Introduction to Ductile Iron

Material Overview
Corrosion Performance
Transmission Applications

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EPRI Fall Task Force
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www.epri.com

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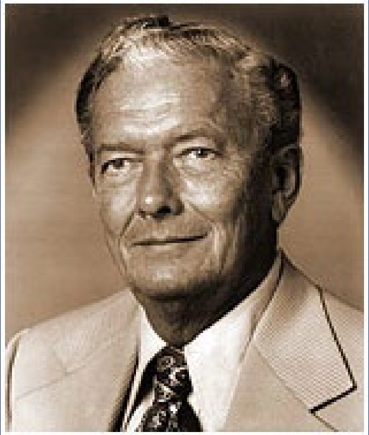
History & Applications

Ductile Iron – History & Applications

Creation

- During WW2, civilian shortages of chromium drove the need to find alternatives for wear-resistant iron
- Keith Millis of the International Nickel Co. is credited with discovering a magnesium alloy of iron resulting in a spheroidal graphite structure



Keith D. Millis from rpi.edu HOF

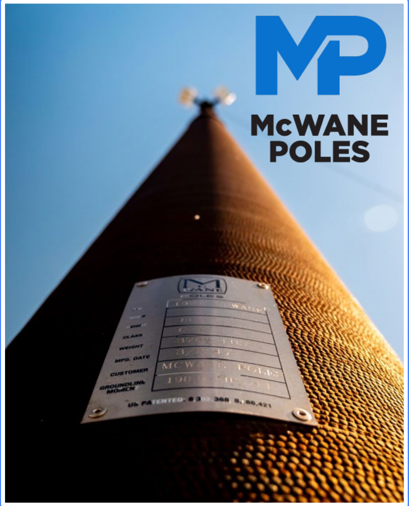
Adoption

- Since 1955, pipe industry standard for water and wastewater systems

- Manufacturing of complex shapes for the agricultural and automotive industry

Transmission

- McWane Poles founded in 2008 creating ductile iron poles for the utility industry
- Developed under the McWane family of companies, traditionally focused on iron piping



