Recent Developments in Stainless Steel Application and Welding

By R. BANERJEE*

1.0 INTRODUCTION

Stainless steels play a key role as materials for construction for the chemical, petro-chemical, fertiliser, nuclear and food processing industries. Their ability to handle a wide range of corrosive media, excellent mechanical properties and good formability and weldability have led to their ready acceptance and use in all the process industries.

Keeping pace with the chemical industries, efforts to achieve increased plant output and service life, greater operating efficiency and higher product purity, steel makers have developed new grades of stainless steel to meet the higher operating pressures/temperatures or liquor concentrations demanded by such modern plants.

These new grades of stainless steel pose a challenge to the manufacturers of welding consumables and equipment to develop suitable processes, consumables and equipment to meet the welding requirements of the industries concerned.

For higher productivity and better quality welds, new processes like mechanised TIG, hot wire TIG and flux-cored MIG are being increasingly used. Pulsed arc welding using both TIG and MIG processes is becoming popular due to improved control on penetration and deposition leading to excellent quality welds. The plasma-MIG process recently developed appears to have a good potential for overlaying and surfacing.

In the area of welding consumables also, a large number of new electrodes and filler metal compositions have been introduced. In fact the number of standard stainless steel electrode compositions classified in AWS A5.4-78 has gone up to 32 types from 23 types classified in AWS:A5.4-69. The new revision of IS:5202 under print also follows the same pattern. Apart from these, there are a large number of modified compositions developed by individual manufacturers to suit specific applications and service requirements.

2.0 THE TRADITIONAL STAINLESS STEELS

The traditional grades of stainless steel used in the fabrication of chemical plant and equipment have been the AISI 304 and 316 types along with their low carbon versions, 304L and 316L or the stabilised grades 321 or 347 where inter-crystalline corrosion is to be avoided. The moly bearing grades are used where resistance to pitting corrosion or improved general corrosion resistance is desired.

The unstabilized grades are usually suitable for welding sheet materials upto about 8-10 mm thick. For higher thickness plate, the heat input during welding

*The author is with Indian Oxygen Ltd. This paper was presented at N. W. Seminar 1981 held in Bombay,

may be sufficient to cause sensitisation and the ELC or stabilised grades should be used.

Apart from these, the higher alloyed AISI 309 and 310 grades have mostly been used for high temperature applications such as preheaters, vessel liners, furnace liners and trays etc.

A considerable amount of the ferritic AISI 430 grade of steel is also used for high temperature oxidation resistance. It is also used in nitric acid plant and for applications involving stress corrosion conditions in chloride ion media. However, due to difficulties in fabrication by welding and development of new types, this steel is becoming less popular these days.

2.1 Field of Application and Limitations of the Traditional Steels

In general the commonly used stainless steels resist corrosion by

(1) Nitric acid of all concentrations, commonly used being 304L and 430

(2) Sulphuric acid—above 85% conc.—304 L may be used; below 5% conc. & 40°C—316 L may be used (provided solution is aerated.)

(3) Phosphoric acid—Cold—304 L; upto 100°C —316 L

(4) All Alkalies-except hot caustic under stress.

(5) Most organic chemicals, food stuffs, pharmaceuticals 304/304L/321—for general corrosion resistance.
316/316L—general corrosion plus improved resistance against pitting and higher temperatures.

They do not resist corrosion by—

(i) Hydrochloric acid—all concentrations

(ii) Oxidising chlorides

(iii) A few organic acids, like oxalic acid

(iv) Sulphuric acid in the intermediate concentrations and hot phosphoric acid.

2.2 Thus some of the limitations of the traditional grades of stainless steel which have led to evolution of new grades have been :

(1) Low proof stress—35% of U.T.S.

(2) Sensitive to stress corrosion in acidic Cl or F ion media above 70°C and also hot caustic.

(3) Sensitive to pitting corrosion in more aggressive acid chloride media.

(4) Preferential attack on the ferrite phase in strong oxidising media (urea carbamate).

