Corrosion Prevention in Weldments : A Review of Present & Future Trends

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INTRODUCTION

Industrial success depends substantially on correct use of all types of resources including finance. Engineering economy may permit comparisons of potential alternate avenues to monetary terms, such as extending the service life periods of the structures, equipments and components. Hence, the corrosion behaviour of selected materials turn out to be a major consideration in the economic evaluation of the industrial projects. Downtime, maintenance and time value of money have a bearing on selection of the best available material in relation to corrosion resistance. In fact, ellis Verink, E. L. Grant, G. J. Thuesen and the others in recent times, have worked out corrosion economic evaluation methods for specific equipments and for even components. Known and proven technologies, besides evaluation for prevention of corrosion when appropriately applied, could result in savings to the tune of 20 to 30% during long time and varying temperature services.

When we talk of corrosion prevention in construction materials/ related weld joints, there are a few questions, the answers for which itself could open up new techniques of corrosion prevention :

- Is the service life of the system known? If so, how far reliable ?
- Is the system prone for corrosion? If so, what are the types of corrosion the system may encounter ?
- Is the corrosion rate known ? If so, is it related to time period, mechanical and thermal treatments ?
- Is there any serious consequence of the corrosion failure of the system (particularly in terms of life or monetary loss)
- Is risk evaluation of the particular system known and reliable ?
- Is it economical - if prevention through design changes or material selection is opted for rather than corrosion protection, after complete consideration of failure consequences and risk evaluation related to design factors other than corrosion ?

Welding being a part of the manufacturing/fabrication process of the structures of the systems, an attempt is made here to project basic aspects of weld metal corrosion, together dealing with the present and future trends for prevention of corrosion, adopting techniques, such as in (f).

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CORROSION IN WELDS

The latest developments in the field of corrosion evaluation lead us to believe that, 'Weld Corrosion' is a contradictory phenomenon on occasions i.e., there are instances, where the welds display both resistance as well as susceptibility to certain corrosive attacks and to that extent exhibits differential corrosion properties to wrought material.

With this background, weld metal corrosion, its causes, protection and prevention are discussed in brief for general engineering materials intended for corrosion service.

CARBON STEEL WELD CORROSION

In the multipass C-Steel welds, weld passes undergo thermal expansion and contraction resulting in high level of residual stresses, due to weld shrinkage. Wide range of microstructural changes are also possible across a weld and its HAZ. The probable type of corrosion C-Steel welds encounter, its causes and prevention are considered below :

- **Preferential HAZ corrosion in aqueous solution (Ref. Fig.1)**
  - Hardened HAZ may cause preferential attack.
  - Suitable thermal treatement is recommended.
- **Preferential weld corrosion.**
  - The nature of deoxidation products in the flux coating could be the causes. Basic coating shows higher level of corrosion rate than rotile coated versions.
  - Deoxidation products present may retard corrosion. Consideration of microstructure may also apply as in the case of HAZ.
- **Galvanic corrosion in sea water**
  - If welds are anodic to base metal, unexpected galvanic corrosion failure may occur e.g., E6013 & E8018 are anodic to A53 grade B. checking the nature of galvanic coupling of the weld to other component materials of the system and assessment of the corrosion in service recommended.

- **Stress corrosion cr acking.**
  - SCC is mainly due to residual welding stresses. Soft structure around the weld may be aimed at through suitable stress relief treatment.
- **Stress corrosion cracking in oil refineries.**
  - Carbon Steel weldments in Sulphur recovery units develop SCC due to certain inherent characteristics. In the several case studies carried out abroad, inadequate PWHT has been reported.
  - Oxide removal preferably by sand blasting, close monitoring of the system and right PWHT for welds may be recommended.
- **Weld corrosion in deaerated tank.**
  - Stress cracks, geometry, location, nature, such as intergranular and transgranular from the initiation points for pitting.
  - To maintain water chemistry and low level Oxygen may be deemed probable solutions for better corrosion resistance.

MEASURES TO PREVENT CORROSION : CARBON STEEL WELDS

Areas for prevention of corrosion in the C-Steel welds are discussed below, which calls for an awareness on effect of each factor coupled with evaluation of performance experience of the system for related corrosion environments :

AQUEOUS ENVIRONMENT

Dissolved salts : A study and understanding is necessary on the effect of dissolved salts, such as KCl, NaCl, $MgCl_2$, $CaSO_4$ and $MgSO_4$ in the aqueous environment on selected material, Stringent control over the fresh water chemistry is desirable.

