Investigating the effect of the ultra-high absorbent polymer on the sealing property of concrete

Moayyad Al-Nasra

Abstract: Researcher studied the effect of adding several admixtures to the concrete mix for the purpose of changing and controlling the properties of the final concrete product including the concrete strength, water tightness, concrete sealing capability, and concrete quality. In this study, ultra-high absorbent polymer (UHAP) is added to the concrete mix in order to study its effect on the sealing property of concrete. Other concrete properties will also be studied including the concrete strength and the water tightness. The UHAP has the capability to absorb up to 800 times its weight converting the polymer to a gel of water content that might reach 99%. The volume of the gel increases substantially. This property of the UHAP is utilized in this study. The superabsorbent polymer can absorb water up to 500 times its own weight. The increase in volume of the UHAP inside the concrete mass helps in sealing the concrete cracks and blocking the water flow through the concrete. Cylindrical core is drilled through the concrete cubes to study the sealing property of concrete mixed with UHAP. The cylindrical hole in the concrete cubes is filled with water subjected to high pressure reaching up to 400 kPa.

Subjects: Materials Science; Concrete & Cement; Structural Engineering

Keywords: concrete strength; concrete water-tightness; concrete sealing; superabsorbent polymer; concrete quality

ABOUT THE AUTHOR
Moayyad Al-Nasra, Dr. Moayyad Al-Nasra is currently professor of civil engineering at the American University of Ras Al Khaimah-AURAK. He taught at several Universities in the USA for about 27 years before joining AURAK. Published over 80 articles including books, journal papers and conference papers. His research interest includes structural mechanics, project management, engineering materials, and fracture mechanics

PUBLIC INTEREST STATEMENT
A new type of concrete can be produced using Ultra-High Absorbent Polymer as one of its ingredients. This special ingredient changes many important properties of concrete. The most desired property is water tightness and water sealing property. This helps in preventing water leaks through the concrete by blocking the water flow through the concrete solid mass. Also, this type of concrete can block the water flow through the cracked concrete. This type of concrete can be used in many structures where water tightness is highly desired such as water tanks, retaining walls, and basement walls. Also, this type of concrete can be used to reduce or prevent a wet basement. The polymer inside the concrete expands if exposed to moisture, leaving no room for the water to pass through the concrete mass.
1. Introduction

Researchers added almost all kinds of admixture in the concrete for the purpose of improving its properties. In this study, a special kind of high-absorbent polymer is added to the concrete to study, mainly, its sealing capability. The sealing capability of concrete is a very significant property related to special concrete structures, especially when dealing with water tanks, nitrification basins, and basement walls. In this study, the concrete is subjected to water pressure to simulate the real-life case. Adding a gel-like material to the concrete improves the fresh concrete plasticity. The high-absorbent polymer absorbs a large amount of water producing gel-like material. This gel-like material volume increases substantially. This increase in volume helps in blocking the water flow through the concrete mass. At the same time, this gel-like material of high-water content provides the concrete with the moisture it needs for the internal curing. Internal curing is especially critical for vertical structural concrete members, where regular curing methods are not quite effective. Several cubes are prepared to study the concrete strength of the concrete mixed with UHAP.

Adding the UHAP at the very beginning of the mix allows the UHAP to absorb a limited amount of water in the mix. The optimum amount of water left for the UHAP to absorb during the concrete mixing process is the excess water after the amount of water needed for the hydration process. This converts the UHAP into gels of relatively high-water content out of the excess water. This helps in providing great internal curing, but at the same time, the gel occupies a large volume in the concrete mass, which in turn, reduces the concrete strength if the volume of voids becomes excessive. Adding the UHAP at the very end of the mix, just before casting, allows the UHAP to absorb as little as possible of water in the mix. In this case, the internal curing is provided but with a limited amount of internal water. This small amount of internal water is proven to be sufficient for the hydration process as well as curing. The produced gel is not saturated, and it does not occupy a large volume in the concrete. This helps in increasing the concrete strength without providing unnecessary large void space. In this study, and after trying tons of batches of concrete, the UHAP is added at the very end of the mixing process, just before casting.

