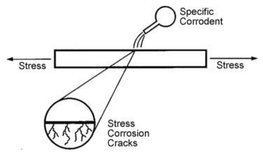
Singh Research Group: Corrosion of Metallic Materials

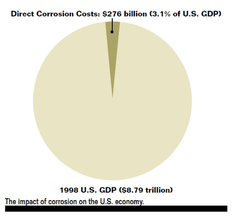
Group Overview

Environmental Degradation of Metallic Materials

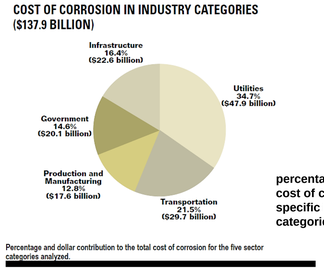
- **Corrosion Mechanisms in Different Alloy/Environment Systems**
  - **i. General and Localized Corrosion**
    - Aqueous Corrosion
    - High Temperature Oxidation
    - Molten Salt Corrosion
    - Environmental Sensitive Cracking
      - *Corrosion Fatigue*
      - *Stress Corrosion Cracking*
      - *Hydrogen Embrittlement*
  - **ii. Understanding Passivity**
- **Corrosion Control**
  - **i. Alloy Selection and Microstructural Effects**
  - **ii. Environmental Modifications (Inhibitors etc.)**
  - **iii. Surface Modification (Metallic and non-metallic coatings, Hydrophobic surfaces)**



stress corrosion cracking.



Direct Corrosion Costs" account for 3.1%, or $276 billion, of the U.S. GDP in 2002.



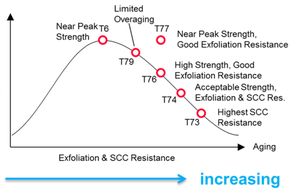
percentages of the cost of corrosion in specific industry categories.

Study Sponsored by Federal Highway Administration, McLean, VA. Office of Infrastructure Research and Development, 2002.

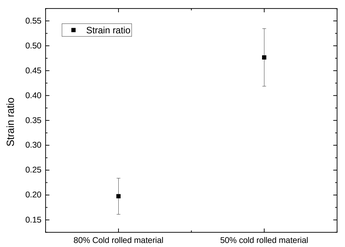
Stress Corrosion Cracking

- Aluminum alloys are increasingly replacing the steel in automotive vehicles due to its high strength to weight ratio.
- Unfortunately some of these high strength aluminum alloys suffer from various structural forms of corrosion such as intergranular and stress corrosion cracking at peak aged tempers.

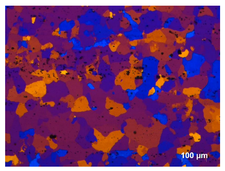
- **Objective**: The principle aim of this project is to asses the effect of composition and processing conditions on the microstructure of the high strength aluminum alloys resulting in stress corrosion cracking and corrosion fatigue.



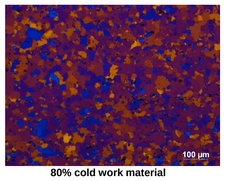
Effect of ageing on mechanical and corrosion properties of high strength aluminum alloys.



Effect of grain size on the SCC susceptibility of high strength Al alloy



50% cold work material



80% cold work material

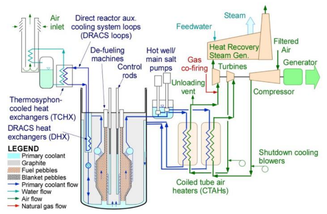
Corrosion in Fluoride and Chloride Molten Salts

- Molten halide salts have been proposed as coolant for several emerging energy technologies, including advanced fission reactors, fusion reactors, and high temperature concentrated solar power storage.
- Corrosion of containment materials, which include nickel-based alloys and austenitic stainless steels, is a challenge due to the harsh chemical environment at typical operating temperatures, which exceed 650°C.