Dissolved gases : Enough control of dissolved gases particularly O_2, CO and H_2S in the environments to which the welds are subjected to.

Velocity : Exercise of control over the flow rate of the aqueous solutions/velocity by suitable alterations in weld design with particular reference to bends. Fig. 2B

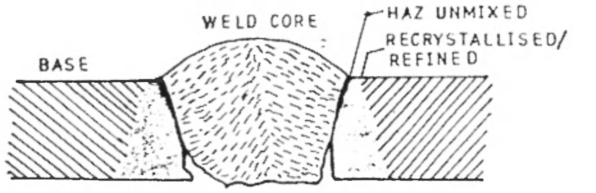


Fig 1 : Preferential HAZ corrosion attack in carbon steel weld Aqueous (Environment)

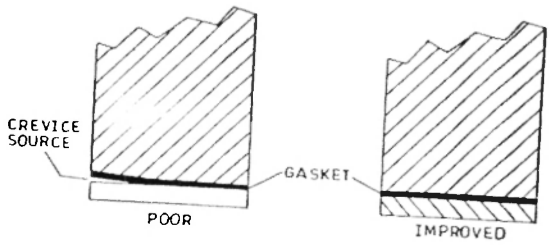


Fig 2a : Seals & Gasket

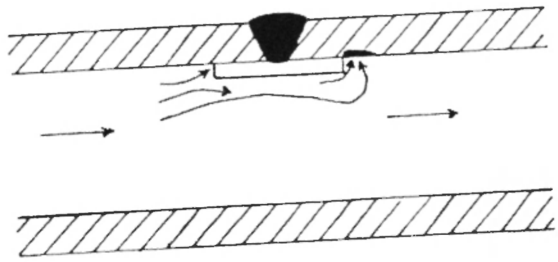


Fig 2b : Weld backing plate for ring cause turbulence and crevice

SEA WATER ENVIRONMENT

Sea water corrosion : Mill scale over C-Steel base metal is found cathodic. Removal by pickling to minimise corrosion in sea water could be effected for prevention of chloride corrosion in the structures. Besides, dissolved oxygen is linear to sea water corrosion rate. Deep Sea applications call for richer alloy additions in base as well as welds, unless known surface coatings are found really effective. A guideline for the prevention techniques for C-steel weld corrosion environments are presented in Table-1.

CORROSION IN STAINLESS STEEL WELDS :

Ferritic Stainless Steel Weld Corrosion

Ferritic Stainless Steel Welds are susceptible to intergranular corrosion and embrittlement in as welded condition. Corrosion in this grade of welds is generally related to the problems of insufficient joint preparations. Due to pick up of interstitial elements and resultant precipitation of carbides and nitrides, intergranular corrosion occurs. Proper joint preparation and cleaning may ensure prevention of carbon pick up in the case of MMA welding. In gas shielded welding, purity of Argon eliminates the possibility of Nitrogen pick up in the welds.

Table 1 : GUIDELINES FOR CARBON STEEL WELD CORROSION ENVIROMENTS

Prevention	Atmosphere	Soll	Water Natural/Fresh	Sea Water	Steam	Acid
1. Chemical treatment	Effective	Not used	Little Effective	Not recommened	Not recommended	Not recommended
2. Cathodic protection	Not recommended	Effective	Little Effective	Effective	Not recommended	Fairly Effective
3. Removal of Oxygen	Not recommended	Not Recommended	Not Recomended	Very Effective	Very Effective	Not recommended
4. Chossing coupling	Not Necessary	Little effective	Effective	Absolutely necessary	Desirable	Not effective
5. Inhibitor System	Not recommended	Not recommended	Effective in Coolling Water	Fairly effective	Very effective	Very effective
6. Alloy additi-ons for weld under cost consideration	Very effective (Cu bearing)	Not effective	Not effective	High alloys desirable	Cr-Mo effective	High alloying necessary

Austenitic Stainless Steel Weld Corrosion

Austenitic SS welds are generally resistance to all forms of corrosive attack except the types met by weld precipitates. as is well known , ferrite tends to transform to and chi intermetallic phases when the jobs are subjected to heat treatment between 570-850°C. As a result, precipitation could become a problem area causing preferential corrosion attack in low concentration reducing media and high concentration oxidising media depending on service temperatures intended. Moreover, microsegregation and coring in weld dendrites may cause preferential pitting, specially in oxidising conditions in SS welds. However, pitting corrosion is found independent of microstructural effects. In the paper plants, particularly for bleach plant components E316, E317L welds containing slightly higher Mo helps corrosion resistance service against pitting at elevated temperatures, in joints of wrought and cast metals.

