The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 3

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ACI Member **Mitsuo Ozawa** is an Assistant Professor at Department of Civil Engineering, Gifu University. He received his PhD in Civil Engineering from Gifu University, Gifu, 2003. His research interests include estimation of early-age stress in concrete, crack control, moisture transfer in concrete, fire resistance of concrete.

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

Gifu University Mitsuo Ozawa
Hiroaki Morimoto

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

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◆Jute Fiber
◆Experiment
◆Results and Discussion
◆Conclusion

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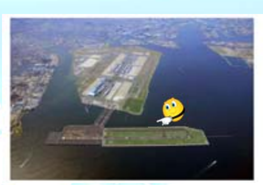
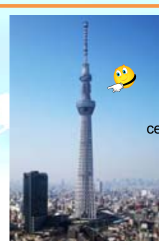
Introduction



Tokyo International Airport (Haneda)

http://www.taisei.co.jp/giken/report/2009_42/



Tokyo sky tree

http://www.skytree-obayashi.com/pointview/

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.

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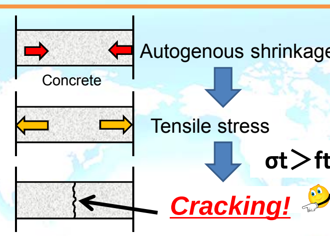
Introduction



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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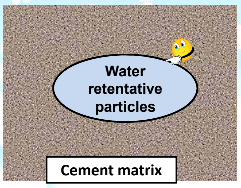
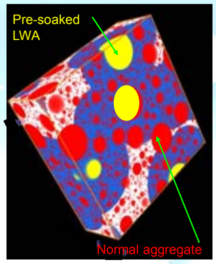
Introduction: Internal curing





Computer simulation by Dale Bentz, NIST

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

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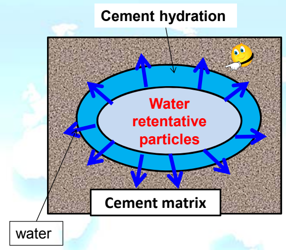
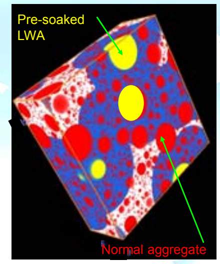
Introduction: Internal curing





Computer simulation by Dale Bentz, NIST

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

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Recent research of Internal curing

- Light Weight Aggregates:
  Bentz et al(2005)
  Cusson et al.(2008),
  Henkensiefken et al.(2009) etc
- Super-absorbent polymer(SAP):
  Jensen et al.(1995) etc
- Recycled aggregate:
  Suzuki et al(2009) etc
- Cellulose fibers:
  Kawashima et al (2011) etc

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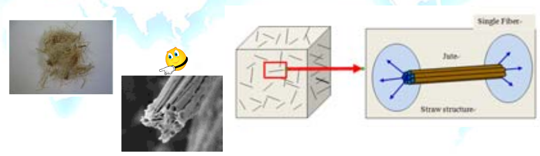
Purposes

◆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.



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Outline of experiments

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Mixture proportion

Jute fiber content (vol%)	W/C	Unit weight (g/L)			(g/L)
		C	W	SP	Jute fiber
0	0.25	1762	405	35	0.0
0.5					6.5
1.0					13.0
2.0					26.0

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.

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Mixture proportion

Jute fiber content (vol%)	W/C	Unit weight (g/L) C	W	SP	(g/L) Jute fiber
0	0.25	1762	405	35	0.0
0.5					6.5
1.0					13.0
2.0					26.0

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

Jute fiber

- ◆Type of plant: Tiliaceae
- ◆Place of Origin: India, Bangladesh
- ◆Applications:
  - Packaging materials
  - Agricultural materials
  - rope

Jute fiber

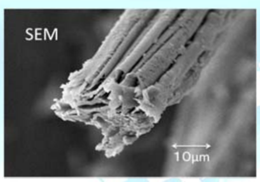


Photo 1 Shape of Jute fiber

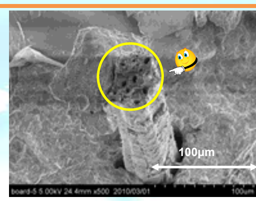


Photo 2 Jute fiber in Concrete (SEM)

Figures show the jute fiber by itself and in the concrete, respectively. The straw-like structure of the jute fiber seen in the scanning electron microscope (SEM) photograph allows it to retain water internally for curing.

