Tube shape alterations for improved concrete pouring survivability in vascular self-healing concrete

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ABSTRACT

The upscaling of self-healing mechanisms for concrete from simple laboratory experiments to full-size industrial applications remains a huge challenge. In the present work, the potential for upscaling of vascular self-healing is investigated. The vanes of the vascular system, should on one hand be strong enough to survive the rather aggressive concrete production conditions, i.e. casting and pouring, while on the other hand they should be brittle in order to break when a crack in the hardened concrete surpasses them in the hardened concrete. Until now, the search for suitable materials received most attention and often the influence of the geometry was neglected. This work the shape is altered in order to investigate its influence on the survivability of the system under real production conditions. For vascular systems, the vanes should be able to resist the high forces when concrete is poured onto it. A comparison between different shapes is made, i.e. circular, square, droplet and ellipsoidal (i.e. rugby-ball) shaped cross section. From this study it can be seen that the shape is a parameter that could help to survive the pouring process.

1. INTRODUCTION

Many researchers in the field of self-healing concrete report on the challenge of making capsules survive the concrete mixing and casting process [1]–[4]. In this research, the survival of a vascular system during concrete casting is investigated. The advantages of such a vascular system over capsules are repeatable self-healing and the possibility of replenishing the healing agent [5]–[7]. A practical drawback is that such a system should be placed inside the mold before casting the concrete, similar as steel reinforcement. It is exactly at the stage of casting concrete that the vascular system could already break. Therefore, a variation in cross section shapes of these tubes and the influence on the survivability during the concrete casting process is investigated.

It is known from fluid and aerodynamics that the shape is of great influence on the resistance (i.e. stress) the object experiences, this has to do with the drag and turbulence behind the object. Which is different in our case, because there is no continuous flow of concrete but rather a short moment where concrete flows to fill up the mold. Fluid and aerodynamics can thus be a source of inspiration [8]. It is clear that cutting through a piece of butter is easier (i.e. less force is needed) with a sharp knife, than with a rectangular piece of wood.

2. MATERIALS

Two encapsulation materials are considered in this research to produce the tubes, inorganic phosphate cement (IPC) and clay. Both were chosen because of their good bond with concrete, ability to contain healing agent and ease of use to manufacture tubes.

IPC is a cementitious material engineered at the Vrije Universiteit Brussel, it is often used in glass fiber composites. IPC consists out of two systems, a calcium silicate powder and a phosphate acid based solution of metaloxides. It is a fluid and after curing at 60°C it becomes a solid with similar properties to cement-based materials.[9]

Clay is known to have a good bonding with concrete, the clay that is used, consists out of SiO_2 (77.6%) and Al_2O_3 (18.3%) (4.1% other materials). It is flexible at first and becomes a brittle solid material after heating up to 1050°C.

	IPC	**Clay**
E-modulus (GPa)	18	22.8
Tensile strength (MPa)	6-14	13.35

3. METHODS

In order to investigate the relation between the cross section of a tube and the resistance against casting of concrete, different cross sections were manufactured out of IPC and clay as can be seen in
Figure 1. They were then tested under a flow of sand, representing mortar. The tubes were simply supported and a strain gauge was attached in the middle, at the bottom-outside of the tube. The strain gauge is type FLK-6-11, gauge length of 6mm and gauge factor of 2.12.

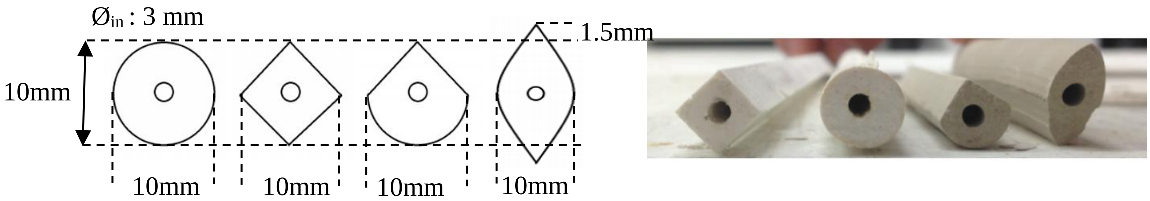

Figure 1 : Different cross sections of the tubes, the square and circular tube in the picture right are made out of IPC, the droplet and ellipsoidal are made out of clay.

