The Mixology Table: Controlling porosity in ceramics from nano-porous to micro-porous

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Ceramic material has long been used as the medium to purify water and it has expanded its territory to air filtration system. Such properties as porosity allowing the flow and resistance to corrosion let on the various research topics in ceramic as an effective filter agency. Although architecture has exploited ceramics in numerous ways in history, there still exist certain parameters of the material worth exploring for architectural application. The filtration capacity of ceramics might be able to offer a new opportunity for controlling air, water, light, and sound conditions. This research explores porosity of ceramic as a means of a potential architectural filtration system. The emphasis is set on controlling a scale and position of porosity in ceramics from nano-porous: the inherent property of ceramics, to micro-porous: the engineered property of ceramics. The level of nano-porosity is experimented through differentiating the thermal curing temperature of a kiln. The size of micro-porosity is dependent on the size of a swollen hydrogel and its position is specified through the rotation and time. Future research opportunities for this controlling porosity of ceramic and potential applications in architecture are discussed.

Introduction

This research emerged from our interest in porosity of basalt in Jeju Island South Korea. Jeju island is the largest island locating just off the coast of South Korea, and is known for volcanic landscape of craters and cavelike lava tubes. Basalt, a type of volcanic rock with a porous surface made during volcanic activity, is abundant and local material in Jeju Island. It has been used across scale and is known for basalt walls which is commonplace and unique in Jeju Island. The basalt wall is built by simply stacking stones without applying any adhesive. It is surprisingly more substantial than walls filled with holes, because the force pushing the wall is dispersed into the holes when the wind passes through the holes in the stone wall. This method applies to any kind of medium that passes through this porous stone. Fishnets were built under the water to catch fish using the ebb and flow of the tide in Jeju. Nano-porosity of basalt allows part of water to escape through the holes and some are dispersed so that the water cannot easily tobble the fishnets in Jeju. By utilizing this porous property of basalt into ceramic, a mass production and global usage can be introduced.


Figure 1. Basalt porosity in Jeju Island

The emphasis of this research is set on controlling scale and position of porosity in ceramics from nano-porosity:the inherent property of ceramics, to micro-porosity: the engineered property of ceramics.

Hydrogel is introduced as the secondary material to create micro-porosity in ceramics. The starting point of this work involved studying the properties of materials, hydrogel and porcelain slip, and refining dependent variables. Though experiments, different scales of porosity are controlled in two ways. Nano-porosity is experimented through differentiating the thermal curing temperature of a kiln. The size of micro-porosity is dependent on the size of a swollen hydrogel and its position is specified through the rotation and time. The goal of this study is to develop a filtration ceramic material that exhibits properties of basalt in Jeju.

Due to the high density of porcelain slip (1.74), hydrogel has tendency to float when mixed with the slip. Therefore, density and viscosity of the slip are crucial controlling factors to design porosity in ceramics. Movement of robot arms and drying time are dependent variables in digital fabrication. This research fundamentally explores the relationship between properties of hydrogel mixed with slip and movement of robot and curing time.

Background Research

Ceramic material has long been used as the medium to purify water and it has expanded its territory to air filtration system. Such properties as porosity allowing the flow and resistance to corrosion let on the various research topics in ceramic as an effective filter agency. However, most of the uses are confined to product scale and there are still certain parameters of the material worth exploring for architectural applications.

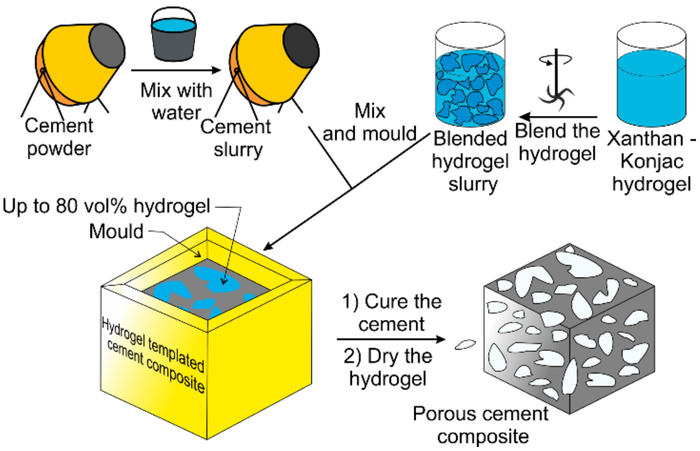


Figure 2. A typical production mechanism of porous cement composite [1]