The concrete sealing capacity under high water pressure is studied using several batches of concrete. Each batch is mixed with the same ingredient but different amounts of UHAP, to study the effect of the UHAP on the concrete sealing capability. Adding UHAP to the concrete mix improves substantially the sealing capacity of the concrete subjected to high water pressure. At the same time adding a calculated amount of UHAP improves the concrete strength.

Several batches of concrete were prepared. All these batches were prepared with the same ingredient, but the amount of the UHAP added to the mix was the only variable. The batch that has no UHAP is used as the control sample and is given a designation of 0.00% UHAP. The amount of UHAP used in this study is expressed in terms of percentage. The percentage is calculated by the ratio of the weight of the UHAP to the weight of cement multiplied by 100%. The percentages used in this study range from 0% to 0.6%.

The normal weight concrete of everyday application is prepared by mixing aggregates, Type I Portland cement, and water at moderate room temperature. The water is normally added after mixing all the dry ingredients. Adding the water triggers the chemical reaction. Usually, the concrete is produced with more water than needed for the hydration process. The excess water decreases the concrete strength and increases the drying shrinkage. Adding the UHAP at the very end just before casting the concrete into molds or forms, helps in absorbing the excess water. The perfect balance is when the UHAP absorbs only the excess water forming a gel of high-water content. This gel releases this excess water slowing with time in a form of what is called here as internal curing. Absorbing too much of the water mixed in the concrete helps the internal curing but reduces the concrete strength, while absorbing a little amount of water reduces the amount of the water available for the internal curing.
Providing water gels inside the concrete improves the insulation properties of the concrete. Researchers studied adding a special type of superabsorbent polymer to concrete mix on the insulation capability of plain concrete (Al-Nasra, 2013). He concluded that the increase in the amount of superabsorbent polymer in the concrete increases the insulation property of the concrete. The increase in the amount of high-absorbent polymer on the concrete strength is also explored by many researchers (Jensen, 2013). The effect of adding a special type of high-absorbent polymer in concrete on the concrete shrinkage has been investigated by many researchers (Jensen & Hansen, 2001). It has been proven that adding a superabsorbent polymer to the concrete mix reduces the build-up of stresses. This type of stress is the one which is claimed to be responsible for generating concrete cracks in high strength concrete (Jensen & Hansen, 2002).

Optimum amount of superabsorbent polymer to be added to the concrete mix without jeopardizing the concrete strength has been explored using a special type of superabsorbent polymer (Al-Nasra, 2013). Several samples of different amounts of superabsorbent polymer were prepared and tested to figure out the optimum amount of the superabsorbent polymer to be used, which maximizes the concrete strength. Adding a large amount of superabsorbent polymer reduces the concrete strength by generating voids in the concrete. Adding a very small amount of superabsorbent polymer exhibits no change in the concrete properties.

Several studies are available that focus on the concrete crack sealing capability of concrete using a special type of high-absorbent polymer (Snoeck, Tittelboom, De Belie, Steuperaert, & Dubrueel, 2012). Concrete cracks expose the concrete to unfriendly agents that may help in accelerating the concrete deterioration. The high-absorbent polymer in the concrete mass swells and shrinks as the amount of the absorbed water changes. This helps in bringing in fine materials into the concrete cracks. This fine material along with the un-hydrated cement particles help in sealing the concrete cracks. The water of the hydration process is provided by the gels.

The constant shrinking and swelling of the concrete hardened mass mixed with superabsorbent polymer invite fine particles to accumulate in the concrete cracks. This drying and wetting process is controlled by the amount of moisture in the concrete. The fine material deposit has the potential to seal the concrete cracks with time by forming a solid mass of sediments. Temperature, moisture and time are the right recipes to transform these fine particles into a solid mass. This solid mass has the potential to seal the concrete cracks under certain conditions.

The texture of the fresh concrete mixed with high-absorbent polymer changes substantially (Al-Nasra & Daoud, 2013). The workability of the fresh concrete along with its consistency and its plasticity changes too (Al-Nasra, Daoud, & AbuLebdeh, 2015). The gel-like material provides cushioning to the large aggregate particles, which in turn, helps in improving the concrete stability of the fresh concrete (Al-Nasra & Daoud, 2017). The increase in the volume of the polymer helps in sealing the cracks inside the concrete mass (Al-Nasra, 2018). These changes to the fresh concrete are yet to be explored further.

