Welding of 80 Kg/MM² H. E. T. Welten-80 Steel for Kalinadi Project

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Synopsis

The first indigenously fabricated penstock was erected for the Madras State Electricity Board during the year 1939. Thereafter a number of schemes have been completed by using M.S. and High Tensile Steels for the fabrication of penstock pipes. It was in the year 1965 that T_1-A steel, which is an Extra High Tensile Steel, was used for the first time in the country for the Sharavathi Hydel Project in Karnataka. The reason for using this steel was economic advantage over the conventional type of steel. The total tonnage used was about 20,000. Upper Silleru was the next project to use this steel in 1966 and about 524 tonnes were used for fabrication. The third project to use T-1 steel was the Beas-Sutlej Link Project.

The present paper deals with the Extra High Tensile Steel (Welten-80) 80 Kg/mm², used for the fabrication of penstock pipes for the Kalinadi Project in Karnataka State. The paper deals with the physical and chemical properties of the material, welding technique, preheat, interpass and post heat treatment, preservation of electrodes, etc. The paper also deals with the problems in welding this type of steel, both at the factory and at the site of erection. The discussion reviews the developments within the guidelines of relevant codes and standards, with a view to meet the developments of future requirements.

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Introduction

Welten-60 steel (60 Kg/mm²) was used for the first time in Japan in the year 1960 for the fabrication of penstocks. High strength steel (70 Kg/mm²) was used in the year 1970, for the construction of large pumped hydro-electric stations. Welten-70 was used for the construction of the Numahara Power Stations with an installed capacity of 675 M.W. Welten-80 steel (80 Kg/mm²) was used in the year 1973, for the construction of Ohira Hydroelectric Project with an installed capacity of 500 MW. In view of the experience and the confidence gained in successfully welding the 80 Kg/mm² steel, a series of pumped storage hydro electric stations of 1000 MW have been planned by using Welten-80 steel in large quantities. This steel is very economical in the construction of high head penstocks. The fabrication and transport costs are reduced by nearly 75 to 80%. The design and fabrication by welding is based on the technical standards titled "Watergate and Penstock Society of Japan. The Mysore Power Corporation imported both A-285 Gr-'C' (M.S.) and Welten-80 steel from Japan under the Yen credit plan for the construction of Kalinadi Project.

Brief Description of the Project

Kalinadi Hydro Electric Project—Nagjhari Scheme (First Phase) envisages Hydro Power development from the river Kalinadi which flows westwards in the Dharwar and North Canara districts (Karnataka, India) and finally joins the Arabian sea. The Kali valley has an estimated power potential of 1.3 million KW which is proposed to be developed in several stages. It is proposed to install 6 Nos. of 135 MW generators at Nagjhari power house and 2 Nos. of 50 MW generators at Supa Power house in the first stage. The gross head is 1202 ft. Water will be supplied from the surge tank through 3 main pressure shafts 4.75 M.dia. branching off to 6 penstocks of 3.5 M.dia. The pressure shaft which has an inclination of 50° is lined with A-285 Gr-'C' (M.S.) and the branch penstocks are lined with Welten-80 steel (ASTM 517 Gr-'F') (Fig. 1).

Specification of Welten-80 Steel

Welten-80 is a quenched and tempered low-alloy steel. Welten-80, an equivalent of T-1 and T-1A of the U.S. Steel Corporation, has properties of superior weldability and toughness of weld bond. It is used for fabrication of penstocks, spherical tanks, pressure vessels and bridges.

It can be readily cold worked, cold bent and sheared. It provides high corrosion and abrasion-resistance as it contains copper and chromium.

This type of steel has not yet been standardised by the Japanese Welding Society and is being identified by its brand names by other Japanese steel makers. Welten-80 steel is being manufactured by Nippon Steel Corporation, Japan.

Fabrication (Gen.)

Fabrication of Welten-80 steel is based on A.S.M.E. Section VIII 1971. All the plates are accurately marked, trimmed to correct size by gas cutting or by edge planing. The plates are then cold rolled to a true circle, once the edges are correctly made. The gas cut edges are ground 2 to 3 mm to remove hardness.