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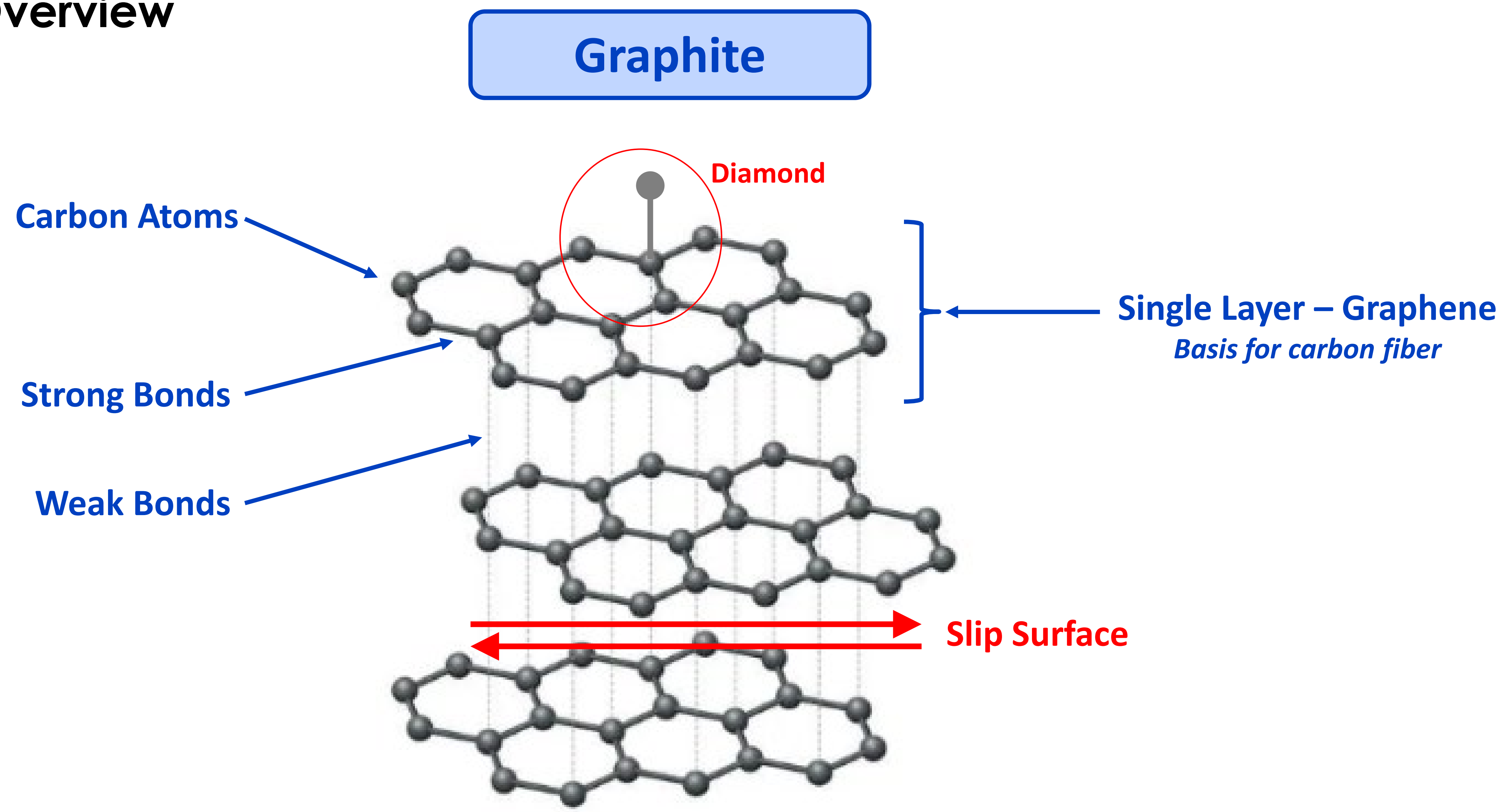
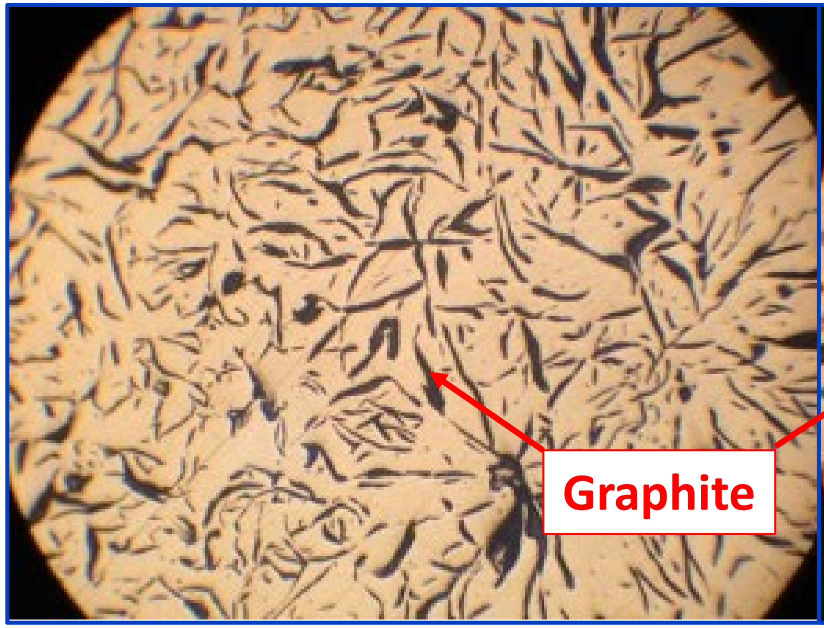
Material Overview

