Stainless Steels in Process Industry Applications

C.V. Manian and M. Suresh
Research & Development, Group II, Larsen & Toubro Ltd., Powai Works, Mumbai-72

Introduction

Process industries are associated with handling, storing and processing of various types of chemicals ranging from acid, alkali, hydrocarbons, inorganic chemicals and water with divergent qualities. In some of the process industries such as refinery and petrochemicals, both extremes in terms of temperature and pressure are likely to coexist, for example cryogenic and fired heaters, and vacuum to high pressure as high as 200 Kg/ cm^2. As a result, the equipment handling these process chemicals demand materials of construction with good corrosion resistance and appropriate mechanical properties. Stainless steels as a class of materials, with wide ranging corrosion resistance characteristics and mechanical properties, fit in these prerequisites very well.

The use of stainless steels for industrial applications in developed countries is about 70% and kitchenware (15%) and appliances (15%) are sharing the rest (1).In India, Stainless steels are utilised in industries for a meagre 20-25% of which about 10 to 14% is in the process sector (1,2). Figure 1 shows the pie diagram for segment-wise consumption of stainless steels in Indian process industries. Table 1 gives the projected demand for the next 5 years. Therefore, there is a good potential for increased use of stainless steels in process industry applications.

Stainless steels

In the commonest applications, where relatively milder process and corrosion conditions are involved, conventional austenitic grades such as 304 and 316, martensitic grades such as 410 and ferritic grades such as 430 are widely used. Table 2 lists the composition of some of these conventional grades.

These conventional grades of stainless steel contain 12-18% Chromium. However, for more corrosive and high temperature conditions, special grades of stainless steels with primarily higher chromium and molybdenum than these grades have been developed. A few other minor alloying elements such as copper, silicon, aluminium and rare earth elements have also been incorporated to provide better corrosion resistance or mechanical properties. Nickel is also higher in some of the high alloy stainless steels. High alloy stainless steels are more often proprietary grades and are also called high performance stainless

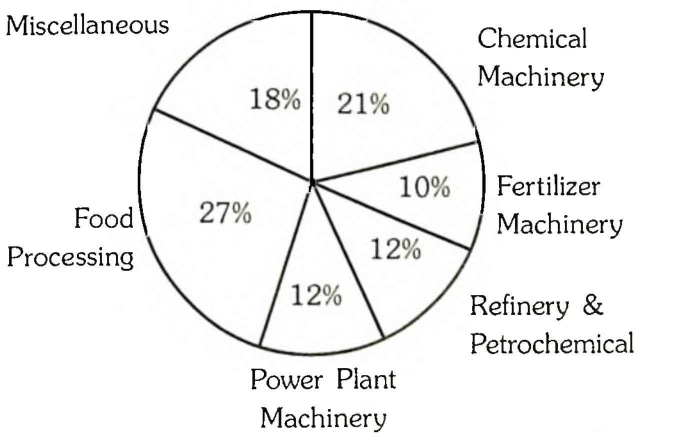

Fig.1: Sectorwise Stainless Steel Consumption in Indian Process Industtries

steels or corrosion resistant alloys (CRA).

High alloy stainless steels for corrosion resistance application in process industries can be grouped into three categories viz., Super austenitic stainless steels, Super Ferritic stainless steels and Duplex stainless steels.

Super Austenitics

Super austenitics Super austenitics are steels with higher content of Chromium, Nickel and Molybdenum. Super austenitics with chromium as high as 28% (for example Sanicro 28), nickel up to 35 % (in HP modified 36X) and 6% (A1 6X) are available. Besides nitrogen (up to 0.20%) and copper (2-4%) are intentionally added. Super austenitics with higher chromium, molybdenum and nitrogen have been deveioped to resist pitting corrosion cracking in chloride-containing media. Along with these elements, nickel helps in imparting chloride stress corrosion cracking resistance. Super austenitics with copper is beneficial in handling corrosive acids such as sulphuric acid and phosphoric acid. Besides, they possess good resistance to chlorine and bromine. Heat resistant super austenitic grades contain Carbon up to 0.4% and higher nickel and chromium. Nickel and Carbon offer creep strength whereas chromium improves oxidation resistance at higher temperatures. Chemical composition of some of the high alloy austenitic stainless steels is provided in Table 3.

Super Ferritic Stainless Steels

Ferritic stainless steels are nickel-free iron-chromium steels with typically chromium up to 29% and carbon up to 0.12%. For aqueous phase corrosion resistance, the carbon level is restricted to a minimum to avoid intergranular corrosion and molybdenum is added up to 4% to improve pitting resistance.