Crevice attack in SS welds is generally considered related to residual weld flux impurities, cracks and fissures due to expansion and contraction in a multipass system, another cause being engineering design lapses which could be corrected with a bit more care e.g., in urea plant service, subjected to attack by urea synthesis process fluids, gasket facings may form potential source of crevice corrosion, if seal design is poor. Few improved design alterations are indicated in figure 2A. However, selection of right flux-core combination and adoption of proper welding techniques are equally essential.

300 series of SS welds are prone for weld decay resulting in poor corrosion resistance. As is well known, carbides in the HAZ are detrimental. However, low carbon version of indigenous SS electrodes are available in all grades for fertiliser, chemical plant and petrochemical industries for the purpose of arresting weld decay in the joints. For Ammonium carbamate service there are indigenous welding consumables available with carbon as low as $<0.025\%$ with matching ratio of the other alloying elements to exhibit exceptional general corrosion resistance when subjected to the range of maximum carbide precipitation temperature.

Stress Corrosion cracking of SS welds is common with caustic concentration exceeding 25% at service temperature of 100°C and above. Corrosion failure in such cases could be arrested only by the right selection of the filler metal by experience, such as in one case study in USA, the vessel was weld overlayed by Nickel at a high cost, still with ambiguous service performance reported.

Electrodes for Urea Synthesis :

Urea Synthesis service in the fertiliser industry poses peculiar corrosion problems. Indian Welding Electrode Industry has carried out enormous R & D to develop special electrodes to meet stringent corrosion resistance called for. The electrode is available now to build equipments for urea production subjected to high temperature service at 600-800°C. It is a weld, Mn-N bearing type exhibiting excellent resistance to hot cracking. Though the electrode does not fall in the AWS category, corrosion resisting elements have been kept richer compared to E316L. The welds match equipments made of nitrogen bearing steel subjected to annealing after welding. This may be considered on exceptional achievement for welding electrode industries in the recent times, duly accepted by the fertiliser/plant fabrication units.

Duplex Stainless Steel

Resistance to sulphide stress corrosion cracking and intergranular cracking in wet sour gas service calls for using Duplex SS welds. The grade is balanced for different proportions of austenite and ferrite and as such welding parameters play in important role in improving corrosion resistance. Proper arc energies may be maintained while welding duplex SS. In marine cargo service, as in the case of cargo tanks and chemical tankers containing halides, duplex SS, is the candidate material. However, for good resistance to SCC, FN level should not be $<25\%$ but for repair weld ferrite may be restricted to $<70\%$.

METALLURGICAL FACTORS INFLUENCING CORROSION OF WELDS

Welds in general, show certain amount of hetrogenity compared to base metal resulting in inferior corrosion resistance at some instances. Besides, the material grades undergo wide changes in microstructure while weld cooling and PWHT. The factors influencing corrosion of welds could broadly be classified as :

- Microsegregation.
- Secondary, ternary and multi phase, if any, present in the weld.
- Unmixed zone formation close to fusion line in the weld.
- Elemental losses from the molten weld pool.
- Recrystallisation/grain refinement in HAZ.
- Contaminations : Slag and segregations..
- Gaseous entrapment particularly oxygen. Impurity of sheilding gases in the case of gas shielded welds.

CORROSION PREVENTION IN THE WELDS

There are methods of corrosion protection but it is felt that avenues of minimising and preventing corrosion by various means is expected to be the future trend in corrosion technology. Some of the effective prevention techniques for corrosion in welds are discussed in brief :

- Ensuring proper balance of alloy composition to inhibit certain precipitation reactions and avoid undesirable precipition reactions.
- Removing chromium enriched oxide is as much necessary as the protection of chromium depleted zone from thermal surface contacts. In short, maintaining proper welding parameters is essential.
- Best possible shielding for molten metal is necessary to avoid contact with active gases.
- When weld bead is stressed, the defects, such as lack of fusion, porosity, slag inclusion may be covered/removed, being the potential sites for crevice , pitting etc.
- Ensuring proper grinding process for the debris not getting fused in the overlay and the spatter controlled away from the welds is important.
- Post weld clearing, either pickling or application of passivation pastes may be desirable before putting into service, as uncleaned weld surface from the zones of preferential corrosion attack.

