Development and Application of a Test Method to Determine the Content of Sulfates and Sulfides in Concrete Foundations

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THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

Overview

- Background and Motivation
- Overarching Goal and Research Approach
- Wavelength Dispersive X-ray Fluorescence Methodology
- Statistics
- Future Direction
- Conclusion

Background and Motivation

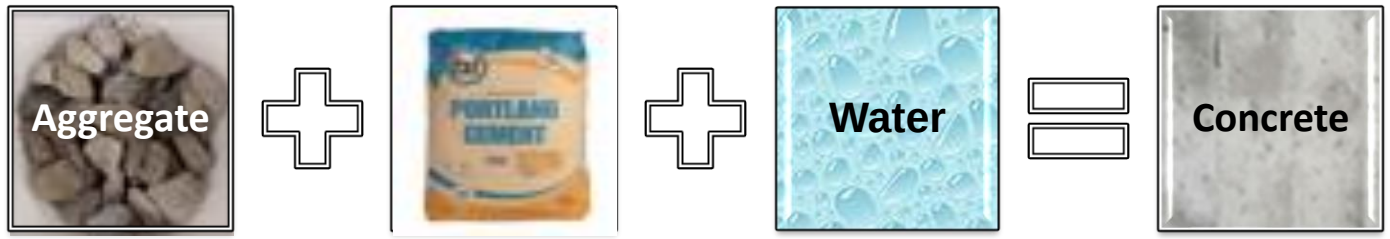
Crumbling concrete

Millions more needed as thousands still have homes with deteriorating foundations

By Eric Bedner / Journal Inquirer Feb 25, 2023 1

An Ellington home is seen here in 2016, being lifted at the expense of its owner to replace its crumbling concrete foundation. Since 2019, the captive insurance company that's helped to pay for fixing crumbling foundations has completed more than 700 homes. But an additional $100 million is needed to repair the thousands left that are affected. And some current funding could be on the legislative chopping block.

Buy Now



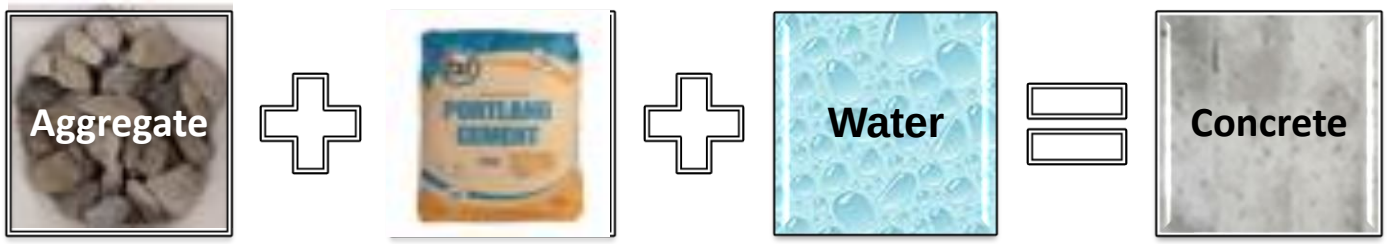
May contain sulfides S^{2-} in **Pyrrhotite ($Fe_{1-x}S$)**

0.6 – 1.8% total S as **sulfate $S^{6+}(SO_4^{2-})$ in gypsum**

MIN 0.08 – 0.28% total S as sulfate from cement
Additional S from aggregate

- The presence of sulfide rich aggregates in the production of concrete foundations has led to early deterioration.
- Over 40,000 homes are impacted in CT alone.
- The oxidation of pyrrhotite is expansive and releases sulfates attacking the concrete internally.

