WELDING STAINLESS AND 9% NICKEL STEEL CRYOGENIC VESSELS

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Welding Stainless and 9% Nickel Steel Cryogenic Vessels

Austenitic stainless and 9% nickel steel are well-suited for storage vessels and equipment because they maintain excellent mechanical properties at cryogenic temperatures

BY RICHARD E. AVERY AND DAVID PARSONS

Gases are often more efficiently stored and shipped as liquids at cryogenic temperatures. Pure gases commonly stored below liquefaction temperatures include oxygen -297°F (-183°C), argon -302°F (-186°C), nitrogen -320°F (-196°C), hydrogen -423°F (-253°C) and helium -452°F (-269°C). Natural gas is also transported and frequently stored as liquefied natural gas (LNG) at temperatures below -261°F (-163°C). Storage tanks for the pure gases are generally shop fabricated in sizes that can be shipped by conventional carriers— Fig. 1. Smaller LNG vessels for over-the-road and railroad fuel applications are also shop-fabricated. Figure 2 shows a rail-mounted tank designed to supply liquefied natural gas to locomotives. Another example of a tank installation is shown in Fig. 3. LNG terminal storage tanks are generally field-erected vessels fabricated from 9% nickel steel in sizes of 50,000 to 100,000 m^3 (315,000 to 630,000 bbls). This article focuses on welding practices for shop-fabricated vessels and equipment.

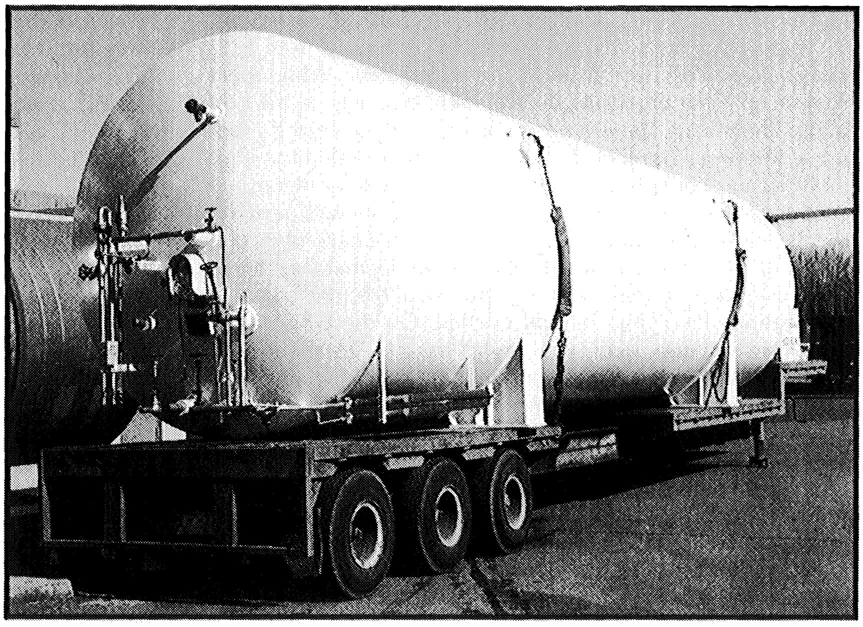

Fig. 1 — A 15,000-gal (57 m^3) liquid nitrogen storage tank fabricated from stainless steel and configured for over-the-road delivery. (Photo courtesy of Process Engineering, Inc.)

It is well known that ferritic steels, including the low-alloy steels, lose toughness and ductility at low temperatures. The ductile-brittle transition temperature, *i.e.*, a temperature below which a metal becomes brittle, is affected by steel-making practices. Alloys with increasing nickel content substantially increase low-temperature toughness. Finally, improved test methods and equipment for measuring toughness can improve yields by alleviating unnecessary rejects.

