Quality Assurance & Inspection for Weldments Used in Steel Plants

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This paper intends to hightlight the various measures to be taken to achieve consistent quality level in welding in Steel Plants through systematic and balanced approach with regard to proper selection of materials, consumables, welding procedures and processes, joint preparation and fit-up, inspection and testing of weldments, evaluation of defects, acceptance criteria on the basis of past experience and National/ International codes & standards.

INTRODUCTION

Welding plays a very prominent role in the construction of Steel Plants as most of the other joining methods have almost become obsolete. Today, Steel Industry is marching ahead in a big way with various modernisation and expansion programme. This involves large tonnage of welded fabrication of technological structures, equipment and pressue piping under optimum design consideration and this calls for high quality in welding work. The quality welds should be achieved at economic cost with adequate margin of safety under the conditions of service for which the weld joint is designed. The strength of the weld joint should match the designed strength.

The following aspects should be taken care to ensure required quality level in the weldment :-

1. Selection of materials 2. Joint preparation & fit up. 3. Selection of welding procedure and process 4. Selection of consumable 5. Quality control measures 6. Inspection & testing of weldment 7. Acceptance criteria

1. SELECTION OF MATERIALS

Materials should conform to the specification indicated in the drawing. Relevant material test certificates and identification marks are to be examined. Material should be free from rust,scales, pitting, laminations, cracks etc. Normally flame cut edges of the plates and sections should be examined visually to ensure that the materials are free from laminations. Materials for critical applications should be examined ultrasonically.

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2. JOINT PREPARATION AND FIT-UP

Plates should, preferably be cut by Flame Cutting Machine. Flame-cut edges should be made free from notches, burrs and serrations before fit up. Fit up should be as per drawing or as per IS-9595 / IS- 4353 / AWD-D 1.1 (prequalified joint design)/ API / ASME /BS / DIN / IBR, etc.

3. SELECTION OF WELDING PROCEDURE AND PROCESS

3.1 Welding of the structural may be done by AC or DC Welding machines. However, DC Welding machines should be used for pressure piping, pressure vessles and all critical joints.

3.2 Electrodes must be rebaked in drying - oven prior to use and carry oven should be used for transferring electrodes from drying oven and holding at work place. Normally following rebaking temperatures are to be maintained prior to use :- i) Rutile type electrodes conforming to AWS-E-7016/7018 at 245 ± 15 deg. C for two hours.

3.3 Electrodes stored more than 1 months should not be recommended for quality welding / critical application without re-testing.

3.4 Only qualified welders /welding operators should be engaged for welding jobs and established welding procedure should be followed.

3.5 Stub-ends of used electrodes should not be exceed 50 mm.

3.6 Consumables should be properly utilised.

3.7 Any electrodes having damaged flux coating should not be used.

3.8 Root run of butt welded joints of steam, hydraulic, lubrication and Oxygen piping - where sealing run is not possible, should be done by TIG Welding process.

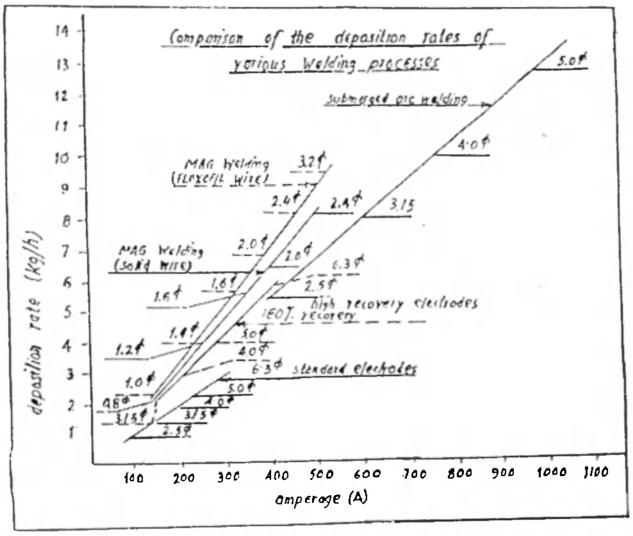
3.9 Cranes, gantry girders, heavy columns and other built-up structures should, preferably, be welded by submerged arc welding process to avoid defects due to start-stop phenomenon.