Material Overview



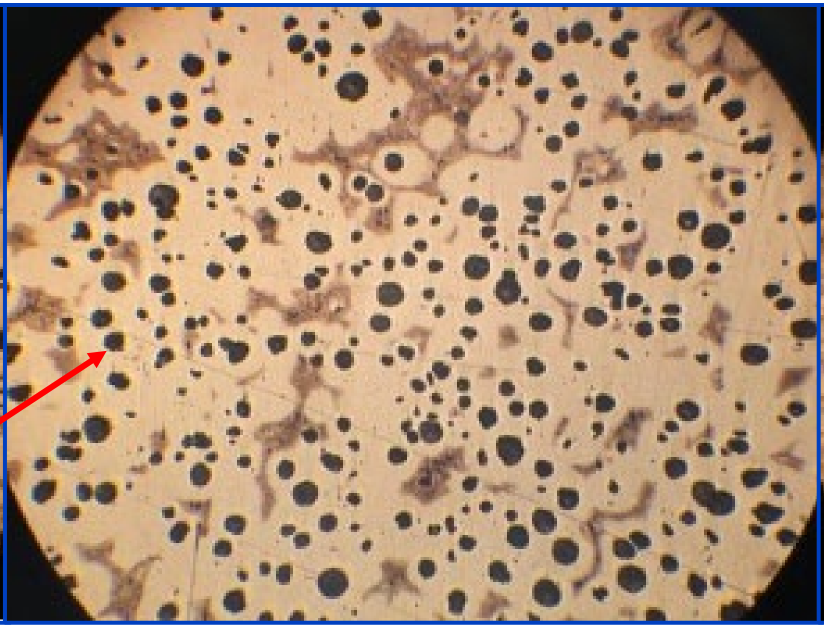
Material Overview

Cast Iron



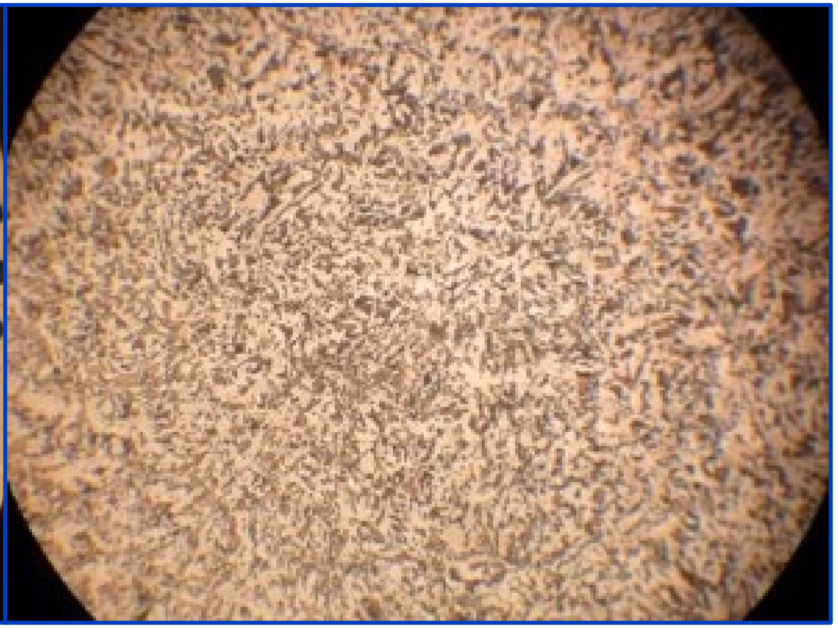
- Graphite exists as flakes
- Low ductility
- Brittle

Ductile Iron



- Invented in 1943
- Addition of magnesium causes graphite to spheroidize
- Higher ductility and tensile strength than cast iron

Carbon Steel



- Much lower carbon content than cast/ductile iron
- Improved ductility, toughness and strength

Material Overview

	Cast Iron *ASTM A48 Cl 40*	Ductile Iron *Per McWane Poles* **Per DI Tension Gr 65-45-12*	Carbon Steel *ASTM A572 Gr 65*
Density *(pcf)*	450	440	490
Modulus of Elasticity *(ksi)*	16000-20000	24000	29000
Hardness, Brinell	183-234	167*	159
Tensile Yield Strength *(ksi)*	N/A	42	65
Tensile Ultimate Strength *(ksi)*	40	60	80
Carbon Content	3.25-3.5%	3.0-3.8%*	≤ 0.26%
Iron Content	91.9-94.2%	90.7-94.2%*	≥ 97.9%

