STAINLESS STEEL WELDING & APPLICATIONS

–A BRIEF REVIEW

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The world as we know it today owes immensely to the development of stainless steel. Right from the pen you hold to write a letter, to the stainless steel utensils in your kitchen, to the huge tanks and vessels in chemical and petrochemical industries, to the building of huge ships, to the critical components in the power generation industries, to the space shuttles that put man on the moon, stainless steel in its myriad forms has permeated every area of human activities.

What makes stainless steel so indispensable in the world of fabrication today is its ability to handle a wide range of corrosive media, excellent mechanical properties with good formability and weldability and its capability to be tailor made to suit the application at hand. The applications may be as varied as simple corrosion resistance, as that found in stainless steel utensils and office furniture, to the highly critical service conditions like that of very low temperature toughness in cryogenic service and maintenance of mechanical properties under severely corrosive, high temperature conditions like that found in thermal power plants. To handle this wide variety of service conditions an expansive variety of stainless steels are available tailor made to suit the particular service condition. And this huge expanse of stainless steel is ever increasing as the material scientists the world over develop, newer varieties of stainless steels which are better and in most cases cheaper than its predecessors, as better economy without a compromise on the basic properties is one of the most critical deciding factors in the industry today. This constant flux of ever increasing varieties of stainless steels poses a challenge to the development of suitable welding consumables and processes to meet the fabrication requirement of the industries concerned.

In India the stainless steel market may be divided broadly into six market segments:

(1) Chemical & petrochemical industry	–30%
(2) Fertilizer industry segment	–10%
(3) Power sector segment	–10%
(4) Ship-building industry segment	– 5%
(5) Heavy Engg & construction segment	–40%
(6) Transport segment	– 5%

Let us analyze each of these segments in some detail :

CHEMICAL AND PETROCHEMICAL INDUSTRY

The Chemical and petrochemical industry is going through a boom phase as some very large petrochemical complexes are coming up like that of Reliance Industries in Jamnagar, Haldia Petrochemical etc. Stainless steel materials forms a very intrinsic part of a petrochemical complex as most of its vessels and tanks are exposed to severe corrosion from simple general corrosion to pitting corrosion to high temperature intergranular corrosion all of which necessitates the use of various grades of stainless steels like the 18Cr 8 Ni type (304, 304L) to the pitting corrosion resistant Mo bearing grades to the intergranular resistant Nb bearing stainless steel grades (321, 347, 348 type). In such an industry it would be safe to approximate the following break-up for the main types of stainless steel electrodes used:

E308 & E308L	30%
E316 & E316L	30%

E309 & E309L	15%
E347	25%

In India though a major portion (65%) of the fabrication of stainless steel consumables is still carried out through MMAW, other processes like MIG / TIG welding, Submerged arc welding, Flux cored welding, and new processes like Electroslag strip welding are gaining increasing popularity.

FERTILIZER INDUSTRY

The fertilizer industry plays a key role in the Indian economy as India's is primarily an agricultural economy. The production of fertilizers like Urea lead to very corrosive atmospheres, hence its production units require special fabrication and that is achieved by E316L with low ferrite. The fertilizer industry also uses E308 and E316 in good quantities in fabrication as well as for annual maintenance.

POWER SECTOR

In the power sector, stainless steel is used in large quantities in the fabrication of high temperature components that are exposed to high temperatures hence running the risk of poor high temperature strength, intergranular corrosion, etc. Stainless steels find wide use in many forms from the simple E308 and E308L type to the E310, E410 type consumables which are resistant to high temperature oxidation, and E347 type for high temperature intergranular corrosion resistance.

SHIP BUILDING INDUSTRY

This industry though is still not very stainless steel intensive, new varieties of stainless steel are finding increasing acceptance in this segment. The Duplex stainless steels and its newer evolution the super duplex stainless steels are being used as it provides the same pitting and crevice resistance as some of its older counterparts like bronze used to provide and at much lesser cost. Though care has to be taken to weld duplex stainless steels, today specialized duplex and super duplex steel compatible welding consumables are available with excellent welding expertise backing it to provide for trouble-free weld joints.

HEAVY ENGINEERING AND CONSTRUCTION INDUSTRY

Traditionally this is the segment that accounts for the largest share of the stainless steels that are used in our country and hence the maximum share of stainless steel welding consumables. This industry is not really stainless steel electrode specific and uses simple stainless steel electrodes (E308, E308L, E316, E316L, E309, E309L) to more alloyed varieties like E309Cb, E309Mo, E310LMo, E347 which are all used for their respective properties like high temperature resistance to intergranular corrosion (E347) oxidation (E410) etc.

