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Study on The Adhesion Properties of Light-ransmitting Concrete Based on Different Matrix Materials

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Abstract: Light-transmitting concrete prepared by the combination of light-transmitting materials and concrete matrix is a new building material with functions of energy saving and consumption reduction. In this paper, the current research status of scholars in this field at home and abroad is integrated and explored, so as to carry out the analysis of the interfacial bonding performance between the light-transmitting material and the concrete matrix of light-transmitting concrete. This paper selects acrylic as the light-transmitting material, silicate cement mortar, alkali magnesium sulfate cement mortar, ordinary mortar with cork particles, ordinary mortar with expansion agents, ordinary mortar with basalt fibers, and self-compacting cement mortar as the matrix materials, and tests the interfacial bonding performance of different substrates of light-transmitting concrete made by them. Through the interfacial bonding performance test and compressive strength test, the results of the study showed that the interfacial bonding between the concrete matrix and acrylic with the addition of basalt fibers was superior.

Keywords: Light-transmitting Concrete, Interfacial bonding performance, Acrylic, Energy conservation.

1. Introduction

With the increasing level of urbanization and building density, the level of natural lighting in the city decreases year by year and can only rely on a large number of artificial lighting. According to research, in the lighting process, 75% of the energy is consumed in the form of heat, and only 25% of the energy is used for luminescence, resulting in a huge waste of energy, while also not in line with the national low-carbon, green requirements. The development of new building materials is an important driving force to promote the development of green energy-saving buildings. As a new type of composite material, light-transmitting concrete has certain material structure performance and low-carbon environmental protection and art decoration functions, and has become a research hot spot for many scholars to discuss.

Light-transmitting concrete is a new functional material with energy-saving and decorative functions, which can turn the original opaque concrete into light-transmitting one and increase the natural light area of the building without losing the original wall insulation capacity, thus reducing the building energy consumption and playing an energy-saving and emission reduction effect. The use of light-transmitting concrete products to produce prefabricated envelope structure, etc., not only can achieve the traditional wall envelope and decorative functions, but also can significantly improve the indoor daytime lighting conditions, and thus save electricity for lighting. Therefore, light-transmitting concrete, as a carrier of buildings, is simultaneously endowed with light-transmitting properties, which reduces lighting energy consumption to a certain extent. And it is a development trend of building energy saving and emission reduction.

Research on translucent concrete has been conducted since 2008, but from the research of various scholars it can be found that the development of light-transmitting concrete has been hampered by many obstacles. One of the main factors affecting its development is that the implantation of light-transmitting materials leads to a significant decrease in the mechanical properties of concrete. The reason for this is that cement itself has shrinkage and has a weak bonding ability with light-transmitting materials, resulting in a low interfacial strength. Therefore, to solve this problem, this study analyzes the methods to improve the mechanical properties of light-transmitting concrete from the perspective of admixture and cementitious interface. The aim is to improve the binding ability of the interface of translucent concrete, improve the strength of concrete, and extend the application range of light-transmitting concrete.

In this paper, we will select commonly used admixture active admixtures or organic polymers to improve the strength of concrete for experiments on light-transmitting concrete. In-depth study of their effects on interfacial bond strength and structure of translucent concrete as well as the mechanism of action. as well as the mechanism of action. Suitable admixtures will be selected to improve the performance of light-transmitting concrete and to promote the development of light-transmitting concrete.

2. Literature Review

The development trend of green building and building industrialization will promote the development of building materials towards having functional qualities. The energy consumption of residential facades, roofs and windows in China is 3.4 times higher than that of developed countries. Therefore, the corresponding measures to make concrete with a certain degree of light-transmitting properties will reduce the energy consumption of lighting to a certain extent [1]. Light-transmitting concrete is such a new building material with light-transmitting function, which is formed by compounding light-transmitting materials on the basis of traditional cement substrate. Light-transmitting concrete has a good light-transmitting effect, changing the previous gray and monotonous image of concrete products, making them bright and lively. Buildings using light-transmitting concrete as external walls can clearly show the outline of indoor and outdoor objects, and can present a colorful effect with the cooperation of light. Light-transmitting concrete not only has a good decorative effect, but also makes the interior have natural light, which plays the role of light, green and energy saving [2]. Therefore, light-transmitting concrete is a new building material with good application prospects and is a research hotspot in the field of cement concrete science [3].

