WELDING 9% NICKEL STEEL— A REVIEW OF THE CURRENT PRACTICES

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

Nº 1208

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Welding 9% nickel steel - a review of the current practices

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The history and various commercial applications of 9%Ni steel are reviewed. The welding procedures used in shop and field fabrication of 9%Ni steel are presented in detail. Emphasis is on large containers for transportation and storage of LNG. Background information on the development and metallurgy of this material is included.

The mechanical properties and chemical compositions as listed in the specifications of various industrial countries are included. Consideration is given to the allowable design stresses which may be based on either tensile strength or yield strength. Also, the mechanical properties and chemical compositions of some of the welding products used to weld 9%Ni steel are discussed in detail.

The various welding processes that have been used in commercial production of large 9%Ni steel storage tanks are reviewed. The processes covered are manual shielded metal-arc, submerged-arc, and metal inert gas including spray arc, short-circuiting arc, and pulsed spray arc. The excellent weldability of this material is covered including the fact that preheat is neither required nor suggested. Also, in thickness of 50mm and under there is no need for a postweld stress relief.

INTRODUCTION

This Paper reviews the current worldwide practices for welding 9%Ni steel. This nickel alloy steel has excellent toughness and strength at temperatures as low as -196°C. During the last ten to fifteen years 9%Ni steel has been used extensively for containment of various liquefied gases. There has been a growing demand for natural gas for heating homes and office buildings and also for the generation of electric power. Increased need for this clean fuel has created a demand for more and larger storage tanks and recently for ocean-going tankers designed to transport liquefied natural gas (LNG). Most of the land-based storage tanks have been about 47 000m^3 (300 000 barrels) in capacity and storage tanks having a capacity of 159 000m^3 (1 000 000 barrels) are a possibility. Shown in Fig. 1 is a view during construction of a large LNG storage tank. The LNG is normally stored at a maximum pressure of 69 mbar (1psig) and a temperature of -162°C. Increased use of oxygen in steel production has created a need for LOX vessels. Various liquefied industrial gases have been

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stored in 9%Ni steel vessels designed to operate at about 4.1 bar (60psi) and a maximum capacity of about 45 600 litres (12 000 gallons). This type of vessel is commonly known in the USA as a 'customer service unit'.

Prior to discussing details of welding procedure it may be advantageous to review the history and metallurgy of 9%Ni steel.

HISTORY

The 9%Ni steel was developed in 1944 in the product research laboratory of The International Nickel Company Inc., the US subsidiary of The International Nickel Company of Canada Ltd. By 1960 numerous pressure vessels, referred to above as customer service units, had been built for the storage of liquefied gases. In 1960 the first field-erected tank for the storage of LNG was completed. Today there are over seventy field-erected 9%Ni steel LNG storage tanks in service throughout the world, some as large as 94 000m^3 (600 000 barrels). One application, for service other than LNG, is a large fractionating column 36.4mm x 3m dia. (1-7/16in. x 10ft) diameter and 32m (105ft) long operating at 38 bar (550psig) and -196°C.

One of the contributing factors to the worldwide acceptance of this material was 'Operation Cryogenics'.[1] This was a programme to demonstrate the suitability of 9%Ni steel for vessels and other equipment to store, produce, and transport liquefied gases at temperatures as low as -196°C. One of the results of this test programme was approval by the American Society of Mechanical Engineers (ASME) for the use of 9%Ni steel in thicknesses up to 50mm without a postweld stress relief. The results of these tests have been well documented. Since the original qualification tests were conducted the fracture mechanics concepts of toughness have been developed more fully. Hence, today the various fracture mechanics qualification methods require these welds to contain controlled artificial notches to simulate defects. Nonetheless the results of 'Operation Cryogenics' served the industry well and many thousands of tons of 9%Ni steel have been successfully fabricated and placed in service. These vessels and tanks operated without a single failure which could, in any way, be attributed to lack of fracture toughness of the plate or weld metal. Successful field service is being achieved with both double normalised and tempered and quenched and tempered material.

METALLURGY

The presence of 9%Ni confers a considerable degree of hardenability to the steel, as is evident from the general form of the relevant isothermal transformation diagram shown in Fig. 2. A microstructure consisting of low carbon martensite is normally found in plates and sections of this steel when water quenched or cooled in air from the austenitising temperature.[2] The usual heat treatments prior to welding are either:

(a) normalising at 900°C, plus normalising at 790°C followed by 'tempering', preferably at 570°C, or

(b) water quenching from 800°C and tempering as above.

During the tempering treatment a small amount of austenite is re-formed. This phase is stable at subzero temperatures, and is believed to contribute to toughening of the steel.

It is customary to weld this steel in the fully heat treated condition and the thermal effects of fusion welding can be expected to induce changes in microstructure of the steel in the heat-affected zone (HAZ). The composite photomicrograph of Fig. 3 depicts the HAZ obtained by metal-arc welding with INCO-WELD* A Electrode. Adjacent to this weld deposit is the most severely heated and quenched region of the HAZ: the structure is clearly acicular, and different from that of the parent metal which is visible towards the right-hand side of the Figure.

Hardness and impact tests made on these HAZs confirm that changes in structure and properties have occurred. The general form of the property-survey curves is indicated in the two diagrams of Fig. 4. At the left is the curve of hardness change in the HAZ of as-welded steel and, as expected, peak hardening occurs adjacent to the welds. The right-hand diagram illustrates the trend in Charpy V notch impact strength at -196°C as a function of the distance of the test area from the weld interface. The thermal effect from this manual metal-arc weld produced no marked reduction in the impact strength of the steel.

