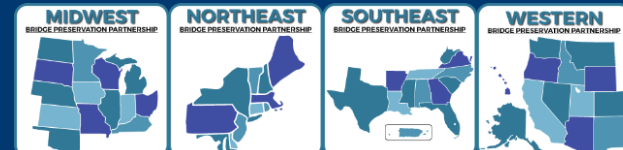


MALP Stops Corrosion but Can We Live with the Cracks?

Coatings & Corrosion Protection Session I
Tuesday September 10, 2024
Imperial Ballroom C/D

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TOPICS:

- Magnesium Cements – MALP & MKP
- KU *Preliminary* Research
- MALP Field Observations
- Cracking and Delamination Issues
- Combination MALP VO repair with MKP VO topping
- pH Measurements
- Conclusions

Magnesium Cements

MALP

Magnesium Alumino Liquid Phosphate (aka Magnesium Aluminum Phosphate)



- Liquid aluminum phosphate activated
- **Very rapid setting (typically traffic-ready in less than 1 hour)**
- Working time under 10 minutes (can be extended by cooling activator)
- No off-gassing

MALP concrete = Magnesium Aluminum Phosphate - 2 component mix. Dry mix bags containing MgO, SCM, and aggregates. Liquid Activator containing Mono Aluminum Phosphate and SME-PS
SME-PS - Soy Methyl Ester, Polystyrene. An admixture added to the liquid activator and also used for curing.

Magnesium Cements

MKP (sometimes MPPC)

Magnesium Potassium Phosphate Cement Concrete



- **Water-activated**
- Rapid setting (typically traffic-ready in less than 3 hours)
- Working time under 20 minutes (can be extended using boric acid admixture)
- No off-gassing

SME-PS - Soy Methyl Ester, Polystyrene. An admixture added to the liquid activator and also used for curing MKP.

Note that magnesium phosphate cements have been used for rapid infrastructure repairs for 30 years. Newer formulations have eliminated the outgassing problems.

Portland Cement

Chemical composition

Portland cement is made up of four main compounds:

- tricalcium silicate ($3\text{CaO} \cdot \text{SiO}_2$),
- dicalcium silicate ($2\text{CaO} \cdot \text{SiO}_2$),
- tricalcium aluminate ($3\text{CaO} \cdot \text{Al}_2\text{O}_3$), and
- a tetra-calcium alumino ferrite ($4\text{CaO} \cdot \text{Al}_2\text{O}_3\text{Fe}_2\text{O}_3$).

In an abbreviated notation differing from the normal atomic symbols, these compounds are designated as C_3S , C_2S , C_3A , and C_4AF , where C stands for calcium oxide (lime), S for silica, A for alumina, and F for iron oxide. Small amounts of uncombined lime and magnesia also are present, along with alkalies and minor amounts of other elements.

Summary Material Properties

MALP Pro's:

- **Corrosion Resistance** 😊
- **Rapid Setting**
- **Good Freeze – Thaw resistance**
- **Can apply below freezing**

MALP Con's

- **Short working time**
- **Surfaces must be dry to apply**
- **Shrinkage leads to cracking especially on larger repairs**

MKP Pro's:

- **Adequate working time**
- **Water cured – User Friendly**
- **Slightly expansive**
- **Shotcrete Friendly**

MKP Con's

- **Poor Corrosion Resistance**
- **Poor Freeze – Thaw Properties**
- **Can not apply below freezing**