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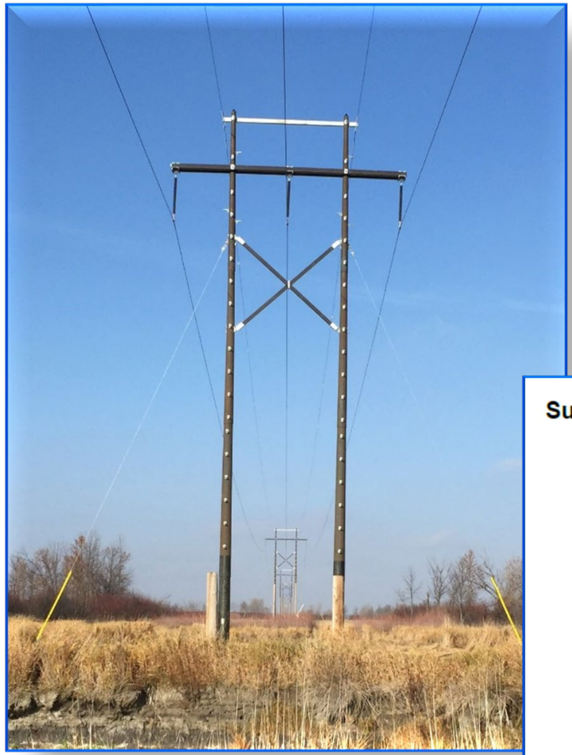
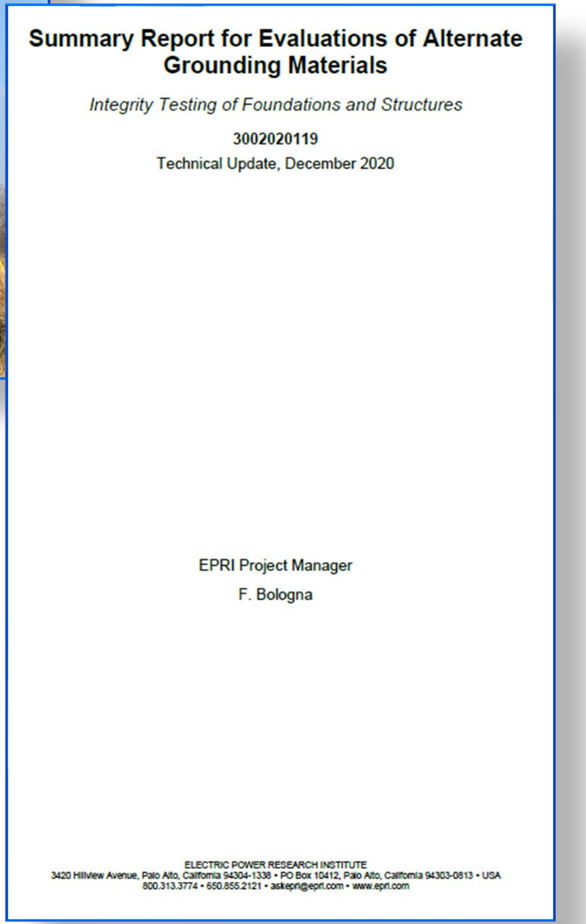
Corrosion Resistance

Corrosion Resistance

- Increased carbon content of ductile iron relative to steel improves corrosion resistance
- EPRI deliverable *"Summary Report for Evaluations of Alternate Grounding Materials " (PID 3002020119)* released in 2020 addresses this.
- Report presents high-silicon cast iron as an alternative grounding material
- Desired grounding material properties include low corrosion rate and low cost