3.10 Automatic/Semi Automatic processes should be adopted for welding thicker sections. Semi-automatic processes are finding extensive application in the Indian fabrication industry. The comparison of various welding processes from deposition efficiency are as follows :

Welding Process	Deposition efficiency (%)
Sub-merged Arc	99-100
CO_2 Solid wire	90-95
CO_2 Flux cored wire	80-85
Stick Electrodes	65

$$\text{Deposition Efficiency} = \frac{\text{Wt. of deposited wire}}{\text{Wt. of consumed wire}}$$

(Ref. Deposition rate Vs. Amperage curve in sheet no.1)



4. SELECTION OF CONSUMABLES

4.1 Electrodes, filler wires and flux must be of radiographic quality.

4.2 Agglomerated type of flux is preferred for better weld chemistry in case of submerged arc welding. However, this requires baking prior to use.

4.3 Rutile type electrodes conforming to AWS-E-6013 (medium-heavy and heavy coated only) should be used for structural upto 16 mm thick and for carbon steel piping upto 12 mm wall thickness or pressure rating upto 10 bar. Hydrogen controlled electrodes should be used for pressure piping above 10 bar or for heavy sections where combined thickness exceeds 32mm or Carbon equivalent exceeds 0.45%.

4.4 The physical & chemical properties of weld metal should match the base metal and this should be ensured by satisfactory procedure qualification test.

4.5 Size of the consumables should conform to the established parameter.

5. QUALITY CONTROL MEASURES

5.1 Welding procedure qualification test & welder's performance qualification test should be conducted as per national and international codes/standards.

5.2 Qualified welders should be provided with Identity Card with photograph duly affixed. The identity card should contain details such as process qualified, plate, pipe, tube, consumables permitted, period of validity and duly signed by Testing/Inspecting authority.

5.3 Requalification test of welders should be conducted after 24 months or when the welder is not continuously engaged in the job for 3 months or when there is any change in the process or procedure at site.

5.4 Welding should be avoided under such weather conditions that may effect the efficiency of the weld joint adversely.

5.5 Extension piece must be provided during welding of flange/web plates of girders, columns, L-seams of piping etc. to maintain uniform full throat thickness.

5.6 Sequence welding should be followed to minimise distortion.

5.7 Suitable cable connectors, earth clamps, electrodes holders and gouging torches should be used.

5.8 Connection of the welding & earthing leads should be checked from time to time for tightness.

5.9 Current should be checked at the holder with tongue tester from time to time.

5.10 Welding and testing equipment should be well maintained to ensure that they are in perfect working condition.

5.11 Tack weld should not be less than four times the thickness of the thicker part or 50 mm whichever is less.

5.12 Tack welds should not be made at extreme ends of the joints.

5.13 Cross joints should be avoided.

5.14 Members distorted by heat of welding may be straigtened by mechanical means or by careful heating with temperature not to exceed 650 deg. C (dull red heat). The heated portion should not be quenched under atmospheric condition only.

5.15 Post-weld heat treatment should be done in accordance with the standard. Hardness survey and microstructures are to be examined for the welded samples to ascertain the requirement of post - weld heat-treatment.

5.16 Material beyond 25 mm of each end of the crack should be removed.

5.17 All welds should be cleaned of slag and other deposits after completion. Painting should be done only after inspection of the joints and the surfaces to be painted should cleaned of spatter, rust, loose scales, oil and dirt.

5.18 Consumables should be procured as per the standards for welding at site.

5.19 Stagewise inspection, right from material preparation, fit-up, completion of welding etc. should be done by the fabricator. Random inspection should also be carried out.

5.20 It has been observed that some of the fabricators are very reluctant to use DC welding machine even for pipe welding since manufactures of electrodes indicates suitability with AC & DC current. To avoid this confusion, manufacturer of electrodes should indicate that for consistent quality weld, DC welding machines with Fully Thyristorized power regulation should be used and these equipment can obviate the need of using even motor generator sets for Radiographic quality welding.

5.21 Supervisors engaged on the job should be imbibed with quality consciousness. Their approach should be practical and pragmatic. Application of codes/standards should be realistic.

5.22 Welders should monitor their own jobs stagewise and should be trained in taking effective remedial measures for rectification/ prevention of weld defects.

5.23 Supervisors/Inspectors should also be trained with welding inspection techniques, non-destructive testing and its evaluation and acceptance criteria based on various codes and standards.

5.24 Quality awareness dialogues and seminars on welding from time to time, will help development of supervisors and technicians to a great extent.

5.25 Sample of each batch of electrodes should be tested to ensure satisfactory mechanical property.

5.26 Documents of test results should be maintained.

6. INSPECTION AND TESTING OF WELDMENTS

6.1 Weld joints should be visually checked.

6.2 Quality level should be maintained as per relevant standards or as specified by the designer.

6.3 All full strength type butt weld joints should be checked by DP test after back gouging upto the sound weld metal and by Ultrasonic or Radiography or both at random or as specified based on criticality of the joints.

