International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

Comparison of Weld Built-up by FCAW and MIG Welding on Damaged Low Cr-Mo Alloy Steel Tube in Boiler Application

Amit Kumar * and Vijayakumar P

Department of Mechanical Engineering, PRIST University, Vallam Thanjavur, Tamil nadu, India.

International Journal of Science and Research Archive, 2023, 08(02), 492–505

Publication history: Received on 13 February 2023; revised on 22 March 2023; accepted on 24 March 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.8.2.0243

Abstract

In boiler application low Cr-Mo tubes are being used and in manufacturing or working these tubes are getting damaged. ASTM and ASME BPVC (Boiler Pressure vessel code is allowing wall thinning of tubes by 10%. Any damage more than 10% of wall thickness is causing rejection of Tube. As ASTM and ASME has provision for weld build-up on defected or damaged portion of Boiler Tubes, hence I am going to compare two welding process for the weld built-up on low Cr-Mo alloy steel tubes. In current practice the damaged tubes are being scrapped in boiler manufacturing as well as in running boilers. After this demonstration we can compare mechanical Properties of reworked tubes with original one. The Two methods adopted are MIG Welding and FCAW. Metal Inert Gas (MIG) welding is known for high deposition welding technique will minimum defect possibility. Flux Cored Arc Welding also has high weld deposition rate with minimum defect possibility.

Keywords: Built-up; SA213T22; MIG Welding; FCAW; Boiler Tubes

1 Introduction

In the current scenario of manufacturing sector of boiler, the profit gain to the manufacturers are very marginal. Providing a good quality product is always the first goal of Indian leading power equipment manufacturer, Bharat Heavy Electricals Limited. And for satisfying its quality BHEL is compromising in many areas. The rejection of boiler pressure vessel tube is one of its major concerns. The damage of steel tubes occurring in almost in every header due to processing parameters. To reduce such rejection of steel tubes we are going to establish a process of buttering on the steel tubes which has not been practiced yet in BHEL

1.1. Problem identification

The tubes are getting damaged by following reasons

- Wrong parameters during welding
- Wrong handling during movement by cranes
- Carelessness during machining
- Surface defects like Arc strike, Cone touch
- Rubbing of tube surface against each other in operation

* Corresponding author: Amit Kumar

Figure 1 Tube damage due to lifting chain rubbing

1.2. Remedies

ASTM A1016/A1016M-18a says, the damage tube can be the repair welded to damaged portion provided consumables should have same composition of tube being welded. Also welding should be done by a qualified welder. Each length of welded tube is subjected to non-destructive testing. Hence we are going to do build-up on tubes by FCAW and MIG welding and compare the properties with original tube properties.

2. Methodology of study

2.1. Introduction of Build-up Process

Build-up as the name suggest, is the process of build-up or depositing foreign (same of different) metal over a component by means of some diffusion process so that after buttering the deposited metal and parent material is considered as single element.

In our case we are going to deposit the material by Flux Cored Arc Welding which is firmly known as FCAW.

2.2. Reason for choosing FCAW and MIG Welding

- As the wires of these two process can be of 1.2 to 1.6mm hence lesser arc energy required to get good weld compared SMAW.
- This lesser arc energy results in lesser heat input to the tube being welded.
- Lesser heat input keeps hardness of weldment within limit without PWHT (Post Weld Heat Treatment).
- Also chances of getting defect is less in these two process.
- Reason for not choosing TIG welding is, in application is quite slow process compared two these two methods. Also, in Operational boiler tube repair TIG welding may not be suitable due to accessibility and position.

In our case the tube thickness will be maximum 13mm and for such low thickness a turbulent and finger form weld pool may create a problem as through penetration, wide heat affected zone and internment zone which are the result of any solid wire method whereas the Flux Cored wire deposits as a spray and supply of gas reduces the spatters and make a sound weld. The weld pool of FCAW and MIG welding is calm and circular which are desired parameters for buttering. Also FCAW and MIG welding surface finish is better than SMAW and due to this there will be less grinding work after built-up on the tube.