8' Refrigerated trailer rentals and sales

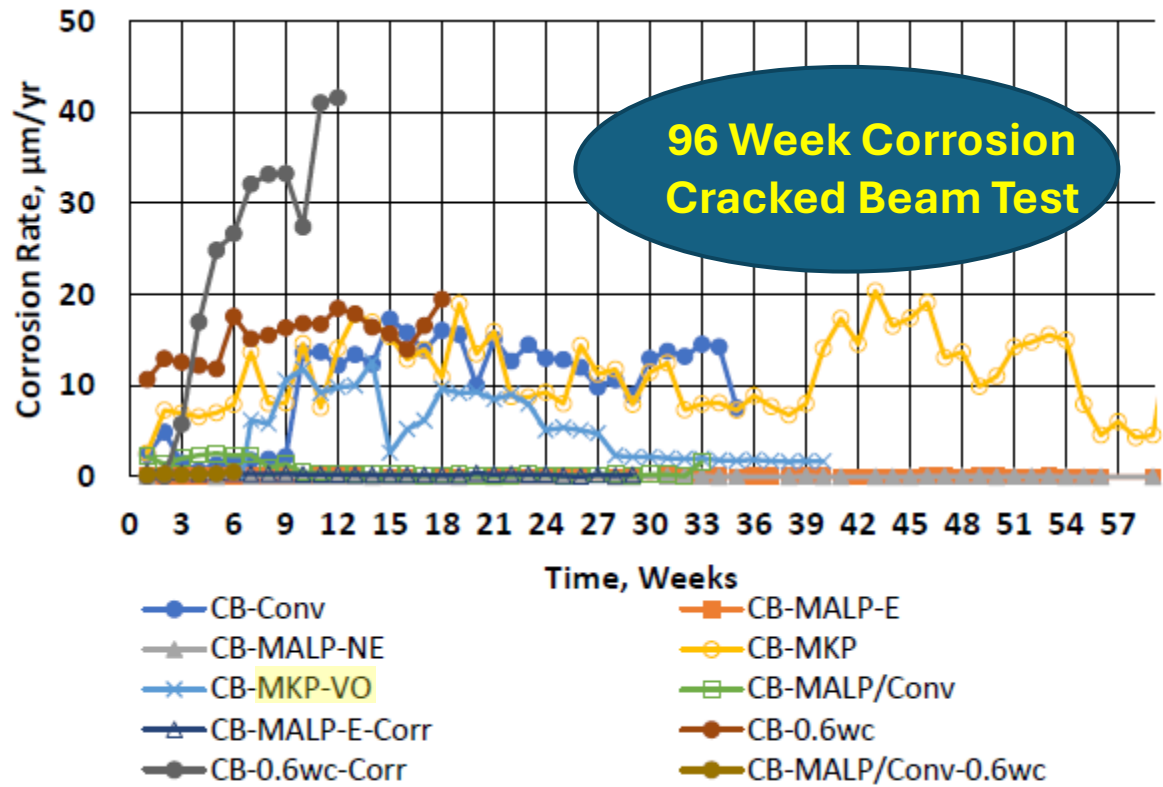


Note that MALP Working time can be improved by freezing the materials which would allow shotcrete application.

Limiting the size of patches will help to keep the cracks small.

Daily Rental: \$165 - \$185 | Weekly Rental: \$910 - \$1,010 | Monthly Rental: \$3,185 - \$3,320

Preliminary KU Research on MALP and MKP



Average macrocell corrosion rates of specimens in the cracked-beam test.

MALP has great corrosion resistance.
 MKP has poor corrosion resistance **except MKP VO.**
 Note: E = SME-PS