This segment is also the most sensitive to high productivity and as such is most readily open to new technologies that show promise of high productivity and satisfactory quality. Innovative technologies like electroslag strip cladding (with productivities at least twice that of conventional submerged arc strip cladding) are finding rapid acceptance by such large Heavy Engineering giants as Larsen & Toubro, BHEL, etc. New generation fluxes and wires for this technology and other innovative variations of the existing technology (like flux-cored wire submerged arc welding, etc.) are available and are creating a new awareness of the expanse of welding technology.

TRANSPORT SEGMENT

The Transport segment in India is still not very stainless steel intensive in comparison with its counterparts in the developed countries. The major areas of application of stainless steels is in the automobiles sector, railway transport etc. The main use of stainless steels in this segment is for surface protection against atmosphere, and in catalytic converters, etc. The main use of stainless steels in this segment is for E308, E308L type. The type E347 for high temperature intergranular corrosion resistance is also used though to a lesser degree. In the aviation sector, stainless steels have given way to aluminium and its alloys like Duralumin in a major way. In the Railways sector, the use of stainless steel is limited to repair and maintenance.

In response to the ever increasing material property demands from the various industry segments, material scientists have developed ever increasing varieties of stainless steels, tailored to suit the highly critical service conditions like high and low temperature toughness on the one hand, to developing cheaper varieties of stainless steels without compromising on the basic qualities of stainless steels, as in the case of duplex stainless steels and super duplex stainless steels.

EVOLUTION OF STAINLESS STEEL GRADES

We may study the evolution of stainless steels from the traditional grades to the super duplex stainless steels of today as under :

The traditional varieties of stainless steels that are used for traditional jobs like the fabrication of chemical plants and equipment are AISI 304, 316 along with their low carbon varieties 304L, 316L and the stabilised grades 321, 347 and 318 where intercrystalline cracking is avoided. The Moly bearing grades 309, 309L are used where resistance to pitting corrosion or improved general corrosion resistance is desired and also for high temperature applications such as preheaters, vessel liners, furnace liners and trays etc. The ferritic AISI 430 grade is also used where high temperature oxidation resistance is required. It is also used in nitric acid plant and for applications involving stress corrosion conditions in chloride ion media. The traditional varieties of stainless steels suffer from various limitations which have led to the development of the next generation of stainless steel grades :

Limitation : Low proof stress - 35% of UTS

Development : **High proof strength Nitrogen alloyed steels.** These steels are nitrogen bearing varieties of AISI 304L, 316L, 317L designated as 304LN, 316LN, 317LN ; besides higher 0.2% proof stress have improved austenitic stability.

Limitation : Sensitive to stress corrosion cracking (SCC) in acidic Cl- or F-ion media above 70° C and also hot caustic soda.

Development : **Duplex steels.** These steels have reduced nickel content, below 6% as at these levels the stainless steels are much lesser susceptible to SCC when compared to the traditional 316 grades. These steels have been used in heat exchangers for fertilizer plant, digesters and preheaters for sulphite pulps, suction rolls in the industry, centrifuge baskets, etc.

Development : **Super Duplex Steels.** These steels combine the very useful mechanical properties of duplex stainless steels with the corrosion resistance of some of the super austenitic stainless steels. This is achieved by increasing Cr to about 25% and Mo up to 4% to improve pitting corrosion resistance and by increasing Ni to about 7% and N to about 0.25%, also to increase pitting resistance and maintain microstructure balance. Some of the Super duplex steels also contain Cu and W. Mostly weldmetal is over alloyed with Ni by about 2-3% which ensures that the weldmetal will have the right microstructure balance even under conditions of rapid solidification. That means sufficient austenite to give corrosion resistance and toughness and sufficient ferrite to give stress corrosion cracking resistance and strength.

Development : **Super ferritic stainless steels.** These are basically ferritic stainless steels with 18-27% Cr and 1-2% Mo with very low interstitial elements (C+N+O < 0.1 %). However, they should not be used for service temperature above 300°C as they are susceptible to 475°C embrittlement. These steels have been successfully used in heat exchangers, handling of hot caustic soda, handling sea water and also for bleaches in the paper industry.

Limitation : Sensitive to pitting corrosion in more aggressive acid chloride media.

Development : Molybdenum has been found to be the single most effective element to resist pitting corrosion by chloride and fatty acids at high temperatures. Steels of the types 317LM (18% Cr ,15% Ni 4Mo), 317L plus Allegheny have found wide use in thermal power plants, steam condenser tubing in coastal sea water operated power plant, etc.

