STUDY ON A NEW TYPE OF NON-AUTOCLAVED CONCRETE BRICK AND ITS BINDER

RUI-XI DAI, HUA CHENG*, GUO-XIN ZHENG, JUN-RU REN, CHAO-SHAN YANG, XIN-HAO ZHENG
Department of military facilities, Army Logistics University PLA, Chongqing 401311, China

In this study, a new type of concrete brick, which is suitable for island environment and non-autoclaved, is developed, and the mechanical properties of the bricks are tested. The results show that the compressive strength, flexural strength and compression ratio of the concrete brick can reach 28 MPa, 4.58 MPa and 0.16 respectively after 28 days. The study also discusses the binder which can be used in the brick material, and puts forward the design idea of the special binder. These experimental and theoretical results can be applied to the construction of new masonry structure in island environment, and have certain guiding significance and application prospect for island engineering.

Keywords: *non-autoclaved; concrete brick; superabsorbent polymer; special binder; island environment*

1. Introduction

The South China Sea is an important channel of international ocean transportation. There are rich fishery and oil and gas resources and extremely important strategic position. In order to safeguard marine rights and interests, China has begun to carry out large-scale military and related civil engineering construction in the South China Sea by relying on natural islands and reefs. However, due to the long distance of island reef from the inland, the lack of available building resources and the difficulties in and long period of transportation and construction of the island reef engineering, it is impossible to prepare fast building materials by traditional methods such as firing clay[1]. And it is a reliable technical approach to prepare fast building materials based on concrete [2]. In this study, the rapid construction materials suitable for island reef engineering are developed by seawater aggregate concrete. The concrete with porous structure similar to seawater aggregate also includes foamed polystyrene concrete [3] and foamed concrete [4]. Seawater aggregate concrete [5] is a new type of concrete which appears in recent years. A large amount of concrete coarse aggregates is prepared by using a small amount of Superabsorbent polymer [6] (SAP) which is transported or stored, greatly reducing the transportation volume of crushed coarse aggregate and the cost of concrete. The pore structure system [7] in seawater aggregate concrete not only can reduce the density of itself so as to prepare brick materials, but also can use the seawater absorbed by superabsorbent polymer for constant curing to improve the strength and durability. The seawater aggregate concrete has been applied to the breakwater project (Fig.1) and the yard road project (Fig.2) at the island reef of the South China Sea.

Fig.1 - Breakwater project.

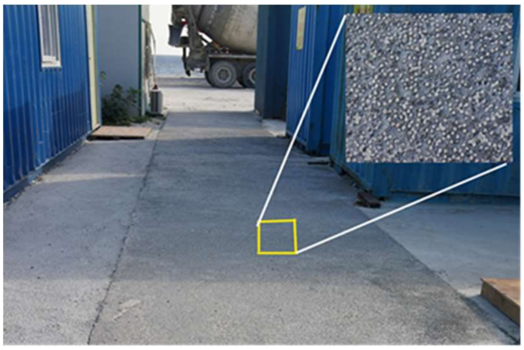


Fig.2 - Yard road project.

At present, there are few research achievements on seawater aggregate concrete,

**Corresponding author*,
E-mail: chwjct@163.com

which mainly focus on the preparation technology, mechanical properties, functional characteristics and so on. The development and application of other building materials such as brick masonry based on seawater aggregate concrete are still lacking, and the related fields need to be further studied.

