Welding Of Pipelines For Oil Industry

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1.0 Introduction

Increasing energy demands has brought about the necessity of exploring newer sources of natural gas and crude oil and the necessity of enlarging the construction activities of pipeline for transportation of oil, gas and associated products. Transmission pipelines have long been recognized as an economical method of transporting fluids and gases over long distances. Despite large capital investments more and more pipelines are being built to transport a variety of fluids and to meet more and more stringent service requirements of corrosivity, pressure and temperature. To meet the requirements of demanding applications, newer materials have been developed which have much higher strengths, toughness and much greater resistance to corrosive environments. Newer process have been developed and greater understanding have been gained about the welding of pipelines.

Though every aspects cannot be covered, in a short time, an attempt has been made in this paper to highlight some of the salient aspects of the welding of pipelines used for transportation of petroleum products.

2.0 General

For reasons of economy, it is necessary to carry out the pipeline installation within the shortest possible period of time. Therefore, it is advisable to choose the material and it's dimensions which will not create any problem at any time during the construction and operation of the pipeline. While calculating the total time required for the laying of pipeline, joint welding of the individual pipes and pipe sections represents one of the major time consuming operations. Therefore, economic and safe construction of pipelines does mainly depend on the base material of the linepipes, its' dimensional tolerances, the welding technology and the welding consumables used. We shall proceed to briefly touch upon these salient points in the following sections.

3.0 Materials

The internationally recognized American Petroleum Institute Specification API 5L gives the general requirements for linepipe steels. A number of specification modifications have been attempted for ensuring better weldability, greater resistance to sour gases and better properties, by a number of international companies. These efforts have lead to the development of steels to the present level of quality and reliability.

It was generally accepted that decreasing the Carbon level would greatly contribute to the increase in weldability of linepipe steels and toughness. Lowering of the Carbon necessitated some other means of increasing the steels' strength level. This was achieved by the introduction and use of controlled rolling and subsequently by the wider and more extensive use of micro-alloying elements in conjunction with controlled rolling. The same effect had also been achieved by quenching and tempering. The range of compositional types and steel processing routes for linepipe steels has continued to expand.

Increased demands for higher strengths, heavier wall thicknesses, tougher pipes with excellent weldability under severe field welding conditions etc., have further widened the range of steel types. Recent addition to this range is the ultra-low Carbon controlled rolled bainitic steels produced by on-line accelerated quenching (OLAC) route. Today we have steels with as low as 0.01 % of Carbon

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strenghthened by the alloying elements such as Mn, Nb, B, Ti, developed to API 5L X70 and API 5L X80 specification requirements. Typical composition of linepipe steels used for cross country pipelines are listed in Table-1.

Whenever pipelines are to be used for sour gas service they shall have to possess resistance against Hydrogen Sulfide. Since more and more wells in offshore fields are turning sour or could turn sour at later stages of it's productive life, due to the action of sulphate reducing bacteria, most of the pipelines are being made to sour service requirements.

The requirements for sour service linepipe materials is that they shall have excellent resistance to Hydrogen induced cracking (HIC) and sulfide stress corrosion cracking (SSCC). To a large extent this could be achieved by controlling the hardness of the materials and by modifying the inclusion content and it's morphology.

The hardness control without affecting the strength is achieved by controlling the contents of the elements that contribute to its hardenability. The requisite strength and toughness, then, can be achieved by adding micro-alloying elements such as Ti, Nb, B, N_2 etc.,

The principal inclusion that contribute to the susceptibility to HIC is the Manganese Sulfide which depends both on Mn and S contents. MnS, if present, would become sharp cornered, elongated inclusions, during the rolling or any directional mechanical working and thus form favourable sites for Hydrogen accumulation which contributes to HIC.

It would be necessary to restrict the total content of Mn by controlling the Mn and S contents in the molten metal. In addition, whatever MnS is present would be rendered spherical in shape by the addition of Calcium in the laddle. Recent works have indicated that a Sulfur levels of $< = 0.003\%$ would be required and steels need to be produced to low Oxygen levels of less than 0.014%, in order to serve satisfactorily in sour environment.

Basic openhearth furnace or L.D. converter, in association with vacuum degassing process, has enabled ultra-low-Oxygen levels (0.003%) and Hydrogen levels (1.5 ppm) to be achieved. This has also permitted the production of ultra clean steels with precise control on chemistry. Desulphurization and inclusion shape control by Calcium Carbide and Calcium Silicide injection have enabled Sulphur content to be progressively reduced to values much below 0.003% and in the best of the available steels, brought down to 0.001%.

A typical pipe material specification used by Engineers India Ltd. for procuring steels suitable for sour service is given below :

Product Analysis :

C	Max % :	0.14
Mn	Max % :	1.4
Si	% :	0.15 - 0.35
P	Max % :	0.02
S	Max % :	0.003
Nb(Cb)	Max % :	0.05
Ti	Max % :	0.05
V	Max % :	0.10
Cr	Max % :	0.25
Ni	Max % :	0.20
Al	% :	0.01 - 0.05
N	Max % :	0.01
Cu	% :	0.20 - 0.35
B	Max % :	0.0005
Al/N	Min :	2.0
Cr + Mo	% :	0.025
Cu + Ni	% :	0.40

Carbon equivalent calculated by the formula shall be less than 0.36.

$$\text{C.E.} = \text{C} + \frac{\text{Mn}}{6} + \frac{\text{Cr} + \text{V} + \text{Mo}}{5} + \frac{\text{Cu} + \text{Ni}}{15}$$

The Pcm calculated by the following value shall not exceed 0.18.

$$\text{Pcm} = \text{C} + \frac{\text{Si}}{30} + \frac{\text{Mn} + \text{Cu} + \text{Cr}}{20} + \frac{\text{Mo}}{15} + \frac{\text{Ni}}{60} + \frac{\text{V}}{10} + 5\text{B}$$

Recently, many fields have shown significantly higher quantities of H_2S, Chlorides and CO_2 along with H_2O. These are highly corrosive sour environments in which the traditional Carbon steels cannot be used. This necessitated the use of newer materials. After extensive studies, EIL had decided to use duplex stainless steels (DSS).

Duplex stainless steels were developed in an attempt to combine good properties of ferritic and austenitic stainless steels. These properties include the ductility and general corrosion resistance of the austenitic type and the strength and resistance to stress corrosion cracking of the ferritic type.

These duplex steels contain a mixture of austenite and ferrite in the proportion of 50 : 50 and are obtained by balancing the contents of Cr, Mo, Ni, C and N. These steels are used in quench-annealed condition. The most popular grade of DSS in use for sour gas transportation is UNS 31803.