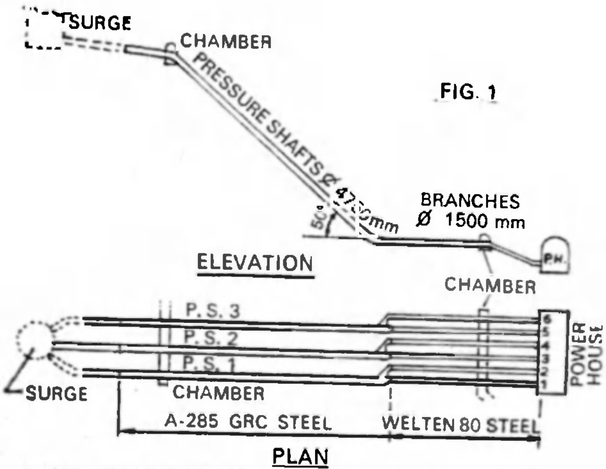

FIG. 1

KALINADI HYDRO ELECTRIC PROJECT-SCHEMATIC DIAGRAM

Welding Procedure

Fitting : The edge prepared plates after bending are matched properly with matching screws and thereafter sufficient finger bars are welded to keep the joint in correct alignment before welding. Joint preparation adopted for welding the Welten-80 steel both at shop and field are shown in Fig. 2.

Groove Accuracy and alignment

Although extensive tests have not been conducted, the following conditions are supposed to ensure good welding. For oneside welding of circular joints, the edges should be ground to prevent the occurrence of welding defects.

Offset	Less than 2 mm.
Fit up	Less than 2 mm.
Root Gap	For Shop 5 mm.
	For field 6 mm.
Root face	3 mm.

Root faces exceeding 3 mm must be ground down to 3 mm. A root gap of 6 mm is permissible if the heat input can be well controlled.

Welders' Qualification Tests and Procedure Tests

Before the fabrication is started, procedure tests and welders' qualification tests are carried out in accordance with Section IX ASME Code or equivalent I.S.I. In addition to the tests specified in the code, the following tests were carried out in the case of Welten-80 steel. This is as per the recommendations of steel manufacturers.

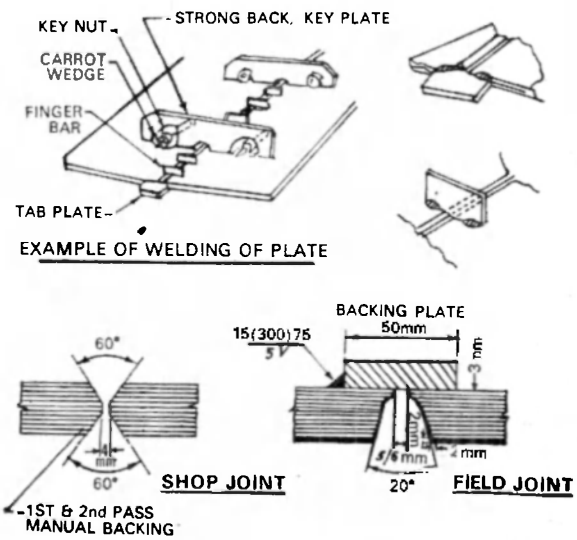

FIG. 2

TABLE 1

Chemical Composition and Mechanical Properties

Chemical Composition %	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	B
	0.16 Max.	0.15-0.35	0.60-1.20	0.030 Max.	0.030 Max.	0.15-0.50	0.40-0.80	0.40-0.80	0.30-0.60	0.10 Max.	0.006 Max.

		Heat treatment	Quenched & tempered.
		Available Thickness Range mm.	6 to 100 incl.
		Thickness mm.	Kg/mm² (psi)
	Yield Point Min, KG/mm² (psi)	6 to 50 incl. Over 50 to 100 incl.	70 (1,00,000) 68 (96,700)
Mechanical Properties	Tensile Strength KG/mm² (psi)	6 to 50 incl. Over 50 to 100 incl.	80.95 (115-135,000) 78.93 (110 900-132,200)
	Elongation %	Thickness mm 16 Over 16 Over 20	%Min. 16 24 16
		Thickness mm.	Ratio of bend radius to specimen thickness.
	Bending Property (Dia. of bend 180°)	6 to 32 Excl. 32 to 100 incl.	1.5 t 2.0 t (k. Plate thk.)
	Notch Toughness	Thickness mm.	Charpy 2mm V Notch Impact Value.
		13 to 32 mm. incl. over 32 to 100 incl. Over 32 to 100 incl.	3.6 Kg-M (26 ft. lbs) at —15C°. 3.6 Kg-M (26 ft. lbs) at —20°C.
Max. Weld Hardness to be tested when the value of carbon equivalent.	Carbon equivalent (see note)	Thickness, mm. ...	HV.
	In case of 0.60 and over.	13 to 100, incl.	403 Max.

