The 2020 World Congress on
The 2020 Structures Congress (Structures20)
25-28, August, 2020, GECE, Seoul, Korea

Utilization of 3d Printing for Concrete Dragon Boat Model

*Y.Q. Feng[1)], K.H. Zhang[2)], A.Q. Tan[3)], K. Ma[4)], Y. Xiao[5)]

[1), 2), 3)] *Zhejiang Univ.-Univ. of Illinois at Urbana Champaign Institute, Jiaxing, Zhejiang, China*
[4)] *Department of Civil & Environmental Engineering, University of California, Berkeley, CA, USA*
[4)] *kema@berkeley.edu*

[5)] *Zhejiang Univ.-Univ. of Illinois at Urbana Champaign Institute, Jiaxing, Zhejiang, China / Department of Civil Engineering, University of Southern California, Los Angeles, CA, USA*
[5)] *yanxiao@usc.edu*

Corresponding and presenting author: Y.Q. Feng, email: yiqi.17@intl.zju.edu.cn

ABSTRACT

In comparison with conventional concrete prototyping methods which involves pouring mixtures into certain pre-set mold, the technique of concrete 3d printing has a tremendous advantage in speed of shaping. Albeit being more efficient and adjustable, the technique of concrete 3d printing remains immature on account of the difficulty involved during spraying and overlapping. This paper introduces an innovative technology of rapid concrete formation, which employs a new type of lightweight aggregate ECC (engineered cementitious concrete) as raw material, combined with 3D printing technology to print the frame, and uses FRP (fiber reinforced polymer) ribs and FRP fabrics as structural components. More specific scenarios of applications of the technology are then further investigated so as to broaden the prospect of this project, such as full-scale concrete dragon boats, etc.

[1)] Undergraduate Student
[2)] Undergraduate Student
[3)] Undergraduate Student
[4)] Graduate Student
[5)] Professor

1. INTRODUCTION

Properly designed and manufactured light-weight concrete has many advantages such as light meight, high strength and durable performance etc., which could be a good material for boats. However, the traditional method for casting the boat shape with concrete in a pre-built mold, cannot provide the required strength. We proposed a new method to build a strong, robust and wearable model, and it was used to participate in the International Concrete Dragon Boat Competition.

The competition is hosted by the Zhejiang University, co-organized by American concrete institute (ACI), and sponsored by Qinshan Construction Company.

The competition is consisted of four parts: the aesthetic consideration, the material testing, the speed racing, and the steeplechase. In the first part, aesthetic consideration, participators were asked to show their boats to the judge and do a brief presentation upon their poster. This part was aimed to select boats with good looking and proper adoption of theories.

In the second part, participants were asked to provide several testing samples of concrete which should have exactly the same formula as the concrete used on their boat. Then, their samples were placed under a weight, the samples that can bear the weight falling in highest height could gain the highest score in this part.

In the third part, participators were asked to have a racing in a straight track, as shown in Figure 1. It was a time trial so the competitor that complete the game in minimum time duration could have the highest score.

Fig. 1. Speed racing

In the fourth part, participators were asked to complete the game without getting in touch with the obstacles, and also in minimum time duration. The track was shown in Fig. 2.

Fig. 2. steeplechase

The competition asks the competitors to apply concrete, an essential material for modern engineering, to construct a dragon boat with traditional Chinese cultural elements, and participate in racing and competitive events, also through evaluations of material mechanics and technical paper. Each group of participants demonstrated their own talent and imagination, as well as analytical calculation ability. The composition not only relies on the players' understanding and comprehension of the new cutting-edge concrete materials technology to create feasible structure but also requires the players to use interdisciplinary knowledge, creativity and artistic designing ability.

2. DESIGN CONSIDERATIONS

This project uses a new type of lightweight aggregate ECC concrete as raw material, combines with 3D printing technology, and USES FRP bars and FRP fabrics as structural components, to research and develop a new type of special special-shaped concrete rapid prototyping technology.

2.1.1 Engine selection

About engine selection, the whole project is aimed at exploiting the advantages of concrete while fixing its problems, expanding our knowledge of concrete through engineering practice. However, concrete is just a material, and material evolves as scientific progress advances. New material such as FRP rebars show even better performance than traditional steel rebars.

Fig.3 Selection of engine and remote controller

2.1.2 The 3d printing of the frame

A plastic hull is needed for this model, primarily for the shape control of the self-hardening FRP clothes. To achieve better dynamic performance, hull is modeled to be smooth and continuous - NURBS interposition of key points. Therefore, 3D-printing technology is adopted for precise realization of the model. The software was used for fluid mechanics analysis and to draw streamlined structures similar to those of traditional dragon boats, as shown in Fig.4.

