Protective Steel Pipe Coating with Ductile Engineered Cementitious Composites (ECC)

Gregor Fischer  
Li, Fischer, Lepech & Associates, LLC  
MECC Technologies, Inc.

Vlad Popovici  
Bredero Shaw

Klas Sorger  
Wacker Chemie AG

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Company Overview

- Commercialization of ECC technology for oil and gas pipeline protection applications through MECC Technologies, Inc.
- Other Projects and Applications: Façade panels, pipe coating, tunnel lining, repair mortar, specialty structural elements, impact resistant cladding
- Markets: Europe, Russia, Asia, North and South America, Africa
Project Partners

• Bredero Shaw
  – ECC coating design and evaluation
  – Coating application processes
  – Pipeline coating market assessment
  – ECC coating commercialization

• Wacker Polymers
  – Polymer binders, microstructure modification, interfacial bond
Agenda

• What is ECC?
• Applications of ECC in Civil Engineering
• ECC Pipeline Coating
• ECC Coating Application
• ECC Coating Markets and Benefits
• Next Steps
Crack formation in unreinforced concrete

from Li et al., 1992
Cracking Control in Concrete

- **Goal:** Active control of crack width
- **Internal fiber reinforcement**
- **Tension softening after crack formation**
- **Brittle deformation behavior remains**

![Graphs showing crack formation and fiber reinforcement comparison](image)

(from Li et al., 1992)
Hardening After Crack Formation

\[ \sigma_{B,\text{peak}} > \sigma_{f_c} \]

\[ G_{\text{tip}} < \sigma_{B,\text{peak}} \delta_{\text{peak}} - \int_{0}^{\delta_{\text{peak}}} \sigma_B(\delta) d\delta = C \]
ECC Deformation Behavior

- Classification
  - Brittle (concrete)
  - Tension softening (FRC)
  - Strain hardening (ECC)

- Effect of ductile deformation behavior on:
  - Design
  - Structural detailing
  - Durability
  - Economy

Tensile stress-deformation behavior of different cementitious composites
ECC - Concept

Single fiber → Individual crack → Composite

- Single fiber: $\sigma_f, E_f, d_f, l_f$
- Individual crack: $E_m, a, G_{tip}$
- Composite: $\sigma_C$

Strain hardening, multiple cracking

$P - \delta, \sigma_B - \delta, \sigma_c - \varepsilon$
ECC in Tension

• ECC
  – Design concept for ductile concrete on the basis of fracture mechanics
  – Ductile fiber concrete with moderate fiber volume fraction (2 Vol.-%)
ECC in Flexure
ECC Composition

Mix proportion for 1m³ ECC
ECC in seismic resistant structures

- Deformation tolerance in ECC
- Energy absorption by crack formation and yielding of steel reinforcement
- Yielding/buckling of reinforcement
- Failure of concrete

Reinforced ECC vs. reinforced concrete
Applications in seismic resistant structures

Nabeaure Yokohama Tower
Kajima Corp., 2007

ECC coupling beam
Surface Repairs

Resurfacing of an ASR damaged retaining wall in Japan
Infrastructure Rehabilitation

Replacement of chloride-contaminated concrete on a motorway bridge
ECC pipeline coating

<table>
<thead>
<tr>
<th>Minimum ECC Coating Thickness</th>
<th>8 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2100 kg/m³</td>
</tr>
<tr>
<td>Minimum Impact Resistance</td>
<td>600 J</td>
</tr>
<tr>
<td>Penetration Resistance</td>
<td>2mm at 60 kN</td>
</tr>
<tr>
<td>Minimum Compressive Strength (28 days)</td>
<td>60 MPa</td>
</tr>
<tr>
<td>Tensile Deformation Capacity</td>
<td>&gt;3%</td>
</tr>
</tbody>
</table>
ECC-coated steel pipe bending test