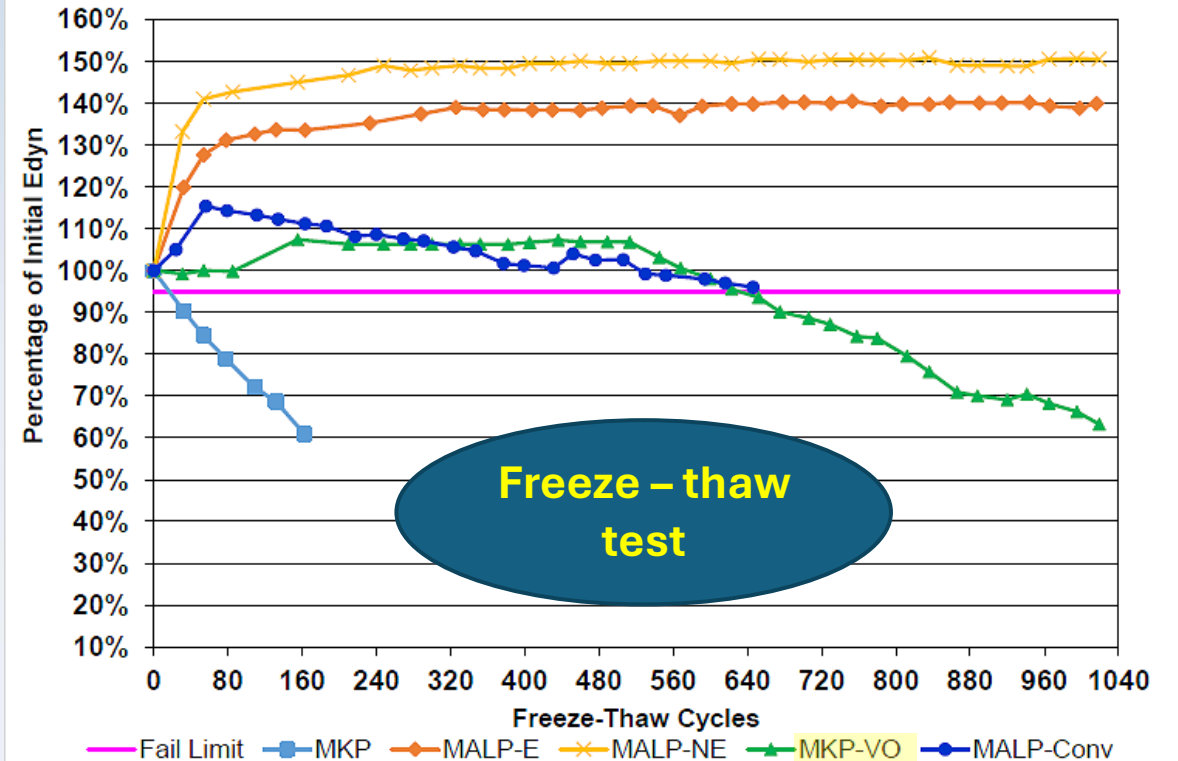
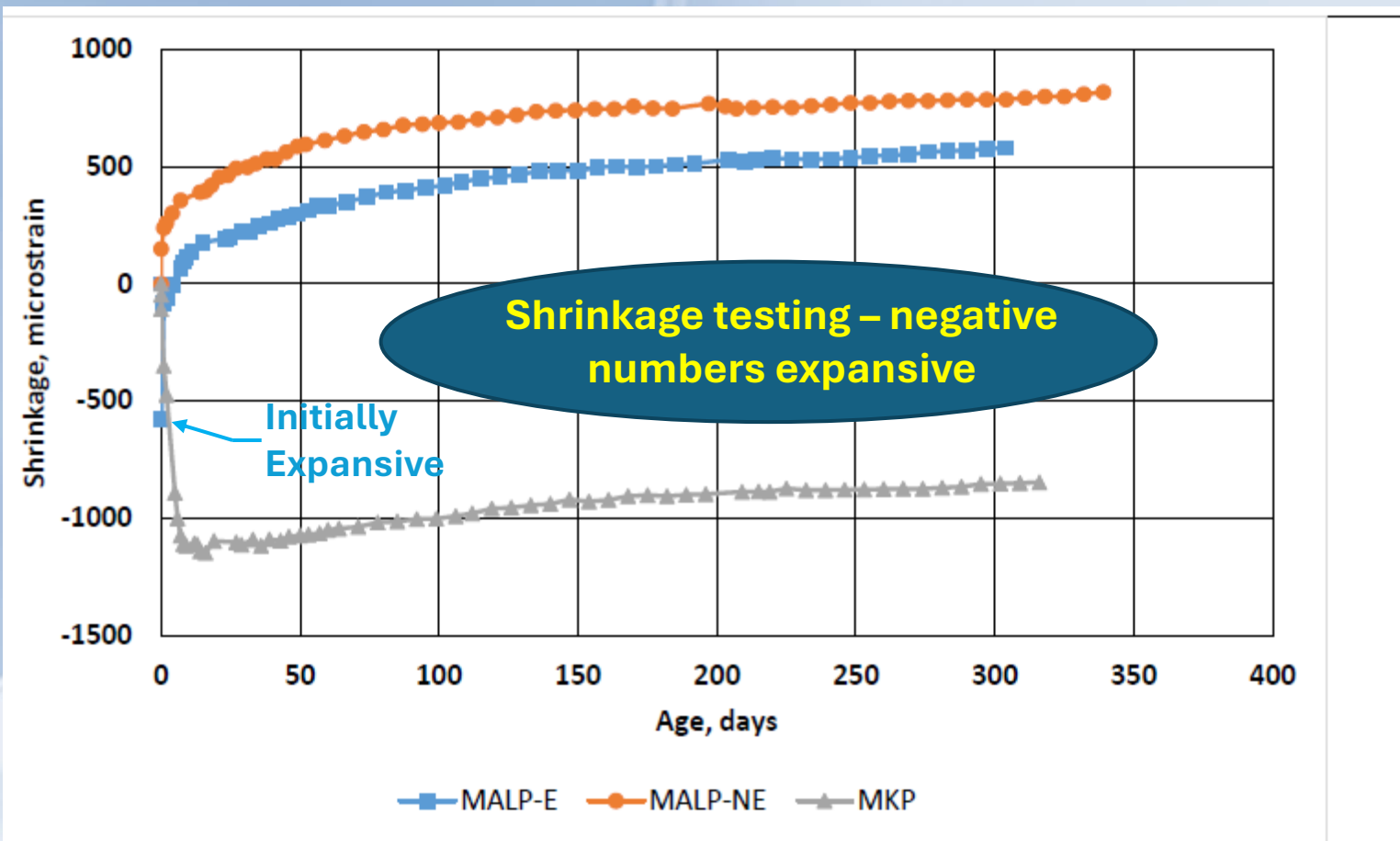


Figure 7 – Percentage of initial dynamic modulus of elasticity vs. number of freeze-thaw cycles.

MKP with VO (small amount of MALP) seems to have acceptable freeze – thaw for 500 cycles.
 Note: VO = Mix design for vertical / overhead placement

Note Where MALP is weak, MKP is Strong and where MKP is weak, MALP is Strong

MALP while initially expansive has issues with shrinkage leading to cracking. Due to the initial expansion, no need to seal the edges of the repair.



Average shrinkage, microstrain vs. number of days after casting for specimens containing MALP and MKP.