Some of the super ferritic stainless steels are 29Cr-4Mo, 29Cr-4Mo-Ni, 26Cr-3Mo-2Ni and 26Cr-1 Mo the composition of which are given in Table 4.

Super ferritics find extensive applications for low pressure, high temperature heat exchanger applications and have proved to be the best for service in flue-gas handling systems. They possess very good oxidation resistance at high temperatures. Up to 1100°C, they resist attack from sulphurous and carbon oxides in flue gases.

The corrosion resistance of these grades is outstanding in aqueous medium and they can be used for seawater and severe chemical environments. These ferritic stainless steels show excellent resistance or immunity to chloride stress corrosion cracking. In addition, they are suitable for use in oxidising acids, and mixtures of reducing and oxidising acids. Resistance to chloride contaminated organic acids is also excellent for ferritic alloys with 25% or more chromium.

Duplex Stainless Steels

Duplex stainless steels are characterised by a microstructure containing nearly equal parts of ferritic and austenitic phases. They combine some of the best features of both the austenitic and ferritic grades and are sometimes referred to as Ferritic-austenitic stainless steels. They inherit Chloride stress corrosion cracking resistance characteristics of Ferritic stainless steels and better fabrication properties of Austenitic stainless steels. The chemical composition of some of the typical grades is given in Table 5.

The excellent combination of strength and corrosion resistance of duplex stainless steels find particular applications in pump and valve industry for handling sea water, brines and dilute acids. Because of lesser wall thickness, they turn out to be more economical compared to conventional stainless steels in some corrosive applications, where higher strength is an additional requirement.

In this paper, application of various types of stainless steels in key process industries such as fertiliser, oil and gas and power plants have been reviewed.

Fertiliser plants

The major processes in a fertiliser complex are geared for the production of ammonia, urea, sulphuric acid and phosphoric acid and a mixture of various grades of fertilisers. These chemicals are corrosive to many of the materials and the equipment handling these chemicals require careful attention. Further, corrosion incidence of these chemicals is aggravated by the presence of contaminants such as sulphides, chlorides, fluorides and ferric ions present in the process medium. Therefore, proper materials selection is crucial. Stainless steels are widely used in fertiliser plants for the different range of corrosion resistance properties requirement.

Some of the major process plants in fertiliser complex and the equipment with both conventional and high alloy SS metallurgy in these plants are discussed below.

Sulphuric Acid Plant

Sulphuric acid is one of the basic chemicals in many of the process industries, more so in the case of fertiliser plants. Sulphuric acid is produced from many routes. The conventional route has been burning sulphur to form sulphur dioxide, which in turn is converted to sulphur-trioxide followed by absorption in water to produce sulphuric acid. Sulphuric acid is also produced from the sulphur dioxide available as a key by-product in metallurgical operations.

Stainless steels are found useful in the construction of molten sulphur valves, filters, converters, waste heat boilers and absorbers. Another location, wherein SS is used successfully, is in acid coolers. Concentrated sulphuric acid in the coolers is very corrosive at temperature above 100°C, and specially developed silicon containing stainless steels (> 4% Si) are found to resist this attack (4). With anodic protection, even SS 304L /316 L have been utilised for sulphuric acid cooler service without any problem.

Waste heat recovery systems in sulphuric acid plant with the acid temperature of 185-200°C pose very aggressive environments. Here, higher silicon containing stainless steels (5-7%Si) are being successfully used. More details on the SS metallurgy used in Sulphuric acid plant are provided in Table 6.

Phosphoric Acid

Pure phosphoric acid is not very corrosive and conventional stainless steels could be very well used. However, the acid being handled in phosphoric acid plant contains contaminants such as fluorides, chlorides and silicic acid and the corrosion rate of SS 304 and SS 316 grades would be greater than 1 mm per year with the possibility of pitting and crevice corrosion. During concentration, the impurities also get concentrated and hence contribute to the severe corrosive nature in evaporator plant.

In phosphoric acid evaporator plant, concentration is carried out in 3-4 stages from 28% (P_2O_5) clarified acid to 70% P_2O_5 super acid. SS 316L or Alloy 20 is used as material of construction for handling phosphoric acid up to 40% strength. However, phosphoric acid with concentration 40-70% in the final stages are more corrosive with higher concentration of impurities and temperature 121 °C and 177 °C (3).

It is more common to use graphite tubes as the material of construction for higher concentrations in a phosphoric acid evaporation plant. However, because of the high brittle nature of graphite, the tubes tend to break while cleaning the tubes for deposit removal. Stainless steels with higher chromium and molybdenum content and some Copper (1-2.5%) such as Alloy 904L and Sanicro 28 are found useful in such cases. Other stainless steel applications in phosphoric acid plants could be digester, reactor, slurry or acid pumps and filters. Some of the stainless steel grades used in phosphoric acid plants are provided in Table 7.