Austenitic stainless steels, as well as aluminum, are unique in not exhibiting a ductile to brittle transition temperature and

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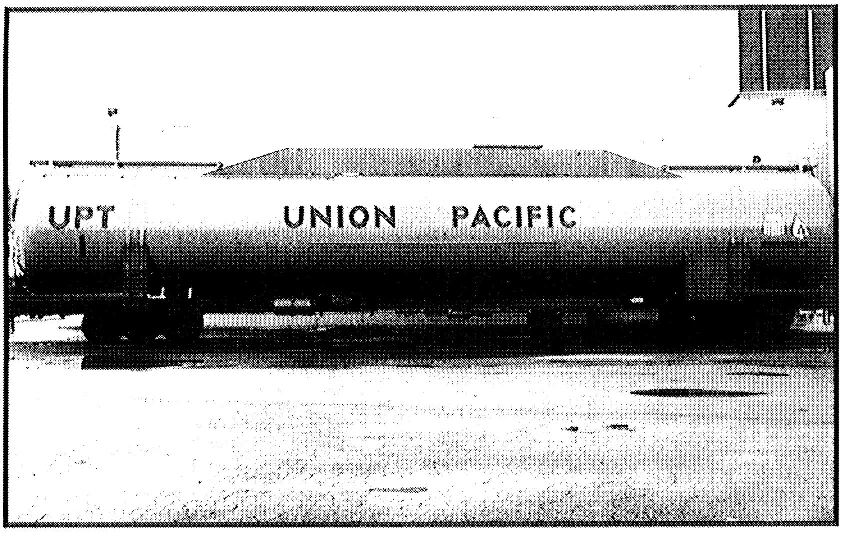

Fig. 2 — A 30,000-gal (11 m^3) LNG fuel car designed to feed two locomotives. (Photo courtesy of Process Engineering, Inc.)

9% nickel steels are ductile down to –320°F. ASME Section VIII, which is widely used for shop-fabricated storage tanks, exempts impact testing for Types 304, 304L, 316, 316L and 347 stainless steel base metals operating at temperatures of –425°F (–254°C) and higher. However, the rules for deposited weld metal are more restrictive and impact tests are required for welds joining austenitic stainless steels operating at temperatures of –325°F (–198°C) and lower when specific conditions are met. Factors that contribute to optimum cryogenic weld-metal properties are low ferrite, low nitrogen, low carbon, high nickel and, in shielded metal arc welding, lime-type electrodes.

There have been many attempts to develop a 9 or 12% nickel steel filler metal to weld 9% nickel steel. While there have been some promising development products, to the best of our knowledge, there is not a commercially accepted product at this time. The nickel-chromium-iron, nickel-chromium-molybdenum, or special austenitic high-alloy filler metals are used to provide the cryogenic ductility and strength requirements. Nickel alloy filler metals have the advantage of a coefficient of thermal expansion (COE) that closely matches that of 9% nickel steel, so there is little or no risk of thermal fatigue in applications involving thermal cycling. On the other hand, austenitic stainless steel weld metal has a COE about 50% higher than 9% nickel steel with an associated higher risk of thermal fatigue in cycling operations.

The difference in mechanical properties between the higher-strength 9% nickel steel and slightly lower-strength and higher ductility nickel alloy weld metal necessitates particular care in test-specimen preparation and test execution. Companies new to welding 9% nickel steels may encounter difficulties in passing welding procedure qualification tests, especially if they employ suboptimal testing equipment and testing procedures.

Stainless Steels

The stainless steel types most commonly used for cryogenic service equipment are Types 304 (S30400), 304L (S30403), 316 (S31600) and 316L (S31603). Standard types such as Type 347 (S34700) and a modified 201, Type 201 L (S20153) (Ref. 1), as well as some proprietary grades, have also been used. The S20153 stainless steel is used for temperatures down to –320°F (–196°C). The 300 series is usually used below that temperature. There is an advantage of 25% higher tensile strength for S20153 over Type 304. Stainless steel plate is usually procured to the ASTM A240 Specification, *Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet and Strip for Pressure Vessels.*

There is a choice between the use of the (L) or low carbon grade, *i.e.*, 304L or 316L with a maximum carbon of 0.03%, or the standard grades of 304 or 316 with a maximum carbon of 0.08%. One advantage of using the standard grades is slightly higher allowable design properties as shown in Table 1. On the other hand, higher carbon tends to contribute to lower toughness, as measured by impact tests.