Despite the hardening that occurs in the HAZ, no cracking of the kind termed 'hard zone cracking' or 'underbead cracking' has been encountered in that region. This type of cracking is encountered frequently in the welding of low alloy structural steels containing more than 0.15%C. The precautions to be

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Table 1 Plate specifications and chemical compositions, wt%

Country	Code or specification	C, max.	Si	Mn	Ni	S, max.	P, max.
Belgium	NBN 630-70 10Ni 36	0. 10	0. 15-0. 35	1. 00 max.	8. 50-9. 50	0. 030	0. 030
France	NFA 36-208 9Ni (1966)	0. 10	0. 15-0. 30	0. 8 max.	8. 5-9. 5	0. 030	0. 030
German Federal Republic	VDEh 680 X8 Ni 9	0. 10	0. 10-0. 35	0. 30-0. 80	8. 0-10. 0	0. 035	0. 035
Italy	UNI 5920-66 X10 Ni 9	0. 10	0. 15-0. 30	0. 90 max.	8. 50-9. 50	0. 035	0. 035
Japan	ASTM A 353-70						
	ASTM A 553-70 Grade A or	0. 13	0. 15-0. 30	0. 90 max.	8. 50-9. 50	0. 040	0. 035
	NV 20-2	0. 08	0. 15-0. 35	0. 40-0. 70	9. 00 min	0. 025	0. 020
Norway	DnV (1971) NV 20-2	0. 08	0. 15-0. 35	0. 40-0. 70	9. 00 min	0. 025	0. 020
UK	BS 1501-509	0. 10	0. 10-0. 30	0. 30-0. 80	8. 75-9. 75	0. 030	0. 025
USA	ASTM A353-70						
	ASTM A553-70 Grade A	0. 13	0. 15-0. 30	0. 90 max.	8. 50-9. 50	0. 040	0. 035

Table 2 Plate specifications and mechanical properties

Condition and property	UK BS 1501:1970		Belgium, NBN 630-70 10Ni 36	France, AFNOR NFA36-208680-70 (1966) 9Ni	Germany, VDEh X8 Ni 9		Italy, UNI 5920-66 X10 Ni 9	Japan	Norway, DnV NV 20-2 (1971)	USA, ASTM	
	509	510								A353-70	A553-70 Grade A
Condition	NNT or QT	QT	-	-	NNT or QT		NNT or QT		-	NNT	QT
Thickness, mm			16-40	30-50							
Tensile properties at 20°C											
Yield stress, min											
10^3lbf/in^2	76	85	77	85	71		71		64	75*	85*
kgf/mm^2	54⌿	60⌿	54	60	50*		50*		45*	53	60
N/mm^2	530	590	529*	588*	490		490		440	520	590
Tensile strength,											
10^3lbf/in^2	100	100	92-121	99	93-120		100-120		93	100-120*	100-120*
N/mm^2	690	690	637-833*	686*	640-830		690-830	See US ASTM A353-70 A553-70 or Norway DnV NV 20-2	640	690-830	690-830
kgf/mm^2	71⌿	71⌿	65-85	70	65-85*		70-85*		65*	70-84	70-84
Minimum elongation, %	18[a]	18[a]	17[c]	19[a]	17[b]		19[a]		20[a]	20[b]	20[b]
Reduction of area, %	-	-	-	-	50		-		50	-	-
Impact resistance											
Longitudinal *											
Type of test	Charpy V	Charpy V	Charpy V	Charpy V	DVM		Charpy V		Charpy V	Charpy V	Charpy V
Temperature, °C	-196	-196	-196	-196	-195		-196		-185	-196	-196
					e	f					
Minimum impact energy, J	34	34	39*	48	24	41	34		34	-	-
daJ/cm^2	-	-	-	6*	-	-	-		-	-	-
kgf m	-	-	4	-	-	-	-		3.5*	-	-
kgf m/cm^2	4.3	4.3	-	-	3.5	6*	4.3*		-	-	-
ft lbf	25*	25*	29	35	21	30	25		25	-	-
Lateral expansion, mm	-	-	-	-	-	-	-		-	0.38	0.38

a - 5.65 S_o

b - 51mm

c - average of three tests

d - 0.2% proof stress

e - transverse

f - longitudinal

* specified value

⌿ specified value originally quoted in tonf/in^2

Table 3 Allowable design stresses.

API 620, Appendix Q	
218N/mm^2 (31 700psi)	
ASME, Section VIII, Div. 1.	
172N/mm^2 (25 000psi) *	
163N/mm^2 (23 700psi)	
ASME, Code 1499	
172N/mm^2 (25 000psi)	

* This value is for unwelded parent metal: all others are for weldments.

taken in welding steels susceptible to this kind of cracking are well known, including preheating, and the use of low hydrogen electrodes, appropriately dried, to ensure low hydrogen contents in the weld zone. Experience with 9%Ni steel in sections up to 50mm thick indicates that this steel does not require preheating.

PARENT MATERIALS

The 9%Ni steel is available commercially either double normalised and tempered or quenched and tempered. It is produced in most industrial countries. The chemical compositions as required by the codes or specifications of various countries are listed in Table 1. The mechanical properties listed in these same codes or specifications are shown in Table 2.

DESIGN STRESSES

Pressure vessels and storage tanks for service in the USA are designed to the requirements of ASME or the American Petroleum Institute. Although these Codes are recognised throughout the world there are also specific National Codes which may take precedence in given cases. Table 3 shows the allowable design stresses used in the USA. The value of 172N/mm^2 (25 000psi) is based on 100% joint efficiency; the other values were developed some years ago based on the use of a 95% joint efficiency. Today it is technically feasible to develop full tensile strength in the weldment and this will be covered in further detail when filler metals are discussed.

In Europe the design stresses permitted depend not only on the appropriate code, but also on the specific requirements of the eventual owner of the installation and the inspection authority. In general terms design stresses are based on a fraction of the yield strength of the weld zone. Design stresses as high as 289N/mm^2 (42 000psi) have been proposed.

WELDING

One of the most important steps in the fabrication of any pressure vessel or storage tank is welding. Whether for cryogenic or other service a complete welding procedure should be developed before actual work is started. It is important to consider the preparation of the parent material, positions involved, best welding process or processes, selection of filler metals, preheat and postweld heat treatments. As stated previously, preheat and postweld heat treatments are not required when fabricating 9%Ni steel in thicknesses up to 50mm.

Preparation of parent material

General cutting operations and weld joint preparations can be performed using the same processes utilised on carbon and low alloy steels. Flame cutting has been successfully employed for general cutting and to shape the edges of plates for butt joints. Usually, a 70^o included angle with about a 3mm land has been used.

