Reduction of Autogenous Shrinkage in Cement Paste by Internal Curing Using Jute Fiber

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Hiroaki Morimoto

The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 3
Tuesday, October 23, 4:00 PM - 6:00 PM, CIVIC SOUTH

Introduction

Recent years have seen increased application of high-performance concrete (HPC) in elements of infrastructure thanks to superior properties such as high strength and low permeability, which are owed to its characteristically dense microstructure.

Since autogenous shrinkage is the dominant influence in HPC volume change, it is widely recognized that the high risk of early-age cracking in such concrete is attributable to significant early-age autogenous shrinkage caused by internal drying of the concrete during binder hydration reactions.

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Contents

◆ Introduction
◆ Jute Fiber
◆ Experiment
◆ Results and Discussion
◆ Conclusion

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Internal curing is an effective method of preventing autogenous shrinkage in early-age concrete.

In this approach, water-retentive particles act as internal reservoirs to supply water to the surrounding cement paste matrix.

Recent research of Internal curing

- Light Weight Aggregates:
  - Bentz et al (2005)
- Super-absorbent polymer (SAP):
  - Jensen et al (1995) etc
- Recycled aggregate:
  - Suzuki et al (2009) etc
- Cellulose fibers:
  - Kawashima et al (2011) etc

The objective of this study was to determine how the early-age shrinkage behavior of cement-based materials is affected by the addition of saturated jute fiber under sealed conditions.

Table shows the mixture proportions. All paste mixtures had a water-cement (w/c) ratio of 0.25 and a 2% addition of super-plasticizer by cement mass.
### Jute Fiber

- **Type of plant**: Tiliaceae
- **Place of Origin**: India, Bangladesh
- **Applications**:
  - Packaging materials
  - Agricultural materials
  - Rope

### Properties of Jute Fibers

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>1.3</td>
</tr>
<tr>
<td>Length</td>
<td>mm</td>
<td>6</td>
</tr>
<tr>
<td>Diameter</td>
<td>mm</td>
<td>0.05</td>
</tr>
<tr>
<td>Water Content Ratio</td>
<td>%</td>
<td>75</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>MPa</td>
<td>320</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>GPa</td>
<td>20</td>
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</tbody>
</table>

### Mixture Proportion

<table>
<thead>
<tr>
<th>Jute Fiber Content (vol%)</th>
<th>Unit Weight (g/L)</th>
<th>(g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W/C</td>
<td>C</td>
</tr>
<tr>
<td>0</td>
<td>0.25</td>
<td>1762</td>
</tr>
<tr>
<td>0.5</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>13.0</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>26.0</td>
<td></td>
</tr>
</tbody>
</table>

The natural jute fiber with addition ratios of 0, 0.5, 1.0 and 2.0% by volume.

### Mixing and Casting

The jute fiber was placed in a plastic bag with water for 24 hrs. A two-liter Hobart mixer was used for mixing.

The flowability of the mortar was evaluated in a flow test. The cone mold used for the test had a top diameter of 70 mm (2.73 in.), a bottom diameter of 100 mm (3.9 in.) and a height of 60 mm (2.34 in.).
Mixing and casting

After the flow test, fresh paste was inserted into a corrugated tube.

Shrinkage tests: ASTM

After the flow test, fresh paste was inserted into a corrugated tube.

Measurement of Temperature

Cement paste in Corrugated tube Dial gauge (3/1000 mm)

Measurement basement
(Made of Invar steel or stainless steel)

Autogenous shrinkage was measured using the corrugated tube approach proposed by Jensen and Hansen, the setup for which is shown in Figure.

The sensitivity of the dial-gauge used was 3/1,000 mm, and three measurement systems were adopted.

The base stands of these systems were made of Invar steel (thermal expansion coefficient: 0.1 μ/°C, number of pieces: one) and stainless steel (thermal expansion coefficient: 17.3 μ/°C, number of pieces: two).

Each test was run for 8 days in a condition-controlled room set at 20 ± 2°C, and readings were taken every 10 minutes for the entire duration of the test.

The internal temperatures of the specimens were measured using corrugated polyethylene tubes of approximately 200 mm in length and 30 mm in diameter.
Shrinkage tests: ASTM

Measurement of Temperature

Cement paste in Corrugated tube Dial gauge (3/1000mm)

Measurement basement
(Made of Invar steel or stainless steel)

The zero time of measurement was defined as the point at which the temperature started to increase (PTSI). Because it was difficult to determine the setting time via a Vicat needle test.

Results and Discussions

Flow tests

The flow value of the control paste without fiber was 300 mm, while that for the cement paste with 0.5% of jute fiber by volume was actually higher at 377 mm.

The value for cement paste with 1.0% of jute fiber by volume showed a slight decrease in comparison to the 0.5% specimen was 317 mm. The value for cement paste with 2.0% of jute fiber by volume showed a drastic decrease to just 163 mm.