6.4 Supervisors & Inspectors should be well versed with the interpretation of DPT, UT & RT results as per various national/international codes to achieve designed weld quality level as indicated below:-

Weld Quality Level		Application and Test Requirement
Stringent -	Class 1/Class A AS/AK	For critical joints. Process control + 100% RT/UT for achieving weld joint efficiency - 100%
Medium -	Class 2 / Class B BS / BK	For less critical joints. Process control + RT/UT at random (max. 10%) for achieving weld joint efficiency at least 85%.
Moderate -	Class 3/Class C CS/DS/CK	For non critical joints. Process control for achieving weld joint efficiency atleast 70%.
	AS/BS/CS/DS	Quality classes for fillet welds.
	AK/BK/CK	Quality classes for fillet welds
	ISO 9000	Process/System Control /Quality Management and Quality Assurance Standards for excellence.

7. ACCEPTANCE CRITERIA

7.1 Surface flaws are to be accepted on the basis of Document No. IIW-778/DIN-8563/AWS-D 1.1 or as specified by the designer.

7.2 Radiographic test results are to be accepted in accordance with the Clause No. U W-51 & 52 and Appendix - 4 of ASME Sec. VIII Div.1 or as specified by the designer.

7.3 Ultrasonic test results are to be accepted in accordance with Appendix 12 of ASME Section - VIII Divn. 1 or as specified by the designer.

CASE STUDIES

We now wishs to present the following two Case Studies in regard to Quality Assurance & Inspection of weldments adopted in TATA STEEL for welding the site joints of Top Cone of LD Vessels by Shielded Metal Arc and GMA processes; and the imported Blast /Furnace shells by ELECTROSLAG WELDING and GMA processes with indigenously available consumables.

CASE STUDY - 1

Welding of Top Cone of LD Vessels:
(Ref. Sketch No. I)

First time in Tata Steel, Top Cones of both the LD Vessels were replaced after 7 years of satisfactory service. Top cones were made in sixteen segments from 60 mm thick plates conforming to IS: 2062 Gr.B for first vessel and IS:2002 Gr.2A for second vessel.

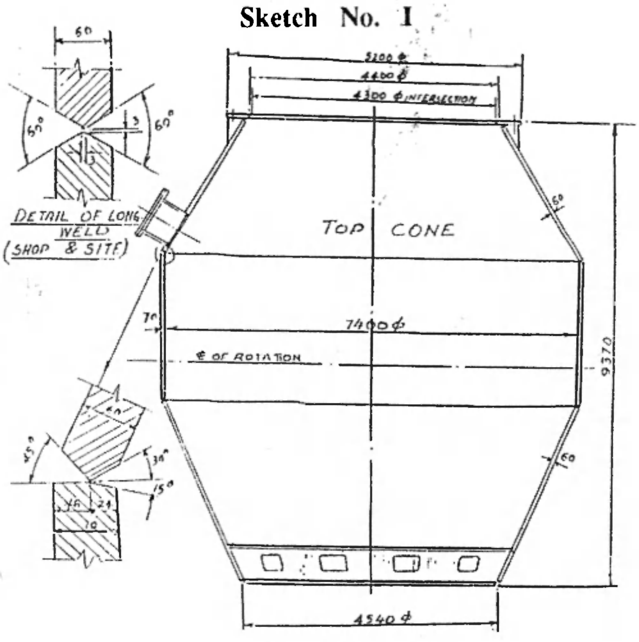
The segments of each vessel having double bevelled edges were assembled and 14 longitudinal joints were welded in two halves of the cone at shop to facilitate transportation and remaining two longitudinal joints of the cone were welded after assembly of the two halves at the vessels charging floor by Shielded Metal Arc Welding process.

The K-type circumferential joint between the existing 70 mm thick barrel and the Top Cone was welded by FCAW process with flux cored type filler wire. Preheating of the joints was done with the help of Mixed Gas (Coke Oven & Blast Furnace Gas). Adequate arrangement was made at site for continuous heating of the longitudinal and circumferential joints of the vessel.

Considering consistent quality, economy and higher productivity, this process was adopted. Accordingly procedure was established and performance test for welders conducted. Only qualified welders were engaged in the job.