Properties of jute fibers

Density	g/cm^3	1.3
Length	mm	6
Diameter	mm	0.05
Water content ratio	%	75
Tensile strength	MPa	320
Elastic molulus	GPa	20

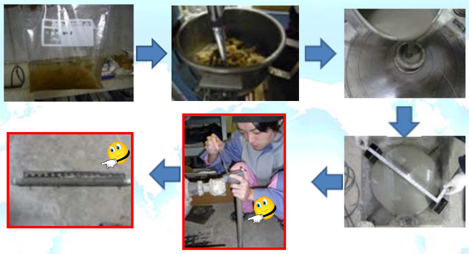
Mixing and casting

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

Mixing and casting

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(2.73in.), a bottom diameter of 100 mm(3.9in.) and a height of 60 mm(2.34in.).

Mixing and casting



After the flow test, fresh paste was inserted crrugated tube.

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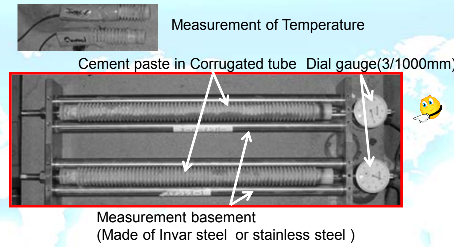
Shrinkage tests : ASTM



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

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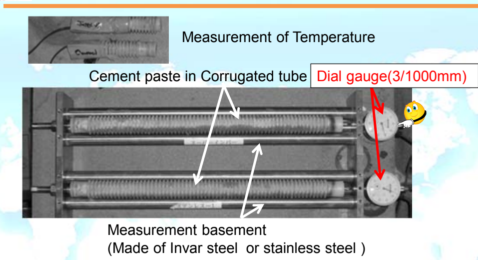
Shrinkage tests : ASTM



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

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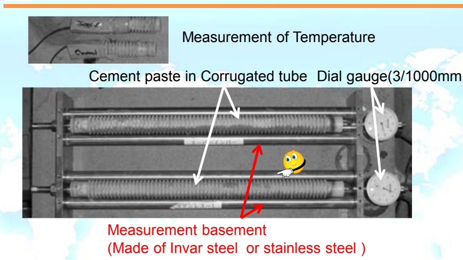
Shrinkage tests : ASTM



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).

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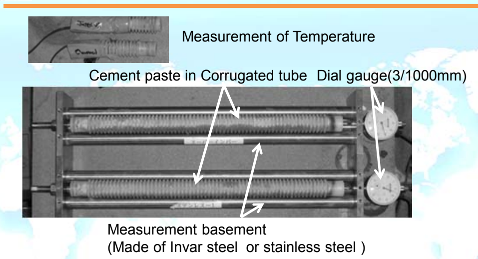
Shrinkage tests : ASTM



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.

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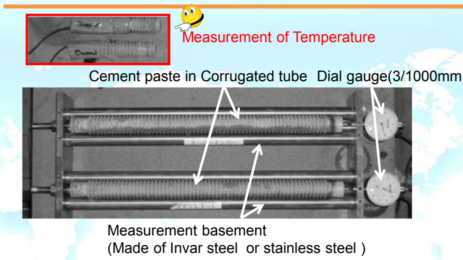
Shrinkage tests : ASTM



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

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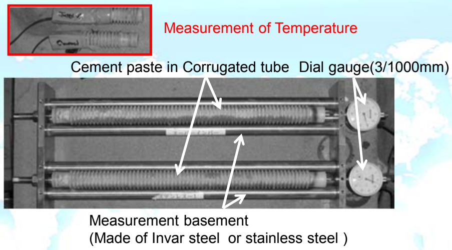
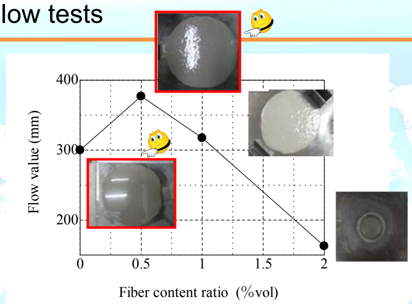
Shrinkage tests : ASTM



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.

