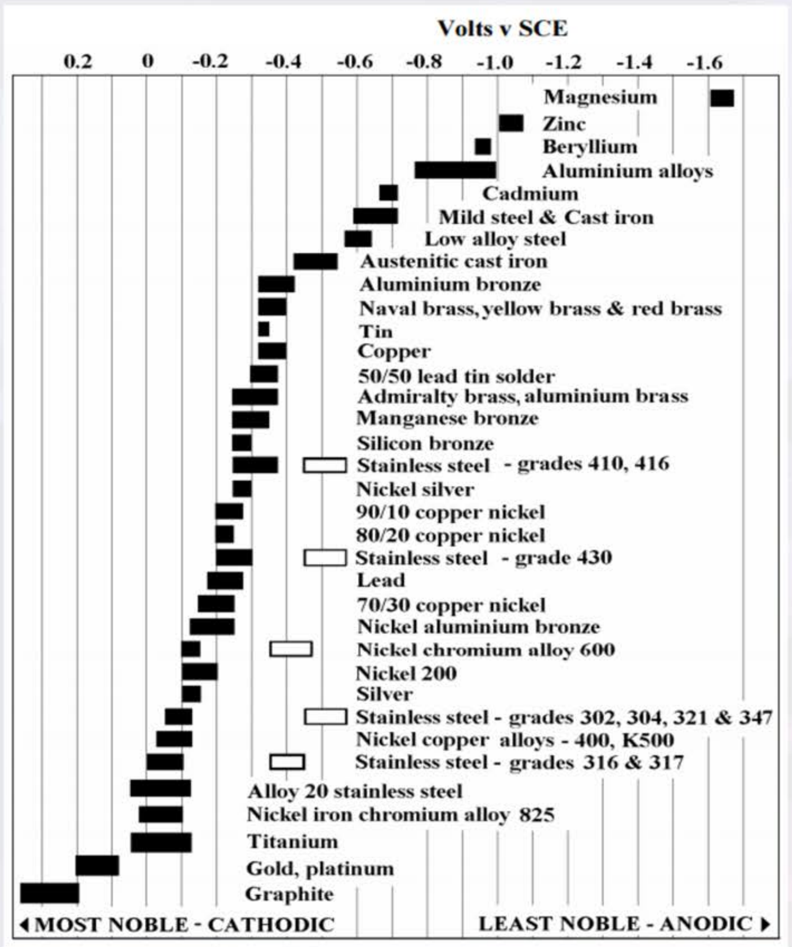
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

RIC 2016

Aging Management of Selective Leaching (Dealloying)

Overview of Selective Leaching (Dealloying)

Definition **-** Selective leaching, also known as dealloying, involves selective corrosion of one or more components of an alloy. When dealloying occurs, the least noble component of the alloy is preferentially corroded, leaving behind a network of the more noble component in a porous state. A dealloyed component often retains its shape and may appear to be unaffected, but the functional cross-section of the material has been reduced.



[1]

Susceptible Materials **-** The Generic Aging Lessons Learned (GALL) Report, Revision 2, identifies:

- Copper alloys with a zinc content greater than 15 weight percent (>15% Zn); de-zincification
- Copper alloys with an aluminum content greater than 8 weight percent (>8% Al); de-aluminification
- Gray cast iron: iron leaching or de-ironification. Also commonly referred to as graphitic corrosion

Aging Management of Selective Leaching **-** The NRC recommends the GALL Report Aging Management Program (AMP) XI.M33, "Selective Leaching," to ensure the integrity of susceptible components. In order to detect selective leaching, the AMP recommends the following:

- Visual inspection (color, porosity, abnormal surface conditions)
- Macroscopic hardness testing
- Destructive testing (such as chipping and scraping)

