Assembly Welding of India's First 300 Tonne Convertor

By ANIL PANDYA*

The increase in steel plant size in recent years has been accompanied by a corresponding increase in convertor vessel capacity and consequently its size. At Bokaro Steel Plant, a convertor of 300 Tonnes capacity, the first of its kind in India, is presently under assembly and installation. The convetor shell having a diameter of 8614 mm and a height of 10,770 mm has a shell plate thickness varying from 60 mm to 100 mm. The entire shell is supported on a trunnion ring, comprising of a box section made of plates 60 mm web thickness and 100 mm flange thickness. The depth of the section is 2.5m.

The shell was supplied by the USSR in 17 unit parts to be assembled and welded at site. The 17 parts comprise of the shell bottom, middle, the neck portion and 4 unit parts of the trunnion ring also to be welded and assembled at Bokaro.

Detailed considerations of the shell metal properties, shell plate thickness and service conditions of the shell, made apparent the need for excessive care in selection of the filler metal and conditions of deposition dictated the choice of manual electrodes.

SELECTION OF THE ELECTRODE

In terms of electrode development, the steel used for the convertor shell i. e.Gr2cl Soviet grade, is not among the conventional structural steels available in India, and the entire electrode manufacturing industry of the country had to be fully exploited to develop an electrode suitable for welding of the same. The mechanical properties of the shell plate material and its chemical composition as furnished by the manufacturer are given in Tables 1 & 2.

Anticipating high thermal stresses induced during welding as a consequence of external restraint, and stresses and strain produced in the weld by internal restraint due to different rates of cooling during the cooling stage of the thermal cycle, an electrode was to be chosen such that the weld metal had a perfect plastic behavior and high ductility so as to minimize cracking tendencies, by taking advantage of the capacity of the weld metal to deform within limits of resistance required of the joint.

Another important aspect influencing the electrode selection was the keeping of the tensile level of the weld metal such that it reasonably matches with the tensile level of the shell plate material and the weld metal conforms to the generally accepted standards governing the quality of weld metal intended for use in structures of prime importance.

A proper selection of the electrode size is as important as selection of the electrode class for obtaining a satisfactory and economical operation. Principal considerations given to the joint design, thickness of the

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Table 1

Mechanical properties of the shell plate material

Thickness	U.T.S. in Kgf/mm²	Yield Point in Kgf/mm²	Elongation %	Impact value in Kgf.m +20°C	—20°C	—40°C	Remarks
50	45	28	22	18	3.5*	3.0*	*These values indicate only the minimum requirement.
100	44	18	18	18	3.5*	3.0*	

Table 2

Chemical composition of the Shell plate material

C %	Si %	Mn %	S %	P %
0.12	0.5 to 1.7	1.3 to 0.8	0.04	0.04

weld layer. premissible heat input and welding position which was expected to be primarily vertical or horizontale for this operation led to the choice of 4 mm ϕ electrode size.

An electrode manufacturer in India after proper study, came up with an electrode satisfying the conditions of requirement in compatibility with above described considerations. This electrode also matched with the Soviet electrode E 42A, recommended by the suppliers of the convertor shell, for welding of the same. In Table 3 the weld metal mechanical properties are given, and Table 4 furnishes the chemical composition of the weld metal.

However, before putting the electrode to use, it was deemed necessary to study the mechanical and metallurgical behaviour of a joint welded with the same, and a series of tests were conducted to confirm its suitability.

Impact properties were studied both on the parent metal heat affected zone and weld metal, using a 2 mm notch. The impact specimens with a notch at the weld centre, the fusion face and the heat affected zone, were samples from a joint prepared in accordance with the procedure shown in Figure 1. The test specimen dimensions were 1cm $\times$ 1cm $\times$ 5.5 cm long. The charpy impact results as obtained are presented in Table 5 below. Figure 2 shows the relation as obtained between the charpy impact values and temperature, for specimen with a notch in the weld metal. It can be seen that the weld metal exhibits a very high notch toughness. The macroscopic appearance of fracture surfaces of charpy V notch specimens with the notch at the weld metal

Table 3

Mechanical properties of the weld metal

U. T. S. Kgf/mm²	Yield Point Kgf/mm²	% Elongation	Impact in Kgf. m +27°C	0°C	—20°C	—40°C	Remarks
46	38	26	22	19	18.5	17.5	

Table 4

Chemical analysis of the weld metal deposit

C%	Mn%	Si%	S%	P%
0.06	0.6	0.20	0.018	0.016

(prefixed-I), notch at the fusion face (prefixed-F), notch in the heat affected zone (prefixed-H), and tested at —20°C and 40°C are represented in Figure-3.A. Estimated percentage of shear fracture is also indicated in the figure.

Specimens with a notch in the weld metal exhibited a smooth-silky texture and a considerable change in width. Specimens with a notch at the fusion face showed a grey coloured fine grained surface in the specimen marked F-6, and a fine grained texture with a mating surface seen towards the left in the specimen marked F-2. Change in width is observed in both specimens. The specimen with a notch in the heat affected zone exhibited a flat face fracture with a bright granular texture and hardly any change in the specimen width.

The changes in surface appearance are representative of fracture energy, as can also be seen from the impact test results, and the change in width of specimens with

Table 5

Notch in weld metal

Temp.	0°C			—10°C			—20°C			—40°C			+28°C		
Marking	I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15
Impact value in Kgf.m	19.2	16.8	17.0	16.4	16.2	12.4	17.2	15.8	17.8	14.2	14.0	14.0	16.8	17.9	18.1

Notch in Fusion Boundary

Temp.	—20°C			—40°C		
Marking	F-1	F-2	F-3	F-4	F-5	F-6
Impact value in Kgf.m	16.8	10.2	14.4	12.0	5.6	8.0

Notch in H. A. Z.

Temp.	—20°C			—40°C		
Marking	H-1	H-2	H-3	H-4	H-5	H-6
Impact value in Kgf.m	7	7.4	3.4	3.4	1.0	4.8

notch in the weld metal is indicative of a good notch ductility.