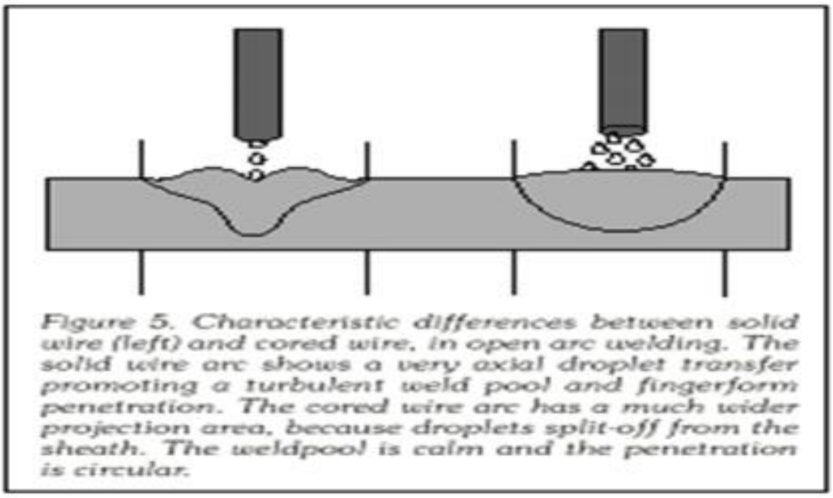


Figure 2 Weld pool representation of FCAW and MIG Process Compared to SMAW

2.3. Working Principle of FCAW

The flux cored arc welding process is similar to gas metal arc welding, with the exception that the tubular in shape and is filled with flux. Cored electrodes produce a more stable arc, improve weld contour and produce better mechanical properties of the weld metal.

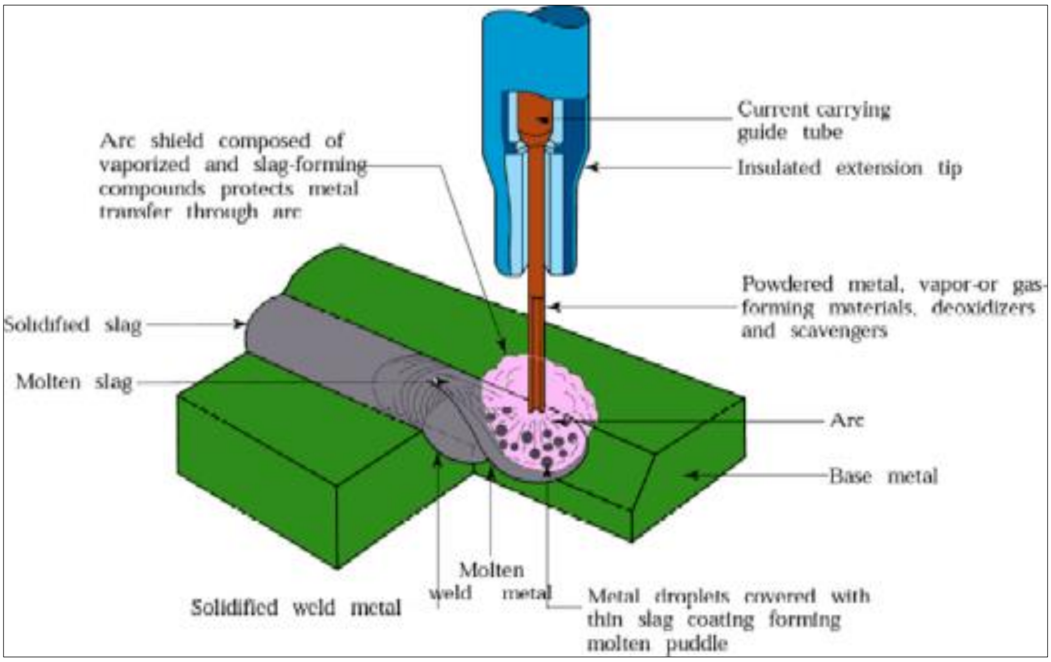


Figure 3 Schematic illustration of the flux cored arc welding process.

The wire is fed automatically through a nozzle which has a supply line of shielding gas and current conductor. The feed mechanism is controlled by two rollers which is responsible for speed of deposition and the speed of rollers depends upon the movement of welding torch and current used.

The flux in these electrodes is much more flexible than the brittle coating used on SMAW electrodes, so the tubular electrode can be provided in long coil lengths. The electrodes are usually 0.5mm-4mm in diameter and the power required is about 20 kW.

Self-shielding electrodes are also available which don't need any external shielding. Small diameter electrodes have made the welding of thinner materials not only possible but often preferable. Also, small diameter makes it relatively easy to weld parts in different position and the flux chemistry permits the welding of many metals.

2.4. Working Principle of MIG Welding:

Metal Inert gas, as the name suggest in this process we are using inert gas such as Helium, Argon for shielding process.

The MIG welding process is based is based on the principle that a consumable metal electrode is used to produce an arc in between the metal electrode and the work-piece. The arc so produce creates a large amount of heat and this heat melts the solid welding wire and some portion of work-piece and thus joining of two plate takes place. This whole process takes place under a shielding inert gas to prevent the weld from atmospheric contamination.

