Scholar Publishing Group
International Journal of Engineering Technology and Construction
https://doi.org/10.38007/IJETC.2021.020404
ISSN 2789-7176 Vol. 2, Issue 4: 32-49

Formation Mechanism and Performance of Polymer Cement Concrete Composite Structure

Antoun Feenistra*

Vrije University Amsterdam, Netherlands

**corresponding author*

Keywords: Polymer, Cement Concrete, Mechanical Properties, Aggregate-cement Ratio, Formation Mechanism

Abstract: Ordinary cement concrete has the shortcomings of a brittle material with large elastic modulus, low compressive and flexural strength, too high rigidity, insufficient flexibility, small deformation ability, and low durability. In large-scale bridge projects such as the bridge deck paving project of the steel laminated beam composite structure, diseases such as cracks and plate damage are prone to occur. At the same time, the environment is constantly changing, and the harsh environment may cause serious damage and destruction to the concrete. Especially in the environment of medium and high humidity, high temperature, high salt pollution, and high acid mist condensation, there are many problems of peeling of concrete protective layer and corrosion of steel. Therefore, people have been looking for ways to improve cement concrete, and later discovered that adding polymers to concrete can improve the most basic properties of concrete, reduce concrete rigidity, increase flexibility, and reduce the ratio of compressive strength to flexural strength. The concrete made by adding polymer is called polymer cement concrete composite. In this paper, through the experiment of incorporating polymers and some other substances, it is concluded that when the ratio of polymer to ash is 15%, the amount of defoamer is 7%. When the fiber content is 0.2%, the performance of the composite material is the best.

1. Introduction

1.1. Background

Polymer mixed with concrete began to appear as early as 1930, but it is always limited to a small range. It was not until May 1975 that the first Global Polymer Concrete Conference was held in London, England. At this conference, representatives from 22 countries participated, and the title of "polymer concrete" began to be adopted. With the national "One Belt One Road" marine strategy and the rapid development of China's coastal economy, some engineering structures such as bridge piers, tunnels, ports and water towers have been continuously constructed. Cement has gradually become the main building material of this construction, and its consumption is also increasing. , And gradually formed the widest range and the highest amount of building materials. With the country's "One Belt, One Road" marine strategy and the rapid development of coastal economy, some industrial structures such as bridge piers, tunnels, ports and water towers have been continuously constructed. But in fact, the ordinary series of cement concrete regression has many defects, such as low tensile strength, easy cracking, high brittleness, and insufficient toughness. If it is used as a protective repair material for buildings and structures, it will inevitably cause interface adhesion. Unreliable knots, easy cracking and other phenomena leave safety hazards. We commonly use ordinary cement concrete to have these performance defects, and polymer cement mortar can effectively improve these shortcomings.

1.2. Significance

The so-called polymer-modified cement concrete refers to a composite material formed when cement, aggregate and polymer materials are mixed. The polymers used for mortar modification mainly include water-soluble polymers, liquid polymers, and dispersed latex powders. The use of polymer materials in cement has the following advantages. (1) The shrinkage of cement mortar is reduced. (2) High flexural strength and stronger. (3) Improve the bonding strength with old concrete. (4) The density of cement mortar is increased, and the internal pore structure is obviously improved. (5) The impact resistance is greatly improved. (6) High fluidity and low water consumption. With the continuous expansion of the application range of concrete materials, various projects have higher and higher requirements for their performance. When discussing the future industry, the US Department of Labor predicted that the post-maintenance of buildings (structures) will become contemporary and future. It is one of the hot industries for hundreds of years. This fully reflects the urgency and broad prospects of the problem of concrete protection, so our country is also actively involved in the research of this topic.

1.3. Related Work

Since the application of polymer cement concrete, many people have carried out relevant research on it. Khankhaje E studied the use of palm oil fuel ash (POFA) in ordinary concrete and geopolymer concrete. One of the main findings is that, based on the weight of cement, the concrete mixed with 20% fine POFA shows better performance than OPC concrete. Durability performance. In addition, 100% cement-free geopolymer concrete can be produced using mixed ash, such as POFA and fly ash. This research is highly innovative but lacks practicality [1]. Cao V D added MPCM to the concrete, and a significant decrease in compressive strength was observed. However, the compressive strength still meets the European regulations for machinery for concrete applications (EN 206-1, compressive strength class C20/25). Finally, after the sample is subjected to 100 thermal cycles at high heating/cooling rates, MPM concrete provides good thermal stability, but the disadvantage is that it does not take into account the natural factors in the actual process [2]. Uebachs S has tested a large number of experimental results in the laboratory and some practical applications of geopolymer concrete (Wagners Earth Friendly Concrete (EFC)), as well as a binder made of ground granular blast furnace slag, fly ash and customized activator. With regard to the special performance of this system, the mixture system proposed a concrete admixture, but this experiment requires high equipment and is not practical [3]. Wang R's discussion concluded that various chemical interactions may occur between cement and different types of polymers. Understanding these chemical interactions will play an important role in elucidating the relationship between the microstructure and macrostructure of polymer-modified cementitious materials. It also proved a belief that the organic-inorganic (polymer-Portland cement) composite material chemically bonds with certain components, and at the same time physical interaction, will become the next stage of concrete technology progress [4]. Shehab H K developed 18 concrete mixtures to evaluate the impact of key parameters on the mechanical properties and behavior of concrete. The test results show that replacing fly ash as a base geopolymer can improve the mechanical properties of concrete. Compared with the compressive strength, splitting tensile strength, flexural strength and bond strength produced by 0%, 25%, 75% and 100% cement substitution rate, the compressive strength of substitution of 50% is higher. This experiment Practicability is strong but the percentage of cement set is small [5]. Neupane K proposed that geopolymer is a new binding material, synthesized by alkali activation of aluminosilicate compound, compared with conventional Portland cement (OPC) concrete, made of geopolymer binder The concrete has better engineering, thermal and durability properties, such as higher mechanical strength, higher resistance to sulfate and acid attack, and higher heat resistance. This conclusion needs to be further demonstrated in practice [6]. Dahou Z considered two types of concrete: ordinary Portland cement (OPC) concrete and a new type of concrete technology, namely geopolymer (GPC). The bond strength was studied by conducting pull-out tests on ribbed steel bars with a nominal diameter of 10 mm and/or 12 mm. The specimens were tested at various ages ranging from 1 to 28 days. The main goal of an extensive research program involving 260 pull-out tests was to establish a combination of the steel-concrete bond strength of OPC and geopolymer concrete with the average compressive strength of concrete, empirical model of intensity correlation [7]. In order to further clarify the near surface mounting (NSM) carbon fiber reinforced polymer (CFRP) technology, Al-Saadi N uses the finite element method (FEM) to simulate the adhesion between the NSM CFRP strip and the cement-based adhesive in the single-turn shear test. End behavior. The nonlinear finite element experimental results and can be used in the design of reinforced concrete members reinforced with NSM CFRP bars. This research method is more difficult [8].