Standard oxyacetylene equipment is suitable for use on 9%Ni steel. The quantities and pressures of oxygen and acetylene are similar to those recommended for mild steel, although the cutting speed for nickel steel is somewhat slower. Examples of cutting conditions employed are shown in Table 4. In Europe oxypropane cutting has been satisfactorily used for 9%Ni steel plate, and hardness in the HAZ did not exceed 250VPN. Clearly propane can be considered as an alternative fuel gas, if the cutting equipment appropriate for the oxypropane process is employed.

It has been observed that a very shallow layer of overheated steel is present after flame cutting which is normally removed by the grinding operation. This grinding operation also removes surface oxides which might contribute to formation of porosity in subsequent weld deposits. Bend tests on the flame cut face have shown no loss of ductility in that region or in the layers immediately behind the cut face, despite slight hardening in the HAZ. Typical hardness surveys for gas cut sheet and plate, before and after welding, are shown in Fig. 5. The thermal effects of welding superimposed on those of the gas cutting operation are apparently not harmful. Laboratory examination of these overlapping zones indicated no weakness nor are any

Table 4 Flame cutting 9%Ni steel

Thickness of plate, mm (in.)	Diameter of cutting nozzle, mm (in.)	Acetylene pressure, g/cm^2 (psi)	Oxygen pressure, g/cm^2 (psi)	Cutting speed, m/hr (ft/hr)
3.2 (1/8)	1.6 (1/16)	211 (3)	1406 (20)	> 19.8 (65)
15.9 (5/8)	1.6 (1/16)	211 (3)	1757 (25)	19.8 (65)

undesirable metallurgical structures present.

Filler metals

When it comes to a discussion of filler metals the choice is almost as complex as the selection of the welding process. However, it is desirable to list all the filler metals that have been used in the construction of commercial cryogenic tanks and vessels made of 9%Ni steel. In Tables 5 and 6 the filler metals for manual shielded metal-arc, inert gas metal-arc, and submerged-arc welding are listed. Only materials used in actual construction have been included.

When the vessels for 'Operation Cryogenics' were built the INCO-WELD A Electrode was the most suitable. The toughness of the weld metal was excellent but the tensile strength was slightly lower than that of the parent plate. Recently, INCONEL* Welding Electrode 112 was developed[3] and weldments made with this product developed 100% joint efficiency, based on tensile strength of the parent metal. INCONEL* Welding Electrode 182, due to slightly better operating characteristics for positional welding, was used in some cases where overhead welding was necessary.

Under some codes allowable design stress may be based on yield strength rather than tensile strength. In such cases the fabricator should select one of the welding products which develop high yield strength. As a general guide mechanical properties of some products used for welding 9%Ni steel are listed in Table 7. It is important to note that the data were obtained from various sources, hence direct comparison may not be valid. Testplate thickness, electrode or wire diameter, joint preparation, and test specimen are a few of the variables that could affect the results.

When discussing the properties to be obtained in weldments made using bare wire it is necessary to consider the shielding gas or submerged-arc flux used. The INCONEL Filler Metal 92, or one of the other wires listed in Table 6, used with the metal inert gas (MIG) welding process, utilising spray arc, short-circuiting arc, or pulsed spray arc, in all cases develop 95% joint efficiency, based on tensile strength of the parent metal. When it is desirable to develop full strength of the plate in the weldment, the INCONEL Filler Metal 625 or ChroMET*6 should be used. Most of these wires can be used for submerged-arc welding with commercially available submerged-arc fluxes. Again, the INCONEL Filler Metal 625 and ChroMET 6 will develop 100% joint efficiency, based on tensile strength of the parent metal.

WELDING PROCESSES

9%Ni steel has been welded using most of the commercially available processes, but in this Paper only those which have been widely used in commercial production will be considered. These processes include: manual shielded metal-arc, MIG including pulsed spray arc, short-circuiting arc, and submerged-arc.

Manual shielded metal-arc

When considering manual shielded metal-arc most of the work has been done using a high nickel filler metal. The high nickel welding electrodes are not deep penetrating nor does the weld metal flow, or wash, the walls of the joint as readily as ferritic weld metals. This does not mean that welding with these electrodes is difficult, only that it is different. Once the welder is advised of this difference and allowed to familiarise himself with it, he should have no problem welding 9%Ni steel.

The root run of a butt weld or of a fillet weld is the most critical to produce because weld metal cracking may be encountered unless certain precautions are taken. Completely satisfactory results can be obtained by using a 3mm diameter electrode and a moderate welding current. Only slight weave should be used, in conjunction with a fairly rapid forward speed of

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Table 5 Coated electrodes — nominal chemical composition, wt%

Electrode	Ni	Cr	Mo	Mn	Fe	C	Nb	Ti	W
Inco-Weld* A Electrode	70.0	15.0	1.5	2.0	9.0	0.03	2.0		
Inco-Weld* B Electrode	70.0	15.0	2.5	2.5	9.0	0.13	2.5		
Inconel* Welding Electrode 182	67.0	14.0		7.75	7.50	0.05	1.75	0.40	
Inconel* Welding Electrode 112	61.0	21.5	9.0	0.3	4.0	0.05	3.6		
Nyloid• 2	65.0	13.0	6.0	3.0	Bal	0.08	1.2		1.2
Nicrexø 9	52.0	13.0	5.5	1.5	Bal	0.09	0.8		0.8
OK 69.45x	12.5	16.0		7.5	Bal	0.20			3.5
Grinox T-Skola≠	13.0	17.0		9.0	60	0.25			3.5
Yawata+ Weld B	70.0	15.0	2.0	9.0	0.03	0.03			3.0
Yawata+ Weld B (M)	68.5	15.4	2.13	2.0	9.55	0.08	2.26		4.0
Cryo-Therm/ 60	51.0	10.0	2.50	2.70	Bal	0.17	1.30		

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• Trademark of the British Oxygen Company
ø Trademark of Murex Welding Processes Ltd
x Trademark of ESAB
≠ Trademark of Messer Griesheim
\+ Trademark of Nippon Steel Corp.
/ Trademark of Champion Industries, Inc.

