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THE STATE UNIVERSITY OF NEW JERSEY

AN INORGANIC COMPOSITE COATING FOR PIPELINE REHABILITATION AND CORROSION PROTECTION

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Outline

- **Introduction**
- **Objective**
- **Background on Pipeline Coating**
  - Inorganic Coating System
  - Anti-Corrosion
- **Work Plan and Tasks**
- **Expected Outcome and Deliverables**
- **Student Advising Plan**
- **Available Facility**

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Introduction

- Pipelines are susceptible to corrosion, mechanical damage, and stress corrosion cracking (SCC) that could increase maintenance cost and cause safety hazards
- Organic coatings, such as fusion bonded epoxy have been commonly used for corrosion protection of pipeline
  - The pipeline coating should resist damage to impact, gouge, and abrasion due to pipe movement and retain adhesion under harsh environments
- The aging and degradation of pipeline system induces the need of cost-effective repair techniques with ease of installation
  - Fiber-reinforced composite repairs are effective for pipelines with external corrosion defects

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Objective

- Develop an inorganic coating system for protection of pipeline from corrosion and mechanical damage
  - Corrosion protection
  - Long-term durability at harsh environment
  - Repair system with fiber reinforcement
  - Environment friendly
  - Ease of application

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Formulations of Inorganic Coating

- The cementing component is potassium alumina-silicate, or polysialate-silox with the general chemical structure:

$$K_n\{-(SiO_2)_z - AlO_{2-}\}_n \bullet wH_2O$$

  Where, $z >> n$ and n is the degree of polycondensation; z is 1, 2, and 3; and w is the binding water amount.
- The matrix is prepared by mixing a liquid component with a powder to a plastic consistency
- Water-based; easy clean; nontoxic and no fumes (VOC) emitted during mixing or curing.
- The inorganic coating system has constituents to provide high abrasion resistance, self-cleaning properties, excellent adhesion to steel surfaces

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Features of Inorganic Coating

- Double-layer coating
  - Top coat – nano-modified
  - Base coat – nano/micro-modified
- Functionally layered system
  - Top layer: low permeability; durability; low friction
  - Base layer: adhesion; abrasion; durability
  - Chemical compatibility between two layers
- Inorganic coating may have better strength compatibility with steel, anti-abrasion, and long-term durability as compared to organic coatings
- Potential to be used for oil pipeline operated at high temperatures

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Coating Application on Concrete Structure

- Bridge column wrapping with coating/carbon fibers
- Field durability of coating on retaining wall

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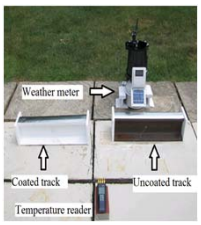
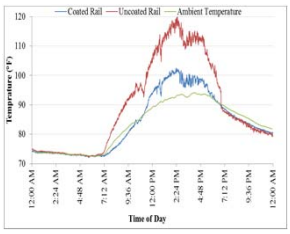
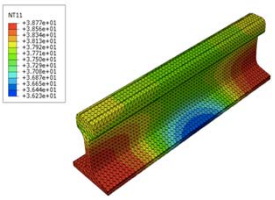
Coating Application on Rail Surface

- Develop and demonstrate field use of a low solar absorption coating for rail temperature reduction and buckling prevention







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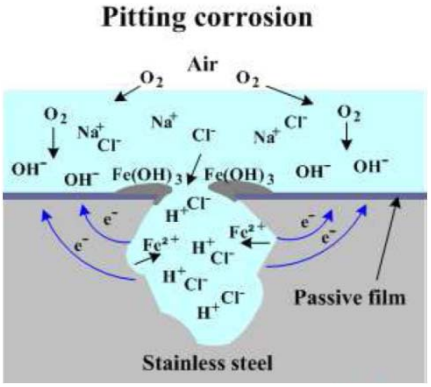
Corrosion Mechanism

- The pitting corrosion is a result of the oxidation reaction of the steel substrate that is determined by the concentration of the corrosive agents and the temperature and humidity of the environment.