TABLE - 1 TYPICAL CHEMICAL COMPOSITION OF PIPELINE STEELS

Elements %	Semi killed	Fully killed normalised	Early controlled rolled	Modern controlled rolled	X70 Steel (with low Carbon Mn. Nb, B, Ti)	X80 Steel (with low Carbon Mn, Nb, B, Ti)
C	0.20	0.20	0.16	0.12	0.020	0.018
Mn	0.87	1.54	1.31	1.42	1.89	2.01
Si	0.03	0.41	0.23	0.30	0.13	0.16
S	0.031	0.005	0.012	0.011	0.002	0.003
P	0.021	0.012	0.018	0.014	0.020	0.019
Al	0.005	0.039	0.027	0.046	0.044	0.041
V	0.005	0.094	0.049	0.015	Ti	-
Nb	0.005	0.005	0.028	0.018	0.048	0.052
Cr	0.020	0.016	0.035	0.016	-	-
Mo	-	0.005	0.018	0.020	-	0.30
Cu	0.040	0.027	0.056	0.020	-	-
Ni	0.030	0.005	0.027	0.040	-	0.32
Ti	-	-	-	-	0.016	0.18
N	-	-	-	-	0.0025	0.0024
B	-	-	-	-	0.001	0.001
CE	0.35	0.50	0.40	0.37	0.335	0.353

Recently, use of Nickle based alloys have gained momentum, in order to combat more severe sour corrosion environments. Nickel base alloys, viz Incoloy 825, is being used either as a solid or as a clad over a Carbon steel base metal in order to balance the cost. Incoloy 825 and API 5L grade linepipes suitable for sour service are now under construction in India.

4.0 Welding

Welding of these three categories of material had posed a number of problems from time to time. These problems had been successfully solved and much knowledge had been gained. We shall present here some of the welding processes and practices successfully employed for the pipeline welding.

Welding Processes

There are four prominent welding processes which have been successfully employed for fixed position girth welding of the linepipes. These processes are :

- Shielded Metal Arc Welding
- Semi-automatic Gas Metal Arc Welding
- Automatic Gas Metal Arc Welding
- Automatic Gas Tungsten Arc Welding.

Shielded Metal Arc Welding Processes

Conventionally, pipeline welding is generally carried out with pipe in horizontal fixed position using vertical downward technique, in which the welding proceeds from top to bottom centre of the pipe. This technique,known as 'Stove Pipe' welding technique, using cellulosic type electrodes of the codes, AWS Exx10, is the most commonly used welding technique in pipeline industry.

Typical electrodes of the type generally used for various material specifications are given in Table 2.

TABLE - 2 Typical Electrode Classifications Used In Pipeline Welding
(As per AWS 5.1-86)

Pipe Grades	Root Pass	Hot pass	Hot Filler	Filler Pass	Cap Pass
5L X42	E 6010	E 6010	E 6010	E 6010	E 6010
5L X46	E 6010	E 6010	E 6010	E 6010	E 6010
5L X52	E 6010/E 7010G	E 6010/E 7010G	E 7010G	E 7010G	E 7010G
5L X56	E 6010/E 7010G	E 6010/E 7010G	E 7010G	E 7010G	E 7010G
5L X60	E 6010/E 7010G/ E 8010	E 6010/E 7010G/ E 8010	E 8010	E 8010	E 8010
5L X70	E 6010/E 7010G/ E 8010	E 6010/E 7010G/ E 8010	E 8010	E 8010	E 8010

The recommended edge preparation for Shielded Metal Arc welding is shown in Figure-1.

DC electrode positive is used and the recommended welding parameters are shown in Table-3.

A relatively thin cross section of root bead, low heat input, coupled with high weldmetal hydrogen content of Exx10 types of electrodes, make this root pass prone to cold cracking. To reduce this problem, low hydrogen, vertical down electrodes have been developed recently and two or three good brands are available in the world market.*

TABLE - 3 Recommended Welding Parameters For SMAW

Pass	Electrode diameter m.m.	Current amps.	Heat Input Kj/cm
Root Pass	4.0	100/140	8
Hot Pass	4.0	110/140	8
Fill Pass	4.8	120/210	12
Capping Pass	4.8	140/210	12

Semiautomatic Welding Process

In semiautomatic welding, filler wires of small diameters are used at relatively high current densities, resulting in high deposition rates. The gas shielding normally used is Carbondioxide or a mixture of Argon and Carbondioxide.

To make use of the relatively high deposition rates available from the process, it is necessary to weld vertically downwards. The welder must effectively balance the gravitational force, causing the weld pool to flow downwards, by the arc force pushing it upwards. If the balance is interrupted, then, the weld will flow down aheadf the arc, creating small areas of lack of fusion. Defects at the root may escape detection on radiography because of the lack of slag within them. Typical welding conditions are given in Table-4.

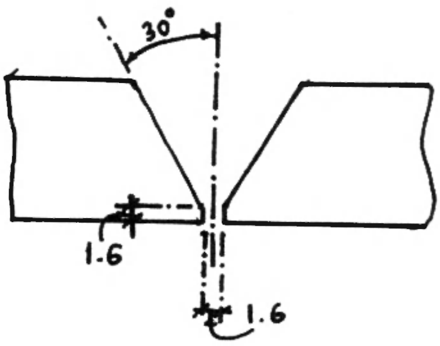

Fig. 1 *Recommended edge preparation for SMAW*

TABLE - 4 Recommended Welding Parameters For GMAW

Parameters	Root Pass	Hot Pass	Filler and Cap Passes
CO_2 flow rate		20 - 22 Litres / min	
Transfer mode		Short arc	
Current, amps	160 / 170	180 / 190	190 / 200
Voltage, volts	20 / 21	21 / 22	23 / 24
Trv. speed, cm/min	23 / 25	27 / 29	Decreases as single pass width increases

Automatic Gas Metal Arc Welding Process

The development of fully automatic gas metal arc welding system which can be used to make girth welds without depending on the welders' skill has long been the dream of the industry. Several systems have reached the first stage of development i.e. the welding head is mechanically tracked along the weld seam. A few systems are known to have reached an advanced stage. Each of these rely entirely on CO_2 shielding or A + CO_2 gas mixture shielding,with a relatively small wire diameter of 0.9 to 1.0 mm. In all cases, the edges are prepared to produce a narrow angled joint. The edge preparation at the site just before commencement of welding is recommended to provide clear, accurate and undamaged edges for welding. All the systems use a relatively high current for the wire size (approx. 180 to 270 Amp), thus ensuring a high metal deposition rate around 2.5 Kg/hr for rapid joint completion as well as ensuring adequate heat input to fuse the sidewalls. All welding is carried out, normally, vertically downward and fusion is also aided by weaving the welding head across the joint for filling and capping passes. The following are some of the systems which have been developed by various companies :

- CRC CROSS Automatic-CRC Automatic Welding, USA
- HC Price Automatic-HC Price Company, USA.
- CRC Automatic Welding System
- Saturne System-Serimer Dasa, ETPM, FRANCE.
- PASSO System-SAIPEM-ARCOS

CRC Automatic Welding system employs a novel device whereby welding heads are built into the internal line up clamp to make the root run from inside the pipe, this being fused into closely following the root run from outside.