It may be of interest here to also present in microphotograph the fracture faces of samples I-9 & I-10. The sample I-9 was fractured at—20°C. The microphotograph of the fracture face indicates ferrite grains of mixed sizes with carbides mostly dispersed along the grain boundaries (Fig-3B). The sample I-10 was fractured at—40°C. The microphotograph of its fracture face shows ferrite grains with non uniform and at places needle-like dispersion of carbides (Fig-3C). This

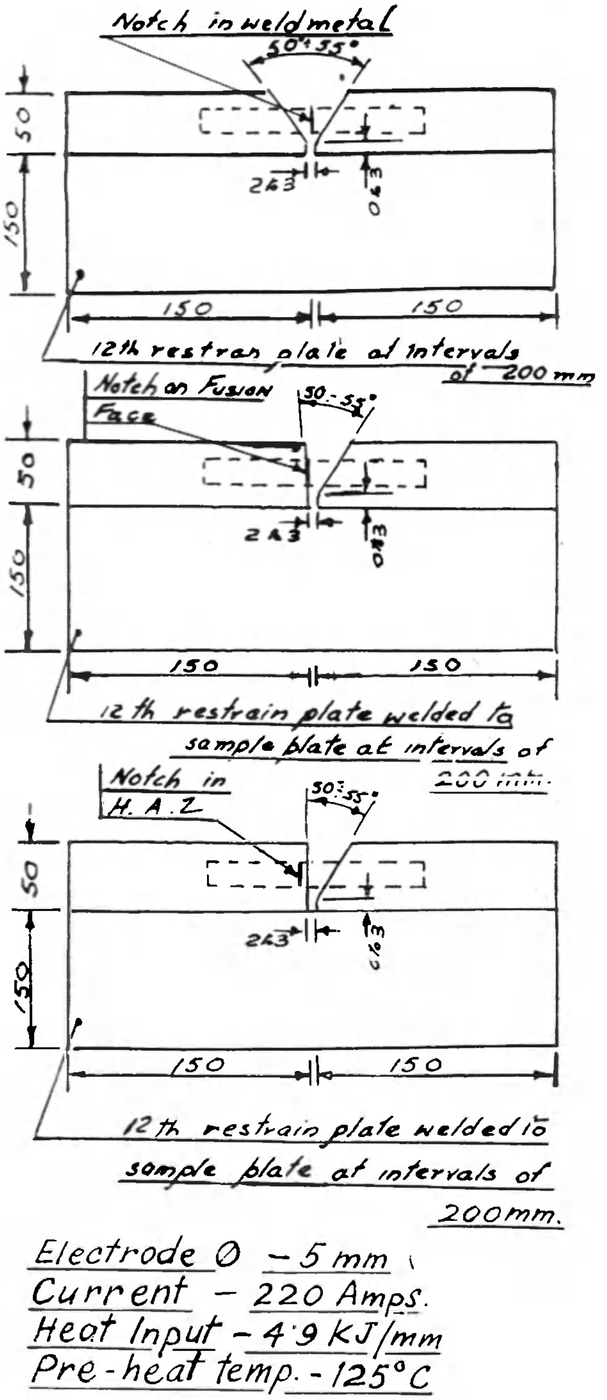
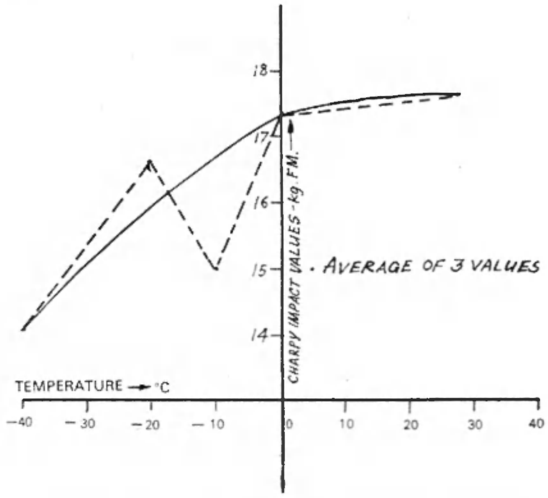


FIG. 1



RELATION BETWEEN WELD METAL CHARPY IMPACT VALUES AND TEMP.

FIG. 2

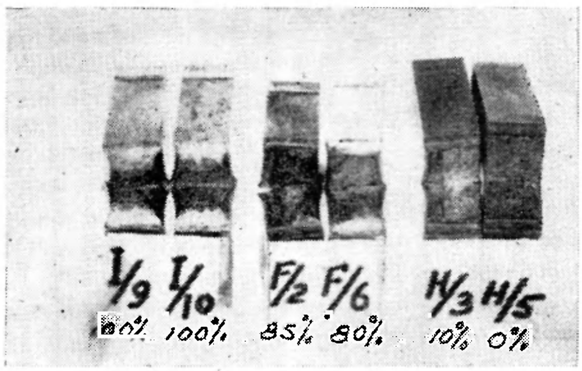
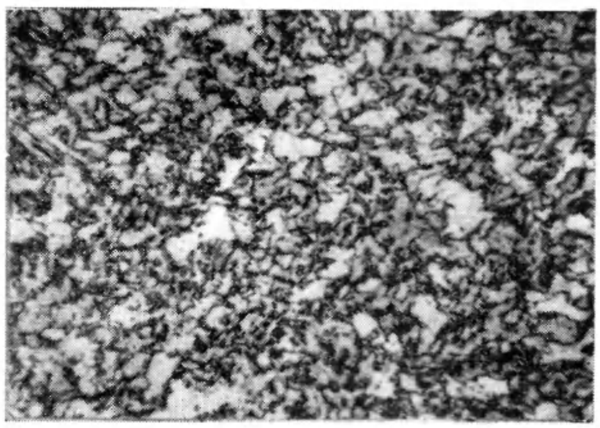
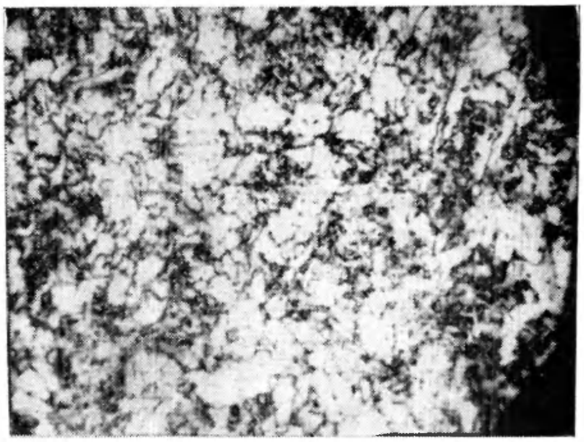


Fig. 3A Macrophotograph of charpy impact specimens.