Summary Report for Evaluations of Alternate Grounding Materials

Integrity Testing of Foundations and Structures

3002020119

Technical Update, December 2020

EPRI Project Manager

F. Bologna

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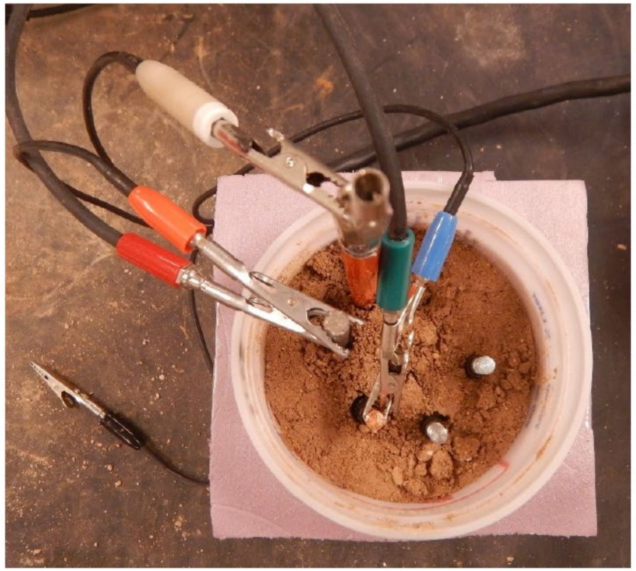
Corrosion Resistance

- Laboratory tests were set up comparing the corrosion rates of different grounding materials



Corrosion Rate for Different Materials Exposed to Soil in Lab – Test #3

Material	Current *µA*	Potential *V*	Corrosion Rate (Calculated) *mils per year*
High Silicon Cast Iron	0.34	-0.13	0.14
Steel	7.17	-0.70	1.44
Zinc	7.90	-1.07	2.02

Corrosion Resistance

- A field test was conducted measuring corrosion current using a Zero Resistance Ammeter
- Comparison made between a HSCI and copper grounding system

Field Corrosion Rate Measurements Between Buried Anode and Steel Pole– Test #5

Material	Current *μA*	Approx. Corrected Current *μA*
High Silicon Cast Iron	665 - 1220	665 - 1220
Copper	2401 - 3903	1201 - 1952

Coating Evaluation

Coating Evaluation

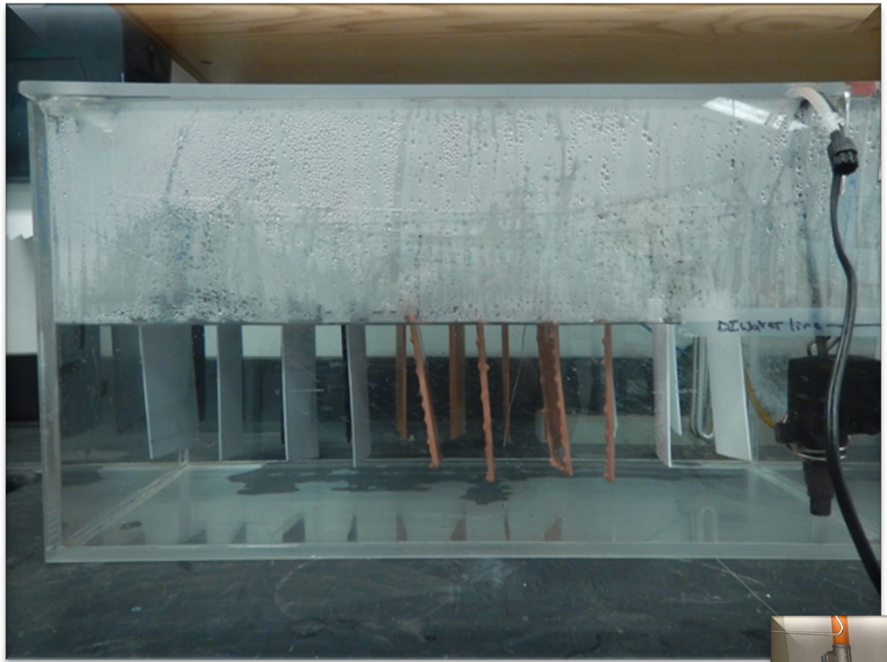
- McWane Poles applies groundline level coating for additional protection

- In 2019, tests were conducted by EPRI on Induron Permasafe™ 100 coating from McWane Poles
  - Amine-cured epoxy resin
  - Can be applied to steel, non-ferrous metals, and concrete
  - Best for immersion environments

