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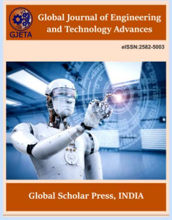


(Research Article)

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# Self-sealing concrete mixed with ultra-high absorbent polymer

Moayyad Al-Nasra [1, *] and Batoul Alshamali [2]

[1] *Department of Civil and Mechanical Engineering, School of Engineering, Shippensburg University of Pennsylvania, 1871 Old Main Drive, Shippensburg, Pennsylvania, USA.*

[2] *Civil and Infrastructure Engineering Department, School of Engineering, American University of Ras Al Khaimah, Ras Al Khaimah, UAE.*

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## Abstract

One of the most undesirable properties of concrete is that the concrete cracks due to many reasons including shrinkage and applied loads. Normal concrete has the tendency to seal these cracks on its own utilizing the un-hydrated cement particles and the deposited fine particles. This tendency has a very limited success to deal with live expanding cracks. This study helps the concrete to seal these cracks by using the Ultra-High Absorbent Polymer (UHAP). This polymer absorbs large quantity of water to form gel-like material. The moisture content of that polymer can reach up 99%. The volume of the polymer increases with the increase in the amount of water absorbed. The gel has the tendency to fill out any surrounding void in the concrete mass including the cracks when subjected to moisture. This phenomenon helps in preventing water leaks and water flow though the concrete mass. At the same time the gel releases water slowly with time in a process considered helpful for the internal curing of the new concrete. This study will explore the ability of the UHAP to stop the water flow through an artificially created crack in the concrete samples subjected to constant (constant head). Several cubes of 5 cm side length were prepared.

**Keywords:** Self-sealing; Concrete cracks; Water leaks; Super-absorbent polymer; Ultra-high absorbent polymer

## 1. Introduction

Different types of admixtures are added to the concrete mix to alter and change the properties of the final concrete product [1]. Most of these admixtures are used for the purpose of improving the concrete strength especially in tension. In this study the admixture used is for the purpose of preventing the water flow through the concrete mass and the concrete cracks. Ultra-High Absorbent Polymer (UHAP) is used in this study to explore the ability of this polymer to block the water flow in the concrete mass and the concrete cracks subjected to water pressure [2]. This UHAP polymer is very similar in composition to what is called Super-Absorbent Polymer (SAP) [3]. The absorption capacity of UHAP is higher than the SAP. This high absorption rate helps stop water flow though the concrete cracks in a much shorter period of time. Different amount of UHAP is used to investigate the sealing capability of this polymer. The amount of UHAP polymer used in the concrete is the main factor that helps seal the concrete cracks.

The effect of the use of UHAP on the concrete strength is also one of the main objectives of this study. Parametric study is conducted to investigate the effect of the UHAP on the concrete strength. The concrete mix design is kept the same for all samples. The only difference is the amount of UHAP used in the mix. This amount ranges from 0.00% to 0.60% of the weight of cement used in the mix. The batch of 0.00% of UHAP is used as a control sample and as a reference. The increase in the amount of the UHAP increases the potential of the concrete to seal the cracks sooner. At the same time

* Corresponding author: Moayyad Al-Nasra
Department of Civil and Mechanical Engineering, School of Engineering, Shippensburg University of Pennsylvania, 1871 Old Main Drive, Shippensburg, Pennsylvania, USA.

the increase in the amount of UHAP in the concrete increases the void space in the concrete mass which will, in turn, weakens the concrete strength. Figure 1 shows the UHAP in its dry condition in the concrete mass leaving a considerable void space [4]. The use of UHAP in the concrete, also, helps in storing water inside the concrete mass. This stored water will be released, which shows helping in the internal curing process. Providing source of moisture to help in internal curing increases the concrete strength. As a conclusion, there must be an optimum amount of UHAP to be used to help in internal curing, and in cracks sealing without jeopardizing the concrete overall strength.


**Figure 1** Polymer particles in its dry condition in the concrete mass

Self-sealing property of concrete is of important significance especially in structures which are in constant contact with water or liquid such as water tanks and nitrification basins. The UHAP absorbs water and expands in volume filling the surrounding voids in the concrete mass as well as the concrete cracks. This process prevents the water flow through the concrete structures [5]. The more water absorbed by the UHAP the larger the volume of the generated gel, allowing the gel to expand its sealing capacity in the surrounding voids including cracks. This mechanism causes moderate internal pressure in the concrete enough for the gel to fill the voids but not strong enough to cause any internal cracks.