Etched 4% NitalX450

Fig. 3b Micro Structure of Fractured Face of Sample 1-9



Etched 4% Nital-X450
Fig. 3c Microstructure of Fractured Face of Sample 1-10

photograph indicates relatively a more brittle structure, as also indicated by the impact tests.

The transverse and all weld metal tensile properties were also studied. The test specimens were samples from joint prepared in accordance with the procedure laid down in relevant Russion GOST specifications. The results of the test are presented in table 6 below. The results indicate a very good matching of the tensile levels of the weld metal and the parent plate,

The root bend and face bend tests were also carried out in accordance with I.S. specification and the results found satisfactory.

Table 6 a

Results of the All Weld Tensile Test

Sample No.	U.T.S. in Kgf/mm^2	Yield Point in Kgf/mm^2	%Elongation on 5D
WT-1	49	40	32
WT-2	46	38	30
WT-3	47	38	30

Table 6 b

Results of the Transverse Tensile Test

Sample No.	U.T.S. in Kgf/mm^2	Remarks
TT—1	47.4	Failure in Parent plate.
TT—2	49.0	
TT—3	47.0	

Failure of engineering structures can be caused by deformation, corrosion and cracking which may result in leakage or complete fracture. As the mechanical properties of the material are changed by the welding process, the properties of the transformed H.A.Z. can affect any of the above possible failure modes. In this study, the emphasis was placed on fracture. Whether a fracture will initiate depends upon the stress level and the presence of a defect of sufficient size. Thus the engineering significance of any embrittled region will depend upon the probability of a defect being present in the embrittled area. The critical size of the defect will depend on the degree of embrittlement and therefore it may be expected to vary with the different metallurgical zones of the weldment, in view of which a study of the microstructures of the weld metal and heat affected zones was considered imperative.

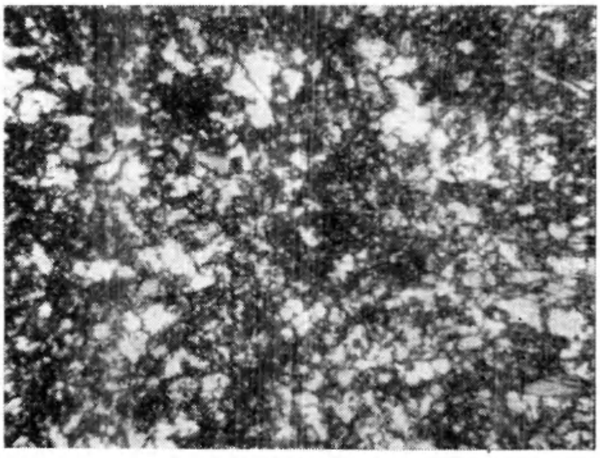


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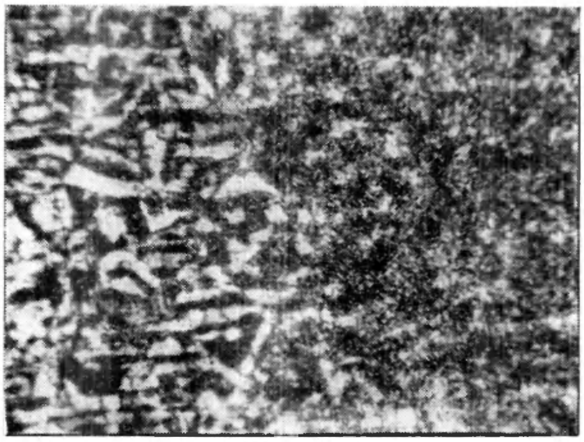
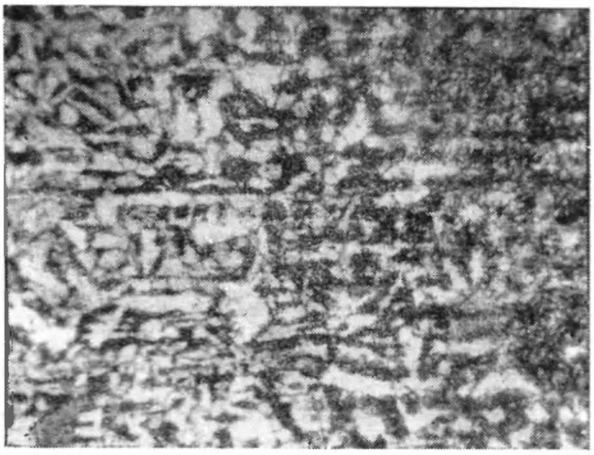
Fig. 4A Weld Metal Microstructure



Etched 4% Nital-X100
Fig. 4B Microstructure near Fusion Boundary showing Grain Coarsening in the H. A. Z.



Etched 4% Nital-X100
Fig. 4c Microstructure in the H. A. Z.

Etched 4% Nital-X450
Fig. 4d Microstructure of the H. A. Z. showing spheroi dized carbides in a Ferrite Matrix

The ranges of microstructure produced in the weld metal and the heat affected zone are shown in Figures 4A to 4D. The parent metal microstructure was a typical hot rolled structure and consisted of banded pearlite in a ferrite matrix.

The weld metal structure Figure 4A, is fine grained ferrite with a non uniform carbide dispersion.