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* Editorial note : To reduce the susceptibility to Hydrogen induced crack formation, the Stove Pipe Technique prescribes that the 'Hot pass' must be deposited within five minutes of completion of the 'Root Pass' welding. The time is for cleaning, grinding of the groove. This is to heat up the root pass to allow the diffusible H_2 to diffuse out and increase the cross sectional area of the weldmetal to withstand the contractional and external stresses that could lead to cracking. In case of certain types of higher strength linepipe steels, the 'Retained H_2' even, could lead to H_2 induced cracking. In such cases, Low Hydrogen type, vertical down electrodes can be effectively used.

Joint design and standard welding conditions for 0.5 in. wall thickness are shown in Fig. 2 and Table 5.

TABLE - 5 Typical Welding Condition For CRC Automatic Welding

Parameters	Root Inside	Hot Pass	Fill Pass	Fill Pass	Cap Pass
Travel Speed. ipm	30	40	15	15 ±10%	15 ±10%
Wire Speed. ipm	340	500	650	650	390
Argon/CO2 %	75/25	0/100	0/100	0/100	0/100
Flow Rate. cf/h	50	50	100	100	50
Arc Voltage	19.5	23.5	24.5	24.5	20.5
Current. amps	200	265	250	250	200

HC Price Automatic System

Figure 3 illustrates a typical joint design of 19 mm wall thickness which requires six weld passes. The welding parameters for this procedure are shown in Table 6.

TABLE - 6 Welding Parameter Of H.C. Price For 19mm Wall Pipe

	Weld Pass					
Parameters	1	2	3	4	5	6
Arc Voltage. v	23	22	22	21	21	20.5
Weld Speed cm/min	43.2	38.1	33.0	33.0	33.0	28.0

Wire diameter. 0.9 mm
Shielding gas 50 % Ar + 50 % CO_2

Passo System

This is also similar to CRC-Crose and H.C.Price systems, where the use of an end bevelling machine, an internal line-up clamp, small diameter filler wires and GMAW orbital torches are used. A typical joint design employed for welding with Passo system is given in figure - 4

Saturne System

The main component of this system is the 'SATURNE' horse shoe ring. It forms the welding robot, specially designed for quick installation on the joints and to enable easy and precise handling of the four welding torches mounted on them.

Two torches move simultaneously on each side of the horse shoe ring. Welding can be performed both in uphill and downhill directions. Each torch covers one quarter of the circumference and the necessary overlaps between passes which are automatically determined by the machine itself.

The automatic pipe welder is designed for easy access and control by the welding operators. All the welding parameters are precalculated and locked in the master control unit. The side and radial tracking of the axis of the weld is performed automatically by a special mechanical arrangement of the MIG/MAG welding torches. The entire attention of the welding operators can be concentrated on the task of adjusting the stick-out and the lateral position of the welding torches in the groove just before starting, and occasionally during welding.

Joint Design in inches

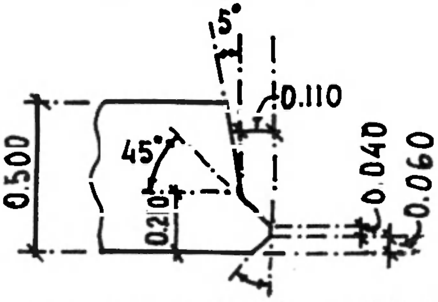

Fig. 2(a) *Joint design for CRC Automatic Welding System*

Operation Sequence

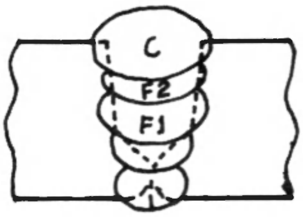

Fig. 2(b) *Joint land abutted*

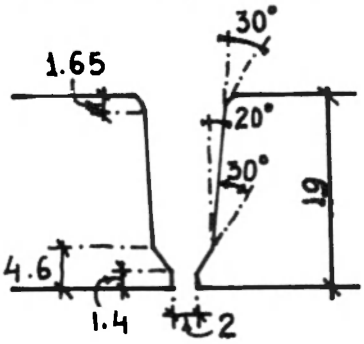

Fig. 3 *Joint design of H.C. Price for 19mm thickness (Dimensions in milimeters*

Dimensions in mm

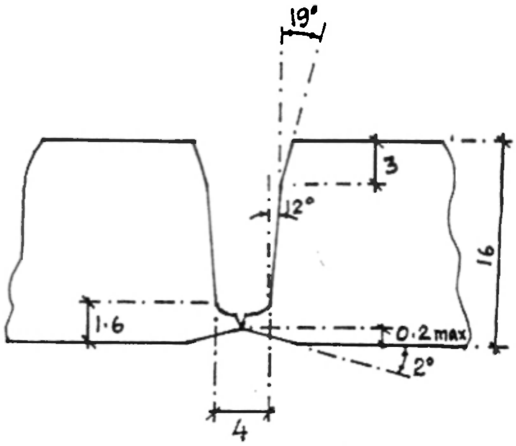

Fig. 4 *The joint design used with Saipem-Arco 'Passo' System*

The bevel configuration used with Saturne system is shown in Figure-5.

Automatic Tig Welding

Automatic Marine Pipeline Welding System-McDermott (USA) selected Gas Tungsten Arc Welding (GTAW) to complete a quality weld on 36in.diameter, 0.625 in. wall pipe in minimum time. The joint design used with the AMPWS does not require a root gap (Fig.6), which greatly simplifies line-up of the two pipe ends at the first welding station. Typical welding parameters for the system are shown in Table-7.