TABLE—1
COMPARATIVE MECHANICAL PROPERTIES OF PLAIN AND NITROGEN-BEARING AUSTENITIC STAINLESS STEELS
(As per German DIN 17740-72 Specification)

Nearest AISI Steel		304L	304LN	316L	316LN
Werkstoff number (DIN)		1.4306	1.4311	1.4404	1.4429
Condition		Annealed & Quenched		Annealed & Quenched	
0.2% P.S. (N/mm²)		175	270	195	300
1% P.S. (N/mm²)		215	310	235	340
U. T. S. (N/mm²)		450-700	530-750	450-700	600-800
Elongation	Long	50	40	45	40
	Transverse	37	30	34	30
Impact J					
	Long	85	85	85	85
	Transverse	55	55	55	55

(5) Inadequate corrosion resistance in reducing media such as, hot phosphoric acid or sulphuric acid.

Let us now see how each one of these limitations has led to the development of new types of stainless steel.

3.0 HIGH PROOF STRENGTH NITROGEN ALLOYED STEELS

Due to low 0.2% proof stress of the austenitic steels, approx. 35% of UTS against 50% for carbon and low alloy steels, nitrogen-bearing varieties of AISI 304L, 316L, 317L have been developed. These are designated as AISI 304LN, 316LN, 317LN and besides higher 0.2% proof stress, have improved austenitic stability.

The addition of 0.2% nitrogen increases proof stress by over 15%. As such these grades are being increasingly used as the code allows higher design stresses for pressure vessels and containers. Table I gives comparative mechanical properties with standard grades.

The largest application of such steels has been in the transportation and storage industry. They are used for transporting chemicals, food stuffs, beverages etc. in ships, holds, containerised transport, road tankers etc. In general, 304LN grade is used for food stuffs, edible, oil etc. and 316LN for fatty acids and more corrosive applications.

3.1 Welding

Since nitrogen is a very strong promoter of austenite, care has to be taken while welding these steels to compensate for the loss of nitrogen in the weld in the process of welding. Root passes should be welded with a higher alloyed electrode eg. E309L or E309LMo, the filler and top runs however may be given with standard E308L or E316L. The higher alloyed electrodes should also be used for joining to carbon steel.

4.0. Steels for Improved Resistance to Stress Corrosion Cracking (SCC)

As already stated, the austenitic stainless steels are susceptible to stress corrosion cracking in the presence of chloride and fluoride ions at temperatures above 70°C and this has been responsible for 25-30% failure in the chemical industry.

Most vessels contain residual stresses from welding or other fabrication procedures and it is usually not practicable to eliminate these as furnaces of adequate size are not easily available ; also there is risk of sensitizing the steel during slow cooling after stress relief. Solutions containing even traces of chlorides e.g. from mains water can cause SCC because there are often areas such as crevices and splash zones where concentration of salts will occur. The chlorides may originate from insulating material, from fuel gases of furnaces, rain water leakage etc.

The susceptibility of stainless steels to S.C.C. is very dependent on nickel content and is maximum at 8-10% nickel. Austenitic steels with high nickel contents of the order of 25-40% are much less susceptible to SCC; alternatively the nickel content may be reduced below 6% as in the duplex and ferritic types.

The ferritic AISI 430 grade although much more resistant to stress corrosion cracking are difficult to fabricate due to grain growth during welding and consequent embrittlement. As such, two types of steels have been developed in response to the needs for stress corrosion cracking applications.

(1) Duplex ferritic—austenitic steels

(2) Extra low interstitial ferritic steels.

4.1 Duplex Steels

These steels have excellent resistance to stress corrosion cracking and can give a service life of many years in conditions where ordinary AISI 316 grade would fail in a few weeks. Overall corrosion resistance is similar to 316 with improved pitting resistance. The steels have good weldability by the commonly used welding processess with superior mechanical properties, the 0.2% proof stress being twice that of austenitic steels.

Some typical steels are given in Table II.

TABLE-II

Type or Trade name	*Composition*				
	Carbon	*Cr.*	*Ni*	*Mo*	*Others*
AISI 329L	0.025	28	5	1.5	
SANDVIK 3RE60	0.025	18	5	2.5	
URANUS B50	0.03	20	7	2.5	Cu 1.5
CASTING GRADES					
ACI CD 4 MCu	0.4	26	5	2.0	Cu 3.0
PARALLOY 3 FL	0.3	22	5	2.0	

The duplex steels have been used in heat exchangers for fertilizer plant, digesters and preheaters for sulfite pulps, suction rolls in the paper industry, centrifuge baskets etc.