1.4. Innovation

The innovation of this article lies in (1) a comprehensive analysis of polymer-modified cement concrete composite materials, including its material formation mechanism, composition method and performance improvement. (2) It is verified through experiments that the incorporation of polymers can enhance the compressive and flexural strength, abrasion performance and shrinkage properties of the cement mortar, and obtain a suitable amount of polymer, defoamer, and fiber.

2. Formation and Performance Test Methods of Polymer Cement Concrete Composite Materials

2.1. Polymer Modification Mechanism

The polymer is woven into the network of hardened cement, on the one hand it plays a strengthening role, on the other hand it plays a role in improving durability. The mechanism of the polymer film hinge is as follows: the continuous network structure reflected in the three-dimensional space formed by the polymer corresponds to the fiber state, resists crack propagation, and improves the flexural strength [9]. Many active substances in the polymer emulsion strengthen the wetting of the surface of the concrete mixed material and reduce the porosity, forming a strong polymer film that adheres to the surface of the aggregate well, improving the damage performance, and effectively preventing the occurrence of cracks. The polymer is uniformly dispersed on the cement hydrate to reduce the permeability. Figure 1 is a demonstration diagram of this process.

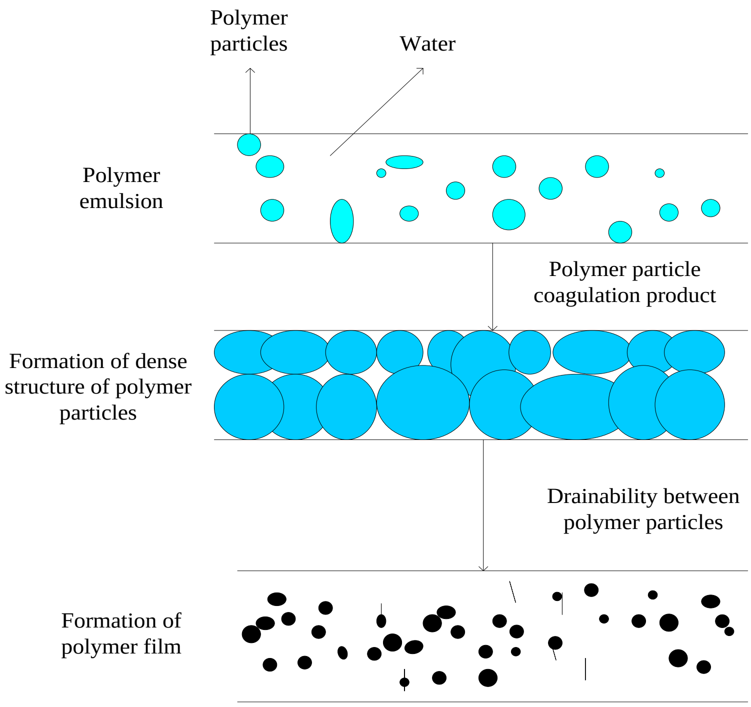

Figure 1. Simple steps of polymer film formation during cement hydration

2.2. Material Composition Design of Polymer Modified Cement Concrete

(1) Composition design method

The material composition design is based on the volume analysis method. The volume composition of concrete is divided into two parts: aggregate and butadiene-styrene copolymer emulsion modified cement slurry. The most ideal state is that the aggregates are piled up to form a dense skeleton, and the voids between the aggregates are completely filled with cement slurry. Butadiene-styrene copolymer emulsion modified cement slurry is the total volume of cement, water, polymer, and defoamer after mixing, vibrating and compacting at a fixed ratio [10]. Define cement mortar interstitial rate VFM as the control index of polymer fiber modified cement concrete material composition design, this index is the ratio of the volume of the slurry V_j to the porosity V_k of the aggregate in close packing, namely:

$$VFM = V_j / V_k \times 100\% \tag{1}$$

Where VFM is the interstitial ratio of cement mortar, V_j is the volume of composite cement mortar, and the volume of internal pores of the aggregate in the stacked state. When the cement mortar interstitial rate VFM=100%, the pores between the aggregates are just completely filled by the cement mortar, and the internal matrix of the concrete forms a "dense-skeleton" structure, reaching the ideal state, so the VFM value is closer 100% is better[11].

(2) Composition design steps

According to the above-mentioned volume analysis method, the polymer fiber modified cement concrete material mix ratio design calculation is carried out. The main components and design steps are as follows:

1) The apparent relative density of composite aggregate

Determine the apparent relative density of each grade of aggregates ρ_1 ρ_2, and determine the blending ratios of aggregates at each level as a, b according to the continuous gradation stacking framework. At the same time, compare with the theoretical design gradation, adjust accordingly, and then make it preliminary Determine the blending ratio of the coagulation aggregate, and calculate the apparent relative density of the composite aggregate according to the following formula:

$$\rho = \frac{\rho_1 \times a + \rho_2 \times b}{a+b} \tag{2}$$

2) The void volume of composite aggregate

The tap density of the composite aggregate is measured as ρ_z. Because the void ratio and void volume of the composite aggregate of the ultra-thin polymer modified cement concrete overlay material are equal in value, the void volume V_k can be calculated:

$$V_k = 1 - \frac{\rho_z}{\rho} \tag{3}$$

Where is the tap density of ρ_z composite aggregate.

3) Paste volume of polymer modified cement concrete material

Butadiene-styrene copolymer emulsion modified cement slurry is made by mixing cement, water, butadiene-styrene copolymer emulsion, defoamer, and fiber (ignored). Assuming the volume of cement paste:

$$V_m = \frac{m_c}{\rho_n} + \frac{m_c \times p/c}{\rho_j} + \frac{m_c \times w/c}{\rho_s} \tag{4}$$

m_c is the amount of cement per unit, ρ_n, ρ_j, and ρ_s are the apparent density of cement, polymer, and water, respectively, p/c is the ratio of polymer to ash, and w/c is the ratio of water to ash.

4) Interstitial rate of cement mortar

Combining the above two formulas can obtain the composition design equation of polymer-modified cement concrete materials:

$$VFM = V_j/V_k \times 100\% = \frac{\frac{m_c}{\rho_n} + \frac{m_c \times p/c}{\rho_j} + \frac{m_c \times w/c}{\rho_s}}{1 - \frac{\rho_z}{\rho}} \times 100\% \tag{5}$$

By testing the test material parameters and using the above equations, the combined ratio parameters of polymer-modified cement concrete materials can be obtained. According to the theoretical mix ratio calculated by the volume analysis method, the trial mix is carried out. At the same time, the bending and tensile strength, compressive strength and performance are used as evaluation indicators to verify and adjust the calculated theoretical mix ratio, and finally determine the polymer modified cement concrete material Actual mix ratio [12].