Precedents of architectural projects that filtrate medium through controlled porosity have not been studied. However, a research paper “Sound absorption of porous cement composites: Effects of the porosity and the pore size” has been conducted by The University of Hull in UK focuses on proving the porous property of material can be used as an effective passive sound absorber. Since sound energy is lost by air molecule friction, porous materials are ideal for the purposes of sound absorption[1]. This paper introduces fabrication methodology of porous cement using hydrogel bead slurry.

First, a hydrogel is prepared in water followed by setting of the gel and its further blending. Separately cement is mixed with water. Then hydrogel slurry is mixed with cement slurry. After the hydrogel is evaporated by air-drying, producing a porous cement composite. Note that the size of hydrogel beads determine the pores size in the final porous composite[1] The below proves that the different ratio of hydrogel slurry to cement create different scales of porosity in the composite. This research produces a framework of fabrication methodology which can also be applied to ceramics.

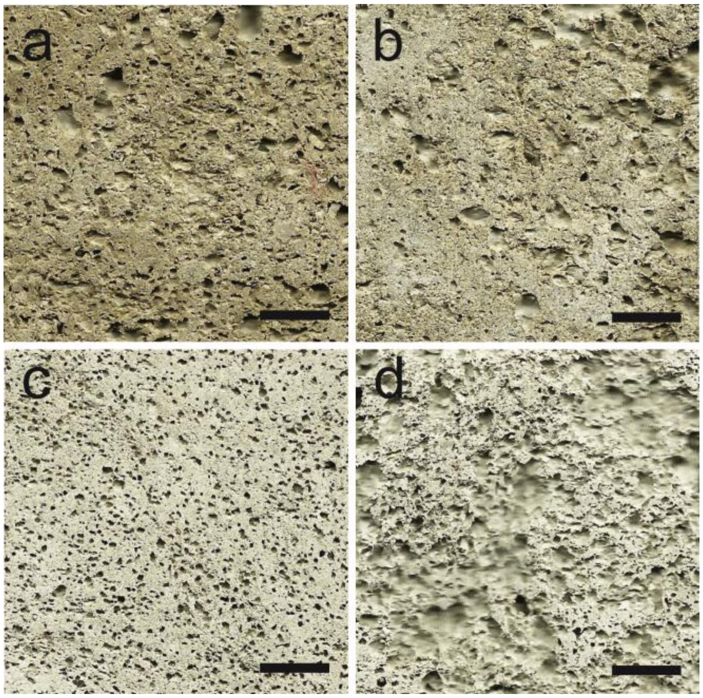


Figure 3. Different scales of porosity in cement composite [1]

Early Studies

Early investigations were mainly on testing the behaviors and attributes of materials used in the research. Slip, liquefied mixture of clay, was tested for its viscosity and density; and the size of hydrogel was tested with the amount of water absorbed. The mixture ratio of these two was also examined through few experiments.

Figure 4. The left shows the original size of the hydrogel and the right shows when they are swollen into 80% of its full size.

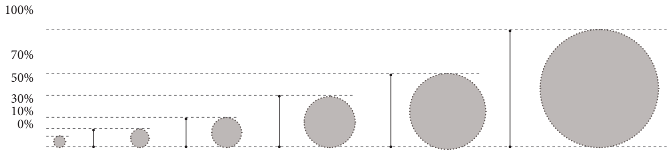


Figure 5. hyrdrogel swelling size test

Hydrogel is introduced as the secondary material in the research to create negative space in the slip. With its material character of swelling, the size of the hydrogel was tested through varying the amount of water and time. The swelling rate of hydrogel was much faster than its shrinking rate.