A flow of sand is cast on this tube, from a height of 500mm, and the strain is measured. The dimensions and material properties of the material are known and the strain is measured in the lowest fiber in the middle of the tube (*Figure 2*). This way, the subjected load can be derived using formula (1). The experiments is repeated three times for each shape.

$$q = \frac{8.E.\varepsilon.I}{y_{max}.L^2} \qquad (1)$$

With

q= the applied load (kN/m)
E= the Young's modules (GPa)
ε= the measured strain
I= the moment of inertia (m^4)
y_{max}= the distance neutral axis to the lowest part of the cross section (m)
L= the distance between the supports (m)

The distance between the supports is 200 mm and the moments of inertia are summarized in *Figure 3*.

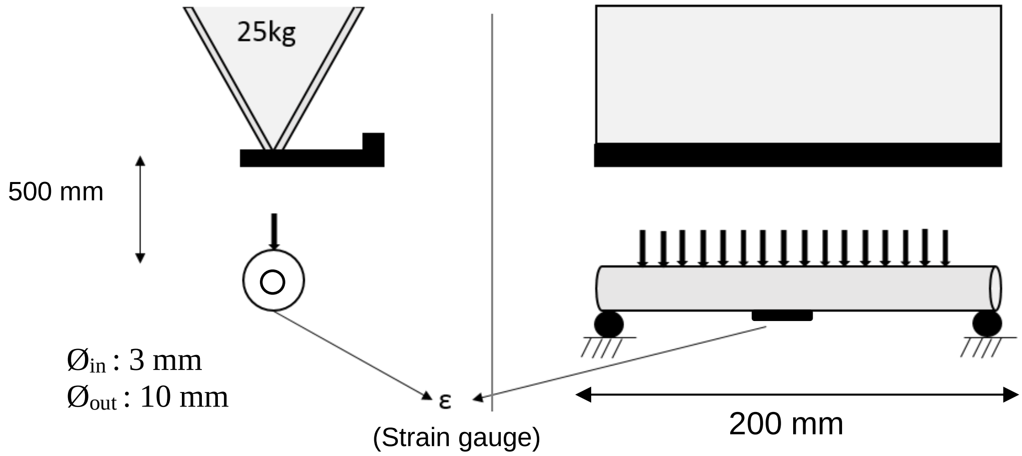

Figure 2: The test setup. Left : frontview, right : sideview

	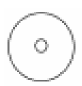	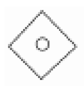	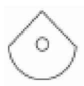	
Moment of inertia (mm^4)	490	211	445	1103

Figure 3: Moment of inertia for the different shapes

4. RESULTS

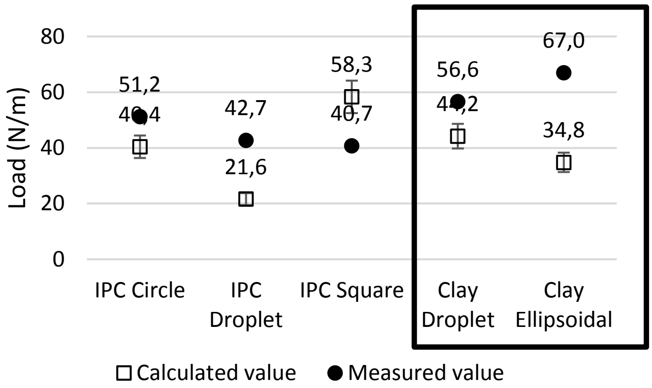

Figure 4: Loads for the different cross sections and materials (n=3)

In *Figure 4* the results for the different cross sectional shapes and materials are shown. The calculated value using formula (1) is compared to the value derived from the results by calibration. For the IPC results, it is clear that by calculation, the droplet shape is the one experiencing the smallest load. The load by calibration is the smallest with the square cross section. This experiment was repeated in clay with only the droplet and ellipsoidal shape. Note that in IPC, an ellipsoidal shape could not succesfully be produced. From the clay results, the ellipsoidal shape experience the smallest calculated load but the biggest load by calibration. One would expect the load to be independent of the material, yet a difference is noted. Formula (1) assumes a perfect material (i.e. without porosities or imperfections) and perfect loading conditions. However it was noted that all specimen had small pores due to small entraped air bubbles, visual inspection showed that IPC tubes had many more pores in comparison to the clay tubes. Comparing the IPC and clay droplet, double the load is experienced by the clay tube relative to the IPC one, indicating that clay tubes contained less pores.

5. CONCLUSIONS

Alteration of the cross sectional shape can increase the survivability of tubes and capsules during the concrete casting process because their relation to the experience load. This study shows the influence of the shape of the tube and proposes the droplet shape as the best compromise of keeping the circle cross section on the lower part of the tube (for the ease of breaking and thus activating the self-healing mechanism) and increasing the survivability during casting. Future work will include repeating these test with concrete instead of sand.

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