A Multifunctional Smart Coating For Autonomous Corrosion Control

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Smart Coatings for Corrosion Control

- The use of "smart coatings" for corrosion sensing and control relies on the changes that occur when a material degrades as a result of its interaction with a corrosive environment.
- Such transformations can be used for detecting and repairing corrosion damage.
- The Corrosion Technology Laboratory is developing a coating that can detect and repair corrosion at an early stage.
- This coating is being developed using pH sensitive microcapsules and microparticles that deliver their contents when corrosion starts to:
  - Detect and indicate the corrosion location
  - Deliver environmentally friendly corrosion inhibitors
  - Deliver healing agents to repair mechanical coating damage.

Electrochemical Nature of Corrosion

Metal is oxidized (anodic reaction); something else is reduced (cathodic reaction)

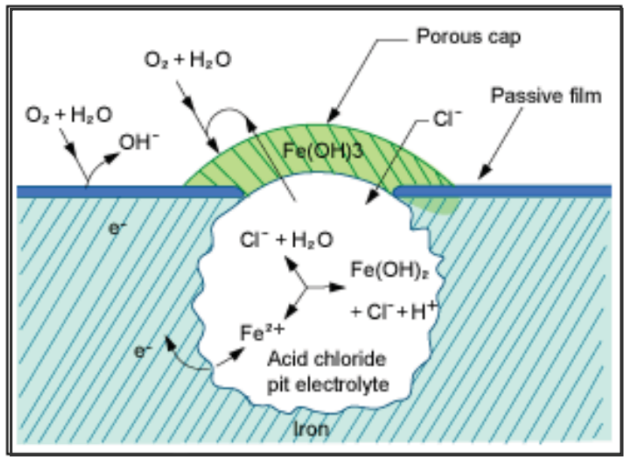
Overall Reaction:

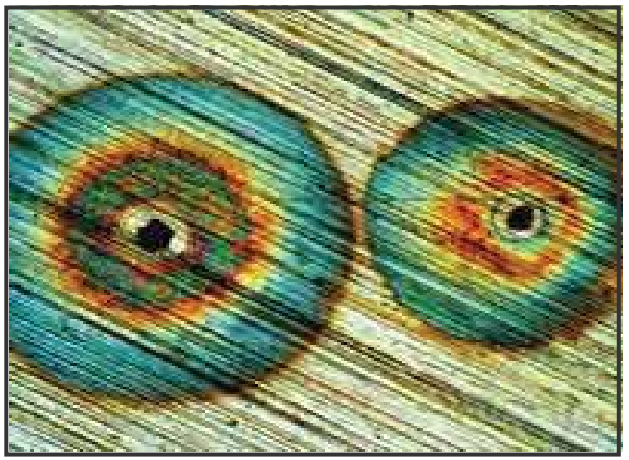
$$2H_2O + O_2 + 2Fe \rightarrow 2Fe^{2+} + 4OH^-$$