Background and Motivation



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Additional S from aggregate

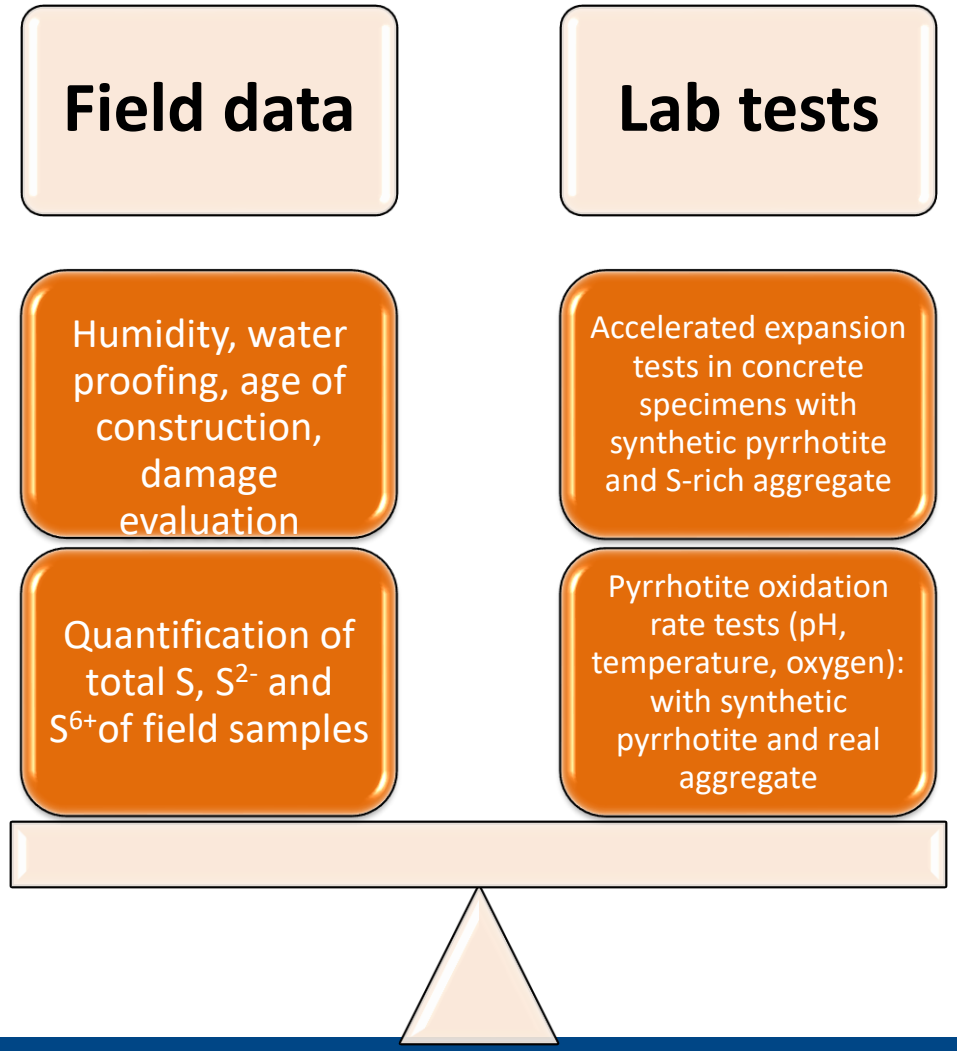
$$Fe_{1-x}S + \left(\frac{10-3x}{4}\right)O_2 + \left(\frac{4-3x}{2}\right)H_2O \rightarrow (1-x)Fe(OH)_3 + SO_4^{2-} + H^+$$

Sulfide S^{2-} → Sulfate S^{6+}

Kinetics Control Damage

Secondary Reactions
And Expansion

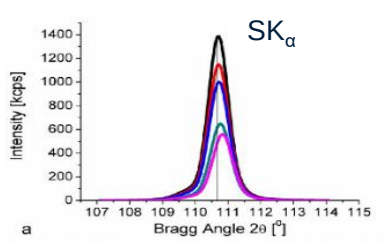
Overarching Goal and Research Approach

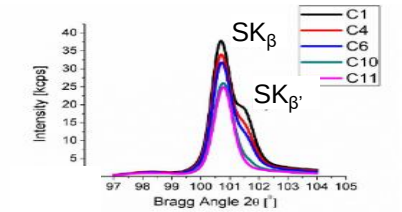


Develop a **risk assessment** framework to evaluate the probability of deterioration as a function of **time and field conditions** to assist homeowners and stakeholders with **decision making**.

Wavelength Dispersive X-ray Fluorescence Methodology

WD-XRF

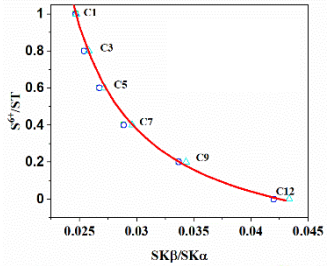




Powdered concrete samples

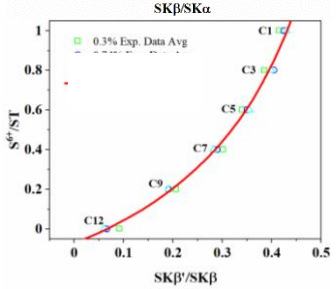
Relative Concentration of Sulfur Speciation