Nitric Acid Plant

Nitric acid is produced normally by catalytic combustion of ammonia to obtain acid in three different concentrations, viz., < 68%, 68% and 95-99%. For nitric acid up to 70%, for example in preheaters and cooling coils for absorption towers, SS 304 or SS 304L, preferably the latter, is generally used. Stainless steels with chromium content greater than 20%, for example SS 310, are the equipment metallurgy for handling acid up to 70% in gas coolers and residual gas heaters (5). Still better grades such as 904L and Sanicro 28 are required, if the cooling water on the other side is brackish.

For highly concentrated acid at higher temperature however, silicon containing stainless steels are more corrosion resistant. For instance, 1.4361 with 4%Si and Nicrofer 2509 with 7% Si are employed for highly concentrated acid storage and handling in some plants.

Ammonia

In ammonia plants, severe corrosion is encountered mainly in reformers due to reducing environment with CO and H_2 that leads to a phenomenon called metal dusting. Earlier HK-40 was used as the tube material in ammonia reformer. However, better materials such as HP-Mod, Micro alloys and Alloy 800H with higher stress rupture strength are available and have replaced HK-40 centrifugally cast tubing in ammonia plant reformers in the recent past. Alloy 800H tubes possess better ductility and excellent creep strength properties. Similarly alloy 800H has been found very useful for the header, cones, manifolds and pigtails and also the high temperature transfer piping between the primary and secondary reformers and for the quenching system (6).

Ammonia containing environments cause nitridation in reducing environments at higher temperatures. This process is due to the formation of nitrides in the microstructure, which results in local or widespread loss of strength. Nitridation environment could be found in nitric acid and nylon-making processes. Up to about 600°C, stabilised versions of stainless steels such as SS 347 is found to be resistant in nitriding environment.

Urea

Though there are many urea production processes available, they involve mainly the basic reaction of liquid ammonia and gaseous carbon dioxide to form urea. The reaction is carried out in urea reactor at about 160-210°C and 150-200 bar pressure. A corrosive intermediate product known as ammonium carbamate forms and the product leaving the urea reactor is a mixture containing urea, ammonium carbamate, water and excess ammonia.

Subsequently, in the urea stripper unconverted ammonium carbamate and ammonia are separated by using CO_2 or ammonia.

In urea reactor and strippers, even 316L is found to be inadequate and special grades of stainless steels developed for urea service such as SS 316L UG (urea grade) are used. This SS 316L UG contains higher nickel and nitrogen contents, which impart lower corrosion rate and better stress corrosion cracking resistance to ammonium carbamate solution (7).

In high-pressure strippers and ammonium carbamate condensers 1.4466 (Cronifer 2522 LN, Sandvik 2 RE69) is used. High pressure piping in urea plants is often made of Duplex 2205 stainless steel metallurgy.

NPK Plants

In NPK and other auxiliary plants in fertiliser complex, mainly conventional grades are used. Some of the process components making use of SS metallurgy are given in Table 8 (3).

Oil and Gas Industries

Requirement of material properties in oil and gas Industries is mainly corrosion resistance coupled with adequate strength and ductility at process temperature and pressure. Chlorides, hydrogen sulphide, carbon dioxide, and acidic conditions are the widely prevalent corrosive species in the hydrocarbon industry.

The corrosive environment in oil and gas production industries could be classified into two types, viz., sweet and sour.

Sweet Conditions

Sweet environment in oil and gas industries is predominantly with carbon dioxide and H_2S partial pressure less than 0.05 psi. This may also contain varying amounts of brine.

Sweet environment is normally acidic with pH less than 3-5. This is due to the formation of carbonic acid by the reaction between carbon dioxide and water.

$CO_2 + H_2O$ -.H_2CO_3

Carbon steels and SS 304 and SS 316 grades are not suitable for carbonic acid as they corrode at excessive rates. Generally 12-13% chromium containing martensitic stainless steels are the cost effective materials for mild sweet conditions with less chlorides and negligible H_2S and Oxygen (9).

Duplex stainless steels and Incoloy 825 are selected for severe corrosive sweet environment with high amounts of chloride(10). Some of the equipment facing sweet environment in oil and gas industries are listed in Table 9.

Sour Environment

The environment is considered to be sour if the partial pressure of H_2S in the process medium is greater than 0.05 psi. H_2S content in sour environment could be sometimes as high as 28% to 46%. They may also contain carbon dioxide with or without brine.