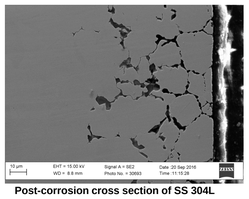
Objectives are to: (1) Study effect of salt impurities to improve understanding of corrosion mechanisms, (2) Develop and test corrosion mitigation strategies such as redox control, (3) Develop stable reference electrodes for studying the changes occurring in alloys in molten fluoride and chloride salts

Results:

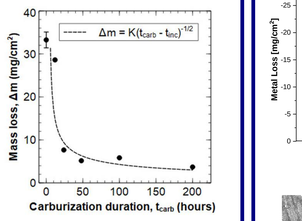
- Selective dissolution of chromium is the primary corrosion mechanism.
- Presence of impurities such as oxides and moisture drive this corrosion behavior
- A surface chromium carbide layer acts a diffusion barrier to reduce chromium dissolution.
- Addition of a higher-reacting element, such as Mg in molten chloride salts or Li in molten fluoride salts, inhibits corrosion.
- Corrosion can also be inhibited by purifying the salt or by cathodic protection



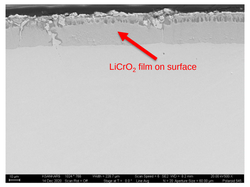
Fluoride Salt-cooled High Temperature Reactor (FHR).



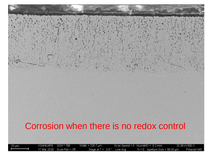
Post-corrosion cross section of SS 304L

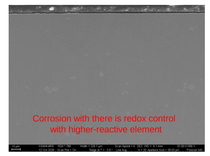


Mass loss of pre-carburized Cr samples after 100h exposure to molten FLiNaK at 700°C.

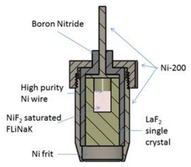


Cross section of SS 316H sample showing $LiCrO_2$ film, which forms in 700°C FLiNaK salt with oxide impurity.





Cross-sections of Hastelloy N Samples in molten fluorides

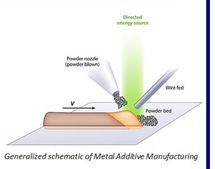


Ni^+/Ni reference electrode for fluoride salt environments.

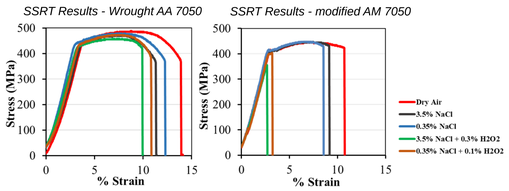
Corrosion Behavior of Additively Manufactured Alloys

- Additive manufacturing(AM) or 3D printing is a disruptive approach to traditional manufacturing process, enabling creation of superior parts with more flexibility and efficiency.
- Microstructural differences due to AM processing conditions and much higher solidification rates in AM alloys, their corrosion or stress corrosion cracking (SCC) behavior can be different from the equivalent wrought alloys.

Objective: To understand the effects of processing, microstructure, and environment on corrosion susceptibility and stress corrosion cracking behavior of additively manufactured vs. wrought aluminum 7xxx alloys.

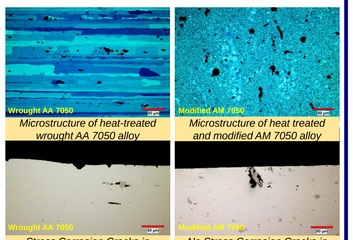


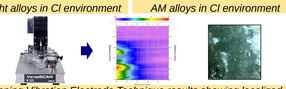
Generalized schematic of Metal Additive Manufacturing



Results:

- AM 7050 alloys used in this study are found to have higher resistance to stress corrosion cracking in chloride environments.
- In presence of oxidizing conditions (with H_2O_2 in chloride solution), these AM 7050 alloys showed intergranular cracking near necking region.
- Presence of Ti and Al rich particles in AM 7050 alloys used in this study lead to mechanical cracks originating from the interface.





Scanning Vibration Electrode Technique results showing localized corrosion activity

High-Temperature Corrosion

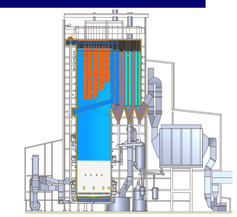
Objective: To evaluate the resistance to high temperature corrosion of candidate superheater tube (shown in orange) materials for an increase in boiler operating temperature.