A novel example of the casting grade-Paralloy 3 FL has been in the construction of a building for decorative architecture. The building actually hangs on an open lattice constructed of centrifugally cast tubes and nodes of this alloy.

4.1.1 Welding

TIG welding is mostly preferred for thin walled tubes and root passes using 316L Si filler wire. Manual metal arc welding is done with a modified E 316L composition 19 Cr 7 Ni 2.7Mo which gives high ferrite (20-30%); alternatively Incoloy 182 or E312L modified electrodes may be used. These steels are susceptible to embrittlement by sigma phase formation and should not be used over 350°C for long periods.

4.2. Extra Low Interstitials or Super Ferrites :

These are basically ferritic stainless steels with 18-27% Cr and 1-2% Mo with a very low level of interstitial elements (C+N+0<.10%). This results in improved ductility and weldability and particularly avoids embrittlement of the HAZ due to grain growth during welding. However, they should not be used for service above 300°C as they are susceptible to 475° embrittlement.

Commercial production of these steels have become possible after recent developments in vacuum melting and remelting techniques e.g. AOD & VOD and EBW refining. Tubes and sheets upto 3 mm thick are available ; some typical steels are shown in Table III.

The E-Brite 26-1 type has been successfully used to handle hot caustic. The other grades like A268 grade 29-4, Monit 2502 have been used in tubing for heat exchangers handling sea water and also for bleaches in the paper industry.

Welding is restricted to TIG or Plasma, using autogenous process. However, for joining to carbon steels or other stainless steels, E316L or Incoloy 135 type electrodes may be used.

5.0 STEELS FOR UREA SERVICE & STRONG OXIDISING MEDIA

With the rapid expansion of the fertilizer industry, the demand for improved steels particularly for the urea reactor, strippers, condensors etc. have increased.

Traditionally the (316 L urea grade) Sandvik 3R60 or Assab 724L steels having slightly higher chromium & nickel with nil ferrite were used. These may be welded with either.

(1) E316L (Standard ferrite) electrodes for the root pass & filler. E 316L (0.6% max ferrite) for the capping passes.

(2) A modified E316 L (with 4-5% Mn) having much improved resistance to micro fissuring and cracking even with fully austenitic weld metal.

For stronger oxidising conditions of modern fertilizer plant and increased output, a modified AISI 310 composition steel has been developed. Typical steels SANDVIK 2RE69 and Assab 725 LN composition 0.11C, 25Cr, 22Ni, 2Mo, 0.1N. FCI plans to use such steels for future plants in India also.

TABLE—III

Type or Trade name	COMPOSITION				
	C	Cr	Mo	Ni	Others
AISI 444 Nyby-Elit 1803MoT	0.025	18	2	—	Ti 0.4
E-brite	0.003	26	1	—	—
ASTM-A268					
Grade 29-4	0.02	29	4	—	—
Nyby—Monit 2502	0.02	25	4	4	Ti 0.4

TABLE—IV

Type or Trade Name	Cr	Ni	Mo	Cu
Sandvik 2RK65 Addenholm 904L HV 9A Nyby 20-25 UMo Cu	20	25	4	1.5
Carpenter 20 Cb 3	21	35	3	3
Incoloy 825	21	40	3	2

(Cr, Ni, Mo, Cu under the heading COMPOSITION)

Welding may be done using manual electrodes having a matching composition with the addition of 4-5% manganese to counteract the micro-fissuring tendency.

6.0 STEELS FOR STRONG REDUCING MEDIA

For service in strong reducing media such as sulphuric acid at intermediate concentrations and hot phosphoric acids, steels of the type 20Cr- 25Ni—4 Mo—2 Cu have been developed. Due to the presence of copper and increased nickel content, these steels give much superior service in reducing conditions.

Typical steels are given in table IV. It may be noted that the Carpenter 20 Cb 3 and Incoloy 825 are even more highly alloyed and are immune to stress corrosion cracking also.

These steels are already in use in India in various fertilizer and chemical plants. Apart from this, they are finding increasing application in power plants for flue gas scrubbing equipment and absorption towers and also for pumps and equipment handling sea water.

While the carpenter 20 Cb 3 alloy is welded with E320 electrodes, the other alloys like Sandvik 2 RK65 and HV 9A are welded with matching composition electrodes.