Preliminary Research Summary

Test	MALP	MKP
Corrosion	Good	Poor
Freeze-Thaw	Good	Poor
Shrinkage	Poor	Good
Scaling	Poor	Good

Packsaddle Bridge – Repaired March 1, 2017

Very Little Surface Preparation Required



Slide
From
2018
NBPP



NATIONAL BRIDGE PRESERVATION PARTNERSHIP CONFERENCE 2018

PRACTICES WE CAN NOT AFFORD TO DEFER

MALP - Packsaddle Bridge Repair

NBI 21132, US-283 over South Canadian River, Roger Mills – Ellis Counties



**Labor intensive
minimal
training
required
Note that
application
does not
require a lot of
skilled labor**



Comparison 2017 photo to 2024 photo



Large Cracks appeared on the exterior face middle portion in early 2017



Cracks felt very solid when tapped with a hammer.



**Hammered on
the bridge in
2023 and 2024.
Video was
made in
February 2023.**

I-35/Adams St. Column Repair, McClain Co., Repaired April 25, 2021 (Approximately three years old).

Column Condition at time of MALP Placement, Note that MALP Converts iron oxide to iron phosphate

Flash Rust

NBI 16938 Built 1967



Potential Concerns with MALP Repairs



Appears to be spalling on the side of the column

Close up of cracks – vary from 0.01 to 0.025”



Other Locations: MALP Joint Headers

NBI # 13065
STRUCTURE NUMBER 2520-08.87X
COUNTY GARVIN
FACILITY CARRIED SH 29
FEATURE INTERSECTED WEST ROCK CREEK
02/09/2023
PIER # 2 JT. NOSING CRACKS &
CRACKS TO DECK SPANS # 2 & 3 WB LANE

NBI 13065 & 13082
SH-29 over W & E
Rock Cr. Garvin Co.

Cracks
Typical

Total 8 Headers
Approximately 2+ years old

NBI 19986 & 19987, US-75 over
SH-117, Tulsa County

← **2' Failure**

Total 4
Headers
4 years old

← **MALP This Side Only** →

11/21/2023



Removing MKP and MALP Materials from Rusty Rebar



This makes you wonder how well the products bond to steel. Note product was removed after approximately two hours.

Repair with Combination of MALP VO and MKP VO, I-35 Frontage Road over I-35, NBI 17566, Murray County



NBI #: 17566 Str #: 5032 0575 XF Facility Carried: I-35 FRONTAGE RD. 2023-02-09
 Murray I-35 Feature Int.: I-35 UNDER Pier 2

Repair Treated with SME-PS (Soybean product)