The heat affected zone could be divided into two distinct regions :

(1) The region of grain coarsening immediately adjacent to the fusion boundary, where peak temperatures probably exceeded 1100°C, (Figure-4B). It appears that austenite grain growth took place and controlled cooling rates through the critical range produced a structure consisting of pearlite and ferrite.

(2) The region of partial transformation which probably experienced peak temperatures in the approximate range of 900-750°C (Figure 4C&4D). The regions richest in carbon where partial dissolution of pearlite occured exhibited fine grain structures, while the ferrite became less affected as the peak temperature diminished. No trace of martensite is observed. Some spheroidization of pearlite also occured, (Figure 4D). The lamellar carbides have partially dissolved and reformed as spherical particles on cooling. Beyond this region, structural changes were not observed by optical microscopy. It can be seen that the poorest notch toughness properties are associated with the region of grain coarsening.

The variation in hardness across the joint was as below :

Zone	VPN
Parent Metal	128
Heat affected zone	133
Fusion boundary	134
Weld Zone	162

In general, the hardness increases on approaching the weld, with the maximum at the weld zone.

PROCESS DETAILS AND THE WELD SEQUENCE

Consideration of welding process variables necessarily begins with the thermal cycles associated with welding. Several variables affect temperature distribution and metallurgical change in the vicinity of the weld, notably the heat input of the arc, the preheat temperature, weld design and thermal conductivity of the base metal. The allowable arc heat input varies directly with the increase in section thickness and inversely with the preheat temperature.

For any specific class of covered electrodes, deposition rates are primarily a function of the current setting at which the electrode is used. The type and size of the welding electrode and the welding position determines the current ranges to be used. Manufacturers of this particular electrode recommended the following current ranges, (Table-7), at different welding positions, for which their product may be used.

Table 7

Current ranges adopted

Position	Electrode ϕ in mm	Polarity	Current in amps	Remarks
Down hand	4	DC (+)	160 — 200	
	5	DC (+)	220 — 250	
Horizontal	4	DC (+)	160 — 200	
	5	DC (+)	220 — 250	
Vertical	4	DC (+)	140 — 180	
Overhead	4	DC (+)	140 — 180	Overhead position should be avoided.

Direct current power sources used in arc welding wih covered electrodes have a drooping external characteristic to ensure that the welding operation is satisfactorily carried out. They provide an almost constant current with slow variations, but in welding with basic coated electrodes, they often produce brief sharp short circuits which occur irregularly several times per second. This alternate arcing and shorting during welding is basically due to the metal transfer mode of the electrode The level of this current depends upon the dynamic characteristics of the power source.

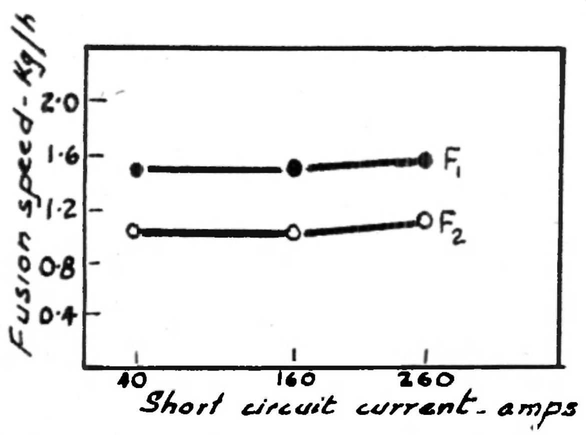


Fig. 5 Deposition efficiencies of electrode at varying short circuit current during welding

FL_1 = *Values of metal wt of electrode fused in down hand welding.*

FL_2 = *Values of the total wt of electrode fused in down hand position*

OV_1 = *Values of metal wt of electrode fused in over head position*

OV_2 = *Values of total wt of electrode fused in over head position.*

A study made by Dr. P. Stular & Mr. N. Ozaki throws light on the suitability for welding by a D.C. power source with reference to the short circuit metal transfer phenomena. Relation between the short circuit current, fusion speed and deposition efficiency as arrived at by Stular & Ozaki are presented in figures 5 & 6. It can be seen that the deposition efficiency of the electrode is increased by reducing the short circuit current while there is no marked effect on the fusion speed due to variation of the short circuit current. This study made particularly in welding with basic coated electrode leads to the following conclusions :

(1) Welding with reduced short circuit current reduces turbulence in the weld pool and lack of fusion and improves the bead appearance as well as the deposition efficiency of the electrode

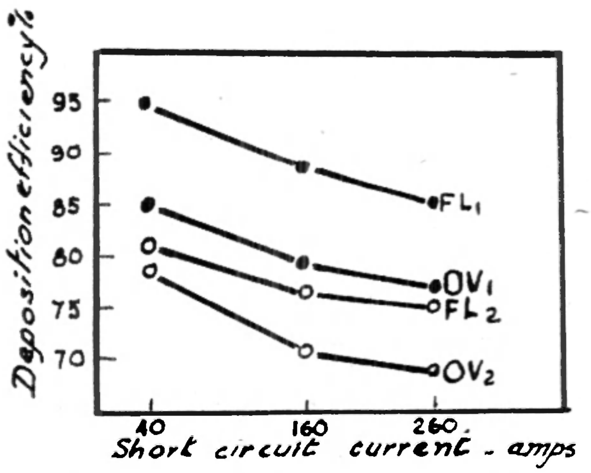


Fig. 6 Fusion speed of electrode at varying short circuit current under constant arc current.

F_1 = *mass of fusioned core & iron powder*

F_2 = *mass of fusioned core*

without changing the fusion speed, the penetration characteristics or the structure of the weld bead.

(2) Metal transfer with formation of liquid bridges can be sustained even at a dynamic short circuit power level of zero.

(3) Welding can be carried out both in the down hand and over head positions with short circuit current lower than that of the arc.

Thus for better welding characteristics, use of a D.C. welding unit enabling the dynamic short circuit current to be varied was recommended.