Table 6 Filler wire - nominal chemical analysis, wt%

Filler wire	Ni	Cr	Mo	Fe	C	Mn	Nb	Ti
Inconel* Filler Metal 92	71.0	16.4		6.60	0.03	2.30		3.2
Inconel* Filler Metal 82	72.0	20.0		1.00	0.02	3.00	2.5	0.55
Inconel* Filler Metal 625	61.0	21.5	9.0	2.5	0.05	0.25	3.65	0.2
ChroMET + 6	68.0	20.0	9.00	10.0	0.06		3.0	
Chromenar #	67.0 max.	20.0		1.00	0.04 max.	3.0	2.50	0.50

Notes: 1 - most of these wires can be used in MIG and submerged-arc welding processes.
2 - some of the submerged-arc fluxes and Incoflux* 4, Linconweld ø 880, and Arcosite # N82H.

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\# Trademark of Arcos Corporation.

Table 7 Typical mechanical properties

Electrodes or filler wires	All weld metal: 0.2% PS, N/mm² / 10³lbf/in²	All weld metal: TS, N/mm² / 10³lbf/in²	All weld metal: Elong., %	All weld metal: CVN-196°C J / ft lbf	Transverse 9%Ni steel weldments: TS, N/mm² / 10³lbf/in²	Transverse 9%Ni steel weldments: Elong., %	Transverse 9%Ni steel weldments: CVN-196°C J / ft lbf
Inco-Weld A Electrode	370 53	620 90	30	68-81 50-60	700 101	28	68-81 50-60
Inco-Weld B Electrode	455 66	745 108	32	60 44			
Inconel Welding Electrode 182	340 50	590 85	30	68-81 50-60	700 101	28	68-81 50-60
Inconel Welding Electrode 112	510 74	790 115	36	64 47	790 115		64 47
Nyloid 2	430 62.5	660 96	35	34 25	695 100.8	15	45 33
Nicrex 9	420 61	660 95	35	54-75 40-55	740 108	15	73 54
OK 69.45	440 64	590 85	40	56 41	830 120	7.5	56 41
Grinox T-Skola	490 71	590-720 85-105	30	27 20	740 108	26	56 41
Yawata Weld B (M)	417 60	690 100	44	71 52			
Cryo-Therm 60	461 67	675 98	29	46-64 34-47	740 107	27	
Inconel Filler Metal 625 MIG-Pulsed Spray	540 79	820 119	29	73 54	770 112		
Sub Arc-Incoflux 4	460 66	770 111	32		750 109		
Inconel Filler Metal 92 MIG-Pulsed Spray	450 65	720 105	39		870 126		
Inconel Filler Metal 82 Sub Arc-Incoflux 4	380 55	670 97	39	109 80.5	700 101		
Chromenar 382 MIG-Spray	390 57	620 90	55		680 98		
Sub Arc-Arcosite N82H	370 53	590 85	50		660 95		

electrode travel, to restrict the size of the weld bead. At the end of the root bead, the welding arc should not be broken abruptly; such a break would cause a deep crater and cracking which may spread from this crater into the hot weld metal. It is preferable to lead the electrode to the side of the joint, accelerating the rate of movement to reduce the size of the weld pool. The manner in which the restrike is made will have a significant influence on the soundness of the weld. A reverse or 'T' restrike is recommended. The arc should be struck at the leading edge of the crater and carried back to the extreme rear of the crater at a normal drag-bead speed. The direction is then reversed, weaving started, and the weld continued. This restrike method has three advantages:

1 the correct arc length can be established away from the unwelded joint

2 some preheat is applied to the cold crater

3 the first drops of quenched or rapidly cooled weld metal are placed where they then can be remelted to minimise porosity.

Metal inert gas welding (MIG)

The inert gas metal-arc welding process, spray transfer, has been used to weld 9%Ni steel mainly in the shop on customer service units. It has an advantage over coated electrodes in that it can be used in a semi-automatic or automatic operation. Usually the wire is 1. 6mm in diameter and pure argon gas is the shielding medium. Owing to the relatively high heat input, typical welding conditions being 27-32V and 250-300A with 1. 6mm diameter wire, the weld pool is large and fluid making the technique best suited for use in the flat position. In these circumstances it is capable of being fully automated with the associated economic benefits.

Over the last ten years two variations of this process have been introduced: short-circuiting arc and pulsed spray arc. Both of these processes can be used for vertical, overhead, and horizontal welding. The pulsed spray arc has found the greater acceptance and now is used extensively on the vertical seams of large LNG tanks.

Short-circuiting arc technique

Typical welding conditions for this technique would be 19-23V and 100-180A with a 0. 8mm diameter high nickel filler wire, and argon-helium shielding gas mixture. The low heat input associated with this process results in a weld pool which solidifies rapidly and thus makes the technique admirably suitable for welding in the vertical and overhead positions. Another important use of this technique is for the control of weld bead penetration in root passes in any position. Thus the welder has a means for accommodating variations in the root gap.

Although in some materials lack of side-wall and interrun fusion has been a problem using the short-circuiting arc technique, this is not considered to be serious with 9%Ni steel. It is advantageous to restrict its root passes, and the use of the correct welding conditions and techniques is imperative.

Pulsed spray technique

This process has been in production use on 9%Ni steel for several years. It has been found to be extremely versatile, combining some of the advantages of the short-arc technique, e. g. positional capability, with those of the spray transfer technique, e. g. higher heat input and lower susceptibility to lack of fusion defects.