The light-transmitting material bears the load together with concrete in the structure, and the physical and mechanical properties of the light-transmitting material and concrete differ greatly. The stresses generated during the curing process are easily constrained by each other to produce cracking and debonding phenomena. Therefore, the strength of the combination of light-transmitting material and concrete, that is, the bond strength, largely determines the overall load-bearing capacity of the light-transmitting concrete material. Not only that, the bonding performance of the light-transmitting materials to the concrete also has a significant impact on the overall durability of the material (impermeability, frost resistance, erosion resistance, etc.) [4]. Therefore, in order to solve this problem, this study starts from the interfacial bonding performance, and thus investigates and analyzes how to better improve the interfacial bonding performance and mechanical properties of the light-transmitting concrete.

It has been found that the cracks unfold from the interface between the light-transmitting material and the cement matrix when the light-transmitting concrete specimens are subjected to compression damage. Therefore, it is necessary to enhance the interfacial bonding performance between the cement matrix and the light-transmitting material in order to effectively improve the overall mechanical properties of light-transmitting concrete. In this regard, many scholars have analyzed light-transmitting concrete from the perspective of interfacial bonding [5]. Guangjing Xiong [6] et al. introduced silane coupling agents in improving the interfacial bonding properties of old and new concrete. Their results showed that the silane coupling agent could generate chemical forces between the old and new concrete interfaces, which substantially improved the overall mechanical properties of the material and optimized the fine structure of the transition layer of the old and new concrete. Peiling He [7] et al. analyzed different interfaces before and after interfacial modification using epoxy resin AB adhesive based on the internal microstructure and light transmission mechanism of resin-based cementitious light-transmitting concrete materials using two instruments: environmental scanning electron microscopy as well as X-ray diffractometer. The test results show that after the epoxy resin AB adhesive is evenly coated on the surface of the contact between the cementitious matrix and the resin block, the epoxy resin AB adhesive will have some reactions with the cementitious matrix and the resin block, making the contact surface rough and the adhesion significantly enhanced. Xuna Ye [8] et al. prepared light-transmitting concrete using silicate cement and observed the interfacial properties of light-transmitting concrete by means of microscopic tests with scanning electron microscopy. The results of the study showed that the interfacial products of the optical fiber and cement paste after the application of interfacial modifier remain unchanged, but change the phase of hydrated calcium silicate, a hydration product. The use of the interfacial modifier will improve the bonding properties of the optical fiber to the cementitious material and improve the overall mechanical properties. Sijia Chen [1] et al. selected alkali magnesium sulfate cement mortar and silicate cement mortar as cement-based matrix and resin as light-transmitting material to prepare light-transmitting concrete. The test blocks were also subjected to compressive strength test and oblique shear bond strength test. The test results showed that the interfacial bonding ability of basic alkali magnesium sulfate cement mortar matrix and resin was better than that of silicate cement mortar.

In summary, the combination of the light-transmitting material and the cement matrix improves the light-transmitting properties while generating a light-transmitting material/cement matrix interface. The interfacial bonding has a great influence on the mechanical strength of light-transmitting cement matrix composites. In order to make high-performance light-transmitting cementitious composites, improving the interfacial bonding performance becomes an urgent problem. There are many methods to improve the strength of concrete, but there is a lack of systematic and comprehensive research on the methods to improve the strength of light-transmitting concrete. Therefore, this paper will select acrylic as the light-transmitting material, silicate cement mortar, alkali magnesium sulfate cement mortar, ordinary mortar with cork particles, ordinary mortar with expansion agents, ordinary mortar with basalt fibers, and self-compacting cement mortar, which are six different concrete matrix materials, respectively, to study the interfacial bonding performance of the test blocks made for further research on the interfacial bonding performance of light-transmitting concrete. This will provide a basis for further research on the interfacial bonding properties of light-transmitting concrete.

3. Test Materials and Methods

3.1. Testing Raw Materials

Table 1. Concrete matrix types and characteristics

Types	Characteristics
silicate cement mortar	Small self-weight, good thermal insulation, fire resistance, sound insulation.
alkali magnesium sulfate cement mortar	It can effectively protect light-transmitting materials from corrosion.
ordinary mortar with cork particles	Using cork as a light aggregate to fill concrete can effectively improve the thermal and moisture properties of concrete
ordinary mortar with expansion agents	The expansion agent will significantly reduce the self-shrinkage of concrete and increase its basic creep deformation.
ordinary mortar with basalt fibers	The appropriate amount of basalt fibers produce bridging and hoop effects, which inhibit the development of cracks and improve the compressive and splitting tensile strength of concrete.
Self-compacting cement mortar	It is possible to consume various waste materials generated from industrial activities and is environmentally friendly.