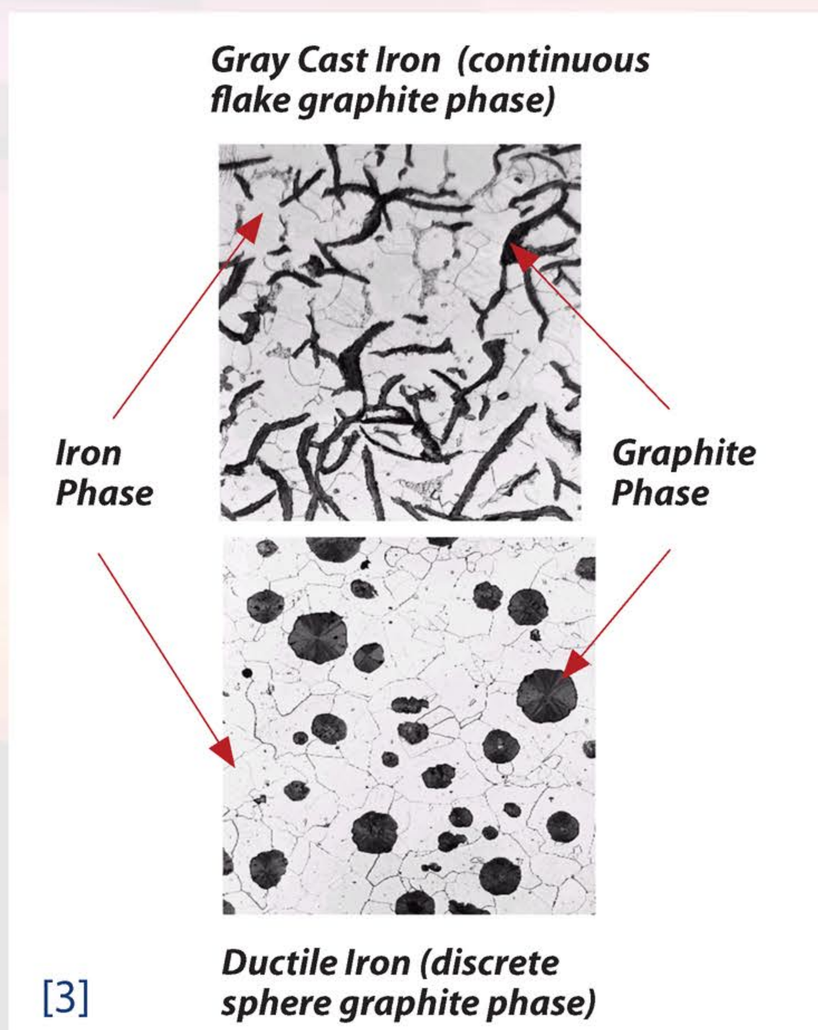
Emerging Topic: Selective Leaching of Ductile Iron

Background **-** Cast irons are a group of ferrous alloys (including gray cast, ductile, compacted, and malleable iron) containing between 2.1-4.5 weight % carbon. The only cast iron identified in the GALL Report, Revision 2, as being susceptible to selective leaching is gray cast iron. There is universal agreement that gray cast iron has a microstructure susceptible to selective leaching; however, consensus has not been reached regarding the susceptibility of ductile iron. Recent events have shown that ductile iron may also be susceptible to selective leaching.

- At the July 2015 Electric Power Research Institute (EPRI) Buried Pipe Integrity Group (BPIG) meeting, a licensee presented results showing evidence of selective leaching of ductile iron components
- In August 2014 a licensee identified graphitic corrosion on buried ductile iron piping
- Open literature indicates that ductile iron is generally less susceptible, but not immune, to selective leaching when compared to gray cast iron

[2]

Cross-section of ductile iron pipe showing signs of selective leaching



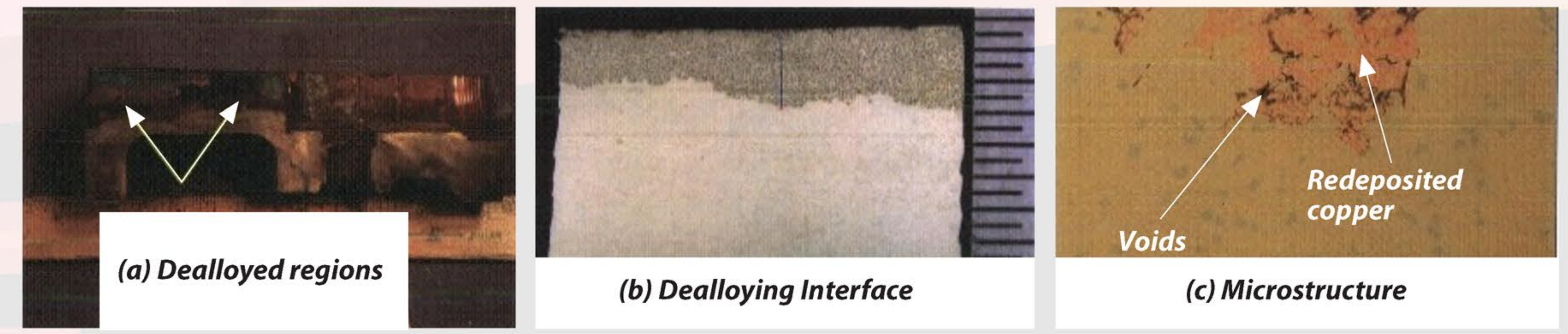
[3]

Influence of Microstructure **-** Both gray cast and ductile iron consist of graphite and iron phases (shown on left). In order for selective leaching to occur, the graphite phase must be able to physically support iron-oxide corrosion products. It was originally thought that only gray cast iron, with a continuous network of graphite flakes surrounded by iron, could provide a network to retain or 'hold-on' to corrosion products. Further investigation has shown that this is an over-simplification and that susceptibility depends on graphite morphology, graphite particle size/distribution, environmental conditions, and other factors (i.e. ductile iron, with a discrete spherical graphite phase, is susceptible to selective leaching).