TABLE - 7 Typical Welding Parameters For AMPWS - McDermott

Parameters		Root Pass	Fill Pass	Cap Pass
Travel speed	(ipm)	12	15	11.5
Filler wire speed	(ipm)	110	280	150
Welding current	(amp)	340	500	350
Welding voltage	(volts)	9.4	11.5	11.5
Helium/Argon (%)		75/25	75/25	75/25
Electrode size	(inches)	0.156	0.156	0.156
Electrode type		EWTh-2	EWTh-2	EWTh-2
Filler wire size	(inches)	0.045	0.045	0.045
Filler wire type		E70S-5	E70S-6	E70S-6

5.0 Weldability Of Carbon Steels

The response of a steel to welding thermal cycles and practices encountered during field joining can be loosely defined as weldability. Alternately, a steel that is very resistant to HAZ cracking may still crack in root bead if poor fit up, joint geometry or excessive external stresses are encountered. The risk of cracking in pipeline field welding can be correlated with their primary variables, viz., hydrogen content, microstructure and stress as illustrated in Figure-7.

In turn the magnitude of the importance of the individual factors depends on the interaction of secondary variables.

Dimension in mm

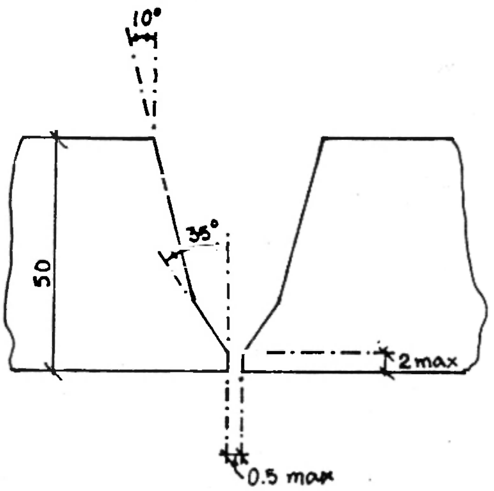

Fig. 5 *The joint design used with Saturne System*

Dimensions in inches

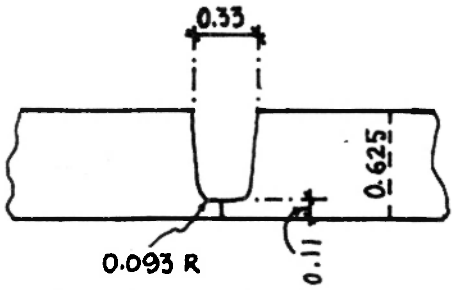

Fig. 6 *The joint design used with the AMPWS does not require a root gap*

Hydrogen

For many years the principal metallurgical problem associated with the field welding of high-strength linepipe was that of hydrogen induced cold cracking.

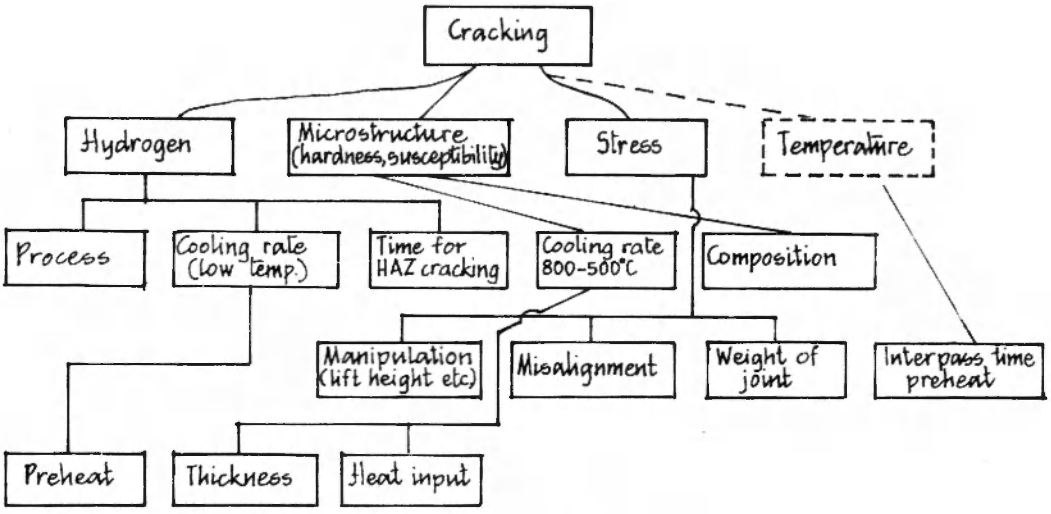

Fig. 7 *Interrelationships between the factors affecting cracking of weldments*

TABLE - 8 Welding Variables And Test Results Of Experiments Of Shiga (see Fig.10)

Pass	Data	Experiment Codes				
	Heads	C	CC	CL	L	LL
Root Pass	Electrode Type	E7010	E7010	E7010	E7010	E7010
	Diam. in.	5/32	5/32	5/32	1/8	1/8
	Welding Condition *	A	A	A	B	B
Hot Pass	Electrode Type	-	E7010	E7016	-	E7016
	Diam. in.	-	-	5/32	5/32	-
	Welding Condition *	-	C	D	-	D
Diffusible Hydrogenml/100g		29.6.	19.9	10.6	2.7	1.1
	Preheat Temp. ^{0}F #		302	284	212	158

* A : 145 A-24 V : 12 in/min : 17.4 kj/in. B: 140 A-25 V : 12 in/min : 17.4 kj/in C : 165 A-24 V : 10 in : 23.8 kj/in.

\# Preheat temp (^{0}F) assuring no root cracking because of the presence of diffusible hydrogen.

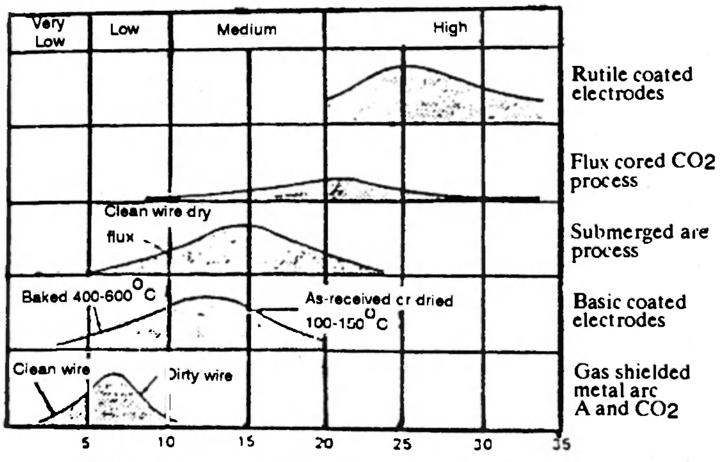

Fig. 8 *Typical range of values of hydrogen content expected for various welding processes & electrodes.*

The extremely high hydrogen potential of the cellulosic electrodes used in the 'stovepipe' technique, the very low heat inputs adopted in the interests of welding speed for the root pass, and the relatively high Carbon Equivalents of many traditional, high strength linepipe steels combined to virtually guarantee cracking problems. Only the strict application of carefully designed and qualified welding procedures, with controlled interpass temperature and, often, the application of appropriate preheat, could ensure a reasonable degree of freedom from this defect.