7.0 STEELS FOR INCREASED PITTING RESISTANCE

Molybdenum has been found to be the single most effective element to resist pitting corrosion by chlorides and fatty acids at high temperatures. Starting with the standard 317 and 317L grades a number of steels have been developed to give increased resistance to this type of corrosion, with increasing amounts of molybdenum. Some typical steels are given in table V.

TABLE—V

Type or Trade Name	*Cr*	*Ni*	*Mo*
317L	17	13	3
DIN W No. 1.4438	18	14	4
317LM 317L Plus	18	15	4
Allegheny A1-6X	20	24	6

(*Cr*, *Ni*, *Mo* under the heading *Composition*)

These alloys are being used for handling fatty acids, SO_2 scrubbers in thermal plant etc. The Allegheny AL-6X has exceptional resistance to pitting by chlorides and has been used for the steam condensor tubing in a coastal sea water operated power plant.

7.1 Welding

The presence of increased amounts of molybdenum promotes tendency of sigma phase formation in ferrite containing weld metal, resulting in reduced ductility and corrosion resistance of the weld.

As such, the steels are welded with matching composition electrodes but with the addition of 4% manganese and/or 0.2% nitrogen., whereby a fully austenitic structure is stabilised in the weld at the same time, tendency for micro-fissuring is reduced.

Apart from the development of steels fer service in specific corrosive media, two other areas where recent progress has been made are :

(1) Welding of stainless steels fer cryogenic purposes

(2) Development of high strength-heat resistant casting alloys along with compatible welding consumables.

8.0 STEELS FOR CRYOGENIC SERVICE

The most widely used grades of austenitic steels for cryogenic service i.e. equipment operating at sub-zero temperature down to -269°C (B. P. of Helium) are the AISI 304 & 304L type. Types 316, 316L, 321 and 347 are also used depending on the service requirements and availability: In general, the un-stabilised grades are preferred for applications below -200°C.

The nitrogen bearing grades AISI 304LN and 316LN are being increasingly used. Recently quite a few LNG and LPG tankers hold have been fabricated from AISI 304 steel. The type AISI 304 also remains popular for construction of A.S.U. plant for Oxygen and Nitrogen production, liquid oxygen tanks etc.

Impact value requirements for the weld metal as laid down by the ASME Code, specifies CVN at-106 C° of 2.8 Kgf-m and lateral expansion value of 15 mils minimum. Standard E308L type electrodes were found to give marginal value for impact strength.

Based on recent research work, it has been determined that within a specific grade, optimum impact properties could be achieved by having low ferrite, low carbon, low nitrogen, high nickel and basic coattings. As such, it has now become possible to achieve satisfactory impact values with modified basic coated electrodes of both 308L and 316L types, having increased nickel and ferrite controlled to +2FN to+3FN respectively, at the same time having reasonable resistance to micro-fissuring. However, development work is still continuing in this field.

Note : For the purpose of comparison of relative crack sensitivity with ferrite level, Szumachowsky & Raid have brought in the concept of negative ferrite number and modified the Delong diagram. These consist of series of broken lines parallel to the 0FN line with a distance equal to the distance between 0FN and 2FN lines between them. The broken lines are assigned negative ferrite number (-FN).

9.0 STEELS FOR HIGH TEMPERATURE SERVICE

Although the straight chromium ferritic steels have good high temperature oxidation resistance, they cannot be used in applications where strength is necessary. Also they tend to become brittle when cooled to room temperature after prolonged use at elevated temperatures.

As such, the austenitic AISI 310 steel has been widely used for furnace equipment etc., at temperatures upto 1100 C. However, for applications requiring higher creep strength, certain casting alloys such as HK-40 etc., have been developed (table VI.)

TABLE—VI

Type or Trade Name	*Composition*			
	C	*Cr*	*Ni*	*Others*
HK40	0.4	25	20	
IN519	0.3	24	24	Nb
IN638	0.4	26	35	Co, W & Nb
	0.1	20	32	
IN657	0.05	50	50	Nb

These steels have been used in steam and hydrocarbon reformers, naptha cracking furnaces etc. in the petro-chemical and fertilizer industry. For headers and manifolds, the more ductile 20 Cr 32 Ni alloy is used. The IN657 alloy has been developed for high temperature use in highly corrosive atmospheres such as sulphur, sodium and vanadium from residual fuel oils.