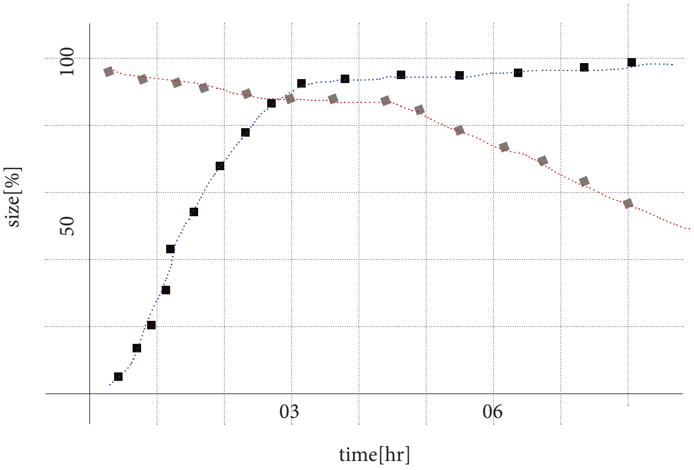


Figure 6. hydrogel swelling rate ■····■····■
hydrogel shrinking rate ◆····◆····◆

Figure 7. The left shows the viscosity difference of slip and the right shows the density test.

Density and viscosity were the variables of porceline slip to be tested. By controlling the amount of water in slip, 1.74 found out to be the adequate density for our research. Viscosity was controlled through adding epsom salt into the slip. Viscosity affects the movement of hydrogels in slip.

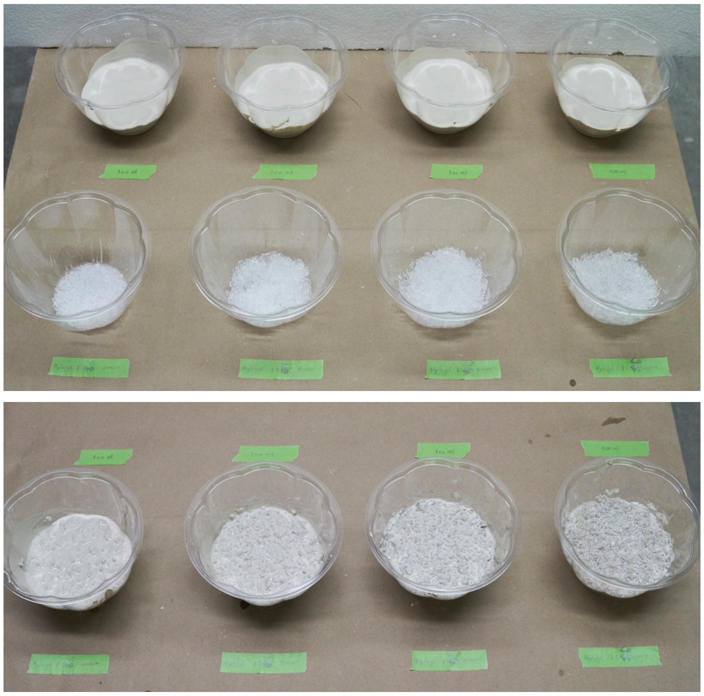


Figure 8. The above shows the hydrogels swollen with different ratio to water. From left, 1 to 10, 30, 45 and 60. The below is when mixed with porceline slip.

After each material's character and behaviors were learned, the mixture ratio of the two different materials was tested. To find the right ratio of hydrogel to slip, hydrogels swollen with different amount of water were examined. The tested ratios of hydrogel to water were 1 to 10, 30, 45 and 60. These were each mixed with same amount of slip and 1 to 45 found out to be the right ratio to be used later on with the slip casting. The mixture should neither be slurry nor thick. This critically affects the later on fabrication process of slip casting.

The following experiment shows the first trial of slip casting with hydrogel-slip mixture. The sphere hydrogels were 70% swollen to its original size, and mixed with porceline slip. Into the first plaster mold created, the mixture was poured in and set for few days to dry. The first batch of the piece created interlocking porosity in the mold. The porosity was clearly made, yet the sphere shapes seemed to be too redundant and expected. So different types of hydrogels, powder, rectangular shapes and amorphous shapes were also examined. The hydrogel with more unexpected shapes were later used to create the final piece.