NOTE : Carbon equivalent is calculated by the following formula :
C+1/6Mn+1/24 Si+1/40 Ni+1/5 Cr+1/4 Mo+1/14V.

TABLE 2

Specification of Solid Wire for SAW

	C	Mn	Si	Ni	Cr	Mo
Chemical Composition %	0.18	1.64	0.17	2.56	0.52	0.7

TABLE 3

Specification of Flux for SAW

	SiO_2	CuO	MnO	Al_2O_3	NbO	CaF_2
Chemical Composition %	38.6	15.2	18.1	8.6	3.8	14.2
Mesh Size	20×200					

TABLE 4

Typical Chemical and Mechanical Properties of All Weld Metal for SAW

Wire Flux Combination : As described in Table II & III.

	C	Mn	Si	Ni	Cr.
Chemical Composition %	0.06	1.26	0.30	2.38	0.41

	Yield Point	Tensile Strength	Elongation	V. Charpy
Mechanical Properties	74.1 Kg/mm^2	84.8 Kg/mm^2	22%	7.9 Kg-M (—15°C.)

TABLE 5

Specification of Manual Welding Electrodes

Chemical Composition %

Classification	C	Mn	Si	Ni	Cr	Mo
E10016 (L-74)	0.07	1.0-1.4	0.35-0.60	2.0-2.4	0.10-0.30	0.25-0.55

Mechanical Properties

Classification	Yield point	Tensile Strength	Elongation	V. Charpy Min. Kg-M
E10016 (L-74)	63 Kg/mm^2 min.	74-85 Kg/mm^2	20%	4.8 (—15°C)
E7016 (16LH)	42 Kg/mm^2 min.	50-58 Kg/mm^2	28%	12.8 (—27°C)

Classification of Electrode	E10016	E7016
Diffusible Hydrogen Max.	0.03 cc/gm.	0.04 cc/gm.

(1) Window Cracking Test

This is a restraint cracking test, commonly used to study the occurrence of Transverse cracks in multi-layered weldmetals, in joints made out of 80 Kg/mm^2 class tensile strength steels.

(2) Y-groove Restraint Cracking Test

This test is the most common and is a highly effective method of testing root cracking in tack welds and in the initial layers of main welds.

(3) Circular Patch Test

In the welding of grout holes in penstocks, possibility of weld cracking is considered to be relatively high. The circular patch test is to be conducted to investigate cracking in the grout hole welding, since the welding is carried out in a condition of restraint.

(A) Diffusible Hydrogen Tests

This checks the amount of hydrogen in the electrode.

Choice of Electrode

The electrodes for S.M.A. and S.A.W. were imported from Japan, based on the recommendations of the steel suppliers. The electrodes and fluxes are manufactured by Nippon Steel Welding Products and Engineering Co. Before taking the decision to import the electrode from Japan, our company had sent the indigenous electrodes manufactured in our country to the R & D Laboratory of N.S.C. for studying the suitability. Extensive tests were carried out in the R & D Laboratory by using indigenous electrode on Welten-80 steel. The investigation revealed minute cracks especially in the window cracking and circular patch tests.

In view of the extremely difficult working condition in the tunnel at the Kalinadi Project, where the humidity is more than 90%, the steel manufacturers recommended the following combination of electrode to get the best results. This recommendation was based on the tests carried out by them and also the experience they had gained while fabricating pipes for Ohira and Numahara Projects.

Drying of Welding Materials

One of the most important considerations is to preclude hydrogen from weld metal as much as possible, because, hydrogen is a major cause for cracks. Most penstocks are fabricated and installed using the covered electrode and/or SAW process, although the CO_2 and MIG processes are particularly suited for this purpose. Coated electrodes and fluxes should be redried before use and their handling should be closely controlled so that they will not absorb moisture from atmosphere.

Combination of Welding Materials :

	Type of Weld	Type of Welding	Location	Root Pass	Filler Pass
(1)	Long Joint	SAW	Shop	E 10016* (Nittetsu L74)	Nittetsu Y-80M wire and Nittetsu NF16 Flux
(2)	Cir. Joint	SAW	Shop	E 10016* (Nittetsu L74)	Nittetsu Y-80M wire and Nittetsu NF16 Flux
		SMA	Shop	E 7016** Nittetsu 16LH	E 10016 Nittetsu L-74
(3)	Fillet Weld Welten-80 + Welten-80 MS + Welten-80	SMA	Shop	E 7016/E 7018 Nittetsu 16LH	E 7016/7018
(4)	Cir. Joint Welten	SMA	Site	E 7016 Nittetsu 16LH	E 10016 Nittetsu L-74
(5)	Cir. Joint MS + Welten	SMA	Site	E 7016	E 7016

* Remove the root pass by gouging.
**Strength should be secured by gouging.

