FABRICATION OF HIGHLY CORROSION-RESISTANT STAINLESS STEELS AND NICKEL ALLOYS

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Stainless steels and various nickel alloys are used mostly in the chemical industries because of mainly their excellent corrosion to resistant property. Alloying elements, chromium and molybdenum together with oxygen form a dense passive layer on metalic clean surface. This passive layer which acts as a barrier between the metallic surface and its environment reduces considerably susceptibility to various corrosion media.

Welded joints in the chemical industry are important structural elements. Therefore, all the welded joints should be of a highest integrity and should have atleast same corrosion resistant property as that of parent metal which is not affected by the heat input.

In the chemical and other industries stainless steels are used in the passive range. The passive layer is not a reliable protection under all operating conditions.

Often under certain service conditions, the passive layer present on the surface of the stainless steel gets destroyed locally which results in considerable corrosion attack eg. are :

(1) Intergranular corrosion

(2) Chloride induced stress corrosion cracking.

Intergranual Corrosion

There has been steady, development in the melting process of stainless steel since the year 1910. In the electric furnace, oxygen is injected by a water cooled gun by AOD or VOD process which results in decarburisation of the stainless steel. Figure 1 shows carbon content of the stainless steel acording to the development of the melting process from the year 1910 to 1990.

Since carbon content in the modern stainless steel is extremely low - less than 0.01% hence, these modern stainless steels are resistant to intergranular corrosion without stabilisation.

Alloying elements and Corrosion Resistance of the Stainless Steel

In general, by increasing the amount of suitable alloying elements, corrosion resistance of stainless steel can be increased / augmented.

When nickel content in the stainless steel is increased to more than 20%, its residence to stress

Table - 1

Steel	Chemical Composition (%)					Structure
	Cr	Mo	Ni	Cu	N	austenitic
1.4439	18	4.5	14	--	0.15	"
1.4539	20	4.5	25	1.5	--	"
254 SMo	20	6	18	0.7	0.2	"
1.4529	20	6	25	1.5	0.15	"
1.4563	27	3.5	31	1	--	"
Ferrite Stainless Steel						
18Cr 2 Mo	18	2		(with Ti)		Ferritic
1.4575	28	2		4 with Nb C +	N< 0.04	Ferritic
Ferritic austenitic (Duplex)						
1.4462	22	3	5.5	X	0.15	Duplex
1.4515	26	3	6	1	0.2	"
FALC100	25	3.5	7	0.7	0.25+W0.7	"

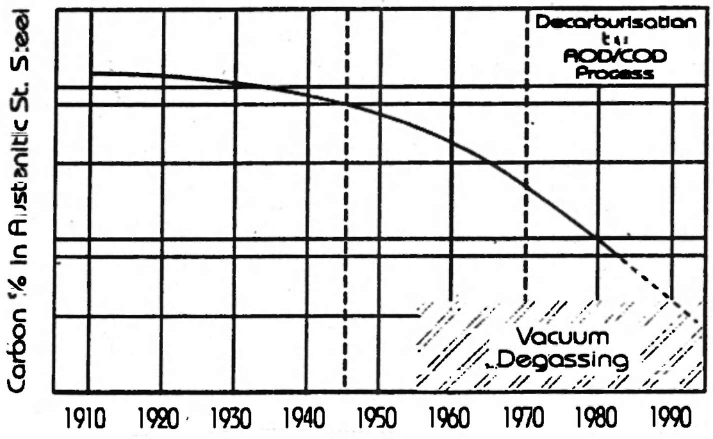

Fig 1

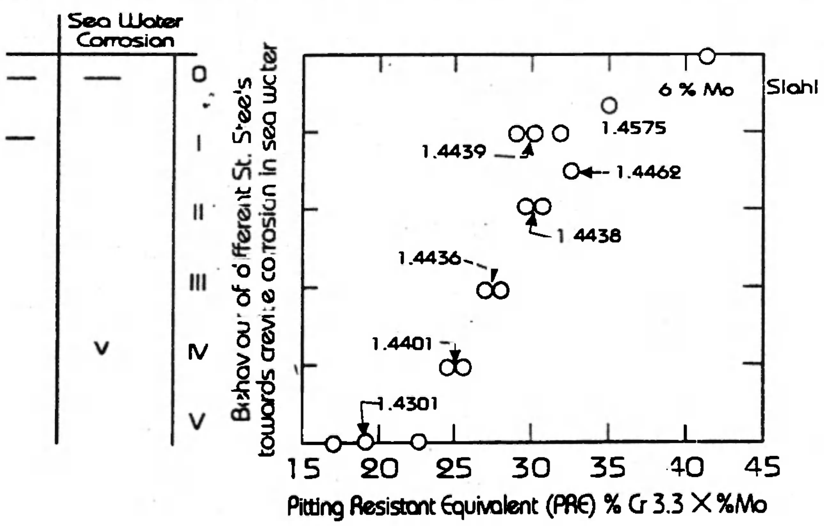

Fig 2

Table 2 : STAINLESS STEELS WITH HIGH RESISTANCE : PRE ≥ 32

High alloyed stainless steels	PRE	PRE with Nitrogen
1.4439	32.9	35.3
1.4539	34.9	--
1.4563	38.6	--
1.4529	39.8	42.2
245 SMO	39.8	43.0
1.4462	31.9	34.3
1.4515	35.9	39.1
FALC 100	36.6	40.6
1.4575	34.6	--

corrosion cracking in media containing chloride also increases.