Further Action **-** The NRC plans to issue an Information Notice to inform licensees regarding the susceptibility of ductile iron to selective leaching.

Emerging Topic: Crediting Mechanical Properties of Dealloyed Copper Alloys

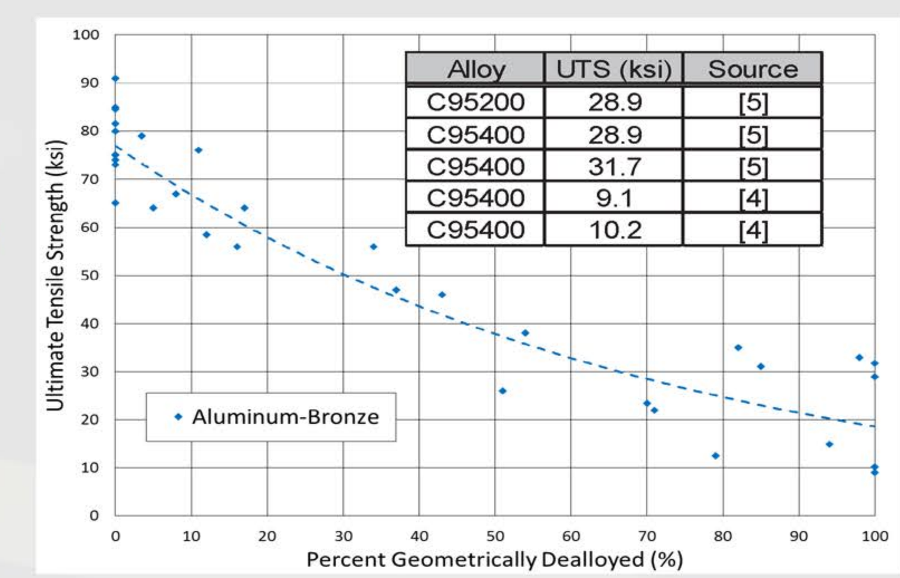
Background **-** Certain copper based alloys are known to experience dealloying when exposed to aqueous environments. In these susceptible brass (>15% Zn) and aluminum-bronze (>8% Al) alloys it is the Zn and Al, respectively, that is preferentially electrochemically removed from the microstructure. The GALL Report recommends that components fabricated from susceptible alloys and exposed to aqueous environments are managed for the aging effect of "loss of material" using AMP XI.M33.



Aluminum-bronze valve depicting dealloying: (a) Macroscopic view; (b) cross-section of dealloyed region; and (c) microstructure depicting unaffected phases, redeposited copper, and voids [4]

Aging Effect **-** Dealloying of copper based alloys is known to occur in either a uniform layer-type or localized plug-type morphology. The dealloyed region of the component is generally comprised of various volume fractions of unaffected phases, redeposited copper, and voids. In order for the dealloyed front to progress through the microstructure it must be in contact with the aqueous environment; therefore the voids in the dealloyed volume must form an interconnected network. The removal of alloying elements to produce this porous interconnected network of voids is a form of 'loss of material' even though the geometry of the component in the dealloyed region is retained. Destructive testing has demonstrated that the dealloyed region retains some degree of mechanical properties. However, the lower bounding values of the mechanical properties of dealloyed material have not been established.

Dealloyed Mechanical Properties **-** In order to manage the change in material properties associated with dealloying, minimum property values need to be determined and substantiated. Using the data available for dealloyed aluminum-bronze the staff has estimated a lower bound value of ultimate tensile strength (UTS). The statistical evaluation [6, 7] estimated that only 75% of the population will equal or exceed a minimum UTS value of ~12ksi with a confidence of only 75%. At higher confidence and population exceedance levels the strength is further reduced to essentially zero which supports loss of material as the appropriate aging effect. Similar statistical analyses would be needed for each material property used to support operability of the component.



Alloy	UTS (ksi)	Source
C95200	28.9	[5]
C95400	28.9	[5]
C95400	31.7	[5]
C95400	9.1	[4]
C95400	10.2	[4]

[1] Atlas Steel Technical Note Number 7, "Galvanic Corrosion"

[2] National Research Council Canada, NRCC-44218, "Failure Modes and Mechanisms in Gray Cast Iron Pipe"

[3] Materials Science and Engineering: An Introduction, William D. Callister, Jr., Seventh Edition, page 367

[4] ADAMS Accession No. ML13091A038, Alternative Request IR-3-17 to ASME Section XI for Repair/ Replacement of Class 3 Service Water System Valves – Millstone Power Station 3, March 28, 2013.

[5] ADAMS Accession No. ML14224A151, Response to Requests for Additional Information for the Review of the South Texas Project, Units 1 and 2, License Renewal Application – Set 26, July 31, 2014.

[6] ONR Report AD1418179, "Tables for One Sided Statistical Tolerance Limits," November 1, 1957.

[7] MIL HDBK 5J, Department of Defense Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures, January 31, 2003.