Covered Electrodes

The electrodes after being taken out of the container shall be dried at 400°C ± 15°C for about 3 hours before use. The electrode thus dried should be transferred on to storage ovens immediately and maintained at 120 to 175°C. Only the electrode required for an hour's use shall be removed at any time. If an electrode is exposed to the atmosphere for more than an hour, it shall be redried under the same conditions as before. The redrying can be done only once. If the drying temperature is too high or the electrode is dried more than four times, the coating will embrittle and peel off during welding.

Fluxes

Fluxes for SAW shall be dry and free from contamination of dirt, mill scale or other foreign material. In principle, the flux should be of fusion type.

(i) As a rule, neutral type flux should be dried at a temperature of 250°C for 2 hours and highly basic type of fluxes at a temp. of 400°C for 2 hours. For uniform drying, the flux should be spread in a thin layer and dried in an agitated oven.

(ii) After drying, the flux should be placed in an oven at 150°C.

(iii) Flux should be used within 60 minutes of removal from the oven.

(iv) If the flux has been exposed to the atmosphere for more than 60 minutes after removal from the oven, it must be dried again before use.

(v) If the flux has been kept in an open container or hopper for more than 4 hours, the upper 25 mm should be discarded.

(vi) While using the flux recovered from previous jobs, care should be taken to see that the impurities are removed before using.

Preheating & Interpass Temperature

A preheat and interpass temperature of 150°C to 200°C shall be maintained. The preheat shall be uniform and continuous. Electric stepheaters or gas burners may be used for preheating the longitudinal and circular joints in the shop. It is necessary to heat each part over a width of 100 mm ($4 \times t$) or more and maintain satisfactory temperature control. It should be kept in mind that the surfaces to be welded must be absolutely moisture free. When the preheat temperature is too high, or welding is locally concentrated, the interpass temperature may become too high and adversely affect the toughness of the weld metal or the heat affected zone. Therefore, the interpass temperature should be controlled in accordance with the limits. When thermostats are not available, frequent measurements of temperature by indicating crayons or other similar type heat indicators should be made. The interpass temperature measurements should be taken as close to the welding line as possible. Local preheating may be carried out while repairing the welding defects of main joints revealed in the radiographic tests. The recommended heat input is less than 45,000 Joules/cm in Welten-80 steel. Hence input should not exceed 50,000 J/cm.

Heat Input Restrictions

In order to prevent embrittlement and softening of the fusion line and heat affected zone, the heat input by welding must be restricted as described below :

Classification of plate thickness (mm) :

6 to 13	13 to 19	19 to 26	26 to 40
25,000 J/CM Max.	35,000 J/CM Max.	45,000 J/CM Max.	48,000 J/CM Max.

Tabulated below are typical examples of shielded metal arc welding conditions :

Welding Position	Electrode Dia. mm	Welding Current A	Welding Speed mm/min	Heat Input J/cm.
Flat	3.2	100 to 120	100 to 180	12,000 to 18,000
	4.0	160 to 180	100 to 180	13,300 to 27,000
	5.0	200 to 230	100 to 180	17,000 to 34,500
Vertical	3.2	90 to 110	40 to 120	22,500 to 37,000
	4.0	130 to 150	40 to 120	30,000 to 45,000
Horizontal	3.2	110 to 130	100 to 180	12,000 to 15,000
	4.0	160 to 180	100 to 180	13,500 to 17,000
	5.0	200 to 230	100 to 180	17,500 to 34,500
Overhead	3.2	90 to 110	40 to 140	12,000 to 18,700
	4.0	120 to 140	40 to 140	12,500 to 17,500

Welding voltages commonly range from 24 to 26 volts, when welding is done with proper arc length. The actual welding heat input (Joule/cm), can be calculated from the formula.

Heat input (Joule/cm) =

Current × Voltage/1000 × Speed in/cm/min

In the case of SAW also, this formula holds good.