Concrete slabs performance is expected to improve by increasing its strength and its water tightness. The three-dimensional geometrical changes to the slabs and flat plates are also proven to improve its performance (Al-Nasra, 2017b). Adding simple and minor central rise helps to increase the slab strength significantly (Al-Nasra, 2017b).

2. Experimental investigation
Adding a gel-like material to the concrete improves the fresh concrete plasticity. Several cubes are prepared to study the concrete strength of the concrete mixed with UHAP. The cubes are of 5.9 in. [15 cm] in side length. Cylindrical core is drilled through the concrete cubes to study the sealing property of concrete mixed with UHAP. The diameter of the core varies from 1.6 in. [4 cm] to 3.9 in [10 cm]. The cylindrical hole in the concrete cubes is filled with water subjected to high pressure reaching up to 58 psi [400 kPa]. The concrete sealing capacity under high water pressure is studied.
using several batches of concrete. Each batch is mixed with the same ingredient but different amounts of UHAP, in order to study the effect of the UHAP on the concrete sealing capability. The amount of UHAP varied from 0.00 to 0.60% of the weight of cement used in the mix design. The water flow quantity through the walls of the hollow cubes is measured with time. This water discharge is measured under high internal water pressure. The focus is to study the effect of the UHAP on the water flow through the concrete solid mass. Also, this study investigates the effect of the UHAP on the concrete compressive strength.

2.1. Materials
The Ultra-High Absorbent Polymer (UHAP) is like any other polymer (Many Parts), is composed of many polymers all having the ability to absorb a large quantity of liquid. These polymers have the elastic property to expand when they get in contact with water. This water will be absorbed and moved inside the chemical of the chains. The UHAP used in this study is sodium polyacrylate which is hydrophilic (water-loving) non-toxic polymer. This type of polymer is a three-dimensional cross-linked polymer that has the ability to absorb water several hundred times its own weight\(^{13}\). The UHAP can absorb water up to 800 times its own weight. The dry form of this polymer is composed of solid chains of polymers. These polymers are coiled in their dry condition and expand when they get in touch of water as shown in Figure 1. The polymer chains have the tendency to straighten out but are restrained due to the three-dimensional cross-linking forming the gel-like shape. The hydrogen bonding of the water H-O-H around the polymer chains causes the coiled chains to unfold and straighten (Snoeck et al., 2012). Also, adding water to the polymer chains breaks the chains into negative and positive ions as shown in Figure 2. Figure 3 shows the polymer chain network on a large scale.

Figure 4 shows the UHAP in its solid state before absorbing water, and the shape of the UHAP after absorbing water. The UHAP moves from solid state to a semi-liquid state in a form of gel depending on the amount of liquid absorbed.

Twenty-one cubes were prepared with seven different amounts of UHAP mixed in the concrete. Seven batches of concrete were prepared. Each batch is made of the same ingredients but different amounts of UHAP expressed in terms of percentage of the cement used in the mix.

Figure 1. Expansion of the polymer chains.

Figure 2. Chemical composition of the polymer when water is added.
Table 1. Concrete ingredients used

| Material                        | Weight (lb) | Weight (N) |
|---------------------------------|-------------|------------|
| Water                           | 17.6        | 78.4       |
| Portland Cement Type I (PC-I)   | 38.7        | 172.5      |
| Course Aggregates               | 108.2       | 482.2      |
| Fin Aggregates                  | 75.0        | 334.2      |

Table 2. Amount of UHAP used

| UHAP used as Percentage of PC-I by weight | Weight (lb) | Weight (N) |
|------------------------------------------|-------------|------------|
| 0.0%                                     | 0.0000      | 0.000      |
| 0.1%                                     | 0.0387      | 0.172      |
| 0.2%                                     | 0.0774      | 0.345      |
| 0.3%                                     | 0.1162      | 0.517      |
| 0.4%                                     | 0.1549      | 0.690      |
| 0.5%                                     | 0.1936      | 0.862      |
| 0.6%                                     | 0.2323      | 1.035      |

Table 1 shows the list of the concrete ingredients used in this study. Table 2 shows the amount of UHAP used in the concrete mix. Six groups of concrete cubes were prepared in addition to the control sample (samples with 0% UHAP). The concrete cubes used in this study are of 5.9 in. [15 cm] side length. The samples were tested a week after casting. The concrete ingredients were mixed according to the ASTM C192M. The ambient temperature ranged from 24° to 26°. The
humidity also ranged between 47% and 56% for all of the concrete batches. The workability of the fresh concrete was not the concern in this study, so it was not measured. Figure 5 shows the concrete ingredients used in this study.