(3) Preparation technology of polymer cement concrete

1) The design of polymer-modified cement concrete is similar to that of ordinary cement concrete. It is designed based on workability, strength, deformability, impermeability, and chemical

stability. The difference lies in the design process. The polymer-modified cement concrete has to determine the proportion of polymer cement, and its sinking sl is calculated by the following formula [13]:

$$sl = j^{\phi} - k(1 - s/a) \quad (6)$$

Among them, j and k are constants. The compressive strength of polymer cement concrete can be predicted according to the polymer cement ratio and the glue-to-air ratio a. The water-cement ratio (W / C) and the unit volume dosage are functions of the glue-to-air ratio (α), and the relationship is as follows:

$$w/c = -am + n; c = fa + r \quad (7)$$

Where m, n, f, r are empirical constants.

2) Simple process for preparing polymer cement concrete

First, prepare the emulsion, which is composed of polymer, surfactant and water, then mix cement, sand and water into cement mortar according to the mass ratio, then mix the emulsion and cement mortar and add accelerator and defoamer, then It becomes polymer cement concrete, and the final product is obtained through curing. High-quality polymer cement concrete must be of uniform quality, without holes, and without discontinuities. During the mixing process of mortar and emulsion, a large amount of air will be introduced, and foam may even be formed, so choose a good mixing method such as manual operation to reduce the amount of air and add defoamer. Figure 2 is a simple process of polymer cement concrete manufacturing [14].

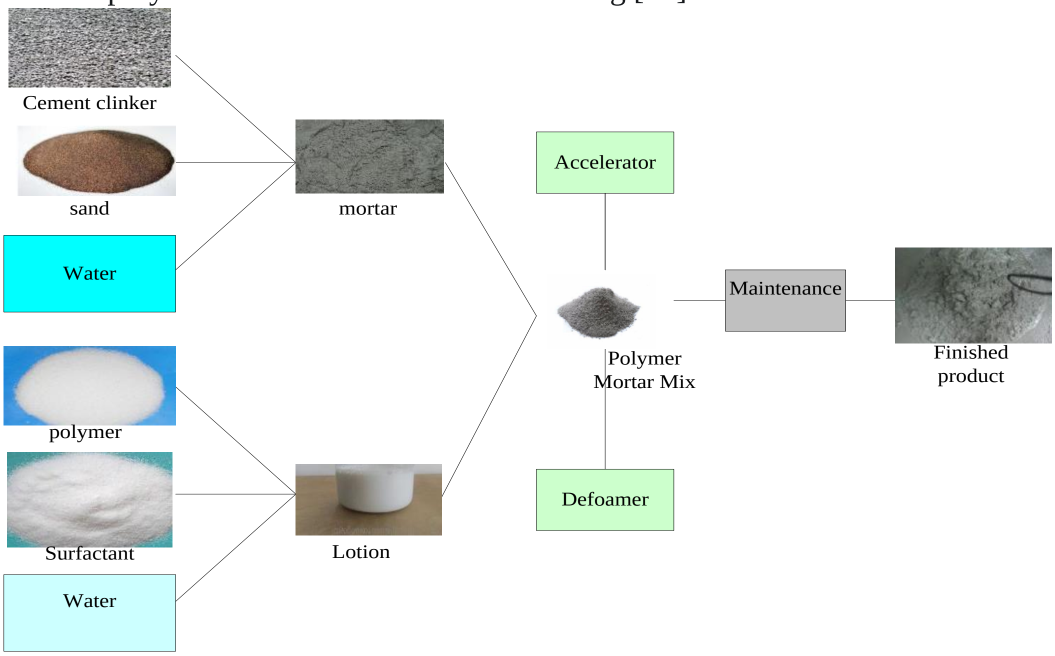

Figure 2. The basic preparation process of polymer cement concrete

2.3. Performance Test of Polymer Cement Concrete

As a raw material in construction engineering, the most basic performance of concrete is mechanical properties, so here we discuss the basic physical and mechanical properties of polymer concrete.

1) Compressive strength of cube

Cube compressive strength is not only the most important mechanical property index in the research of concrete materials, but also the most basic design index in the design of concrete structures. The size of the test piece used for the test is 100mm × 100mm × 100mm is a non-standard test piece. The process is to set parameters for the test first, and then click the start button on the screen to start the test. After the test is completed, the gauge shall be removed in time after the test piece is crushed, and the pressure plate shall be cleaned to avoid affecting the test of the next test piece[15]. The test diagram is shown in Figure 3:

Figure 3. Compressive strength experiment

The calculation formula is:

$$f_{cp}=\frac{F}{A} \tag{8}$$

Where f_{cp} represents the compressive strength; F represents the failure load of the specimen; A is the area of the specimen contacting the machine.

2) Splitting tensile strength

Tensile strength is an important basis for the failure analysis and strength theory of concrete materials[16], and it plays an important role in the study of concrete performance. Its calculation formula is

$$f_s=\frac{2F}{\pi A}\approx 0.637\frac{F}{A} \tag{9}$$

Where f_s is the splitting tensile strength, F is the failure load of the specimen; A is the area of the specimen contacting the machine.

3) Static elastic modulus

The magnitude of the elastic modulus determines the deformability of the material, which is a major and difficult issue in material research. Calculated as follows :

$$E_c=\frac{F_a-F_0}{A}\times\frac{L}{\Delta n} \tag{10}$$

$$\Delta n=\varepsilon_a-\varepsilon_0 \tag{11}$$

Where E_c is the modulus of elasticity, F_a is the load when the stress is 1/3 of the axial compression, F_0 is the initial load, A is the pressure-bearing area of the member, and L is the measuring gauge length.ε_0 epresents the strain value corresponding to F_0,ε_a is the strain value corresponding to Fa [17].

4) Compressive strength of shaft

The axial compressive strength is the compressive strength obtained by the prism experiment, and its calculation formula is:

$$F_{cp} = \frac{F}{A} \tag{12}$$

In the formula, F_{cp} is the compressive strength of the axis, F is the failure load of the specimen, and A is the area of the damaged surface of the specimen. In many cases, the decompressive strength of the axis is equal to the compressive strength of the cube.