DESIGN MODIFICATIONS AND ECONOMICS OF CORROSION PREVENTION IN WELDS

A review of existing design aspects of equipments/components and related welds may be a positive way to minimise corrosion problems. Practical approach will be to develop an understanding on the environments, selected material properties and general engineering considerations e.g. Table-2 classifies materials for resistance to SCC vs environment serving as a guide for proper selection. It may also be noted that, material selection has other aspects of consideration, such as economy, availability and solutions to maintenance problems of the systems.

Table - 2 **MATERIALS FOR RESISTANCE TO SCC Vs ENVIRONMENT**

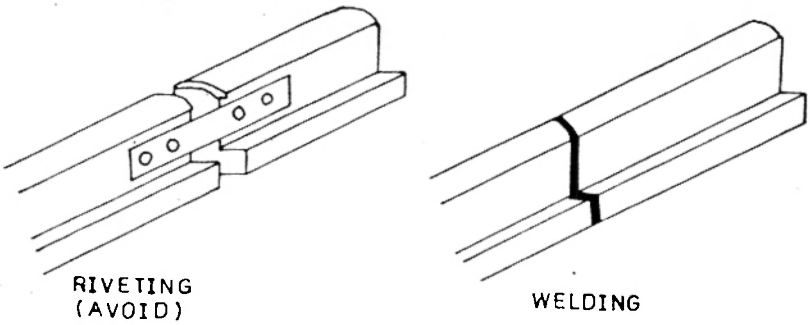
	Material	Environment	Welding Consumable
1.	C + Low alloy Steels	OH^{-} NO^{-}_3 HCO^{-}_3/CO^{-2}_3 $CO/CO_2/H_2O$ H_2S/H_2O	E 7018, E 7018-1 E 7018 - Al E 8018-B2, E 9018-B3 E 502, E 505 E 11018 M
2.	Duplex SS	H_2S/H_2O	2 O93L
3.	Austensitic SS	Cl^{-} OH^{-} Polythionic Acid (PTA)	E 316, E 321 (Clads) E 347, E 347L E 308. E 308L E 309
4.	Copper alloys	NH^{+}_4 Low molecular wt. amines SO_2	
5.	Aluminum alloys	Cl^{-} acidic	Aluminium alloys electrodes
6.	Titanium	NO Anhydros methanol	Titanium electrodes

However, certain simple design modifications may ensure much better corrosion resistance in service. In certain instances, welded constructions may eliminate crevices normally found in bolted and/or riveted assemblies, thus scraping the sources of crevices (Refer Fig.3). In the case of L sections, spot welds could prove a source of crevice attack. Continuous welding (Fig. 4) can eliminate this. In the case of stiffener design, certain modification ensures by way of continuous welds crevice attack could be arrested (Refer Fig.5).

Modifications in equipments may permit prevention of corrosion, such as in the case of storage vessels and structural members represented in Fig. No. 6A & b.

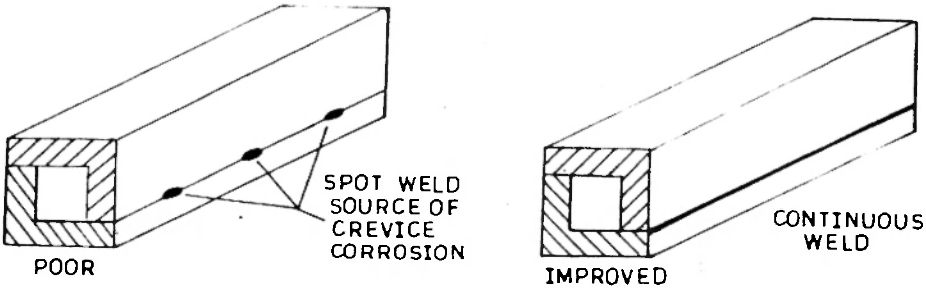
Design changes could also permit agitation of aqueous mixture which could prevent pitting, as stagnant systems are considered source of pitting.

In structural supports and members design is effected to drain away the aqueous environment of drain lines are relocated possibly eliminating pitting corrosion as indicated in Fig. 7a & b. In few cases of design modifications cavitation/impingement, erosion etc. are minimised by providing controlled flow of liquids. Design changes may involve change of direction, velocity of the flow in the case of liquids and gases to ensure that corrosion takes place at a more acceptable location.



