Application of green building materials in the field of construction and sustainable development

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Abstract. Green building materials are a new category. Compared with the past building materials, ideal building materials have a series of characteristics such as reducing energy consumption, reducing emissions, saving resources, and being recyclable, which makes them become an important reference for sustainable development. This article focuses on foam glass, green walls, and ecological cement. During the research process, it was found that foam glass has better characteristics than ordinary glass, and less waste is generated during the production process, which reduces pollution; The green wall can not only reduce energy consumption, but also absorb harmful substances, and the plant exterior wall can also make people comfortable; Ecological cement can be made from waste materials, which greatly saves resources and realizes recycling. In short, green building materials are an important method to achieve sustainable development and will certainly play an important role in the future construction field.

1 Introduction

The development of science and technology and the city's expansion have further increased the demand for accommodation of the population, resulting in a gradual shortage of living space. To balance the engineering quantity (that is, the total number of houses) and efficiency, many buildings in today's metropolises usually do not include "sustainability" in the selection of building materials, resulting in environmental damage [1]. At the same time, the industrialized building materials also cause hidden dangers to the health of residents because of their chemical composition [2]. But buildings need to rely on environmentally friendly materials with sustainable development characteristics to achieve livability. This research explores the feasibility analysis and application scope of building energy-saving materials by reviewing appropriate and cost-effective materials to achieve sustainable development of buildings.

2 Methodology

The research is conducting in 2 stages. The first stage is talking about why this research and the way used to analyze cases. The second stage is the case study.

2.1 First stage: qualitative analysis

The research used qualitative analysis to analyze. Because global warming caused lots of environmental problems, this research wanted to find out how to release pollution in construction that can be released by changing the new type of materials. This research aims to determine the relationship between energy conservation and resource solutions in different parts of construction. Based on other useful research, this research concluded for new type green materials that can analyze the relationship between energy conservation and resource solution from now on. This research hopes to appeal to people to use environmentally friendly materials after they finish reading this research.

2.2 Second stage: case study or precedents: Analysis of the relationship between energy conservation and resource solution.

In the main body, chose useful examples that release the aim. In the first paragraph of the main body, this research chose cases from the whole world to analyze foam glass. To protect the environment, finding out the recycled materials is necessary, and foam glasses are made from waste glass, and their application is developed for almost a century. This research chose foam glass data, the advantages of foam glass, how foam glass is used in the whole world nowadays and what foam glass will be developed and used in the future. In the second paragraph of the main body, this paper chose cases about different types of the green wall. Walls are important to both outdoor and indoor constructions, so it is necessary to find more economical wall materials. This research analyzed
the relationship between energy conservation and resource solution in 2 different types of green walls and the future of the 2 types of innovative green walls. The cases in the third paragraph of the main body are about eco-cement. This research wanted people to pay attention to one of the most important constructions that people cannot see in the face. Paragraph analyzed cases about what the eco-cement is, the advantages of the eco-cement and how the eco-cement will be developed and used in the future.

Figure. 1. The diagram of research progress

3 Main body

3.1 Foam glass

Foam glass is only about one-tenth of ordinary glass. It has physical properties such as small density, high strength, low thermal conductivity, thermal insulation functions, heat insulation, sound absorption, moisture-proof, waterproof, fire prevention, etc. Compared with other building materials, foam glass material overcomes the defects of other building materials such as perlite, light calcium carbonate, foam plastics, cork, and so on. It has the advantages of thermal insulation, waterproof, moisture-proof, fire prevention, acid and alkali resistance, small density, and high mechanical strength. In addition, it has the inherent advantages of permanence, safety, reliability, chemical corrosion resistance, and protection from ants and rats. It can be used in thermal insulation of internal and external walls of buildings [3].

Table 1. Determination of properties of foam glass made by the American company

| Characteristic                        | Numerical value |
|--------------------------------------|-----------------|
| Density/kg · m-3                     | 128~160         |
| Compressive strength/MPa             | 0.9709          |
| Flexural strength/MPa                | 0.6865          |
| Tensile strength/MPa                 | 0.5786          |
| Modulus of elasticity/MPa            | 1372.9          |
| Thermal conductivity/W · (M · K)-1    | 0.0576 (10℃)    |
|                                     | 0.0791 (150℃)  |
| Specific heat/kJ · (kg · K)-1        | 0.8368          |
| Thermal expansion coefficient / 10-7 · ℃ -1 | 72              |
| Volume water absorption rate / %     | 0.2             |
| Sound absorption coefficient / %     | 0.12            |
| Density/kg · m-3                     | 128~160         |