The applied water pressure is a major factor to control water flow rate. The increase in the water pressure increases the water discharge. The UHAP ability to block the flow of water is tested in this study subjected to different values of water pressure. The sealing capacity of the UHAP decreases with the increase in water pressure.

UHAP absorbs water fairly quickly, transforming the polymer into gel of varying moisture content. Adding UHAP at the beginning of the mixing process allows the UHAP to absorb more water initially and expand in volume. This process limits the ability of the UHAP to absorb additional water and consequently it limits its efficiency to fill out the surrounding voids. Tests showed that better results can be achieved if the UHAP is added at the very end of the mixing process leaving the UHAP with least amount of water absorbed. In this case the volume of the gel generated by the UHAP is minimum. This helps in minimizing the adverse effect of the UHAP in the concrete strength, and in increasing the UHAP capacity to block the water flow. The gel constantly gaining and losing moisture. In this process the gel volume increases and decreases depending on the gel moisture content.

## 2. Research Significance

An improved concrete can be produced using this type of ultra-high-absorbent-polymer. This type of polymer if mixed with concrete can help with the internal curing process. This will result in increased concrete strength. This property is desirable especially in hot-weather climate where the concrete loses moisture very rapidly. Also, this type of polymer, if contained in capsules, can help in sealing concrete cracks and stopping leakage.

## 3. Ultra-High Absorbent Polymer

Polymer can be defined as something made of many parts forming a chain of connected units. The word polymer is an old Greek word meaning many parts. When UHAP, or SAP encounters water, it absorbs this water through a process known as osmoses process where the water passes from outside the polymer to the inside of the polymer causing it to swell. The absorption capacity of the polymer is limited to the polymer stretching capacity to hold water. SAP, and UHAP are also called hydrophilic (water loving) polymer that has the capacity to absorb water several hundred times its own weight. Some of the common high absorbent polymer used in the market includes sodium polyacrylate, polyacrylamide crystals, polyacrylamide plant spikes, and Gro-Creatures. Figure 2 shows a typical chemical composition of the highly absorbent polymer. Figure 3 shows the polymer in its dry form when subjected to water [6].

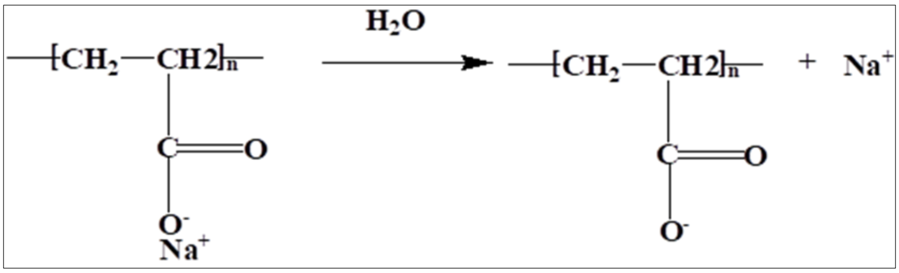

**Figure 2** Typical chemical composition of a high absorbent polymer

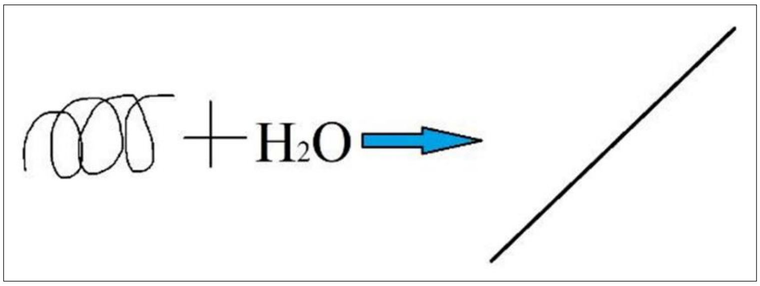


**Figure 3** Water absorbent polymer behavior when subject to water

## 4. Concrete Compressive Strength mixed with UHAP

Several 5 cm cubes were prepared to study the effect of adding UHAP to the concrete strength of concrete. The amount of UHAP varied from 0.0% to 0.6% by weight of cement in the concrete mix. The mix design used, requires 2:1 ratio of sand to cement with water cement ratio of 0.5. Figure 4 shows the results of testing 18 cubes, three of each UHAP percentage used in this study (0.0%, 0.10%, 0.20%, 0.30%, 0.40%, 0.50%, and 0.60%). The figure shows that there is an optimum amount of UHAP that can be used to maximize the strength of concrete. This optimum amount is unique for this concrete mix. Different optimum values can be reached depending on the type and amount of ingredients used. Gradation also plays significant role in determining the optimum value of UHAP.