- These tubes are faced with various corrosive gaseous species and smelt deposits which accelerate tube failure, leading to boiler explosions.
- Samples were tested in a variety of gaseous environments with and without salt similar to that found in recovery boilers.

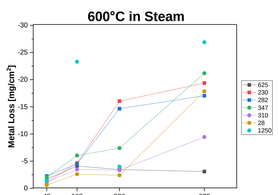
Results:

i. Alloy performance in steam environments at 772 hours show that esshete 1250 had the worst corrosion resistance, while Haynes 625 had the best corrosion resistance.

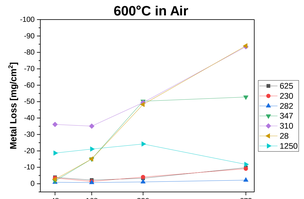
ii. XRD of 347H and Esshete 1250 show the surface oxides present contain mostly Fe and Mn based oxides, for steam environments containing the simulated recovery boiler deposit.



Schematic diagram of recovery boiler.



Exposure testing of candidate alloys.



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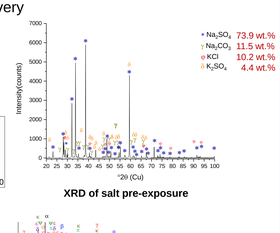
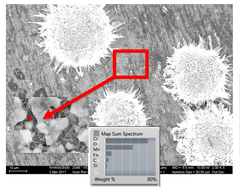
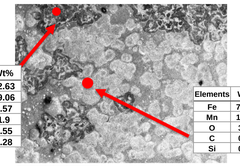




Elements	Wt%
Fe	62.63
O	29.06
Mn	5.57
C	1.9
Cr	0.55
Si	0.28

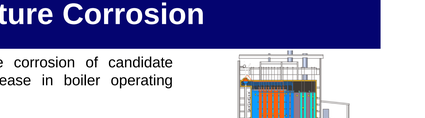


Elements	Wt%
Fe	76.18
Mn	19.99
O	3.38
C	0.33
Si	0.13

Surface SEM image of which underwent oxidation testing at 600°C for 336 hours in steam with simulated recovery boiler salt (A) 347H (B) Esshete 1250.

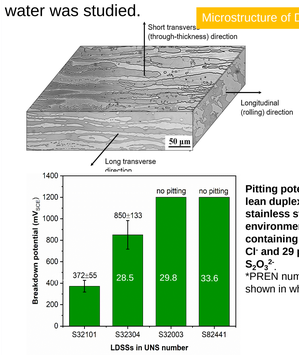
Pitting Corrosion

Pitting corrosion behavior and mechanism of lean duplex stainless steels in paper machine white water was studied using potentiodynamic polarization test and scratch test method. Materials factors including alloying elements and heat-treatment and environmental factors in terms of chloride and thiosulfate concentration were studied. Pit initiates in the phase that is most susceptible to pitting corrosion.



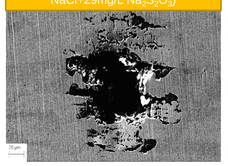
Results: Pitting corrosion behavior and mechanism of lean duplex stainless steels in paper machine white water was studied.

Microstructure of DSSs

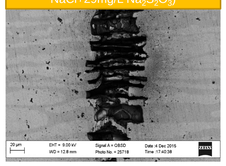


Pitting potential of lean duplex stainless steels in environment containing 300 ppm Cl^- and 29 ppm $S_2O_3^{2-}$.
*PREN number shown in white.

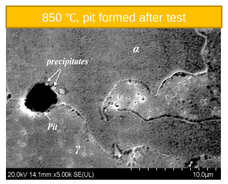
Pit on DSS 2304 in (300mg/L NaCl+29mg/L $Na_2S_2O_3$)



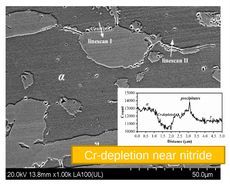
Scratch on DSS 2101 in (300mg/L NaCl+29mg/L $Na_2S_2O_3$)



850 °C, pit formed after test



Cr-depletion near nitride



Group Members

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