Typical hydrogen contents of weld metal deposited by the welding electrodes & processes are shown in Fig.8. The cellulosic electrodes commonly used for 'stovepipe' welding give hydrogen levels at the upper end of the range shown (i.e. >35ml/100g of weld metal).

Recently, the gradual introduction of semiautomatic and automatic gas shielded processes, with their much lower hydrogen potential, has to some extent reduced the emphasis on cold cracking, and the development of these techniques has been largely concerned with the elimination of process-related, rather than metallurigical problems. Nevertheless, a large proportion of pipeline laying activities continues to be based on the 'stovepipe' technique. The industry has developed hydrogen control measures and ways of minimizing restraint and external stresses, while the steel industry has developed steels with significantly reduced susceptibility to cold cracking.

Hydrogen Control Measures

Since cracking is related to stress, microstructure, and hydrogen content, care is taken in the field to control one or all of these factors by preheating the pipes and controlling the time lapse between the root pass and the hot pass.

The concentration of diffusible hydrogen is related to the low temperature (< 300° C), cooling rates, and preheat.

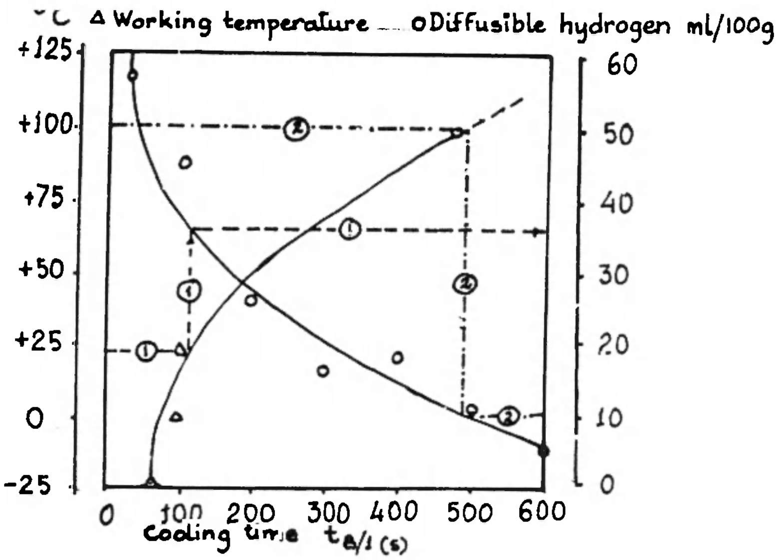

Fig. 9 *Effect of working temperature on cooling rate and hydrogen diffusion welded with cellulosic electrodes*

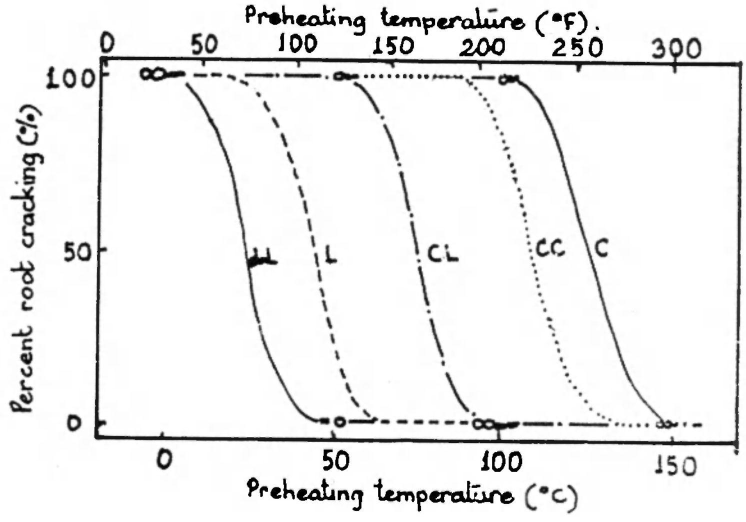

Fig. 10 *Effect of preheat and electrode type on the incidence of root cracking*

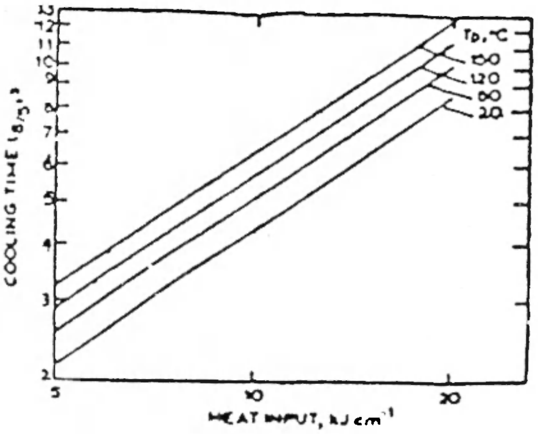

Fig.11 *Cooling time t 8/5 as a function of heat input and preheating temperature*

Duren et. all. have constructed a quantitative diagram, which is reproduced in Fig. 9.

The diagram can be used as follows to illustrate the effects of preheat. Welding undertaken at room temperature (line 1) produces a cooling time of approximately 100s, resulting in approximately 35ml/100g of diffusible hydrogen in the deposited metal.In contrast, the cooling time from 800°C-100°C is increased nearly to 500 sec at a welding temperature of + 100°C and the diffusible hydrogen content drops approximately to 10 ml/100 g. The effectiveness or necessity of preheating depends on the type of electrode used,as shown in Figure-10 and Table -8. The different combinations of electrodes and procedures give

rise to welds of different hardness levels and hydrogen contents. (See Table 8). For welds having the highest hydrogen content (29.6ml/100g) a preheating temperature of 302°F (150°C) was required to reduce root cracking to an acceptable level. This temperature may be required to be even higher when welding pipes with wall thicknesses typical of pumping station construction.

Microstructure

The cooling time between 800-500°C is considered very critical since during this temperature decomposition takes place in the microstructure of weld and HAZ. The hardness is dependent on microstructural constitutents. The cooling time is dependent on factors such as heat input, preheat and thickness of pipe weld.

The relationship between cooling time for 800-500°C, heat input and preheat temperature are given in Figure-11.

[Cooling time t8/5 as a function of heat input and preheating temperature for three dimensional heat flow (bead-on-plate welding with cellulosic electrodes)].