$$\frac{SK_\beta}{SK_\alpha} \rightarrow \frac{S^{6+}}{S_T}$$



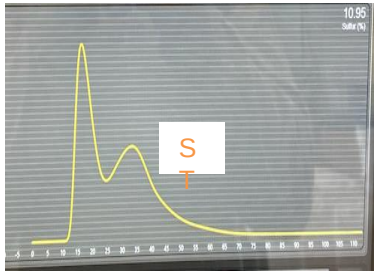
Derivation

$$\frac{SK_{\beta'}}{SK_\beta} \rightarrow \frac{S^{6+}}{S_T}$$



Calibration Curves

Elemental Analyzer



Total Sulfur
S_T in wt.%

Absolute Concentration of Sulfur Speciation

$Sulfate\ S^{6+}$ in wt.%

$$S^{2-} = S_T - S^{6+}$$

$Sulfide\ S^{2-}$ wt.%

Concentration of Pyrrhotite

Pyrrhotite in wt.%

$$Fe_7S_8 = \frac{S^{2-}}{0.39}$$

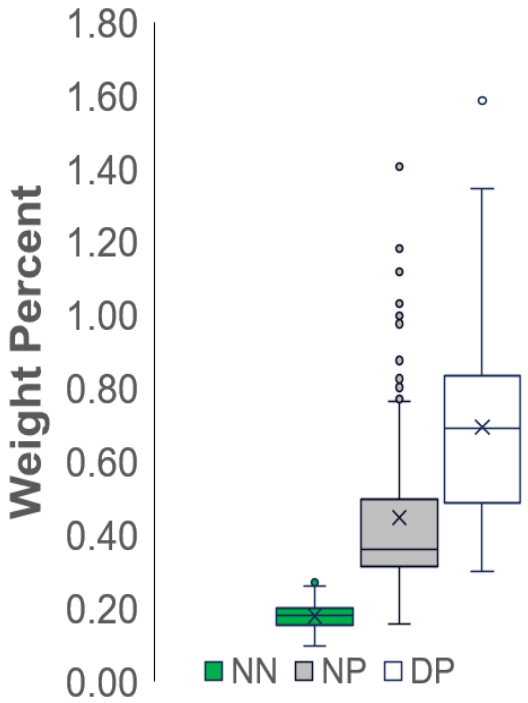
Statistics: Dataset

Home Description	No of homes	No of samples	No of ST analyses	No of WD-XRF analyses
NN (No damage – No pyrrhotite)	57	260	780	780
NP (No damage – Pyrrhotite detected)	49	225	675	675
DP (Damage – Pyrrhotite detected)	67	232	696	696
TOTAL	173	717	2151	2151

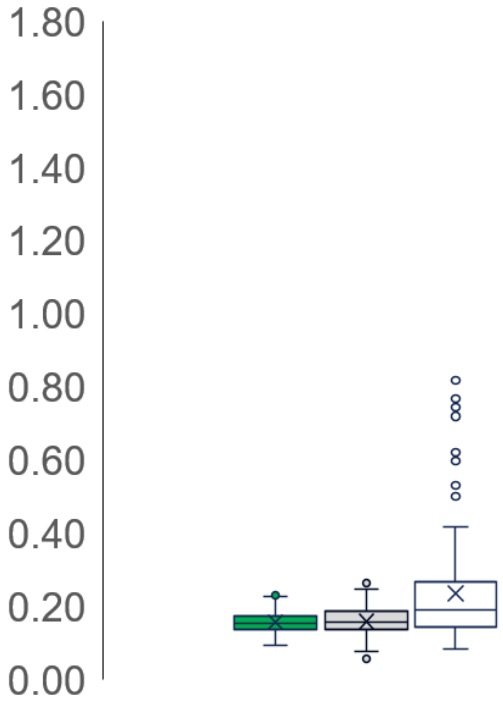
- The number of samples include all individual samples from all homes; every home typically has between **3 and 7 samples tested**, with the average home having **5 samples**.

- Each sample consists of approximately **150 g of homogenized powder**, which is tested for ST, sulfate and sulfide in triplicate.

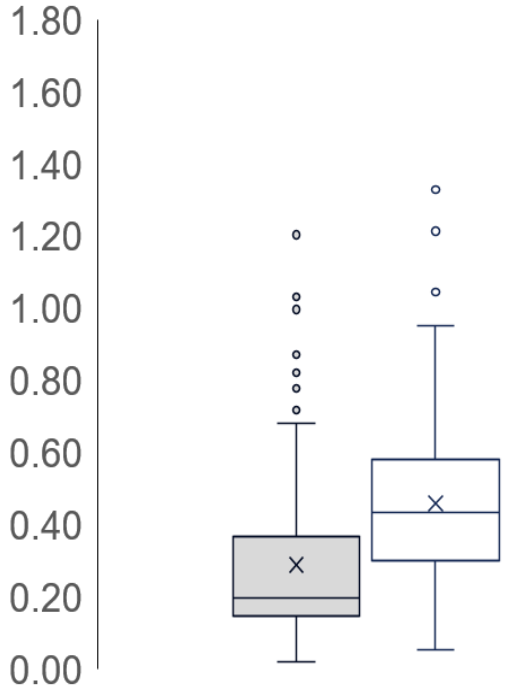
Distribution of Total Sulfur (ST) in NN, NP, and DP samples



