Evaluation of the Effect of Gel Materials on the Concrete Life

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Abstract. The life of concrete is the main factor affecting the safe service life of a building. The reason is that concrete, as the main structure of a building, plays an important role in structural support and resisting the erosion of natural environment. However, there is growing interest in the lifespan of concrete. At present, the life of some concrete may not be able to meet the requirements of some specific environments such as high temperature, cold areas and deep sea. Based on the existing experimental data and research, the action mechanism of gel material and its influence on concrete are analyzed in this paper. In addition, this paper also summarizes the shortcomings of different types of gel materials, so that designers and construction departments can have a better understanding of gel materials. These findings may contribute to a deeper understanding of gel materials and their potential to improve the life of concrete.

Keywords: Gel material; concrete life; mechanisms of action; experimental methodology.

1. Introduction

At present, concrete has a significant position in building materials because of its low price and abundant raw materials. According to the "Concrete Structure Durability Design Code" (GB/T 50746-2019), the service life of concrete is mainly affected by durability. The durability of concrete is mainly affected by environmental type, structural form, material and protective coating [1]. According to the International Standards Organization (ISO 16204: 2012), the life of concrete is defined as the number of years in which a concrete member or structure can be designed for safe use. It can be seen that the life of concrete plays an important role in ensuring the safe use of a building during its design life. With the increasing awareness of building safety today, in order to meet the safety requirements of buildings, researchers have conducted continuous research on the life of concrete. In recent years, emerging gel materials have attracted much attention, and their gel has the advantage of self-healing concrete cracks [2]. Some gels can improve the toughness and ductility of concrete and reduce the thermal conductivity of concrete. In addition, some gels have waterproof properties and resistance to osmotic pressure [3-4]. The main purpose of this paper is to explore the different effects of different types of gel materials on the performance of concrete, so as to improve the service life of concrete.

2. Analysis of Different Gel Materials

In recent years, with the development and progress of science and technology, gel materials have attracted the attention of experts in various scientific fields. The gel has two main characteristics, solid and liquid, and its own small molecule diffusion coefficient and soft solid mechanical properties are in a high state. In general, the definition of the gel material is more complicated than that of the gel material because its own structure shows porous and has many cavity structures with different shapes. The reason for this is that the gel material is generally determined by its properties, which depend on the composition of the polymer with which the gel material is made. When most of its cavity is occupied by water, such gels are said to be hydrogels. When most of it is occupied by gas, it is called an aerogel [5]. This paper is mainly based on the problems that concrete will face in building construction, and then classify the gel material in order to achieve the purpose of solving the corresponding problems. More detailed descriptions and classifications is shown in Table I.

2.1. Self-healing Gel Mechanism of Action and Experimental Methods

2.1.1. Mechanisms of action

By adding a hydrogel containing bacterial spores and biological reagents to the concrete. None of the bacterial spores that have been identified so far would be able to survive in concrete. And encapsulation through hydrogel. Which, because of its own porous structure, can provide a living environment for bacterial spores. And the pore size of the gel is very small to avoid the entry of harmful components, so that the protection of bacterial spores is greatly improved. This allows the bacterial spores to survive in the concrete for an extended period of time. During this time the bacterial spores continue to induce calcium carbonate to precipitate, achieving the effect of repairing cracks of less than 1mm [6]. Thus, concrete cracking can be effectively avoided.

2.1.2. Experimental principles and results

Elaboration based on T Zheng, C Qian et al. In the first step, concrete mortar with crack lengths of 0.2mm-0.3mm was repaired for 28 days in an open box (oxygen supplied through a pipe) containing 30°C water. In the second step, the cracks were photographed using the stereomicroscope at the same altitude (Fig. 1). In the third step, the image-j software was used to simulate the initial picture before and after the healing of the numerical pictures with gray value analysis. In the fourth step, the range of grayscale values of the cracks was set to 115 to facilitate the separation of the ranges, and the cracks on the surface of the samples with different healing times were calculated using (1) [7]. The survival of bacterial spores in solution with and without protection was also compared and plotted (Fig. 2).