Most shop-fabricated stainless steel cryogenic vessels are built to the ASME *Boiler and Pressure Vessel Code*, Section VIII. Field-erected vessels often use API 620 Q. Section VIII does not require impact tests on Types 304 (S30400), 304L (S30403), 316 (S31600), 316L (S31603) and 347 (S34700) stainless steel base metal operating at –425°F and above. This temperature limit excludes helium with a liquefaction temperature of –451°F (–269°C). The code does require production impact tests of deposited weld metal on each lot of consumables and every 400 ft of weld joining austenitic chromium-nickel stainless steels operating at temperatures below –325°F, provided that other provisions are met. Some of these conditions are: carbon, less than 0.10%; welding processes limited to gas metal arc, shielded metal arc, gas tungsten arc and submerged arc; and weld impact tests in accordance with the welding procedure specification at temperatures at least as low as the minimum design temperature. The Charpy impact specimens are required to meet impact-strength and lateral-expansion specified values for the particular specimen size. The standard 10 x 10-mm specimen should always be used when material thickness permits. Sub-size specimens tend to give less reliable results. ASME Section VIII, Part ULT, allows the designer to take advantage of the increased strength at low temperatures. For example, the allowable stress at –320°F is 10% higher than the allowable stress at room temperature. Unfortunately, there are offsets to this allowance since Part ULT imposes a number of special design and welding requirements that need careful attention.

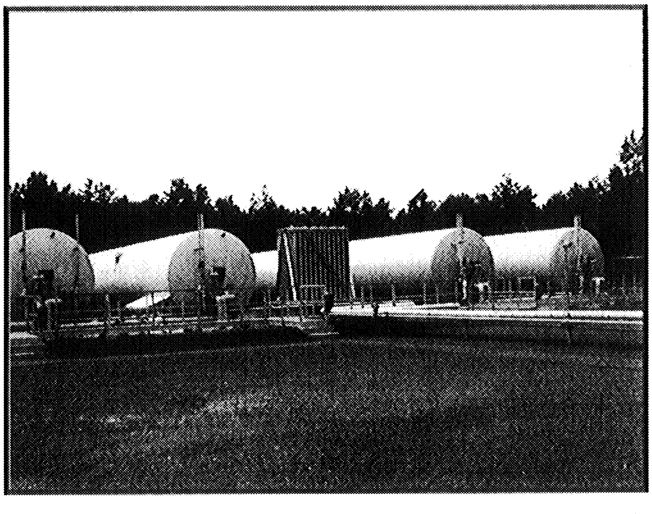

Fig. 3 — An installation of four 50,000-gal (19 m^3) LNG storage tanks at a Midwest natural gas distribution company. (Photo courtesy of Process Engineering, Inc.)

Table 1 — Mechanical Properties of ASTM A240 Plate, Sheet and Strip

		Tensile Strength min		Yield Strength min		Elongation in 2 in.
UNS	Type	ksi	MPa	ksi	MPa	min
S30400	304	75	515	30	205	40.0
S30403	304L	70	485	25	170	40.0
S31600	316	75	515	30	205	40.0
S31603	316L	70	485	25	170	40.0

Stainless Steel for Cryogenic Equipment

Austenitic stainless steel is the material of construction for approximately 60% of the shop-fabricated cryogenic market with the balance of the market using 5 and 9% nickel steels or aluminum. Three areas where stainless steels find wide use are the following:

◆ Small- to medium-sized vessels that operate at moderate pressures with wall thicknesses of 3/8 in. (9.5-mm) or less. When high mechanical strength is required, 9% nickel steel is often more cost effective.

◆ Where contamination from the metal surface must be avoided. The semiconductor industry is an example where stored gases must be free of metal or oxide pickup.

◆ Service and transfer piping. Stainless steel piping is widely used for cryogenic piping systems. The pipe is available in a wide range of sizes and finishes, including electropolished internal surfaces.