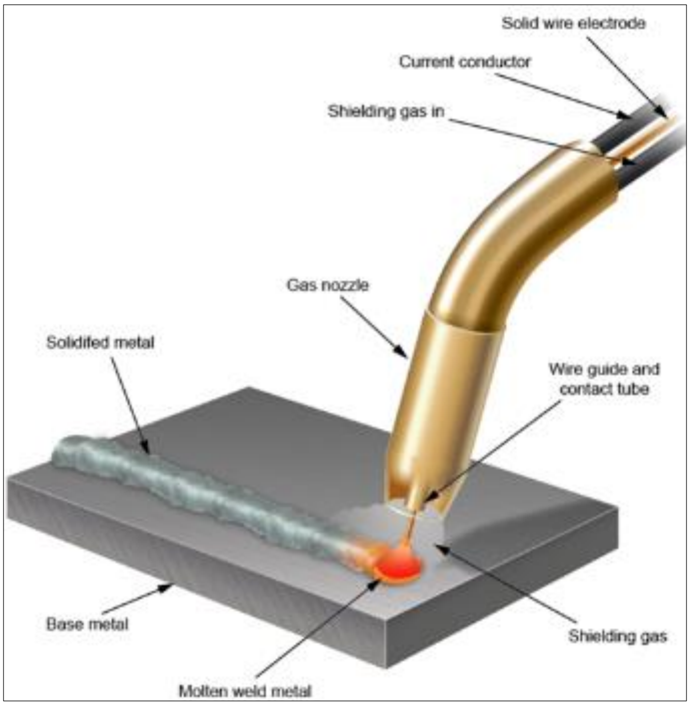


Figure 4 Schematic illustration of MIG welding process

MIG welding wires can have dia. ranging from 0.8mm to 2.0mm

2.5. Types of FCAW and MIG electrode wires:

2.5.1. FCAW Electrode Wires

There are four type of electrode is available and base upon the requirement we select the type of electrode has to be used. The different types of electrodes are as follows:

- Seamless electrode
- Butt seam electrode
- Joggle seam electrode, and
- Complex section electrode

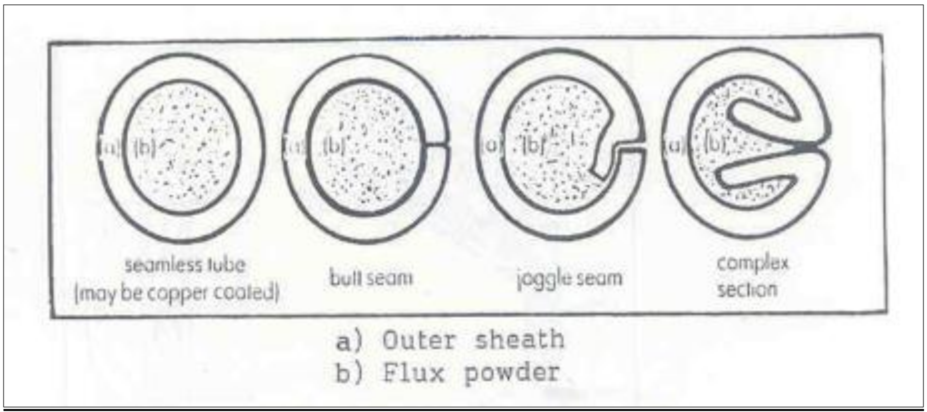


Figure 5 Different types of FCAW electrodes

2.5.2. Type of MIG Welding Wires

These wires are copper coated solid wires. The diameter of wires ranges from 0.8mm to 2.0mm in general application.

Type M1: Superior Usability in Thin Sheet Welding [Arc Stability, Burn-through resistance etc.]

Type M2: Low Spatter, Superior Bead Shape and Suited for Plate Thickness from 7 to 16 mm suitable for Steel construction & Bridge etc.

Type M3: High deposition efficiency suitable for Thick Plate Welding

2.6. Advantages of FCAW

There is numerous advantage of FCAW but following are the advantage from buttering point of view

- Wider arc reduces chances of burn-through.
- Low weld metal hydrogen content.
- Resistance to moisture re-absorption.
- Improved penetration.
- Reduced risk of fusion defects.
- Smooth finishing.

2.7. Advantages of MIG Welding

- MIG welding is fast. With any welding, the time taken has to reflect the difficulty of the join and the quality desired from the finished weld.
- Ease of use.
- MIG weld quality is way better than other process.
- Long-pass welding is possible
- Penetration matter can be controlled easily
- Fewer stops and starts.
- MIG works with many metals or alloys.