The choice of welding sequence and technology was decided in consideration of its influence on restrained stresses resulting from structural constraint and external stresses arising from various circumstances of fabrication, which may act upon a welded joint during and after its execution, independently of this execution e.g. the parts own weight, elastic reaction in the parts, clamping of the parts etc.

As will be seen subsequently, a major portion of shell assembly involves welding in the horizontal & vertical positions. The sequence adopted for welding of vertical joint seams is as under :

The entire length of the vertical joint to be welded is divided into sections such as I, II, III etc. as shown in Figure-7, each section being of length not more than 300 mm.

Welding is started from the top, the first weld run starting from the bottom of the first section and moving towards the top. The second run moving from bottom of the second and moving towards the top, covers the first run as the bead approaches section I. So also the subsequent runs should be followed as shown in Figure-7.

The stringer bead technique is used in depositing of weld and weaving is kept to the minimum. The diameter of electrode for welding in vertical position was recommended to be 4 mm.

WELD SEQUENCE FOR JOINTS IN HORIZONTAL POSITION

The sequence adopted for welding in horizontal position is as follows :

The joint circle is divided into 4, 6 or any number of suitable major segments, such as mkd. I, II, III & IV in Figure-8.

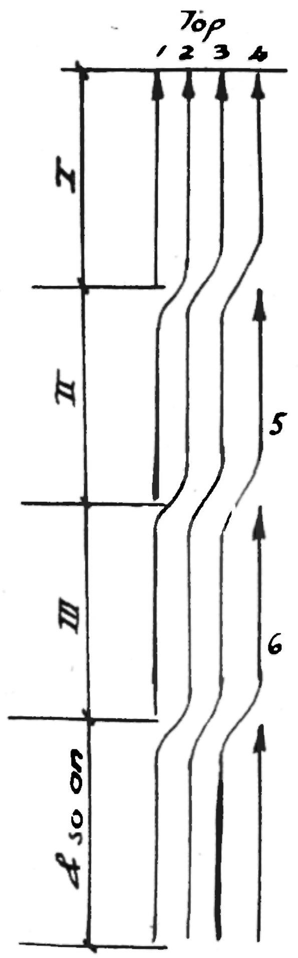


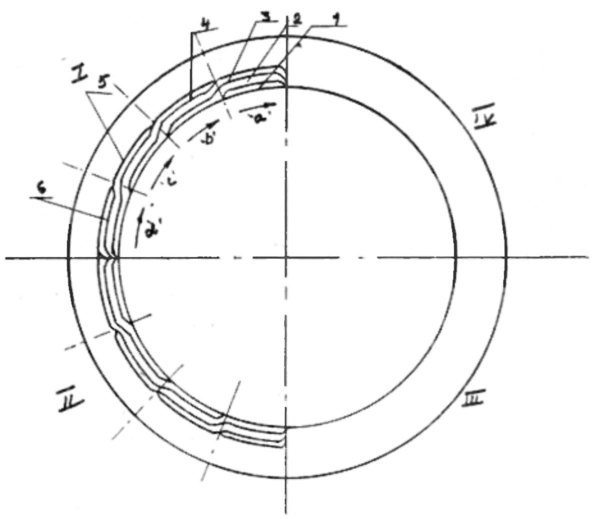
FIG. 7

Back step block sequence for vertical joints

Each segment is further subdivided into small sections of lengths not more than 500 mm, such as marked 'a', 'b', 'c', and 'd' in Figure-8.

After preheating the entire joint surface and parent metal to about 150 to 200 mm on either side of the joint, to a temperature of 125°C to 150°C, welding is started simultaneously on all the segments.

The first run is deposited say, over section 'a', commencing the welding from a distance of 500 mm away from the starting point and moving clockwise. The next root run is started from the end of section 'b' and continued over the deposited run at section 'a' till the



Welding sequence for horizontal joints.

FIG. 8

starting point, and this sequence is followed till completion of the joint welding.

WELD DEPOSIT SEQUENCE FOR SINGLE AND DOUBLE 'V' GROOVES

Welding of single 'V' joints in 60 to 80 mm plates is completed in three phases.

(i) The entire 'V' groove is filled up from the top by the multirun welding technique.

(ii) The root of the weld is then gouged out by air carbon arc gouging to reach sound weld metal

(iii) After thorough cleaning of the gouged portion, the sealing runs are deposited to complete the joint

Welding of double 'V' joint in 100 mm thick plate is completed in 4 phases :

(a) Half of the upper 'V' of the joint is first welded by the multirun technique.

(b) The root is then gouged by air carbon arc gouging to reach sound weld metal

(c) After thoroughly cleaning the gouged portion the lower 'V' groove is fully welded using the multirun technique

(d) Finally welding of the upper 'V' of the joint is completed in the same manner

Coming to the precautions relating to the welding technology with regard to the cooling time and its effect on hardening, susceptibility of cracking, defect prevention, prevention of hydrogen pick up from external sources such as relative humidity of the atmosphere, moisture on the steel in the vicinity of the joint, hydrocarbons possibly present etc., the important considerations and features are summarised as follows

(a) All joints were to be heated to a temperature of 125°C to 150°C before welding, and the pre-heat temperature maintained throughout the welding cycle

(b) Cleaning of joints and parent metal before welding to an extent of 50 mm on either side of the joint from dirt, paint, rust, oil etc., till the appearance of a clear metallic shine, was recommended.

(c) After depositing each run, slag removal was essential and the bead surface cleaned before depositing a second run.

(d) Where the joint did not match perfectly, protruding material was gas cut, and excessive gaps built up by weld deposits, and subsequently ground smooth.

(e) Before use, the electrodes were baked in an oven at a temperature of 250°C to 300°C, for a period of 2 hours, and then cooled to 100°C, after which the electrodes were shifted to another oven with a preset temperature of 50°C, from which these were drawn for direct use.

(f) To stress relieve, peening was done after depositing each run, with a pneumatic hammer of 5 mm radius blunt head. All but the root and cover passes were peened. Peening was done so as to flatten the surface of the weld beads, but not cut into it.