To amplify a bit on the use of stainless steels, where contamination may be a design factor, consider that nickel steels can rust the same as ordinary steels and contribute a metal oxide to the stored gas. For ultraclean gas storage, stainless steel vessels are welded, shell and heads, without backing bars. Welding is followed by grinding and polishing or electropolishing all inside surfaces. The closing head has an 18-in. OD dropout in the center, so that tank welds can be made from the inside. When welding and final internal cleaning are completed, the dropout is fitted and GTA welded in place using an argon gas backing.

Factors Affecting Low-Temperature Weld Properties

Low-temperature toughness of stainless steel castings and deposited weld metal may vary from lot to lot and is usually lower than that of the comparable wrought alloy. Factors that affect weld toughness have been reported by a number of investigators (Refs. 2–5). Recognition of the following factors is useful in developing the welding procedure specification for cryogenic equipment.

◆ *Low ferrite.* It is well known that ferrite in austenitic stainless steel welds, *e.g.,* 4 to 8 FN, is a strong deterrent to microfissures and cracks. However, ferrite over 3 to 4 FN reduces the low-temperature impact strength, while ferrite as low as possible, or even strongly austenitic, provides higher impact strength. A safe compromise at about 2 FN yields the highest possible impact strength and good resistance to hot cracking. The shape of the weld metal ferrite also affects impact strength, however, this is a factor that is difficult for production shops to control.

◆ *Low carbon.* Low carbon, preferably in the range of 0.03% or less, provides better weld metal toughness.

◆ *Low nitrogen.* Nitrogen increases the tensile and yield strength of stainless steel welds, but decreases the low-temperature toughness. One study suggests that the weld deposit of Type 304 and 316L is preferably held below 0.05% nitrogen (Ref. 3).

◆ *Higher nickel.* Higher nickel, within the permissible specification range, has been found to increase weld metal toughness (Refs. 2, 3). Some investigations indicate that weld toughness is significantly increased when nickel is increased from 10 to 20%, however, the higher-nickel stainless filler has not been commercialized (Ref. 5).

◆ *Lime-type electrodes.* Shielded metal arc welding (SMAW) lime-type electrodes have higher low-temperature toughness than titania-type electrodes and are largely the standard electrode for cryogenic components (Refs. 2, 3).

◆ *Low weld metal inclusion content.* It has been shown that in Type 316L welds, a low inclusion content increases low-temperature toughness. The welding process and welding procedure can have a strong influence on the inclusion content. For example, fabricators usually find the gas metal arc welding (GMAW) process to be more reliable than the submerged arc welding (SAW) process in meeting the production weld impact test required at temperatures below –325°F. Since weld inclusions are usually some type of oxide, low oxygen levels in the shielding gas aid in keeping inclusions to a minimum.

Stainless Steel Welding Processes

Comments on the welding processes used for cryogenic service welds follow.

◆ *Submerged arc welding.* SAW is usually the fastest and most cost-effective process for shop-fabricated vessels. There are a number of commercially available stainless steel submerged arc fluxes for use with Type 308 (S30880), 308L (S30883), 316 (S31680), and 316L (S31683) filler metals. The fabricator must develop and qualify the welding procedure specification for the particular flux-filler metal combination and perform impact tests down to the lowest expected service temperature. Experience indicates it is difficult to consistently meet impact requirements below –320°F with submerged arc welds; as a result, the GMAW process is usually chosen for equipment below this service temperature.

◆ *Gas metal arc welding.* While not as fast as SAW, GMAW has excellent properties below –320°F, and it may be used as semiautomatic or automatic welding. Since a low weld-metal inclusion content is important for good low-temperature toughness, gas-shielding practices and type of gas used are important elements of the welding procedure. Low oxygen in the shielding gas minimizes inclusions, however, there has been little work done to quantify inclusion count to gas purity.

◆ *Shielded metal arc welding.* As stated earlier, the ferrite number should be low, a good compromise being 2 FN. Also, welds made with lime-coated electrodes have better low temperature properties than those made with other coatings. Some electrode manufacturers produce stainless steel electrodes specifically designed for cryogenic service.

◆ *Gas tungsten arc welding.* GTAW is widely used in piping systems for cryogenic service. Welds made with this process easily meet low-temperature test requirements.