pH

Observations

HYDRION pH Pencil: 1.0 pH, 4 1/2 in Overall Lg, 1/2 in Overall Wd, 75 Tests, pH

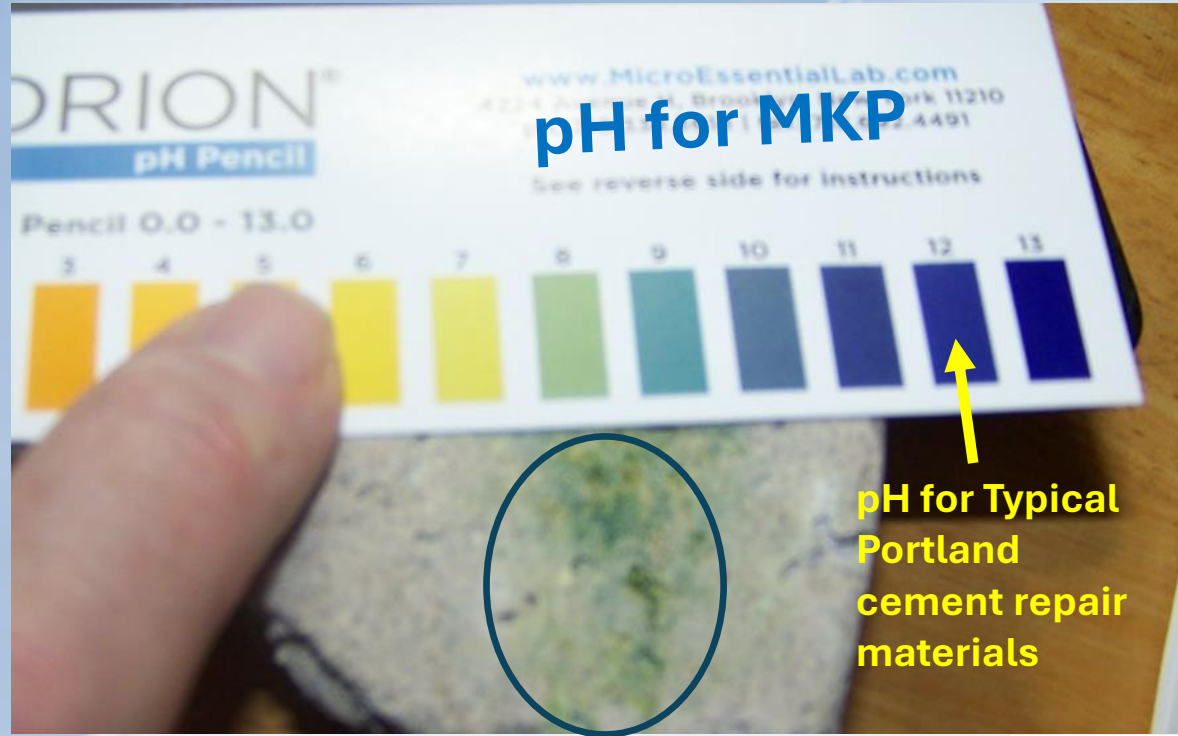


pH is the measurement of acidity or alkalinity of a substance. It is expressed as a number from 0-14. pH is the concentration of hydrogen ions commonly expressed in terms of the pH scale. Low (pH 0-7) corresponds to high hydrogen ion concentration. A substance that when added to water increases the concentration of hydrogen ions (lowers the pH) is an acid. A substance that reduces the concentration of hydrogen ions, raises the pH, (pH 7-14) is an alkali base.

Reference is made to **ASTM D4262** for testing procedures.

Note: pH is important for paint application on concrete surfaces.

pH Testing Magnesium - Based Cements



MKP (sometimes MPPC)

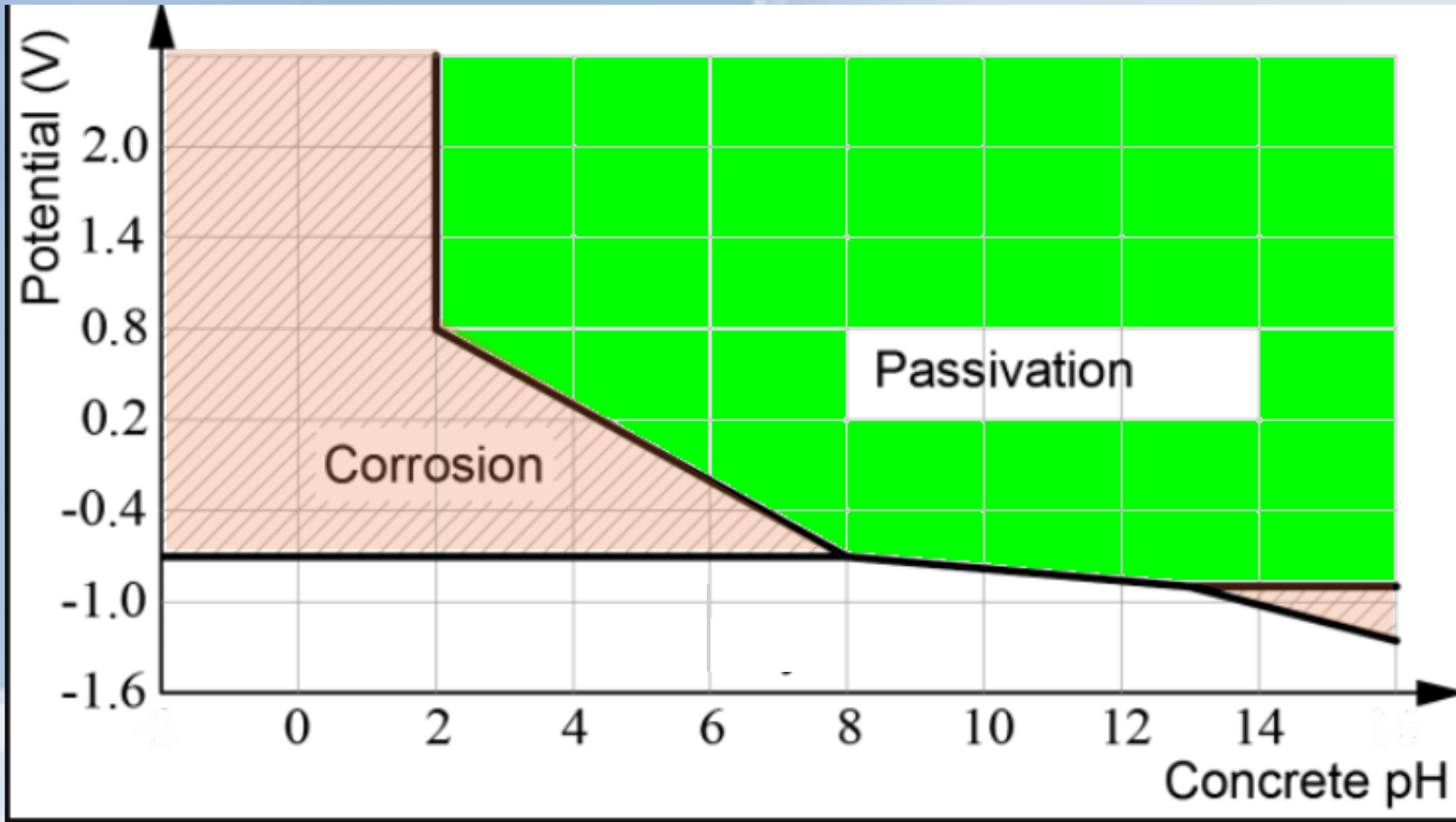
Magnesium Potassium Phosphate Cement Concrete
 $\text{MgO} + \text{KH}_2\text{PO}_4 + 5\text{H}_2\text{O} \rightarrow \text{MgKPO} \cdot 6\text{H}_2\text{O}$
 Resulting Acid: H_2PO_4