Following welding parameters, sequence of welding and test procedures were adopted :-

Sketch No. I



130[T] L. D. Vessel

(i) Welding of longitudinal joints of the cone (14 shop joints & 2 site joints for each vessel):

Process	:	Shielded Metal Arc
Joint design		Double bevelled (shown in sketch - I)
Electrodes	:	AWS - E-7018
Size	:	3.15, 4 & 5 mm dia
Preheating & Interpass temp	:	150 - 200° C
Rebaking temp of electrodes prior to use	:	235 ± 15° C
Post Weld Heat Treatment (PWHT)	:	On the basis of hardness survey & micro-structure, Metallurgists advised stress relieving requirement at 580 deg C. But this was not done as this would lead to distortion of the joints and would be much time consuming and very inconvenient at site. However, the tensile and bend.

Sequence of Welding

- Welding was done from inside upto 2/3 of the groove depth.
- Back gouging was done upto sound weld metal from outside and then welding was completed from outside after DP.
- After that remaining welding from inside was completed.
- Starting and ending points of each electrodes was ground to ensure no slag entrapment.
- Portable carry-oven was used by each welder for transferring the electrodes after rebaking and for holding at work place.
- Weaving of electrodes was done within 3 times the diameter of the electrodes. Preheating was done upto 50 mm width on either side the of joint.
- Pre-heating temperature was checked with temp-stick.
- Magnifying glass (5x) was used for checking any crack/slag inclusion in the weldment after each run.

(ii) Welding of circumferential joints between 70 mm thick barrel & 60 mm thk Top Cone:

Process	:	Gas Shielded Metal Arc Welding
Joint Design	:	K-type (indicated in sketch I)
Filler wire	:	Flux Cored Type
Filler wire analysis %	:	C = 0.05 - 0.08 Mn = 1.20 - 1.40 Si = 0.25 - 0.40 S < 0.03 P < 0.03
Size of wire	:	1.2 & 1.6 mm dia.
Preheating and interpass temp	:	150-200° C
Voltage	:	28-30
Amps	:	200-250
CO_2 flow rate	:	20 to 22 litre/min

- Hardness survey of the sample :

Weld	HAZ	Parent
155, 164, 165	222, 223, 224,	187, 184
177, 198, 183	183, 187	183
HV/30 Kg	HV/30 Kg	HV/30 Kg

- Microstructure:

  HAZ for the sample was extended upto 25 mm.

- Tensile & bend test-results of welded sample : Satisfactory

Post weld heat treatment :

Not done though advised as this would lead to distortion of the joints, time consuming and inconvenient at site.

Sequence of Welding :

- Welding upto 2/3 of the groove depth from outside was done.
- Back gouging was done from inside and checked with DP and then welding was completed from inside. After that outside welding was completed.
- Four welders were engaged at a time in four quadrants and welding was done in the same direction. All welders started and finished welding at a time.
- Preheating of the joint upto 150 deg. C was continued from other side when welding was done from one side *(Ref. Sketch No. II)*
- Preheating temperature was checked with temp-stick.
- After completing the welding, the welded joint was heated upto 200 -250 deg. C for two hours and then covered with Asbestos cloth for slow cooling.
- Anti-spatter-spray was used to facilitate easy cleaning of the nozzle.
- Proper working of CO_2 preheater was ensured.
- Magnifying glass of (5x) was used to check any crack/ slag inclusion in the weldment after each run.

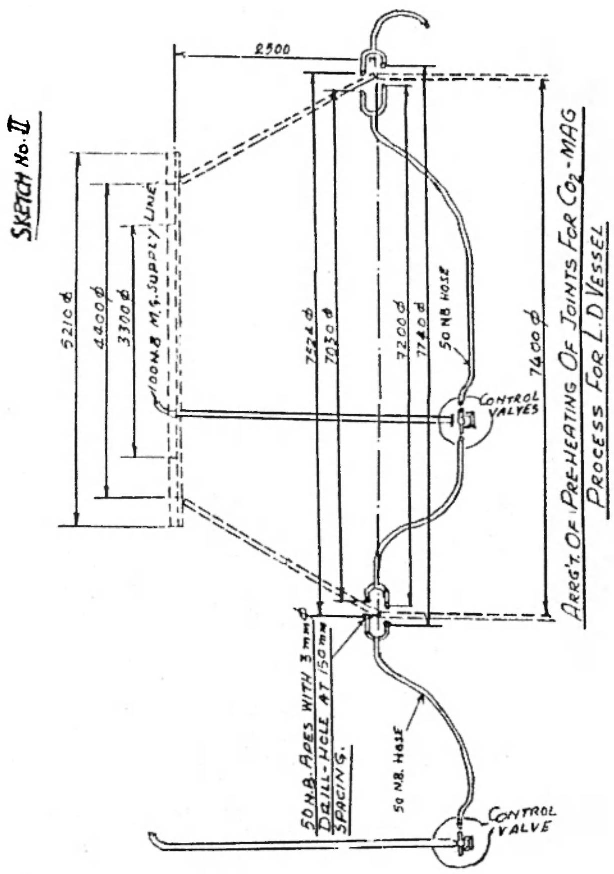
NDT done on weld joints : (longitudunal & circumferential)