Stainless Steel Piping

Cryogenic piping for industries, such as the semiconductor

Table 2 — Typical Mechanical Properties for Welds in 9% Nickel Steel[a]

Welding Product and Process	Type Test	Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	% Elongation in 2 in.	Failure Location	Charpy V-notch Impact Strength ft.-lb. (J)			
						Weld		HAZ	
						80°F	–320°F	80°F	–320°F
1) Inco-Weld A	AWM	97	53	39	—	74.7	65.7	91.0	57.0
	Trans	101	—	—	Weld	(101)	(89)	(123)	(77)
2) Inconel Filler Metal	AWM	119	79	29	—	67.5	53.7	99.3	62.0
625						(92)	(73)	(135)	(84)
Pulsing Arc	Trans	112	—	—	Plate & Fusion Line				
3) Inconel Filler Metal 92	AWM	105	65	39	—	134	126	81.0	66.0
Pulsing Arc	Trans	103	—	—	Weld	(182)	(171)	(110)	(89)
4) Inconel Filler Metal 82	AWM	97	55	35	—	84.6	80.5	64.2	41.5
Incoflux 4	Trans	101	—	—	Weld	(115)	(109)	(87)	(56)
5) Inco-Weld B	AWM	105	63	32	—	—	44	—	53
	Trans	100					(60)		(72)
6) Inco-Weld Ni-9	AWM	102	62	35	—	—	60–65		
	Trans	104					(81–88)		
7) Sandvik 16.13.CMnW	AWM	97	65	50	—	144	66		
Spray arc						(195)	(89)		
8) Sandvik 16.13.CMnW	Trans	112	—	—	base metal	—	51	—	150
Submerged arc with						(0.034 in.)	(69)	(0.080 in.)	(203)
Lincoln ST 100 Flux						(0.86 mm)	(1)	(2.0 mm)	
9) ER NiCrFe-6	Trans	105	—	—	Weld	—	120	—	33
							(163)		(45)
Short circuiting arc						(0.085 in.)	(1)	(0.016 in.)	(1)
						(2.3 mm)		(0.41 mm)	
10) Sandvik 16.13.CMnW	Trans	103	—	—	Weld	—	48	—	31
Submerged arc with							(65)		(42)
Lincoln 880 Flux									
						(0.036 in.)	(1)	(0.019 in.)	(1)
						(0.91 mm)		(0.48 mm)	
11) ERNiCrMo-3	Trans	109	—	—	base metal	—	60	—	48
Pulsed arc							(81)		(65)
						(0.046 in.)	(1)	(0.028 in.)	(1)
						(1.2 mm)		(0.71 mm)	

(a) These properties are quoted as typical values only, and are not intended for use as minimum or design values. Mechanical properties can vary with technique, test input, and, in some cases, joint design.
(b) lateral expansion—average of 3 or 4 tests.
AWM = All Weld Metal
Trans = Transverse
N.A. = Not available
Sources: Inco Alloy International Inc., Sandvik Steel Co., Process Engineering, Inc., Hobart Bros. Inco-Weld, Inconel and Incoflux are trademarks of the Inco family of companies.

industry, requires a smooth internal surface as free as possible of surface discontinuities. To meet this requirement, pipe with an electropolished internal surface has become quite common. Great emphasis is also placed in making butt joint welds with minimum roughness, weld ripples and oxides. Automatic orbital GTAW welding equipment is capable of meeting these requirements with a high level of reproducibility. An orbital pipe- welding setup is shown in Fig. 4. The practice is to use low welding currents without pulsing to make welds that are ripple free on the ID. Joint preparation on thinner walls is usually an accurately machined square butt, free of burrs, to ensure a tight fit. Shielding gas is often an argon-hydrogen mixture and is sometimes specified as the purging gas to aid in obtaining a smooth internal root surface. Some procurement specifications require an acceptance weld sample on each pipe diameter before production welds are made. These tests are repeated after ten production welds or when the tungsten electrode is changed.