When cut in section, the positions and density of porosity in the piece were clear. The Figure 5. shows the negative space created as the hydrogels shrank. Since the shrinking rate of hydrogel is much slower than the slip drying time, it allowed the negative space to be left in the piece. The fast swelling character of hydrogel also accelerated the drying process of slip. Since both slip and hydrogel are directly related with water, they also create interesting interaction themselves.

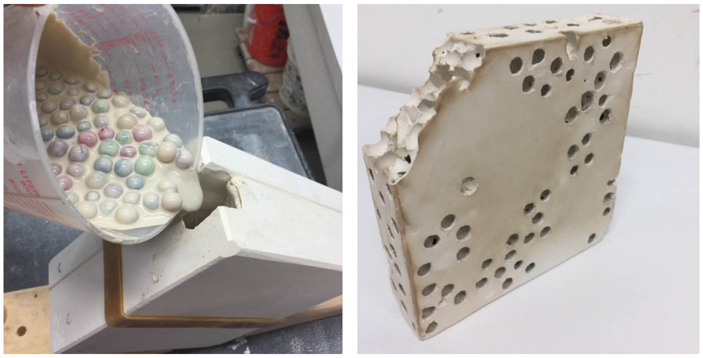


Figure 9. The left shows the process of pouring mixture into plaster mold and the right shows the resulting porous piece from the mold.

Figure 10. The above shows the negative space created through swollen hydrogel. The hydrogels went back to the original size.

Fabrication

Once the ratio of slip to hydrogel was tested, the fabrication process was also examined. The size of the plaster mold and the number of necessary parts of the mold were examined.

Figure 11. The left shows the clay work of making plaster mold and the right shows when the plaster is poured and set.

Figure 12. The mixology kit

Prior to the digital fabrication, necessary elements were constructed and 3d printed. The left is the three parts plaster mold for the mixture to be poured in. The front piece is the lid to close the mold- this was necessary as the mold would be rotated and moved to different positions in the digital fabrication process. The next two are the 3d printed cutting boards for the dried ceramic piece to be cut into sections. These allowed the porosity to be revealed more clearly in the piece. The behind is the 3d printed funnel used to pour the slip mixture into the plaster mold. The rightmost piece is the attachment to the robot. The plaster mold would be put in to the box and locked. The holes on the box let the plaster mold breathe and help the drying process. All above were used constantly in the research to design the porosity in the ceramic slip.

Peripheral Stratifications of Slip

For slip casting, ceramic objects are surrounded by plaster on all sides with a reservoir for a slip. Once slip is poured into the mold, the plaster starts to absorb the water from the outside layer of clay. Such layering is uniform in its internal shape of the mold, shown in Figure 1, and also gradual toward the core of the mold, shown in Figure 2. After a period for further absorption of water, the outer layer of clay thickens over time and eventually becomes a single solid piece. Through experimentation of the stratifications of slip, a period taking to have a solid piece, which is firm enough to cut without losing its core shape, was exponential, shown in Figure 3. As an attempt to study how hydrogel affects the hardening time, different ratio of hydrogel was added to the slip and cast in the mold. The ideal ratio mentioned in the previous section reduced the amount of time to have a solid piece with the same volume by 65%, shown in Figure 3.

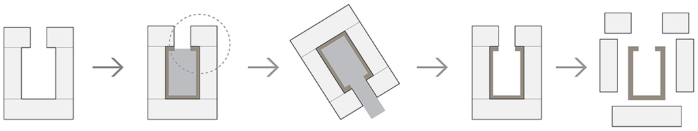


Figure 13. Single Layer Slipcasting

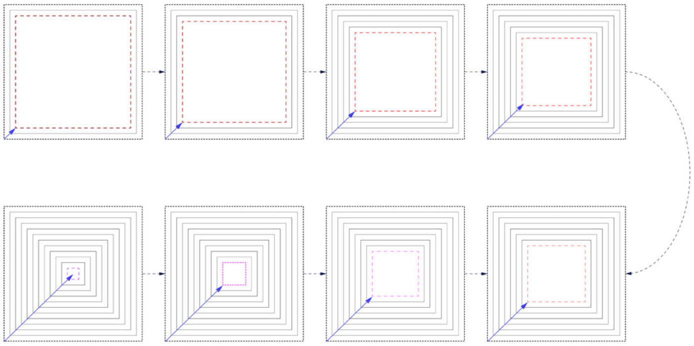


Figure 14. Multiple Layer Slipcasting (Stratifications of Slip over time)