8° deflection angle
ECC coating-PE interface modification

- Apply suitable bond coat on PE
- Cover with ECC (3 mm)
- Store (dry/wet; 7d, 28d)
- Bore test specimen (Ø: 5 cm)
- Glue metal pull-head plates
- Determine adhesion tensile strength with tensile testing machine acc. to DIN 18555-6.
## ECC coating-PE interface modification

<table>
<thead>
<tr>
<th>bond coat</th>
<th>ECC</th>
<th>adhesion tensile strength, N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>7 d, dry</td>
</tr>
<tr>
<td>none</td>
<td>without polymer</td>
<td>n.a.*</td>
</tr>
<tr>
<td>polymer dispersion</td>
<td>without polymer</td>
<td>0.43</td>
</tr>
<tr>
<td>polymer dispersion</td>
<td>1% ETONIS 850</td>
<td>0.29</td>
</tr>
<tr>
<td>polymer dispersion</td>
<td>2% ETONIS 850</td>
<td>0.47</td>
</tr>
<tr>
<td>polymer dispersion</td>
<td>4% ETONIS 850</td>
<td>0.61</td>
</tr>
<tr>
<td>polymer dispersion + filler</td>
<td>2% ETONIS 850</td>
<td>0.63</td>
</tr>
<tr>
<td>polymer disp. + filler + cement</td>
<td>2% ETONIS 850</td>
<td>0.89</td>
</tr>
<tr>
<td>ECC + ETONIS 850</td>
<td>2% ETONIS 850</td>
<td>0.58</td>
</tr>
</tbody>
</table>

* no adhesion: immediate delamination or delamination during boring
Impact resistance (acc. to GW 340)

- Varying drop height (1.0m, 1.5m, 2.0m)
- Drop weight (500N)
- Indenter (steel ball, d=25mm)
- ECC coating (t=10mm)
- PE layer (t=3mm)
- Steel plate (t=12mm)
Impact resistance of ECC coating
Impact energy 1000J

Above coating

Below coating

PE-layer
Multiple impacts (500J, 750J, 1000J)

Specimen surface after three impacts
ECC Coating Application

• Application flexibility – ECC coatings can be applied using any of the most common application processes:
  - Spraying (impingement) process
  - Side-wrap process
  - Molding process

• Easy application – ECC’s lower fiber content compared to other fiber-reinforced concrete mixes allows for easy mixing and application using standard batching or mixing equipment
ECC Coating Application

• The most economic application process for the ECC coating is the *side-wrap application in a mobile concrete coating plant*

• Advantages of side-wrap application in a mobile plant:
  - *Reduced project time* – plant setup time is only 2 weeks
  - *High throughput* – up to 25 joints/hour (for 20-24” pipes)
  - *Reduced pipe logistic costs* – mobile plant is set up close to the project site (ROW)
  - *Guaranteed quality* – mobile plants have strict production and quality control procedures
ECC Coating Markets

TARGET MARKETS

• *Mechanical protection* for onshore pipelines
  - rocky areas
  - projects in remote regions
  - projects in cold climates
  - challenging trench materials - frozen materials, clay, silt, etc.
  - challenging terrain configuration – steep slopes, limited access to ROW, etc.

• *Structural resistance and mechanical protection* for onshore pipelines
  - projects in earthquake-prone regions
ECC Coating Benefits

• **Unique mechanical protection** for onshore pipelines – impact and penetration resistance
  
  - 10 mm of ECC coating will offer the same impact resistance as 8-9 cm of 3LPE !!
  - up to 60% more mechanical protection than the existing concrete coatings

• **Superior constructability and economics**
  
  - no limitations in terms of terrain configuration, trench materials, climate
  - no additional equipment, manpower, or materials required for the installation of the ECC-coated pipe
  - lower total lifecycle cost and installation time compared to other mechanical protection systems

• **Environment-friendly coating**
  
  - less environment disturbance
  - green coating materials – by using fly ash, the ECC coating avoids CO2 emissions
Next Steps

• Finalize ECC coating design for targeted applications and markets
• Finalize coating application process
• ECC coating commercialization in target markets
• Assess new pipeline protection applications – offshore „reelable“ concrete coatings, etc.
Thank you for your attention