Anodic: $$Fe \rightarrow Fe^{2+} + 2e^-$$

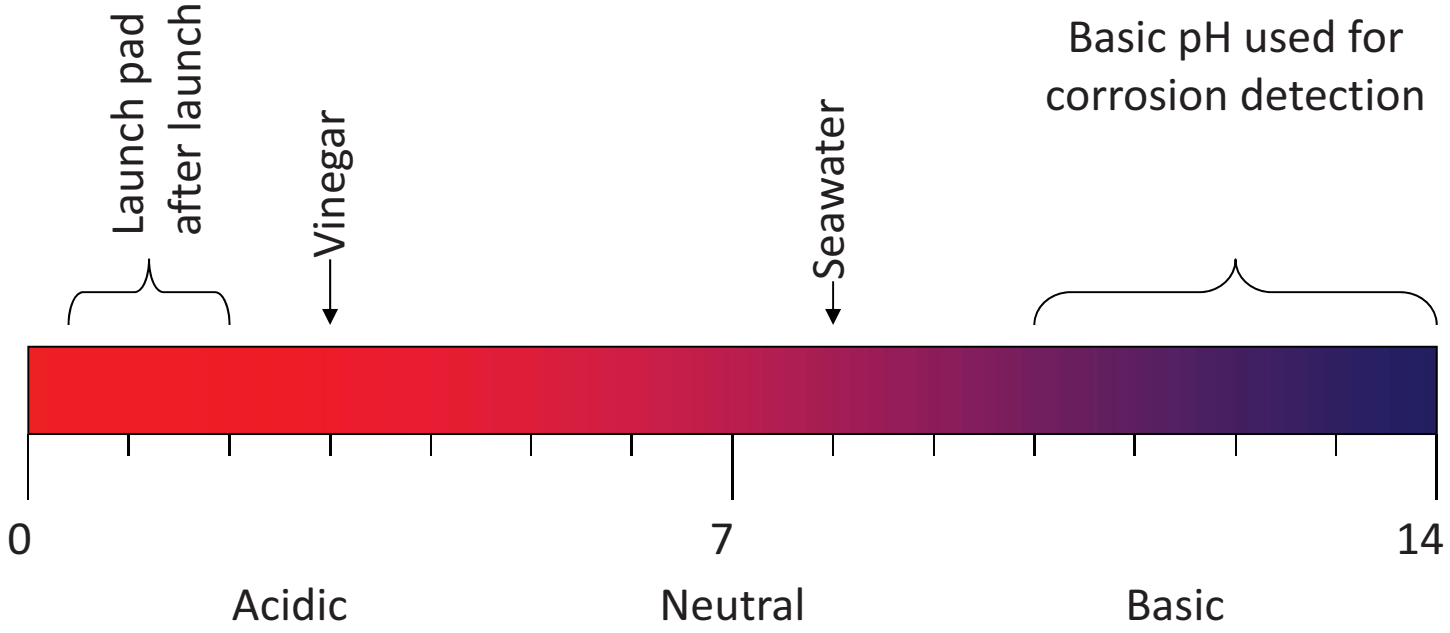
Cathodic:

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$$





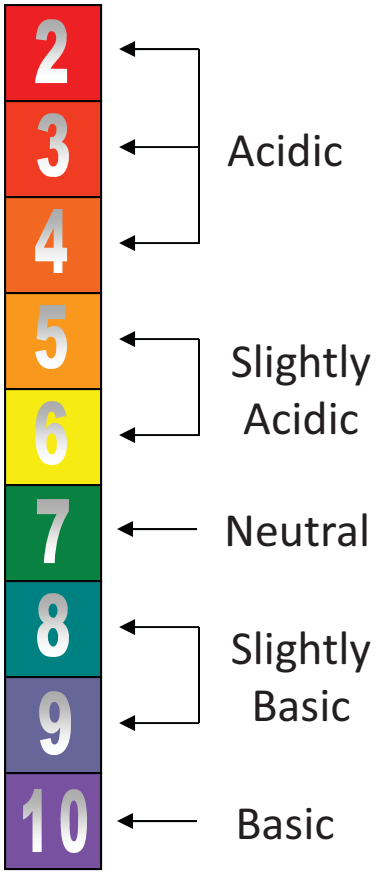
Corrosion and pH

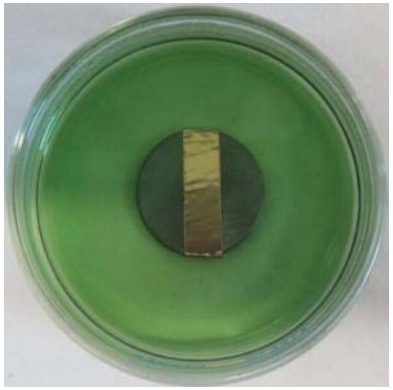


pH Scale

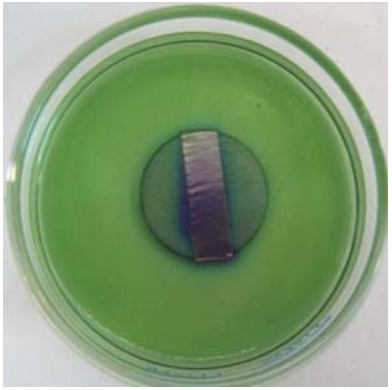
Corrosion Indication

pH changes that occur during corrosion of a metal

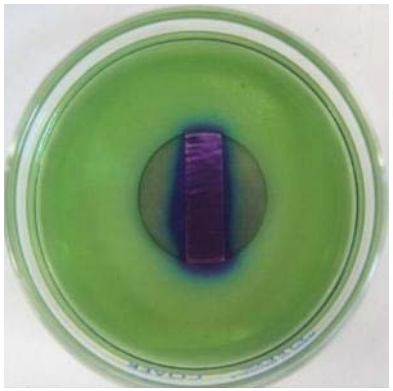




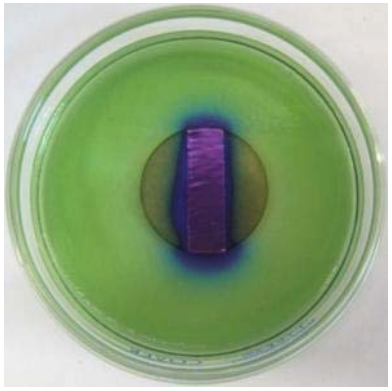
Elapsed Time: 0 hours



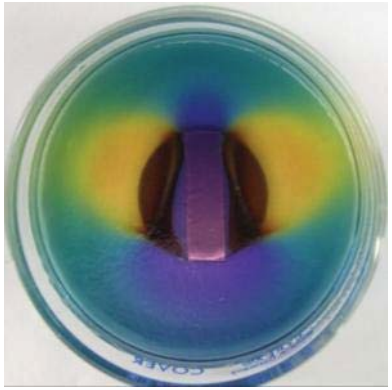
0.5 hours



1.5 hours



4.5 hours



3 days

Smart Coating "Brain"

Corrosion indication, detection, and healing of mechanical damage can be achieved using **microencapsulation technology**

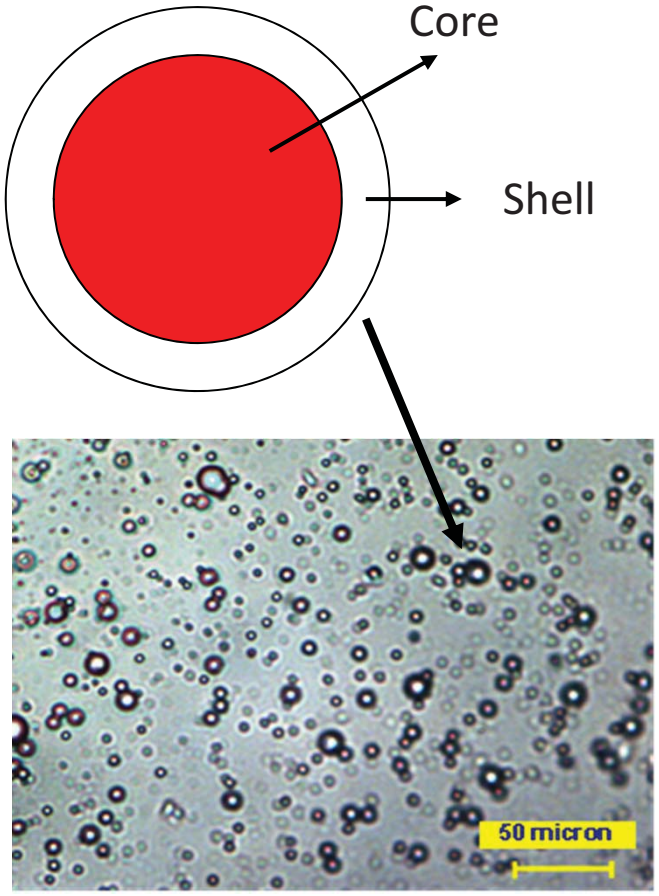
What are microcapsules?

Particles or liquid drops coated in polymers.

These microcapsules, some as small as the point of a pin, can carry any material that needs protection or controlled release.