Duplex Stainless Steel

Because of their duplex structure, stainless steel containing higher, amount of ferrite shows higher strength than austenitic stainless steel. As a result of their structure and strength, these duplex stainless steels have lower susceptibility to stress corrosion cracking. In principle high alloy ferrite steels are insusceptible to chloride stress corrosion cracking. However, these steels have low toughness and poor weldability. Weldability of these steels could be improved by reducing carbon and nitrogen content.

Table 1 shows few steels with increased resistance to stress corrosion cracking.

Resistance to pitting and crevice corrosion

If contents of alloying elements chromium and molybdenum are increased in the stainless steels then resistance to pitting and crevice corrosion is definitely improved.

The appearance of pitting and crevice corrosion does not depend on any microstructure of the stainless steel.

To assess resistance to pitting and crevice corrosion, the Pitting Resistance Equivalent (PRE) is calculated as follows :

PRE = % Cr + 3.3 X % Mo

For Duplex Stainless Steel which are alloyed with Nitrogen PRE is modified as under

PRE = % Cr + 3.3 X % Mo + 16 X % N

PRE = % Cr + 3.3 X (% Mo + % W) + 16 X % N -

Super Duplex Stainless Steel.

Figure 2 shows the behaviour of different stainless steels towards pitting and crevice corrosion in sea water as a function of Pitting Resistance Equivalent (PRE). The higher the value of the PRE the higher the resistance to pitting in aqueous solutions containing chlorides.

Table 2 gives information about various recently developed stainless steels having increased resistance to pitting and crevices (PRE).

Role of Molybdenum as an alloying element in Stainless Steel

Higher molybdenum content in stainless steels increases resistance to pitting and crevice corrosion in comparison to increase in chromium content of the stainless steels.

It is observed that there is increasing tendency of segregation if molybdenum content is increased beyond certain limit in the welding consumables. The segregation is observed in heat affected zone (HAZ) as well as in the weldmetal during welding.

Nickel Alloys

There has been rapid advances in the development of corrosion resistant nickel alloys during last few years.

For severest corrosion conditions encountered in chemical process industry and in environmental pollution control systems, nickel chromium (Molybdenum) alloys of various compositions have been developed.

- Increase in chromium content in NICr alloys increased resistance to corrosion - stress corrosion cracking in extremely pure water examples

Inconel 600	**Inconel - 690**
LC-NICr 15 Fe	LC - NICr 29 Fe
C = 00.04	NI = 21%
NI = 76.00	Cr = 29%
Cr = 16.00	Fe = 9%
Fe = 7.00	TI = 0.25%

- Increase in chromium, cobalt and molybdenum contents in nickel alloys increase resistance to corrosion in hydrous and gaseous corrosive media upto 1100°C.

Inconel 625	**Inconel 617**
NI Cr 22Mo 9Nb	NICr 23 Co 12 Mo
Ni = 63%	Ni = 54%
Cr = 22%	Cr = 22%
Mo = 9%	Mo = 9%
Fe = 2%	Co = 12%
Nb = 3.4%	Al = 1%
	TI = 0.4%

Table 3 : NICKEL ALLOYS AND MATCHING WELDING CONSUMABLES

Nickel alloy steel	Chemical composition					Matching welding consumables
	Ni	Cr	Mo	Fe	Others	
NiCr29Fe Inconel-690	61	29	--	9	T1-0.25	
NiCr22Mo9Nb Inconel-625	63	22	9	2	Nb 3.4	EL-NiCr22Mo9Nb
NiCr23Col2Mo Inconel-617	54	22	9	--	Co-12 Al-1 Ti-0.40	EL-NiCr21Co12Mo
NiMoCr16Ti Hastalloy C-4	66	16	16	6	Ti-0.3	EL-NiMo15Cr15Ti
NiMo16Cr16W Hastalloy C-276	57	16	16	6	w-3.25	EL-NiMo15Cr 15W
NiCr21Mo14w Hostalloy C-22	57	21	13	4	W-3.20	

Table 4		
Highly alloyed stainless steel	**Maching welding consumables**	**Over alloyed consumables for severe corrosion property**
DIN 1.4439 X 3 CrNiMon 17135	E 18 165 L	E 20 25 5 CuL
a. DIN 1.4539 X 2 NiCrMoCu 20.25.5	E 20.25.5. CuL	ELNiCr20 Mo9 Nb
b. 254 SMo Steel DIN 1.4529 X 2 NiCrMoCu 25.20.6	ELNiCr 28Mo	EL-NiCr20Mo9 Nb
DIN 1,4563 X 1 NiCrMoCu 31.27	ELNiCr 28 Mo	EL-NiCr20Mo9 Nb

Corrosion resistant properties of NI-Cr-Mo alloys are equal to nickel-chromium alloys in oxidising agents. Corrosion resistant properties of NI-Cr-Mo alloys are equal to nickel-moly alloys in reducing agents. By raising "Cr" content, corrosion resistant property of Hastalloy C-22 alloy was increased in acid oxidising agents.

