld L confirms that with higher heat input, the ductility is better because of softer weld metal.

Table 6 – Charpy V-notch impact test results

Base Material		NP		L		H	
Sample ID	Impact energy, J	Sample ID	Impact energy, J	Sample ID	Impact energy, J	Sample ID	Impact energy, J
B1	208	NP1	06	LI	12	H1	40
B2	210	NP2	14	L2	10	H2	38
B3	198	NP3	08	I3	10	H3	46

3.4. Charpy V-notch impact testing

Charpy V-notch toughness values for the specimens tested at room temperature using a subsize specimen as per ASTM E23 are compiled in Table 6.

Charpy V-notch impact toughness values for welds were found to be very less compared to the base material. Among the three conditions experimented and tested, the toughness values were found to be very less in the not heat treated condition followed by weld made with higher heat input and then the PWHT weld made with comparatively lower heat input. The loss in impact toughness with welding is a common phenomenon in this grade of material. Without heat treatment, in case of NP, the low toughness values could be attributed to the hard and brittle weld. Comparatively better impact toughness values with H (lower heat input parameter) could be due to finer prior austenite grain size obtained with high cooling rates. Hence, the results confirm that the toughness values could be improved in autogenous welding of P91 material with lowest heat input possible. This is in line with the observation of the current author in laser welding of P91 material [11].

3.5. Microhardness measurements

Microhardness survey was performed across the weldments, using a Vickers microhardness tester with an inter indent spacing of 500 µm using a load of 300 g. The variation in hardness values with the three conditions are presented in Fig. 4.

The peak hardness was in the weld region for all the three conditions with NP having a peak hardness of 550 HV, H having around 350 HV and L

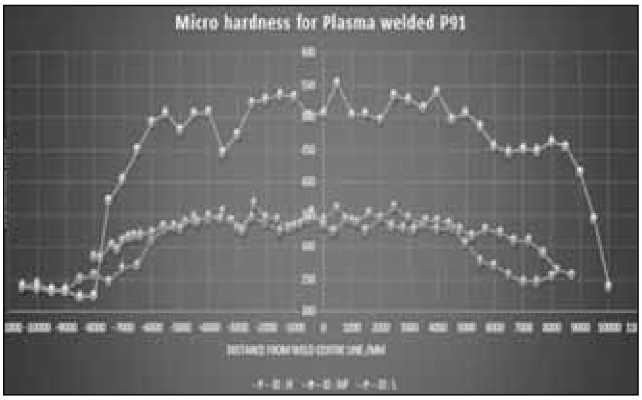


Figure 4 – Microhardness survey across weldments

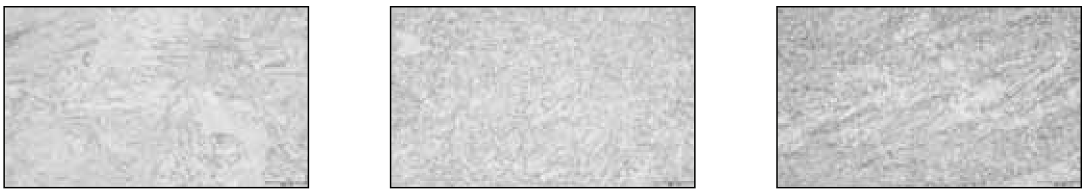
with a peak hardness value of around 340 HV. HAZ had a hardness in the range of 375-450 HV in NP, 250-270 HV in H and 240-260 HV in the L. Very high hardness in the NP condition is the reason for reduced ductility, face bend test failure and very low impact toughness. Among the PWHT specimens, peak hardness was found to be marginally high in the case of lower heat input parameter, which could be because of higher cooling rates encountered during welding solidification.

3.6. Microstructures

The microstructures in the weld and HAZ are presented in Fig. 5 for all the three parameters.

In case of NP specimen, the weld and CGHAZ had a microstructure comprising of untempered lath like martensite, which could be the reason for elevated hardness and poor ductility. L and H have tempered martensitic structure in the weld and CGHAZ. The microstructure didn't show any presence of δ-ferrite in the weld except near the fusion boundaries (FB). Very small amount of delta ferrite observed near FB with L and H are shown in Fig. 6b. Base material microstructure shown in Fig. 6a.