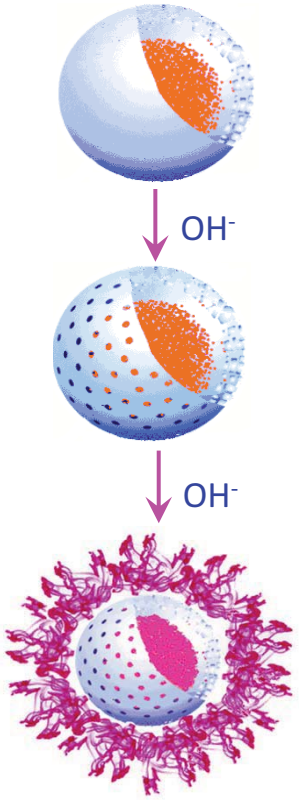
Why microencapsulate a material?

- To achieve controlled-release.
- Make active materials easier/safer to handle.
- Compartmentalize multiple component systems.
- Protect sensitive materials from their environment.
- Versatility



Microcapsules developed at KSC

Technology Development



Microcapsule containing pH indicator (inhibitor, self healing agents)

The shell of the microcapsule breaks down under basic pH (corrosion) conditions

pH indicator changes color and is released from the microcapsule when corrosion starts

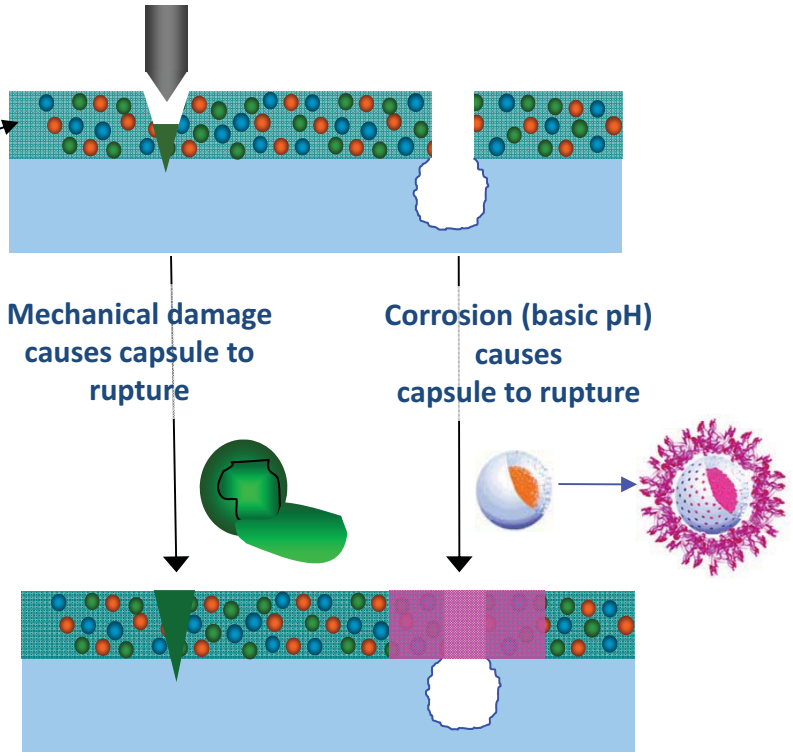
Smart Coating Response to Corrosion and Mechanical Damage