9% Nickel Steel

Nine percent nickel steel is often the most economic material of construction for larger-size shop-fabricated vessels for service down to –320°F where high strength is required. The nickel steels do not exhibit a "stainless" behavior and can oxidize or rust in many environments. For this reason, the steels are not suitable for storage of gases such as argon where contamination can be a concern, *e.g.*, semiconductor applications. A larger application of 9% nickel steel is for large LNG field storage tanks and for containment vessels on LNG tankers. Welding practices for field construction may be similar to shop procedures, although fabricators often develop proprietary welding procedures for certain welds. The applicable codes for field construction are usually different from those used for shop-fabricated vessels.

Two material specifications widely used for 9% nickel steel plates are:

◆ ASTM SA-353/SA-353M, *Specification for Pressure Vessel Plates, Alloy Steel, 9% Nickel, Double-Normalized and Tempered.*

◆ ASTM SA-553/SA-553M, *Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 8 and 9% Nickel.*

A major difference between the two specifications is the heat treatment, *i.e.*, quenched and tempered vs. double-normalized and tempered. SA-353 and SA553 Type 1 have the same chemical composition (8.50 to 9.50% nickel), but the yield strength of SA-353 is 75 ksi (515 MPa) compared to 85 ksi (585 MPa) for SA-553. In practice, most plates for vessel shells are quenched and tempered (SA-553) while formed components, such as tank heads, are double-normalized and tempered (SA-353).

Most shop-fabricated 9% nickel steel cryogenic vessels are built to ASME *Boiler and Pressure Vessel Code,* Section VIII or to equivalent international codes with similar requirements. Since the properties of the weld metal directly affect design

Table 3 — Typical 9% Nickel Steel Welding Procedures

	Weld (9) in Table 2	Weld (10) in Table 2	Weld (11) in Table 2
Welding process	GMAW-short circuiting	SAW	GMAW-pulsed arc
Filler metal	ERNiCrFe-6	Sandvik 16.13.CMnW	ER NiCrMo-3
Manual-Automatic	automatic	automatic	manual
Plate thickness and joint design	½ in. (12.7 mm)—60-deg included angle, ⅛ in. gap copper removable backing bar	⅞ in. (22 mm)—60-deg included angle, 3⁄16 in. gap, steel backing bar	7⁄16 in. (11 mm)—60-deg included angle, root opening 0 to 1⁄16 in. root face 0 to 1⁄16 in.
Filler metal diameter	0.045 in.	3⁄32 in.	0.045 in.
Shielding gas/SA flux	90 He-10 Ar	Lincoln 880 flux	75 He-25 Ar
Amps-volts	150–160 A 23–24 V	270–300 A 26–29 V	130–140 A 26–29 V
No. passes	6 passes	7 passes	7 passes face-1 back
Travel speed range	9–11 in./min root, decreasing to 4–5 finish passes	10–14 in./min	8–13 in./min
Stringer or weave bead	weave	stringer bead	slight weave

considerations, the codes have a number of special design and welding requirements in addition to the regular provisions.

Some important Section VIII requirements for welded construction of 9% nickel steel vessels include:

1) Welding procedure qualifications, performed in accordance with Section IX, require impact tests of weld metal and the heat-affected zone in addition to transverse tensile and bend tests. Impact tests are made at −320°F (196°C) or at the lower of design or operating temperature.

2) Charpy V-notch tests (three specimens each test) are required to meet a minimum of 0.015-in. (0.38-mm) lateral expansion rather than a ft-lb or J energy criteria.

3) Impact test plates are required for each 400 ft of production welds. Tests are made of the weld and heat-affected zone at −320°F or at the lower of design or operating temperature. Nickel-based filler metals exempted from production weld testing are the electrodes SFA5.11, ENiCrFe-2, ENiCrFe-3 and bare filler metals SFA-5.14 ERNiCrFe6 and ERNiCr-3.