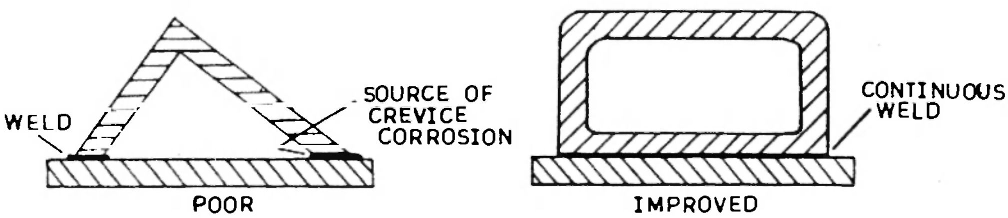
WELDING SCRAPS CREVICE SOURCES

FIG. 3



L- SECTION

FIG. 4



STIFFNER DESIGNS

FIG. 5

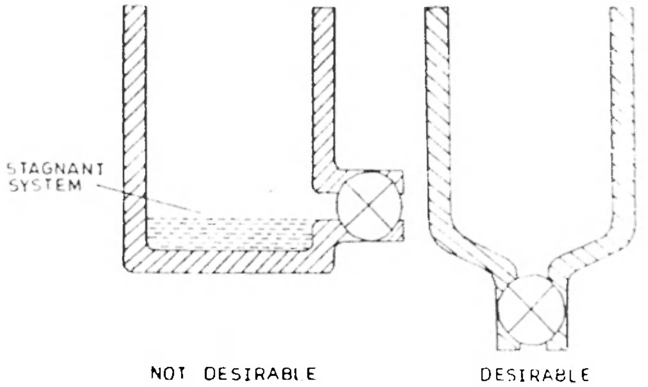


Fig 6a : Storage Vessels

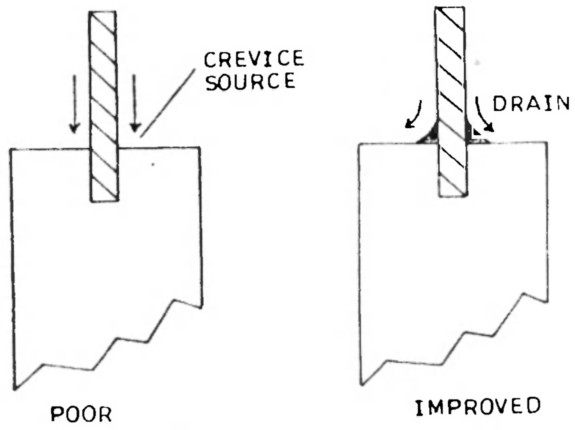


Fig 7a : Structural Support

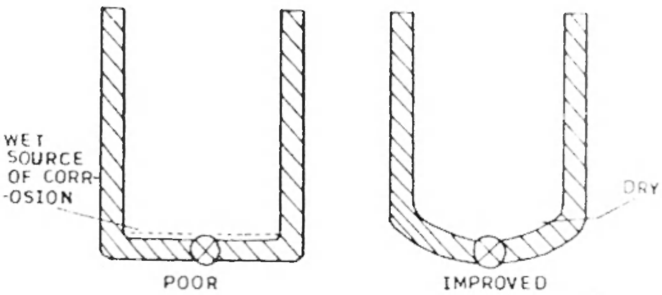


Fig 6b : **Drain Valves**

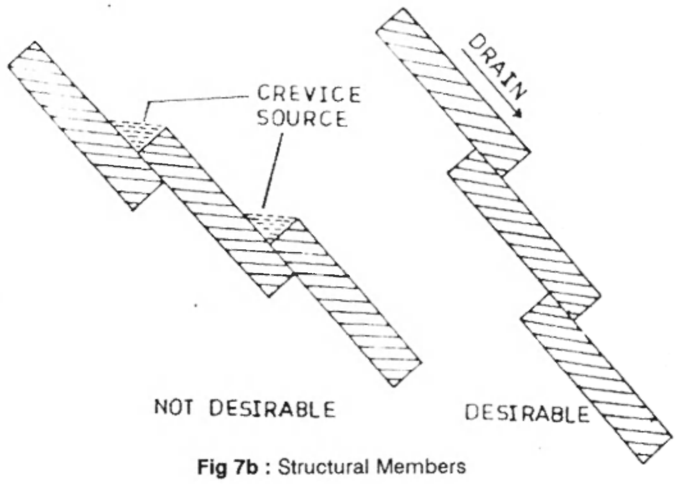


Fig 7b : Structural Members

In conclusion, it has to be stressed that while redesingning welds improvement may take place in one type of corrosion resistance, but should be ensured not to cause new corrosion problems, such as galvanic corrosion, It should also prove economical, when material selection is made out from corrosion point of view. Here, it is necessary, a corrosion engineer uses his discretion based on an understanding of material selection, design aspects related to corrosion as well as others, weld corrosion and overall economics of equipment building.

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