Table I. Types of gel materials and their characteristics.

Typology	Main component	Mechanisms of action	functionality	Drawbacks
Self-healing Gel	Hydrogel, bacterial spores, biological reagents	Through a series of hydration reactions or reactions of polymerized substances within the cement matrix	Repairing cracks	(1) Works only on very narrow cracks (2) Requires a continuous supply of water (3) Limitations on the age of the concrete
Thermal Insulation Gel	Sio2 aerogel	Aerogel constrains the movement of gases through its own pores with small pore sizes, making them less likely to collide with each other.	Reduces thermal conductivity and improves thermal insulation.	Decrease in mechanical properties of concrete.
Corrosion-resistant Gel	NMK nano-metakaolin and NSF nano-silica fume	Formation of hydrated CSH gels fills the concrete pores, reduces porosity and slows down chloride corrosion of steel reinforcement.	Improve the corrosion resistance of reinforcing steel to avoid failure of concrete structure and enhance the strength of concrete.	The application is limited by the necessity to use the appropriate corrosion-resistant gels for the respective conditions.
Fiber Gel	Made of steel, glass, plastic and other natural materials	By adding fine fibers, which are evenly distributed in the concrete, the toughness and tensile resistance of the concrete are improved.	Enhances concrete strength and controls cracking. Increase flexural and compressive properties.	(1) Difficult to control the content (2) It is difficult to control the dispersion of fibers in concrete.
Sealing Gel	organosilicon	Change the porosity of concrete by applying organosilicon to change the internal structure of hydration products in concrete.	Forms an umbrella-like protective network, thus achieving waterproof and water-repellent effect.	(1) Limited time of use (2) Requires regular maintenance

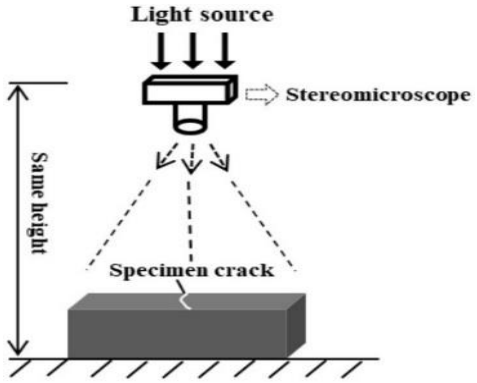


Figure 1. Schematic diagram of the device [7].

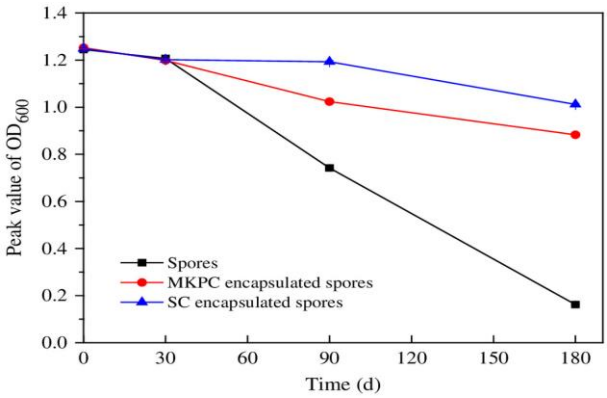
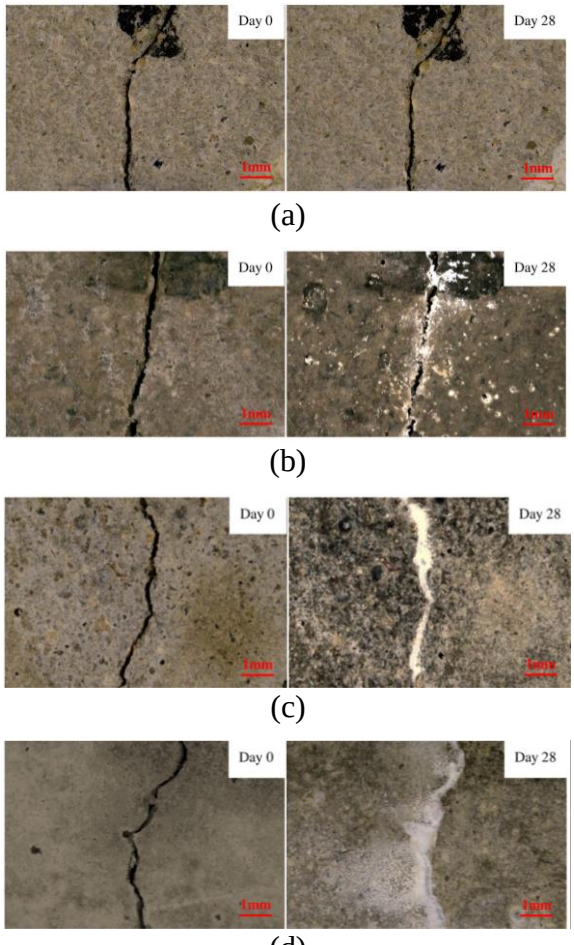