All **NN** samples have **ST<0.3 wt.%.**

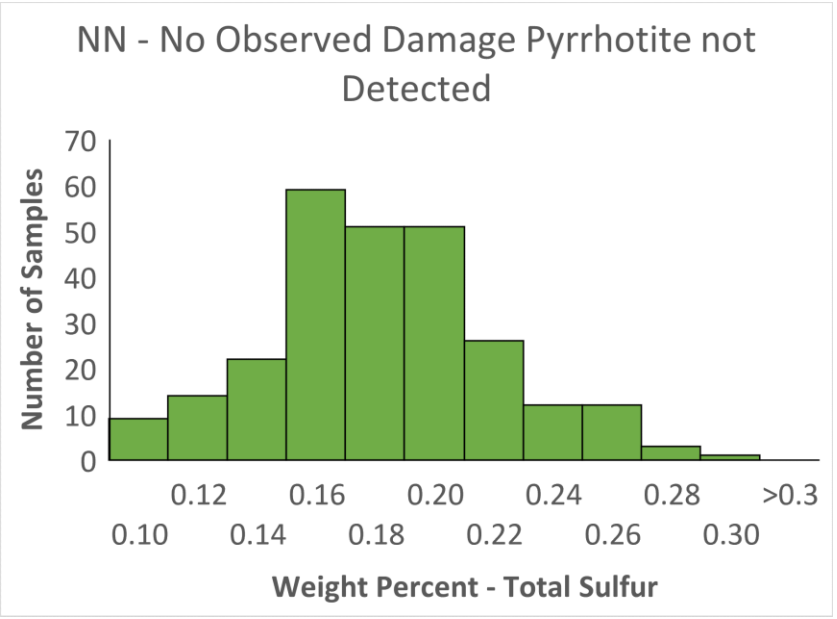


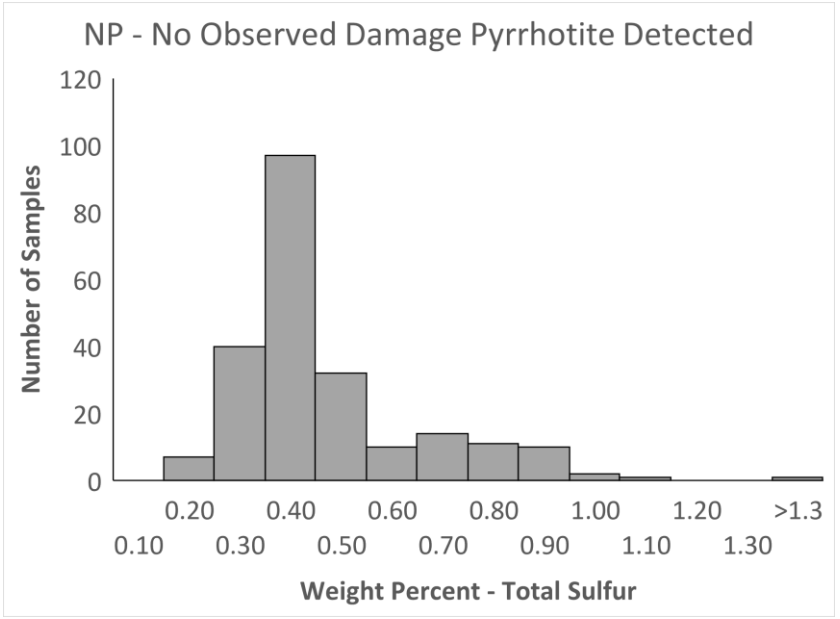
No significant difference between the **Sulfate wt.%** mean between the 3 categories