2.2. Specimens
A cylindrical core is drilled in the 5.9 in. [15-cm] cubes of variable diameter ranging from 1.6 in. [4 cm] to 3.9 in. [10 cm], leaving the minimum wall thickness of values ranges from 2.2 in. [5.5 cm] to 1.0 [2.5 cm], respectively. The cavity inside the concrete cubes is subjected to high water pressure to study the water tightness property of the concrete. Figure 6 shows a typical cube used in the water tightness tests. The center of the cube is filled with pressurized water. The water tightness is measured by the amount of water leaked through the walls of the cube per unit time under a given water pressure. Figure 7 shows the machine used to supply the cubes with pressurized water at its center. The shown machine represents the experimental set-up of the test. Twenty-one cubes were tested using this machine. The tested cubes are of the same concrete ingredients but different amounts of UHAP expressed in terms of percentage of the cement weight. As shown in the figure the water is supplied at the bottom of the cube through a tube. The top of the cube is sealed by a plate of hard rubber, leaving the water of high pressure inside the cube. The upward arrows show the direction of the water pressure supplied by the compressor shown in the
Figure 6. 3.9 in [10 cm] in diameter core is drilled out of 5.9 in. [15-cm] cube.

bottom of Figure 7. The horizontal arrow shows the location of the rubber plate to seal the top of the hollow cubes. Figure 8 shows a typical cube subjected to internal water pressure. The diameter of the internal cylinder varies from 1.6 in. [4 cm] to 3.9 in. [10 cm]. The minimum wall thickness changes according to the diameter of the internal cylinder from 2.2 in. [5.5 cm] to 1.0 in. [2.5 cm].

2.3. Items of investigation

The unsaturated UHAP occupies space in the solid concrete mass. This space is limited in order to reduce the negatives effect on the concrete strength. This unsaturated UHAP, when subjected to water moisture, expands further filling any nearby space with a gel of variable viscosity. This process helps in sealing the voids in the solid concrete mass and improves the water tightness property of concrete. The increase in the amount of UHAP in the concrete improves the water tightness property of concrete by sealing more voids in the solid concrete mass. Figure 9 shows two UHAP particles inside the concrete. The picture on the left shows the UHAP before subjected to moisture, while the picture on the right shows the same UHAP after subjected to moisture. The UHAP, upon subjected to moisture, expands filling the cavity around it and any neighboring crack in the concrete. The dry UHAP occupy smaller space than available. This space is created initially by the UHAP gel, while the concrete was fresh and plastic. After the concrete hardens, the space is reserved and kept in the same shape of the UHAP gel. When the UHAP is subjected to water
moisture again it will expand occupying the cavity and any other extra space available as shown in the right side of the figure. The polymer inside the concrete mass expands if exposed to moisture, leaving no room for the water to pass through the concrete mass. The UHAP performed as planned for, occupying the available surrounding space when subjected to moisture.

3. Analytical investigation

The water discharge through the solid concrete mass is measured as shown in Figure 10. The Figure shows the rate of water flow through the concrete solid mass as a function of the concrete wall thickness without UHAP. The internal water pressure of 50 psi [345 kPa] is kept constant during the entire experiment. This water flow depends on the concrete mix design and the concrete compaction. For a given concrete mix design and standardized procedure for the concrete sampling, the water flow is measured to show the effect of the wall thickness on the water discharge subjected to high water pressure. Equation 1 relates the water discharge to the wall thickness under the water pressure of 50 psi [345 kPa]. The residual sum of squares is calculated to be 0.9987.