Typical examples of heat input are as under :

Thickness in mm	Preheat & Interpass Temp. O°C	Heat Input in Joule/cm
25 mm	150 to 200	44,200
38 mm	150 to 200	45,000
50 mm	150 to 200	45,000

Nature of Welding Current

The current used for welding shall be D.C. straight polarity.

Welding Technique

In the fabrication and installation of penstocks, welding is performed at three different locations, the fabrication shop, temporary site workshop and the installation site.

Generally S.A.W. and S.M.A. welding are carried out at the shop and S.M.A. at the Erection site.

Submerged Arc Welding (SAW)

Long Joint : Long joint shall be butt welded either by SAW or by MMA.

Circular Welding : When the long welding is completed, the shells are matched with sufficient finger bars to maintain alignment during welding. S.A.W. is allowed only if the thickness is more than 19.2 mm. If it is less than 19.2 mm. only SMA process should be adopted.

In SAW, penetration is relatively greater and the chemical composition of the deposited metal varies widely with dilution of the base metal for this reason, the mechanical properties or crack sensitivity of the deposited metal are easily affected by the speed of cooling. Therefore, in the selection of wire, flux, sufficient consideration should be given to the type of joint, build up, method of preheat, interpass temperature, heat input etc.

Manual Welding

In manual welding, the arc length should be as short as possible, consistent with maintaining satisfactory operation. The straightforward stringer bead method is preferred for welding of Welten-80 steels. Weaving is permissible if a steady arc length is maintained, but the width of the weave should not exceed 3 times the diameter of the electrode used in the vertical position and twice the diameter of the electrode used in the down flat position (Diameter of Core wire). When welding is performed in the vertical position, all beads must progress from the bottom to top, except the first pass, which may be uphill or downhill and the finish or wash beads may be run top to bottom using 3.2 mm or 4.0 mm dia. electrodes using either 2 or 3 stringer beads to cover the uphill passes.

The tack welding of jigs shall also be welded under the same conditions as for regular welding (welding of the main body). The bead length shall be 80 mm minimum.

In periods of high wind, the operator and joint shall be protected to prevent the protective gas blanket of the welding arc from being blown away.

No welding shall be performed when water is falling/dropping on the surface to be welded, unless the work is properly protected.

Precautions during Welding

Extreme care should be taken to remove slag during each pass and inspect the surface with the naked eye. Never deposit the next bead without looking for defects such as overlap, pit, excessive undercut, etc. Any defects that appear on the surface of any bead of welding, shall be removed by grinding or gouging before depositing the next successive bead of welding. No arc strike is allowed on the base metal, except in the groove. If this happens, that part of the base metal will be hardened abnormally and may become the starting point of crack.

Inspection of Welds

The welds shall be ground till all weld ripples and surface irregularities are removed and the weld surface is left smooth, but not necessarily flush with plate surface. All double welded butt joints shall be examined in accordance with the requirements of paragraph UW51 of Section VIII-1971, ASME unfired pressure vessel code. Longitudinal joints and the circumferential joints shall be X-rayed 100% of the length of welds in the shop. Radiographs shall not be taken until 24 hours have elapsed after completion of welding.

Welds whose radiographs disclose them as defective shall be arc air gouged or chipped out, rewelded, re-x-rayed and the cycle repeated until satisfactory results are obtained.

All fillet welds, joining diaphragm plates, rings, lugs, etc., must have smooth transitions into the sides of plates with toes of the weld made before depositing the major bead. The surfaces shall be ground to merge smoothly into the plate surfaces. The fillet joints are subjected to magnetic particle testing. The procedure of carrying out the above test shall be as per Appendix 6 of ASME Code Section VIII. 1971.

Grout Plug Welding

Grout holes are provided in the pipes for grouting purposes in the field after the same is installed in the tunnel. Welding of grout plugs in the field is difficult in the case of Welten-80 steel due to the difficult conditions and high percentage of humidity. Hence an M.S. nozzle with reinforcement plate is welded in the shop as shown in Fig. 3. All precautions are taken while welding to prevent any under bead cracks. The grout holes are welded with E 7018 electrodes both at the shop and at the field for plug welding. As there is no scope to carry out radiographic tests, the grout holes are plugged temporarily and hydraulic testing is carried out to make sure that there is no leakage. The plugs are of M.S. and the same will be welded in the field after the grouting operation is completed.

Field Welding

The shop assembled pieces are aligned at the site along the alignment. Sufficient finger bars shall be used on circumferential joints to maintain alignment during welding. No tack welds in the joints are permitted. As there is no access to weld the joint from outside, only inside welding is contemplated with back-up bar. The back-up bar used for this purpose shall be mild steel having low carbon content (bars with carbon 0.18 max).