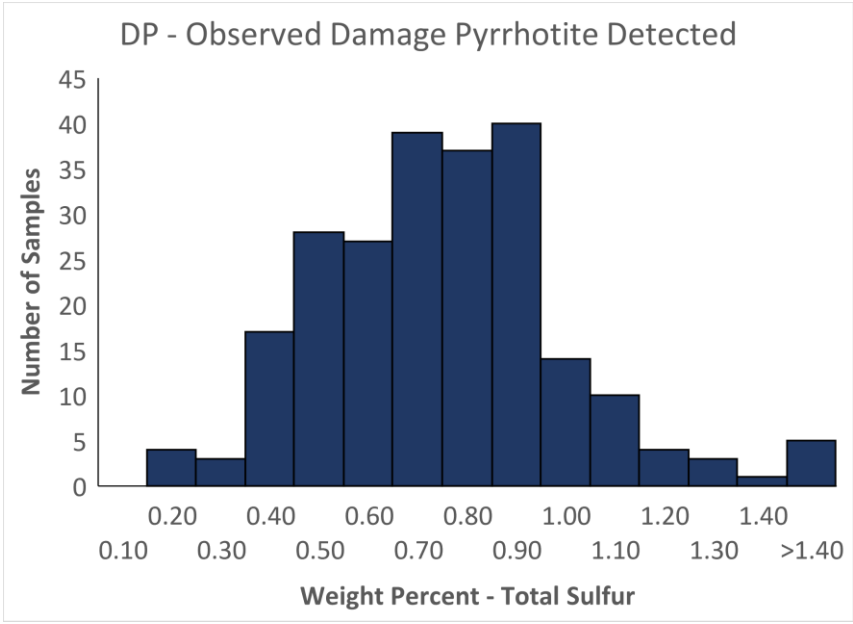


ST> 0.3 wt.% is driven by **sulfide**

Distribution of Total Sulfur in NN, NP, and DP samples





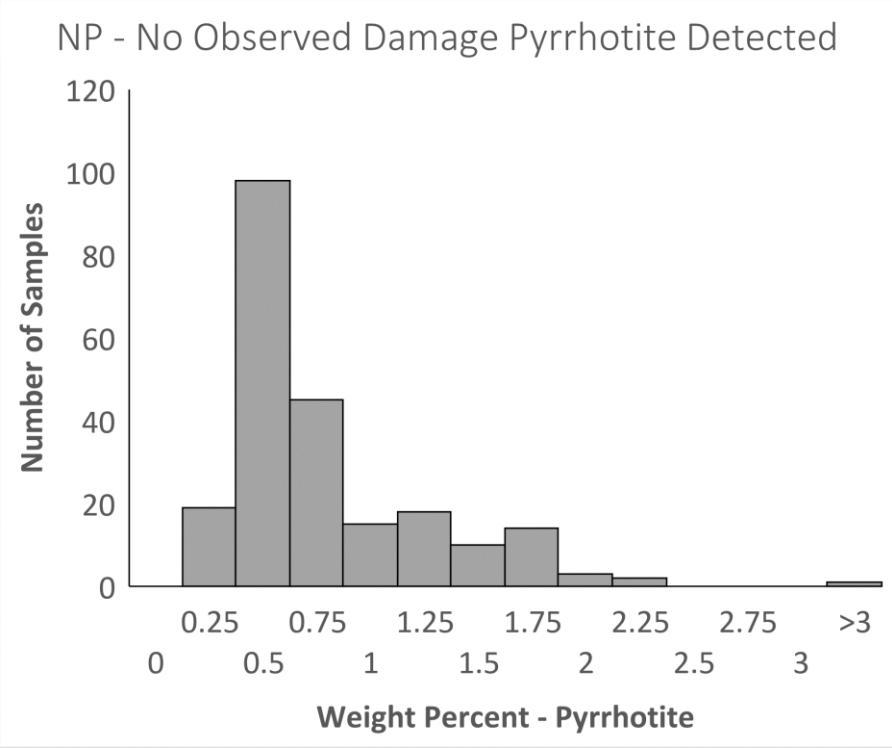


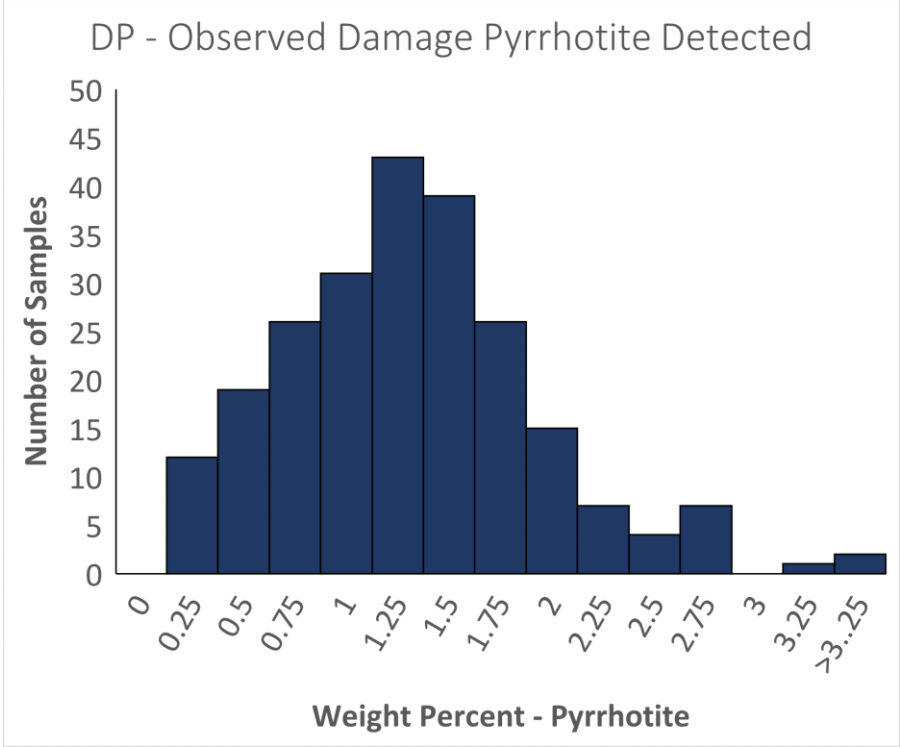
NN samples with no visible damage and no pyrrhotite had a total sulfur median concentration of **0.17 wt.%**

The large majority of **NP** samples had a total sulfur concentration between **0.3 and 0.5 wt.%.**