$$Q = 12.25w^2 - 149.7w + 466.74 \text{ (ml/hr)}$$

Where; $Q$ is the water discharge in ml/hr, and $w$ is the wall thickness in cm.
Adding UHAP to the concrete mix reduces the water flow through the concrete solid mass by the effect of expanding gel-like material. This gel produced by the UHAP expands due to absorbing water with time. The longer the gel is exposed to water the more water it absorbs. The water content of the gel may reach up to 99%. This increase in the amount of water with time increases the volume of the gel filling the surrounding void space. This results in reducing the water flow rate through the concrete wall with time. The adopted optimum value of UHAP is 0.30% of the weight of cement. This optimum value shows a steady reduction in the flow rate with time. This changes in the flow rate with time is shown in the following equation:

\[
Q = -0.26 \ t^3 + 3.8 \ t^2 - 18.4 \ t + 29.96 \ (\text{ml/hr})
\]  

Where; \( t \) is the time in hours.
The 0.30% of UHAP was able to stop the flow through the 1.4 in. [3.5 cm] wall thickness subjected to 50 psi [345 kPa] water pressure in about 5 hours. The rate of flow decreases at an accelerated rate from $7.9 \times 10^{-3}$ gal/hr [30 ml/hr] to $7.9 \times 10^{-5}$ gal/hr [0.3 ml/hr] in the fourth hour.

4. Experimental results and discussion

4.1. Compressive strength

Figure 11 shows the experimental set-up for concrete compressive strength. The procedure used for testing the samples is the standard ASTM C39M testing procedure. The sample is subjected to static load till failure. The maximum load capacity is recorded at the end of each test.

Figure 12 shows the loading response of the tested cubes. The increase in the percentage of the UHAP in the concrete mix increases the strength of the concrete to some certain extent, due to mainly two reasons; the internal curing, and the limited space allocated to the UHAP gel minimizing the negative effect of the void space on the concrete strength. The increase in concrete strength reduces slightly ductility. All specimens were tested 7 days after casting. All samples were air cured, in order to study the effect of the internal curing provided by UHAP on concrete strength.

Figure 13 shows the effect of the UHAP on the concrete strength. The amount of the UHAP is limited to up to 0.6% in order to avoid the negative effect of the extra void space in the solid concrete mass. As can be seen from the figure that, the increase in the amount of the UHAP increases the concrete compressive strength. This increase reaches an optimum value around the 0.30% of UHAP. Substantial increase in the amount of UHAP beyond the 0.3% will not contribute significantly to the increase in the concrete compressive strength. The extra amount of UHAP in the concrete mass provides unnecessary void space. This extra void space has the potential of reducing the concrete strength.

Figure 11. Compressive test set-up.
4.2. Water tightness

The wall thickness plays a significant role to limit the water flow of water through the solid concrete mass. Several cubes were prepared with different core sizes. The diameter of the internal cylindrical cavity varies from 1.6 in. [4 cm] to 3.9 in. [10 cm], making the minimum wall thickness varies from 2.2 in. [5.5 cm] to 1.0 in. [2.5 cm], respectively. The water flow through the solid concrete mass varies depending on the concrete mix design as well as the level of compaction. In this experiment, these two variables are kept the same as much as possible.

Figure 14 shows the effect of the UHAP on the water flow rate through the concrete solid mass subjected to the high pressure of a value of 50 psi [345 kPa]. The minimum wall thickness is kept constant of 1.4 in. [3.5 cm], making the diameter of the internal cavity of 3.15 in. [8 cm]. Several cubes were prepared of different amounts of UHAP polymer. This amount is expressed in terms of a percentage of the weight of cement. This percentage varies from 0.0 to 0.6%. As can be seen from the figure, the increase in the amount of UHAP reduces the water flow substantially. The 0.6% concrete sample is capable of blocking the water flow of water under 50 psi [345 kPa] pressure completely within the first 20 minutes, while the 0.4% sample was able to block the water flow subjected to the same water pressure in about 2 hours. The 0.20% sample was able to block the water flow in about 5.5 hours. The sample of 0.10 of UHAP was not able to block the water flow completely, but it reduced the flow rate substantially in the first 24 hours and kept the flow rate at an almost constant value at about $8.7 \times 10^{-3}$ gal/hr [33 ml/hr] afterward. The 0.00% sample exhibited almost constant water flow of about $2.4 \times 10^{-2}$ gal/hr [91 ml/hr] with a slight increase with time.
5. Further research
It is desirable to test specimens of standard crack size subjected to high water pressure in order to measure the effect of the UHAP on the sealing capability of cracked concrete. The effect of the water pressure on the sealing capability of the concrete mixed with UHAP is also of special interest. The results of such studies will benefit the concrete construction industry.