Corrosion indicators

Corrosion inhibitors

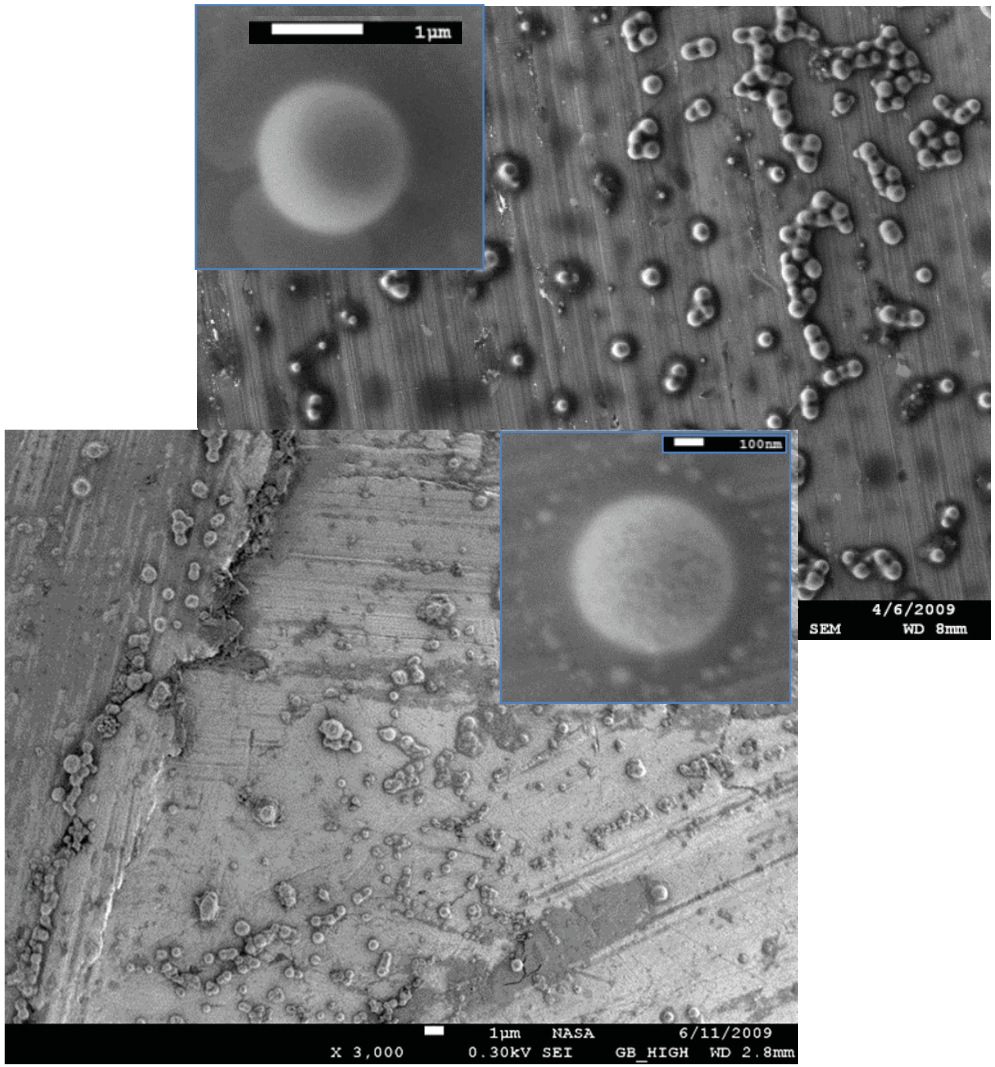
Self-healing agents

Microcapsules are incorporated into smart coating



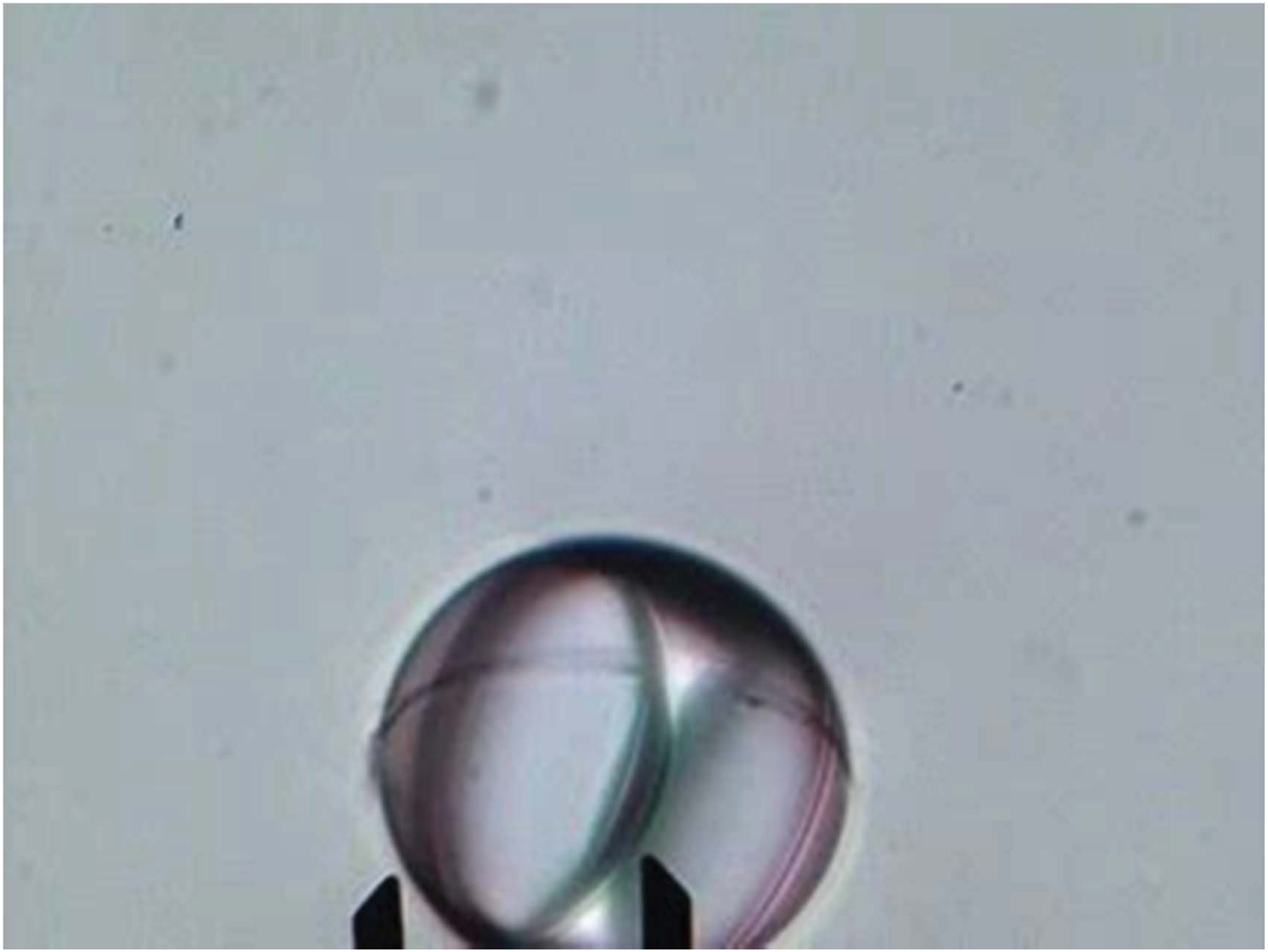
Microcapsules for Corrosion Indication and Inhibition