Weld – 200 X



HAZ-200X

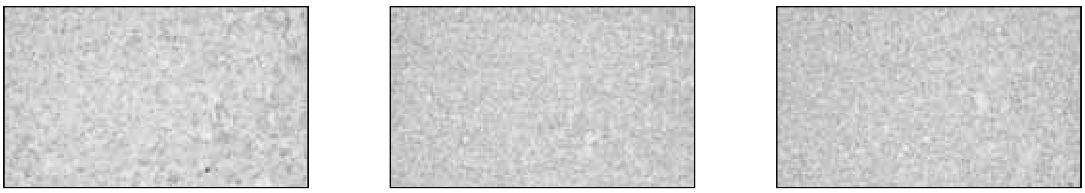


Figure 5 – Microstructures of Welds and HAZ

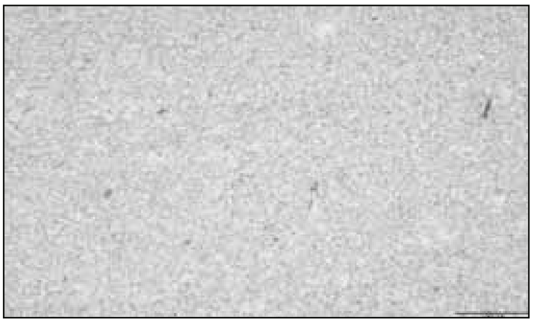
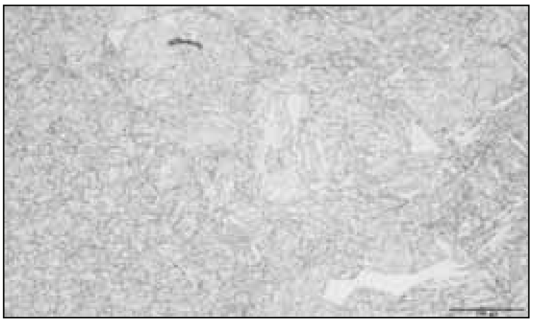


Figure. 6a - Base material microstructure



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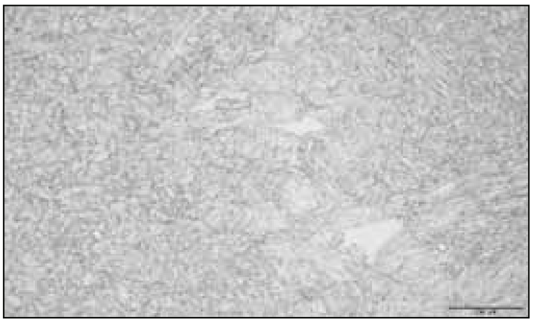

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Figure 6b – Microstructures of welds with δ - ferrite

This could be explained based on the results obtained by prior reported works [16, 17]. The formation of δ-ferrite in the weld depends on chemistry of the base material in terms of Cr_{eq} and Ni_{eq} and also on the cooling rates encountered in the particular region. The formulae for calculating Cr_{eq} and Ni_{eq} are as given below

$$Cr_{eq} = Cr + 2Si + 1.5\,Mo + 5V + 1.75\,Nb + 0.75W$$

$$Ni_{eq} = Ni + 0.5Mn + 30C + 25N + 0.3Cu$$

For a weld metal to be free from δ-ferrite, the Cr_{eq} should be <13 and the difference between Cr_{eq} and Ni_{eq} shall be < 8[4]. In the present case, the Cr_{eq}, Ni_{eq} and the difference between Cr_{eq} to Ni_{eq} are respectively 12.6, 6.05 and 6.55. As per the chemistry of the base material, the weld should be free of δ-ferrite, however, as explained by the reported literature [16], the cooling rates play an important role in the formation of δ-ferrite. In case of autogenous weldments, the cooling rates shall be more near the boundaries compared to the weld centre, which was favorable for δ-ferrite formation. Hence, in autogenous keyhole plasma welding, δ-ferrite could be observed in the FB of both the weldments. However, this has not shown up in hardness survey, because δ-ferrite was in islands and not as a continuous network, because of which indentation would not have fallen in δ-ferrite regions.

4.0. Conclusions

- Autogenous keyhole plasma welding process has been established for welding of 8.5 mm thick P91 material in pipe configuration.
- Welds had excellent tensile properties, good bend ductility in the PWHT condition. However, impact toughness of the welds was found to be much lower compared to the base material. The impact toughness values were found to be sensitive to heat input and heat treatment after welding.
- Welds had tempered martensitic structure after PWHT and δ-ferrite was found to be forming near the fusion boundaries due to very high cooling rates.