5) Permeability coefficient

Permeability coefficient is a very important indicator for measuring concrete. At present, most of the permeability coefficient tests of permeable materials are based on Darcy's law, and concrete is no exception. Darcy derives the following formula[18]:

$$Q = KA(h_1 - h_2)/L \tag{13}$$

In the formula: Q represents the volume of water flow per unit time; A is the cross-sectional area; $h_1 - h_2$ is the head difference; L is the length. The physical basic expression of K is:

$$K = (cd^2)\left(\frac{g\rho}{\mu}\right) \tag{14}$$

C is the particle shape and structure coefficient; d is the average particle diameter; g is the acceleration due to gravity; ρ is the fluid density; μ represents the hydrodynamic viscosity coefficient[19].

6) Flexural strength

The flexural strength tester is a hydraulic universal testing machine, and the test piece is taken out of the standard curing room to check whether the size of the test piece meets the requirements. The size of the test piece in the test is 100mm×100mm×400mm. Then put the 15 qualified test piece on the movable support, adjust the distance between the supports to 300mm, so that the test piece is geometrically aligned. During this process, the test piece and the machine must be balanced and stable. The operation is shown in Figure 4 [20]:

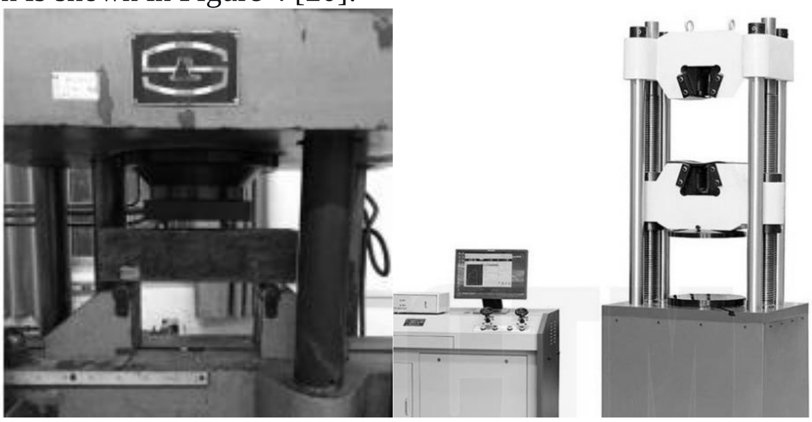

Figure 4. Flexural strength test

The formula for calculating the flexural strength of concrete is as follows :

$$f_m = \frac{F_{max} \cdot l}{bh^2} \tag{15}$$

Where is the flexural strength of f_m concrete; F_{max} is the maximum load; l is the spacing between the supports; b is the section width of the test block; h is the section height of the test block.

7) Drawing bond strength

The pull-out test is mainly used to evaluate the bond strength between the waterproof bonding material and the steel plate. The adhesion test sample preparation is divided into five steps: steel plate grinding-clearing-painting of waterproof bonding material-bonding spindle-testing. Coat the prepared bonding material on the processed steel plate, and after it is completely hardened, stick the slider on the test piece with a special adhesive. After being completely hardened, perform a test according to the specified test conditions to calculate the bond strength[21]. The test chart is shown in Figure 5.

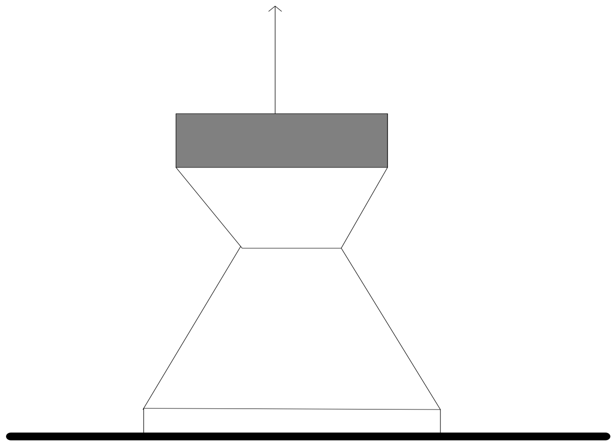

Figure 5. Schematic diagram of bond strength test

The bond strength is:

$$P=F/S \tag{16}$$

P is the bonding strength, F is the tensile force value when the sample is pulled apart and broken, and S is the cross-sectional area of the test column coated with the bonding material.

2.4. Salt Resistance Mechanism of Polymer Concrete

(1) Salt corrosion mechanism

The corrosion mechanism of salt is because the salt lake contains a lot of NaCl, KCl, NaSO, KSO, MgSO. Except for BaSO, most of the sulfates have a great corrosive effect on concrete. This is mainly caused by the reaction of sodium sulfate and potassium sulfate plasma with calcium hydroxide to form calcium sulfate, which then reacts with calcium aluminate hydrate to form vanadinite. As a result, the solid content is greatly increased. There is considerable crystal expansion stress, which can cause expansion, peeling, and even damage. Taking sodium sulfate as an example, its effects are as follows[22].

$$Ca(OH)_2 + NaSO_4 \cdot 10H_2O = CaSO_4 \cdot 2H_2O + 2NaOH + 8H_2\mathrm{O} \tag{17}$$

$$4CaO \cdot Al_2O_3 \cdot 10H_2O + 3(CaSO_4 \cdot 2H_2O) + 8H_2O = 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + Ca(OH)_2 \tag{18}$$

In particular, magnesium sulfate has a great corrosive effect on cement, and it reacts with calcium hydroxide in cement as follows:

$$MgSO_4 + Ca(OH)_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + Mg(OH)_2 \quad (19)$$

Magnesium hydroxide has extremely low solubility and is easy to precipitate out of the solution, so that the reaction continues to proceed to the right. At the same time, magnesium sulfate can decompose calcium silicate hydrate and make its cementing performance worse. Its effect is as follows[23]:

$$3CaO \cdot SiO_2 \cdot aq + 3MgSO_4 + nH_20 \rightarrow 3[CaSO_4 \cdot 2H_2O] + 3Mg(OH)_2 + 2SiO_2 \cdot aq \quad (20)$$

Because Cl^- ions penetrate into the concrete, it will promote corrosion and cause damage. On the other hand, due to the low relative humidity and high wind speed in this area, the water that penetrates the surface quickly evaporates, and the remaining salt crystallizes. If the crystalline particles continue to grow, large internal stresses will occur, and expansion failure and peeling will occur[24].

(2) Salt corrosion resistance mechanism of polymer concrete

In summary, increase the density and strength of concrete, reduce capillary pores, and improve the impermeability and salt corrosion resistance of concrete. The water permeability of porous materials is directly proportional to the permeability coefficient of the material, and the permeability coefficient satisfies the following relationship:

$$K = \frac{C \cdot \epsilon r^2}{n} \quad (21)$$

Where ϵ is the total porosity; r is the hydraulic radius of the pore; n is the viscosity of the fluid; C is a constant. Therefore, in the mixing process of polymer cement concrete, it is necessary to reduce the ratio of water and cement, increase the density, and reduce the porosity. As long as the water permeability is reduced, corrosion can be effectively inhibited[25].