Figure 2. Schematic diagram of bacterial survival vs. number of days [7].



(a) (b) (c) (d)

Figure 3. Concrete cracks healing effect diagram [7].

$$Area\ repair\ rate = \frac{A_0 - A_t}{A_0} \times 100\% \quad (1)$$

Where A_0 is the number of crack area pixel dots before healing, and A_t is the number of crack area pixel dots at time t.

The experimental results showed that the protected bacterial spores survived longer than the unprotected ones. And according to the literature it is known that sulphoaluminate cement (sc) is a gel material. This shows that the bacterial spores encapsulated by the gel survive longer and are more effective in repairing concrete cracks. The final result was calculated that the repair rate of the crack area of the bacterial spores protected by the gel was 78% higher than the repair rate of the unprotected bacterial spores. The experimental results are shown in Fig. 3. Here is some note for Fig. 3: No bacteria were added in (a); 1 g of unprotected bacteria were added in (b); 10g of bacteria were protected by the addition of potassium magnesium phosphate (MKPC) in (c); and 10g of bacteria were protected by the addition of sulphoaluminate cement (SC) in (d).

2.2. Thermal Insulation Gel

2.2.1. Mechanism of action

Insulation gel achieves insulation in three main ways. The first is the low thermal conductivity of the aerogel itself, which effectively absorbs heat and reduces heat transfer. The second is that the aperture of aerogel itself is smaller than the diameter of the gas molecules in the air, which hinders the collision of molecules with each other, and the collision of molecules in general will produce heat. Therefore, this effectively reduces the heat generated by the external environment. Third, the gel material is a three-dimensional nanoporous structure, which can effectively reduce the heat generated by thermal radiation [8]. Avoid shortening the service life of concrete due to thermal expansion in hot weather.

2.2.2. Experimental principles and results

Its thermal conductivity was measured by hot-wire thermal conductivity instrument. Formation of aerogels incorporated into cementitious composites (AICs) by immersing cement in a solution containing aerogels and then determining the thermal conductivity for different number of days. And compared when the thermal conductivity of AICs changes with the amount of water absorption. The experimental results are shown in Fig. 4 [9].