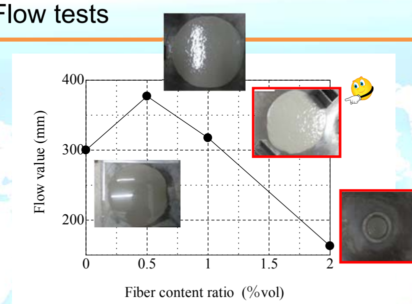
Results and Discussions

Flow tests



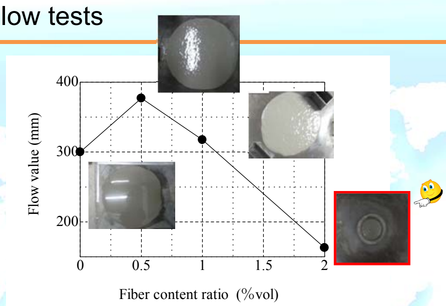
The flow value of the control paste without fiber was 300 mm, while that for the cement paste with 0.5% of jute fiber by volume was actually higher at 377 mm.

Flow tests



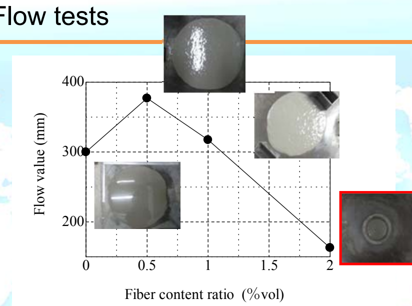
The value for cement paste with 1.0% of jute fiber by volume showed a slight decrease in comparison to the 0.5% specimen was 317 mm. The value for cement paste with 2.0% of jute fiber by volume showed a drastic decrease to just 163 mm.

Flow tests



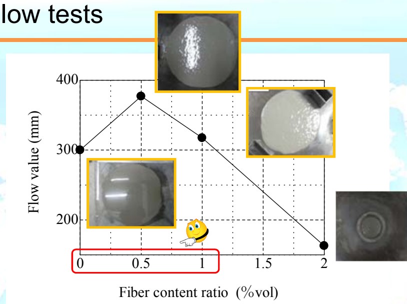
It was observed that a cluster of jute fiber remained at the center of the flow spread after the removal of flow cone.

Flow tests



It was difficult to make shrinkage measurement specimen with 2.0% of jute fiber by volume.

Flow tests



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.

Compressive strength

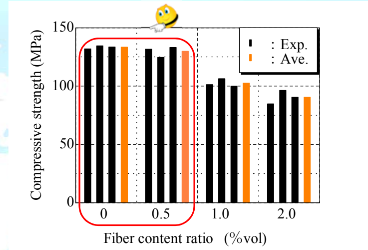
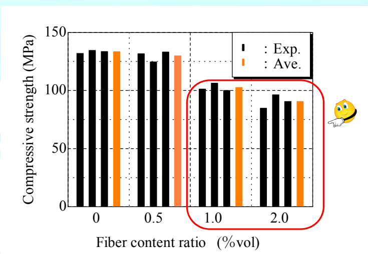


Figure shows the relationship between compressive strength of the cement paste specimen and fiber content ratio.
The compressive strength of the control specimen and the 0.5%-volume specimen were very similar at 133 MPa and 129 MPa, respectively.