3. Experiment and Analysis

In this experiment, the cement concrete was modified by adding polymer to improve the wear resistance of cement concrete pavement. Adding an appropriate amount of polymer can reduce the brittleness of cement concrete, improve flexibility, improve deformability, and greatly improve the wear resistance of concrete. This chapter uses the butadiene-styrene copolymer emulsion to modify the cement mortar, comprehensively analyzes the workability of the cement mortar and the surface function of the pavement after forming, combined with the indoor abrasion meter and the mechanical performance indoor test, and proposes that it has excellent workability, The design parameters of road concrete slurry material that have abrasion resistance and meet the basic mechanical properties of the road.

3.1. Material Selection for Polymer Cement Concrete Test

(1) Polymer

The addition of polymer to cement concrete can significantly improve its working performance, cohesion, adhesion and flexural tensile strength. Compared with ordinary concrete, polymer modified concrete has a dense internal structure and some pores in the matrix. Filled with polymer, the water seepage is reduced, the chemical stability is improved, and its durability is obviously improved. In this experiment, a butadiene-styrene copolymer emulsion was used. The basic parameters are shown in Table 1.

Table 1. Parameters of butadiene-styrene copolymer emulsion

Performance	Company	Test method(KR-01)	Injection stage	Film grade(KR-10)
Density	g/cm^3	D-792	1,01	1,01
Elongation	%	D-638	20	ADTM-882
Transparency	%	-	90-95	ADTM D-1003
Haze	%	D-1003	1.0	1.1

(2) Defoamer

After adding butadiene-styrene copolymer emulsion to cement mortar and concrete, due to the strong air-entraining effect of butadiene-styrene copolymer emulsion, a large number of bubbles will be produced in the prepared polymer-modified concrete. Therefore, a defoamer with better compatibility with the butadiene-styrene copolymer emulsion used in this experiment was selected to be added to the cement concrete to eliminate the large bubbles introduced by the addition of the polymer in the matrix and improve the compactness of the concrete. Reduce the shrinkage rate of concrete. In this experiment, the powdery solid defoamer produced by Guangzhou Tengtang Chemical Co., Ltd. was selected, and the main component was polysiloxane.

(3) Cement

Grade 42.5 quick hardening sulphoaluminate cement is selected. The grade of quick hardening sulphoaluminate cement is expressed by 3D compressive strength, which is divided into three grades: 425, 525 and 625. The compressive strength of each age shall not be lower than the values in Table 2:

Table 2. Age compressive strength of fast hardening sulphoaluminate brine mud

Grade	12h	1d	3d
425	29.4	34.4	41.5
525	36.8	44.1	51.4
625	39.2	51.5	62.3

(4) Water

In this test, tap water was used to mix and maintain the repair materials, and the water quality met the requirements of the current "Sanitary Standards for Drinking Water".

(5) Fiber

Incorporating a certain proportion of fibers can inhibit the occurrence and development of cracks in the repaired surface, thereby improving the crack resistance of the road surface and reducing internal defects. This experiment uses polypropylene fiber, which meets the specification requirements of "Highway Cement Concrete Fiber Material Polypropylene Fiber and Polyacrylonitrile Fiber".

(6) Fine aggregate

The choice of the particle size and type of fine aggregate will have a great impact on the water consumption and cement consumption in mortar and concrete mixing, and is an important guarantee for good workability. The fine aggregate for preparing high-quality mortar and concrete should be preferably medium sand or medium coarse sand with complete gradation and relatively hard texture. The fineness modulus of fine aggregate should be controlled within the range of 2.7~3.1 as far as possible. After the sand has been coarsely mixed, the internal friction resistance of the concrete is large, it is difficult to vibrate and form, and the workability is also difficult to meet the design requirements. Basalt manufactured sand selected in this test.

3.2. Explore the Basic Properties of Polymer Cement Concrete with Different Proportions

(1) Test mix ratio of polymer modified cement mortar

The butadiene-styrene copolymer emulsion modified cement mortar is prepared with machine-made sand, in which the amount of fixed fine aggregate is 1350kg/m3, the amount of cement is 450 kg/m3, and the polymer-cement ratio is 5%, 10%, 15%. , 20%, and at the same time add 5%, 7%, 9% defoamer under different polymer content, and determine the fluidity of butadiene-styrene copolymer emulsion modified cement mortar under the water-cement ratio of 0.5 , Testing of flexural tensile strength, compressive strength and abrasion resistance.

(2) Research on fluidity of polymer modified cement mortar

Table 3 shows that the butadiene styrene copolymer emulsion has strong water reducing ability. The greater the aggregate cement ratio, the greater the fluidity of modified cement mortar and the improvement of workability. It can be seen from the test data that when the aggregate cement ratio is less than 10%, the polymer fails to give full play to the effect, and when the aggregate cement ratio is greater than 10%, the workability of the mortar begins to improve. The addition of butadiene styrene copolymer emulsion increased the water reducing effect more obviously, and the mortar fluidity increased by 24%. The addition of defoamer will weaken the water reducing effect of polymer. With the addition of defoamer from 3% ~ 9%, the fluidity growth of modified cement mortar slows down.

Table 3. Fluidity of cement mortar

Ash concentration ratio /Dosage of defoamer	0%	5%	10%	15%	20%
3%	20	16	17	23	24
5%	20	17	18	21	22
7%	20	17	18	20	21
9%	20	15	17	18	19

The above results show that when the butadiene-styrene copolymer emulsion content reaches 10%, the fluidity of the fresh cement mortar can be significantly improved, and the workability of the mortar can be enhanced. This effect is mainly caused by the addition of the butadiene-styrene copolymer emulsion to introduce air into the cement mortar and the "balling" effect; at the same time, the surface active ingredients in the butadiene-styrene copolymer emulsion will make the cement particles Dispersion occurs between them. With the increase of the polymer content, the polarity of the particle surface increases, and the water contained in the flocculation structure produced by cement hydration will be released, thus reflecting the water reducing effect of the polymer.

Based on the above test results of the fluidity of the butadiene-styrene copolymer emulsion modified cement mortar, it can be found that the addition of polymer can increase the fluidity of the cement mortar. When the same fluidity is reached, the butadiene-styrene copolymer emulsion is modified. The cement mortar can reduce water consumption, and at the same time improve the workability of the cement mortar and facilitate construction.

(3) Experiment on mechanical properties of polymer modified cement mortar

1) The influence of defoamer and polymer-cement ratio

The main mechanical properties of cement mortar are compressive strength and flexural strength. Here, a cement mortar pressure testing machine is used to test the compressive and flexural strength of polymer-modified cement mortar specimens. The following Figure 6 shows the experimental results of compressive strength under different defoamer dosages and different polymer-to-ash ratios.