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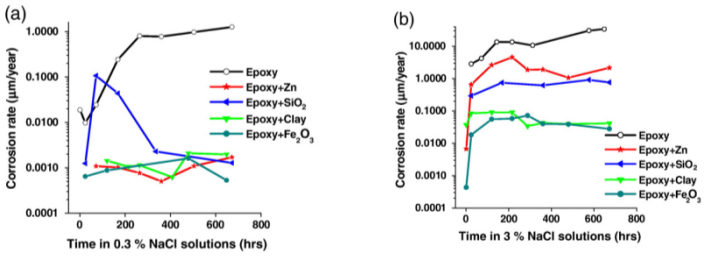
Anti-Corrosion with Nano Modification

- The mechanisms of nano-modification for corrosion protection on steel substrate are mainly from two aspects:
  - Reduced porosity of coating and prevent diffusion path
  - Improve the bonding strength of coating to the steel substrate
- Previous studies at MSU have found that the addition of nano particle (SiO_2, Fe_2O_3, Zn, and nano clay) was a promising approach to remarkably increase the anti-corrosion performance of organic coatings on steel substrate



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Task 1 Development of Inorganic Coating with Nano Modification

- Identify the promising nanomaterial for developing corrosion-resistant coating material
- Achieve uniform dispersion of nanofillers in the matrix material
  - Both physical and chemical methods will be considered: 1) using functionalization (adding functional group to the surface of nanomaterial) or chemical surfactant; 2) using high shear mixing and/or ultrasonication technique
- Advanced characterization tools, including Atomic Force Microscopy (AFM), Scanning electron microscopy (SEM) will be applied to analyze the microstructures of the nano-modified coatings

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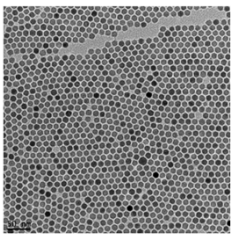
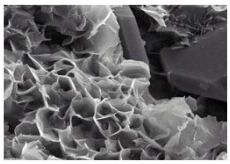
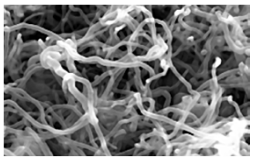
Candidate Nano Materials

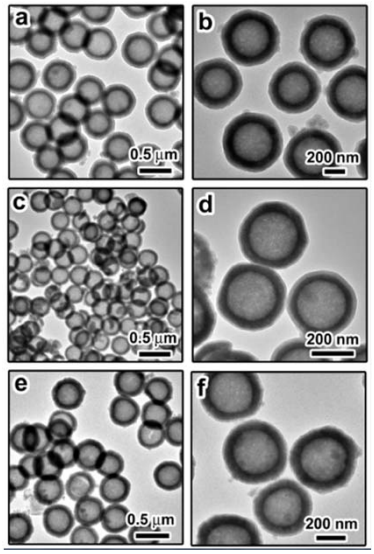


Oxide Nano particles





Nanoclay (montmorillonite) carbon nanofiber



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Task 2 Corrosion Testing of Coating

- NACE/ASTM TM0169 G0031- Standard Guide for Laboratory Immersion Corrosion Testing of Metals
- Electrochemical test method
  - Electrochemical impedance spectroscopy (EIS)
  - Potentiodynamic weak polarization
- Assess the corrosion inhibition benefits of the nano-modified inorganic coatings in selected soil environment
- Elucidate the mechanisms underlying corrosion inhibition

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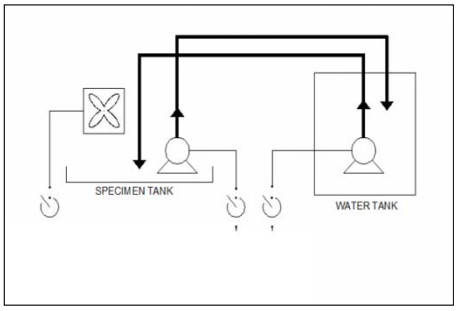
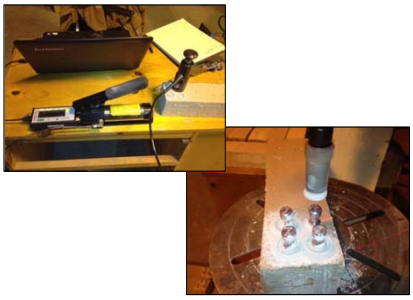
Task 3 Durability and Adhesion Testing of Coating

- Investigate the durability (crack resistance, blistering, rust, and pull-off strength) of the coating under thermal cycling conditions
- Effect of wet/dry circles and surface treatments





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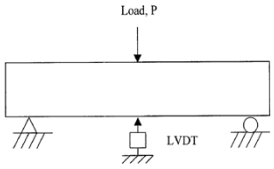
Task 4 Strength Testing of Fiber-Reinforced Coating Composite