(1) The Choice of Light-transmitting Materials

In this experiment, acrylic material was chosen as the light-transmitting material for the light-transmitting concrete, with the dimensions of a cylinder of 3 *mm* in diameter and 45 *mm* in length.

(2) Selection of Concrete Matrix

A total of six different concrete matrix materials were used in this experiment: silicate cement mortar, alkali magnesium sulfate cement mortar, ordinary mortar with cork particles, ordinary mortar with expansion agents, ordinary mortar with basalt fibers, and self-compacting cement mortar, and the characteristics of each concrete matrix are shown in Table 1.

3.2. Test Method

(1) Matrix Material Matching Ratio

In order to ensure the accuracy of the experimental results, the matching ratio of the matrix needs to be strictly controlled. By consulting relevant information, based on the existing data and combined with the specific operation in the laboratory, the better fitting ratio of six different matrixes was obtained after adjustment. As shown in Table 2-7.

Table 2. Matching ratio of ordinary silicate cement mortar

Material type	Silicate cement mortar	Sands	Water	Water reducer	Coal ash
weight/g	337.5	472.5	135	2.025	101.25

Table 3. Matching ratio of alkali magnesium sulfate cement mortar

Material type	Silicate cement mortar	Sands	Water	Water reducer	Coal ash
weight/g	302	397.31	136.76	1.755	85

Table 4. Matching ratio of ordinary silicate cement matrix with cork particles

Material type	Silicate cement mortar	Sands	Water	Water reducer	Coal ash	Cork particles
weight/g	270	378	108	1.62	81	6.42

Table 5. Matching ratio of ordinary silicate cement matrix with expansion agents

Material type	Silicate cement mortar	Sands	Water	Water reducer	Coal ash	Expansion agents
weight/g	337.5	472.5	135	2.03	101.3	62.90

Table 6. Matching ratio of ordinary silicate cement matrix with basalt fibers

Material type	Silicate cement mortar	Sands	Water	Water reducer	Coal ash	Basalt fibers
weight/g	336.49	471.08	134.60	2.02	100.95	0.06

Table 7. Self-compacting concrete matrix mix ratio

Material type	Silicate cement mortar	Sands	Water	Water reducer	Coal ash
weight/g	302	523	114	25	85

(2)Specimen Preparation

The test block fabrication process described in this paper can be summarized in the following steps (as shown in Fig.1).

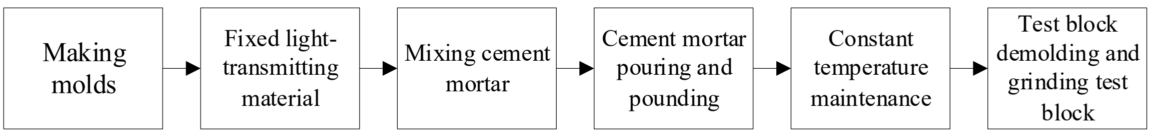

Figure 1. Test block production process

a.Test block size and mold making:The test block used in this experiment is in the form of a board, the size of 150*mm* × 150*mm* × 30*mm*, as shown in Figure 2 below: the wood board material in the actual construction project in general use of high, and the wood board material itself low cost, can be reused, environmental pollution and other characteristics.

Therefore, the composite wood board is chosen as the mold material. Its internal dimensions are the same length and width as those of the test block, and the height (36*mm*) is slightly higher than the height of the test block. It is designed due to the consideration of spilling cement mortar in the process of dumping and handling (as shown in Fig.3).

Figure 2. Schematic diagram of test block size (150×150×30)

Figure 3. Schematic diagram of the mold (150×150×36)

b. Fixed light-transmitting material: The concrete matrix and acrylic were combined in the experiments by means of the first-planting method. Acrylic that is not well fixed may have an impact on the subsequent experiments such as compressive strength. In order to better avoid the phenomenon of uneven distribution of acrylic, in the process of mold preparation, holes of the same cross-sectional size as the light-transmitting material were reserved on the bottom of the mold in advance and did not penetrate the bottom of the mold (as shown in Fig.2). After the acrylic material is inserted into the reserved hole, the cement mortar is then poured, so that the specimen poured out does not affect the subsequent experiments while also having strong operability.

