Mechanical Properties of Macro-Synthetic Fibre Reinforced Concrete (MSFRC) under Static loading for Railway Transoms Application

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Investigate the Feasibility of Macro-Synthetic Fibre Reinforced Concrete (MSFRC) towards replacing existing transoms as railway bridge components.
Project Overview

Numerical Analysis & Experimental Investigation (full size transoms)

Cost-Benefit Analysis

Adaptation of Dynamic Effects

Design Guidelines

Stage 1: 2018
Stage 2: 2019
Stage 3: 2020
Overview of Presentation

- Introduction
- Experimental Methodology
- Results & Discussions

Conclusions & Further Research

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Rail Way Bridges

- California
- Serbia (323 m, Max span – 82 m)
- Hungary (674 m, Max span – 93 m)

Open Bridge Ties
Ballasted track ties
Slab tracks

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Introduction

- Sleepers are among the most costly and frequently replaced track components throughout the Australian railway network requiring in excess of 2.5 million timber sleepers annually;

- Existing sleepers do not satisfactorily meet all the requirements of a sleeper.

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Introduction

• Sleepers are among the most costly and frequently replaced track components throughout the Australian railway network requiring in excess of 2.5 million timber sleepers annually;

• Existing sleepers do not satisfactorily meet all the requirements of a sleeper;

• High demand for alternative material such as composites for railway sleepers’ applications.
Alternative Sleeper Material

Factors to consider

• **Similar strength and elastic modulus**
  • Prevent differential settlement of the ballast
  • Avoid local stress increments

• **Low cost**
  • Initial cost
  • Maintenance cost
  • Life cycle cost

• **Sustainable**
  • Durability
  • No or lesser environmental damage

• **Easy to handle**
Alternative Sleeper Material

1. Polymer matrices
   - Superior strength characteristics
   - Durability
   - High Cost
   - Slow production process

2. Reinforcement of existing materials
   - Enhanced strength characteristics
   - Relatively low cost
   - Core material (i.e. timber & concrete) susceptible to failure
Alternative Sleeper Material

Modified Concrete

- Geopolymer Concrete

- Fairly limited applications for sleepers due to high cost & unknown long-term durability

- Natural, glass, steel & synthetic fibres

- Better crack resistance
- Chemically inert, eco-friendly nature and enhance strength characteristics
Crack Controlling & Crack Bridging

Mechanical Properties of MSFRC under Static loading for railway transoms applications

Without fibre reinforcement

With fibre reinforcement

Aggregate bridging

Fibre prestressing

Fibre bridging

Total response

Stress (MPa)

Crack width (m)
Fibre Factors

Geometrical Properties

Mechanical Properties

Volume Fraction

Fibre-Concrete Bond Strength

Fibre dispersion and orientation

Performance of FRC

Mechanical Properties of MSFRC under Static loading for railway transoms applications
## Mechanical Properties of MSFRC under Static loading for railway transoms applications

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Tensile Strength (MPa)</th>
<th>Modulus of Elasticity (MPa)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Fibre</td>
<td>~1300</td>
<td>200000</td>
<td>7850</td>
</tr>
<tr>
<td>Synthetic Fibre (Poly Vinyl Alcohol)</td>
<td>1500</td>
<td>42000</td>
<td>1290</td>
</tr>
<tr>
<td>Synthetic Fibre (Polypropylene)</td>
<td>250-350</td>
<td>3000 - 4000</td>
<td>910</td>
</tr>
<tr>
<td>Natural Fibre (Coir)</td>
<td>-</td>
<td>-</td>
<td>2057</td>
</tr>
<tr>
<td>Basalt Fibre</td>
<td>4500</td>
<td>75000</td>
<td>2560</td>
</tr>
<tr>
<td>Barchip Fibre</td>
<td>640</td>
<td>12000</td>
<td>910</td>
</tr>
</tbody>
</table>

### Static Compressive Strength

### Static Flexural Strength

1. Steel Fibre
2. Synthetic Fibre
3. Coir Fibre
4. Other Fibre

*Al-Masoodi et al. 2016; Chien Yet, Hamid & Kasmuri 2012; Fu et al. 2018; Ghadban, Wehbe & Underberg 2018; Hao & Hao 2013; Noushini, Samali & Vessalas 2013; Xu, Hao & Li 2012*
Suitability of Steel Fibres in Sleepers?

- **Steel fibre corrosion**
  - Limited to surface in uncracked samples
  - Gradual degradation of mechanical properties of FRC

- **Stray current of the rail**
  - Steel fibres perform better than pre-stressing wires
  - Still it can act as a by pass
  - Steel corrosion can increased with current

- **Corrosion and electrical resistance**

- **Evolution of Synthetic fibre industry**
  - Fibres with higher tensile strength and elastic modulus
Geometrical Properties

Synthetic fibers

- Micro fibers (Staple Fibre)
  Diameter < 0.3 mm

- Macro fibres
  Diameter ≥ 0.3 mm
    - Monofilament
    - Multifilament
    - Bundelled

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Fibre-Concrete Bond Strength

Type of the fibre? Length of the fibre?