Compressive strength



However, the values for the 1.0%- and 2.0%-volume specimens were 103 MPa(14,900psi) and 90 MPa(13,100psi), respectively, corresponding to reductions of 22% and 33%.
Soroushian reported that fibers generally have negative effects on the compressive strength of cement-based matrixes.

The point at which the temperature started to increase(PTSI)

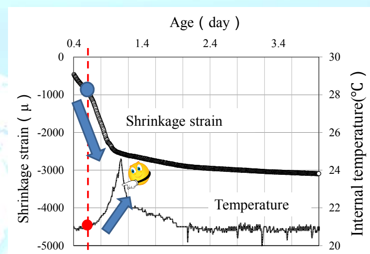
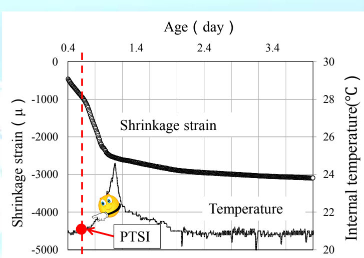


Figure shows the length change and internal temperature of a cement paste specimen. It can be seen that the length change began to increase drastically after half a day, and that the internal temperature also started to increase after this time, reaching a maximum value of 24.4° C at 1.2 days.

The point at which the temperature started to increase(PTSI)



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).

Autgenous shrinkage strain(Average)

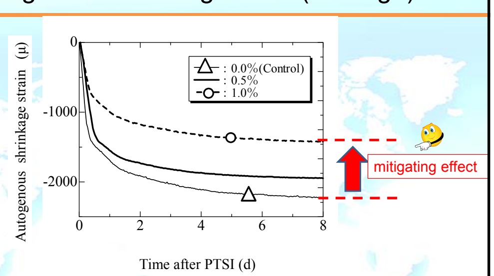


Figure shows the autogenous shrinkage strain values of the cement paste samples with and without added jute fiber, the control specimen.
It can be seen that with addition in sufficient amounts jute fiber up to 1.0% by volume had a mitigating effect on autogenous shrinkage.

Shrinkage strain vs.fiber content ratio

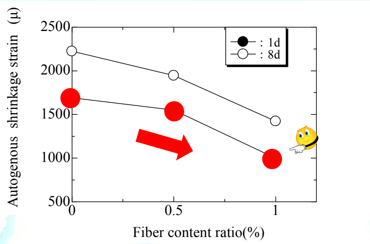


Figure shows autogenous shrinkage at a material age of 1day and 8 days.
Shrinkage values at 1 day for the control specimen, the 0.5%-volume specimen and the 1.0%-volume specimen were 1,691μ, 1,550 μ and 999μ, respectively.

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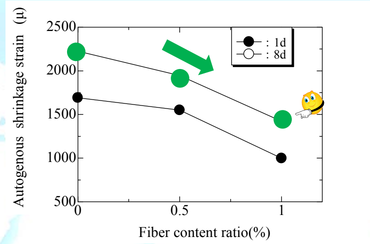
Shrinkage reduction ratio vs.fiber content ratio



Shrinkage values at 8 days for the control specimen, the 0.5%-volume specimen and the 1.0%-volume specimen were 2,240 μ, 1,950 μ and 1,420μ, respectively.

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Shrinkage reduction ratio vs.fiber content ratio

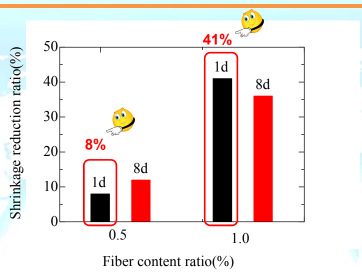

Figure shows relationship between Autogenous shrinkage reduction ratio and fiber content ratio.
Shrinkage reduction ratio at 1 day, for the 0.5%-volume specimen and the 1.0%-volume specimen were,8% and 41%, respectively

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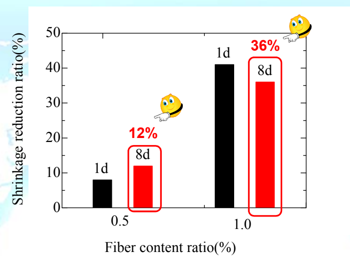
Shrinkage reduction ratio vs.fiber content ratio



Shrinkage reduction ratio at 8 days, for the 0.5%-volume specimen and the 1.0%-volume specimen were 12% and 36%, respectively.