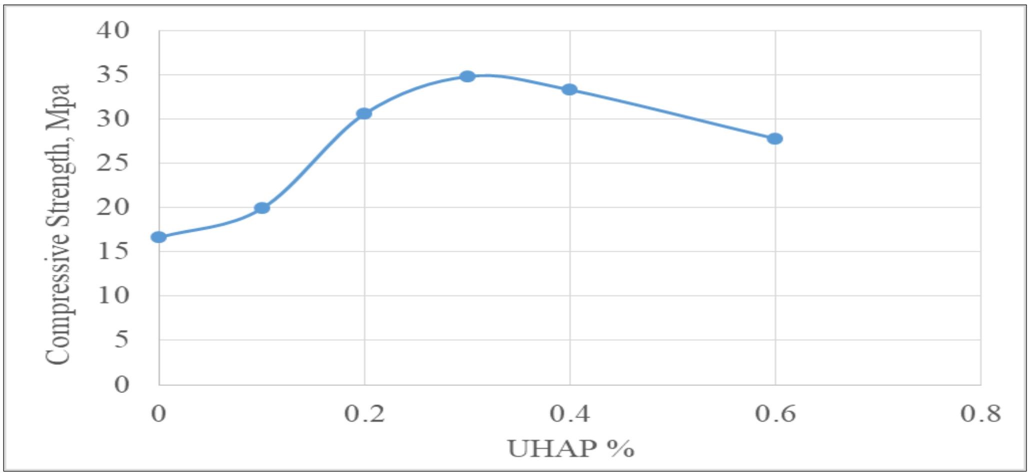


**Figure 4** Effect of the UHAP on the concrete compressive strength

## 5. Water Flow

To maximize the absorption capacity of the UHAP, several capsules were prepared. These capsules were filled with dry UHAP of variable quantity and sealed at both ends. These capsules keep the UAHP in its dry condition until subjected to rupture. In this case the UHAP will come in contact with water. Once the capsule if opened, the UHAP immediately forms gel, and starts filling up the cracks. Figure 5 shows the mechanism of triggering the UHAP action when the capsule is cracked opened and subjected to water. Figure 6 shows a theoretical model of the capsule action inside the concrete mass when subjected to moisture.