DP test	:	After back gouging to sound weld metal.
Ultrasonic Test	:	100% with angle probe and at random with normal probe.
Radiography Test	:	Shop welded T- joints and repaired joints.

Acceptance Criteria :

Ultrasonic Test and Radiographic test results were accepted in accordance with UW - 51 and Appendix - 4 & 12 of ASME Section - VIII Div.1.

Sketch No. II



Arrg't of Pre-heating of Joints for Co_2 - MAG Process for L. D. Vessel

CASE STUDY - 2

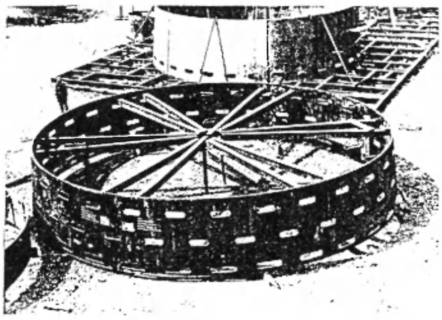
Welding of Blast Furnace Shell Joints :
(Ref Sketch No. III)

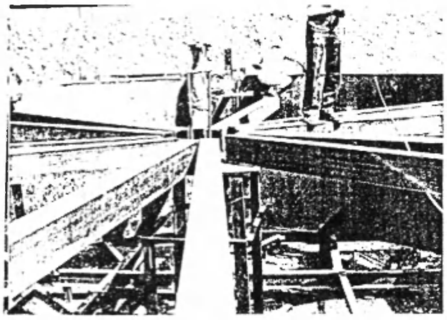
Pre-rolled shell plates in 82 segments were imported from SN Portugal with edge preparation for square butt welding for the longitudunal joints and K-type for the circumferential joints of the shell plates of 'G' Blast Furnace for TATA STEEL. The thickness of the segments was varying from 30 to 90 mm for 14 shell courses.

The segments were assembled at site and the gap between the segments of the vertical joints was kept 16 to 20 mm to maintain the specified diameter of the furnace. However, welding procedure/ parameter for welding such joints was not available from the supplier.

Considering the heavy sections of the segments and 16 to 20 mm gap between the edges of the segments, it was decided to resort to ELECTRO SLAG WELD-

Sketch No. III





Blast Furnace - "G" *Vertical Joint of Shell Course*

ING process. Accordingly, Electro Slag Welding machine was arranged. But this had the capacity for welding plates upto 70 mm thick. Initially various tests were conducted at site with alternative indigeneous consumables and procedure was established for welding upto 90 mm thick plates after minor modification of the nozzles. Simultaneously welding operator was trained and qualified.

About 200 metres of vertical joints were welded by Electroslag Welding process. This has increased productivity, minimised distortion and repair work. Less than 1% of the joint had to be repaired at the place of interruption.

The K-Type circumferential joints of about 500 metres between 14 shell ring course of the furnace were welded by FCA welding process with flux cored type filler wire. Considering high productivity, consistent quality and economy, this welding process was adopted and procedure for welding plates upto 90 mm thick was established.

Adequate arrangement was made as shown in sheet, No II to VI with spiders, C - clamps to avoid distortion of the joints during welding, pre-heating of the circumferential joints with mixed gas for FCA welding. The distortion of the joints during welding was monitored with the help of dial indicators.