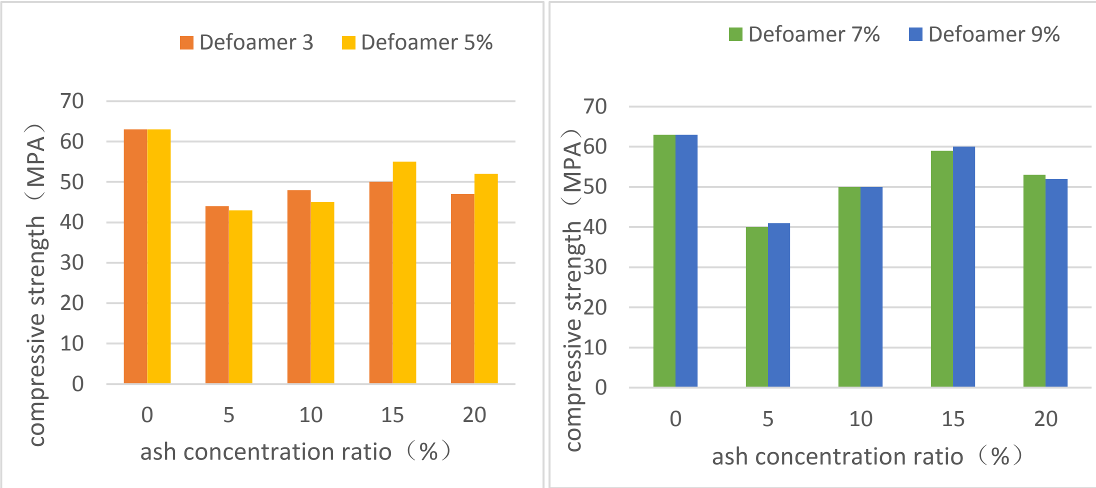

Figure 6. The relationship between compressive strength and polymer-to-cement ratio and defoamer

It can be seen from the figure that the influence of different polymer content on the mechanical properties of cement mortar has no obvious regularity, and the defoamer has little effect on the compressive strength. Only by comparing polymer-modified cement mortar and ordinary cement mortar, it is found that with the addition of butadiene-styrene copolymer emulsion, the compressive strength of cement mortar begins to decline rapidly. The compressive strength began to show a slowing trend, and gradually decreased after 15% polymer-cement ratio, and the compressive strength of cement mortar fell by 7% to 33%. The following Figure 7 shows the experimental results of the flexural strength of different defoamer dosages and different polymer-to-cement ratios.

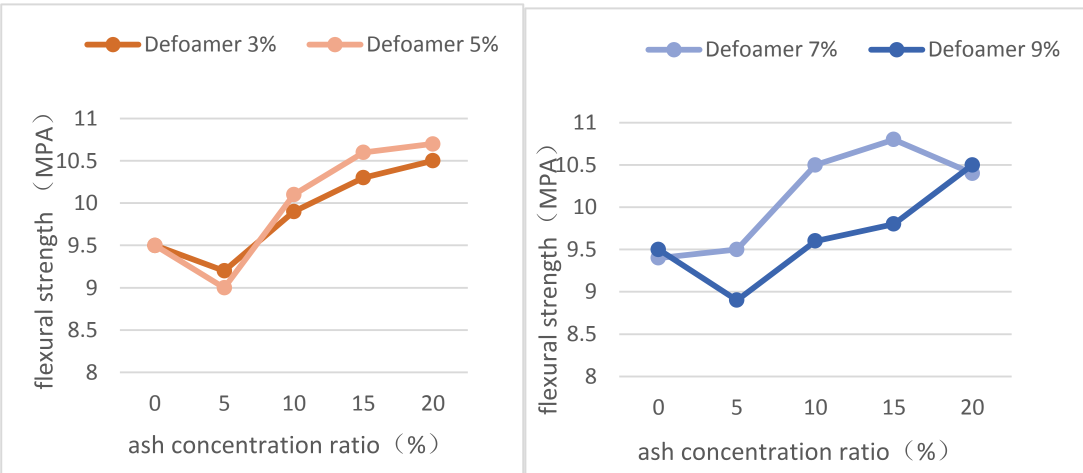

Figure 7. The relationship between flexural strength, polymer-to-cement ratio and defoamer

Compared with ordinary cement mortar, the flexural tensile strength of polymer modified mortar decreases briefly before the aggregate-cement ratio is 5%. When the aggregate-cement ratio is 5% to 15%, the flexural tensile strength begins to show an upward trend. When the ratio is 15%, the peak value of the defoamer is 7, which is an increase of 21.6% compared with ordinary mortar. Calculating the compression ratio of the butadiene-styrene copolymer emulsion modified cement mortar, it can be found that the compression ratio decreases with the increase of the poly-cement ratio, and the larger the polymer content, the corresponding decrease in the compression ratio will also be Get bigger. It can be inferred from this that the brittleness of the polymer-modified cement mortar decreases and the deformability increases.

2) The influence of fiber

After understanding the conditions under which the polymer-to-cement ratio and defoamer have the best compressive strength, we will now discuss the effect of fiber content on the compressive strength. The experimental results are shown in Figure 8.

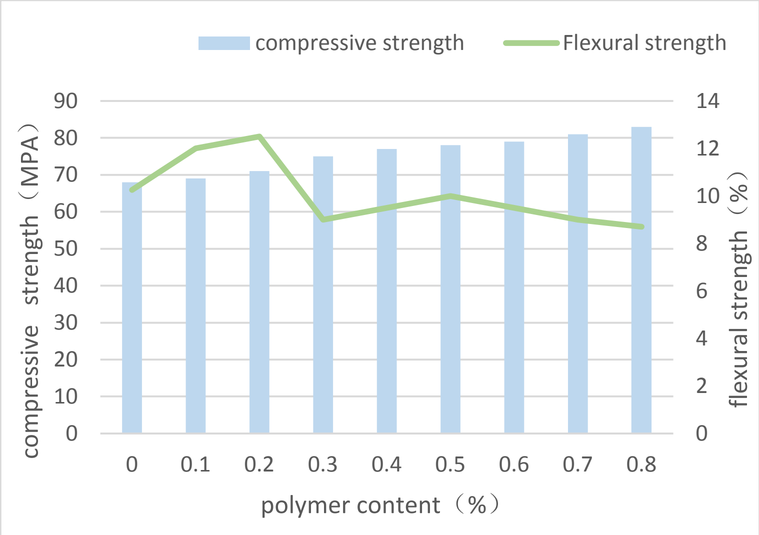

Figure 8. The relationship between fiber content and mechanical properties

It can be seen from the figure that the addition of fibers significantly improves the compressive and flexural strength of polymer cement concrete. When the fiber content is less than 0.2%,the compressive and flexural strength of the composite increases with the increase of fiber content, and increases to the maximum. However, in the range of 0.2%-0.3%, when the fiber content increases, the flexural strength decreases to about 9MPa. After 0.3%, the compressive strength increases steadily, but the flexural strength tends to be about 9.5MPa; considering that the preferred fiber content is 0.2%.