Filler Metals and Welding Procedures

Nickel-alloy filler metals have the desirable features of very high cryogenic toughness and a coefficient of thermal expansion very close to that of 9% nickel steel. However, the standard nickel-alloy filler metals initially used in the late 1950s required careful procedures to produce welds with a transverse tensile strength equal to the base metal, *i.e.*, 100-ksi (690-MPa) tensile strength even though the all-weld-metal tensile strength is lower. Filler metals such as the following were in common use: ANSI/AWS A5.11 ENiCrFe-2, ANSI/AWS A5.14 ERNiCrFe-6, and ANSI/AWS A5.14 ERNiCr-3.

The current trend is toward higher-strength nickel-alloy filler metal, often of the NiCrMo type that provides a more comfortable strength margin. An exception to nickel-alloy fillers is Sandvik 16.13.CMnW (Cr16.5, Ni 12.6, Mn 6.9 W 3.3, bal. Fe), which has good strength and a COE close to that of 9% nickel steel.

Table 2 shows typical mechanical properties for 9% nickel steel welds made with different filler metals and various welding processes. Table 3 has welding procedure details for three of the representative welds listed in Table 2.

A problem with arc blow was encountered in some early 9% nickel steel fabrications, but this problem is seldom seen today when the plates and heads are properly handled at the steel mill, during transportation, and at the fabrication shop. Precautions include the avoidance of magnetic handling, demagnetization and quality control checks to ensure that magnetic fields are below 50 Oersted. When arc blow is encountered, the approach is to use an AC covered electrode, which is usually needed only for the first pass or two. Alternately, the area can be demagnetized by using a coil of welding cable attached to an AC transformer or by using some other demagnetizing technique.

Preparation and Testing of Test Specimens

Special care and attention in the preparation and testing of welding procedure qualification test specimens can save considerable expense and avoid invalid rejections. The combination of the high-strength 9% nickel steel base metal and the more ductile and often lower-strength nickel-alloy weld is not as forgiving to minor test deviations that would pass undetected in materials such as carbon steel.

Transverse tension tests are normally reduced-section plate tests made in accordance with the applicable code. Take care to avoid notches or sharp edges that may be incurred by machining and specimen preparation. The speed of testing is important. High test speeds tend to give lower values to the tension test results, possibly below the expected 95 ksi (MPa 655) or 100 ksi (MPa 690). ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, specifies the range of allowable test speeds.

Guided-bend tests may be transverse or longitudinal-bend tests. Bend specimens are preferably removed from the test plate by mechanical cutting. Surface roughness, notches and sharp discontinuities should be removed by grinding.

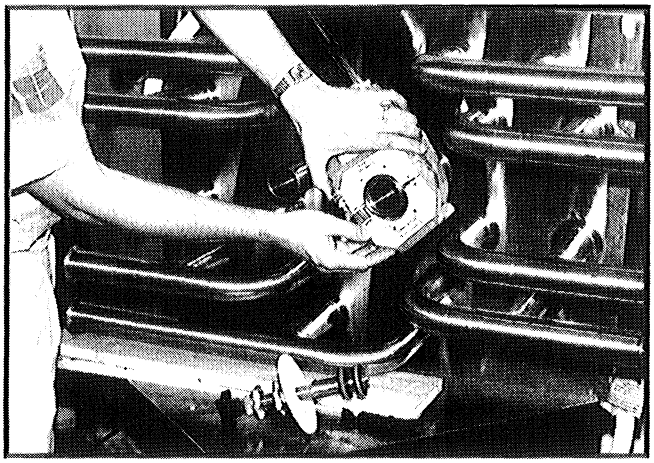

Fig. 4 — An orbital pipe-welding unit. The inert gas-purging unit is shown at the bottom of the photo. (Photo courtesy of Arc Machines, Inc.)

Edges in the bend area should be ground to the radius allowed by code. When the transverse bend is used, four side bends are usually used for plates 3/8 in. (9.5 mm) and over, rather than two face and two root bends. Codes such as ASME Section IX permit three types of bend fixtures; the guided-bend jig, the guided-bend roller jig, or the guided-bend wraparound jig. The authors favor the wraparound jig where each sector across the weld joint is progressively made to elongate. With this arrangement there is no chance of the specimen slipping, causing all of the elongation to take place in one area. With care, successful bends can be made with the other types of jigs.