When corrosion begins, the microcapsule will release the contents of the core (indicator, inhibitor, and self healing agent) in close proximity to the corrosion.



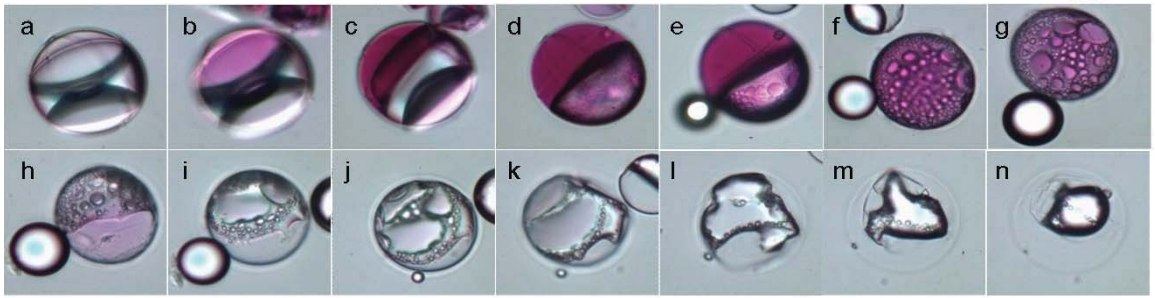
SEM images of microcapsules with indicator (top) and inhibitor (bottom).