Sour environment is considered to be very corrosive and only a few materials can withstand without any appreciable corrosion. More than uniform corrosion, many of the metallic materials are subjected to stress corrosion cracking in hydrogen sulphide. NACE (National Association of American Engineers) International standard MR-01-75 'Standard Material Requirements for Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment' (11). NACE MR-O1- 75 standard requirement is included in the materials specification of all oil and gas industries wherever applicable.

13%Cr Martensitic stainless steels, though resistant to sweet conditions, are susceptible to sulphide stress corrosion cracking (SSCC) even in small amounts of H_2S (12). However, with strict control on hardness including on weld zones, it could be used in mild sour environments for example in gas gathering flowlines and Christmas-tree piping. Duplex stainless steels offer better resistance to (SSCC) and other corrosion forms in environments containing H_2S and chlorides. However, duplex stainless steels may have to be stress relieved before putting into service. Sanicro 28 is SSCC resistant even in cold worked condition and is being used in sour gas and oil applications for production tubing, liners, compressor coolers on gas lift platform, casings, crude oil heaters and wire lines. Alloy 825 has increasing resistance to H_2S with increasing temperature and is useful for ipelines carrying 500 psi H_2S even at 150-225°C. Alloy 825 has been extensively used for process piping between the well and the oil/gas/water separators and manifolds (13).

Refineries

Corrosion in refineries is mainly due to chlorides, sulphur compounds and organic acids commonly known as naphthenic acids and the respective components facing these environments should be adequately resistant.

Hydrogen Chloride

Hydrogen chloride (HCl) forms in crude distillation units and to a lesser degree in reforming and hydrotreating units by hydrolysis of chloride salts present in the crude. These chloride salts originate from the crude formation water, brines injected for secondary recovery; from contamination by seawater ballast in marine tankers and/or from aluminium chloride catalyst. Hydrogen chloride is formed primarily from chlorides aluminium, calcium and magnesium contaminants and not from sodium for chloride. Hydrogen chloride thus rmed at temperature above 120°C is in vapour form and is not corrosive in the dry form. However, wet HCl a killer wherever it condenses below water dew point and corrodes the equipment at excessive rates. Normally HCl acid corrosion occurs in crude distillation units on overhead exchanger tubes and top column trays.

Super austenitic stainless steels such as Sanicro 28 could be used in these areas. These stainless steels resist corrosion by not only HCl but also H_2S, which is present the crude (14).

Sulphur Compounds

Even if a crude containing lower H_2S is used, the refinery equipment at temperatures above 230°C are reported to face hot sulphide corrosion. This is mainly due to the decomposition of organic sulphur containing compounds present in the crude oil, which decompose and form corrosive H_2S. At high temperatures and partial pressures of hydrogen sulphide, H_2S presence causes cracking problem in the case of carbon steel and alloy steels. 12% Cr stainless steels are however resistant to such cracking and is normally used as the metallurgy for hot portions of preflash, hotter heat changers and associated pumps and valves. In areas of higher turbulence and for higher H_2S concentrations, 17% Cr stainless steels would be a better material of construction (15).

Naphthenic Acid

Organic acids are always present in crude oil as naphthenic acid or saturated ring acids. Naphthenic acid is thermally stable and tends to concentrate in the atmospheric and vacuum columns in the true boiling point range of 204-427°C. Naphthenic acid causes corrosion of low alloy steels, when the total acid number measure of any organic acid concentration) is above 1.7. Vacuum furnace, furnace transfer lines, column flash zone, thermo wells and orifice plates are normally affected by naphthenic acid. Even

12% Cr and 17%Cr stainless steels and SS 304 are not reliable for crude containing napthenic acid in such applications. Austenitic stainless steels containing molybdenum have provided good resistance to naphthenic acid crrosion. Usually SS 316 L or SS 316 Ti with molybdenum > 2.5 wt. % is used. Alternatively, SS 317L (3-4% Mo) could also be used to tackle naphthenic acid corrosion problem (15).

Refinery equipment using stainless materials of construction have been compiled in Table 10 (16).

High Temperature Corrosion

High temperature applications in process industries call for materials with high stress-rupture strength, good ductility, adequate stability and low coefficient of thermal expansion. Most common process temperatures, especially in oil refining and petrochemical plants range from 450-800°C and higher.

Stainless steels as a family of materials possess very good creep properties at high temperatures. Normally for high temperature applications up to about 700°C, martensitic type stainless steels containing 12-14 % chromium are used. Stabilised and unstabilised versions of 300 series Austenitics and Ferritic stainless steels with chromium up to 27% are used for still higher temperatures. If higher creep properties are needed, Austenitics with more than 8% Ni such as AISI 310 (20% Ni) are employed.