The low-temperature production process is widely used in Germany, which reduces equipment costs and saves energy. The raw materials are mainly colored or colorless sodium calcium silicate glass and the foamed glass produced has good thermal insulation properties [4]. On the premise of keeping the wall thickness unchanged, improving the thermal insulation performance of various enclosure structures is an important research topic in the construction industry. Reducing the average apparent density of lightweight concrete to 700-900 kg M-3 is the most effective way to improve the thermal insulation performance of the building envelope. Foam glass as a lightweight building concrete aggregate first appeared in France. Granular foam glass can be directly used as lightweight aggregate concrete [5], and Japan has also reported [6]. On the other hand, about 80% of the volume of concrete is sand and stone aggregate. It is necessary to excavate rocks to destroy vegetation to obtain these raw materials, resulting in soil erosion and landslide. The river bed must be dug, the height, shape, and position of the river bed must be changed. The dykes and river channels must be destroyed, the river must be polluted, and even the river channel must be changed, to lose the beautiful beaches and other natural landscapes [7]. Using foam glass as a lightweight aggregate can not only reduce...
pollution but also save resources. It is an effective way to realize green building materials. Previously, researchers in Japan have studied foam glass as a lightweight filler material and have been successfully applied to municipal engineering.

Foam glass is an excellent thermal insulation material. It can be applied to building energy efficiency and has a simple construction and good weather ability. Therefore, it is worthy of popularization and application. With the emergence of new foam glass products and new foam glass products with foam glass manufacturers such as Germany and Japan, the demand for the foam glass market has suddenly increased in recent years. In the early 1990s, China’s foam glass market demand was only 6000 m³, and the market demand in the mid-1990s was about 8000 m³ [7]. By the end of the 1990s, the demand for foam glass had risen to 20000 m³. Therefore, the demand for foam glass in the international market will show an increasing trend in production and sales. Foam glass producers should take advantage of this opportune moment to vigorously develop, promote and export high-quality foam glass products. This high-quality building material will be widely used in actual production and construction to achieve economic and sustainability.

Table 2. Comparison of the main properties of four kinds of commonly used insulation materials

| Materials                  | Thermal Conductivity/W·(M·K) | Density/kg·m⁻³ | Bibulous rate/% | Common Thickness/MPa | Fire-proof level | Correction coefficient |
|----------------------------|-------------------------------|-----------------|-----------------|----------------------|-----------------|------------------------|
| EPS plate                  | 0.038~0.041                   | 18-22           | ≤ 4             | -                    | Not less than E   | -                      |
| Rock wool board            | ≤ 0.04                        | ≥ 140           | ≤ 1             | ≥ 0.04               | A1              | 1.2                    |
| Inorganic insulation mortar| ≤ 0.08                        | ≤ 450           | ≤ 20            | ≥ 0.8                | A1              | 1.25                   |
| Foam glass                 | ≤ 0.058                       | ≤ 160           | ≤ 0.5           | ≥ 0.50               | A1              | 1.05                   |

From the data in the Table 2, it can be seen that in terms of thermal insulation performance, EPS is the best, combined with the correction factor, rock wool, and foam glass thermal insulation performance is equivalent, inorganic thermal insulation mortar is the worst: EPS as an organic thermal insulation material is the worst in terms of fire performance; water absorption rate Foam glass is the best and inorganic thermal insulation mortar is the worst; in terms of compressive strength, inorganic thermal insulation mortar and foam glass are better, and the other two thermal insulation materials are poor. However, as the EPS board for wall insulation, more than 80% of the actual application is non-flame retardant; the water absorption rate of rock wool is high, and the thermal insulation effect is easily affected; the thermal insulation effect of inorganic thermal insulation mortar is poor. In view of the above-mentioned shortcomings of EPS, inorganic thermal insulation mortar, and rock wool board, foam glass thermal insulation has the following advantages: non-combustibility, sticking firmness, and waterproofness.

In summary, while the foam glass insulation system preserves the advantages of the other three materials to the utmost extent, it basically overcomes its shortcomings. The application of foam glass to building energy-saving insulation has incomparable advantages over other materials.[8]

3.2 Green Wall

Green wall materials, a type of commonly-used green materials. It worked by using green ingredients that can absorb methanal and green ingredients with almost no methanal to decrease pollution. There are many types of green wall materials, like Innovative decorative walls, innovatively developed walls, etc. Innovative decorative walls have many new green types of walls, like green
facades and living wall systems (LWS) and bio cork panels. Green facades and living wall systems (LWS) offer numerous ecological and environmental benefits and positively influence the comfort and well-being in and around the building, besides social and aesthetical value [9]. Green facades and living wall systems (LWS) can use in both outdoor and indoor. Bio cork panel is developed from the normal panel by bio-ecological retrofitting [10]. It can use inside of the wall and develop the construction quality. These 2 examples use biology to fulfill the environmental protection goal. The green facades and living wall systems are a name for all walls related to plants, like direct facade greening system, indirect greening system, and living wall system.