The specification of the sheel plates is as follows :

Material of construction	:	Fe 510 - 2 KW BHN 160 to 180
Shell Thickness	:	30 to 90 mm
Chemical analysis (specified)	:	C <= 0.20 Mn <= 1.6 Si <= 0.4 P max 0.035 S max 0.035

The following parameters were adopted for welding the longitudunal and circumferential joints of the furnace of the shell :

Welding of longitudinal (vertical) joints :

Process	:	ELECTROSLAG WELDING
Size of Wire	:	3.15 mm dia.
Filler wire analysis	:	C = 0.10 to 0.18 Mn= 1.65 to 2.15 Si = 0.20 Cu = 0.35 Mo= 0.45 to 0.65 S = 0.035 P = 0.025
Flux analysis	:	SiO2 = 40.88 Al203 = 13.06 Fe as Fe203 = 5.58 CaO = 9.07 MgO = 0.80 CaF2 =2.20 MnO = 27.90 S & P - not specified

Parameters :

Voltage	:	45 - 60 Volts
Amperage	:	550 - 900 Amps
Wire feed speed	:	216 - 384 metres/hour
Polarity	:	Electrodes (+) ve Job (-) ve
Wire dia	:	3.15 mm.
Gap between two parallel faces of the plate	:	16 to 20 mm.

Table - I

Parameters Adopted for Welding

Vertical Joints of Shell Courses of BL. FE "G" by Electro Slag Welding

Sl. No.	Course No. mm	Thick-ness	Length Weld mm	Weld Gap mm	Size of Wire mm	Voltage Volts	AMPS	Gear Speed mtr/hr	Pool Depth mm	Duration of Welding Hours
1.	1.	50	2.537	17120	3.15	48/50	600-650	216	5.0	1.25/1.40
2.	2.	50	2.670	16	"	48/49	650-700	-do-	50	1.09/1.20
3.	3.	50	2.660	16	"	48/49	600-650	-do-	50	1.14
4.	4.	85	2.100	16	"	62/64	850-900	384	50	1.11
5.	5.	90	2.257	17/18	"	64/66	850-900	384	50	1.25
6.	6.	85	2.100	16	"	62/64	850-900	384	50	1.11
7.	7.	60	2.379	16	"	48/51	600-700	258	50	1.15
8.	8.	45	2.375	16/17	"	47/48	600-650	216	50	1.03/1.08
9.	9.	40	2.365	16/17	"	46/47	600-650	216	50	0.70/0.85
10.	10.	35	2.353	16/18	"	46/48	600-650	216	50	0.50/0.56
11.	11.	30	2.688	16	"	43	550-600	216	50	1.0
12.	12.	30	2.688	16	"	43	550-600	216	50	1.0
13.	13.	30	2.688	16	"	43	550-600	216	50	1.0
14.	14.	35	1.000	16/17	"	45/46	550-600	216	50	0.25

ESW machine Type	:	A - 820 K - T4
Make	:	Russian

(Thickness-wise parameters are indicated in Table I)

Destructive test results of the sample of 90 mm thick plate welded by Electro Slag Welding Process:

Microstructure of the weldment	:	WIDMANSTATTEN STRUCTURE
Grain Size	:	00 to 1 1/2 ASTM
Hardness survey (from weld to parent metal)	:	199, 201, 206, 215, 223, 223, 218, 185, 181, 178 HV/30 Kg.
Impact results at ambient temp.	:	62, 60, 50, 56, 58 Joules
Nitrogen content (ppm)	:	82, 82, 82, 82, 79, 83
HAZ of the plates	:	very coarse grain
Preheating	:	Not done

Post - weld heat treatment :

Not done though advised by metallurgist on the basis of hardness survey & microstructure (similar to the values indicated under case study - 1 for weld joint by FCAW)

Welding Sequence :

- Welding upto 2/3 of the groove depth from outside was done.
- Back gouging was done from outside. After DP, welding was completed from inside and then outside welding was completed.
- Four welders were engaged at a time in four quadrents and welding was done in the same direction. All welders started and finished welding at a time.
- Pre-heating of the joint at 150-200 deg. C was continued from other side when welding was done from one side.
- Pre-heating temperature was checked with temp stick.
- After completing the welding, the welded joints were heated upto 200-250 deg. C for two hours and then covered with Asbestos cloth for slow cooling.
- Anti-spatter spray was used to facilitate easy cleaning of the nozzle.
- Proper working of CO_2 gas preheater was ensured.
- Magnifying glass (5x) was used to check any crack/slag inclusion in the weldment after each run.

Post - weld heat treatment :

Normalising of the weld joints at 880 ± 20 deg. C was advised by metallurgists as the weldment and HAZ had very coarse grain structure (micro structure indicated in Fig. 1 & 2 of sheet No. VIII). Normalising treatment was not done as this would lead to distortion of the joints, time consuming and very inconvenient in handling such voluminous job at site. However, tensile and bend test results of the welded samples were satisfactory. We understand, no post weld treatment was done for the weld joints done by Electroslag welding process at Visakhapatnam Steel Plant also.