The root and face longitudinal bend is an acceptable alternate to transverse bend tests. With the longitudinal bend, each area across the weld joint is forced to elongate the same amount and results are not influenced by the test specimen slipping in the jig.

Most codes require notch-toughness tests of the Charpy V-notch type on the weld metal and heat-affected zone at –320°F. The test procedures, apparatus and acceptance criteria should conform to ASTM A370. The test results can be in the form of impact energy (ft-lb or Joules), fracture appearance (percentage shear fracture), or lateral expansion (increase in specimen width on the compression side). Acceptance for vessels constructed to ASME Section VIII is based upon lateral expansion. The importance of accurate, high-quality machining of the Charpy impact-test specimens cannot be overemphasized. Poor specimen machining is usually responsible for more failures and scattered results than poor welding.

Study of 9% Nickel Steel after Long-Time Service

San Diego Gas and Electric recently dismantled two 9% nickel steel LNG storage tanks after about 29 years service. A study of the 9% nickel steel and the tanks was made during, and after, dismantling (Ref. 6). One purpose of the study was to confirm, through field experience, the ability of 9% nickel steel to maintain its excellent resistance to the initiation and propagation of brittle fracture over long-term service. Extensive laboratory studies by the Gas Research Institute had established these expectations (Ref. 7). Although the study involved field storage tanks, the 9% nickel steel findings should be applicable to any cryogenic service tank or equipment.

The three material areas investigated and the pertinent observations follow.

◆ *Long-term 9% nickel mechanical properties.* While it was not possible to make a direct comparison with original mechanical properties and Charpy toughness-test data due to the unavailability of the original test records, all material tested was comfortably beyond the present requirements of American Petroleum Institute, API 620, Appendix Q. The toughness-test values far exceeded the minimum code requirements. These results suggest that toughness is not expected to deteriorate below code minimums after much longer service life than the 20 years already experienced.

◆ *In-service crack propagation.* The question addressed was whether preexisting discontinuities, primarily in the welding, may lead to slow crack growth during the service period. The investigation focused particularly on the effort to find crack-like discontinuities to determine whether or not they might lead to slow crack extension. No slow crack extension was found and the tank materials demonstrated good resistance to crack initiation as well as the capability to arrest cracks that might be initiated by accident.

◆ *Corrosion.* There was no significant amount of corrosion found to any of the 9% nickel-steel surfaces.

Summary

While the fabrication and welding of shop-constructed cryogenic vessels and equipment involve some special attention, any fabricator accustomed to quality stainless steel and nickel alloy work has the capability to produce acceptable stainless steel and 9% nickel-steel products.

For stainless steel cryogenic components, the fabricator should recognize the following points:

1) Codes, such as ASME Section VIII, exempt impact testing on standard stainless steel wrought forms for service down to –425°F, but do require tests on welds below –325°F (–198°C).

2) Stainless steel vessels and equipment are well-suited for handling liquefied gases where contamination from metal surfaces is a major concern.

3) Factors that promote weld metal toughness are low ferrite, 2 FN is a good compromise; low carbon, preferably below 0.03%; low nitrogen, preferably below 0.05%; lime-type electrodes have better toughness than titania-type; low weld-metal inclusion content.

4) The SAW, GMAW, SMAW and GTAW processes are all used, although SAW is usually not used for equipment that will operate below –320°F.

Key points for 9% nickel steel fabrication include:

1) The high mechanical properties or 9% nickel steel make it most cost effective for medium to large fabricated vessels. Service temperatures are limited to –320°F or above.

2) Nickel alloy filler metals of the NiCr, NiCrFe, NiCrMo, and high manganese-tungsten austenitic stainless types are commonly used.

3) SAW, GMAW and SMAW procedures have been developed and widely used for shop-fabricated equipment.

4) Careful preparation and testing of test specimens for welding procedure qualification and production testing should be observed to avoid unnecessary rejections.

5) Arc blow can be avoided by proper handling at the mill, during transportation and during fabrication.

6) Recent tests of 9% nickel steel plate after 20 years LNG service indicated no deterioration of mechanical properties, no tendency for a crack to propagate, and no significant corrosion.◆

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