Plastic Fiber Concrete Design and 3D Printing Techniques

Idea Presentation: Qingli (Barbara) Dai
Michigan Technological University
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Presentation Outline

- **Motivation**
- Plastic fiber concrete for 3D structure printing
  - Plastic micro-fiber types
  - Mixture design for printing concrete
  - Fiber concrete rheology and setting time to adapt for 3D construction printing
- 3D concrete structure printing techniques
  - Contour crafting techniques
  - Layer printing with insulation polymer layer
  - Additive printing techniques using recycled or smart materials
  - Other 3D concrete printing techniques
Motivation

- Use Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) techniques to precisely printing concrete structure components and building
- Additive manufactures allows for using functional gradient materials, recycled materials and smart materials (including fibers and sensors) for rapid building construction
- Save construction labor and cost and shorten construction time
- Provide a practical platform to apply modern CAD and CAM techniques for civil infrastructure construction such as building or bridge structural components
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Plastic fiber types

- **Fiber types**
  - Polyvinyl alcohol fiber (14 um diameter and 6 mm length)
  - Polypropylene (PP) fiber (0.18 mm diameter and 12 mm length)

- **Effect of the added fiber**
  - The added fiber can enhance the mechanical performance and mitigate the drying shrinkage of printing concrete due to low water/cement ratio

Demonstration of PVA fiber  Demonstration of PP fiber
Mixture design for printing concrete

- Component materials for printing concrete materials
  - Cement (Type I Ordinary Portland Cement)
  - Fine Aggregate (Size range [100, 600] um)
    - The ratio of Binder/Fine aggregate is one of major factors need to be optimized during the mixture design
  - Secondary Cementitious Materials (Fly ash, GGBS and Silica fume)
    - The added fly ash and GGBS can enhance the durability performance and increase the flowability at fresh stage
    - The added silica fume can enhance its durability performance and self-supporting ability
  - Concrete admixtures (Superplasticizer, Rheology Enhancing Admixture, Accelerator and Retarder)
    - The accelerator and retarder are applied to speed up and slow down the setting process respectively, which content will be adjusted based on the construction requirements
Optimization of Printing Concrete Mixture design

- Parameters need to be determined for the concrete mix design
  - Water/Cement Ratio
    - Low water/cement ratio (0.25-0.3) was applied to achieve self-supporting ability.
  - Cement/SCMs ratio
    - SCMs are added to enhance durability and improve the fresh stage workability
  - Sand/Cement Ratio
    - The sand/cement ratio varies in different references from 0.3 to 3.5.
  - Dosages of Addictive
    - The dosages will be adjusted based on the workability and open time requirement.
  - Fiber content
    - Dependent on the fiber type and size
    - The volume fraction can vary from 0.2% to 2%.
Typical mixture design for printing concrete

- Mixture design
  - The percentage of cement, SCMs, Fine aggregate, VEA and HRWR are based on the mass ratio of binder.
  - The fiber content is based on the volume fraction.
  - The maximum possible fiber content can increase with the binder/fine aggregate ratio

<table>
<thead>
<tr>
<th>Cement</th>
<th>SCMs</th>
<th>Fine Aggregate</th>
<th>Fiber content</th>
<th>VEA</th>
<th>HRWR</th>
<th>W/B ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Slag: 0.5</td>
<td>0.325</td>
<td>PVA: 2%</td>
<td>1%</td>
<td>0.25%</td>
<td>0.25</td>
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<tr>
<td>0.78</td>
<td>Fly Ash: 0.22</td>
<td>3.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
</tr>
<tr>
<td>0.78</td>
<td>Fly Ash: 0.22</td>
<td>2.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
</tr>
<tr>
<td>0.78</td>
<td>Fly Ash: 0.22</td>
<td>2.1</td>
<td>PP: 0.1%</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
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<tr>
<td>0.78</td>
<td>Fly Ash: 0.22</td>
<td>1.66</td>
<td>PP: 0.4%</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Properties and performance of the fresh stage printing concrete

- Early-age rheology and setting properties
  - Extrudability
    - The ability for the transpiration of fresh printing concrete through pipe and nozzle
  - Open time
    - The time that the fresh spray concrete can maintain sufficient workability
- Workability
  - The flowability of fresh concrete, which can significantly affect the extrudability
  - The flowability can be measured based on shear vane test instead of traditional slump test
- Buildability
  - The adhesion and cohesion between or within different printing concrete layers
  - The self-supporting ability of the printing concrete
Rheology property measurement with shear vane test

- The shear strength and rheological parameters can be obtained with the shear vane test.
- The test will be conducted at three different positions for one sample as shown in the figure below.

Indication a shear vane test with measuring positions (Le et. al. 2012)
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Contour crafting techniques

- Smooth, accurate and free-form surface can be achieved with the contour crafting technique, which is a computer aided fabrication technology.
- The two trowels are utilized in the contour crafting method to generate smooth outer and top surface.
- The side trowel can deflected according to the computer control to generated non-orthogonal surfaces.

Demonstration of the contour crafting process (Khoshnevis and Bekey, 2003)
Layer printing with insulation polymer layer

- The system requires one nozzle and one manipulator, which are used for the printing of cementitious and polymer layer installation.

Demonstration from redshift.autodesk.com
Additive 3D printing for concrete structure construction

- Additive printing with recycled materials
  - The Polypropylene fiber fabricated with the waste bottle material can be applied in the printing concrete production

- Additive printing with smart materials
  - Fibers
  - Self-sensing concrete with added carbon materials (Graphene, Carbon Nanotubes and Graphene Nanoplatelets)
  - Polymer bonding materials between layers
Other 3D printing techniques

- D-Shape: Deposits powders and sands, and locally apply binder material to harden and compact the shape.
  - Advantage: unhardened sand as support for layers above and allow shapes beyond layer-by-layer extrusion
  - Disadvantage: Sand has to be spread and compacted for each layer. Once the element was print, the unused sands has to be removed

D-shape by Enrico Dini (Denintech.it. 2014)
Thank you for your attentions!