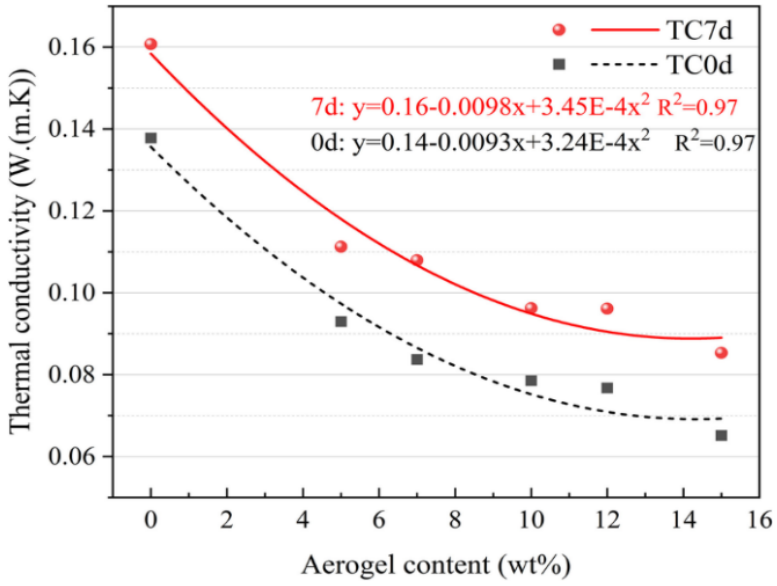


Figure 4. Schematic diagram of the relationship between thermal conductivity and gel content [9].

The results show that as the gel content in concrete increases, its thermal conductivity decreases continuously, which effectively protects the concrete, but the water content decreases its thermal conductivity. This is worth noting in real life.

2.3. Corrosion-resistant Gel

2.3.1. Mechanism of action

Because concrete is usually encased in steel reinforcement, and corrosion of the reinforcement can lead to a significant reduction in the mechanical properties of concrete [10]. If nanosized metakaolin (NSF) and nanosilica fume (NMK) are added to the concrete can react to produce hydrated CSH gels that cover and fill the surface of the concrete. It also enhances the sealing of concrete, anti-permeability, and effectively reduces the intrusion of chlorides [11]. It makes the reinforcing steel not easy to be corroded, which effectively avoids the shortening of concrete life due to corrosion of reinforcing steel.

2.3.2. Experimental methods and results

This experiment was based on the methodology of T Kiran et al. Because rebar corrosion itself is an electrochemical reaction and is primarily due to the effects of chlorides, experiments were conducted based on this principle. In the first step, both sides of the concrete containing the reinforcement were exposed to NAOH and NACL solutions. In the second step, wires were connected to form a complete circuit, and a data logger was connected and provided with power. In the third step, the concrete porosity was observed using an electron microscope. Final test for chloride permeability according to ASTMC1202 standard [11].

According to the experimental results, NSF and NMK can reduce the corrosion potential by reducing the pore size. Moreover, NMK/NSF improves the microstructure of the pores resulting in a significant decrease in chloride ion permeability.

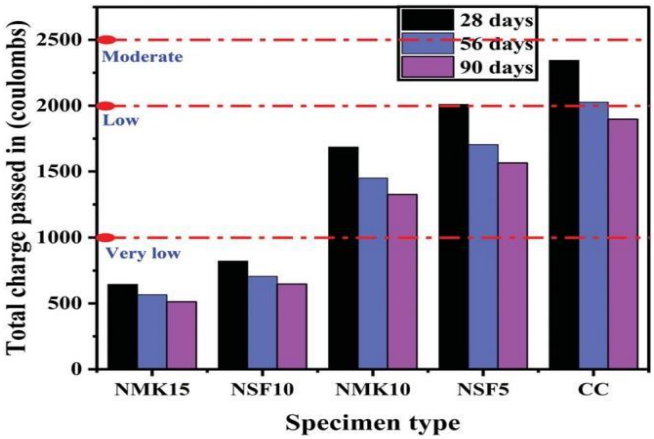


Figure 5. Chloride penetration value of concrete specimens (Note: CC is control concrete; NMK10% is concrete with 10% NMK. other meanings are the same.) [11].

2.4. Fiber Gel

2.4.1. Mechanism of action

The fibers themselves are resistant to stretching. Through its uniform and close distribution in the concrete, and thus improve the strength and toughness of concrete, can effectively control the cracking of concrete [12]. And long fibers perform better [13]. Thus, by this method the toughness of the concrete is increased and the collapse due to excessive live loads is effectively mitigated.

2.4.2. Experimental methods and results

Here polypropylene fibers are used as the object of study. Add fibers with contents of 0.25%, 0.5%, 0.75%, and 1% respectively into the concrete and conduct compression and tensile experiments. Compare with the steel bars without fibers added. The experimental results is investigated by using the relevant compressive testing machine and splitting tensile strength equipment [14].