c. Mixing cement mortar. 6 kinds of cement mortar matrix are used small concrete mixer for on-site mixing, in order to ensure the quality of the finished matrix, each time to mix a test block of mortar amount, the mixer adopts the first slow speed mixing 1min, and then fast mixing 2min way, so that all kinds of materials mixed evenly, after the end of the finished matrix material.

d. Cement mortar pouring and pounding. To facilitate the smooth release of the mold, brush the mold with mold release agent 20min before pouring cement mortar. After the cement mortar is mixed, it is quickly added to the mold and placed on the concrete vibrating table for vibrating to make the concrete dense and combined in order to eliminate the phenomenon of concrete honeycomb and pockmarking.

e. Constant temperature maintenance. The specimens were maintained at a constant temperature of 20 (±2) °C for 28 d using a standard maintenance chamber available in the laboratory (shown in Fig. 4 and Fig. 5 below).

Figure 4. Concrete constant temperature steam curing box

Figure 5. Specimen block in constant temperature steam maintenance

f. Test block demolding and grinding test block. After maintenance, the test blocks were demolded and polished to obtain the finished concrete test blocks (as shown in Fig. 6).

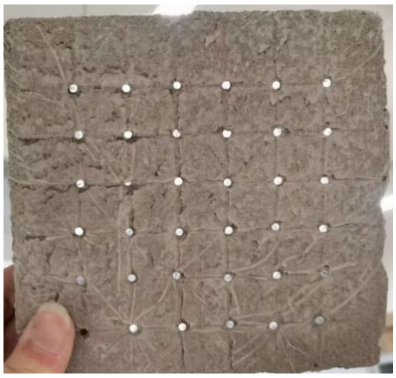

Figure 6. Concrete test block after grinding

(3) Performance Testing

a. Interfacial Bond Performance Test

The microcomputer-controlled electro-hydraulic servo universal testing machine was selected to test the interfacial bond strength of the test blocks, and the specific experimental steps were as follows.

Prismatic light guides with a diameter of 45 mm, a length of 62.5 mm on one side and 17.5 mm on the other, and an angle (α) of 45° between the interface and the vertical direction were fixed to the bottom of a cylindrical mold with a diameter of 45 mm and a height of 80 mm. The test blocks were divided into six groups. One group for each matrix material, as well as the group of ordinary cement mortar used for comparison, with three test blocks cast in each group.

After the samples hardened for 24 h, the molds were removed and then the samples were placed in a room temperature environment to maintain until the age of the test.

After allowing 28d curing, the slant shear experiment was performed using a universal testing machine at a loading rate of 5 mm/min. The pressure when the sliding displacement of the Alec light guide and cement mortar occurred was recorded (P_V). Calculate the downward shear force along the inclined plane by force equilibrium. (A_S). Then the force equilibrium of the interface:

R_a——Resistance generated by the bonding force between resin and cement mortar at the interface;

$$A_S = R_a + R_f + R_k \quad (1)$$

R_f ——Frictional resistance created by pressure perpendicular to the inclined plane;

R_k ——Impedance forces at the interface due to mechanical occlusion;

Assume that the bond strength at the interface isS_{b0},he calculation of bonded shear strength is shown in the formula [4]:

$$S_b = 0.314 P_v \quad (2)$$

b. Compressive Strength Test

The microcomputer-controlled electro-hydraulic servo universal testing machine was selected for the compressive strength test, and its specific test procedure is as follows:

Before the test piece is placed on the test machine, the surface of the test piece and the upper and lower pressure plate surface should be wiped clean. The test piece should be placed on the lower pressure plate or pad of the testing machine, and the center of the test piece should be aligned with the center of the lower pressure plate of the testing machine, taking the side of the test piece when it is formed as the pressure-bearing surface. Start the testing machine, the surface of the test piece and the upper and lower pressure plate or steel mat should be in uniform contact. When the compressive strength of cube is less than 30MPa, the loading speed should be 0.3*MPa/s*~0.5*MPa/s*; when the compressive strength of cube is 30*MPa*~60*MPa*, the loading speed should be 0.5*MPa/s*~0.8*MPa/s*; when the compressive strength of cube is less than 60*MPa*, the loading speed should be 0.8*MPa/s*~1.0*MPa/s*. When manually controlling the loading speed of the press, when the specimen is close to damage and starts to deform sharply, stop adjusting the throttle of the testing machine until it is damaged and record the damage load.