Welding Sequence :

Diametrically opposite joint was welded after welding the first joint and the same sequence was followed for all the vertical joints of the shell courses.

II. Welding of circumferential joints :-

Process	:	FCAW
Filler wire	:	Flux Cored
Filler wire Analysis	:	C = 0.05 - 0.08 Mn = 1.20 - 1.40 Si = 0.25 - 0.40 S & P < 0.030
Wire dia	:	1.2 & 1.6 mm
Preheating and interpass temperature	:	150-200 deg. C
Voltage / Amperage	:	28-30 V/200-250 Amps.
CO_2 Flow rate	:	20-22 litre/minute
Tensile & bend test results of welded sample	:	Satisfactory

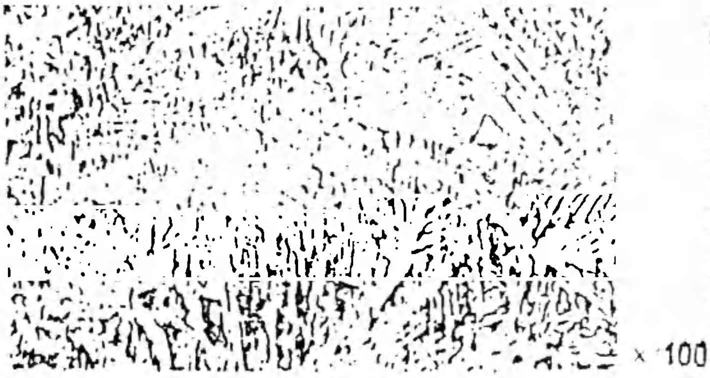
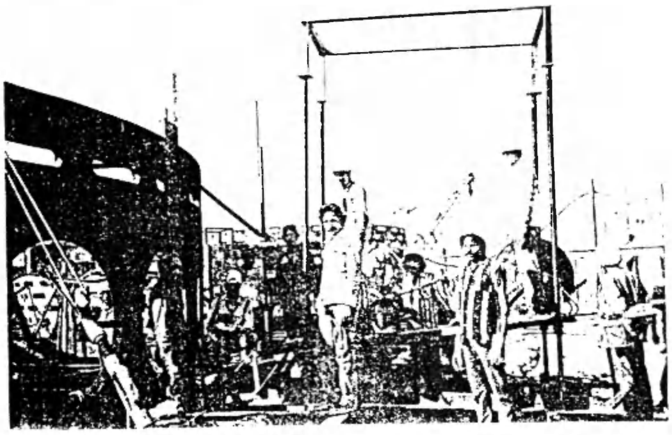


Fig. 1. *Photonucrograph showing coarse grain structure of II A Z of the plate*

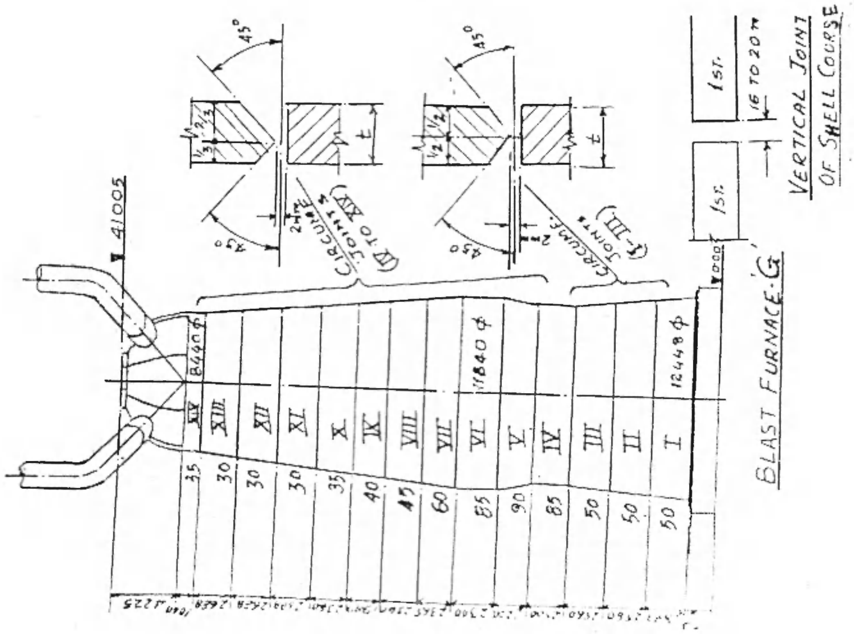
Fig. 2. *Photonucrograph showing fine grain structure of H A Z after normalising*