After multiple experiments, the results show that when the fiber content in the concrete is 5%, both compressive and tensile properties show superior results. The experimental group found that when the fiber content exceeds 5%, the compressive and tensile properties decrease as the content increases.

2.5. Sealing Gel

2.5.1. Mechanism of action

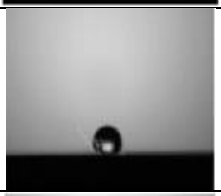
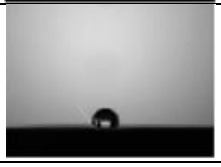
The porosity of concrete is reduced by applying silicone gel, while silicone molecules are combined with silica hydroxyl groups in concrete, concrete hydration products CA $(OH)^{+2}$. KOH, NaOH. The OH (concrete is alkaline) that KOH, NaOH provide undergoes a dehydration condensation reaction to form stable Si-O bonds. And it makes the hydrophobic R group in the silicone cover the concrete surface and concrete pores, playing the role of a protective umbrella. Hydrophobic and water-repellent effect on concrete surface [15]. Failure of concrete mechanical properties due to water intrusion is avoided.

2.5.2. Experimental methods and results

In the first step, the cured concrete was dried at 60°C for 5h in a thermostat. Afterwards, it was dried at room temperature for 12 h. In the second step, silicone was applied (SILRES® BS CREME C paste product, composed of 2, 4, 4-trimethylpentyltriethoxysilane.). When painting, it should be noted that it should be evenly painted 5-7 times in the same direction. Maintain at room temperature for 7 days. The third step is to utilize the JC2000DF contact angle testing instrument to test the concrete surface after dropping the same size water droplets to change the water droplets are shown in Table II. In the fourth step, the experimental material was left in a thermostat at 60°C for 24h, split and sprayed with water on the side to test the penetration length of the silicone coating using the water repellent indication method. As shown in Fig. 6, the fifth step was to analyze the interaction of the organosilicon with the concrete using a Thermo Nicolet 380 Fourier Transform External Spectrometer. Mineral composition of specimens before and after silicone coating was analyzed by a Japanese X-ray diffractometer Ultima IV. The surface of the specimen was observed with a VHX-600K super depth-of-field electron microscope, and the roughness was calculated. Observation of specimen micro-morphology by JSM-7800F scanning electron microscope Fig. 7 [15].

The experimental results show that the contact angle of the concrete surface decreases, and all of them are greater than 90°. The range is 124.50°-130.73°. Exhibits hydrophobicity and hydrophobicity. In the case of multiple coats, the contact angle did not change significantly with increasing amount of coats.

Table II. Results of water droplet contact angle affected by different content of gel material [15].

Painting method	Contact angle diagram	Contact angle (°)
unpainted		72.05
Apply 200g/m2 silicone solution once		130.73
Apply 250g/m2 silicone solution once		125.36
Apply 300g/m2 silicone solution once		124.50

Apply 100g/m2 silicone solution twice		120.26
Apply 125g/m2 silicone solution twice		120.50
Apply 150g/m2 silicone solution twice		122.58