Attribute	Test Name	Governing Standard
Thickness, Filler Material, Test Sample Flaws	Metallography	ASTM E3-01
Electron Endosmosis, Adherence	Adhesion	ASTM D 4541-02
Cathodic Disbondment	Cathodic Disbondment	ASTM G8 (non-conductive) ASTM D714-02 (conductive)
Resistance to Soil Stress	Impact	ASTM D 2794
	Bend	ASTM D 790
	Chipping Resistance	ASTM D3170/D3170M-14
Undercutting	Scribe/Creep	ASTM D1654-92
Inhibition, Adherence, Moisture Vapor Transfer, Ionic Passage, Biological Damage	EIS	ASTM G106-89
Appearance	Color	ASTM D 2244-05
	Gloss	ASTM D 523 (modified)

Coating Evaluation

- 1200 hours – hot water immersion [ASTM D870-02]
- 1200 hours – salt fog [CCT-IV]
- 1200 hours – UV exposure [ASTM G154-06]



Hot Water Immersion

Cyclic Salt Spray Chamber

UV Test

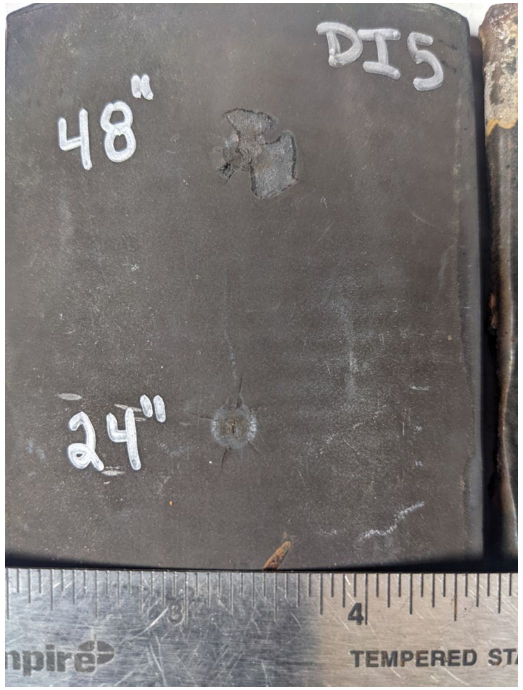
Coating Evaluation | Impact Test

Shows the durability of the coating during rapid deformation from a 2-pound weight.

Rating	Performance Criteria
Excellent	No cracking or exposed sub-layers.
Good	Minor cracking in coating, but no substrate exposed.
Fair	Minor cracking and substrate visible; OR Major cracking but no substrate exposed.
Poor	Major cracking/loss of coating and substrate visible.

Aging Protocol	Drop Height (in)	Degree of Cracking	Substrate Exposed?	Rating
Baseline	24	Major	Yes	Poor
UV	24	Minor	Yes	Fair
Salt Spray	24	Major	Yes	Poor
Immersion	24	Major	Yes	Poor

Baseline



UV

Salt

Immersion

Coating Evaluation | # Cathodic Disbondment

Measures how the coating bonding can handle electrical stresses.

Rating	Performance Criteria
Excellent	No disbonded coating evident
Good	25% or less of exposed area disbonded between/within layers (not to substrate)
Fair	Greater than 25% of exposed area disbonded between/within layers (not to substrate)
Poor	Any disbonding to substrate

Aging Protocol	Area Disbonded (%)	To Substrate?	Rating
Baseline	80%	No	Fair
UV	25%	No	Good
Salt Spray	50%	No	Fair
Immersion	50%	No	Fair