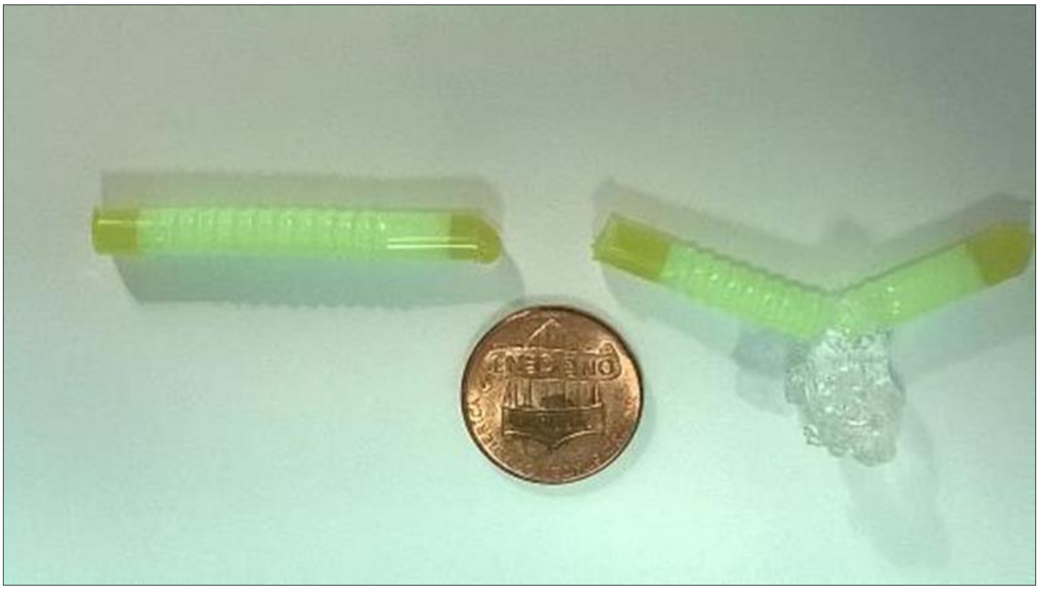

**Figure 5** Capsules filled with UHAP before and after subjected to water

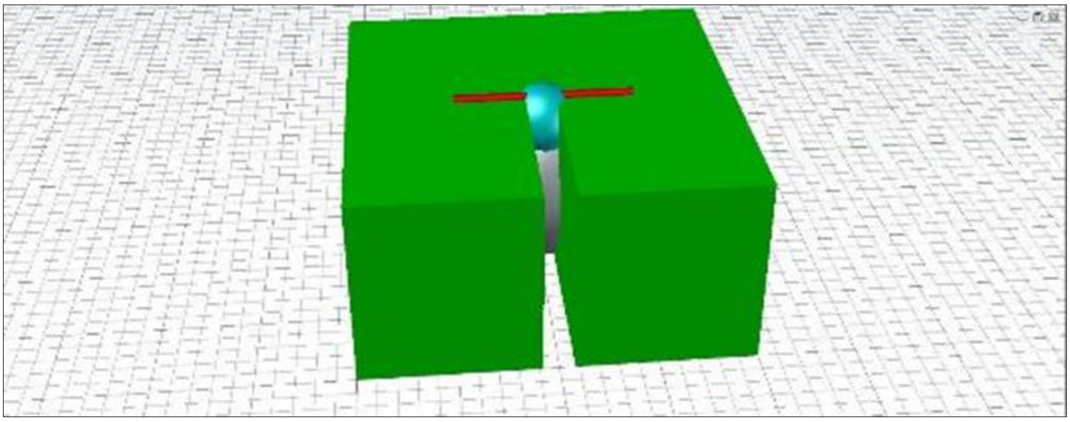

**Figure 6** Theoretical model of the UHAP capsules when subjected to moisture after cracked open

Several 5 cm cubes with embedded UHAP capsules where prepared. These cubes were subjected to artificial crack to simulate the action of the capsules inside the concrete subjected to natural cracks. Three different percentages of UHAP content used to study the water flow in concrete, 0.0%, 0.2%, and 0.5%. A control sample of 0.0% UHAP was used for comparison. The 5 cm cubes were cut in 2.5 cm thick halves. An artificial concrete crack was generated of 1 mm width and 2.5 cm length as shown in Figure 7. This sample was then placed in a cubical container and subjected to 90 cm water pressure. Figure 8 shows the experimental set up of the water flow test.