2. Bricks with Seawater Aggregate Concrete

2.1 Seawater aggregate concrete

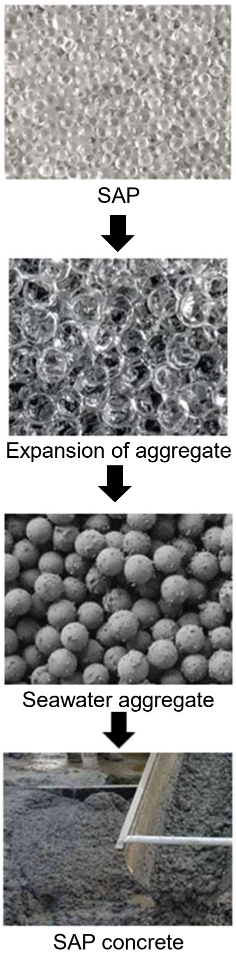


Fig.3 - Preparation process of seawater aggregate concrete with SAP

Seawater aggregate concrete (Fig.3) is prepared with a small amount of superabsorbent polymer and resource-rich seawater according to the idea of "less to more". This aggregate can not only serve as aggregate, but also can establish "reservoir" inside concrete to function as internal curing and self-curing, as well as providing crystallization space for harmful salts in marine environment [8]. The superabsorbent polymer used in the seawater aggregate concrete should firstly allow the seawater to enter, then expands and enlarges to be semi-solid material to meet the requirements of preparation and construction technology, and slowly release the moisture absorbed in the concrete after molding. It provides the moisture needed for hydration reactions of cement and other cementing materials, and improves the hydration degree of cementing materials. In the process of curing of the seawater aggregate concrete, SAP particles lose water continuously, and regular spherical holes are formed in the concrete, and thin layers of dense structure, large hardness and high strength are formed at the hole wall. The single hole as a whole can be regarded as a hollow sphere with a hard shell. The arched surface of the hole is an excellent mechanical structure [9], which can counteract certain external forces. Adjusting the mixing ratio of seawater aggregate concrete it can produce concrete of various strength with a density of 900 ~ 1,850kg/m^3.

The seawater aggregate concrete has the good island reef project adaptability, with the following characteristics:

(1) Porosity. When the curing age of seawater aggregate concrete is reached, saturated SAP releases water completely, and a large number of compact spherical holes with regular shape are formed inside the concrete.

(2) Lightweight. According to different strength requirements, seawater aggregate concrete with different porosity can be prepared. A large number of hole structures (Fig.4) can help to reduce the self-weight of the structure or its components and the construction cost, and facilitate the anti-seismic structure.

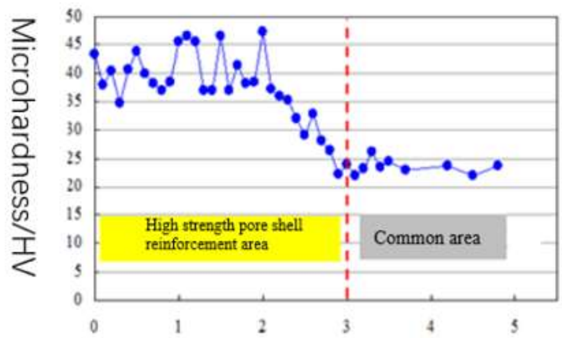


Fig.4 - Mechanical properties of spherical arch shell elements

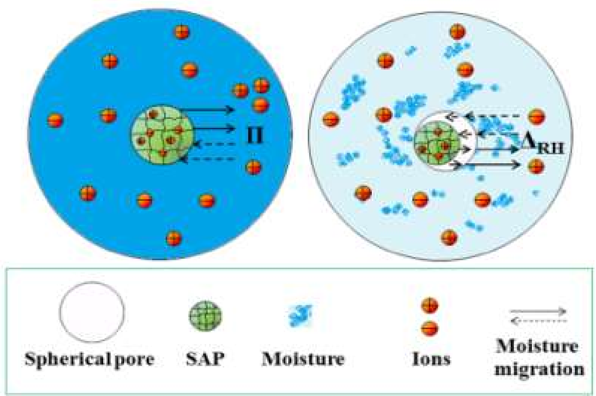


Fig.5 - Self-release water model of seawater aggregate.

(3) Good thermal insulation and sound insulation performance, and obvious energy-saving effect.

(4) It is easy to use local materials. Seawater aggregate concrete does not need crushed stone aggregate. A large amount of expanded aggregate can be prepared with spherical SAP by taking seawater in situ, which greatly reduces the construction difficulty.

(5) Simple curing. After the seawater aggregate concrete is poured, it does not need to use a large amount of fresh water for curing. It only use saturated SAP to realize internal curing and self-curing of concrete (Fig.5). This can prevent the concrete from cracking in the island reef environment, so the operation is simple in practical application and a large amount of fresh water resources can be saved.

Seawater aggregate concrete is a new type of concrete designed and produced for the defense construction of the distant sea. The current study mainly focuses on its preparation technology, mechanism of strength, dynamic and static mechanical properties, sound absorption, thermal insulation properties and so on (see Tab.1).

Table 1

Comparison of the properties of seawater aggregate concrete and ordinary concrete

Technical indicators	Control range of elastic modulus /*GPa*	Apparent density /*kg/m*^{3}	Thermal conductivity /W/($m\cdot K$)	Noise reduction coefficient	60d shrinkage	Friction coeffi-cient	Bending fatigue / Ten thousand times (Stress ratio 0.65)
Ordinary concrete	31	2400	1.5	0.139	5.5×10^{-4}	0.55	40
SAP concrete	2.5-25	1600-1800	0.945	0.348	4.5×10^{-4}	0.75	67

2.2 Seawater aggregate concrete brick

On the basis of the above research, my research group carries out the performance test of seawater aggregate concrete brick.