The green facades and living wall systems (LWS) plant environmental-friendly climbing plants to provide insulation and shade, reducing energy for cooling, and LWS increases the proportion of plants in the city. The direct greening system and the living wall system based on planter boxes are the most effective wind barriers. The reduction of the wind velocity affects the thermal resistance of the building envelope and thus its efficiency [10]. The green facades and living wall systems have already been used by people few decades. However, few buildings in China use green facades and living wall systems, like K11 MUSEA.

K11 MUSEA uses green facades and living wall systems, both indoor and outdoor. The green facades and living wall systems will bring more fresh air to the nearby areas. In the past, some big malls always have strange odors like formaldehyde because some furniture has unclean ingredients like plastic. Bio cork panels have not been used in architecture practice, so that it will be beneficial if they can be used in recent decades. As a new kind of technological panels, Bio cork panels look like normal panels, but it can have a better effect because of different ingredients like cork oak. In addition, bio cork panels will use widely in one day, and if people can use bio cork panels widely, cork oak forests will be devoted, and landscapes will be enhanced. Global warming caused a big ecological crisis. To decrease pollution on the earth, scientists are finding cleaner ways in construction. For requirements of cities, scientists find out that the green facades and living wall systems, and bio cork panel are two kinds of green walls that can release the city pollution. The green facades and living wall systems can produce more fresh air to release air pollution caused by the lack of plants. The bio cork panels can bring lower energy consumption and lower ecological emissions and give people an economical cycle that can help future value developments. Green wall materials can change a whole city's air condition easily, and these materials are beneficial for people's physical healthiness and energy efficiency [10]. To conclude, green wall materials are just the first step for people to protect the environment, and people will find better and better materials to use and increase the environmental quality in the recent future.

| Type            | cost¥/m³ | CO₂/ kg |
|-----------------|----------|---------|
| Core panel      | 47       | 382     |
| Bio-core panel  | 71.5     | 235     |
3.3 Eco-cement

Eco-cement is cement made from municipal waste incineration ash, industrial waste, slag, tailings, sludge, and other wastes as the main raw materials, after treatment, batching, and strict production management [11]. Eco-cement was born in Japan at the end of the last century. The rapid economic development of Japan in the 1990s brought with it a large amount of industrial and domestic waste, especially municipal waste and sewage sludge. To solve the social problems caused by the environmental pollution caused by municipal waste and sewage sludge.

In 2001, the world's first eco-cement production line was built in Chiba Prefecture [12]. The eco-cement plant can effectively convert industrial waste into green cement that is not harmful to the environment, successfully solving the problem of large amounts of garbage accumulation. And cement made from waste materials can also reduce the cost of cement used in the construction industry. Moreover, there is almost no difference in performance between the produced eco-cement and ordinary cement. As shown in Table 4 and Table 5.

Eco-cement (EC), Ordinary Portland cement (OPC), Slag cement (SC) and Loss on ignition (LOI)

Table 4. Comparison of cement chemical composition and mineral composition

| Cement | Chemical composition (%) | Mineral composition (%) |
|--------|--------------------------|-------------------------|
|        | LOI | MgO | SO3 | Na2Oep | Cl | C3S | C2S | C3A | C4AF |
| EC     | 1.05 | 1.84 | 3.86 | 0.29 | 0.053 | 49  | 12  | 14  | 13   |
| OPC    | 1.32 | 1.96 | 1.96 | 0.62 | 0.006 | 52  | 24  | 9   | 9    |
| SC     | 1.41 | 3.36 | 1.93 | 0.52 | 0.005 |     |     |     |      |

Table 5. Comparison of cement physical properties

| Cement | Specific gravity (g/cm3) | Specific surface area (cm2/g) | Stability | Condensability | Compressive strength (MPa) | Hydration heat (J/g) |
|--------|--------------------------|-------------------------------|-----------|---------------|---------------------------|---------------------|
|        |                          |                               | initial   | final         | 3d  | 7d  | 28d  | 7d  | 28d  |
| EC     | 3.18                     | 4100                          | Good      | 2/21 | 3/29 | 24.9 | 35.2 | 52.4 | 342 | 470  |
| OPC    | 3.16                     | 3310                          | Good      | 2/21 | 3/45 | 28.3 | 42.8 | 59.8 | 326 | 379  |
| SC     | 3.04                     | 3750                          | Good      | 3/00 | 4/20 | 20.8 | 34.9 | 60.4 | 290 | 364  |