DP samples **all** had pyrrhotite concentrations exceeding **0.30 wt.%.**

Distribution of Pyrrhotite in NP and DP Samples



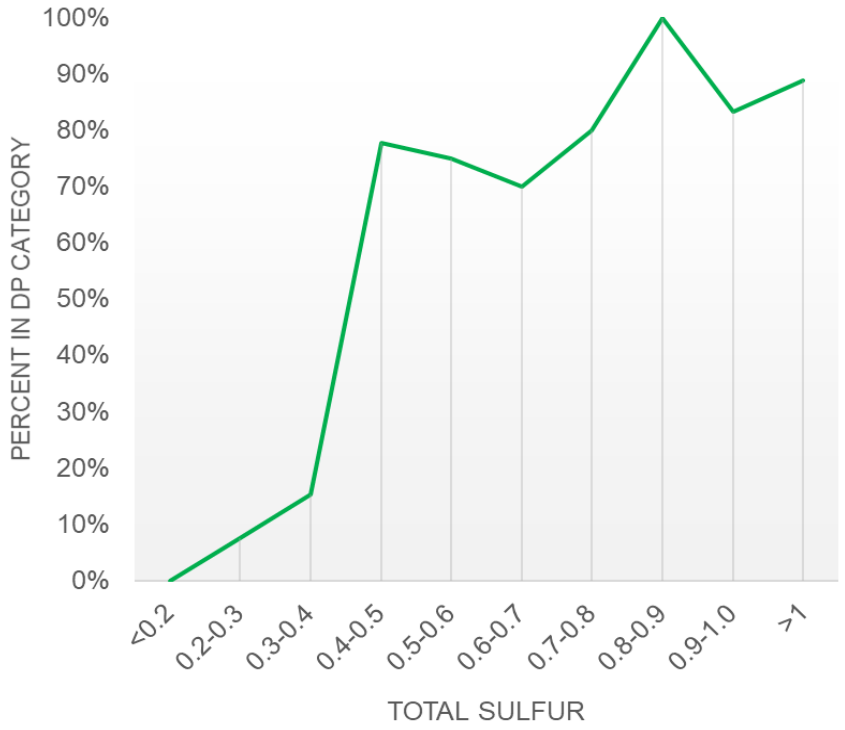


The average concentration of **PY in** the **NP** dataset (0.66 wt.%) is **significantly lower** than the average (1.19 wt.%) in the **DP** dataset.

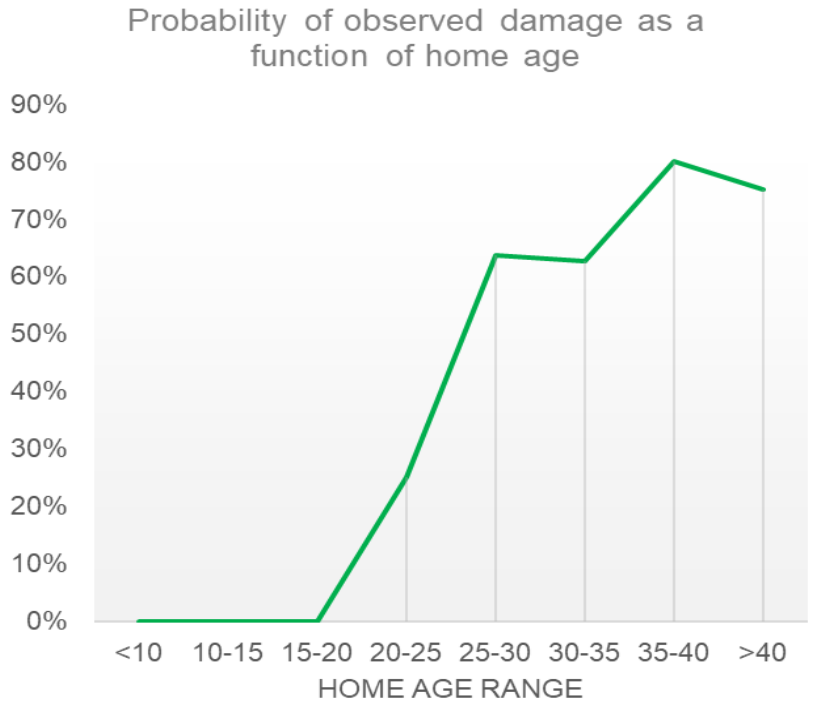
A few NP samples have high PY concentrations, exceeding the average PY concentration of DP homes but have no visible damage.

A number of DP samples have concentrations similar to the average of samples in NP; a lower **PY concentration of equal or less than 0.5 wt.% does not guarantee the absence of visible damage**.

Pyrrhotite Distribution



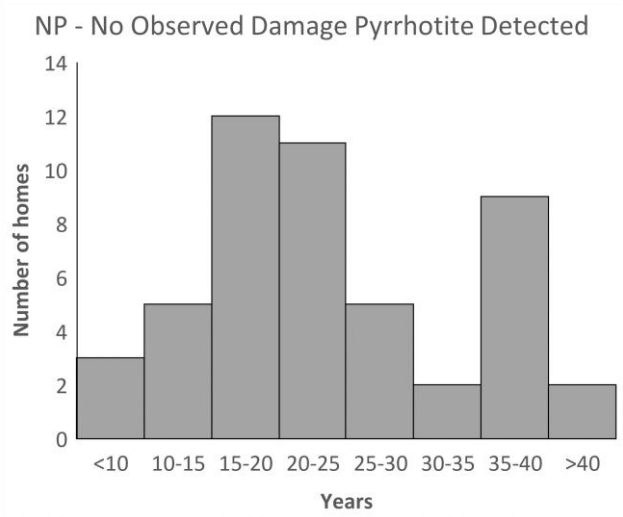
Based on home averages:
Above **ST 0.4%,** ≥80% change of damage

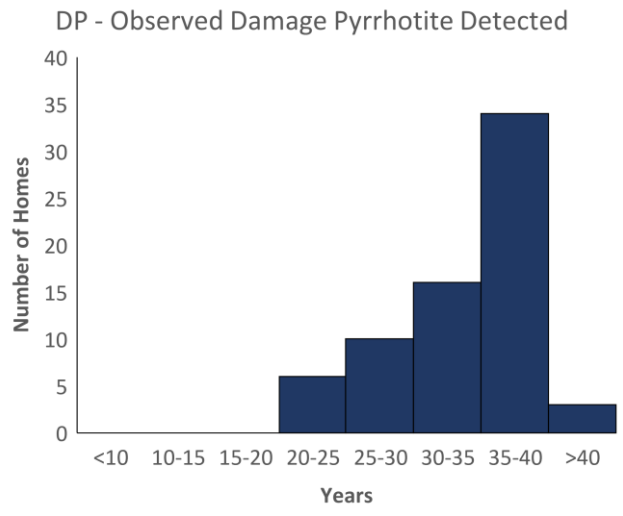


Based on home averages:
Above home age of **30 years,** ≥60% change of damage

Relative influence of pyrrhotite concentration and age cannot be determined using this dataset alone