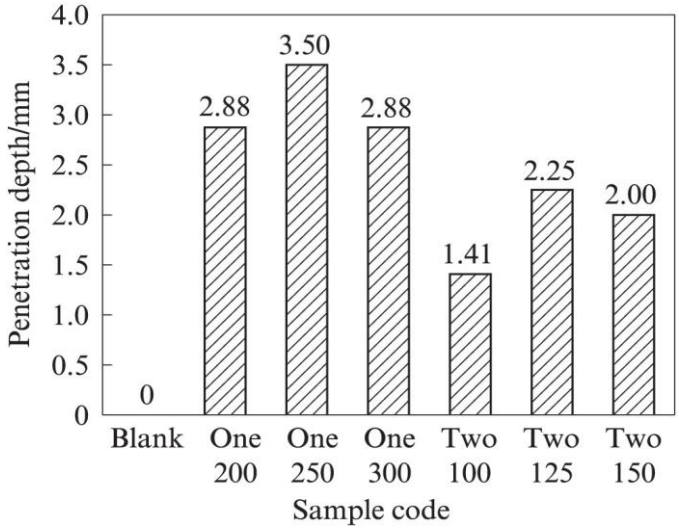
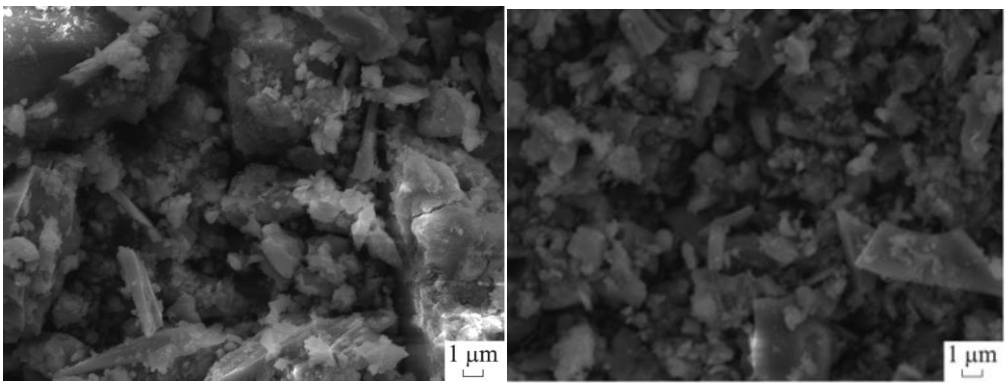


Figure 6. Schematic diagram of the influence of each organosilicon solution on the depth of penetration of the solution [15].



(a) Blank (b) One250

Figure 7. Schematic comparison of internal microstructure of concrete after penetration of organosilicon solution [15].

The reason for this is that the first application of silicone reacts sufficiently with the concrete to prevent subsequent silicone penetration. Secondly, in the case of a painting, the amount of painting in 250g/m2 and above to meet the requirements of the "Technical Specification for Anti-corrosion of Concrete Structures in Highway Engineering". Finally, it was shown that the infiltration of silicone altered the R-base length of the hydrophobic base of concrete, resulting in enhanced waterproofing properties.

2.6. Disadvantages

Currently, although gel materials have greatly improved the mechanical properties and impermeability of concrete during its application, there are still many limitations. Firstly, the high cost of gel materials makes it difficult to be widely used in real life. Secondly, the lifespan of gel materials is generally short, and some gel materials may produce harmful gases after damage, leading to environmental pollution. Thirdly, the preparation of gel requires specific conditions and strict dosage. Fourthly, although the use of some gels may improve one aspect of performance, it may also reduce another aspect, so careful research is needed during the use process. Fifthly, some gels require regular maintenance to maintain their effectiveness, increasing maintenance costs.

3. Conclusions

In the current context of the construction industry, the development of gel materials should have economy, versatility, durability and a wide range of convenient functions for application in the engineering industry.

First, it is necessary to focus on improving the economics of gel material preparation. Compared to traditional gel materials, the high manufacturing cost limits the range of applications. New gels should reduce costs by researching more energy-efficient and environmentally friendly manufacturing processes, improving the variety of raw materials and optimizing preparation methods.

Secondly, the gel material should be versatile. With the development of science and technology, the structure and properties of gel materials can be customized to make them versatile. For example, gel materials can be studied and developed to achieve higher mechanical properties while being able to adjust environmental conditions (e.g. temperature and pH of gel materials). In order to achieve a better protection effect on concrete.

Finally, the gel material must have a long service life. This means that the gel material must have good stability and durability in use. To improve the stability of the gel material, it is possible to start with the preparation process, additive selection, and material optimization. At the same time, by combining long-term use conditions and experimental data, the influence of gel materials on the service life of concrete can be better understood. In this way, more durable and reliable gel materials can be developed to extend the service life of concrete, reduce maintenance costs, and improve the life and safety of buildings.

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