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WELD STAR

WELD STAR FEATURE THE INDIVIDUAL RECOGNITION EARNED BY WRI PERSONNEL

- **Skoch BSE 2016 Award:** WRI has bagged the prestigious Skoch BSE Award 2016 for its innovative technology development initiatives leading to significant gains in quality and productivity. The award was presented on the occasion of Skoch BSE Summit held in Bombay Stock Exchange in Mumbai recently by Mr. Rajeev Kumar Agarwal, Director, SEBI, along with Mr. Ashishkumar Chauhan, MD & CEO, Bombay Stock Exchange and Mr. Sameer Kochar, Chairman, Skoch Group.Mr. R Easwaran, General Manager, WRI, BHEL, Tiruchirappalli and Mr. P. Raguraman, General Manager, Corporate Planning & Development, BHEL, New Delhi received the award. WRI had presented their seven technology initiatives which have been deployed in the manufacturing shop floors, with significant gains in quality and productivity. The award process involved screening and shortlisting of the award proposals, presentations to an eminent jury, shortlisting the top hundred for the Skoch Order of Merit and the final Skoch BSE Awards to thirty organisations in the country for the top projects.

- The flash talk delivered by Mr. B. Shanmugarajan on the topic 'Enhancing Applications for Thermo Mechanical Simulation in Welding', at IIW Research Colloquium at Hyderabad on Apr 9, 2016, which covered some of the innovative applications/R&D carried out with Gleeble Thermal Cycle Simulator available at WRI. The presentation was well received and was adjudged as the best paper by the committee.

The Merit Certificate was presented by the well-known international expert Prof. John Norrish, University of Wollongong, Australia


International Institute of Welding
6th Welding Research & Collaboration Colloquium
Merit Certificate

- A paper titled "Optimisation of Parameters for Laser Welding of P92 Materials using Taguchi Based Grey Relational Analysis" authored by Mr. B. Shanmugarajan, Mgr/WRI has been accepted for publication in Defence Technology, Elsevier Publications

- A paper titled "Operating Experiences of CFBC Boiler Burning Lignite with High Ash Shrinkage Property" co-authored by Dr. A. Lawrence, SM/Labs is published in the proceedings of 22nd FBC International Conference.

- Mr. K. Srinivasan, Sr. Engr., Labs, has won the 'Best Executive Award of BHEL, Trichy for the Quarter of Oct '15 – Dec '15'. This is for the innovative work done by him, which also included bringing back the dip paint tank into use, without having to waste the large quantum of paint available in the tank.

WELD CARTOON

Cartoon Courtesy by A.P. Madhavan Kutty

Yet another example for Work is Worship – an evolution of divine shrine Nandi from a metal

The above picture depicts the underbead formed during parameter optimization in keyhole plasma welding of nickel based superalloys (Nandi spotted by Mr. B. Shanmugarajan)

GRADUATION DAY CEREMONY FOR VIII BATCH BHELES-PSGCT PG CERTIFICATION PROGRAMME

The eighth Graduation Day for the one year PG Certificate programme on 'Welding & Quality Engineering' jointly organized by BHEL Education Society (BHELES) and PSG College of Technology (PSGCT), Coimbatore was held at WRI on June 28, 2016. 24 students who have successfully completed this industry oriented course were awarded the Certificates by the Chief Guest, Sri. S. Gopinath, Executive Director, BHEL, Trichy, Thirumayam and Piping Centre, Chennai. Speaking on the occasion, Mr. S. Gopinath expressed his happiness that the graduands have been able to gain excellent knowledge and good jobs on their own merit. Mentioning that welding is a fascinating and challenging field, he highlighted some of the qualities that the industry expects from such welding professionals. He called upon the graduands not to be satisfied just with being a person of success, but he said it is important to be a person of value to the society. “Your knowledge through application has to transform into wisdom and that has to be ploughed back to the society”, he stressed. He also applauded the efforts taken by PSGCT, BHEL Education Society, BHEL and WRI collectively in grooming the welding engineers of the future. Mr. Gopinath observed that the course has been able to transform the raw engineering graduates into industry-ready, employable professionals.