SEQUENCE OF SHELL ASSEMBLY

The assembly sequence of the shell is as per figure 9. The locations of the erection welds are shown in the figure and also the order in which the joints are to be welded (numbered serially).

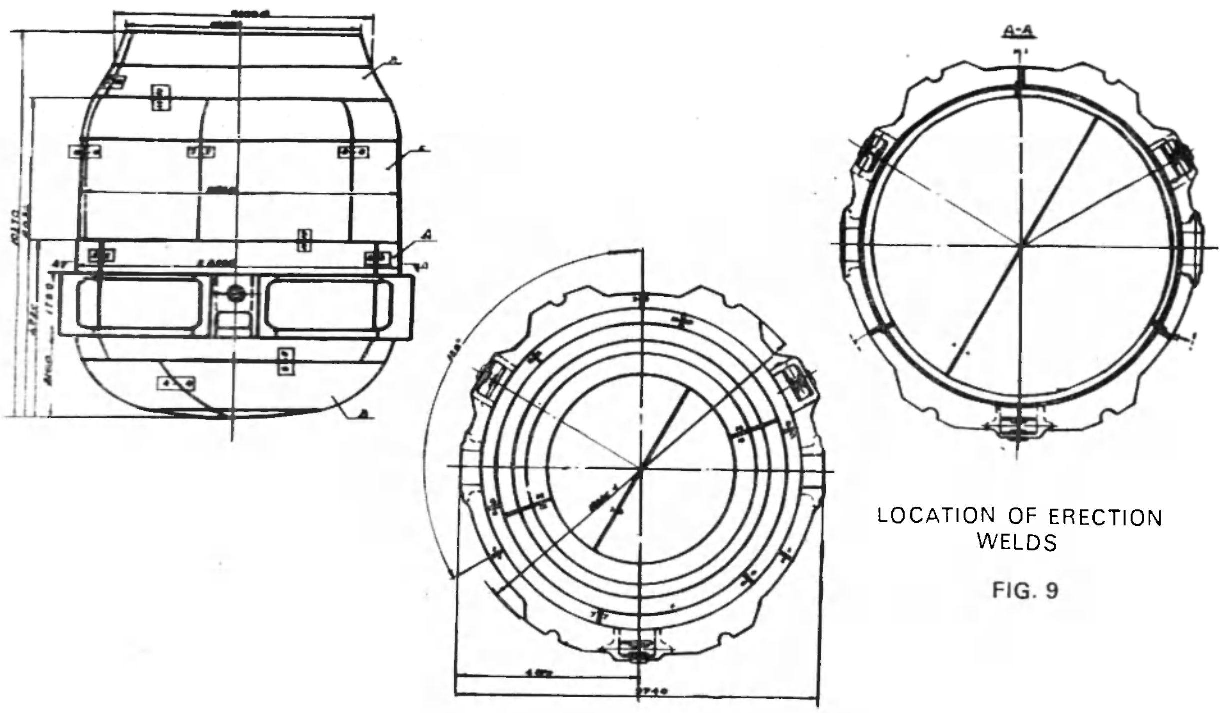
The portion of the shell marked 4 and supplied in 3 unit parts each weighing about 37T is assembled on a firm base with erection brackets and welded in acordance with the parameters discussed earlier, (Figure-10). This is followed by the assembly and welding of the convertor bottom mkd. B, supplied in 2 unit parts weighing about 16 T each. After welding of the shell bottom, it is placed over the part A (Figure-11), and the two parts welded with a joint design as shown in Figure 11. Next the part C supplied in 6 unit parts weighing about 9 Tonnes each is assembled and welded (Fig-12) followed by the welding of the convertor neck mkd D and supplied in two unit part weighing about 24 Tonnes (Figure-13) The neck is then placed over the part mkd C and the two units welded together.

The trunnion ring supplied in 4 unit parts is then assembled (Figure-14) and welded in accordance with the parameters discussed earlier. Finally the welded parts A & B are placed over a saddle (Fig.-15) and the parts C & D placed over these, and assembled with erection brackets. The dimensional parameters are checked and welding of the final joint is completed as per the procedure and sequence discussed earlier.

Assembly welding of the 300 T convertor is a remarkable achievement because welding manually on such a large scale and of such thick plates, to the author's knowledge has not been done before in our country. The severe service conditions of the shell and its structural importance necessitated a weld procedure very critical and exacting in both its layout and execution. The credit for the success of this job and the experience gained must go to the Management of Bokaro Steel Plant, for their decision to proceed to work with Indian manufactured electrodes, and the very valuable guidance given at every step by the Soviet specialists.

This operation also confirmed the suitability of the low tensile and high impact value electrodes for welding steel in the low tensile strength range and on the basis of the test results obtained it can be concluded that this electrode could be very suitably used for welding mild steels under conditions of heavy impact loading.

The author is grateful to Sri H. S. Aswath, Assistant General Superintendent (MR) for the help rendered in