Microcapsule Response to pH Increase



Microcapsules for Corrosion Indication

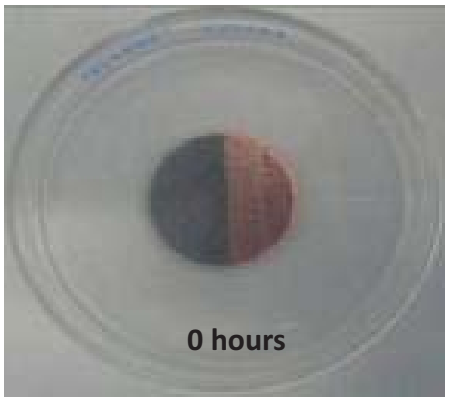
pH sensitive microcapsules with corrosion indicator for corrosion detection

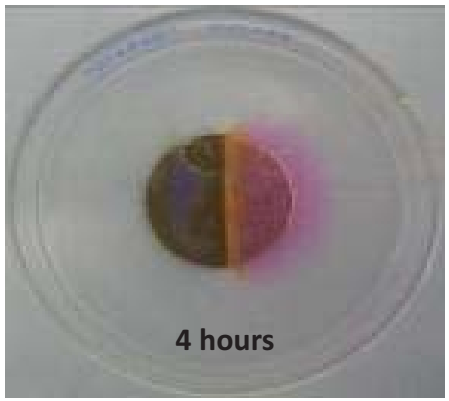


Time lapse pictures of a microcapsule with indicator breaking down under basic pH conditions.

Significance:

Damage responsive coatings provide visual indication of corrosion in hard to maintain/inaccessible areas (on towers) prior to failure of structural elements.



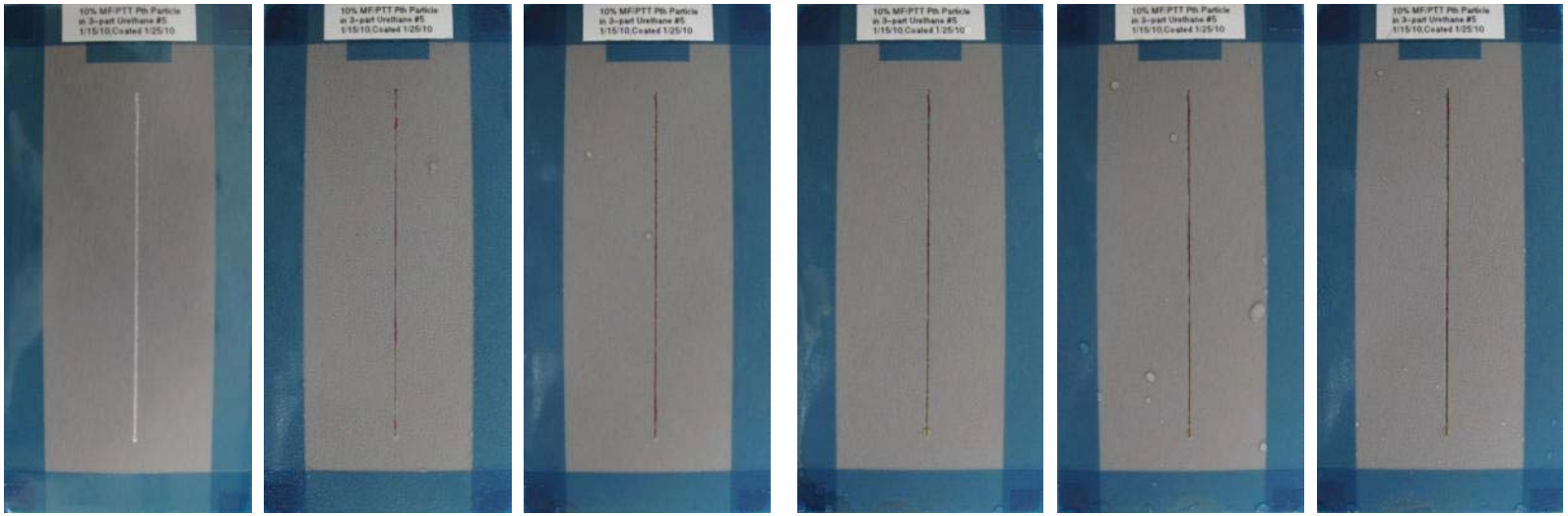


A galvanic corrosion test cell consisting of a carbon steel disc in contact with copper tape was immersed in gel with microcapsules containing a corrosion indicator. As the carbon steel corrodes, the encapsulated corrosion indicator is released and its color change to purple shows the initiation and progress of corrosion