2.2.1 Raw materials for the preparation of bricks:

(1) Cement: Ordinary Portland cement (OPC) 42.5, with the Brian fineness of 318 m^2/kg was used..

(2) River sand: The fine aggregate has a fineness modulus of 2.8 and a moisture content of 3%.

(3) Mixing water: It consist by sea crystal and tap water.

(4) SAP: Super Absorbent Ploymer (specially made), instead of coarse aggregate.

(5) Fiber: Polypropylene fiber (PP) prevents SAP from floating, homogenizes pores, and strengthens and toughens them.

(6) Admixtures: Silica fume (SF) with Brian fineness of 24,500 m^2/kg, 24,500 m^2/kg, and the content of SiO_2 more than 90%. The water reducing agent (PS) is a powdered polycarboxylic acid superplasticizerr.

According to the orthogonal test on compressive strength and mixing ratio of sea-water aggregate concrete by Ye Min et al. [10], the optimum mixing ratio of seawater aggregate concrete is that the volume fraction of SAP is 25%. Therefore, the SAP volume of bricks made in this test is 25%, and the cube compressive strength is the highest for this mixing ratio. (Table 2)

Table 2

Mixture ratios of materials

Volume fraction of SAP (%)	Mass ratio(related to cement)						
	Cement	Mixed water	Sand	SAP	Fiber	SF	PS
25	1	0.28	0.96	0.35	0.0027	0.051	0.01

2.2.2 Brick preparation process

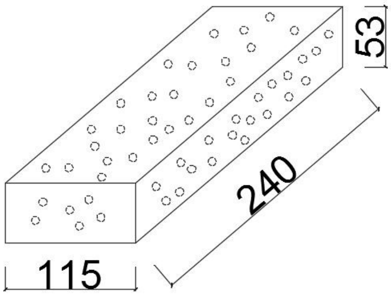
The specification of seawater aggregate concrete brick is a key to its popularization and application. It not only meets the requirements of building modulus and strength specifications, but also fits the habit of single hand operation of masonry workers, without increasing labor intensity but improving labor efficiency. The Terms for Wall Materials (GB/T 18968-2003) [11] states that artificial small blocks used to construct structures or components may be referred to as bricks. The shape of bricks is mostly flat hexahedron, but there are also many kinds of special-shaped bricks, with a length of no more than 365 mm, a width of no more than 240 mm, and a height of no more than 115 mm. We made bricks with dimensions of 240 mm×115 mm×53 mm.

A gravity mixer was used for mixing of the concrete. Firstly, dry mix cement, sand, silica fume, fiber, admixture and other raw materials for 1 min.

Added the water and stir for 40 seconds. After that it discharged.In order to avoid agglomeration of the fibers, the polypropylene fiber need to be treated loosely before being added to the mixer. The seawater aggregate concrete mixture is poured into a self-made standard brick mold (size: 240 mm×115 mm×53 mm), demolded after 24 hours, and then the brick sample is cured in a standard curing chamber (20±2°C, with relative humidity greater than 95%) for 28 days. After 28 days of standard curing, the samples are placed in an indoor environment at 30°C and 65% relative humidity until testing.

The object and model of the bricks are shown in Figure 6.

(a) Object



(b) Model

Fig. 6 - Object and Model of the bricks made of seawater aggregate concrete

2.2.3 Test on compressive strength of bricks

In order to accurately test the strength value of single seawater aggregate concrete brick, we used the methods in the Test Methods of Basic Mechanical Properties of Masonry (GB/T 50129-2011) [12] and Concrete Solid Brick (GB/T 21144-2007) [13] for the compressive strength test of seawater aggregate concrete brick.

The test procedures are as follows:

(1) 12 layers of bricks are extracted from the prepared bricks, and each layer is sawn into two halfs brick to ensure that the length of the sawn half brick is greater than 90mm. Soak the sawn half brick in water, take out after 20 minutes, and use ordinary portland cement to prepare cement paste in proportion of water-cement ratio of no more than 0.3 for standby.

(2) Place a piece of glass on the horizontal test preparation platform, spread a piece of wet newspaper on the glass, and then evenly coat the newspaper with a layer of cement paste with a thickness of no more than 5mm. Wipe the bottom of the half brick with a wrung wet cloth, lay the half brick flat on the cement paste, and press slightly on the brick surface so that the half brick and cement paste are completely bonded, and levelled with a horizontal ruler.