3. Test material and related data

3.1. Material selection

In the header manufacturing BHEL uses medium carbon steel with some other alloying elements, low carbon steels with Cr-Mo as a major alloying element. Following is the list of material we use in header manufacturing.

Table 1 Tube material for boiler component manufacturing

MATERIAL	% C	% Cr	% Mo	% W	%Mn	%S	%P
SA 210 A1	0.27	0.4	0.15	------	0.27-0.93	0.035	0.035
SA213 T11	0.05-0.15	1.0-1.5	0.44-0.65	------	0.3-0.6	0.025	0.025
SA213 T12	0.05-0.15	0.8-1.25	0.44-0.65	------	0.3-0.6	0.025	0.025
SA 213 T22	0.05-0.15	1.9-2.6	0.87-1.15	------	0.3-0.6	0.025	0.025
SA 210 C	0.35	0.4	0.15	------	0.29-1.06	0.035	0.035
SA 213 T91	0.08-0.12	8.0-9.5	0.85-1.05	------	0.3-0.6	0.01	0.01
SA 213 T92	0.08-0.12	8.5-9.5	0.3-0.6	1.5-2.0	0.3-0.6	0.01	0.01
SA 213 T122	0.08-0.12	10.0-12.5	0.2-0.6	1.5-2.5	0.3-0.6	0.01	0.01
SA 213 T23	0.04-0.10	1.9-2.6	0.05-0.3	1.45-1.75	0.1-0.6	0.01	0.01

The above mentioned materials are categorized in three different types:

1. Carbon steel – SA210 A1 and SA210 C
2. Low alloy steel – SA213T11, SA213T12, SA213T22, SA213T23
3. High alloy steel – SA213T91, SA213T92, SA213T22

We select SA213T22 as a test sample, which is most commonly used in headers. As the alloying elements of Sa213T22 are Chromium and Molybdenum so it has very good creep strength as well as good corrosion resistance also.

The reason behind selection of the tube material is if we succeed in buttering on SA213T22 then we can implement the same on SA210A1, SA210C, SA213T11 and SA213T12, which covers 70% of material used in manufacturing of header.

3.2. Properties of SA213T22

The following data represents metallurgical and physical properties of SA213T22. T22 has very good creep strength and can be used up to a temperature of 550°C.

Table 2 Chemical composition of SA213T22

Chemical Composition						
C	**Cr**	**Mo**	**Si**	**Mn**	**P**	**S**
0.05-0.15	1.9-2.6	0.87-1.13	0.5	0.3-0.6	0.025	0.025

Table 3 Mechanical properties of SA213T22

Mechanical properties		
Hardness	Tensile Strength	Yield Strength
163 BHN	415 MPa (minimum)	205 MPa (minimum)

SA213T22 has good weldability with application of pre-heat and post heat. The chances for any weld distortion are less if we follow the welding manual of SA213T22 which is described in AWS.

4. Built-up Process

4.1. Steps involved in testing a build-up on SA213T22 tube:

- Procurement of tube.
- Making a groove by grinding.
- Liquid penetration test on the ground surface.
- Fill-up the groove by FCAW with proper pre-heating and post heating.
- Smooth merging of the welded portion to match the circular profile.
- Non Destructive Test to check the welding soundness.
- Destructive test to check the mechanical and metallurgical properties of the portion where we have done buttering.

4.2. Procurement of tube:

We have to procure the tube through a reputed supplier or through a medium from where we can get test certificates. So we are buying tube through BHEL stores where SA213T22 of 1mtr length is lying as a scrap. After identifying the batch no. on the tube we have verified the tube test certificates and taken the material (3 Nos of same dimension tubes considering 1 no. as spare).

4.3. Test Material Specification:

1. Material : SA213T22
2. Diameter : 51mm
3. Thickness : 11.5mm
4. Length : 1 m

4.4. Making a groove on tube:

We have to make the groove of a length of minimum 150mm so that all the destructive test specimen can be made from the welded portion. We are grinding half of the thickness so that in future we can do repair any defective tube.

4.4.1. Grinding machine used for groove making

The groove we made by a Pneumatic grinding machine on which we mount a cutter wheel.

4.4.2. Safety during grinding

During grinding we have to take care of safety first, hence at the time of grinding use of eye protection glass and breathing mask is necessary. And we have to tighten the wheel carefully. Also we have to try to keep the wheel away from our body.

4.4.3. Groove dimension after grinding

Length of Groove: 150mm

Depth of Groove: 6mm

Arc length of groove on Tube O.D.: 20mm

Figure 6 Groove on the tube

4.5. Non-destructive test on the ground area

As the result of grinding some strain crack may form on the surface of ground area hence before proceeding for welding we have to check the surface finish with Liquid penetration test.