Limitation : Preferential attack on the ferrite phase in strong oxidizing phase in strong oxidizing media (urea carbonate).

Development : A modified **E316L** (with 4-5% Mn) having much improved resistance to micro-fissuring and cracking even with fully austenitic weld metal. A modified version of AISI 310 composition steels have been developed *e.g.,* Assab 725LN (0.11C, 25Cr, 22Ni, 2Mo, 0.1N) which have good service properties in strong oxidizing media like that found in modern fertilizer plants.

Limitation : Inadequate corrosion resistance in reducing media such as hot phosphoric acid or sulphuric acid.

Development : Steels of the type 20Cr-20Ni-4Mo-2Cu have been developed. Due to the presence of Cu and increased Ni content, these steels give much superior service in reducing conditions. These steels find wide applications in fertilizer plants and chemical plants, power plants, and for flue gas scrubbing equipment handling sea water.

Limitation : Poor strength at high temperatures and also the traditional stainless steels tend to become brittle when cooled to room temperate after prolonged use at elevated temperatures.

Development : Casting alloys such as HK-40 (0.4%C 25%Cr 20%Ni) have been developed for applications requiring higher creep strength and find use in steam and hydrocarbon reformers, naphtha cracking furnaces, etc., in the petro-chemicals and fertilizer industry. For headers and manifolds, the more ductile 20Cr 32Ni alloy is used. The IN 657 (0.05%C 50%Cr 49%Ni and Nb) has been developed for high temperature use in highly corrosive atmospheres such as sulphur, sodium and vanadium from residual fuels.

Limitation : Very high strengths are not possible to obtain using the traditional grades of stainless steels for applications where a combination of wear and corrosion resistance is important.

Development : **Precipitation hardened stainless steels.** These steels develop extremely high strengths by a heat treatment process where advantage is taken of both mertensitic hardening and precipitation hardening mechanisms. These steels are available as forgings, castings, bar and plates and are used for compressor blades, pumps, gears for metering chemicals and similar applications.

TYPES OF CORROSION

The most important property of stainless steels is its resistance to corrosion in many different types of environment. In this section we will discuss briefly these different types of corrosion.

Stainless steels are protected against corrosion by a very thin layer of chromium oxide which is formed on the surface of the metal. This passive layer can be damaged by mechanical or chemical action. If the protecting layer is destroyed in an aggressive media, the metal will corrode.

General Corrosion : is a corrosive attack that proceeds at the same velocity over the entire surface. It occurs almost exclusively in acidic or in strongly alkaline solutions. The resistance against general corrosion is mainly improved by increasing the content of Cr and Mo in steel.

Intergranular Corrosion : is a localized attack at and adjacent to the grain boundaries. Some stainless steels can be made sensitive to intergranular corrosion by elevated temperatures (500-900°C) at which carbide precipitation occurs at the grain boundaries resulting in Cr depleted regions. These regions have a decreased corrosion resistance. The precipitation of chromium carbides can be prevented either by a low C content or by a stabilizing element like Nb or Ti.

Pitting Corrosion : is a type of localized attack which is highly destructive, resulting in holes in the metal. This kind of attack is most commonly found on stainless steels in chloride containing environments. The resistance to pitting is improved with increased Cr and Mo contents. Also N has a favorable influence. The pitting resistance equivalent, PRE, is a way of describing the relative influence of the mentioned elements. One way of expressing is PRE=%Cr +3.3%Mo +16%N. The maximum temperature at which a specimen in a special test solution shows no signs of pitting corrosion is called the Critical Pitting Temperature (CPT).

Crevice Corrosion : is a kind of corrosion which occurs in narrow crevices fIlled with a liquid and where the oxygen level is very low, *e.g.,* on gasket surfaces, lap joints and under bolt and rivet heads.

A special form of crevice corrosion is called the deposit corrosion. This is when the corrosion is found under non-metallic deposits or coatings on the metal surface. Steels with good corrosion resistance to pitting corrosion have also good resistance to crevice corrosion.

Stress Corrosion Cracking (SCC): is a corrosion attack on a metal subjected to a tensile stress and exposed to a corrosive environment. During stress corrosion cracking, the metal or alloy can remain virtually unattacked on most of its surface while fine cracks progress through it. For austenitic steels, the risk of SCC is especially more in solutions containing chlorides or other halogenides. The risk increases with increasing salt concentrations, tensile stress and also increased temperatures. SCC is seldom found in solutions with temperatures below 600°C.