It can be seen from Table 4 that the amount of chloride ion in the produced ecological cement is about 0.05, which is slightly higher than the upper limit (0.02) of the Japanese Industrial Standard JIS R5210 (Portland Cement) standard. The mineral composition C3S (3CaO·SiO2), C2S (2CaO·SiO2), C3A (3CaO·Al2O3) and C4AF (4CaO·Al2O3) are the same as ordinary cement, but C3A is higher than ordinary cement. The setting time can be controlled by controlling SO3 at about 4%. It can be found from Table 5 that the strength is slightly lower than that of ordinary cement, but in the long run, it is basically the same as ordinary cement, forming calcium silicate hydrate (C-S-H) and calcium hydroxide water produced by the hydration of C3S and C2S. A highly durable structure composed of hydrates such as hydrates [13]. Nevertheless, people's research on eco-cement has not stopped. In 2003, scientists turned their attention to a new type of ecological cement that can absorb carbon dioxide.
Its characteristic is that it can use waste slag, fly ash, and calcium oxide. The carbon dioxide that brings about the greenhouse effect plays a role in absorption [12].

Eco-cement can save production energy consumption. The raw materials used in its production may use less natural resources and many wastes such as tailings, waste residues, garbage, and waste liquids. The use of municipal waste and sludge to produce ecological cement broadens the source of raw materials, reduces the consumption of natural resources, reduces the cost of cement production, and is conducive to the sustainable development of the cement industry. Significantly reduce CO$_2$ emissions in the production process. In the process of production and use, it is beneficial to protect and transform the natural environment and control pollution. Reasonable utilization of solid industrial waste. The waste landfill treatment process is omitted, no landfill site is needed, and no secondary pollution will be caused during the production process, which is beneficial to environmental protection. The waste can be recycled into resources and can be recycled. Compared with ordinary cement, the production of eco-cement can save natural raw materials such as limestone and clay. At the same time, it can more effectively and reasonably dispose of urban garbage and industrial waste that pollute the environment (500kg of waste can produce about 1t of ecological cement). As a result, there are fewer waste gas and dust emissions during the production process; in addition, ecological cement products can be recycled and reused to achieve the goal of symbiosis with the environment, which is in line with the direction of sustainable development [14]. The specific process is as shown in figure 5.

![Figure 5. Eco-cement recycling system](https://doi.org/10.1051/e3sconf/202130801001)

The raw materials of eco-cement are constantly improving with technology, and more industrial waste can be used to make eco-cement. For example, municipal solid waste incinerators can use the large amount of heat generated to agglomerate raw meat made from incinerator residues, thereby producing ecological cement. Furthermore, the concrete made of this cement can also be activated by the carbon dioxide captured from the emission chimney, thereby reducing the operation's carbon footprint and effectively transferring the carbon emissions in the atmosphere [15]. Even shell ash, rice husk ash, organic waste ash, etc., may also be used to make ecological cement [16].

### 4 Conclusion

This article has researched three mainstream green building materials and analyzed their feasibility and their relationship with sustainable development. The conclusions are as follows:

- Foam glass has excellent characteristics that ordinary building materials do not have and can reduce the generation of dust and waste during the manufacturing process. Moreover, this glass can also be used as a raw material for concrete, reducing environmental damage in the process of mining concrete raw materials, reducing pollution, and saving energy.

- The green exterior wall can directly or indirectly have a benign impact. It absorbs formaldehyde and other harmful substances to the human body while also lowering energy consumption and lower emissions. In addition, the green exterior walls are also green plants to a certain extent. Consequently, strengthening the greening of the city will also bring comfort to human beings.

- Ecological cement uses a large amount of waste as raw materials. While reducing the exploitation of ecological resources also disposes of a large amount of industrial waste and domestic garbage to realize recycling. Moreover, the ecological cement consumes less energy in
the production process, in line with sustainable development.

For those who wish to contribute to the field of green building, this article may be a very good reference material. And this paper puts forward good suggestions for the use of green materials. Although green building materials have not yet been fully promoted and applied, as green building materials production and practical technologies become more mature, they will gradually replace the common building materials currently used shortly.

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