4.5.1. Principle of Liquid Penetration Testing

When we apply dye on the surface it spreads easily and penetrates uniformly throughout the surface. We have to wait for some time after applying the dye so that it seeps into discontinuity. After 5 minutes we have to clean the dye with acetone. Then we will apply a developer on which we can see the dye colour easily. After applying developer wait for 10 minutes, if any discontinuity is there then the entrapped dye will come on the surface by capillary action.

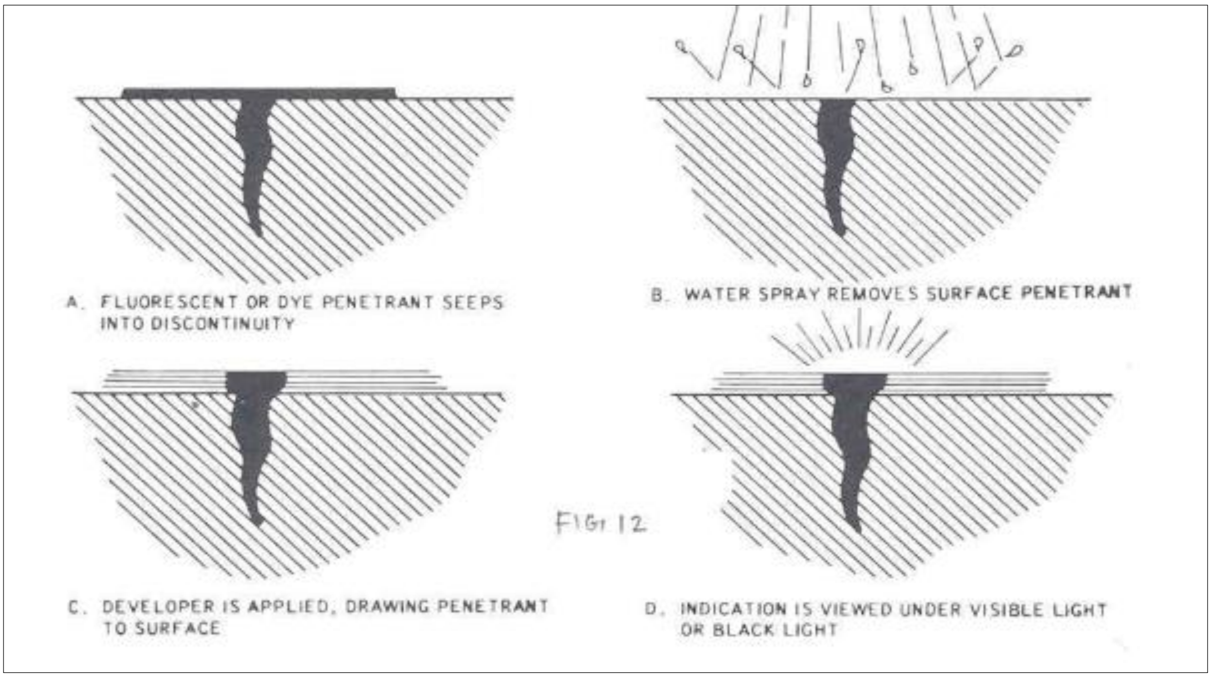
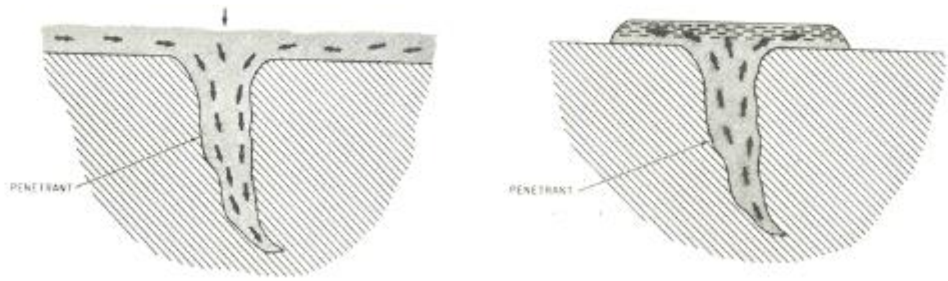


Figure 7 Principle of liquid penetration testing

The pictorial representation of the capillary action of dye can be shown as below:



Applying the dye Applying the developer

Figure 8 Capillary action of dye in LPT

4.5.2. Steps involved in liquid penetration test:

The various steps involved in the Liquid Penetration Test are as below:

- Pre-clean: Before applying the dye we have to clean the surface so that no dust or rust remains on the surface.
- Apply penetrant: We have to apply the penetrant liquid by a brush.
- Clean the penetrant: We have to clean the penetrant by some other liquid. In some case we use water wash and in other cases we wipe the penetrant with application of acetone.
- Apply non aqueous developer: We apply a non-aqueous developer in liquid form which dries rapidly after applying on the surface.
- Post Cleaning: After liquid penetration testing we have to clean the surface by acetone.