(3) Apply a layer of cement paste with a thickness of no more than 3mm between two half bricks. When stacking, make the fracture of the second half brick opposite to that of the first half brick, and then press and level it.

(4) Wait until the cement paste on the test piece solidifies slightly, turn the test piece with the glass under it, press it onto another piece of glass that has been treated in the same way, and level it with a horizontal ruler.

(5) The prepared test pieces are cured in a closed environment at 20 ± 5 °C. After 3 days, take the test pieces out and measure the length and width of the binding surface of each test piece.

(6) Place the test pieces in the middle of the pressure plate, make the pressure perpendicular to the pressure surface when loading(see Fig.7), with a loading speed of 5kN/s. Avoid impact or vibration during the whole process, and record the data after the test loading.

(a) Sample

(b) Loading

Fig. 7 - Single brick compression test piece

2.2.4 Flexural strength test of bricks

The flexural strength test of bricks 10 brick samples were randomly selected from the bricks according to the Test Method for Concrete Blocks and Brick [14]. Loading mode and break mode are shown in Figure 8.

(a) Loading mode (b) Break mode

Fig. 8 - Flexural strength test

2.2.5 Other properties of bricks

The moisture content of bricks is an important factor that influences the compressive strength of masonry.In a certain range, the increase in the moisture content of bricks will improve the compressive capacity of masonry. This is because the large moisture content of the brick is beneficial to the hardening of the mortar after installing masonry and assures a better cure the mortar in the humid environment. The research [15] shows that the compressive strength of brick masonry with 10% moisture content is 25% higher than that of the reference test piece. So it is necessary to wet the bricks with water in the course of construction. This test is conducted with reference to the method in the Test Method for Concrete Block and Brick [14]. The test results are shown in Table 3.

The Uniform Technical Specification for the Application of Wall Materials [16] stipulates that the overall dimensions of block materials meet the requirements of building modulus as well as the porosity of non-sintered porous block materials. The porosity of seawater aggregate concrete is 20.1%, which meets the requirements of specifications for the porosity of load-bearing blocks.

Table 3

Test results of other performance

The sample mass (*g*)	Dry mass (*g*)	Water saturated mass (*g*)	The moisture content (%)	Porosity (%)	Water absorption (%)	Density (*kg/m*^{3})
2381	2146	2478	7.3	20.1	15.4	1467

2.2.6 Test conclusions

The average compressive strength and flexural strength of the bricks were 28.99 MPa and 4.58 MPa respectively. The porosity, moisture content, water absorption and density of the bricks were 20.1%, 7.3%, 15.4% and 1467 kg/m^3 respectively, as it is shown in the Table 3.

The test results show that the strength discreteness of the batch with seawater aggregate concrete bricks, is smaller that, generally speaking, the flexural strength can reflect the brittleness characteristic of bricks, and the flexural strength value is directly affected by the mixture content of raw materials and the compression strength of bricks. Therefore, the brittleness degree of seawater aggregate concrete brick can be reflected by the ratio of flexural strength to its compressive strength of a single brick, and the grade of seawater aggregate concrete brick can be controlled by these two mechanical property indexes. In the Unified Technical Specification For The Application Of Wall Materials [16], the minimum bending strength ratio of load-bearing blocks is given, and the actual bending strength ratio of sea-water aggregate concrete bricks is compared with the standard limits of porous bricks and autoclaved ordinary solid bricks. As they are shown in Table 4,the actual bending strength ratio is lower than the standard limit value of autoclaved ordinary brick and porous brick, indicating that seawater aggregate concrete brick can be used as load-bearing block.

Table 4

Brick strength and specification limits

Ccompressive strength (*MPa*)	Bending strength (*MPa*)	Bending strength/ Compressive strength ratio	Limit value of ratio of autoclaved ordinary bricks	Limit value of ratio of porous bricks
28.99	4.58	0.16	0.16	0.21