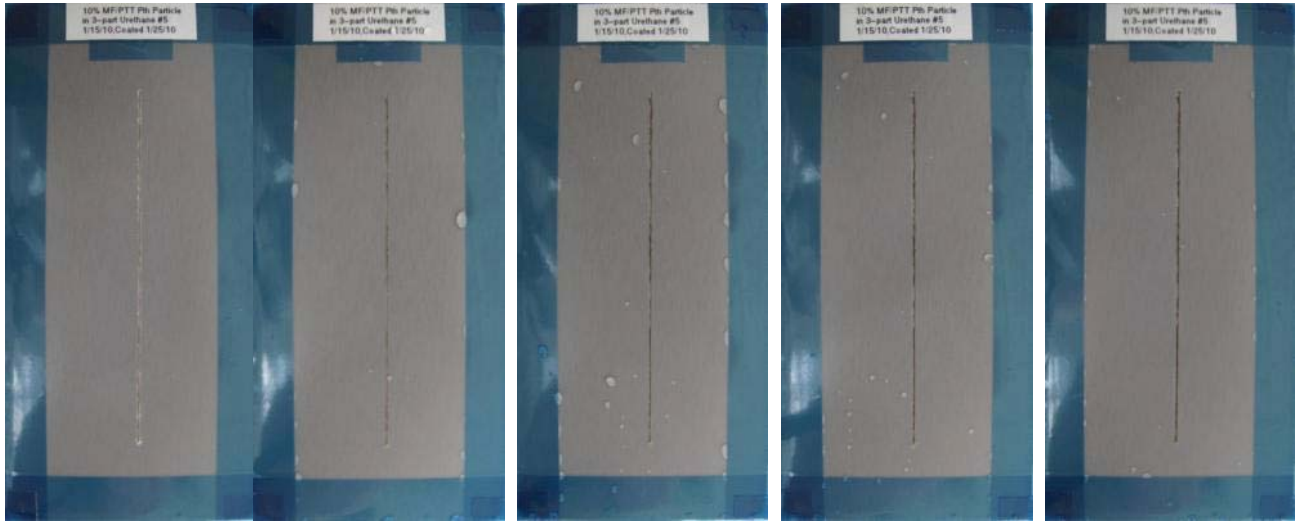
Early Indication of Corrosion

Experimental Corrosion Indicating Coating

Initial 0.5hr 1hr 1.5hr 2hr 2.5hr



0.5hr 1hr 1.5hr 2hr 2.5hr



Corrosion indication test results. Color change observed before rust appears.

Experimental Corrosion Indicating Coating

23.5hr

30.5hr

47.5hr

78.5hr

Conclusions

- A multifunctional smart coating for the autonomous control of corrosion is being developed using pH-sensitive microcapsules.
  - The microcapsules are designed specifically to detect the pH changes that are associated with the onset of corrosion and respond autonomously to indicate its presence early, to control it by delivering corrosion inhibitors, and to deliver self healing or film forming agents capable of repairing mechanical damage to the coating.
- Various pH-sensitive microcapsules with hydrophobic or hydrophilic cores were synthesized through interfacial polymerization reactions in an emulsion.
  - The microencapsulation process was optimized to obtain monodispersed microcapsules in a size range suitable for incorporation into commercially available coatings. The microcapsules can be harvested in suspension or in free-flowing powder form.
- Preliminary results from salt fog testing of panels coated with commercially available coatings, in which the microcapsules were incorporated, indicate that microcapsules can be used to detect corrosion before visible rust appears and to deliver corrosion inhibitors.
- Current work is being focused on optimizing the concentration of indicator in the microcapsules as well as on optimizing the release properties of the microcapsules when incorporated into coatings of interest.
  - Candidate self healing systems have been encapsulated and tested for self-healing performance. Salt fog test results revealed that the 2-capsule siloxane resin system had the best self-healing performance. Methods designed to accomplish good self-healing corrosion control in thinner films are being evaluated.