In laboratory work conducted at the European Research and Technical Development Centre of Inco and subsequently confirmed by experience in several locations in the field, selection of the correct power source characteristic has proved critical. In general it has been found that establishing suitable conditions is more difficult with power sources supplying constant voltage background than with those of a drooping voltage characteristic. This is thought to be caused by collapse of the constant background voltage with a certain critical peak pulse voltage. With the drooping characteristic background, sufficient recovery voltage is available to maintain a low current arc. In pulsed spray arc welding, as with other MIG techniques, Ni-Cr alloy filler wires such as INCONEL* Filler Metal 82 or 92 are generally used. These wires are of a higher electrical resistance than those used for carbon and low alloy steels and for this reason the stickout and contact point can be more critical. However, the melting point of these filler metals is lower than that of the steel and good fusion without deep penetration is obtained. From the metallurgical viewpoint this is advantageous as it limits the propensity to hot cracking Optimum welding conditions can be set by

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initially establishing a short-circuiting droplet arc and then introducing the superimposed pulse until the correct arc length is established. Correct conditions are indicated by a bright weld bead with minimum amounts of surface oxidation. Typical conditions established in the laboratory are shown in Table 8.

The technique has been used for the field erection of large, land-based LNG storage tanks and for a large part of the fabrication of 33m (109ft) diameter shipboard spheres for LNG tankers.

Submerged-arc welding

This process has been used in the shop fabrication of vessels for many years and more recently has been used successfully for the horizontal seams of land-based LNG storage tanks. The horizontal seams in a 46 000m^3 (290 000 barrels) tank were welded using the INCONEL Filler Metal 625 and Lincolnweld* 880 neutral flux. These seams were fully radiographed and found to be satisfactory in every respect.

Two tanks have been completed in Italy and the successful experience has been well documented by Rosa and Bove.[4] The submerged-arc process has been used extensively for welding 25.4mm thick 9%Ni steel petal assemblies for LNG spherical tanks on ocean-going vessels.

Recently, there has been interest in two-pass submerged-arc welding of 9%Ni steel, in the flat position. The results of preliminary work are shown in Fig. 6. The parameters used are listed in Table 9. Since this was a feasibility study, mechanical properties were not determined and it is suggested that other wire-flux combinations should also be investigated.

Preheat

There is no need to preheat 9%Ni steel for welding, arc gouging or cutting with ocyacetylene or similar

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Table 8 Typical pulsed arc welding conditions

Plate thickness, mm	Position	Preparation	Background Volts	Pulse Volts peak 50pps	Average Amps. (approx.)	Wire feed speed, (approx.) m/mm (in./min)
12	Flat	Single bevel 60° incl.	22-24	70-75	120	3.810 (150)
12	Vertical	Single bevel 70° incl.	Constant current	70-75	95	3.175 (125)
30	Flat	Double bevel 60° incl.	22-24	75-80	115	3.810 (150)
30	Vertical	Double bevel 70° incl.	Constant current	75-80	105	3.810 (150)

NOTE : Pure argon shielding gas - wire diameter 1.2mm. Conditions quoted are applicable to the power source used for the welding trials. Meter readings may vary with other types of machine, necessitating 'tuning' of the arc.

Table 9 Submerged-arc welding conditions[1] used to produce welds illustrated in Fig. 6

	Plate thickness, mm	Preparation	Wire dia., mm	Wire type	A	V	Travel speed, mm/min (in./min)	Comment
Weld 1	12	Single V 60^o butt 3.32 root face	2.4	Inconel type[2]	300 300	30 30	305 (12) 305 (12)	
Weld 2	12	Single V 60^o butt	1.6	Inconel type	Root 200 2nd 280 Back 280	30 30 30	508 (20) 254 (10) 508 (20)	Back chipped
Weld 3	6	Square edge (1.5mm) gap	1.6	Inconel type	(1) 280 (2) 280	30 30	762 (30) 762 (30)	No back chip
Weld 4	12 to 6	T fillet standing	2.4	Inconel type	300	30	762 (30) both sides	

NOTES: 1 - Preliminary results
2 - Inconel 82 was used in these trials but settings should be suitable for other Inconel type fillers. Inco Flux 6 in all cases.

heat-producing processes.

Magnetic effects

Although magnetic arc blow created difficulties in the construction of some earlier vessels and tanks built using 9%Ni steel, today it is seldom a problem. A combination of processing at the steel mill and handling in the field to avoid unnecessarily induced magnetic fields is now almost universal. These precautions include principally the avoidance of magnetic handling, demagnetisation, and quality control checks to ensure that the remnant fields are below 50 Oersted. If magnetic arc blow is encountered during fabrication, this condition can be overcome by using one of the recently developed nickel alloy electrodes which are designed to operate on AC rather than DC currents.

Two factors are worth recording here. Firstly, it is possible to demagnetise the weld zone of plates which are giving magnetic blow problems by using a 'Growler' or a coil of welding cable attached to an AC welding transformer. The second is related to the apparent neutralising effect of using AC coated welding electrodes. Suitable AC welding electrodes, e.g. Nyloid 2, INCO-WELD B Electrode, and Yawata B have been developed which effectively overcome magnetic arc blow and have been used successfully in the field.

Difficulty was recently encountered while making submerged-arc welds in the horizontal position because of a measured field strength of 150-200 Oersteds. To deposit a satisfactory root pass AC welding electrodes were used, and subsequent field strength measurements indicated that the magnetic field had been almost completely eliminated. Then it was possible to deposit the remainder of the weld using the submerged-arc technique without difficulty.

Postweld heat treatments

Based on the tests conducted in 'Operation Cryogenics' it was determined that postweld stress relief of

9%Ni steel was not required. This position is supported by the major code regulatory groups which state that postweld heat treatment is not required for material 50mm or less in thickness.

SUMMARY

The available information on welding 9%Ni steel for cryogenic service has been reviewed. Emphasis was placed on the welding processes and products being used in commercial practice. It has been demonstrated that this material can be readily welded using shielded metal-arc, metal inert gas, including short-circuiting arc and pulsed spray arc, and also submerged-arc processes. A large variety of filler metals is available, the majority of which are nickel-base alloys. Such filler metals ensure excellent toughness at temperatures well below that of LNG. Recently developed filler metals readily match the tensile strength of the parent material. These filler metals require different techniques from ferritic filler metals but are not difficult to use.

The parent metal does not require preheat which is frequently necessary with alloy steels to prevent HAZ cracking. Cutting and weld joint preparation can be done using oxyacetylene and similar processes without adverse effects. There is no need for postweld stress relief in thicknesses up to and including 50mm.