4.5.3. NDE (PT) Result

After applying developer, we have found no indication of defect hence we can proceed for the welding.

5 Welding

5.1 Welding parameters for FCAW and MIG Welding

Now the groove is ready for buttering and we have to start welding but before starting the welding we do have calculate the related data for welding and those are:

5.1.1 Pre-heating calculation

Before starting the welding, we have to preheat the tube as per general formula given in AWS

Pre-Heating temperature = (200 x Carbon Equivalent – 20) deg. C

The formula for Carbon equivalent is

Carbon Equivalent = %C + %Mn/6 + (%Cr + % Mo + % V)/5 + (%Ni + % Cu)/15

Putting the value of compositions

C.E. for T22 = 200 x [0.1 + (0.45/6) + ((2.25+1)/5)] - 20

= 200x0.825-20 = 145°C roughly 150°C

Necessity of pre-heating:

- To avoid cold cracking.
- To remove moisture present on the tube surface.
- To minimize the Heat Affected Zone.

We do pre-heat the tube with producer gas burner and check the temperature with thermal chalk which melts on certain temperature.

5.1.2 Welding Parameters of FCAW and MIG Welding

A suitable current and electrode diameter have to be selected for welding. Also the Carbon-di-oxide pressure has to be selected.

The standard wire diameter and current set-up are as follows

Table 4 Standard welding parameters

	Flat Position		**Inclined or Overhead**	
Dia. Of Wire	**Current (A)**	**Voltage (V)**	**Current (A)**	**Voltage (V)**
1.2	150-225	22-26	125-200	22-25
1.6	175-275	25-28	150-200	24-27
2.0	200-375	26-30	175-225	25-29
2.4	300-450	25-32	NA	NA

5.1.3 Power Supply

The type of power supply is the CAV power supply, where a voltage is maintained over a wide ampere range.

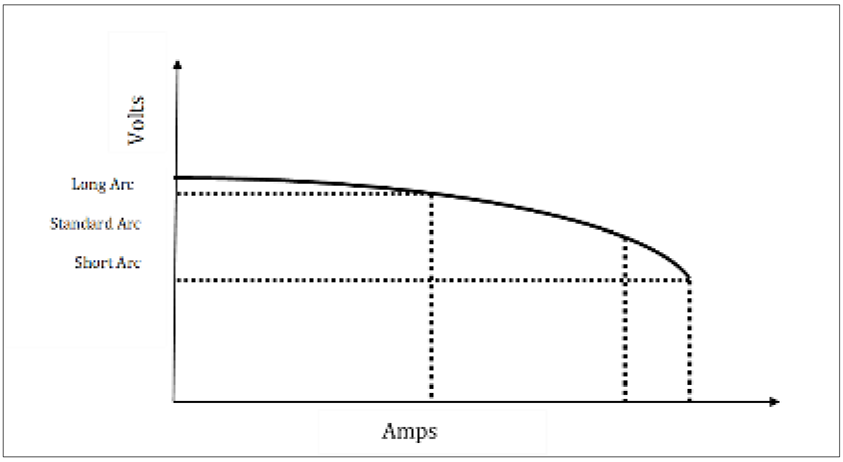


Figure 9 CAV power supply

This CAV power supply permits a wide range of physical arc lengths to be used while maintaining an adequate voltage amperage supply to the arc column. This type of power supply also is helpful in preventing the wire electrode from stubbing, from burning back into the wire contact tips of FCAW gun. The major reason for the use of CAV power supply is that, as the arc length shortens a small amount, there is large increase in welding current that automatically increases the burn off rate of the electrode. The amperage requirements decrease until the standard arc length is reached. If for some reason the operator pulls back or keep the welding gun away from the work so that the arc length becomes longer, the amperage of the CAV power supply would demand that the welding current lessened. Then operator would have to compensate by lowering the welding gun. Therefore, the CAV power supply determines and compensates for arc length, relieving the operator of a large amount of skilled responsibility.

The operator-manipulation-controlled variables are those to which it is difficult to assign any precise measurement, such as the stick-out of the electrode, the nozzle angle, angle of welding gun or the wire feed speed. These variables are controlled in the semiautomatic welding operation by the welder; however, they cause some adjustment of the machined controlled variables.