Stresses

The factors affecting stresses acting on a partially completed weld are as follows:

- Manipulation(lift height)
- Misalignment
- Weight of Joint

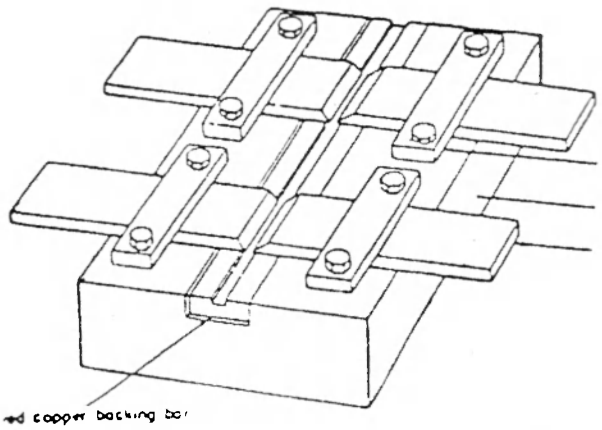

Fig. 12 *Diagram of jig used for restrained butt weld test*

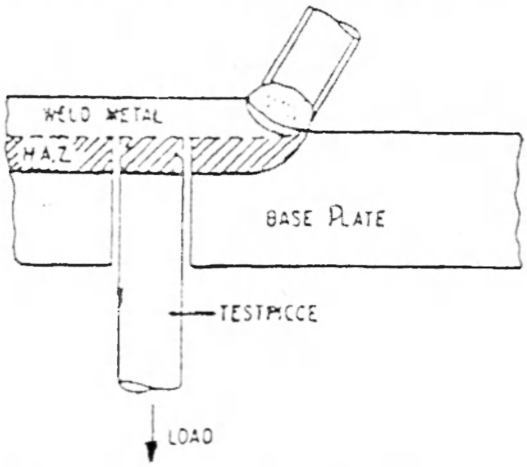

Fig. 13 *Schematic diagram of implant test*

Different steels have variable susceptibilities to cracking. However, probability of cracking for a given applied stress will depend on the interactions between any defects present, the microstructure in question and hydrogen control measures that have been adopted. Also, the different welding processes give rise to characteristic defects having different geometries. For example, semiautomatic GMAW produces much larger bead dimensions than stovepipe welding, thus reducing the ligament stress when movement occurs. However, the presence of 'incomplete fusion' defects could increase the effective stress acting on HAZ and root bead of the weld metalIn general, as welding conditions deteriorate and pipe dimensions increase, there is a considerable increase in the likelihood that high stresses will be inadvertently applied to an incomplete weld. Premature removal of line up clamps or excessive lowering stresses will accentuate the effects of any departure from the welding procedure that have been qualified for given linepipe steel.

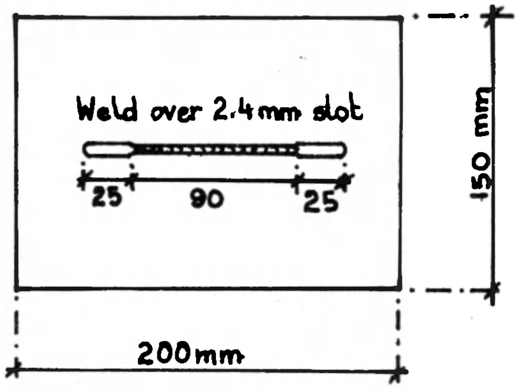

Fig. 14 *Slot weld test specimen design*

Weldability Tests

In the construction of pipelines by the 'stove pipe' technique, the production of girth welds is often accomplished under difficult conditions of weather and terrain, and the use of cellulosic electrode has kept the possibility of cold cracking connected with hydrogen. Further, as the higher strength linepipes, such as X 70 grade, with greater wall thickness are constructed in the Arctic environment, this problem becomes even more serious.

Risk of Cracking

Several kinds of small scale weld cracking tests have been proposed for ranking the susceptibilities of linepipe steels to cold cracking. Examples of the main types of test are :

- Root pass butt weld test (Fig. 12)
- Implant test (Fig. 13)
- Slot weld test (Fig. 14)

The most satisfactory way of assessing the risk of cold cracking is by full scale weldability tests proposed by British Gas Corporation. In this test, full length of pipe, 9m minimum, is welded in the field and the bending moment and shear forces are induced after completion of the root pass by lifting the ends of the fabricated pipe.

Cracking susceptibility index as CE value

For linepipe made from conventional C, Mn, Ni steels, practical experience has shown that the effects of elements present in steel can be satisfactorily summarised by the conventional IIW Carbon Equivalent formula.

$$CE = C + \frac{Mn}{6} + \frac{Ni + Cu}{15} + \frac{Cr + Mo + V}{5} \qquad \text{(IIW)}$$

With changes in linepipe steel composition, effected to lower the carbon and increasing the range of alloy and microalloy additions, the inability of the above formula to