MALP

Magnesium Alumino Liquid Phosphate (aka Magnesium Aluminum Liquid Phosphate)
 $2\text{MgO} + \text{Al}(\text{H}_2\text{PO}_4)_3 = 2\text{MgHPO}_4 \times 3\text{H}_2\text{O} + \text{AlPO}_4 \times \text{H}_2\text{O}$
 Resulting Acid: H_3PO_4

pH Observations



Carbonation in Portland cement can reduce the pH from 12 or more to below 9 at which point initiation of corrosion can occur.

MALP appears to have a pH around 3 – so what keeps the MALP from corroding?

Corrosion Potential

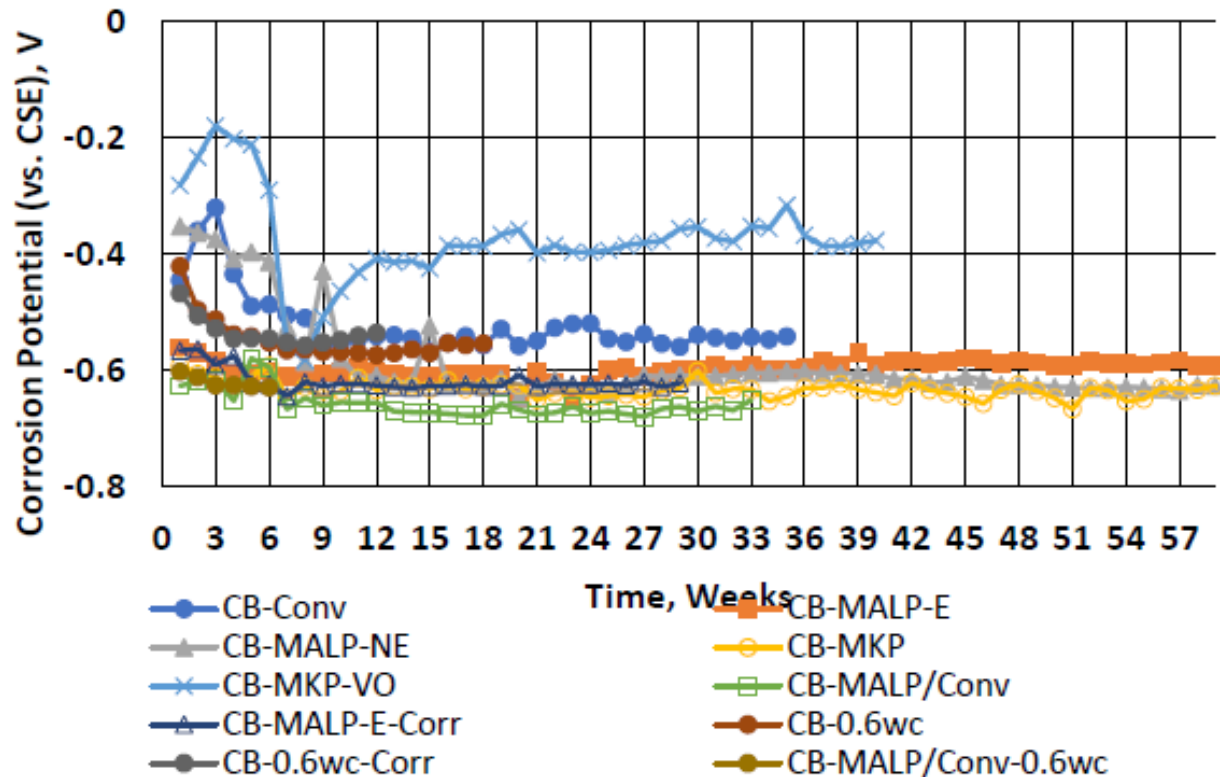


Figure 6 – Average top mat corrosion potentials vs. CSE of specimens in the cracked-beam test.

Research shows significant potential for corrosion, but little or no corrosion is occurring on the MALP materials – WHY?

The manufacturer claims MALP has a rust convertor converting iron oxide to ferrous phosphate but we are not aware of research to support this.

Expert Researchers claim the MALP forms a barrier That prevents corrosion.