(4) Research on the wear resistance of polymer modified cement mortar

A cement mortar abrasion tester was used to test the abrasion resistance of the polymer-modified cement mortar, and the abrasion degree of the cement mortar was tested when different dosages of polymer and defoamer were added. The specific data is shown in Figure 9.

The wear per unit area of polymer modified cement mortar is lower than that of ordinary cement mortar. Under the 0.5 water cement ratio, the wear rate of the modified cement mortar is reduced by 35.3%~52% compared with the ordinary mortar when the cement mortar mixed with butadiene styrene copolymer emulsion has a 5%~20% ratio.

To sum up, by comparing the data of different polymers and defoamer content, it can be found that when the aggregate cement ratio is 15% and the defoamer content is 7%, the modified cement mortar has better compressive and flexural tensile strength and wear resistance.

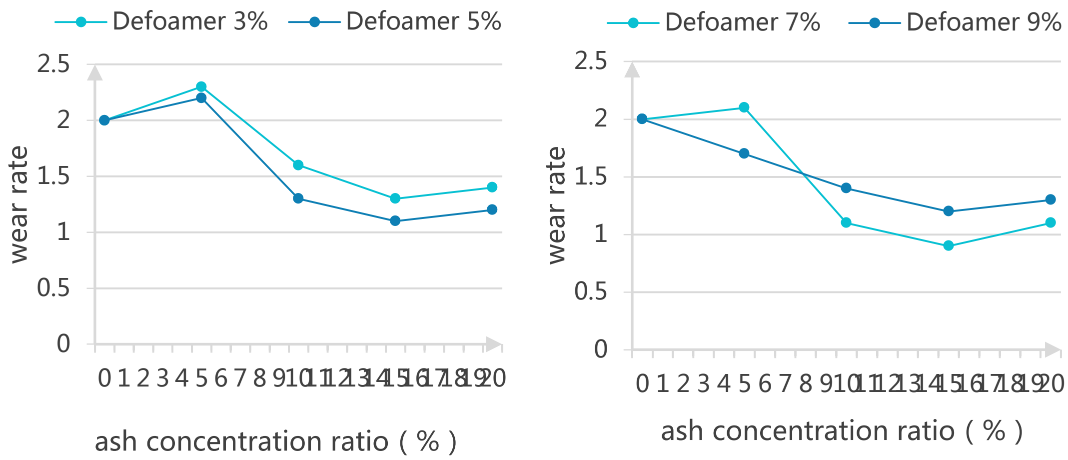

Figure 9. The relationship between abrasion resistance and defoamer and polymer-cement ratio

3.3. Analysis of shrinkage performance of polymer cement concrete

In the above experiments, we have obtained the most suitable poly-cement ratio and defoamer blending data. Now we will explore the drying shrinkage performance of composite materials based on the ratio of these materials, and compare its drying shrinkage performance with that of ordinary cement. For comparison, the result is shown in Figure 10.

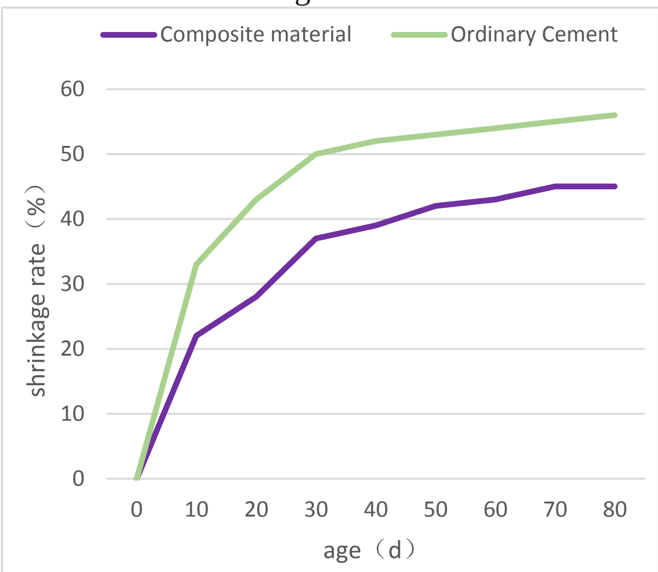

Figure 10. Comparison chart of shrinkage ratio

Comparing the dry shrinkage rates of composite feed and ordinary cement specimens at different ages, it can be seen that both of them increase with the increase of age. This shows that the drying shrinkage of cement materials is a gradual accumulation process, and 80% of the drying shrinkage occurs within the early 28 days, and the final value tends to be stable. The dry shrinkage rate of the composite is relatively small, and the rate of change with age is also low, and the final dry shrinkage is about 85% of the ordinary cement of the same strength. The reason is that some hydration products of sulphoaluminate cement have the property of micro expansion, which delays the dry shrinkage of the specimen. On the other hand, because the polymer is formed into a three-dimensional network, the pore micro-element structure is optimized, the compactness of the specimen is enhanced, and the shrinkage resistance of the polymer-modified cement mortar is improved. In order to further reduce the shrinkage rate of the repair material, a small amount of expansion agent can be added in practical applications, which can also reduce the initial micro-cracks of the cement specimen.

4. Discuss

After more than 50 years of exploration, polymer cement concrete has been widely used as a high-performance material in the construction, power, machinery, and chemical industries of many countries. Although the cost will be higher, it is much stronger than ordinary concrete, with higher strength, abrasion resistance, drug resistance, and high elastic modulus. People have been exploring the modification mechanism of polymers. Many scholars have also conducted a lot of detailed and subtle research on the mechanism of polymer cement concrete and have obtained some results.

Polymer-modified cement concrete is a composite material that conforms to the development trend of modern materials. It has broad application prospects. When studying polymer-modified cement concrete, we must first study the modification mechanism of various polymers, and then make appropriate choices. With the advancement of technology, people's requirements for polymer-modified concrete are getting higher and higher. All countries are working hard to implement the research work of polymer-modified cement concrete. As a result, polymer-modified concrete has also been developed at a high speed.