Welding :

This is done with matching basic coated electrodes. Again addition of 3-4% manganese is beneficial for preventing micro-cracking or fissuring.

10.0. THE PRECIPITATION HARDENING STAINLESS STEELS

These are a group of steels where extremely high strength is developed by a heat treatment, where advantage is taken of both martensitic hardening and precipitation hardening mechanisms. Typical mechanical properties developed after heat treatment are given below :

U.T.S.	0.2% *P.S.*	*Elongation*	*Hardness*
1235 N/mm^2	1080 N/mm^2	10%	400 VPN

TABLE—VII

Type or Trade Name	COMPOSITION				
	C	Cr	Ni	Mo	Others
SA 705-TP630	0.05	17	4	1	Nb 0.3 Cu 3.5
Armco 17/7PH	0.07	17	7	—	Al 1.2
Armco 14/8 PH Mo	0.03	14	8	2.5	Al 1.2
Allegheny AM 250	0.09	17	4	2.75	Nb 1
Carpenter Custom 450	0.03	15	6	1	Nb 0.3 Cu 1.5

The steels have corrosion resistance considerably better than the straight chromium martensitic grades and are being used for compressor blades, pumps, gears for metering chemicals and similar applications where a combination of wear and corrosion resistance is important.

The steels are available as forgings, castings, bar and plate and a few typical compositions are given in table VII :

These steels are welded in the annealed condition, when they have maximum ductility and no pre or post heat is required. Shielded metal arc welding may be used for SA 705—TP 630, Allegheny AM 350 and Carpenter Custom 450 types with E 630 electrode or matching composition. For the Armco 17/7 PH or 14/8 PH—Mo, type TIG or MIG welding should be used due to difficulty in transferring aluminium through the arc.

Following welding, the weldment should be annealed and heat-treated to develop strength. It is possible to weld in the heat treated condition; however, full joint efficiency will not be achieved due to softening of the HAZ by overaging and, in these cases, E 308 or any austenitic electrode may be used.

11.0. DEVELOPMENTS IN WELDING PROCESSES

In the field of stainless steel welding the MMAW process is still predominant with TIG as the next most widely used process. This situation is slightly different to that existing with mild and low alloy steel fabrication where the MIG welding process has shown a spectacular increase and in some of the developed countries now holds an equal share with MMAW.

Two of the factors responsible for this are—

(1) The wide variety of compositions required in stainless steel welding where it may not be economical to develop wires of each type.

(2) Limitations of the conventional MIG process as applied to stainless steel particularly with spray transfer which are

- (i) Oxidation of alloying elements varies with gas composition and welding parameters.
- (ii) High current density values leading to excessive joint penetration and poor control on penetration particularly in V-up welding.
- (iii) Narrow bead width with tendency for undercut.
- (iv) Stop start zones having non-uniform composition thus becoming potential corrosion areas

11.1. In this context, some of the recently developed processes which appear to have a good potential for stainless steel welding are:

(1) Pulsed MIG which gives vastly improved control over deposition and penetration and is particularly suitable for positional welding.

(2) Flux cored MIG—which has the ability to provide deposits of various compositions by modifications to the filler. It also gives better welding characteristics particularly for H—V fillet.

(3) Use of high silicon wires for standard MIG or TIG process which gives improved metal transfer with better welding and bead shape. However high silicon may not be tolerated in all applications.

11.2. Submerged arc Welding

This method has also been successfully used. However, the current and bead size has to be controlled to avoid hot cracking and sensitization of the HAZ.

However, the greatest potential for SAW welding appears to be for cladding by giving stainless steel overlays of required composition on carbon and low alloy steel plate. For this, the availability of strips and suitable welding equipment have to be developed and experience is to be gained to obtain clad material of uniform composition to give adequate corrosion resistance. The Plasma—MIG process has great promise in this respect.

CONCLUSION

From the foregoing, it may be seen that the trend for designers of chemical and process plant will be to use more sophisticated and higher alloyed steels to obtain increasing levels of corrosion/oxidation resistance in different media and environments. Also some of the new stainless steels are being used in applications which were hitherto thought to be the domain of copper-base and nickel-base alloys. This trend is bound to increase with the increasing price of copper and nickel.

For achieving higher deposition rates, certain recent developments in MIG/TIG processes seem to have overcome some of the initial disadvantages of these processes and these should find wider application.