- The strengthening system consists of an initial thin layer of coating, fiber reinforcement, and an additional protective layer of coating
- Our previous studies have proved that carbon fiber reinforced composite is superior to glass fiber in harsh environment and it is cost-effective
- The interface bonding between steel surface and coating will be examined after testing



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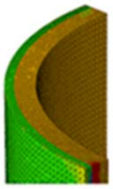
Task 5 Analytical Study of Pipeline Strengthening System

- Analyze structural contribution provided by strengthening system using Finite Element Analysis (FEA)
- Analyze effects of composite layer properties (modulus, strength, thickness, and anisotropy) on pipeline responses to determine the most effective repair strategy
- The developed model will be tailored to consider pipeline geometrical parameters, loss of pipe wall thickness due to corrosion, internal pressure loading, external loading due to ground movement



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Task 6 Guidelines of Coating Application

- An implementation specification and guidelines for applying the coating will be prepared using the information obtained during the laboratory study, numerical simulation, and the existing information on the coating material.

- The guidelines will cover various aspects including: estimation of the amount of required coating material, mixing, curing time (pot-life), surface preparation, application process using brushes, rollers, and paint sprayers, protection against rain in the first 3 hours after application, and disposal of excess materials.

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Schedules

Task*	Quarter							
	1	2	3	4	5	6	7	8
1								
2								
3								
4								
5								
6								
7								

Task 1: Development of Inorganic Coating with Nano-Modification
Task 2: Corrosion Testing of Coating
Task 3: Durability and Adhesion Testing of Coating
Task 4: Strength Testing of Fiber-Reinforced Coating Composite
Task 5: Analytical Study of Pipeline Strengthening System
Task 6: Guidelines of Coating Application
Task 7: Final Report

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Expected Outcome

- The expected outcome is a durable, economical, and environment-friendly coating system for pipeline applications
  - In the class of geopolymeric material with least impact on generation of CO_2 emission
  - Provide protection of pipeline against corrosion in moisture and chemical environment
  - Maintain excellent adhesion with fiber-reinforcement and pipeline surface to strengthen pipeline structural integrity
  - High mechanical strength and abrasion resistance and hence surface damage due to occasional impact or soil movement is protected

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Deliverables

- Kick off Meeting
- Performance Progress Reports (format/content in accordance with SF-RPPR)
  - Quarterly progress reports via email and uploaded to MIS
  - Final Progress Report via email and uploaded to MIS
- Mid-Term Summary (conference call; discussion topics to be provided by PHMSA)
- Draft Final Research Report
- Public Final Research Report
- Internet-Based Presentation

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Student Advising Plan

- Expose MS and PhD students to subject matter that is common to pipeline safety challenges and to illustrate how their engineering or technical disciplines are highly needed in the field
- Two graduate students will participate in the project and their progress will be monitored closely by PI and Co-PI through weekly research meetings, making presentations, and writing technical reports.
- Recruit several undergraduate students to participate the proposed research
- Graduate students are expected to present the research results in conferences in ASCE and ASME and publish the research results in peer reviewed journals

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Available Facility- Rutgers University

- ***Concrete Materials Laboratory***
  - Coating fabrication and mixing
  - Facilities for instrumentation and testing for failure of reinforced and prestressed long-span beams, columns, connections, and large-panel slabs, including compression tester; girder and frame tester; slab, pipe, and frame tester
  - Data acquisition and processing systems
  - Temperature- and humidity-controlled environmental chamber; and facilities for rapid freezing and thawing tests
  - An MTS Closed Loop Electrohydraulic Test System
- ***Computation and Simulation Laboratory***
  - Finite Element Modeling: ABAQUS and ANSYS
  - Discrete Element Modeling: Particle Flow Code (PFC 3D)
  - Molecular Dynamics Simulation: Materials Studio and LAMMPS
  - Multiphysics Modeling: COMSOL and Virtual.Lab Acoustic

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Available Facility- Montana State University

- A wet-bench chemistry lab equipped with Ventilation hoods, Vacuum Pumps, Distilled Water Filtration System, Micro-grinding mill and sonicator, Metal and concrete saws and polishing equipment, and a range of shop equipment and tools.
- An instrumentation room equipped with Potentiostats featuring capabilities for DC voltammetry, AC impedance, and electrochemical noise analysis
- A corrosion testing machine featuring capabilities for NACE/PNSA gravimetric tests, Differential Scanning Calorimeter, Bending Beam Rheometer, Microscopic Camera, and Analytical Balances
- An environmental chamber with precise temperature control and custom-made system for testing of accelerated deicer ingress

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Thank You

Questions ?

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