5. Conclusion

This article explains the basic concept and background of polymer cement concrete, and explains its composition method and performance test method. And through experiments to analyze the performance indicators of polymer cement concrete, in order to get the most suitable substance content. The details are as follows: (1) The composition method and some basic properties of polymer cement concrete are explained. (2) Choose suitable polymers, cements, fibers, defoamers, and fine aggregates for experiments. (3) Test the mechanical properties, abrasion resistance and fluidity of the composite material under different ratios of polymer to ash and defoamer, and the most suitable ratio of polymer to ash is 15% and the best defoamer content Is 7%. (4) The mechanical properties of composite materials were tested under different fiber content, and the best content was 0.2%. (5) Through the experimental analysis of dry shrinkage performance, it is concluded that the dry shrinkage ratio of polymer mixed with composite materials is significantly lower than that of ordinary cement.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

References

[1] *Khankhaje E , Hussin M W , Mirza J , et al. On blended cement and geopolymer concretes containing palm oil fuel ash. Materials & Design, 2016, 89(JAN.):385-398. https://doi.org/10.1016/j.matdes.2015.09.140*

[2] *Cao V D , Pilehvar S , Salas-Bringas C , et al. Microencapsulated phase change materials for enhancing the thermal performance of Portland cement concrete and geopolymer concrete for passive building applications. Energy Conversion & Management, 2017, 133(FEB.):56-66. https://doi.org/10.1016/j.enconman.2016.11.061*

[3] *Uebachs S , Neunzig C , Day J W , et al. Geopolymer Concrete for the Precast Construction: Concrete without cement. Betonwerk + Fertigteil Technik, 2019, 85(2):16-17.*

[4] *Wang R , Li J , Zhang T , et al. Chemical interaction between polymer and cement in polymer-cement concrete. Nephron Clinical Practice, 2016, 64(4):785-792. https://doi.org/10.1515/bpasts-2016-0087*

[5] *Shehab H K , Eisa A S , Wahba A M . Mechanical properties of fly ash based geopolymer concrete with full and partial cement replacement. Construction & Building Materials, 2016, 126(NOV.15):560-565.*

[6] *Neupane K . "Fly ash and GGBFS based powder-activated geopolymer binders: A viable sustainable alternative of portland cement in concrete industry". Mechanics of Materials, 2016, 103(Dec.):110-122. https://doi.org/10.1016/j.mechmat.2016.09.012*

[7] *Dahou Z , Castel A , Noushini A . Prediction of the steel-concrete bond strength from the compressive strength of Portland cement and geopolymer concretes. Construction & Building Materials, 2016, 119(aug.30):329-342.*

[8] *Al-Saadi N , Al-Mahaidi R . Modelling of near-surface mounted carbon fibre reinforced polymer strips embedded in concrete with cement-based adhesive. Construction & Building Materials, 2016, 127(nov.30):383-393.*

[9] *Sanusi O , Tempest B , Ogunro V O , et al. Leaching Characteristics of Geopolymer Cement Concrete Containing Recycled Concrete Aggregates. Journal of Hazardous Toxic & Radioactive Waste, 2016, 20(3):04016002.*

[10] *Azad N M , Samarakoon S . Utilization of Industrial By-Products/Waste to Manufacture Geopolymer Cement/Concrete. Sustainability, 2021, 13(2):873. https://doi.org/10.3390/su13020873*

[11] *Girish M G , Shetty K K , Rao A R . Geopolymer concrete an eco-friendly alternative to portland cement paving grade concrete. International Journal of Civil Engineering and Technology, 2017, 8(7):886-892.*

[12] *Nagajothi S , Elavenil S . Experimental investigations on compressive, impact and prediction of stress-strain of fly ash-geopolymer and portland cement concrete. Journal of Polymer Engineering, 2020, 40(7):583-590. https://doi.org/10.1515/polyeng-2020-0036*

[13] *Dardaei S , H Bagheri. Evaluation effect of polyester content and post curing condition on polymer cement concrete properties. International Journal of Civil Engineering and Technology, 2019, 10(1):2638-2646.*

[14] Liu G J , Bai E L , Xu J Y , et al. Dynamic compressive mechanical properties of carbon fiber-reinforced polymer concrete with different polymer-cement ratios at high strain rates. Construction and Building Materials, 2020, 261(7):119995.

[15] Hammodat W W . Modified cement concrete for highway application using polymer-sand. Journal of Mechanical Engineering Research and Developments, 2021, 44(1):375-381.

[16] Zhang C , Kong X , Yin J , et al. Rheology of fresh cement pastes containing polymer nanoparticles. Cement and Concrete Research, 2021, 144(4):106419.

[17] Thomas B S , Yang J , Mo K H , et al. Biomass ashes from agricultural wastes as supplementary cementitious materials or aggregate replacement in cement/geopolymer concrete: A comprehensive review. Journal of Building Engineering, 2021, 40(7):102332. https://doi.org/10.1016/j.jobe.2021.102332

[18] Sokoowska J J , Zalegowski K . Ultrasonic Quality Assessment Of Polymer-Cement Concrete With Pet Waste As The Aggregate. Archives of Civil Engineering, 2018, 64(2):67-77. https://doi.org/10.2478/ace-2018-0017

[19] Radhakrishna. Strength Assessment in Portland Cement and Geopolymer Composites with Abrams' Law as Basis. Journal of Advanced Concrete Technology, 2020, 18(6):320-327. https://doi.org/10.3151/jact.18.320

[20] Kaze C R , Lecomte-Nana G , Kamseu E , et al. Mechanical and physical properties of inorganic polymer cement made of iron-rich laterite and lateritic clay: A comparative study. Cement and Concrete Research, 2021, 140(106320):1-15.

[21] Wani S B , Ahmed J , Mohammed M , et al. Influence of Nano-modification on mechanical and durability properties of cement polymer anticorrosive coating. Challenge Journal of Concrete Research Letters, 2020, 11(4):92-104. https://doi.org/10.20528/cjcrl.2020.04.002

[22] Liu H , Elchalakani M , Karrech A , et al. High strength flowable lightweight concrete incorporating low C3A cement, silica fume, stalite and macro-polyfelin polymer fibres. Construction and Building Materials, 2021, 281(4):122410.

[23] Pilehvar S , Szczotok A M , Rodriguez J F , et al. Effect of freeze-thaw cycles on the mechanical behavior of geopolymer concrete and Portland cement concrete containing micro-encapsulated phase change materials. Construction and Building Materials, 2018, 200(MAR.10):94-103.

[24] Kim M , Kang S H , Hong S G , et al. Influence of Effective Water-to-Cement Ratios on Internal Damage and Salt Scaling of Concrete with Superabsorbent Polymer. Materials, 2019, 12(23):3863. https://doi.org/10.3390/ma12233863

[25] Mishra J , Das S K , Singh S K , et al. Development of Geopolymer Concrete for the Protection of Environment: A Greener Alternative to Cement. International Journal of Civil Engineering, 2019, 6(3):41-47. https://doi.org/10.14445/23488352/IJCE-V6I3P106