Dr. R. Rudramoorthy, Principal, PSGCT presided over the function. Speaking on the occasion, Dr. Rudramoorthy stressed the importance of having such an Industry-Institute interaction and he felt, this is what makes this course unique and different from the other post graduate programmes that are being offered in the country. He observed that this has evolved as the best model for a Finishing School. He thanked BHELES and the management of BHEL for making such a course possible. He said PSGCT will explore initiating MS programmes in welding discipline in the coming years, taking cue from the success of this initiative.

Earlier, Mr. M. Jayakumaran, President, BHELES and General Manager, Human Resources of BHEL, Trichy delivered the welcome address and highlighted the contributions of BHELES in the field of education at various levels. He also thanked the whole hearted support of PSGCT and WRI in making this course a sustained reality, now in its ninth successive year. Mr. R. Easwaran, General Manager, WRI & Labs gave a brief overview about the course and the improvements done year on year to make it more useful. Dr. P. Gopalakrishnan, Head, Metallurgical Engineering Department of PSGCT felicitated the young graduands. Mr. R.Subbarayalu, Addl. General Manager, WRI proposed the vote of thanks.

6th WELDING RESEARCH & COLLABORATION COLLOQUIUM

Mr. R. Easwaran, GM/WRI & labs and Mr. B. Shanmugarajan, Mgr. /WRI attended the 6th Research Colloquium of International Institute of Welding organized at Hyderabad by Indian Institute of Welding during 7-9 Apr 2016. The research colloquium is an initiative by International Institute of Welding to identify the gaps prevailing in different areas of welding, which can be the seeds for future research in the field. This colloquium had exclusive sessions pertaining to seven different sectors viz., Power & Energy, Defence, Aerospace, Nuclear, Oil & Gas, Heavy Engineering & Shipbuilding and Automotive & Surface Transportation. Each session had four to five presentations from the leading experts in the field. The colloquium had good international participation with around 25 participants from many leading international institutes like ANSTO, University of Wollongong, JWRI, GE, Fronius, etc. Each session chair briefed on the areas of concern before the start of the session. Mr. R. Easwaran, GM/WRI & Labs chaired the session on Power and Energy. From each session, five areas were identified for pursuing future research.

From WRI, a flash talk was delivered by Mr. B. Shanmugarajan on the topic 'Enhancing Applications for Thermo Mechanical Simulation in Welding', which covered some of the innovative applications / R&D carried out with Gleeble Thermal Cycle Simulator available at WRI and a poster presentation was also made on the topic 'Development of Welding Consumables for Better Performance – WRI Experience' highlighting the developments of WRI in consumable front.

Dr. G.V. MEMORIAL LECTURE

Mr. R. Easwaran, GM/WRI & Labs delivered the Dr. G.V. Memorial Lecture on the topic 'Learnings from Fabrication of T23 (2.25Cr-1.6W-V-Nb) Steel Tubes in Power Plant Applications' on May 2, 2016. In this lecture, he recalled the contributions of Dr. G. Venkataraman in the field of metallurgy and welding. The lecture covered an exhaustive overview of the experience gained by BHEL Shops w.r.t. handling T 23 material, experience gained through field fabrication and through various simulation tests at WRI.

- Forty first year of service in the field of welding and allied areas
- Developed and Commercialised more than 50 products / technologies
- Has filed more than 162 patents (Granted-40)
- Served more than 1000 industries in different sectors
- More than 1125 technical papers in national and international journals and conference and 75 awards won
- Has a Memorandom of Understanding with German Welding Institute (DVS) for joint working
- An Agreement on Collaborative Research and Exchange with JWRI, the Japanese Joining and Welding Research Institute.
- A Protocol of Intention signed with University of Hannover, Germany.
- Trained more than 25200 welding personnel through various training programmes
- A reference book on "Industrial welding technology" authored by WRI published by Central Instructional Media Institute (CIMI). Chennai for practising welding personnel
- Important research work carried out in the Institute published in "WRI Journal"
- Recognised by DSIR as a national research facility
- Recognised by DST for training and certification of welders
- Approved by Central Boilers Board for certification of welders as per IBR
- Recognised centre for Doctoral Research (IITs, IISc, NIT & Anna University)
- Approved by NHPC for certification of welding consumables
- Recognised by Industries from Middle East (Dubai, Oman, Sri Lanka, Bhutan and UAE) for training & certification of welding personnel as per international standards.
- Winner of SKOCH - BSE Award 2016

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