The resistance of the austenitic stainless steels is improved by increased Ni content. The ferritic Cr steels totally without Ni are under normal conditions insensitive to SCC as well as steels which are ferritic-austenitic.

WELDING OF STAINLESS STEELS

In this section we will discuss in brief the welding of stainless steels which find the majority of applications in the industry.

Welding Austenitic Steels

Austenitic stainless steels of the standard grade such as 304L and 316L and the stabilized steels 321 and 347, are the most frequently used grades for welded structures in stainless steels. The weldability of these steels is generally excellent and presents few metallurgical problems since no phase transformations takes place. The weldmetal have the same corresponding composition as that of the base metal, the only difference being that the weldmetals are designed to produce some ferrite, which has a beneficial effect on the resistance to solidification cracking. Low carbon weldmetal are generally used except in high temperature applications where high carbon and low ferrite is essential to retard sigma phase transformation and for creep strength. In the case of critical applications, a higher molybdenum content is recommended to ensure that the minimum level of molybdenum in the segregated weldmetal is at least as high as that in the steel itself. 317L weldmetal is used frequently to weld 316LN to produce not only increased corrosion resistance but also to match the strength of the base metal.

Welding Super Austenitic Steels

These steels are high alloyed austenitic steels with an increased molybdenum content up to 6% Mo. These steels have very high resistance to pitting and crevice corrosion. When the Ni content is greater than 18%, the austenitic steels also have enhanced resistance to stress corrosion. The weldmetal should be over-alloyed in terms of molybdenum to ensure that the minimum level is sufficient. At a molybdenum content greater than 5-6%, it is, however, necessary to use a nickel based weldmetal in order to have the same corrosion resistance as the base metal. Weldmetals are alloyed with Mn to improve their resistance to solidification cracking and residues and the oxygen content is kept at a low level. For flux processes such as MMA and SAW, a basic flux improves hot cracking resistance.

Welding Duplex Stainless Steels

The modern nitrogen alloyed duplex steels have fair weldability, but the difficulties increase as the complexity of the alloy increases.

It is very important to control the heat input in relation to heat dissipation (plate thickness) with regard to the effect on the austenite/ferrite ratio. A heat input of between 0.5-2.5 kJ/mm is a normally accepted limit for duplex steels, but the heat input should be kept lower, *i.e.,* 0.2-1.5 kJ /mm for the super duplex types. The interpass temperature should not exceed 150°C. Chromium, molybdenum and nitrogen in weldmetal should be of the same minimum level as in the base material to match the pitting and crevice corrosion. The Ni content is increased to about 9%, thereby ensuring high ductility as a result of increased austenite transformation and a ferrite content of FN 30-70 in the weldmetal.

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The use of post-fabrication steps to eliminate postweld problems varies. For high-purity water and aggressive chemicals, such cleanup practice must be spelled out in detail during procurement. For fresh water little more than degreasing and removing embedded iron are needed. Overall, defining the necessary post-fabrication processes during procurement will avoid cost overruns and possible poor service performance.

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Dissimilar Welding

Dissimilar welds are often required in the construction of process equipment. The expensive stainless materials are only needed in the areas exposed to corrosive conditions and less expensive carbon-manganese steels can be used for supporting structures and external reinforcements. When it comes to joining stainless steels to unalloyed steel, the main requirement is that the weldmetal should withstand the dilution between 30-50%, depending on the process used, without cracking. AISI types 309, 309Mo and 312 weldmetals are well established for joining mild or low alloyed steels to stainless steels. For high temperature applications, NiCrFe weldmetals are used for joining low carbon stainless steel to Cr-Mo steels. The Ni based weld metal prevents carbon migration from the creep resistant CrMo steels.

Cladding

Cladding with stainless steels is often carried out in the construction of heavy walled components for the process industry. The base materials are often carbon-manganese steels or low alloyed creep resistant chromium steels, like those used for petrochemical process reactors. Strip cladding using submerged arc welding (SAW) or electroslag welding (ESW) is excellent for large areas due to the high productivity and the low dilution of the base material. In the case of SAW the first layer on carbon steel must be "over -alloyed" *e.g.,* 309L or 309LMo types, to avoid brittle diluted weldmetals. Two layers of the required type of cladding are then usually overlaid. Due to the low dilution with ESW, it is possible to weld directly with the required type such as 316L or 347, on carbon steels. One typical application is the strip cladding of a hydro-cracker in CrMo steel. Because of heat treatment, it is necessary to control the ferrite content in the stainless steel cladding with FN between 3-8 or max. 10.