5.1.4 Stick-out

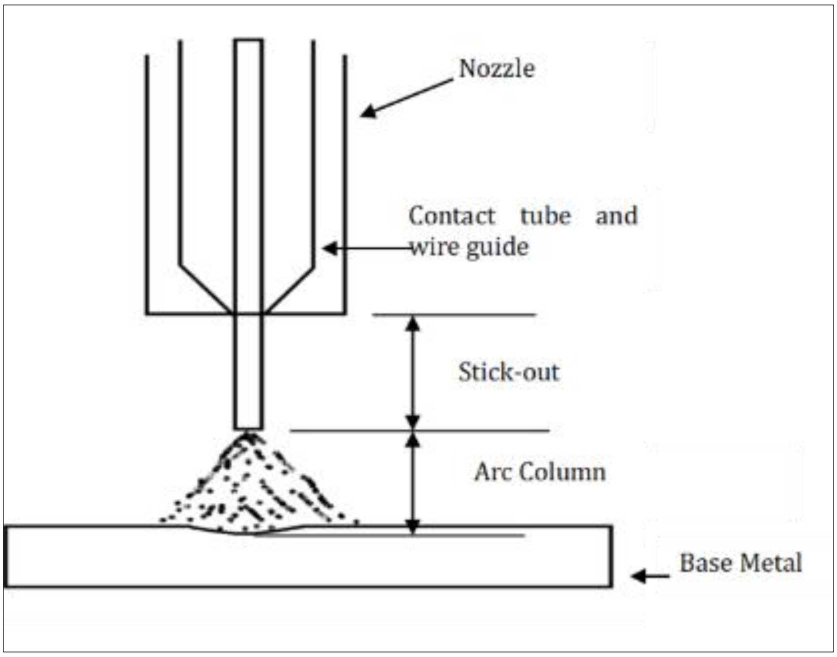


Figure 10 Stick-Out Length

The amount of stick out of the electrode is preset on most wire feed control mechanisms. The wire stick out determines the amount of penetration of the arc column. The stick-out length controls the current density of the electrode. The longer the stick-out of the electrode, the more resistance the electrode has because the electrode that in stick-out position heats. As the temperature of consumable electrode rises, its resistance also raises, which places higher current requirements on the electrode. These current requirements determine the amount of digging action of the electrode as shown in the figure above. The amount of stick-out of the electrode is preset on most wire feed mechanisms. The stick-out length controls the current density of the electrode. The longer the stick-out of the electrode, the more resistance the electrode has because the electrode that is in stick-out position heats.

5.1.5 Nozzle Angle

Another operator variable is the angle at which the welding gun is held to form weld bead as shown in above figure. The three possible angles of welding of a welding gun are the pulling or trailing angle, which would be comparable to the oxy-acetylene method of back hand welding. The neutral position is the one in which the gun has to held perpendicular to the work-piece and third one is pushing technique, which is similar to oxy-acetylene forward hand welding.

5.1.6 Manipulation Pattern

The last major type of operator control is manipulation pattern of the welding gun. There are several patterns as mentioned below:

- Drag
- Whip
- C-type
- U-type
- Lazy 8

But most preferable one is the drag type in which hand movement is almost linear.

5.1.7 Selected welding parameters for FCAW and MIG Welding

Table 5 Selected welding parameters

Sl. No.	Parameters	FCAW Value	MIG Value
1.	Welding Current	180-200 A	200-250A
2.	Welding Voltage	22-25 V	20-25V
3.	Gas Used	Carbon dioxide	75%Argon + 25% CO_2
4.	Pre-Heating Temperature	150 deg. C	150 deg. C
5.	Post Heating Temperature	250 deg. C for 4 hours	250 deg. C for 4 hours
6.	Welding electrode	E 3	ER80S-B3L
7.	Electrode diameter	1.2mm	1.2mm
8.	Power supply	Constant Arc Voltage type	Constant Arc Voltage type
9.	Nozzle angle	Pushing type	Pushing type
10.	Torch manipulation	Drag type	Drag type

5.2 Welding and post heating of Sample-1 and Sample-2

And working on the above parameters we have welded the groove by FCAW and MIG welding separately. Immediately after welding we have to go for post heating as per the standard calculation.

Post heating is the application of adding heat after welding to avoid following unwanted distortion:

- Hot cracking or solidification cracking
- Welding distortion
- Complete transformation of heat affected zone in original structure
- Reheat cracking

For calculation of post heat temperature and time we have to go through TTT of T22 material.