Influence of the Age of the Home on the Basis of the Year of Construction



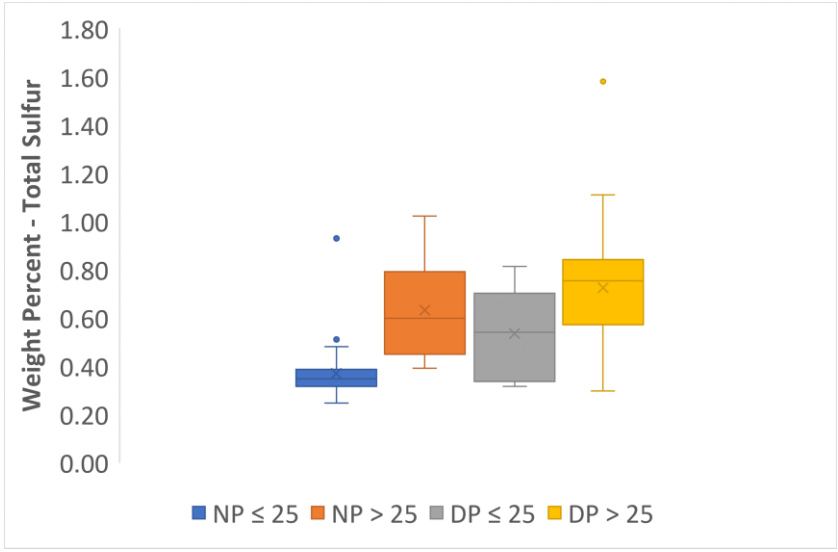


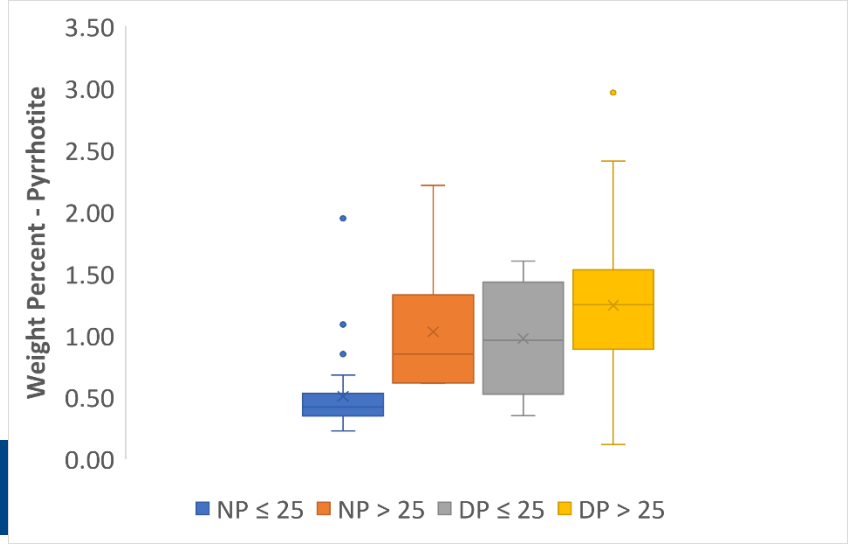
- Every **DP** was older than **20 years,** with only 6 homes between 21 and 25 years of age, the average age being *35 years.*
- **NP** homes had an average age of **25 years**.
- 18 homes older than 25 years of age and no visible damage, and 6 homes that were 21 and 25 years of age and showed damage.

Influence of the Age of the Home on the Basis of the Year of Construction

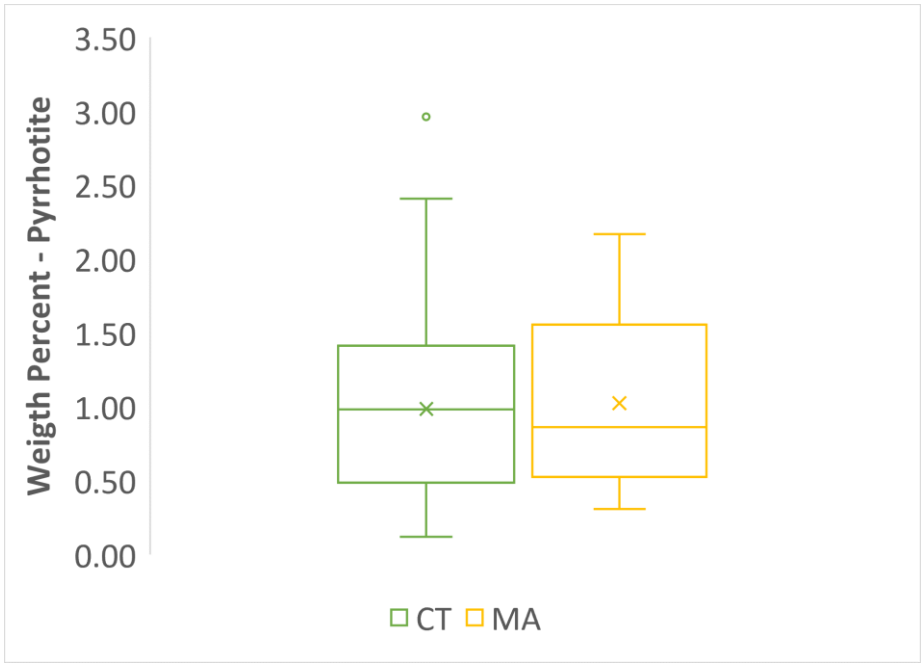
Newer homes (age less or equal to 25 years), PY and ST concentrations are generally lower in NP, potentially indicating variations in the rock mined during different time periods.

