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STUDY OF INFLUENCE OF STRESSED CORROSIVE ENVIRONMENT ON THE AUSTENITIC STAINLESS STEEL

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ABSTRACT

In this reviewed research paper the combined influence of stress and corrosive environment on the austenitic stainless steel has been discussed. Growth of cracks in corrosive environments has been studied. Corrosion is a process created by the reaction (chemical or electrochemical) between a material, often a metal or alloy, and its environment that results in destruction or deterioration of that material. Corrosion has been classified in many different ways. One method classifies corrosion into low and high temperature corrosion. Wet corrosion and dry corrosion is the preferred classification method. The wet corrosion involves liquid solutions, such as corrosion of steel by water whereas dry corrosion is most often associated with high temperatures and occurs in absence of a liquid phase, by mechanisms such as carburization, metal dusting [44]. Some principles and basic aspects of corrosion processes will be discussed in the following subsections. Effect of alloying elements like Cr, Ni, Mo and Si on the corrosion resistance of stainless steels has been discussed in this paper.

INTRODUCTION

Stress corrosion cracking is the cracking induced from the combine influence of tensile stress and corrosive environment. Stress corrosion cracking is the growth of cracks in corrosive environments. It can lead to unexpected sudden failure of normal ductile metals subjected to a tensile stress, especially at elevated temperature in case of metals. The impact of SCC on material usually falls between dry cracking and the fatigue threshold on the material. The required tensile stresses may be in the form of directly applied stresses or in the form of residual stresses. It refers to cracking caused by the simultaneous presence of tensile stress and specific corrosive medium. The two classic cases of SCC of stress corrosion cracking are “season cracking” of brass, and the caustic embrittlement of steel. Stainless steel crack in chloride environments but not in ammonia containing environments, whereas brasses crack in ammonia-containing environments but not in chlorides.

- Stress corrosion cracking is defined as crack nucleation and propagation in stainless steel caused by synergistic action tensile stress, either constant or slightly changing with time, together with crack tip chemical reactions or their environment-induced crack tip effect.
- SCC failure is a brittle failure at relatively low constant tensile stress of an alloy exposed in a specific corrosive environment.

There are three important conditions that must be present simultaneously to promote SCC: a susceptible alloy, a critical environment and tensile stress. Each alloy has a specific critical environment, so environmental specie may cause different damage depending on the type of alloy, as an example, hot aqueous chloride solutions cracks stainless steels but it does not affect carbon steel or aluminum. Pure metals are more resistant to SCC than alloys of the same base metal.

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There is no unified mechanism for SCC. In the adsorption model, specific chemical species adsorbs on the crack surface and it generates zones of stress; about the film rupture model, the stress ruptures the passive film and forms an active-passive cell, which will form a new passive film that will also rupture and the cycle continues until failure; the embrittlement model by hydrogen is one of the most important mechanisms of SCC for steels and other alloys such as titanium. Hydrogen atoms diffuse into the alloy to the crack tip and embrittle the material producing atomic hydrogen at the surface during corrosion. The last one is the pre-existing active path model: in this case SCC may be either transgranular or intergranular, but the crack is always normal to the tensile component of stress. In transgranular failure, the crack propagates across the grains usually in preferential crystal plans, while in the intergranular failure, the crack follows grain boundaries. Both types of failure may exist in the same system, even the transgranular failure be less common.

Chloride stress corrosion cracking (CLSCC) is one of the most common reasons why austenitic stainless steel pipe work and vessels deteriorate in the chemical processing and petrochemical industries. Deterioration by CLSCC can lead to failures that have the potential to release stored energy and/or hazardous substances. Failures in chemical processing and petrochemical plant can be prevented by an awareness of the onset and evolution of CLSCC, and by periodic inspection to monitor the extent of cracking. Although the deterioration of austenitic stainless steels by CLSCC is well known, recent incidents and inspection visits by HSE have found that susceptibility assessments were inconsistent and did not always take account of current knowledge. Discussions between HSE, duty holders and competent bodies identified that the technical justification for setting inspection intervals and the effectiveness of periodic non-destructive examination (NDE) for monitoring CLSCC were additional areas of concern. Austenitic stainless steel pipe work and vessels are particularly vulnerable to CLSCC if they are covered with an insulation material that contains moisture, i.e. conditions that normally cause corrosion under insulation (CUI) of carbon and low alloy steels. This report is primarily concerned with CLSCC from the process environment and from the outside due to the external environment where no insulation material is involved. Nevertheless, some comparisons will be made between CLSCC of insulated and un-insulated austenitic stainless steel.

SCC is only possible in selective environments where a passive films forms at the metal surface. Under tensile stresses if the environment is to aggressive and the film formation rate is very slow then general corrosion occur. If the rate of surface film formation is very fast, then the passive film at the metal surface will immediately repassivate upon rupture. In SCC, the surface is able to passivate, but when the film ruptures the surface of the sample temporarily remains exposed to the environments and locally corrode. Examples of all three conditions are presented , which shows a AISI 316L stainless steel base metal that forms a chromium oxide ($Cr2O3$) passive film. The circled semi-stable film behavior is the one that leads to SCC. SCC usually occurs in certain specific alloy-environment-stress combinations. Usually, most of the surface remains unattacked, but with fine cracks penetrating into the material. In the microstructure, these cracks can have an Intergranular or a transgranular morphology. Macroscopically, SCC fractures have a brittle appearance. SCC is classified as a catastrophic form of corrosion, as the detection of such fine cracks can be very difficult and the damage not easily predicted. Experimental SCC data is notorious for a wide range of scatter. A disastrous failure may occur unexpectedly, with minimal overall material loss.The micrograph on the right (X500) illustrates intergranular SCC of an Inconel heat exchanger tube with the crack following the grain boundaries.