Baseline *UV* *Salt* *Immersion*

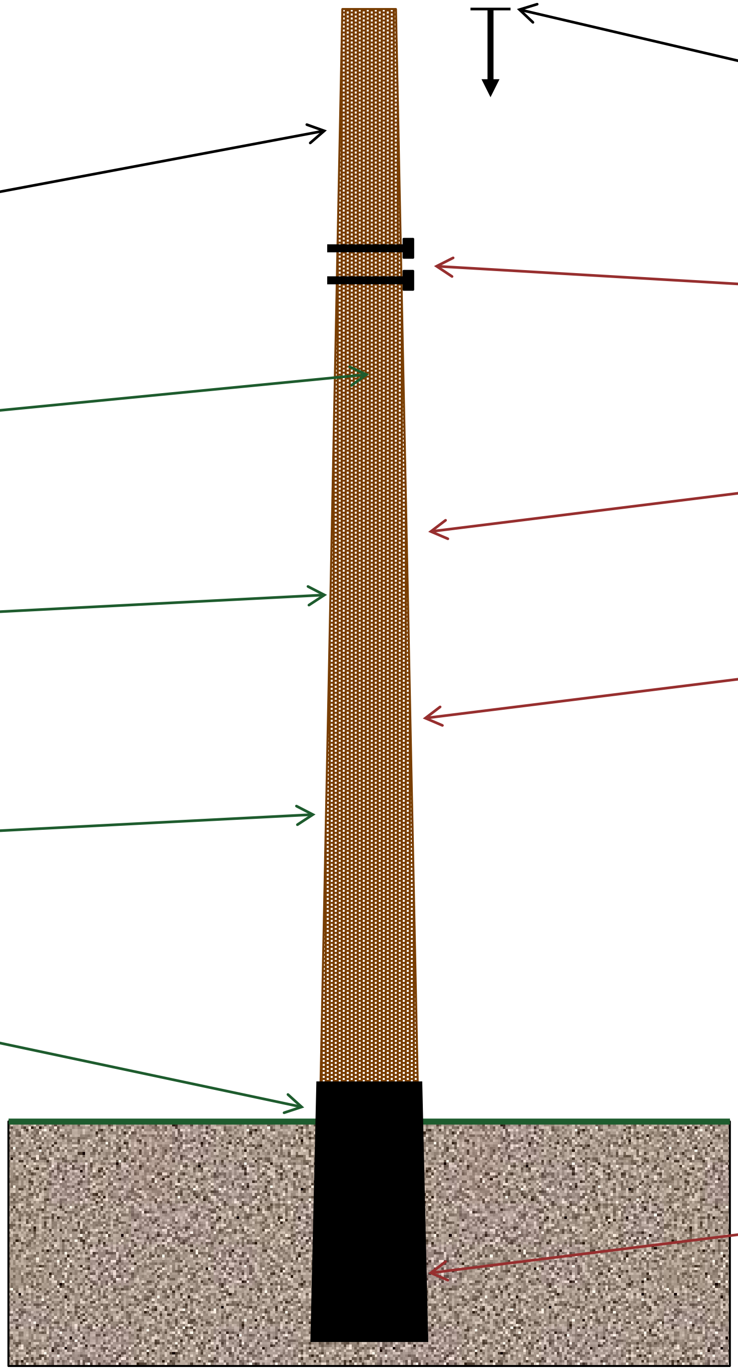
Coating Evaluation | Summary

Aging Protocol	Gloss	Color	Scribe/Creep	Pull-off	Impact (24")	Impact (48")	Chipping	Cathodic Disbondment
Baseline	X	X	X	E	P	P	F	F
UV	P	G	E	E	F	P	F	G
Salt Spray	P	E	P	E	P	P	P	F
Immersion	E	E	E	E	P	P	X	F

Disbondment of painted on coating

Transmission Application Summary

Transmission Applications Summary



Pole heights up to 110ft available (Cl H3)

Circular poles available in weathered finish or coated finish

High carbon content makes welding difficult, slip joints and bolted connections

Typ. Centrifugally cast, no longitudinal weld

Lower yield strength than A572 steel – 42ksi vs 65ksi

~50% the weight of comparable wood pole

Pole sizes/capacities limited by available molds
Less scalable for EHV

Class	Max Height (ft)	Moment Cap. (k-ft)
H3	110	463
H5	95	530
H8	80	641
12.8k	65	698
20k	50	820

Per McWane Brochure 9-23-22

Resistant to fire and wildlife degradation

High corrosion resistance relative to steel

Initial tests on groundline coating show poor impact and cathodic disbondment performance

Key Takeaways

1. Ductile iron has a long history, but less so for transmission applications
2. Ductile iron's graphite shape makes it higher performing than cast iron for structural applications
3. Ductile iron offers superior corrosion performance relative to steel
4. Ductile iron is currently targeted towards the low transmission voltage range (<200kV)
5. EPRI is incorporating ductile iron research into P35.005 starting in 2024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