All the same time resistance to. pitting crevice and uniform corrosion in non-oxidising acid was also increased.

Hastalloy C-22	Hastalloy C-276	Hastalloy C-4
Ni = 57	57	66
Cr = 21	16	16
Mo = 13	16	16
Fe = 4	6	
W = 3.2	3.5	
Titanium		0.3

Welding of highly Corrosion Resistant Materials

Welding of highly corrosion resistant alloys can be successfully carried out using following five shielded metal arc welding (SMAW) processes

1. Manual Metal Arc Welding Process - MMAW
2. Tungsten Inert Gas Welding Process - TIG
3. Metal Inert Gas Welding Process - MIG
4. Submerged Arc Welding Process - SAW
5. Plasma Keyhole Welding Process

Out of the above five processes, first two are the most widely and dependable processes which are used extensively for fabrication as well as for maintenance welding of highly corrosive resistant alloys in our country.

Welding of highly alloyed Austentic Steels

The highly alloyed stainless steels having high corrosion resistant properties have a fully austenitic structure. Therefore all these steels have a tendency to hot cracking during welding (solidification as well as preheat cracking tendency). The cracks are observed in the weld seam as well as in heat affected zone. Hot cracking tendency of these highly alloyed stainless steels can be reduced by adopting following measures.

- Because of continuous welding and high input - the temperature of the weld metal becomes quite high. At such high temperature during welding austenitic steels having high content of chromium and molybdenum segregate following intermetallic phases :

  (a) Sigma phase
  (b) Chil phase

As a result of segregation, certain area of the weld metal as well as HAZ become depleted with chromium and molybdenum content. This segregation results in reducing corrosion resistant property of the auestenitic stainless steel.

Minimum or low heat input can minimise such precipitation of intermetallic phases.

Austenitic stainless steels containing high degree of Molybdenum

During solidification of the weldmetal, the area which gets solidified first has lower content of chromium and molybdenum, than overall content of chromeum and molybdenum of the weld-metal. Pitting type of corrosion is encountered in such weld metal during service operation. Such segregation cannot be removed by solution annealing heat treatment. Overalloyed consumables with Çr and Mo or Ni alloy consumables can overcome the problem of loss or corrosion resistant property.

EXAMPLES

Welding of 25 SMO Steel by TIG Welding Process

During welding of 254 SMO stainless Steel by TIG process without consumable, segregation of molybdenum takes place in the weld area. Mo content in the weld drops to 4% from original level of 6% due to segregation. However, same weld area welded with consumable E1NiCr20 Mo9 (inconel 625 type), exceed the Cr and Mo content of base metal even after segregation.

Welding of Ferritic-Austenitic Stainless Steel

The filler metal used for welding duplex stainless steels is matching except nickel content. An increased nickel content in the weld metal gives optimum mechanical and corrosion resistant properties. While welding duplex stainless steel, heat input should not be too low or too high.

Low heat input results in higher cooling rate which results in high amount of delta ferrite in the HAZ Recommended heat input for welding duplex stainless steel 5 to 25 KJ/CM.

Advantage of duplex stainless steels is their insusceptiblity to chloride stress corrosion cracking.

Nickel Alloys

All welds joints before welding should be perfectly cleaned.

Nickel alloys are welded with matching welding consumables which usually contain TI, Al and or Nb.

All nickel alloys have poor fluidity property, therefore matching welding consumables which are used have selected fluxing ingredients in the coating which have excellent wetting properties. During multipass welding, the oxide layer of the previous layer should be removed by a rotating brush or by grinding.

Postweld heat treatment is not required for welding of nickel alloys.

Table 5 NOMINAL COMPOSITION OF SOME CORROSION RESISTANT ALLOYS

Alloy / Composition	C	Ni	Cr	Mo	Fe	Al	Ti	Nb	Co
INCONEL-600	0.04	76	16	--	7	--	--	--	--
INCONEL-601	0.05	60.5	23	-	14	1.35	-	-	-
INCONEL-625	0.05	61	22	9	3	0.2	0.2	4	-
INCONEL-700	0.12	46	15	3.7	0.7	3	2.2	-	23.5
INCONEL-702	0.04	79.5	15.5	-	0.4	3.4	0.7	-	-
INCONEL-706	0.03	41.5	16	-	4	0.2	1.75	-	29
INCONEL-722	0.04	75	15.5	-	7	0.7	2.5	-	-
INCONEL-x750	0.04	73	15	-	7	0.8	2.5	0.9	-
INCONEL-800	0.04	32	20	-	46	-	-	-	-
INCOLOY-801	0.04	32	20	-	46	-	10	-	-
INCOLOY-802	0.35	32.5	21	-	46	0.58	0.75	-	-
INCOLOY-901	0.05	43	3.5	6.2	34	0.25	2.5	-	-