Plastic Shrinkage Properties of Natural Fiber Reinforced Shotcrete

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KANGWON NATIONAL UNIVERSITY
Outline of Presentation

1. Introduction
2. Natural Fibers
3. Experimental Program
4. Test Results and Analysis
5. Conclusions
Silica Fume in Shotcrete

INTRODUCTION

Western Canada discovers the benefits of silica-fume shotcrete

Tens of thousands of tons of silica-fume shotcrete have been used on more than 20 projects in Western Canada in the last 4 years. It has been used for tunnel lining, rock slope stabilization, and structural rehabilitation.

Why is it so popular? For several reasons: Running water or rising tides do not wash out flexible arc...

This paper was originally published in the proceedings of the CINET/ACI International Workshop on the use of Silica at Columbia International Workshop on the Use of Silica in Concrete in Washington, D.C., USA during April of 1993.
Advantages of using Silica Fume

- Reduction of rebound in shooting
- Increase in build-up thickness
- High compressive and tensile strength
- Very low permeability to chloride and water intrusion
- Enhanced durability
- Increased abrasion resistance on decks, floors and overlays
- Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates
- Higher bond strength in repair
Silica Fume in Shotcrete

- Disadvantages of using Silica Fume
  - Susceptible to plastic & dry shrinkages
  - High susceptible to cracking
INTRODUCTION

Types of Shrinkage

- CARBONATION SHRINKAGE
- THERMAL SHRINKAGE
- Drying shrinkage
- CHEMICAL AND AUTOGENOUS SHRINKAGE
Stages of Shrinkage

**Early age shrinkage**

- **Autogenous shrinkage**
- It is the change in volume of concrete occurring without moisture transfer to the environment, it is rather a result of the internal chemical and hydration heat reactions between the concrete constituents.
- Occurs in the first 24-72 hours after shotcreting.

**Long term shrinkage**

- **Dry shrinkage**
- It is the change in volume of concrete occurring due to moisture transfer to the environment.
- Occurs after the first 24-72 hours after shotcreting.
Fibers in Shotcrete
INTRODUCTION

Purpose of This Study

① Advantage of Silica fume

② Disadvantage of Silica Fume

③ Natural Fiber

Reduce the Plastic Shrinkage by a Fiber

High-performance Shotcrete
Outline of Presentation

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Natural Fiber Types

- **Vegetable Fiber**
  - Plant Hair: Cotton, Kapok
  - Bast Fibers: Flax, Hemp, Jute, Kenaf, Ramie
  - Hard Fibers: Sisal, Henequen, Coconut, Banana, Yucca

- **Mineral Fiber**: Asbestos

- **Animal Fiber**
  - Wool & Hair: Sheep’s Wool, Goat Hair, Angora Wool, Horse Hair
  - Bast Fiber: Genuine Silk, Raw Silk
Natural Fiber Types

:: Introduction of natural fibers

Jute

Kenaf

Coir

Hemp

Flax

Sisal & Abaca
Natural Fiber: Hemp

HEMP

- Customized jute size: 5mm, 10mm, 20mm, 80mm

hemp hurd

100% Raw Hemp Bark Fiber

100% Raw Short Hemp Fiber, Uncombed

100% Degummed Hemp Fiber
Natural Fiber: Kenaf

Kenaf

- Customized Kenaf size: 3mm, 5mm, 10mm, 20mm, 80mm

Photos:
- long kenaf (1)
- long kenaf (2)
- kenaf 10mm
- felt (1)
- felt (2)
- board
Kenaf Fibers
Kenaf Fibers

Bleached Kenaf Fibers
Kenaf Fibers

Bleached Kenaf Fiber Pellets
Natural Fiber in Concrete

Hydrophilic
Balances moisture level concrete
Helps with curing
Natural Fiber in Concrete

Thorny surface
Acting as anchor points

Better bonding
Increase adhesiveness
Natural Fiber in Concrete
Action of Natural Fiber in Shotcrete

**Level 1**
- Natural fiber absorb water in mixing

**Level 2**
- The water is squeezed out by pressure

**Level 3**
- Absorb water by release

**Level 4**
- Natural supply water and act as internal curing

**Pumping pressure**

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Absorb water</td>
</tr>
<tr>
<td>2</td>
<td>Squeezed by pressure</td>
</tr>
<tr>
<td>3</td>
<td>Absorb water by release</td>
</tr>
<tr>
<td>4</td>
<td>Internal curing</td>
</tr>
</tbody>
</table>