4. Results and Discussion

4.1. Interface Bond Strength Test

The experimental results of interfacial bond strength of each concrete matrix test block are shown in Table 8.

Table 8. Bonding strength test results

Substrate material	Light-transmitting materials	Experiment number	Breaking pressure strength MPa	Average value MPa	Original bonding strength of matrix MPa
Silicate cement mortar(I)	Acrylic	1-1	2.05	2.06	0.65
		1-2	2.11		
		1-3	2.03		
Alkali magnesium sulfate cement mortar(II)		2-1	2.63	2.61	0.82
		2-2	2.57		
		2-3	2.62		
Ordinary mortar with cork particles(III)		3-1	3.23	3.23	1.01
		3-2	3.25		
		3-3	3.20		
Ordinary mortar with expansion agents(IV)		4-1	3.25	3.25	1.02
		4-2	3.21		
		4-3	3.28		
Ordinary mortar with basalt fibers(V)		5-1	4.83	4.82	1.51
		5-2	4.78		
		5-3	4.85		
Self-compacting cement mortar(VI)		6-1	4.62	4.63	1.45
		6-2	4.61		
		6-3	4.67		

The bond strength between each concrete matrix test block and acrylic is shown below:

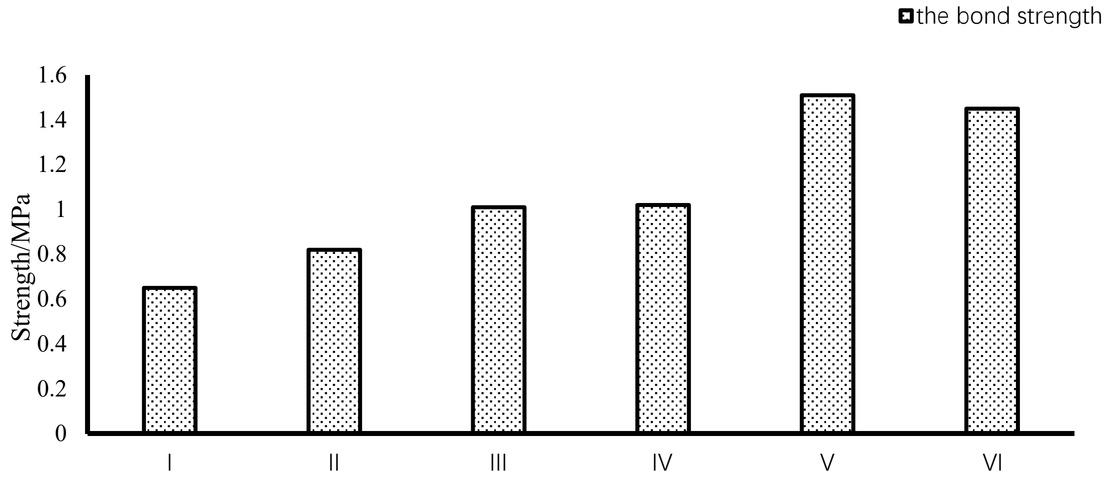

Figure 7. Bond strength between different matrix materials and acrylic

The test blocks were tested for breaking pressure using an oblique shear test, and the oblique shear bond strength was calculated. Three test blocks were tested for each group of specimens, and the average breaking pressure of the three test blocks was used as the breaking pressure of the group. The oblique shear bond strength was calculated according to equation (2), and the experimental results are shown in Table 8.

From Table 8 and Figure 7, it can be seen that the trend of the oblique shear strength is basically similar to that of the compressive strength. The reason why the bond strength is not as large as the compressive strength is that the interface oblique shear damage not only has to overcome the bond force but also the friction force, and the shear force used to overcome the friction force accounts for most of it. According to the data in Table 8, the best bonding ability between the test blocks with basalt fibers in ordinary mortar and acrylic. The next best bonding ability was between the self-compacting cement mortar and acrylic. The worst bonding ability with acrylic was between ordinary cement mortar (silicate cement mortar).

4.2. Compressive Strength Test

The compressive strength of the test blocks was tested by a universal testing machine. Each group of test pieces was tested with 3 test pieces. the average compressive strength of the 3 test pieces was taken as the compressive strength of the group. The experimental results are shown in Table 9.