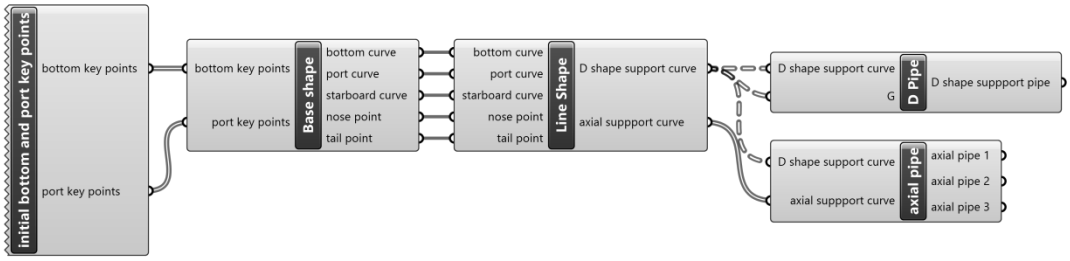

Fig.4 Flow chart of 3D printing design

2.1.3 Concrete

ECC concrete is a type of concrete which includes PVA (polyvinyl alcohol) fiber to increase its tensile strength and crack resistance. Ingredients are listed as in Table 2.

Table 1 Materials

Cement	
Quartz Sand 20-40	1.1
Silica Fume	0.3
Flyash	0.15
Mineral Powder	0.1
Quartz Sand 325	0.1
PVA Fiber	
Water	0.18
Water Reduce Agents	0.10%
Early Strength Agents	0.10%

The FRP material is wrapped outside the frame into a layer, and after the concrete is deployed, the FRP layer is added to the concrete, the uniformity and thickness of the concrete are controlled. Ensure that the vessel receives multiple stresses in water that are balanced. Wait until the concrete is cured, then apply a waterproof coating to ensure that the hull is watertight, as shown in Fig.5.

Fig.5 Fabrication of concrete dragon boat model

2.1.4 Comparison of three model tests

Prototype 1.x focuses itself on boat construction. A boat floating on the water marked success of the first stage. On that occasion, however, path splits for two different prototypes though. Prototype 2.x stays small and is optimized for wireless remote control. A concrete dragon boat (model) competition is later held based on this. Prototype 3.x is developed with optimization for man-powered sailing in a much larger scale - a real concrete dragon boat

3. MANUFACTURE OF BOAT MODEL

Figures 6 and 7 show the model design and realized model frame, respectively. To construct the most competitive concrete dragon boat for the competition, firstly, an informationalized model was built in Rhino with Grasshopper, then, the technology of FDM 3d printing was adopted to build an internal frame of the boat using PLA. Next, the FRP (fiber-reinforced-polymer) cloth was employed to wrap the structure to reach a higher performance in anti-tension. Afterwards, a new formula of concrete, consisting of certain ratio of fiberglass (FRC), quartz powder, PVA fibers, silica fume, pulverized coal ash, was investigated, which could perform better than traditional concrete.