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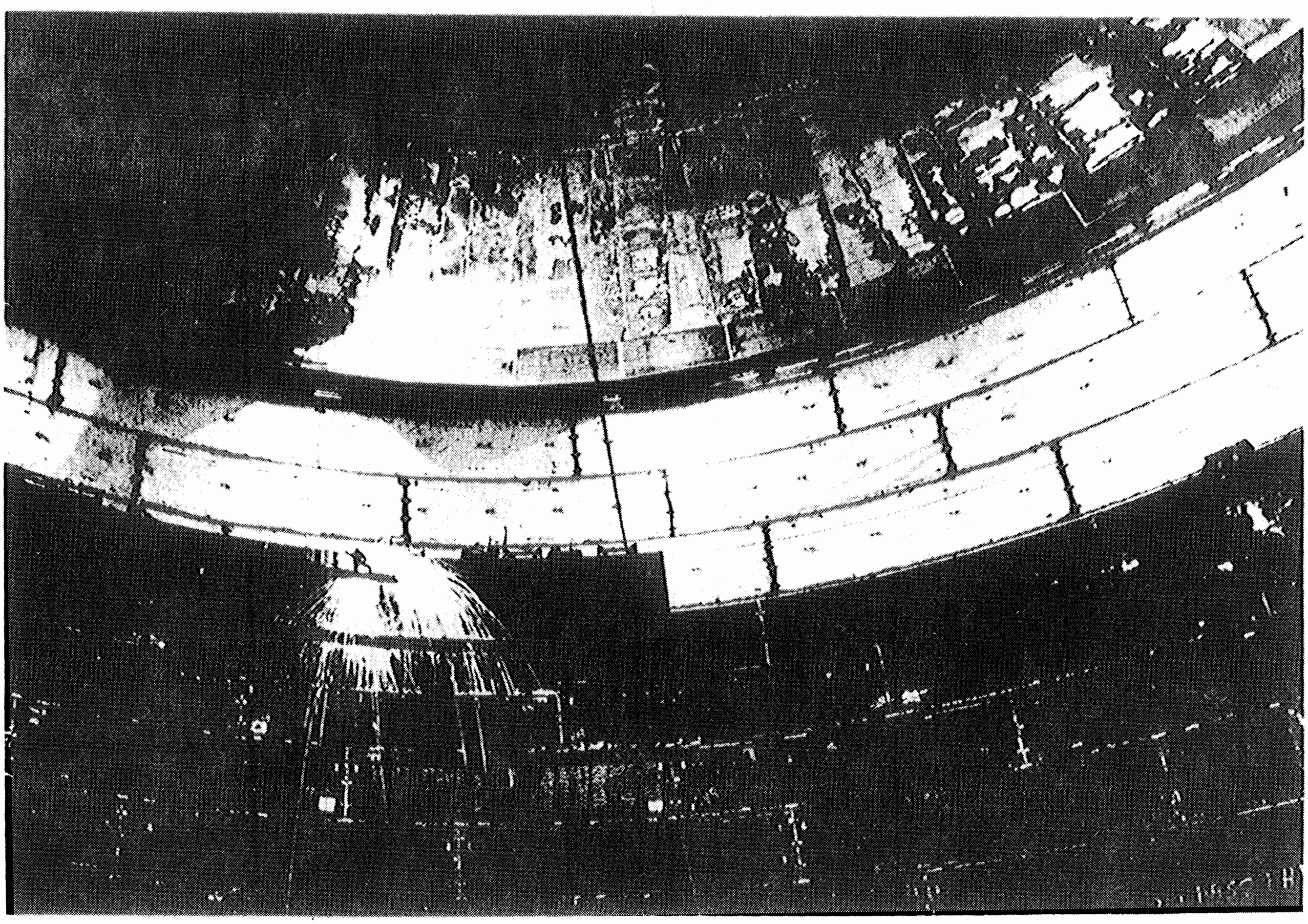
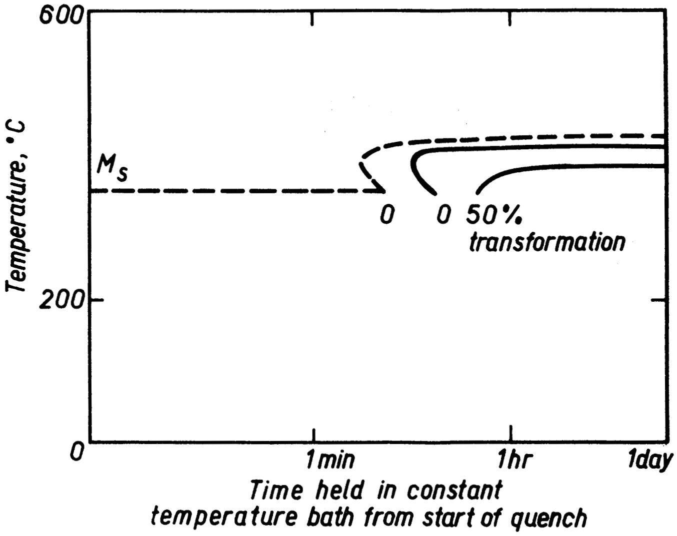
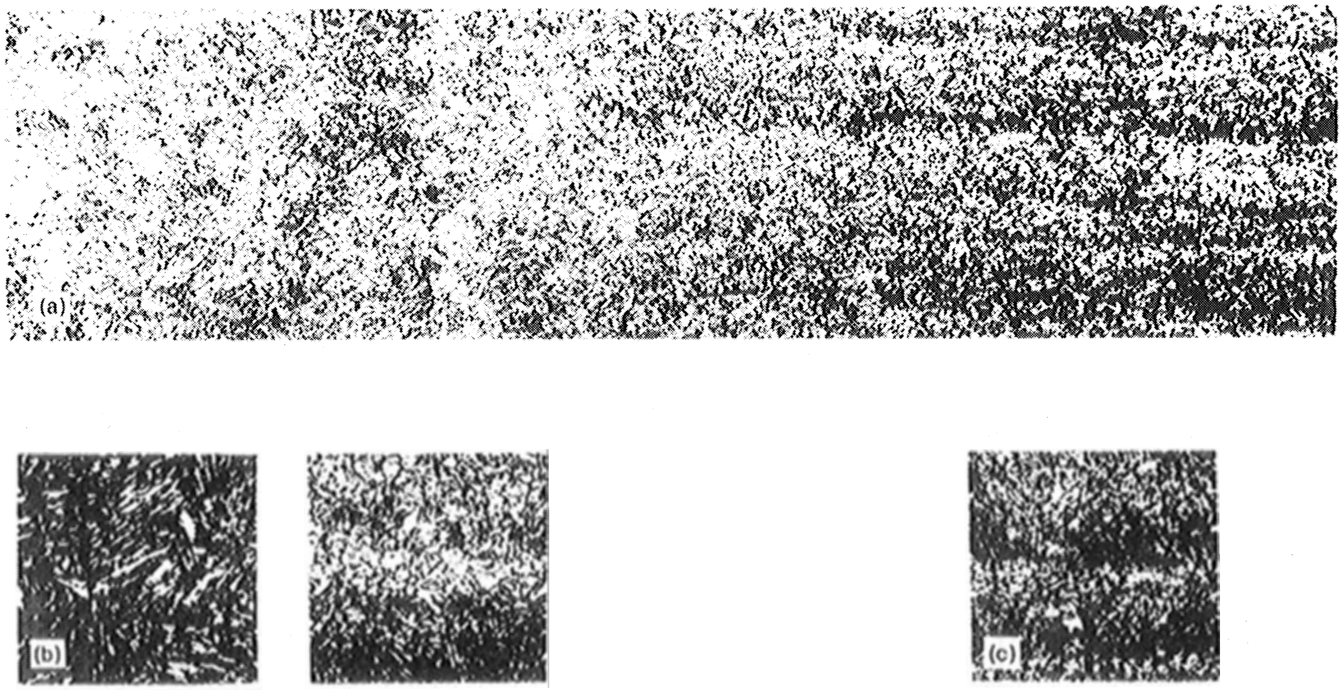
4 ROSA, G.F. and BOVE, O. 'Automatic welding of 9% nickel steel plate for large LNG storage tanks'. Weld. and Metal Fab., 41 (2), 1973, 62-5.