Centuries old Iron pillar of Delhi - **No paint required**



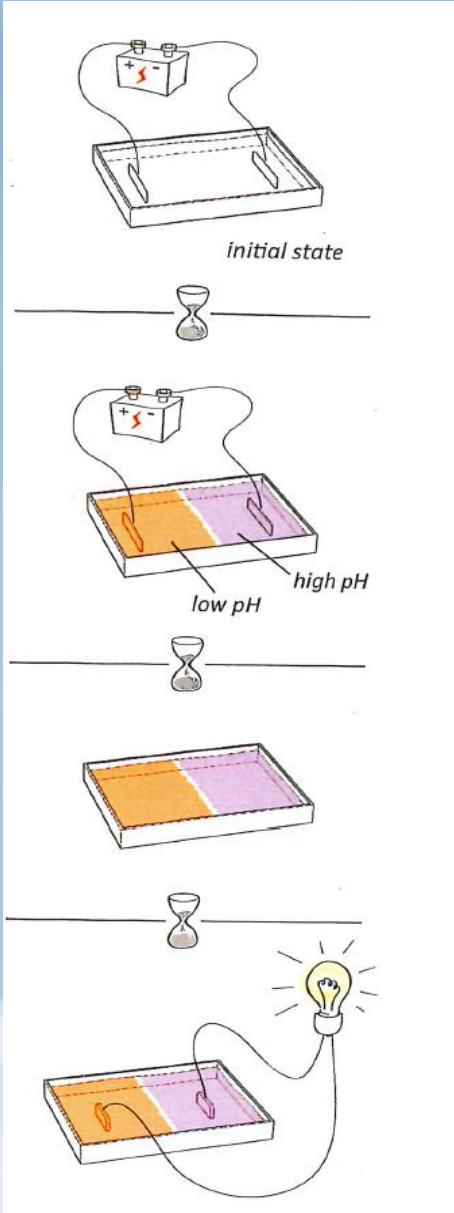
**23'-8" Tall
With
Intricate Iron
details**

Expert Corrosion Engineers attribute the Delhi pillar corrosion resistance to the high phosphorous content in the iron:

“The most critical corrosion-resistance agent is iron hydrogen phosphate hydrate ($FePO_4 \cdot H_3PO_4 \cdot 4H_2O$) under its crystalline form and building up as a thin layer next to the interface between metal and rust.” (Wikipedia)

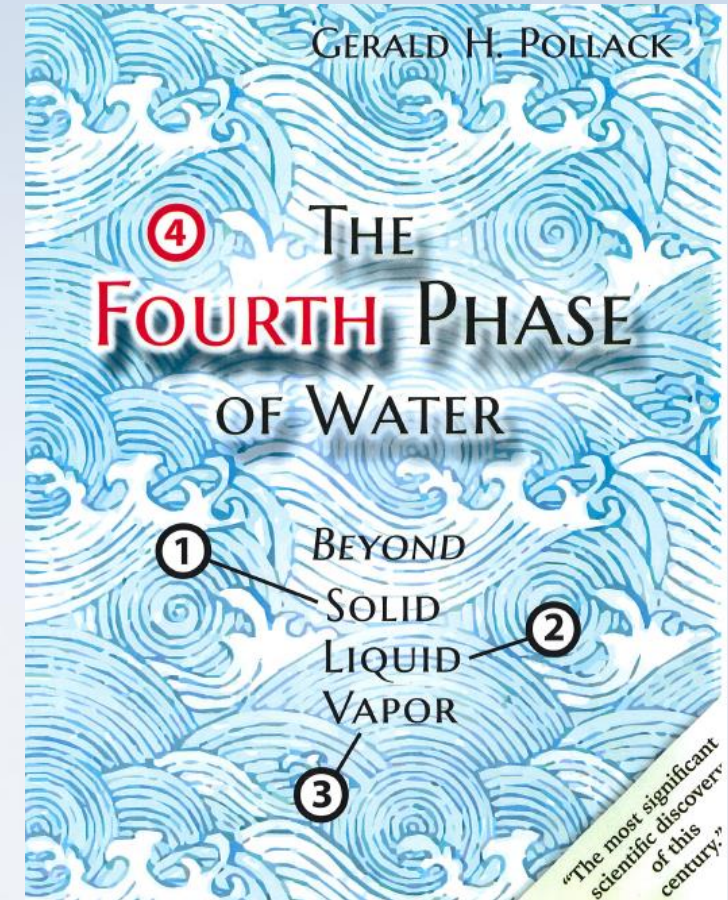
Rust Converter? Barrier?

Something is stopping Corrosion when MALP is present.



Perhaps the Concrete Corrosion can be compared to a Water Battery with high pH on one side and low pH on the other side resulting in a current flow.