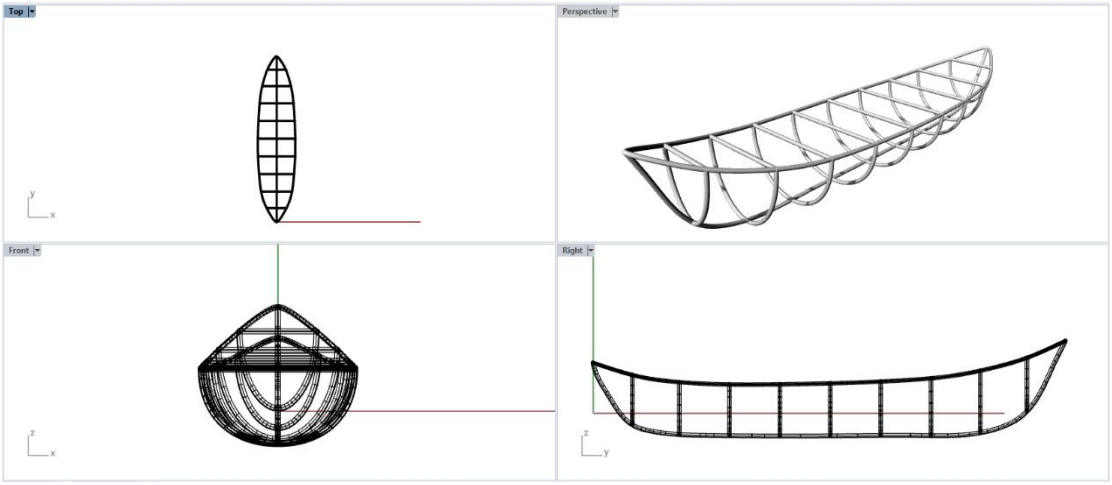

Fig.6 Model design

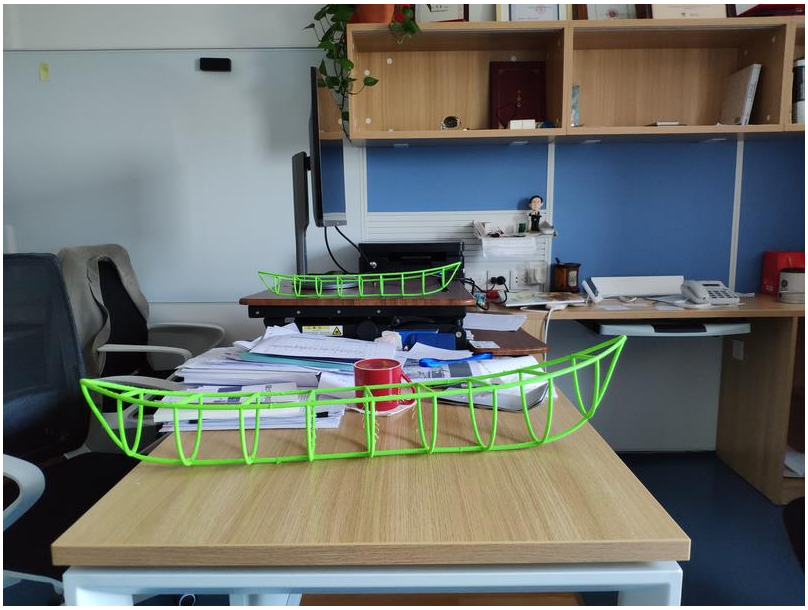

Fig.7 3d printing realized model frame

A new type of boat construction method is proposed. The basic idea is to use a self-hardening FRP material as both concrete model and structural part that provides strength. Things become interesting when several layers of such type

of material are glued together. As FRP fabric is extremely strong in tensile direction, even glue can sustain the relatively less strong shearing force, guaranteeing high bending and shearing strength.

4. MATERIAL TESTING RESULTS

The strength and stiffness of the test block are obtained by increasing the normal stress received at the central axis of the test block, as shown in Table 2.It can be seen from the test results that the cement test block can bear little force before cracking, but it can still bear strong force after bending. Because the cement ratio used is ordinary Portland cement 42.5, so the strength of the cement itself is not high. However, due to the addition of a large amount of fiber and FRP bars, the turbulence and toughness of the cement test block are very strong

Table 2 Test results of load bearing capacity of sample blocks

Load bearing	No cracking	Maximum
Test Block 1	112N	199N
Test Block 2	137N	237.N

5. COMPETITION RESULTS

On June 7th, the Chinese traditional Dragon Boat Festival, 27 delegations from the domestic and overseas universities gathered in the International campus of Zhejiang University to participate to compete at the First International Concrete Dragon Boat Competition (I-CDBC). Figure 8 provides several photograms during the competition. Our team competed fairly, though not winning the top prize.

Fig.8 Continued.

6. CONCLUDING REMARKS

In order to construct the most competitive concrete dragon boat for the competition, our team first adopted the technology of FDM 3d printing to build an internal frame of the boat by PLA, then employed FRP cloth to wrap the structure in order to strengthen it, enabling it resistant to tension. Afterwards we modulated their own formula of concrete, consisting of certain ratio of fiberglass (FRC), quartz powder, PVA fibers, silica fume, pulverized coal ash, apart from traditional cement. In fact, we even build five different kind of models, using disparate choice of body shape, dimension and application of diverse materials, in order to best optimize our model. Several thoughts can be summarized:

(1) The technology that we developed is able to tremendously increase the speed of concrete prototyping owing to the utilization of 3d printing.

(2) Benefited by this special type of technology, our team was able to construct a mighty dragon boat and thus win an outstanding prize in the I-CDBC, though not the top one.

(3) Our team further adopt the technology we investigated to build a full-size concrete dragon boat, about 8 meters in length. However, the procedure is quite different from the small boat. We used laser to cut styrofoam into pieces of specifically-designed-shape part, then placed them in sequence to form the basic shape of the boat. Then we used glass cement and sticks to fix the position of each piece. Afterwards FRP fabrics were again used for reinforcing the structure, with specially modulated concrete covering it. Eventually, the giant concrete boat was painted in red and yellow-two typical jubilant color in China and decorated with dragon head and tail, as shown in Fig.9.

Fig.9 Full-scale concrete dragon boat

7. REFERENCES

Costanzi, Chris Borg, Zy Zeeshan Ahmed, H. Roel Schipper, Freek Bos, Ulrich Knaack and R.J.M. Wolfs. 2018. “3D Printing Concrete on temporary surfaces: The design and fabrication of a concrete shell structure.” Automation in Construction 94 395-404.

Echenagucia, Tomas Mendez, Dave Pigram, Andrew Liew, Tom Van Mele and Philippe Block. 2019. “A Cable-Net and Fabric Formwork System for the Construction of Concrete Shells: Design, Fabrication and Construction of a Full-Scale Prototype.” Structures 18. 72-82.

Mayer, Eric E. 2016. “Properties of Concrete.” Semantic Scholar