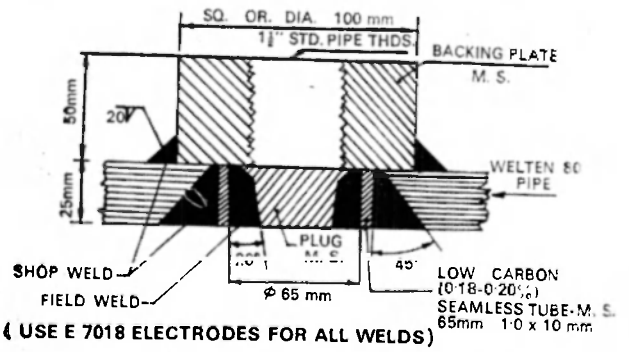

FIG. 3 DETAIL OF GROUT HOLEA PLUG

Preheating and Interpass Temperature

Preheating and interpass temperature shall be the same as followed in the shop.

Welding Technique

In the case of embedded type penstocks where, the welding work is liable to be carried out in highly humid tunnels, the chances of delayed cracking of weld is likely to be more easily induced by hydrogen. To prevent weld cracks, low carbon equivalent steel materials are used and stringent control of preheating temperature, heat input and electrode, is practised. It is recommended that the first pass shall be deposited with a low tensile electrode to prevent any under-bead cracks.

Multipass welded joints of these types have a high possibility of cracks occurring in the root pass. Cracks of this type can be removed by the application of continuous welding. This kind of crack is likely to occur when temperature is under 150°C and when hydrogen contained in the heat affected zone is high. In the case of continuous welding, however, it will take a somewhat longer time before the temperature comes down to 150°C or lower. During this period, hydrogen contained is removed and the possibility of crack occurrence will thus be eliminated.

Welding shall be done continuously, as far as practicable. As a general rule, the working condition shall be so set, that within the groove, continuous welding can be done from the first pass, to one half of the plate thickness. In any case, two passes shall be continuously welded without fail.

The heat input and interpass temperature shall be carried out strictly to get better results.

The tunnel shall be well ventilated, such that temperature and humidity are kept under 30°C and 80% respectively. If the humidity exceeds 90% in the tunnel, the welding work may have to be suspended.

Inspection of Field Joint

The field circumferential joints are to be radiographed 100% for Welten-80 steel. In the case of the Kalinadi Project, due to the lack of space around the pipe, radiographic tests cannot be carried out. Ultrasonic test is the only alternative test that can be carried out for the inspection of welded joints. This test is to be carried out 24 hours after the welding is completed.

The procedure for testing the joint is based on the A.S.M.E. code. The sensitivity is kept higher than what is specified in the code, so that certain defects are not missed while testing.

A.S.M.E. code specifies 2.25 MHZ probes as a general rule for testing. But for testing Welten-80 joints, 70° angle probes of 5 MHZ are recommended for plates with thickness upto 40 mm. The testing and interpretation of U.S.T. requires very good experience to correctly judge the defects. A set of test pieces with defects are prepared and rediographed. Ultrasonic tests are thereafter carried out on the same test plates. The results are then tabulated for reference. The inspectors are trained with the help of these test-pieces to have a correct judgement. Wherever space is available radiographs are also taken and the results compared with UST.

Magnetic Arc Blow in Welding of Welten-80 Steel at Shop

While fabricating the taper (Cone Pipe) piece, the above difficulty was experienced and it was impossible to carry on with the welding. This was at the plate stage while joining two plates with a root gap of 4 to 5 mm. All precautions to minimise the arc blow were considered without any success. There are several methods described in welding manuals to minimise arc blow. Even though we tried all the types, some of the methods were difficult to follow. as winding of cables over the plates was posing a problem. However, this problem was overcome by having an 'X' Groove with a zero gap instead of 4 to 5 mm root gap. This problem was experienced only with shorter length plates. The author took up the matter with the steel suppliers, who suggested the usual method of avoiding arc blow. When this did not solve the problem, they carried out a series of tests in the R & D Laboratory, Tokyo to overcome this difficulty. Nippon Steel Corporation confirmed that 'X' Groove with zero gap which we followed to overcome the difficulty was one of the solutions. In the field, we have not experienced this difficulty. Moreover, the welding of Welten-80 liners has just begun and no difficulty has been experienced as yet.

References

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