More often, the processing gaseous environment at high temperature carries impurities such as carbonaceous and sulphurous compounds, nitrogen, ammonia, hydrogen, the halogens, ash and molten posits. These constituents are very corrosive and act separately or synergistically to the material degradation at higher temperatures. Therefore, alloy selection for high temperature applications in power industries should be based on the resistance to these environments.

Stainless steels for heat as well as corrosion resistant applications are normally alloyed with higher nickel, chromium and silicon. Besides, Al Ti, Cb, W, and rare earth elements are added in some of the grades. Nickel and silicon contribute to creep resistance and Si, Cr and Al offer resistance to high temperature oxidation. Small amounts of rare earth elements such as yttrium, cerium, and lanthanum in these stainless steels develop more resilient scale that delays oxidation and other high temperature corrosion problems such as sulphidation(17).

Carbonaceous environments such as hydrocarbon gases or carbon monoxide cause a corrosion process at higher temperatures, commonly called as carburisation or metal dusting. Carburisation causes formation of metallic carbides on the metal surface or inside that results in loss of mechanical properties such as strength and ductility. Alloys such as SS 430, 300 series experience carburisation at 675-700°C temperature.

High alloy austenitics with silicon are found to have good resistance to carburisation. For example, in pyrolysis piping in ethylene and olefin plants, high alloy austenitics such as HK alloys and Alloy 800H are used to resist carburisation. Also in reformer plant furnace tube applications use of HH, HK, HP alloys and In 519 alloy is common.

In hydrogen containing environments such as hydrotreating, reforming and hydrocracking in refineries, stainless steel cladding is used to resist hydrogen attack of carbon and alloy steels.

Sulphurous environments at high temperatures cause severe corrosion problem to process equipment called suiphidation. Austenitic types such as SS 310, and Alloy 800 are normally used for sulphidation resistant applications such as that exists in coal gasifiers (16).

Some of the stainless steel grades used at elevated temperatures are listed in Table 11.

POWER PLANTS

Stainless steels find their use in power plants in steam generation systems, combustion systems and cooling water systems.

In steam generation circuit, stainless steels are used mainly for low pressure feed water heater, boiler feed water pumps, evaporators, super heaters, generator blades, valves, chemical dosing pumps and chemical storage tanks.

Typical uses in combustion systems include insulation cladding material for furnace wall, super heater tube supports, chimney liners and surface condenser tubes. Stainless steels are also used in flue gas handling systems such as flue gas desulphurisation. Flue gas desulphurisation (FGD) systems are located between the boiler and smoke stack of fossil fuel power plants to treat effluent gases to remove SO_2 and other pollutants. In FGD systems, both the extreme corrosive conditions viz., high acidic and higher chloride exist. Depending on the pH and chloride levels, various grades of stainless steels are chosen(18).

In the power plant cooling water circuit, stainless steels find their use mainly in surface condensers and other auxiliary heat exchangers such as gas turbine coolers and lube oil coolers. The cooling water quality normally dictates the selection of materials for tubes, tubesheets and other parts of the heat exchangers. Cooling water used in power plant could be classified as fresh water, brackish water and seawater.

For fresh water with good cleaning programme, SS 304 or SS 316, preferably the latter, is used. For brackish water with more salinity, higher alloy stainless steels such as SS 446, E-Brite, Alloy 20 and Duplex stainless steels are used {19). For seawater handling however, only high performance stainless steels such as super austenitics, super ferritics and super duplex stainless steels are reported to be useful. Some of the potential seawater grade tubes for seawater condensers are Avesta 254 SMO, AL-6X, 29-4-2 super ferritics etc., More details on the stainless steel grades used in power plant is provided in Table 12.

COnclusions

With the potential growth in Indian Industry in the core sectors, there is bound to be significant increase in the application of stainless steels for various applications. However, each of these cases merit individual assessment in terms of service conditions, environment, contaminants, utility and economical viability. It is very important that the material selection is based on long-term life-cycle costs, rather than on direct capital cost comparison. In such a probability scenario, stainless steels would justify their selection in a majority of the applications.