LOCATION OF ERECTION WELDS

FIG. 9

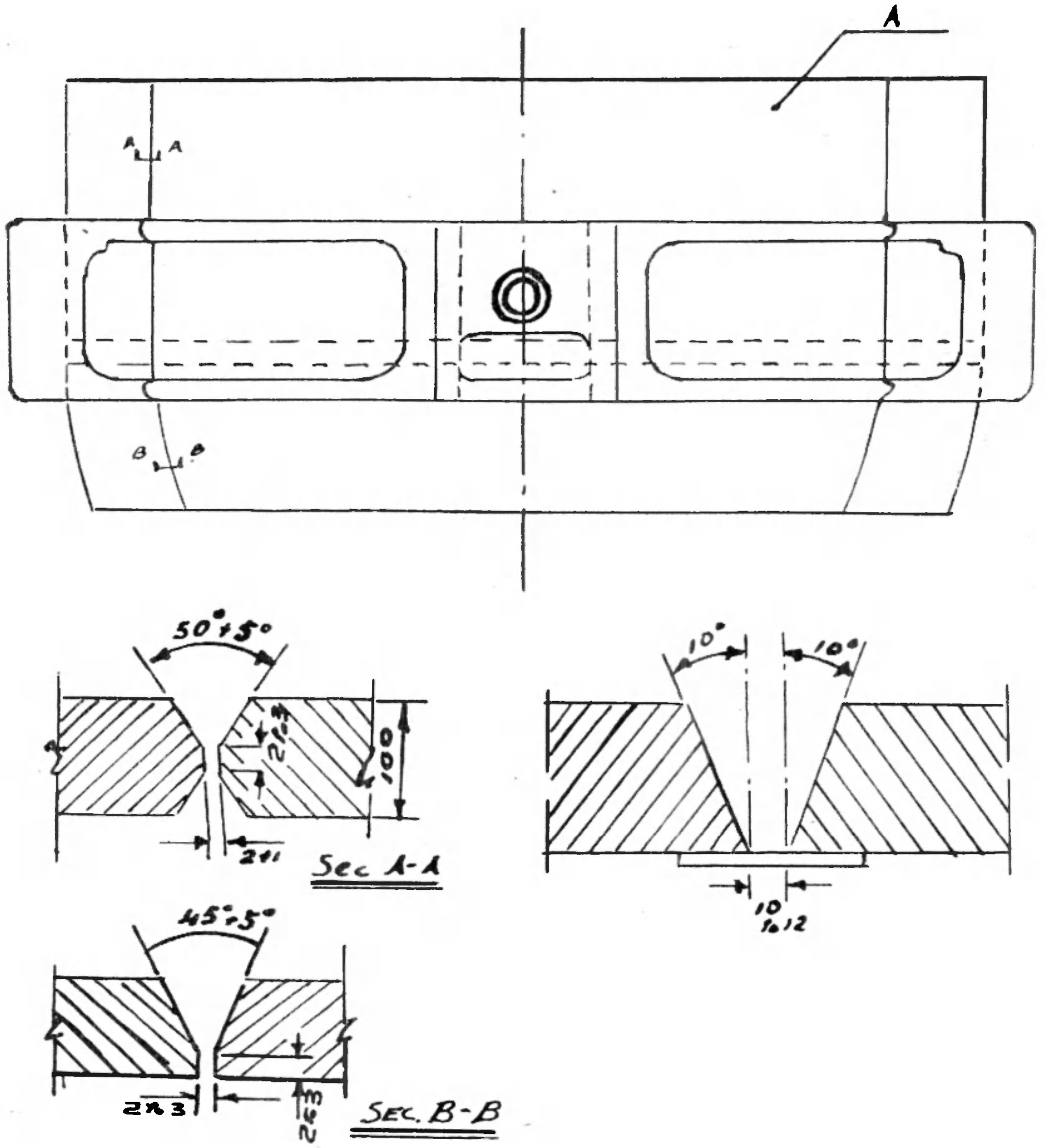


Fig. 10

metallurgical investigations and acknowledges the contribution of Sri G. Tiwari, and S. A.Bhangaonkar. The author is also grateful to the management of Bokaro steel plant for their permission to publish this paper.

REFERENCE

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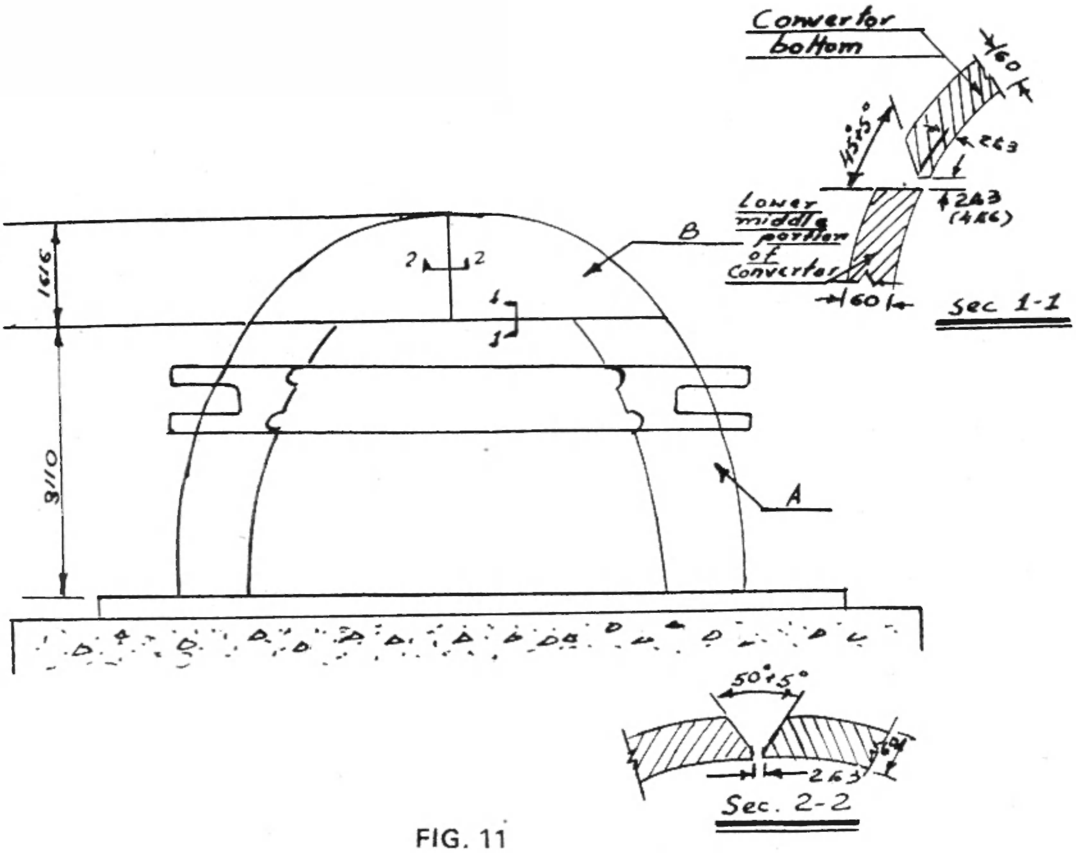
Convertor bottom
60
45±5°
2&3
2&3
(4&6)
Lower middle portion of Convertor
60
Sec. 1-1
B
2
2
1
1
1616
3110
A
50°±5°
2&3
Sec. 2-2