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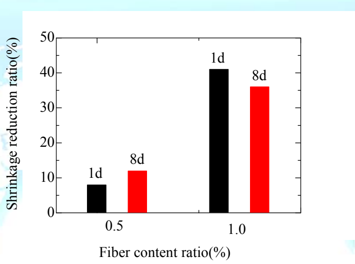
Shrinkage reduction ratio vs.fiber content ratio



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.

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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.

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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?

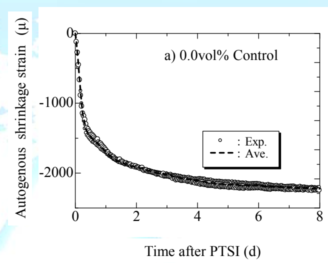
Calculation of Autogenous shrinkage strain

$$\varepsilon_{autoINV}=(\delta_{total}-0.1\times10^{-6}\times L_{base}\times\Delta T_{am})/L_{sp}-20\times10^{-6}\times\Delta T_{cp} \quad [1]$$

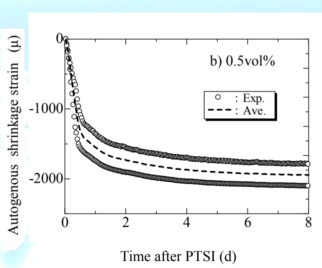
$$\varepsilon_{autoSTA}=(\delta_{total}-17.3\times10^{-6}\times L_{base}\times\Delta T_{am})/L_{sp}-20\times10^{-6}\times\Delta T_{cp} \quad [2]$$

εauto=autogenous shrinkage strain;
δtotal=dial gauge value (mm);
αbase=thermal expansion coefficient of base stand(μ/° C);
Case1 : Invar steel 0.1 μ/° C;
Case2 : Stainless steel 17.3 μ/° C;
Lbase=base stand length (mm) ;
ΔTam=ambient temperature increment (° C) ;
αcp=thermal expansion coefficient of cement paste:20μ/° C ;
ΔTcp=specimen temperature increment (° C) ;
Lsp=specimen length (mm) ;

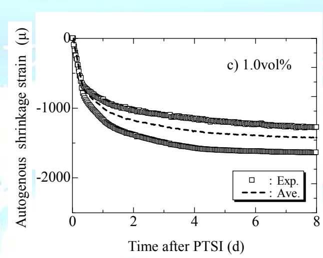
Autgenous shrinkage strain(0%vol)



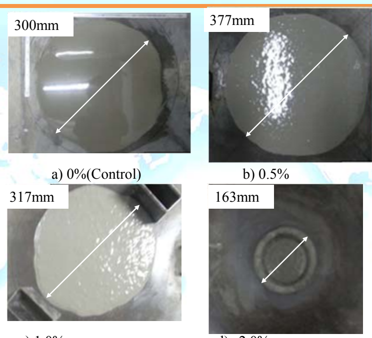
Autgenous shrinkage strain(0.5%vol)



Autgenous shrinkage strain(1.0%vol)



Flow tests-1



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

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Chemical composition of ordinary portland cement

Chemical composition (%)						
SiO_2	Al_2O_3	Fe_3O_3	CaO	MgO	SO_3	Ig.loss
20.3	4.9	2.7	64.6	1.5	3.2	1.06

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Materials

Material	Properties
Cement（C)	Ordinary Portland Cement Density: 3.15 g/cm^3
Water (W)	Tap water density: 1g/cm^3
Super-plasticizer（SP)	Density1.04-1.11g/cm^3 Total alkali content1.1%
Jute fiber（J)	Density 1.30g/cm^3,Length 6mm Diameter: approx.0.05mm Water content ratio 75%(Condition: Absorption 24hr, 5min.desorption)

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