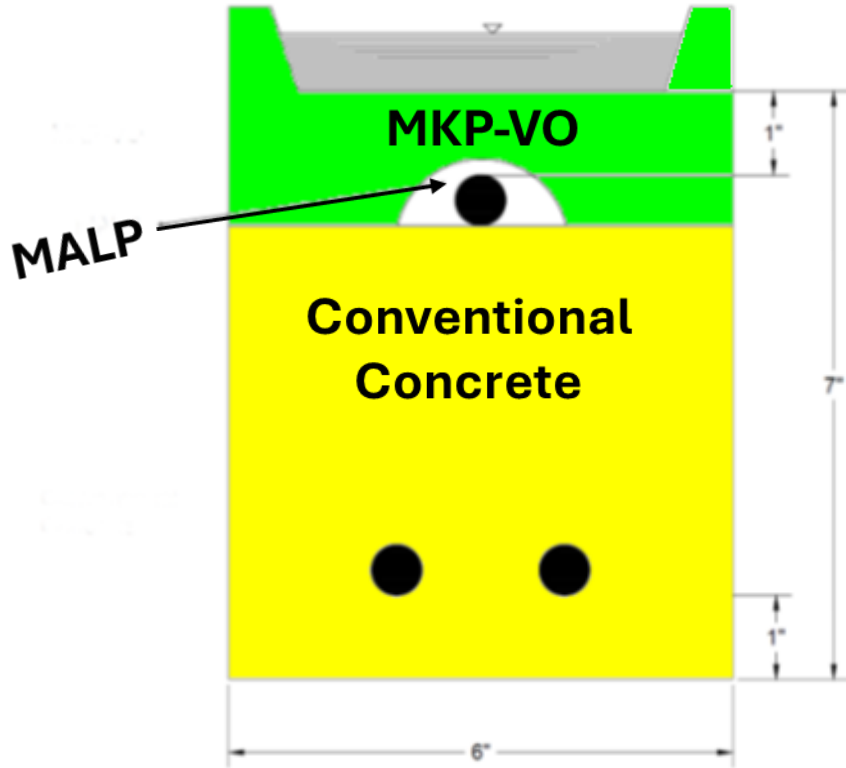
Appears that it is the MALP that cuts the wire and short circuits the battery.



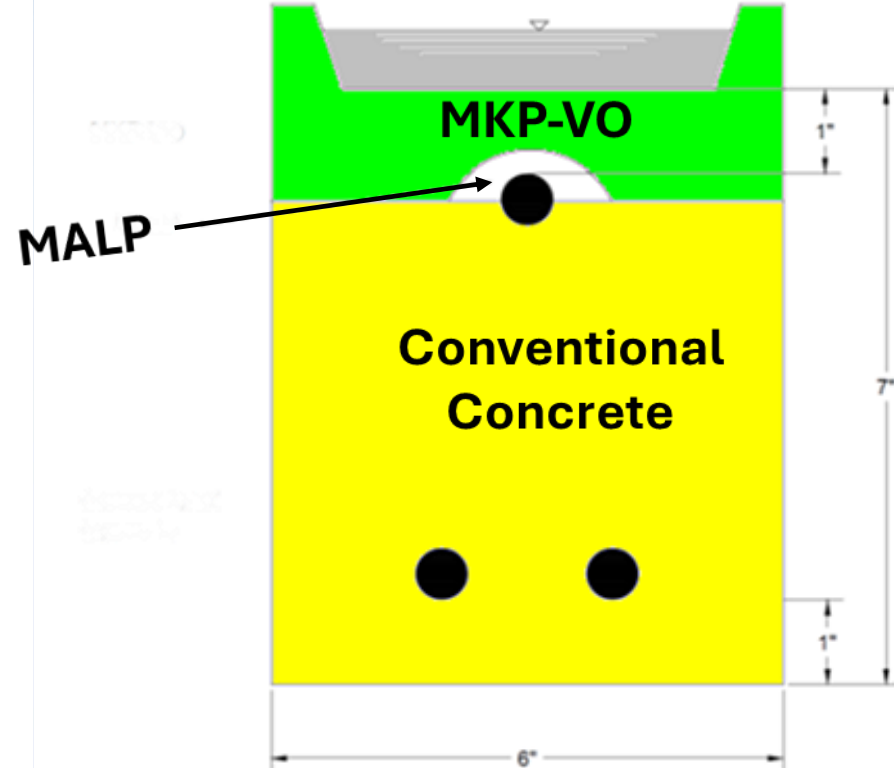
Pages 80 & 81, with permission
(EZ water H₃O₂-),
ghp@u.washington.edu

Proposed Research - Sandwiches

1. Concrete removed to just below the bar, with exposed bar covered with MALP, balance of the repair with MKP-VO



2. Concrete removed exposing part of the bar, with exposed bar covered with MALP, balance of the repair with MKP-VO



Conclusions:

- MALP has very good Corrosion resistance.
- MALP repairs may be subject to cracking and/or delamination.
- MKP VO (with a small amount of MALP) has adequate freeze – thaw resistance.
- Cracks are **undesirable** but could be considered almost an aesthetic issue on some MALP repairs since corrosion activity does not seem to take place.
- Smaller MALP repairs are less prone to cracking.

Conclusions Continued:

- **MALP is not the most user friendly product:**
 - Surfaces must be completely dry for application.
 - Short working time.
 - Expansion followed by shrinkage.
- **MKP is expansive but does not have good corrosion resistance.**
- **Research will try to combine the good properties from MALP and MKP**
- **Research efforts should be doubled or tripled.**

Questions?

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