3. Thin Special Binder

3.1 Background of thin binder research and development

In the construction of masonry with traditional block materials, the traditional binders such as masonry mortar is widely used at home and abroad. Mortar joint [17,18] mostly refer to the mortar layer between two bricks in masonry. The existing specification [18] shows that the mortar joint of the masonry is 8 mm~12 mm thick, which is too large. On the one hand, the larger thickness of mortar joint requires a large amount of mortar, which can greatly increase the transportation volume and the transportation and stacking cost of materials for the distant islands and reefs or the inland remote areas. Taking 240 mm thick wall into account, it is necessary to use about 0.255 m^3 masonry mortar (mortar joint is 10 mm) for 1 m^3 brick masonry in traditional mortar masonry, and the transportation quantity of solid materials is 405 kg. If a thin binder is used, the cement joint is controlled to be 3 mm, and the volume of block is increased by about 80 pieces. However, the total volume of solid material transported can be reduced by 188 kg/m^3, which can realize the secondary reduction of construction material transported in island and reef projects. On the other hand, many studies show that the thickness of mortar joint has a great influence on the mechanical properties of masonry. The results of compression tests of A.J Francis et al [19] show that the greater the thickness of the mortar joint is, the more complex the force is and the greater the deformation of the mortar joint is.

There are many researches on the mechanical properties of masonry with mortar joints in China. Cao Jiwen, Shi Chuxian, Tang F et al found that the excessive thickness of the mortar joint leads to the decrease of the overall bearing capacity of the masonry [20-22]. However, Huang Zhaoming found that when the masonry with thicker mortar joint is subject to load, its vertical shrinkage increases, and then cracks tend to appear [23]. Therefore, regardless of the material transportation cost in the engineering construction for the distant sea island reef or the inland remote area, or the angle of the bearing capacity of the masonry, it is very advantageous to greatly reduce the thickness of the grey joint and the develop the thin special adhesive for the engineering construction. However, at present, there are less researches on thin block binders, most of which focus on thin cement mortar for autoclaved aerated concrete blocks, while for seawater aggregate concrete block materials and special construction environment of offshore islands and reefs, there is no related researches on thin special binder. Therefore, it is necessary to develop a thin special binder suitable for seawater aggregate concrete.

3.2 Several kinds of binders suitable for masonry

Seawater aggregate concrete brick is a kind of polar material from the view of chemical property, and strong polar binders such as epoxy resin glue, unsaturated polyester glue, and inorganic glue should be used. In terms of physical properties, it is a kind of brittle materials with high hardness and brittle texture. In general, thermosetting resin adhesives, such as epoxy resin adhesive, phenolic resin adhesive and unsaturated polyester adhesive, should be selected for binding. According to the application and requirement of the bonded materials, it is a kind of load-bearing members. The structural adhesives with high strength and good toughness, such as epoxy resin adhesive, polyurethane adhesive and modified organic silica gel, should be selected. From the point of using the environment, water aggregate concrete brick masonry is generally used in the south China sea reef engineering, and according to related literatures [24]. The south China sea islands and heat resources are abundant, at the age of high temperature, annual average temperature above 26°C, the absolute lowest temperature 15.3°C, the absolute highest temperature of 34.9°C, no extreme high and extreme low temperatures.In addition, islands in the south China sea have clear dry and wet seasons, concentrated rainfall, abundant precipitation, strong evaporation and strong monsoon wind speed, especially perennial seawater and salt fog [25, 26]. Therefore, moisture-resistance (containing more -CN, -OH, and $-NH_2$ groups) and acid-alkali corrosion resistantce adhesives [27] should be selected, such as epoxy resin adhesive, neoprene adhesive and polysulfide adhesive. In view of the process conditions allowed by the bonded members, the seawater aggregate concrete bricks are generally cured and bonded under normal temperature without pressure, and the curing time generally should be within several tens of minutes to several hours. Therefore, the adhesives conforming to such process conditions should be selected, such as epoxy resin adhesive, polyurethane adhesive, unsaturated polyester adhesive and inorganic adhesive.

To sum up, in terms of the organic adhesive, the epoxy resin adhesive is mainly considered, while in terms of the inorganic binder, the inorganic adhesives such as silicate and phosphate cement mortar are mainly considered.

3.3 Prospects for thin special adhesives

At present, 8~12 mm masonry mortar is often used in masonry technology. There are many problems with this so-called "thick-layer technology" [28]. In particular, the large transportation amount of materials results in a lot of transport costs. But this binding method of "thin-layer technology" more and more popular at present, not only solves the large material transportation volume, but also improves and promotes the masonry's force performance and thermal insulation performance [29]. This "thin-layer technology" requires an advanced dedicated binder system [30-32]. The binding performance of traditional common masonry mortar is very poor, the special adhesive must have a small amount and high-efficiency binding ability.