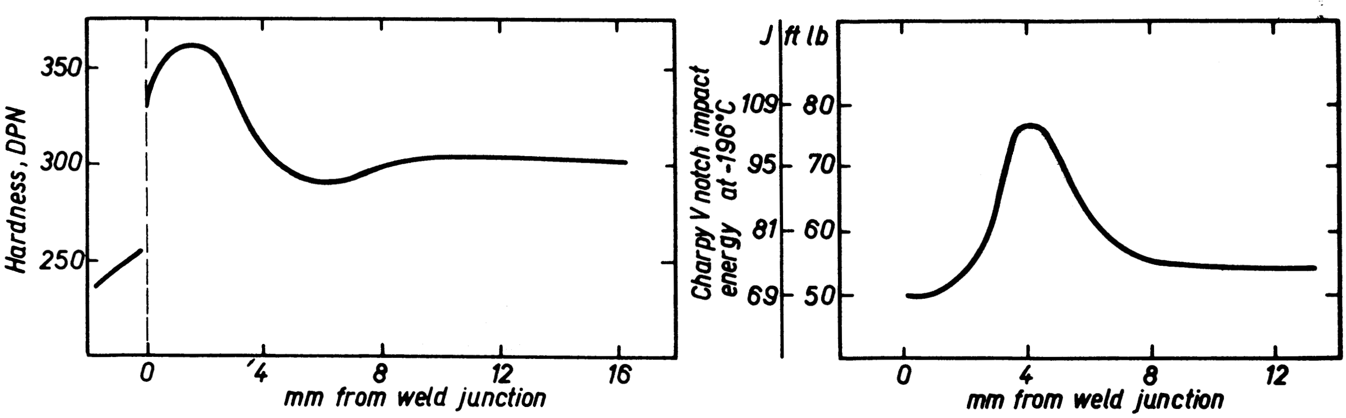
1 Internal view of large LNG storage tank