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Table 1: Projected Stainless Steel Demand for Process Industries in India

SECTOR	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Chemical Machinery	12752	12944	13154	13765	14416	15106
Fertilizer Machinery	5956	5	7206	79Z7	8719	9591
Refinery & Petrochemical	6952	7508	8113	8770	9486	10266
Power Plant Machinery	7422	7797	8191	3609	9048	9511
Food Processing	16683	18609	207B3	232B9	26119	29323
Miscellaneous	10568	11116	11719	12383	13114	13917
TOTAL	60333	64525	69166	74743	80902	87714

Source: NiDI ISSDA

Table 2 Nominal Composition (Wt%) of Conventional Stainless Steels

ALLOY	Fe	Ni	Cr	Mo	Mn	Si	C	Other
AUSTENTIC								
Type 304	bal	9.0	19.0	-	2.0	-	0.75	0.08
Type 316	bal	11.0	17.0	2.0	2.0	-	0.75	0.08
Type 321	bal	10.0	18.0	-	2.0	0.5	0.05	0.4 Ti
Type 347	bal	11.0	18.0	-	2.0	0.5	0.05	0.04 Nb
FERRITIC								
Type 405	bal	-	11.5-14.5	-	1.0	1.0	0.08	0.1-0 3 A1
Type 409	bal	-	10.5-11.75	-	1.0	1.0	0.08	6X%C Ti
Type 429	bal	-	17.0	-	1.0	1.0	0.12	-
Type 430	bal	-	17.0	-	1.0	1.0	0.12	-
Type 436	bal	-	17.0	0.75-1.25	1.0	1.0	0.12	Nb+Ta
MARTENSITIC								
Type 410	bal	-	12.0	-	1.0	1.0	0.15	-
Type 431	bal	1 25-2.5	16.0	-	1.0	1.0	0.20	-
Type 440	bal	-	16.0	0.75	1.0	1.0	0.6-0.75	-

Table 3 Composition of some of the High Alloy Austenitic Stainless Steels

DESIGNATION	UNS NO.	COMPOSITION, %+B20								
		C	Mn	Si	Cr	Ni	P	S	Mo	Others
Type 309S	S30908	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	-	-
Type 309S Cb	S30940	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	-	8x%C min Nb
Type 309 Cb+Ta	-	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	-	8x%C min Nb+Ta
Type 312	-	0.15	2.00	1.00	30.0 nom	9.0 nom	0.045	0.03	-	
Type 317LM	-	0.03	2.00	1.00	18.0-20.0	12.0-16.0	0.045	0.03	4.0-5.0	-
Type 330HC	-	0.40	1.50	1.25	19.0 nom	35.0 nom	-	-	-	-
Type 332	-	0.04	1.00	0.50	21.5 nom	32.0 nom	0.045	0.03	-	-
904L	N08904	0.02	2.00	1.00	19.0-23.0	23.0-28.0	0.045	0.035	4.0-5.0	1.0-2.0 Cu
20Cb-3	N08020	0.07	2.00	1.00	19.0-21.0	32.0-38.0	0.045	0.035	2.0-3.0	3.0-4.0. Cu, Nb
AL-6X	N08366	0.03	2.00	0.75	20.0-22.0	23.5-25.5	0.030	0.003	6.0-7.0	-
Crutemp 25	-	0.05	1.5	0.4	25.0	25.0	-	-	-	-
JS-700 0.005pb	N08700	0.04	2.00	1.00	19.0-23.0	24.0-26.0	0.04	0.03	4.3-5.0	0.5 Cu, Nb
JS-777	-	0.04	2.00	1.00	19.0-23.0	24.0-26.0	0.045	0.035	4.0-5.0	1.9-2.5 Cu
Nitronic 40(XM-10)	S21900	0.08	8.0-10.0	1.00	18.0-20.0	5.0-7.0	0.06	0.03	-	0.15-0.40N
Nitronic 50(XM-19)	S20910	0.06	4.0-6.0	1.00	20.5-23.5	11.5-13.5	0.04	0.03	1.5-3.0	0.2-4N,Nb,V

Table 4 Typical Composition of some of the High Alloy Ferritic Stainless Steels

DESIGNATION	UNS NO.	COMPOSITION, %(b)								
		C	Mn	Si	Cr	Ni	P	S	Mo	Others
E-Brite 26-1(XM-27)	S44625	0.01	0.40	0.40	25.0-27.05	0.5	0.02	0.02	0.75-1.5	0.015N, 0.2 Cu
26.1 Ti(XM-33)	S44626	0.06	0.75	0.75	25.0-27.0	0.5	0.04	0.02	0.75-1.5	0.04N, 0.2Cu, Ti
29-4	S44700	0.010	0.30	0.20	28.0-30.0	0.15	0.025	0.02	3.54.2	-
29-4-2	S44800	0.010	0.30	0.20	28.0-30.0	2.0-2.5	0.025	0.02	3.54.2	-
Monit	S44635	0.25	1.00	0.75	24.5-26.0	3.54.5	0.04	0.03	3.54.5	0.3-0.6(Ti+Nb)
Sea-cu re/Se-1	S44660	0.025	1.00	0.75	25.0-27.0	1.5-3.5	0.04	0.03	2.5-3.5	(Ti+Nb)