It was observed that a cluster of jute fiber remained at the center of the flow spread after the removal of flow cone.

It was difficult to make shrinkage measurement specimen with 2.0% of jute fiber by volume.
It can be considered that the flow value is higher with the addition of jute fiber up to 1.0% by volume because the water in its straw-like structure discharges into the cement paste during the mixing process.

Soroushian reported that fibers generally have negative effects on the compressive strength of cement-based matrixes.

It was considered that the internal temperature started to increase when cement hydration became active. Accordingly, the zero time for autogenous shrinkage was defined as the point at which the temperature started to increase (PTSI).

Figure shows the relationship between compressive strength of the cement paste specimen and fiber content ratio. The compressive strength of the control specimen and the 0.5%-volume specimen were very similar at 133 MPa and 129 MPa, respectively.

Figure shows the length change and internal temperature of a cement paste specimen. It can be seen that the length change began to increase drastically after half a day, and that the internal temperature also started to increase after this time, reaching a maximum value of 24.4°C at 1.2 days.

Figure shows the autogenous shrinkage strain values of the cement paste samples with and without added jute fiber, the control specimen. It can be seen that with addition in sufficient amounts jute fiber up to 1.0% by volume had a mitigating effect on autogenous shrinkage.
Shrinkage strain vs. fiber content ratio

Figure shows autogenous shrinkage at a material age of 1 day and 8 days. Shrinkage values at 1 day for the control specimen, the 0.5%-volume specimen and the 1.0%-volume specimen were 1,691 μ, 1,550 μ and 999 μ, respectively.

Shrinkage reduction ratio vs. fiber content ratio

Figure shows relationship between Autogenous shrinkage reduction ratio and fiber content ratio. Shrinkage reduction ratio at 1 day, for the 0.5%-volume specimen and the 1.0%-volume specimen were 8% and 41%, respectively.

Conclusions

The following conclusions were drawn:
1. Additions of 0.5% and 1.0% of jute fiber by volume of cement paste led to 12% and 36% reductions in autogenous shrinkage strain at 8 days, respectively.
2. Additions of 0.5% and 1.0% of jute fiber by volume of cement paste resulted in 3% and 22% reductions in compressive strength at a material age of 8 days, respectively.
3. The results of the autogenous shrinkage tests showed that jute fibers help to support internal curing.

This behavior may primarily be attributed to the difference in the amount of internal curing water provided by each dosage of jute fiber to the hydrating paste. The results of the autogenous shrinkage tests demonstrate that jute fiber can contribute to the success of internal curing.
Acknowledgements

This experimental work was supported by bachelor student who is Mr. K. Ohashi in Gifu University.

The authors would like to thank Dr. M. Yamamoto of Tesac Co., Ltd. for providing the jute fiber used in the study.

Thank you for your kind attentions!

Questions?

Calculation of Autogenous shrinkage strain

\[ \varepsilon_{\text{aut INV}} = (\delta_{\text{total}} - 0.1 \times 10^{-6} \times L_{\text{base}} \times \Delta T_{\text{amb}}) / L_{\text{sp}} - 20 \times 10^{-6} \times \Delta T_{\text{cp}} \]  

[1]

\[ \varepsilon_{\text{aut STA}} = (\delta_{\text{total}} - 17.3 \times 10^{-6} \times L_{\text{base}} \times \Delta T_{\text{amb}}) / L_{\text{sp}} - 20 \times 10^{-6} \times \Delta T_{\text{cp}} \]  

[2]

**Autogenous shrinkage strain (0% vol)**

- **a) 0.0vol% Control**
- **b) 0.5vol%**
- **c) 1.0vol%**

**Autogenous shrinkage strain (0.5% vol)**

**Autogenous shrinkage strain (1.0% vol)**
Flow tests-1

- a) 0% (Control)
- b) 0.5%
- c) 1.0%
- d) 2.0%

Chemical composition of ordinary portland cement

<table>
<thead>
<tr>
<th>Chemical composition (%)</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₃O₄</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>Ig.loss</th>
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<tbody>
<tr>
<td></td>
<td>20.3</td>
<td>4.9</td>
<td>2.7</td>
<td>64.6</td>
<td>1.5</td>
<td>3.2</td>
<td>1.06</td>
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</table>

Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Properties</th>
</tr>
</thead>
</table>
| Cement (C)| Ordinary Portland Cement  
Density: 3.15 g/cm³ |
| Water (W) | Tap water density: 1g/cm³ |
| Super-plasticizer (SP) | Density 1.04-1.11g/cm³  
Total alkali content: 1% |
| Jute fiber (J) | Density 1.30g/cm³, Length 6mm  
Diameter: approx. 0.05mm  
Water content ratio 75% (Condition: Absorption 24hr, 5min desorption) |