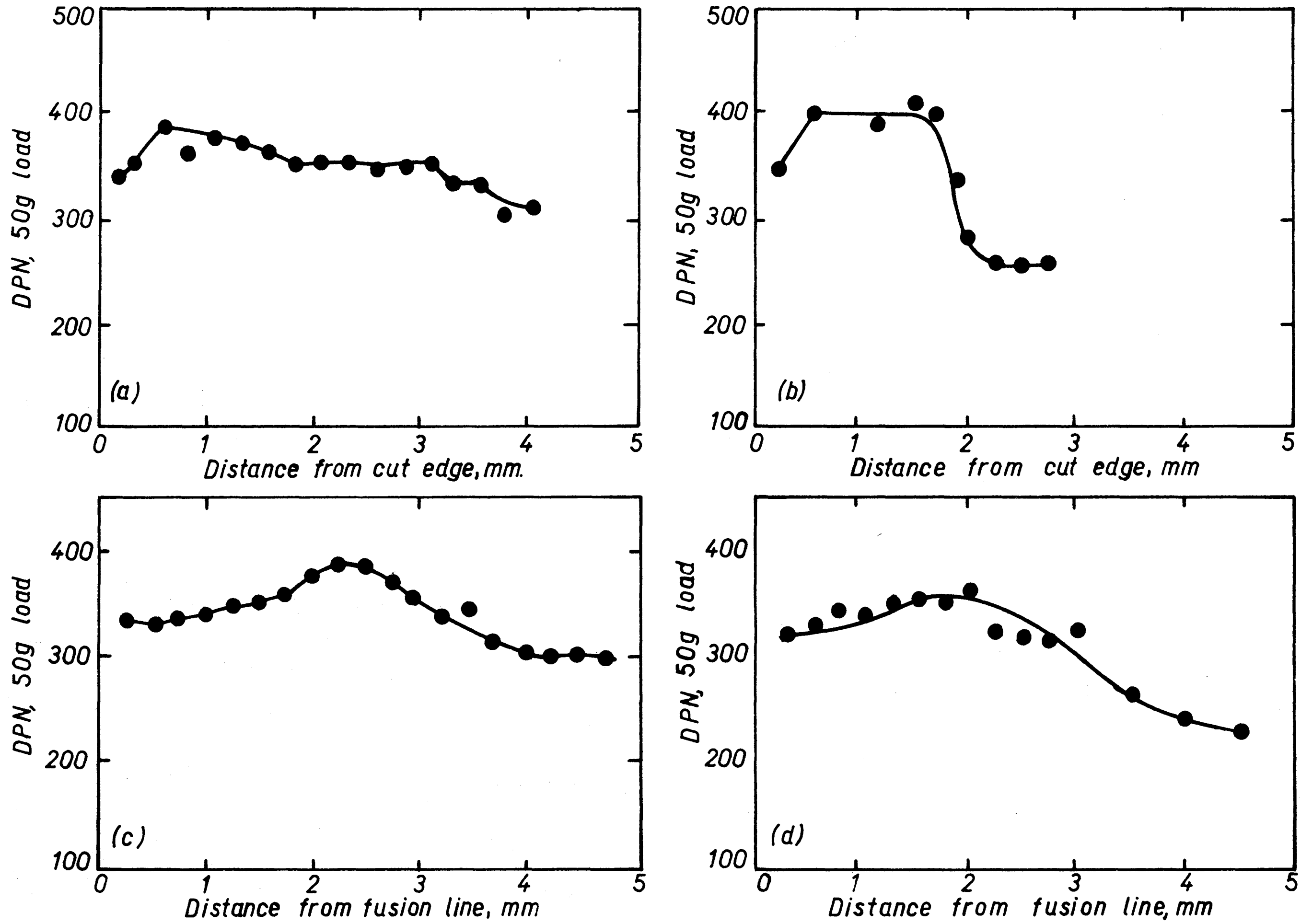
2 Isothermal transformation diagram for low carbon 9%Ni steel austenitised at 900°C (general form)



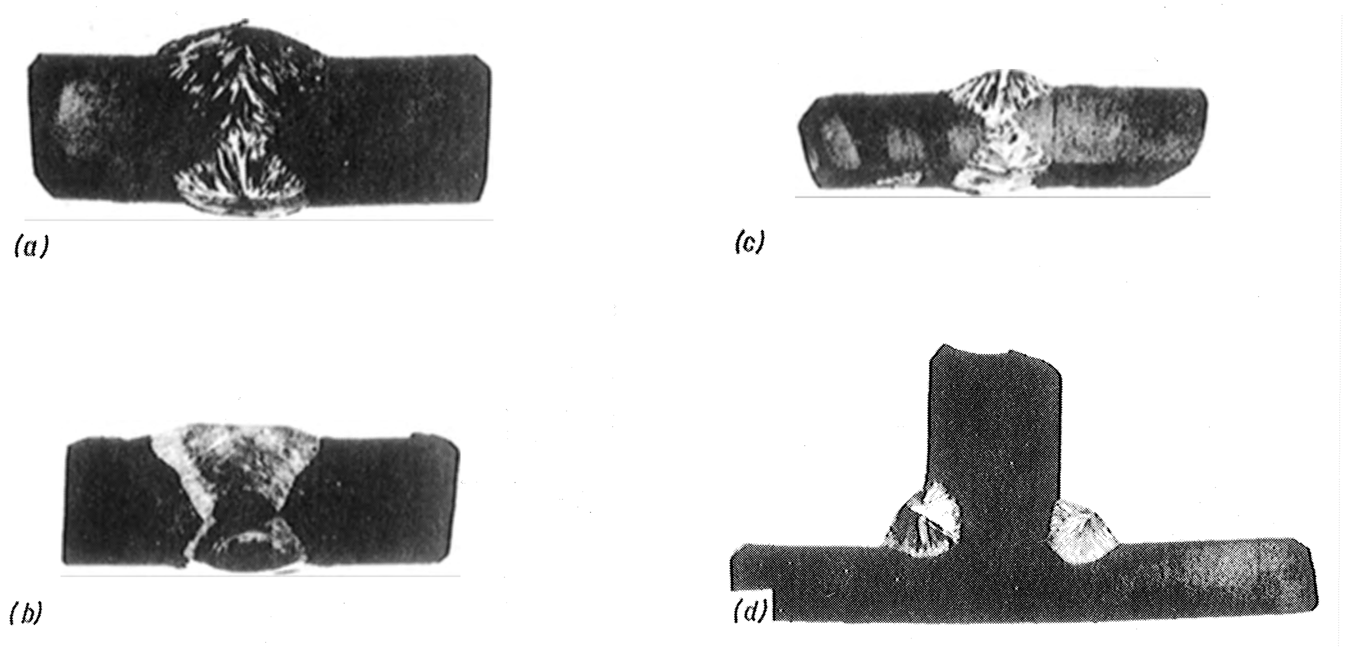
3 Composite micrograph of 9%Ni steel showing microstructure of HAZ obtained by metal-arc welding with INCO-WELD A Electrode: (a) x 25, (b) HAZ, x 250, and (c) unaffected zone, x 250



4 Hardness and toughness in HAZ of 9%Ni steel weldment (INCO-WELD A Electrode)



5 Hardness surveys in HAZ of 9%Ni steel plate: (a) flame cut, 3mm thick, showing microhardness values near flame cut edge, (b) flame cut and metal-arc welded, 3mm thick, showing microhardness values across HAZ of weld, (c) flame cut, 15.8mm thick, showing microhardness values near flame cut edge, and (d) flame cut and metal-arc welded, 15.8mm thick, showing microhardness values across HAZ of weld.



6 Photomacrographs of submerged-arc welds in 9%Ni steel: (a) weld no. 1, (b) weld no. 2, (c) weld no. 3, and (d) weld no. 4