**Natural fiber absorb water in mixing**
- Natural fiber absorb water in mixing
- The water is squeezed out by pressure
- Natural fiber absorb water again by pressure release
- Natural supply water and act as internal curing

**Natural fiber in wet**
- Increased pumpability by increased water content in concrete
- Reduced rebound
- Increase build-up thickness
- Decreased plastic shrinkage
Application Benefits in Shotcrete

 ✓ Natural-friendly
 ✓ Easy to mix without additional equipment
 ✓ Save time with excellent adhesion in shotcrete
 ✓ Smoother finishing surface: less bowling or pooling effects
 ✓ Balanced drying and curing processes in any weather conditions
 ✓ Internal curing and resulted in a reduced cracking
Refer to SOO Industry Co.

http://www.sicnfibers.com/eng/
Outline of Presentation

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Outline of experiment

- Aggregates
  - Coarse: 10mm of maximum size
  - Fine: sea sand + crushed

- Silica fume: 0, 7, 10% by cement weight

- Fibers
  - 0.5, 1.0, 1.5% by cement weight
  - 5, 10, 20 mm

- Mixtures
  - w/c = 0.4
  - s/A = 70%
  - cement content = 390kg/m³
  - targeted slump = 70±20 mm
Plastic Shrinkage Test (ASTM C 1579-06)

- Induce cracking in central
- Restrained in both sides

- Wind speed: 4.7 m/s
- Temperature: 36 °C
- Relative moisture: 30±10%
Plastic Shrinkage Test (ASTM C 1579-06)

- Measure crack width in 10mm space along crack
- Average the crack width
- Calculate CRR (Crack Reduction Ratio)

\[
CRR = \left(1 - \frac{\text{average crack width of fiber-reinforced shotcrete}}{\text{average crack width of plain control shotcrete}} \right) \times 100
\]
Specimen

- 100 * 200 mold casting after sprayed
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TEST RESULTS

Plastic Shrinkage : SF 7%

<table>
<thead>
<tr>
<th>平均裂缝宽度 (mm)</th>
<th>Control</th>
<th>5mm</th>
<th>10mm</th>
<th>20mm</th>
<th>NF</th>
<th>5mm</th>
<th>10mm</th>
<th>20mm</th>
<th>NF</th>
<th>5mm</th>
<th>10mm</th>
<th>20mm</th>
<th>NF</th>
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<tbody>
<tr>
<td></td>
<td>0.31</td>
<td>0.12</td>
<td>0.15</td>
<td>0.20</td>
<td>0.17</td>
<td>0.11</td>
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<td></td>
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</table>
Plastic Shrinkage : SF10%
**Plastic Shrinkage : 0.5% fiber**

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<tr>
<th>Treatment</th>
<th>0.05</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
<th>0.25</th>
<th>0.3</th>
<th>0.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.31</td>
<td>0.12</td>
<td>0.15</td>
<td>0.2</td>
<td>0.17</td>
<td>0.35</td>
<td>0.35</td>
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<td>SF7 5mm</td>
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<td></td>
<td></td>
<td></td>
<td>0.12</td>
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<tr>
<td>SF7 10mm</td>
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<td>0.12</td>
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<tr>
<td>SF7 20mm</td>
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<tr>
<td>NF</td>
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<td></td>
<td></td>
<td>0.13</td>
</tr>
</tbody>
</table>
Plastic Shrinkage: 1.0% fiber

TEST RESULTS

Average Crack Width (mm)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>5mm</th>
<th>10mm</th>
<th>20mm</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF7 1.0%</td>
<td>0.31</td>
<td>0.11</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>SF10 1.0%</td>
<td>0.35</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plastic Shrinkage : 1.5% fiber

Average Crack Width (mm)
The average crack width increase as the amount of silica fume increase from 7% to 10%.

The shorter fiber is better for plastic control.

The optimum fiber length is 5 mm in term of plastic shrinkage control.

The optimum fiber amount is 0.5% in 7% silica fume shotcrete mixture.

CRR decrease as fiber length increase at 0.5% fiber and 7% silica fume shotcrete mixture.
THANKS !!!

Q & A