Table 5 Typical Composition of Selected Duplex Stainless Steels

DESIGN	Cr	Ni	Mo	C	N	OTHERS	% FERRITE
2205	22	5.3	3	0.025	0.15	-	45-60
Mannesmann AF22	21-23	4.5-6	2.5-3.5	0.03	-	-	50-65
Carpenter 7Mo	23-27	5-7	1.2	0.05	-	-	85
Zeron 100	24	7.3	4	0.03	0.22	.7Cu,0.7	-
Nippon 25Cr, SNi, 2Mo	25	5	2	0.025	0.15	1.0Cu	-
AISI 326	26	6.5	-	0.05	-	0.25Ti	-
AISI 329	26-28	4.5-6.0	1.5	0.08	-	-	60-70
Ferrallium 255	25	5.5-6.0	3	0.04	0.2	2.0Cu	-
44LN	25	6	1.7	-	0.15	-	-
Atlas 958	25	7	4.5	-	0.25	-	-

Table 6 Stainless Steel Materials in Sulphuric acid Plant

EQUIPMENT	STAINLESS STEEL GRADE
Sulphur filter	SS 316
Valves for molten sulphur	FA 20
Valves for (93-98%) sulphuric acid Acid coolers	Alloy 20 Saramet, SX and D 205
Waste heat recovery boilers	Remanit 4575, Cronifer 2803 Mo
Mist Eliminator	Alloy 20, Alloy 20Cb3 or Alloy 904

Table 7: Stainless Steel Materials in Phosphoric acid Plant

EQUIPMENT	STAINLESS STEEL GRADE
Digesters and Reactor agitators	SS 317, HV 9
Slurry and acid pump	HV 9, Carpenter 2,CD4MCU, Jessop 700, Worthite
Filter cloth Filter pan	SS 316 Carpenter 20, SS 317
Concentration Section	Sanicro 28, Fermanel

Table 8 Stainless Steel Equipment in NPK & other Auxiliary Plants in Fertilizer Complex

Equipment	Materials of Construction
NITROPHOSPHATE PLANT	
Ammonia Vapouriser Tubes Acidulated Reactor (Agitated vessels) Exhauster fan	SS304L SS316L with water jacket SS 316L
AMMONIUM NITRATE PLANT	
Dissolving Reactor, Phosphate solution handling units, Crystallizer, Preneutraliser, CN reactor & scrubber, AN En. Unit, Neutralisation, heater/Evaporator/ Separator Decanter, Centrifuge Prilling machine & Buckets Fluidized bed cooler	SS 304L SS 316L wetted parts SS 347 1.4549 SS
NITRIC ACID PLANT	
Absorption tower, Degassing Column Ammonia Burners Absorption column	SS304L SS310 & 304L SS304 LN
SODIUM NITRITE PLANT	
Columns for Absorption Centrifuge, Crystalliser, Evaporator	SS 347 SS 304L

Table 9 Equipment subjected to Sweet Corrosive Environment in Oil and Gas industries.

Well head equipment
Tubulars
Valves
Tubing hangers
Undersea pipelines
Oil and gas separator

Table 10 Stainless Steel Components in Refineries

COMPONENTS	STAINLESS STEEL GRADES
FLUID CATALYTIC CRACKING	
Regenerator, Reactor hanger rods	SS 321, 347
Air distributor, flue gas collector, cyclones, over head lines, trays, dip legs	SS 304
Overflow valves, valve stems, reactor liner & cyclones Fractionator	SS 304, SS 405, SS410 SS 405, SS 410
Overhead condensers	Duplex 329, AL-6X, 29Cr-4Mo
DELAYED COKING	
Cokers	SS 405, SS 410 clad or solid
Pumps, heaters, transfer piping, stripper	SS 410, SS 304, SS 316
Coke drums	SS 304, SS 316
Recycle heat exchangers, fractionator overhead condenser	SS 304, SS 316, 18-2 SS, Al-6X, 29Cr- 4Mo 4Mo
HYDROTREATING	
Hydrodesulphurisation and hydrorefining equipment	SS 404, SS 410, SS 430, SS 304, SS 321, SS 347 and SS 308 for weld overlay. (SS 321 or SS 347 for polythionic acid cracking resistance)
Feed Effluent heat exchanger, reactors, Fractionator feed exchanger, fractionator tray	SS 430, SS 304, SS 321 or SS 347
Hot piping, pill box, fired heater tubes, bed supports, reactor trays, nozzles	SS 304, SS 321 or SS 347
Reactor effluent heat exchanger shell	SS 304 clad
CATALYTIC REFORMING	
Catalyst support devices, screes, trays, down comer and beams	SS 304
Final reformer cooler	29-4 ferritic SS
HYDROCRACKING	
Desulphurisation section	SS 304, SS321, SS347, SS410, SS430
Feed effluent heat exchanger	SS 430, E-brite 26-1, 18-2SS, SS 321, SS 347
Feed heater	SS 304, SS 321, SS 347
Furnace tubes	Aluminised SS, SS 347, SS 321
Reactor shell, nozzle	SS 347 clad, SS309, SS308 weld overlay
Air cooler	SS 330
HYDROGEN PLANTS	
Super heater tubes	304, 330 seamless or welded
Reformer	HK40, HK-Mod, Alloy 800
Steam generator, effluent heat exchanger, shift gas piping, solvent reboiler, air cooler, Amine plant equipment	SS 304
FLUID CATALYTIC CRACKING	
Columns, trays, deethaniser,	SS 316
Compressor coolers,	SS 316, SS 329, 26Cr-1 Mo, AL-6X, 29Cr-4Mo
Reboilers	316 lined shell, SS 329, SS 330, 20Cb-3 or AL-6X, 29Cr-4Mo tubes
Depentaniser	SS 329, SS 330, 26Cr-1Mo preheater SS 410, SS 304, SS 316 columns and trays