Table 9. Compressive strength test results

Substrate material	Light-transmitting materials	Experiment number	Breaking pressure strength MPa	Average value MPa	Original breaking pressure strength of matrix MPa
Silicate cement mortar(I)	Acrylic	1-1	44.17	44.24	45.95
		1-2	43.91		
		1-3	44.64		
Alkali magnesium sulfate cement mortar(II)		2-1	24.30	25.01	26.80
		2-2	25.74		
		2-3	24.98		
Ordinary mortar with cork particles(III)		3-1	30.74	30.44	31.66
		3-2	29.69		
		3-3	30.90		
Ordinary mortar with expansion agents(IV)		4-1	29.92	29.94	30.32
		4-2	29.56		
		4-3	30.33		
Ordinary mortar with basalt fibers(V)		5-1	44.40	44.99	45.31
		5-2	45.10		
		5-3	45.48		
Self-compacting cement mortar(VI)		6-1	24.44	24.99	26.92
		6-2	25.64		
		6-3	24.89		

The compressive strength of each concrete matrix test block is shown in Fig. 8.

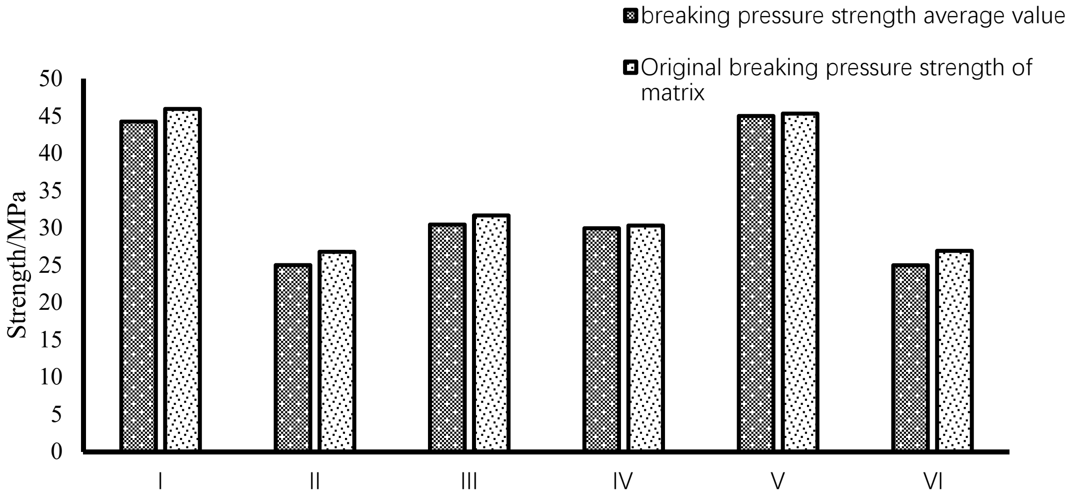

Figure 8. Compressive strength of different matrix materials combined with acrylic

From Table 9 and Fig.8, it can be seen that the change trend of compressive strength after the combination of matrix material and acrylic is basically similar to the original compressive strength of the matrix. The reason why the compressive strength after the combination of matrix material and acrylic is not as large as the original compressive strength of the matrix is that the addition of acrylic rods to the matrix material will reduce the compressive strength of the original matrix material. According to the data in Table 9, the test block of ordinary mortar with basalt fibers in combination with acrylic has the largest compressive strength. The next largest compressive strength was obtained after the combination of ordinary cement mortar with acrylic. The smallest compressive strength after combination with acrylic is the self-compacting cement mortar.

5. Conclusions

By analyzing the above bond strength test and compressive strength test results, a comprehensive comparison of light-transmitting concrete based on six different matrix materials was made. Compared with ordinary silicate cement mortar, the interfacial bonding performance between the light-transmitting material and the cement mortar can be effectively improved by adding basalt fibers to it. In the preparation or use of light-transmitting concrete with acrylic as the raw material, basalt fibers can be added to improve the bonding performance between the light-transmitting material and cement mortar. In addition, because the addition of light-transmitting materials will, to a certain extent, reduce the compressive capacity of concrete test blocks, so its use at the critical points of the structure of the components needs to be avoided.

As a new type of construction material, light-transmitting concrete has certain aesthetic advantages compared to traditional materials while possessing energy saving and consumption reduction. By considering the combination between different matrix materials and light-transmitting materials, the combination between the two is improved and their interface strength is increased. More efforts need to be invested in exploring more quality combinations to achieve the goal of green building.

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