5.3 T-T-T of SA213T22

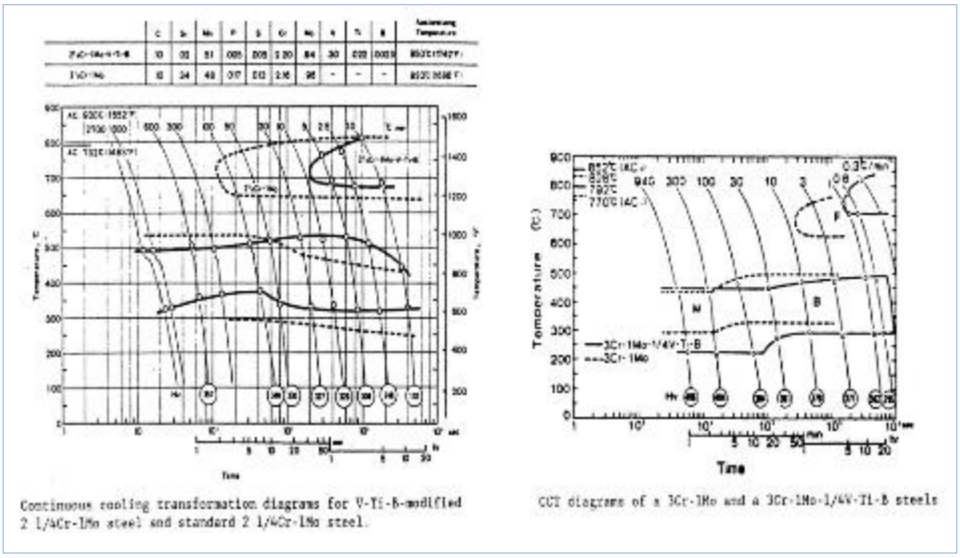


Figure 11 Time-Temperature-Transformation graph of SA213T22

5.4 Calculation of post heat

From the study of above graph we found, we have to maintain the welded tube temperature slight above the martensite formation temperature until the complete transformation takes place.

Time up to nose of C-curve = 10000 seconds = 2.78 hours

Starting of Martensite formation = 240°C

Hence we will post heat the welded tube to a temperature of 260°C for 4 hours.

5.5 Tube Surface after welding of Samples

As in welded condition, tube has a rough surface which has to be made smooth for further process.

Figure 12 Tube surface after completion of post heating

5.6 Grinding on welded zone to match the profile

Now we have tube on which buttering has been completed but the surface is rough and profile of tube is looking odd at the portion where buttering has been done. To match the profile, we have to grind the excess deposited material. The other reasons are as follows:

- To match the circular shape.
- To remove the surface scale after post heating
- To make smooth surface for Magnetic Particle Test

5.6.1 Grinding machine used for groove making

The groove we made by a Pneumatic grinding machine on which we mount a cutter wheel.

5.6.2 Safety during grinding

During grinding we have to take care of safety first, hence at the time of grinding use of eye protection glass and breathing mask is necessary. And we have to tighten the wheel carefully. Also we have to try to keep the wheel away from our body.

Figure 13 Tube Surface after grinding of excess deposition

Caution: Don't grind the weldment just after completion of post-heating because, at temperature range of 225-400°C all steel is blue annealed and poses a hard and brittle structure. If we grind brittle material some micro cracks may develop which causes the failure of material during service (Micro cracks propagates with time and temperature and may form crack through- out the thickness).

6 Results

The tube is meeting tensile requirement which includes hardness, tensile strength, yield strength and metallurgical properties which has been described is ASME BPVC Section IIA

Table 6 Comparison of mechanical properties of test specimen with standard

Sl No	Properties	Original Tube Requirement as per ASME	Tube with FCAW buttering surface	Tube with MIG Welding surface
1	Tensile Strength	415 Mpa (Min.)	522 Mpa	485 Mpa
2	Yield Strength	205 Mpa (Min.)	365 Mpa	320 Mpa
3	Hardness	163 BHN (Max)	150 BHN	159 BHN
4	Elongation	25% (Min)	30%	28%

The buttering on alloy steel tube (SA213T22) fulfils the requirement mentioned for tube in ASME BPVC and ASTM hence we can say that it can be opted for the repairs on the defective tubes.

Conclusion

The destructive testing result of built-up area shows both the welding methods are meeting the standard requirement. Sample welded with FCAW had more tensile strength and yield strength compared to sample welded by MIG welding. This study shows that; we can go for weld build-up on boiler tube instead of replacing them for any local damage.

Compliance with ethical standards

Acknowledgments

The authors are grateful to the management of Bharat Heavy Electricals Limited, Tiruchirappalli, India, and PRIST Deemed to be University, Thanjavur for their support and consent to carry out this study.

Disclosure of conflict of interest

The authors certify that they have No Conflict of Interest in the subject matter or materials discussed in this manuscript.

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