SHEET NO. II



Vertical joint being welded by ESW

SHEET NO. III



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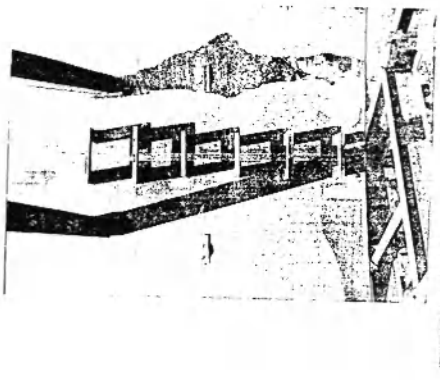
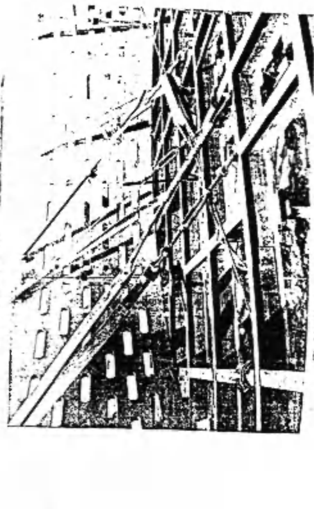
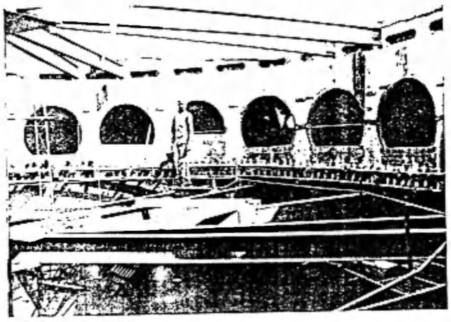
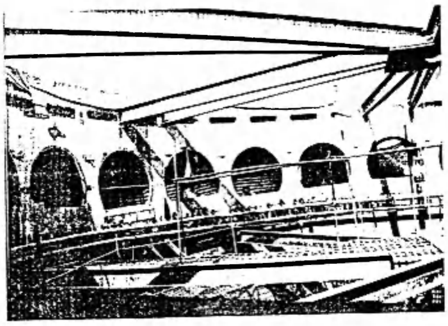




CLAMPING : 'C' CLAMPS & TURN-BUCKLE

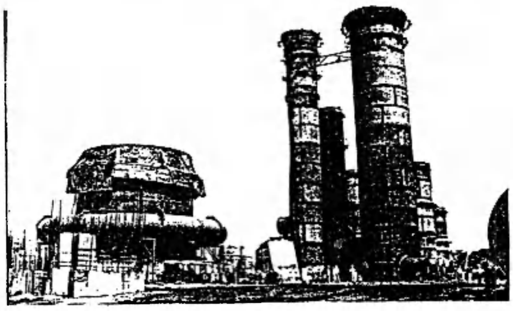
SHEET NO. V





Preheating arrangement for circumferential joint during co_2 - MAG welding

SHEET NO. VI



Bird's eye-view Blast FCE "G"

Repair Procedure :

Places of interruption during Electro Slag Welding and defective spots of the weld joints done by Electro Slag Welding and FCA welding, were repaired by Shielded Manual Metal Arc Welding process, following established procedure with electrodes conforming to AWS-E-7018, and maintaining pre-heating & interpass temperature at 150-200 deg C.

NDT done on the weld joints :

DP test	:	After back gouging upto sound weld metal.
Ultrasonic test	:	100%
Radiographic Test	:	10% at random and all repaired spots.

Acceptance Criteria :

Ultrasonic and radiographic test results were accepted on the basis of UW 51 and appendix 4 & 12 of ASME Sec-VIII Div. 1.

CONCLUSION :

Quality Assurance Measures and Inspection for weldments adopted in Steel Plant Projects are highlighted in this paper. Proper understanding of these measures would ensure quality and reliability of weldments of the components or plant on cost - effective basis. The prime contractor and sub-contractors should engage qualified and competent personnel to ensure quality weld of acceptable standards and create confidence such that the product will perform intended service satisfactorily over the period of design life. The ultimate aim of this paper is to create a general quality awareness amongst various agencies viz, consumables producers, weldling machine manufactures, users, designers, executing supervisors and Inspectors being engaged in Steel Plant welding jobs and to evolve a rational approach to bring down weld rejection rate/premature failure frequency.

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