Table 11 Nominal Composition of Stainless Steels used for High Temperature Applications

ALLOY	UNS No.	Fe	Ni	Co	Cr	Mo	W	Al	Si	C	Others
Type 304	S30400	bal	9	-	19	-	-	-	0.75	0.08	
Type 316	S31600	bal	11	-	17	2	-	-	0.75	0.08	
Type 317	S31700	bal	12	-	18	3	-	-	0.75	0.08	
Type 309	S30900	bai	13	-	25	-	-	-	0.5	0.15	
Type 310	S31000	bal	20	-	25	-	-	-	0.5	0.15	
Type 321	S32100	bal	10	-	18	-	-	-	0.5	0.05	0.4Ti
Type 347	S34700	bal	11	-	18	-	-	-	0.5	0.05	0.04Nb
Type 410	S41000	bal	-	-	12	-	-	-	-	0.1	
Type 430	S43000	bal	-	-	17	-	-	-	0.4	0.10	
Type 446	S44600	bal	-	-	25	-	-	-	0.8	0.20	
E-Brite*(XM-27)	S44627	bal	-	-	26	1	-	-	-	0.01	0.1 Nb
RA* 85H		bal	14.5	-	18.5	-	-	1.0	3.5	0.20	
Type HH	J93503	bal	12	-	25	-	-	-	1.4	0.40	
Type HK	J94224	bal	20	-	25	-	-	-	1.5	0.40	
Type HP		bal	35	-	25	-	-	-	1.5	0.4	1.5 Nb
Type HT	J94605	bal	34	-	17	-	-	-	1.2	0.40	
IN-519		bal	24	-	24	-	-	-	1.5	0.35	1.5 Nb
RA*330	N08330	bal	34	-	19	-	-	-	1.2	0.05	
Fecralloy		bai	-	-	16	-	-	4.7	-	0.02	0.3 Y
Incoloy* DS		bal	37	-	18	-	-	-	2.20	0.03	
Alloy 800	N08800	bal	32	-	21	-	-	0.2	0.4	0.04	0.4 Ti
Alloy 800H	N08810	bal	32	-	21	-	-	0.2	0.4	0.10	0.4 Ti
Haynes* 556 La	R30556	bal	20	18	22	3	2.5	0.2	0.4	0.1	0.6 Ta, 0.02
Multimet*	B30155	bal	20	20	21	3	2.5	-	1.0	0.08	1.0 Nb/Ta
HK40		-	20	-	25	-	-	-	1.50	0.40	
Hp Mod, 36X		-	35	-	25	-	-	-	1.50	0.40	
Hp Mod, 36XS		-	35	-	25	-	Present		1.50	0.45	

Table 12 Stainless Steel Grade I\Materials Used in Power Plant

EQUIPMENT	STAINLESS STEEL GRADE
LP Feed water heater	SS 304, SS 304L
Economiser for high S fuel	SS 316L, Alloy 20
Boiler Feed water pump	SS 304 or SS 316
Outer layer of Evaporator tubes	SS 310
Super heater tubes	SS 304, SS 321, SS 347 and SS 310
Chemical dosing pumps	SS 304 or SS 316
Generator blades	Modified 12% Cr Stainless steels such as ASTM Types 615 and 616, Custom 450
Super heater tube supports	SS 310
FGD	SS 316L, SS 317L, Alloy 20, Duplex
	2205, Incoloy 825
Chimney stack liner	SS 316 or Alloy 20
Surface condenser	Various grades