6. Conclusions
Adding UHAP to the concrete mix improves the concrete strength if used at a very low percentage of less than 0.40% of the weight of cement used in the mix. This increase in strength is possible if the UHAP is added at the end of the mixing process in order to control the amount of the absorbed water. This improvement in strength becomes substantial in the absence of the traditional curing process. This increase in strength is believed to be due to the internal curing process, where the UHAP absorbs water in a large amount and converts it into a gel. This gel releases the water slowly with time. Also, the UHAP improves the water tightness property of concrete. The increase in the UHAP reduces the water flow through the concrete solid mass. The optimum percentage of UHAP to be used in the concrete mix without any other admixtures is believed to be around 0.30% if the concrete is subjected to high water pressure of a value not to exceed 72.5 psi [0.5 MPa]. This percentage increases the concrete compressive strength substantially and improves the concrete water tightness property.

Declaration of Interests
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Author details
Moayyad Al-Nasra
E-mail: malnasra@gmail.com
1 Department of Civil and Infrastructure Engineering, American University of Ras Al Khaimah, Breirat, 10021, UAE.

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References
Al-Nasra, M. (2013). Concrete made for energy conservation mixed with sodium polyacrylates. International Journal of Engineering Research and Application, 3(5), 601-604. https://pdfs.semanticscholar.org/d9af/94d1c985d8b22b509072745c962fed7d43b.pdf
Al-Nasra, M. (2017a). Finite element investigation of dome-like structures. ARPN Journal of Engineering and Applied Sciences, 12(11), 3445–3450. https://aurak.ac.ae/publications/Finite-Element-Investigation-of-Dome-Like-Structures.pdf
Al-Nasra, M. (2017b). Effect of the central rise on the behavior of dome-like structures. Journal of Engineering and Applied Sciences, 12(20), 5317-5322. http://medwelljournals.com/abstract/?doi=jeasci.2017.5317.5322
Al-Nasra, M. (2018). Study of the self-sealing capability of polymer concrete. ARPN Journal of Engineering and Applied Sciences, 13(4), 1297–1303. http://www.arpnjournals.com/jeas/volume_04_2018.htm
Al-Nasra, M., & Daoud, M. (2013). Investigating the use of super absorbent polymer in plain concrete. International Journal of Emerging Technology and Advanced Engineering, 3(8), 598–603. https://pdfs.semanticscholar.org/9192/a5c6d71e3526fb4908beee86797c7cd99.pdf
Al-Nasra, M., & Daoud, M. (2017). Study of the ability of cracked concrete to block water flow, concrete mixed with super absorbent polymer. ARPN
Al-Nasra, M., Daoud, M., & AbuLebdeh, T. (2015). The use of the super absorbent polymer as water blocker in concrete structures. American Journal of Engineering and Applied Sciences, 8(4), 659–665. doi:10.3844/ajeassp.2015.659.665

Jensen, O. (2013). Use of superabsorbent polymers in concrete. Concrete International, 35, 48–52. http://procureusa.com/distributors/wp-content/uploads/2014/04/SAPs-In-Concrete.pdf

Jensen, O., & Hansen, P. (2001). Autogenous deformation and RH-change in prospective. Cement and Concrete Research, 31(12), 1859–1865. doi:10.1016/S0008-8846(01)00501-4

Jensen, O., & Hansen, P. (2002). Water-Entrained cement-based materials: Experimental observations. Cement and Concrete Research, 32(6), 973–978. doi:10.1016/S0008-8846(02)00737-8

Snoeck, D., Tittelboom, K., De Belie, N., Steuperaert, S., & Dubrel, P. (2012). The use of superabsorbent polymers as a crack sealing and crack healing mechanism in cementitious materials, Proc. CRC 3rd International conference on Concrete Repair, Rehabilitation and Retrofitting (CCRRRR 12),CRC Press, pp. 152–157. https://www.researchgate.net/profile/Didier_Snoeck2/publication/240871949_The_use_of_superabsorbent_polymers_as_a_crack_sealing_and_crack_healing_mechanism_in_cementitious_materials/links/0c96052bd7a300852d000000/The-use-of-superabsorbent-polymers-as-a-crack-sealing-and-crack-healing-mechanism-in-cementitious-materials.pdf

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