Effect of alloying elements on the corrosion resistance of stainless steels:

Effects of chromium on the corrosion resistance of stainless steels

Chromium forms a surface film of chromium oxide to make the stainless steel corrosion resistant. It also increases the scaling resistance at elevated temperatures.

Effects of nickel on the corrosion resistance of stainless steels

Nickel stabilizes the austenitic structure and increases ductility, making stainless steel easier to form. It increases high temperature strength and corrosion resistance, particularly in industrial and marine atmospheres, chemical, food and textile processing industries.

Effects of molybdenum on the corrosion resistance of stainless steels

Molybdenum increases corrosion resistance, strength at elevated temperatures, and creep resistance. It expands the range of passivity and counteracts tendency to pit especially in chloride environments.

Effects of silicon on the corrosion resistance of stainless steels

Silicon increases scaling resistance by forming a tight initial scale, which will withstand cyclic temperature changes. It resists carburizing at high temperatures and slightly increases tensile strength and hardness. Small amounts of silicon are added to all grades of stainless for deoxidizing.

Factors affecting Chloride stress corrosion cracking (CLSCC)

A range of environmental factors have been identified that can affect the development of CLSCC which include chloride content, temperature, pH and contact with dissimilar metals. Recent work has also identified the importance of transient conditions such as high temperature excursions. Alloying element content, impurity levels and the degree of cold working are factors that affect the intrinsic resistance of a particular austenitic stainless steel to CLSCC. A significant volume of literature has been published on how CLSCC is affected by environmental factors and by the factors affecting the resistance of specific grades.

Part of this work has been to review published literature to assess the range of factors involved including:

Temperature, pH, chloride content, oxygen level humidity Electrode potential effects, e.g. galvanic coupling and cathodic protection. Applied and residual stress, alloying elements and impurities in the steel sensitization cyclic conditions affect the rate of corrosion in austenitic steel.

Controlling CLSCC

The main options for preventing or controlling CLSCC are management of chloride levels, Temperature and pH. Inhibitors can also be effective where the process allows it. As noted. Above, electrode potential has a major effect on CLSCC susceptibility and while positive Potentials increase cracking, lowering the potential can prevent cracking by cathodic protection. Wrapping with aluminium foil or coating with thermally sprayed aluminium are Established techniques for preventing external CLSCC when the pipe work or vessels are insulated. Austenitic stainless steel heat exchanger tubes are also thought to be catholically protected from pitting and CLSCC when used with carbon steel tube plates and shells. When components are designed, the susceptibility of CLSCC can be reduced by choosing more resistant alloys and by lowering the stress. Alloys with greater resistance to CLSCC include ferritic and duplex (austenitic-ferritic) stainless steels, and alloys containing >42% nickel. Resistance to CLSCC is usually assessed by ranking alloys on their performance in accelerated tests using conditions that promote cracking.

The three most common tests, in order of increasing severity, are boiling acidified sodium chloride, evaporation of sodium chloride using droplets or a wick on a heated surface, and boiling magnesium chloride. Even high alloy grades of austenitic and duplex stainless steel containing >22% chromium and >5% molybdenum can crack in less than 24 hours when tested in boiling magnesium chloride. It should be recognized, however, that while duplex grades and highly alloyed grades are more resistant than the common austenitic types, they might not be immune to CLSCC under severe conditions, e.g. where chloride solutions evaporate. Stress in components can be lowered by down rating working pressures, but where pipe work and vessels are fabricated by welding, there is likely to be residual stress (with a magnitude approximately equal to the parent metal proof stress) from welding. Residual stresses may also arise from cold working during manufacture. A stress relief heat-treatment can lower residual stress but its application is often limited by concerns over distortion, surface finish and sensitization.

General corrosion behavior/ Potential Theory

The general electrochemical behavior of stainless steels can be described by a polarization curve. A hypothetical polarization curve of stainless steel showing active passive behavior and a pseudo-passive behavior has been observed. It shows that stainless steels corrode in the active region, which exists at potentials below the passivation potential (E_{pp}). In the active-passive region represented by AB for a passivating system, current increases with potential until the passivation potential, E_{pp}, is reached. When the maximum current, i.e. the critical current density (i_{crit}) is reached, the current density drops to a very low value, called the passive current density ($i_{passive}$), and the passivation (formation of the protective film Cr_2O_3 layer) is initiated. i_{crit} represents the point of maximum anodic dissolution. During passivation the metal still corrodes but at a significantly lower rate. If the potential is increased even more, then a passive transpassive transition is observed at the transpassive potential, $E_{transpassive}$ or E_{pit}. When the transpassive region is reached, the metal starts to corrode at a high rate again. In the pseudo-passive system, the current does not decrease with increasing potential, but increases beyond point B to C where the current remains constant or increases only slightly. Usually it is difficult to define unambiguously the values for i_{crit}, E_{pp}, and $E_{transpassive}$ from this behavior.

Conclusion

On the basis of the reviewed papers as mentioned in the reference it could be concluded that:

During passivation the metal still corrodes but at a significantly lower rate. When components are designed, the susceptibility of CLSCC can be reduced by choosing more resistant alloys and by lowering the stress. Applied and residual stress, alloying elements and impurities in the steel sensitization cyclic conditions affect the rate of corrosion in austenitic steel.. Chloride stress corrosion cracking (CLSCC) is one of the most common reasons why austenitic stainless steel pipe work and vessels deteriorate in the chemical processing and petrochemical industries.

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