FIG. 11

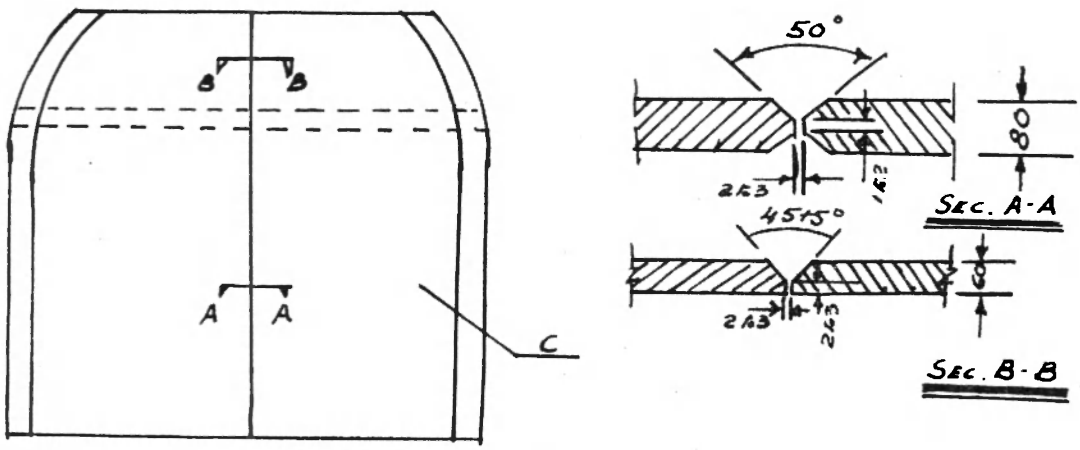
B
B
A
A
C
50°
80
2&3
1&2
Sec. A-A
45±5°
60
2&3
2&3
Sec. B-B

FIG. 12

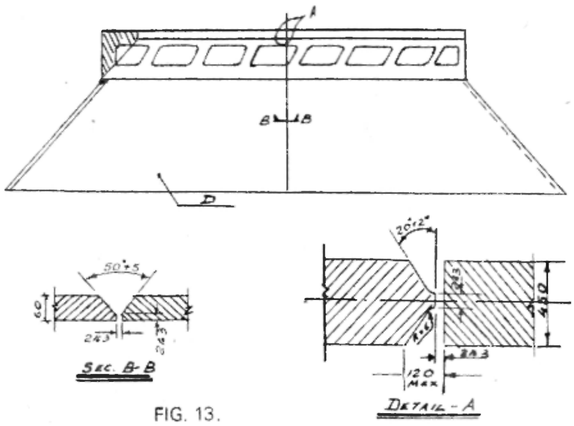

FIG. 13.

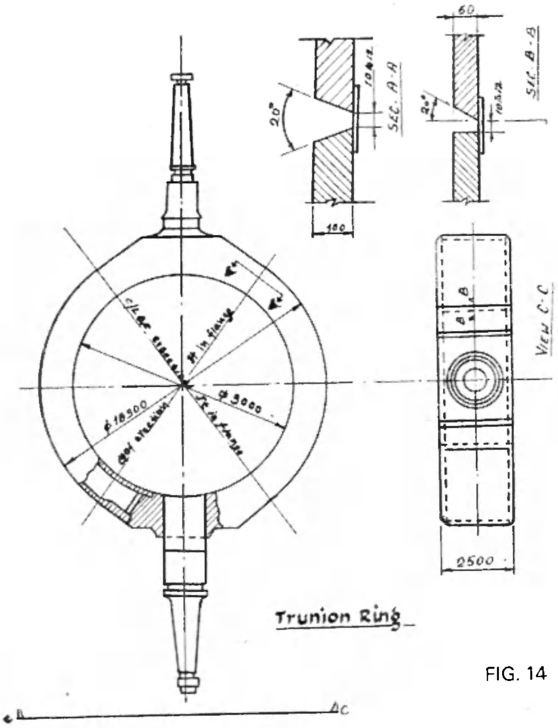

FIG. 14

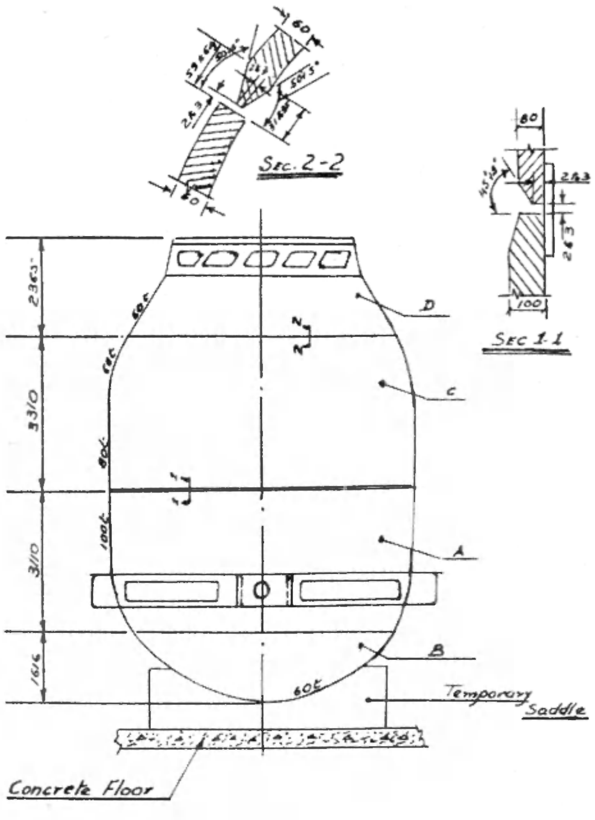

Fig. 15