COMPOSITES AS SUSTAINABLE OVERLAY MATERIALS FOR BRIDGE DECK APPLICATIONS

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Istanbul Bridge Conference, August 11-13, 201
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Introduction

Bridge decks may deform as a result of concrete distress caused by
- heavy repeated traffic loads,
- freeze-thaw cycles,
- abrasion,
- alkali-aggregate reaction,
- excessive cracking or spalling by corrosion effect necessitating the repair and/or maintenance applications in time.
Introduction

The most widely used maintenance technique is the application of overlay material over the existing substratum.
Introduction

While variety of overlay materials that were widely used in the field reported to be adequately durable, the performance is not always stable and nearly half of the overlays incorporating traditional concrete materials fail in service. Therefore, the development of new generation overlay materials is desirable for the sake of increased durability and performance characteristics of repair systems.
Engineered Cementitious Composites

As a new class of HPFRC materials, Engineered Cementitious Composites (ECCs) is a ductile fiber reinforced cementitious composite micromechanically designed to achieve high damage tolerance under severe loading and high durability under normal service conditions.

Typical mixture design of ECC material

<table>
<thead>
<tr>
<th>Cement</th>
<th>Water</th>
<th>Sand</th>
<th>Mineral Admixture*</th>
<th>HRWR **</th>
<th>Fiber (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.58</td>
<td>0.8</td>
<td>Fly ash or ground blast furnace slag</td>
<td>1.20</td>
<td>0.013</td>
</tr>
<tr>
<td>0.013</td>
<td>0.39</td>
<td>0.01</td>
<td>High range water reducer; all ingredient proportions by weight except for fi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Engineered Cementitious Composites

It is a composite material that shows strain hardening behavior similar to many ductile metals through the formation of multiple microcracks.

- 300 to 500 times higher tensile strain hardening
- 100 µm > average crack width
- Enhanced durability properties
Experimental Program

Performance analysis of ECC specimens incorporating low-calcium fly ash (class-F FA) (F_ECC) and ground granulated blast furnace slag (S_ECC) was presented in addition to the micro-silica concrete (MSC) which is widely used for overlaying purposes on bridge decks.
Experimental Program

Materials for F_ECC and S_ECC mixtures:
- Standard CEM I-42.5R Portland cement
- Fly ash (Class F)
- Slag
- Quartz sand
- PVA fibers (%2, by volume)
- Water
- High range water reducing admixture
Experimental Program

Materials for MSC mixture

- Micro-silica
- Combined aggregate
- Water
- Air-entrained Admixture
- Superplasticizers
Experimental Program

Monolithic Samples
- Basic Mechanical Properties
  - Compressive Strength
  - Flexural Strength
Experimental Program

- Dimensional Stability Tests
  - Drying Shrinkage Test
  - Restrained Shrinkage Test
Experimental Program

- Chloride Ion Penetrability
  - Rapid Chloride Permeability Test
Experimental Program

Layered Samples

- Bond Performance - Slant Shear Test
Results and Discussions

Compressive Strength

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 d.</td>
</tr>
<tr>
<td>F_ECC</td>
<td>17.1</td>
</tr>
<tr>
<td>S_ECC</td>
<td>24.6</td>
</tr>
<tr>
<td>MSC</td>
<td>32.8</td>
</tr>
</tbody>
</table>

The reason for the higher early strength of S_ECC specimens can be predicated to the predominant reaction of slag with alkali hydroxide during the early hydration period. This result is also partially a result of the higher rate in hydration of the slag due to its large specific surface area (425 m²/kg) compared to that of FA (290 m²/kg).
## Results and Discussions

**Flexural Performance**

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Flexural Strength (MPa)</th>
<th>Deformation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 d. 7d. 28d. 90d.</td>
<td>1 d. 7d. 28d. 90d.</td>
</tr>
<tr>
<td>F_E CC</td>
<td>5.3 8.8 11.11</td>
<td>4.7 4.4 3.9</td>
</tr>
<tr>
<td>S_E CC</td>
<td>6.7 10.12 12.12</td>
<td>3.3 3.2 3.0 2.9</td>
</tr>
<tr>
<td>M_S CC</td>
<td>4.9 8.3 10.15</td>
<td>0.4 0.2 0.2</td>
</tr>
</tbody>
</table>

-The most probable reason for this trend may be attributed to the fact that flexural strength is governed by more complex material properties, such as tensile first cracking strength, ultimate tensile strength and tensile strain capacity, particularly in the case of strain hardening cementitious materials.
Results and Discussions

![Graph showing flexural stress versus mid-span beam deflection with lines for F_ECC, S_ECC, and MSC.]
Results and Discussions

Drying Shrinkage Test

- The usage of fly ash in ECC reduced the drying shrinkage deformation. A possible mechanism contributing to the reduction of drying shrinkage in F_ECC could be matrix densification due to FA addition which may prevent internal moisture evaporation.
Results and Discussions

Restrained Shrinkage Test

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Crack Width (µm)</th>
<th>Crack Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Minimum</td>
</tr>
<tr>
<td>F_ECC</td>
<td>78</td>
<td>40</td>
</tr>
</tbody>
</table>

- ECC overlay materials has significantly greater resistance to restrained shrinkage cracking than MSC, despite its higher drying shrinkage value. This is due to the large tensile strain capacity of ECC overlay materials, which leads to a negative shrinkage cracking potential and...
Results and Discussions

Rapid Chloride Permeability Test

Charge passed (Coulomb)

F_ECC
S_ECC
MSC

Overlay mixtures

28 Days
90 Days

Chloride ion penetrability

Very low
Low
Moderate
Results and Discussions

Slant Shear Test

<table>
<thead>
<tr>
<th>Mix. ID</th>
<th>Bond Strength (MPa)</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Day</td>
<td>7 Days</td>
</tr>
<tr>
<td>F_ECC</td>
<td>7.1</td>
<td>14.7</td>
</tr>
<tr>
<td>S_ECC</td>
<td>8.3</td>
<td>17.4</td>
</tr>
<tr>
<td>MSC</td>
<td>10.4</td>
<td>14.1</td>
</tr>
</tbody>
</table>

-The test results show that ECC specimens resulted in bond strength that are approximately 15-20% higher than the MSC specimens. It can be concluded that the addition of ECC layer could significantly improve the bond stress measured by slant shear test.
Results and Discussions

MSC – interface failure

MSC – monolithic rupture

F_ECC – substrate failure

S_ECC – substrate failure

Failure through the substrate concrete is always desirable, because failure through the substrate concrete demonstrated that the existing substrate is the weakest component of the ECC/concrete system.
Conclusions

- The test results largely confirm the overlay performance of ECCs as efficient materials to be used in bridge deck applications.

- To sum up, ECC materials possess comparable compressive strength to that of MSC mixtures although flexural strength of MSC was found to be significantly lower than ECCs.

- MSC is a brittle material with sudden fracture failure, on the other hand, F_ECC and S_ECC samples have significantly higher deformation capability than MSC at all testing ages.

- Drying shrinkage deformations of ECCs were found to be higher than MSC.
Conclusions

- ECC mixtures show low and very low chloride ion penetrability like MSC, according to the results of rapid chloride permeability test implying that permeability values of ECC mixtures are acceptable for overlay materials.

- Based on the slant shear test results, it can be concluded that ECC can achieve adequate bond strength with other concretes. All ECC-substrate bilayer specimens had failure plane occur preferentially through the substrate, for both types of mixtures. On the other hand, for MSC-substrate...
Thank you!