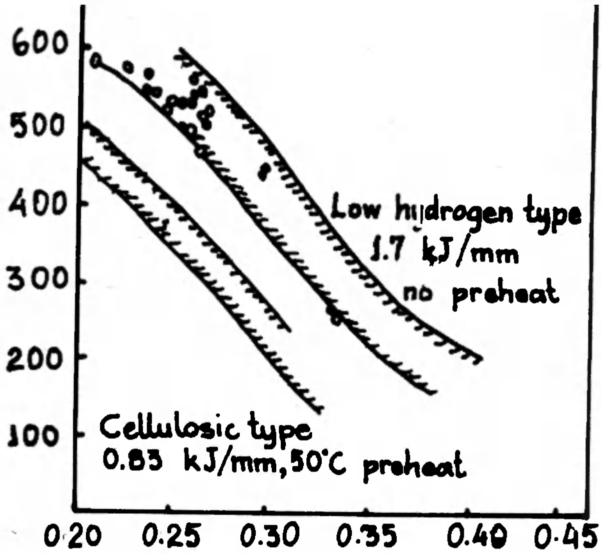

Fig. 15 *Relation of P_{NB} vs. C_{cr}*

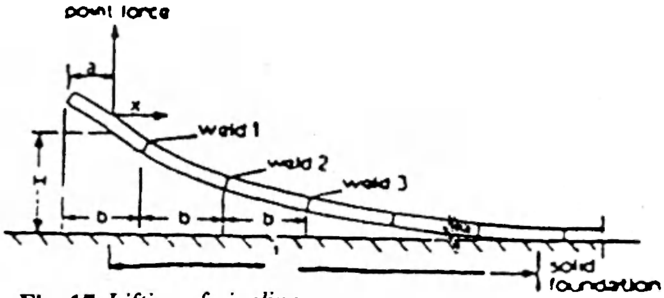

Fig. 17 *Lifting of pipeline*

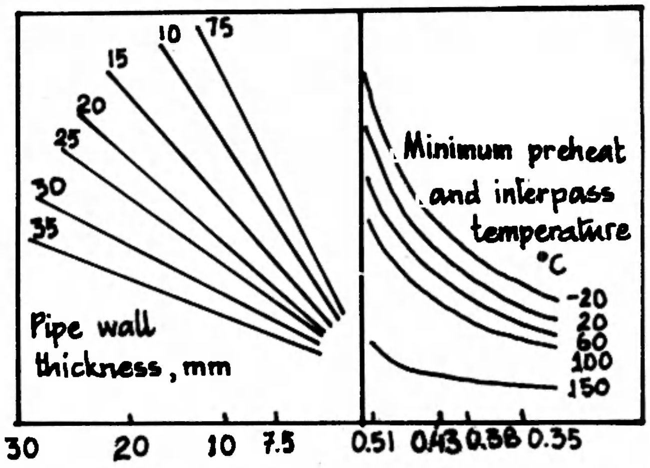

Fig. 16 *Permissible maximum C.E. for butt welds in linepipe using cellulosic electrodes*

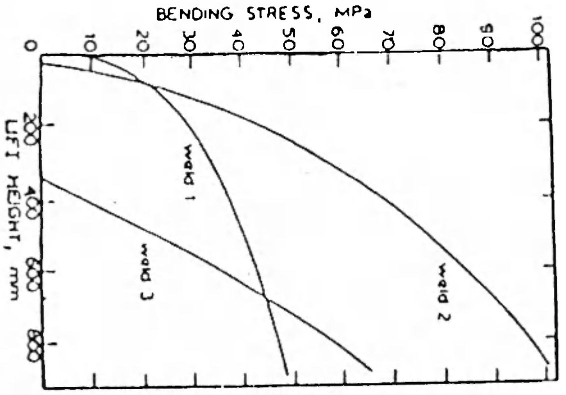

Fig. 18 *Lifting stresses for 18.3 mm lengths of 1219 mm dia. and 13.72 mm wall thickness pipe*

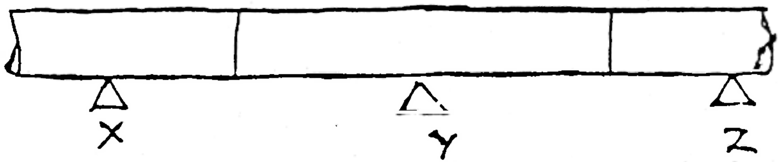

Fig. 19 *Placing of Skids (Skid at point Z too high so that the skid Y is not supporting the pipe)*

accurately rate the risk of cold cracking of such compositions have been pointed out. For the low Carbon high Manganese steels the P_{CM}, i.e.Cracking Parameter, P_{NB} (NKK formula) or CE_{PLS} (Mannesman) have been shown to give a better indication of the relative risks of cracking.

The various formulae proposed for determining the CE Value are listed below :

$$\text{I. } CE = 1000\,C \quad \frac{Mn}{6} + \frac{Cr+Mo}{10} + \frac{Ni}{20} + \frac{Cu}{40} \text{ ...... (Stout)}$$

$$\text{II. } P_{CM} \quad C + \frac{Si}{30} + \frac{Mn+Cu+Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

(Ito and Bessyo)

$$\text{III. } CE_{PLS} = C + \frac{Si}{25} + \frac{Mn+Cu}{16} + \frac{Cr}{20} + \frac{Ni}{60} + \frac{Mo}{40} + \frac{V}{15}$$

(Mannesmann)

$$\text{IV. } P_{NB} = C + \frac{Mn}{10} + \frac{Si+Cr+Mo}{20} + \frac{Cr}{30} \quad \text{(NKK)}$$

When the susceptibilities of linepipe steels are evaluated by the critical rupture stress δC_r from Implant test, it was clear that these were well expressed by P_{NB} values as shown in Figure-15.

Welding Procedures for Avoiding Cracking

Some diagrams to determine welding procedures without field weld cracking have been proposed.

Figure 16, adapted from the work of Cotton and Thomas, shows how a CE(IIW) limit may be used if the welding procedure and wall thickness are selected. The figure, based on field experience and laboratory data, is designed to prevent Vickers hardness of more than 330, which is considered critical threshold for underbead cracking using cellulosic electrodes.

NKK has developed the diagram for predicting preheating temperature if wall thickness, diameter, P_{NB} value, heat input and ambient temperature are given.

Full Scale Weldability Test

Even though inherent weldability of a given pipe composition is suffcient to allow welding without preheat or the welding procedure specifies an adequate level of preheat, cracking can be promoted by inadequate pipe laying procedures. A number of cases can be cited such as

- Release of internal line up clamp and skidding before completion of root bead.
- Excessive pipe misalignment before welding.
- Excessive lift heights
- Employment of delay time exceeding 5 min between root pass and hot pass deposition.

Figure 17 and 18 show the stress introduced in weld for various lift heights.

Although inadequate pipelaying procedures promote girth weld cracking, little information is available defining what can or cannot be tolerated during field welding practice. For example, should some limiting lift height be imposed during skidding operation ? Or, is pipe misalignment (high-low) before welding a contributory or a dominant factor in crack formation ?

A general requirement of pipeline construction is a maximum of 5 min. between completion of the root pass and initiation of the hot pass. However, when welding large diameter (1219 mm) and large wall thickness (13 mm) pipe, hot pass deposition techniques may need to be modified in order to minimize the chances of cracking. For example, even with a three or four-man hot pass crew (as is commonly used for these diameters), 5-6 min may elapse from completion to initiation of the hot pass; it may thus be advisable to complete the critical, overhead position before the remainder of the pipe circumference.

In general, any weld may be subjected to atleast two stress applications, caused by skidding. The first immediately following root bead deposition and the second when the next pipe length is skidded (assuming that second skidding operation lifts the pipe off the previous skid). Generally, these stress applications would be of short duration. However, if the pipe was incorrectly skidded (by employing too high a skid, the pipe joint may be held under load for some time (see Fig. 19). In offshore pipe laying operation, the quantum of laying stress, due to greater angle of pipe profile which are being lowered, are very great and requires much greater care during the operations.

Full Scale Weldability Test Procedures

British gas specification requires that the materials shall be delivered with full scale weldability test procedure of linepipes and fittings. The specification is detailed below.