(1) Organic adhesives (such as epoxy resin), polymer modified mortar (PMM) and magnesium phosphate cement-based materials all have good adhesion to portland cement concrete. Therefore, the binding materials with better comprehensive performance can be selected about the mechanical properties, durability, frost resistance and economic aspects.

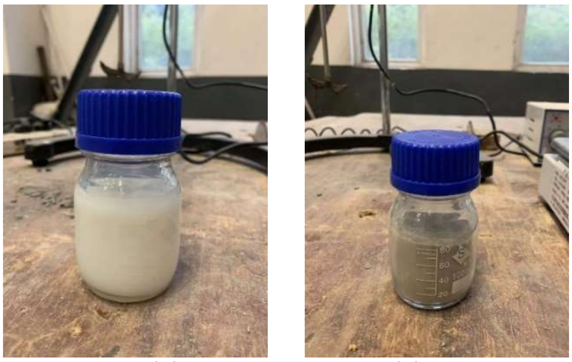
(2) According to the particularity of marine environment and island and reef engineering, the selected binding materials are further modified to achieve the required condition index and good amount binding ability. The initial idea is to combine organic and inorganic materials to make a water solvent.

3.4 Development and performance index of thin special binder

According to the performance requirements of the thin special binder, after a lot of tests, my research group finally selected modified polyurethane as the matrix material, and added ordinary Portland cement as the filler at a mass ratio of 3:1 to obtain a new type of polymer matrix composite binder.

3.4.1 The raw material for preparing the binder

(1) Polymer matrix: modified polyurethane liquid with a solid content of 40% (Figure 9).



(A) (B)

Fig.9 - The composition of the binder (A) Modified polyurethane liquid, (B) Ordinary Portland cement powder

(2) Inorganic filler: ground Portland cement powder (Fig. 9), 45 μm square hole sieve residue not more than 30%.

The binder is composed of polymer matrix 75% and filler 25%.

3.4.2 Preparation method and adhesive process of the binder

The ground ordinary Portland cement powder was mixed into the modified polyurethane liquid, and stirred for 30 s-60 s with a small laboratory mixer, and then stirred evenly. The binder is then poured over a specially made u-shaped steel plate to uniform. The size of the u-shaped steel plate is 240 mm×110 mm×3 mm, and the surface is evenly distributed with circular holes. The binder can enter into the steel plate model through such holes and form a 3 mm thick bond layer, as shown in Figure 10.

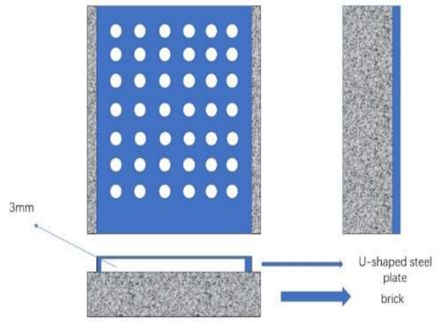


Fig.10 - Adhesive bonding technology

3.4.3 Test contents and results

After a series of tests, including setting time measurement, bonding performance test, shrinkage performance test, compression test and freeze-thaw cycle test. The final performance indexes of the new special binder are shown in Table 5.

Table 5

Performance index of binder

Cure time (*h*)	Tensile shear bond strength (*MPa*)	Flexural bond strength (*MPa*)	The compressive strength (*MPa*)	Shrinkage value (*mm/m*)	Loss of freezing and thawing strength for 50 times
1.5	1.72	1.24	9.87	0.03	0.87%

In this paper, only some performance indexes of the binder were obtained, and no further tests were carried out on the masonry built by the new binder and the brick. The above indexes indicate that the polymer matrix composite has good bonding performance. As for its working performance together with the seawater aggregate concrete brick, it needs to be further tested.

4. Conclusions

(1) Seawater aggregate concrete brick is a

new type of non-autoclaved concrete brick, which is easy to manufacture and especially suitable for marine environment. Its compressive strength is 28.99MPa, its flexural strength is 4.58MPa, its porosity is 20.1%, its water content is 7.3%, its water absorption is 15.4%, and its density is 1,467kg/m^3 after 28 days.

(2) The flexural/compressive strengths ratio of seawater aggregate concrete brick is 0.16, which is lower than the standard limit. Thus, it can be used as a load-bearing brick.

(3) It is necessary to develop a thin special binder for seawater aggregate concrete brick. In this paper, the method is, in the solid content of 40% of the modified polyurethane, at the mass ratio of 3:1 add ordinary Portland cement mixing, the new binder.The experiments show that this binder has good bonding properties. The experiments show that this binder has good bonding properties.

Acknowledgments

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