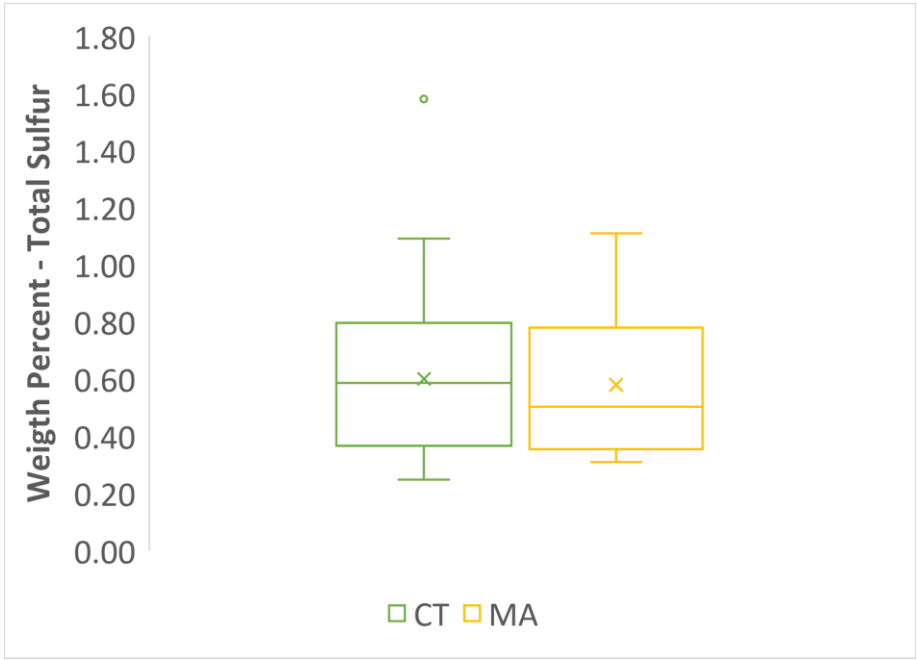
For older homes, there is **no statistical difference in the PY concentration between NP and DP homes.** The absence of visible damage in older homes cannot be attributed to lower amount of pyrrhotite





Distribution of Pyrrhotite and Total Sulfur in CT and MA NP and DP Homes

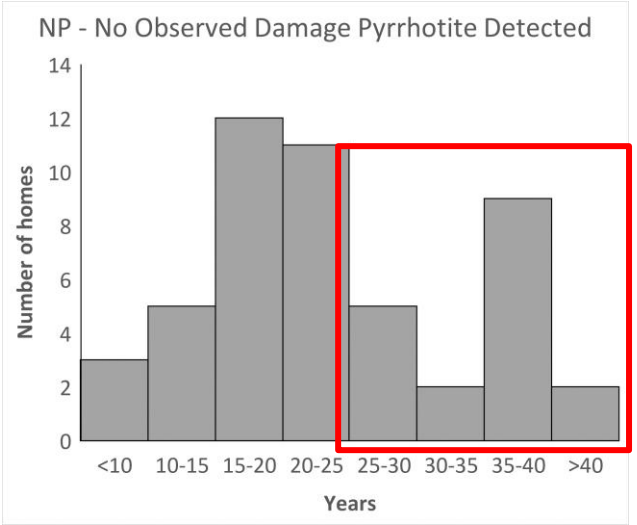




No statistically significant difference in the datasets from homes located in CT versus MA

Future Direction

- Laboratory test (XRD, humidity test) and thorough field inspections (waterproofed basement, drainage system) of older aged (>25 years) NP houses to **understand why there is not damage**.



- Perform **accelerated laboratory experiment**s to better **understand the correlation between age and damage**.

- Use this information to build a predictive model for pyrrhotite-induced concrete deterioration and assist homeowners and stakeholders with decision making

Conclusion

- Homes with ST concentration <**0.30 wt.% = no damage**

- The average PY concentration in **DP homes is higher than NP homes**. However, it's not a guarantee of damage, as some homes with low pyrrhotite concentrations had visible damage, and some with high pyrrhotite concentrations had no visible damage

- **DP homes are older when compared to NP homes**. However, there are older homes without damage and younger homes with damage, indicating that **age alone is not the sole factor determining damage.**

- There are **18 older NP homes** that need further investigation, as they **have pyrrhotite** concentrations **similar to DP homes**. This suggests that additional factors beyond age and pyrrhotite concentration may be responsible for the absence of damage in these homes.

Acknowledgments

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