Weldability testing of linepipe and fittings is carried out on full size components which are selected on the basis of C and Mn contents which are in the upper quarter of the check analysis for the production batch under consideration. In order to introduce a safety margin between test and fieldpractice, the weldability tests are carried out at preheat temperatures significantly below those which will be specified for use in the field. Occasionally, a borderline failure in the weldability test will be accepted, provided the field preheat temperature is increased accordingly.

The weldability test procedures are different for linepipes and fittings, reflecting the different welding procedures used in the field, and are described separately below.

Linepipe Weldability test

Field welding of pipe-to-pipe joints is carried out at a minimum preheat temperature of 50°C, and, therefore, for reason outlined above, the linepipe weldability test is made at an initial temperature of 10°C-20°C. Two pipe lengths, at least 9m long, are welded together using an internal clamp, and standard stovepipe welding procedure, with cellulosic electrodes. The free end of one of the pipe is lifted by 300 mm to 460 mm within 1 min, of completion of the root pass in order to simulate the lowering-off which occurs during pipeline construction. The weld is completed to a strictly controlled procedure and allowed to stand for 24 hours before examination.

Weldability Test of Fittings

Field welding of fitting-to-pipe joints is carried out at a minimum preheat temperature of 150°C and, therefore, the fitting weldability test is carried out at an initial temperature of 70°C, again to maintain conservatism. The fitting and a matching pipe are suitably supported and then welded together using a conventional vertical-up root pass. In this case, no lifting of the joint occurs, the weld being completed using vertical-down welding. Again, the weld is allowed to stand for 24 hours before examination.

Test Acceptance Criteria

The weld is first examined by X-radiography and, in addition, by magnetic particle crack detection after the internal root bead reinforcement has been removed. Subsequently, a minimum of 15 cross-sections are taken from the weld, including any locations shown to be suspect on non-destructive examination. The cross-sections are examined metallographically and are currently aceptable if no internal cracks larger than 1.25 mm in the through-thickness direction and no surface breaking cracks are detected (previously cracking of any type was not allowed). In addition, the maximum hardness in the fitting or pipe HAZ must be less than 330 Hv10.

In addition to the fullscale linepipe weldability test, it would be a sound practice to ask the pipe manufacturer, as a qualification criteria, to conduct field weldability tests on his pipes to show that these pipes are capable of being welded under field conditions. For this purpose, a girth welding would be performed with the lowest possible heat input (approx 1-1.2 KJ/mm for SMAW process).

Whenever the carbon steel pipes are to be used for sour service, the hardness shall be controlled to less than 248 Hv5 as recommended by NACE. In addition, the corrosion tests like SSCC and HIC would be conducted at the welding procedure qualification stage and field weldability testing stage.

6.0 Duplex Stainless Steel

As mentioned already, duplex stainless steels have been developed to combine the best qualities of both austenite and ferrite by having an equal amount of these two phases, in a band type of distribution, in it's quench-annealed condition. Therefore, any fabrication process attempted should ensure that this balance of phases is not upset, for retaining the combination of toughness, strength and corrosion resistance.

On heating, duplex stainless steels show transformation to ferrite at high temperatures with subsequent grain growth, followed by revision to austenite on cooling. Hence, ferrite formation occurs in the heat affected zone around the weld, the extent of transformation depending on the peak temperature and, to a slightly lesser extent, to the heat input and steel composition.

Mechanical Properties and Corrosion Resistance

Any increased ferrite content in the weldment increases the UTS, decreases the ductility and toughness. Also the changes of gamma phase to alpha accompanied by local compositional variation in welds, may result in loss of the corrosion properties as compared with that of the parent metal. Sensitivity to loss of corrosion properties depend on the particular material type and thickness, and on the welding procedures.

Welding Consumables for DSS

A matching composition of the welding consumables will not be suitable, unless the whole pipe could be heat treated. In as-welded condition, as in the case of pipeline welding, the matching composition consumable will result in a weldmetal having an appreciably higher ferrite content than the parent material. Therefore, consumables which are richer in Nickle and Nitrogen compared to the parent material would be required to give higher austenite content. Filler metal for the base material with 5% Ni should have a Nickel content of 7-9%.

General Welding Procedures for DSS Pipelines

Duplex stainless steel show similar fusion characteristics to those of austenitic stainless steels. Therefore, joint preparations and welding procedures used are by and large similar to that of austenitic stainless steel. Other salient points shall be :

- GTAW, SMAW, GMAW and PAW can be used. Pulsing of the current is recommended for root pass when GTAW or GMAW is used.
- Preheating is not needed.
- Maximum interpass temperature shall be 150°C, for avoiding 475°C and sigma phase embrittlement.
- Relatively low heat inputs are recommended. The heat input may be around 12-15 KJ/cm.
- Very high purity Argon gas shall be used for welding and backing. The Oxygen content shall be restricted to less than 10 ppm.
- Moisture pick up by electrode shall be eliminated.
- Post weld heat treatment of pipes shall not be carried out.
- The weldmetal shall have a ferrite content of 30-55%.
- The welding consumables and welding procedures shall be tested and qualified by following a well formulated specification.
- The microstructure and the ferrite content at the weldment shall be closely controlled during production welding.
- The hardness of the weldment shall be restricted to Rc 28.

7.0 Incoloy And Incoloy Clad Carbon Steels

The recently introduced Incoloy 825 and Incoloy 825 clad Carbon steels do not pose much problems except for the location of suitable consumables manufacturer whose product would meet all the specification requirements.

Incoloy 825 shall be welded with a richer filler metal conforming to AWS specification ENiCrMo-3 or ERNiCrMo-3. The process that are likely to be employed are GTAW, SMAW and GMAW.

When Incoloy 825 clad Carbon steel is to be welded for pipelines from outside only,two possibilities exist :

A) The corrosion resistant layer would be welded at the root with ERNiCrMo-3. A second buffer layer of pure iron shall be deposited onto this root weld. Thereafter, the Carbon steel backing material could be welded with a matching Carbon steel filler material.

B) The entire joint can be welded using the filler material conforming to E NiCrMo-3/ER NiCrMo-3.

While the first procedure is expected to be economical compared to the second one, there are some typical problems associated with toughness of an intermediate layer which needs to be taken care of by judicious formulation of the welding procedure. The second procedure is likely to be followed till these problems are solved, even though the second procedure would be costly because of the requirement of huge quantities of Nickel rich filler metal.

8.0 Conclusion

The welding of pipelines for oil industry require a careful consideration. Selection of proper material to meet the service requirements and understanding of the materials' weldability under the extreme conditions of fabrication of pipelines, are absolutely essential requirements for solving problems associated with pipeline welding.

When these precautions are observed and good fabrication practices are followed the defects could be minimized and field welding problems could be reduced to a great extent.

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