- Crimped geometry
  - Long fibres
  - Better Mechanical Anchorage
  - Higher crack bridging capacity

(Bentur, Peled & Yankelevsky 1997; Won, Lim & Park 2006; Babafemi, du Plessis & Boshoff 2018; Suraneni, Bran Anleu & Flatt 2016; Xu, Hao & Li 2012)

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Fibre Dispersion and Orientation

Effect of Aggregate size

Effect of Fibre stiffness

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Fibre Volume Ratio

<table>
<thead>
<tr>
<th>ACI Fibre Type</th>
<th>Fibre Amount</th>
<th>Currently practical FRC ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Moderate&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Steel (SFRC)</td>
<td>0.05%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Glass (SFRC)</td>
<td></td>
<td>0.5%</td>
</tr>
<tr>
<td>Synthetic (SFRC)</td>
<td>0.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Natural (SFRC)</td>
<td></td>
<td>0.5%</td>
</tr>
</tbody>
</table>
Experimental Methodology

Mechanical Properties of MSFRC (Stage-1)

- Fabrication of Specimens
  - Materials
  - Specimens description
  - Casting
- Experimental Setup

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Fabrication of Specimens

1. Materials

<table>
<thead>
<tr>
<th>Design Mix – M50</th>
<th>Quantities (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Builders Cement (containing 30% fly ash)</td>
<td>445.5</td>
</tr>
<tr>
<td>Blue Metal – 10mm Coarse aggregate</td>
<td>869.8</td>
</tr>
<tr>
<td>Nepean Paving Sand (Coarse)</td>
<td>510.0</td>
</tr>
<tr>
<td>Newcastle Sand (Fine)</td>
<td>350.0</td>
</tr>
<tr>
<td>Total Water</td>
<td>175.2</td>
</tr>
<tr>
<td>High-Range Water Reducer (HRWR)</td>
<td>4.4 – 5.3</td>
</tr>
</tbody>
</table>

Water-to-Cement ratio (w/c) ~ 0.39
# Fabrication of Specimens

## 2. Specimen description

<table>
<thead>
<tr>
<th>Experimental Tests</th>
<th>Fibre volume ratio (%)</th>
<th>Fibre Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compression</td>
<td>0.0</td>
<td>Barchip 48</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>48mm</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>Barchip MQ58</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>58mm</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>2. Flexural (residual)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Fabrication of Specimens

3. Casting

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Experimental Setup

Compression Test

Residual Flexural

Beam specimen
150 x 150 x 575 mm

CMOD & LVDT setup

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

1. Spread / Slump Results
2. Compressive Strength
3. Flexural Strength (Pre & Post Cracking)
4. Optimum Fibre Dosage
Results & Discussion

Mix Spread / Slump Results

Control (0.0%) 2.0%

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

Mix Spread / Slump Results

[Graph showing the relationship between Fibre Volume Ratio (in %) and Spread / Slump (in mm), with different markers and colors denoting different materials and properties.]

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

Compressive Strength

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

Failure Mechanism

- BarChip 48 & BarChip MQ58 specimens sustained relatively higher stresses with minimum cracks formation as compared to plain concrete

- Plain Concrete ~ Splitting / conical failure

- MSFRC ~ Splitting / shear failure

- Increased of fibres supressed cracks initiation and propagation
Results & Discussion

*Flexural Strength*

Plain Concrete

BarChip 48 (0.4%)
Results & Discussion

Flexural Strength

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

Flexural Strength

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

Flexural Strength (failure mechanisms)

BarChip 48

Fibre pull-out

BarChip MQ58

Fibre fracture

Mechanical Properties of MSFRC under Static loading for railway transoms applications
Results & Discussion

Optimum Fibre Volume ratio

• Based on the experimental tests – 1.0% of macro-synthetic fibre reinforcement (i.e. BarChip 48 & BarChip MQ58) is recommended

• Significant increase in the post-cracking (i.e. residual) behaviour
• Increase in toughness
• Minimal impact on the compressive strength
• Decrease in workability (i.e. balling effect)
Conclusions (Stage-1)

- **Workability** – Fibres drastically influenced the workability of the concrete mix, implying a reduction of approximately 40% when mixed above a fibre dosage of 1%;

- **Compressive strength** – The bridging effect characteristically reduces the crack propagation towards a more ductile failure. In addition fibres did not noticeably influence the ultimate compressive strengths. However, beyond 1.5% of fibres adverse effects were observed towards decreasing the compressive strength by 12.5% on average;
Conclusions (Stage-1)

- *Flexural behaviour* – Fibres have negligible impact on the ultimate flexural strength (i.e. pre-cracking) of the MSFRC. However, they improved the fracture mechanisms towards a more ductile behaviour, reducing the loss in capacity sustain after the initial cracks. Higher fibre dosages showed better performance in terms of residual flexural strength (i.e. post-cracking), ductility and toughness.
Applications of MSFRC for sleeper

- Partial or complete substitution of conventional steel reinforcement
- Reduction in the tensile crack initiation and propagation
- Increase durability and corrosion resistance
- Environmentally friendly alternative (i.e. CO₂ footprint reduction)

Mechanical Properties of MSFRC under Static loading for railway transoms applications
THANK YOU