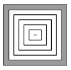
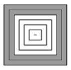
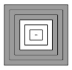
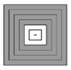
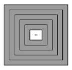
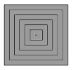
					 Porosity Defined	
Slip(100)	10 min	2 hrs	5 hrs	1 day	3 day	6 day
Slip(77) +Hyd(33)	7 min	15 min	34 min	1 hr	2 hr	5 hrs
Slip(50) +Hyd(50)	5 min	12 min	25 min	47 min	108 min (cracked)	4 hrs

Figure 15. Slip Drying Time with and without Hydrogels

Graded Positioning of Hydrogels

A density of porcelain slip used in the study was 1.78. In contrast, a density of hydrogels containing initially 25% of water up to 93% of water in a mixture of slip was 1.05. As a result, hydrogels have a strong tendency to float in porcelain slip. The viscosity of slip, however, make the floating process slow. Upper parts of hydrogels need to move upward first to make room for hydrogels right below to float. With this tendency, the first study that successfully positioned hydrogels as intended was differentiate angles of mold over time. As the angle changes, the positions and gradient of hydrogels become dynamic and three dimensional. The second experiment to position hydrogel has rotated a mold fast enough to separate hydrogel from much denser porcelain slip, shown in Figure 5. Through multiple tests varying rotational speed and checking tested pieces, it was measured that slip and hydrogel begin to separate in a range between 170-200 rpm. These two ways were utilized as a means of creating graded porosity in ceramic. However, due to the speed constraint on a robotic arm, the former approach which experiments the buoyancy of hydrogels and varying angels of mold have been tested more thoroughly in this study.

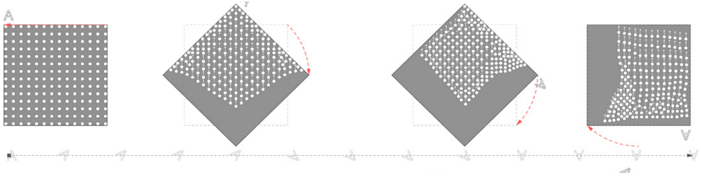


Figure 16. Graded Positioning of Hydrogel Depending on Mold Angles

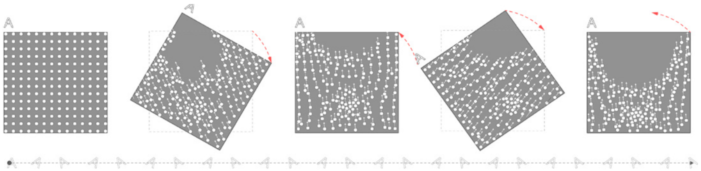


Figure 17. Seperating Hydrogel from Slip through High Rotational

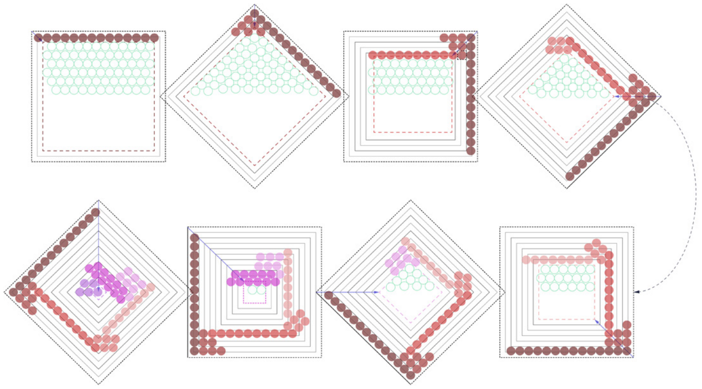


Figure 18. Internal Casts of Hydrogels Overtime