**Figure 7** water flow sample with artificial concrete crack

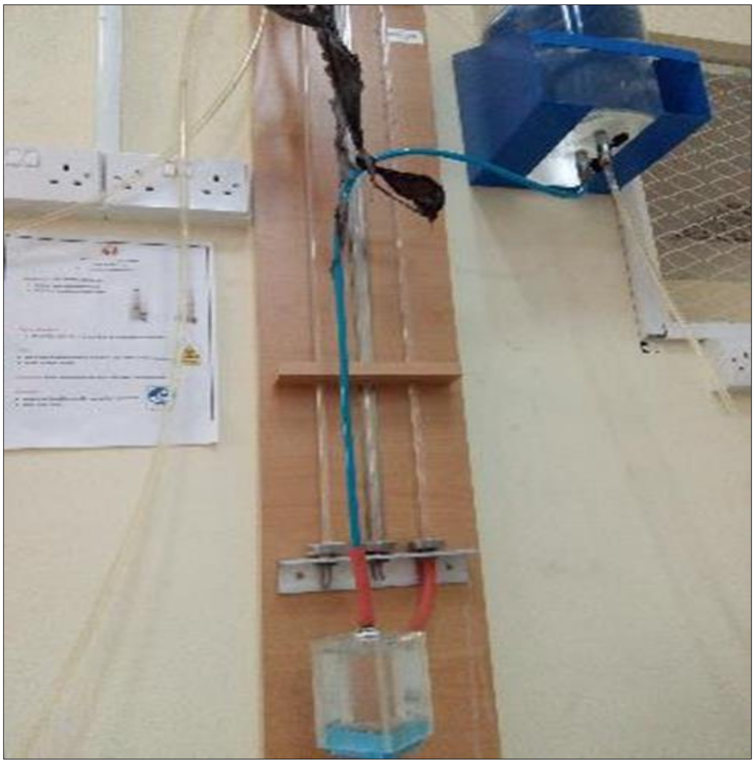

**Figure 8** Water flow test set up

Figure 9 shows the water flow test results over time for three UHAP contents. The very top curve is for the sample of 0.0% UHAP, where the flow rate is almost constant of about 1.06 liter per minute. The middle curve is for 0.2% UHAP. This curve shows rapid sealing of the artificial crack. The flow stopped completely by the end of the 15-minute period. The bottom curve represents the 0.5% UHAP sample. It can be seen from that figure that the water flow stopped completely by the end of 5-minute period in that sample of 0.5% UHAP. Figure 10 shows a crack filled UHAP gel. The gel sealed the crack and was able to stop the water flow when subjected to 90 cm water pressure. Figure 11 shows UHAP filled capsule after being subjected to simulated external forces resulting in a rupture in the capsule wall releasing gel to the surrounding and filling the concrete cracks.

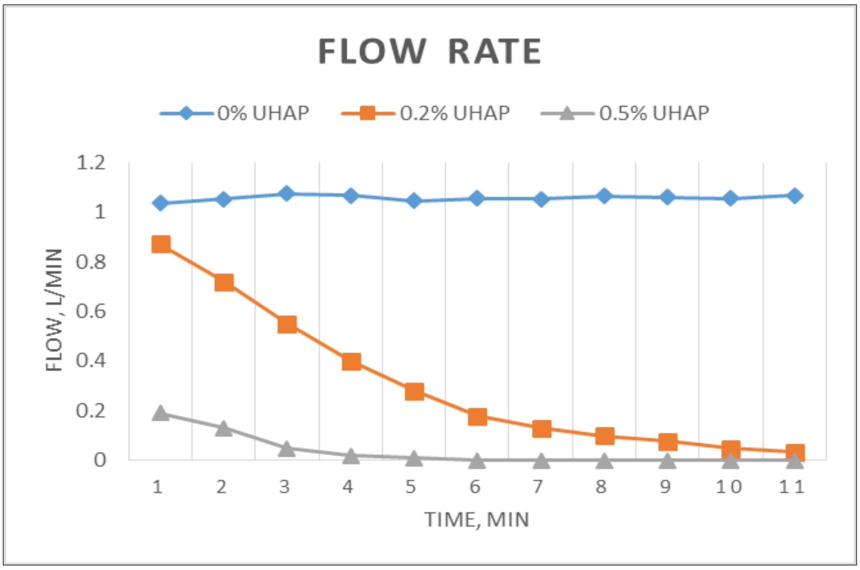


**Figure 9** Water flow test results versus time


**Figure 10** The UHAP gel filling the artificial crack, bottom view of the water flow sample

**Figure 11** A UHAP capsule cracked open inside the concrete mass, ejected sealing gel

For this particular case (where the water pressure was 90 cm, and the crack was 1 mm wide, 2.5 cm long and 2.5 cm deep) the stoppage time related to the UHAP content used in the concrete mix can be expressed as shown in equation 1.

$$Tst = 2.42\ e3.66\ \eta \text{……………………….. (1)}$$

Where;

$T_{st}$ = stoppage time in minutes
$\eta$ = UHAP content expressed in percentage used in the concrete mix.

### 5.1. Further Research

This study showed the potential for this type of polymer to be used in concrete for various purposes including internal curing, and hot weather concreting. More research may be needed to codify the use of hi absorbent polymer in the concrete mix design. Different water pressure can be explored to study the effect of the water pressure on the water flow.

## 6. Conclusion

The highly water absorbent polymers have great potential to be used in concrete to seal cracks and provide internal curing. The best mechanism and the best procedure to add this type of polymers are yet to be determined. In this study, adding UHAP contained inside capsules proven to be effective in filling out concrete cracks subjected to low water pressure values. There must be a balance between the amount of UHAP used in the concrete mix and the desired concrete strength.

## Compliance with ethical standards

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*Disclosure of conflict of interest*

The authors certify that they have no conflict of interest in the subject matter or materials discussed in this manuscript.

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