Proceedings of the 5th International Conference on Art, Design and Social Sciences
DOI: 10.54254/2753-7064/2026.36638

The Relationship Between Building Materials and Carbon Capture and Storage Technology

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Abstract. With the increasing demand for carbon reduction in the construction sector, the development of low-carbon building materials and their potential contribution to carbon capture and storage (CCS) have attracted growing research attention. Over the past five years, many studies have explored new directions in the field of energy-saving building materials; thus, this paper will examine the progress and popular issues in current research to identify recent developments. The potential roles of green decorative materials, renewable materials and adsorptive materials in carbon capture and storage, as well as emission reduction, are introduced. Most of the previous studies have focused on improving energy efficiency and reducing carbon emissions. This paper studies the relationship and optimisation of building materials with CCS, as well as improvements in the efficiency, cost and technical specificity of CCS technology through different building materials. Based on the above studies, it has been shown that combining environmentally friendly building materials with CCS can reduce energy consumption and carbon emissions. In addition, the current deficiencies in research are identified and prospects for promoting the development of this area are proposed.

Keywords: Carbon capture and storage, building materials, energy conservation and emission reduction

1. Introduction

The trend of global warming continues, and carbon emissions from the construction industry are excessively high, currently accounting for nearly 40% [1] of global carbon dioxide emissions, putting immense pressure on the environment. How to achieve low-carbon emissions in the construction sector is also one of the major issues of global concern. Although the previous emission reduction strategies of improving energy efficiency and introducing renewable energy have shown good results, further deep decarbonisation requires the addition of technologies such as CCS; therefore, research is being conducted on how building materials can be used in carbon capture, storage and utilisation processes. Most of the current research focuses on the principles and applications of CCS systems themselves or the low-carbon performance of green building materials. However, all-encompassing research on how building materials can be employed for CO_2 capture and storage, as well as reducing costs and targeted applications for CCS, is still lacking. The high-energy-consumption steps of the traditional CCS system are CO_2 capture, compression,

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transportation and geological storage. As a result of the above processes, there are high investment and operating costs; thus, large-scale application is hindered, traditional methods are not suitable for large-scale use, and reliance solely on traditional CCS technology cannot address the problem. Although many kinds of building materials have appeared, according to the different external and internal conditions of a building, various materials need to be selected to further help CCS technology address this problem. This paper systematically examines the connection among building materials and carbon capture and storage, and analyzes and compares the principles and reasons for some applicable materials. The three sections in the summary are: How green and environmentally friendly decorative materials, renewable materials, and adsorptive materials help improve the carbon reduction efficiency of CCS in the construction industry. Second, materials from all sides will be introduced, and for each method, its applications and technological progress will be presented. The third is a summary and recommendations section, followed by a concluding statement and future outlook.

2. Building materials

Green and Environmentally Friendly Decorative Materials in Construction: Selecting eco-friendly materials for the exterior of a building can reduce damage to nature and promote the construction of an ecologically friendly community. Continuously introduce green and environmentally friendly materials to gradually reduce the use of low-quality building materials and meet the decorative requirements of the buildings [2]. To extend the service life of the building materials and reduce maintenance costs, green and environmentally friendly materials will be used for the exterior construction.

2.1. Green and environmentally friendly decorative materials in construction

Green wall materials can be used on the outside of buildings to recycle waste resources and reduce the environmental impact effectively. For instance, wood biomass biochar is also an insulating, high-porosity material that can be used in concrete systems to improve wall insulation, sound insulation and carbon adsorption capacity. If the rate of urban vegetation is also increased at the same time, in combination with the dual approach of using wood biomass biochar, carbon uptake will be promoted, and the city's carbon-sink capability and additional paths for carbon reduction will be enhanced [3]. Mineralised products in green building materials are also a form of carbon sequestration. Alkaline substances in the solid waste, such as CaO and MgO, can be used directly as starting materials for the production of concrete blocks and bricks by reacting with CO_2 to form carbonates. Alternatively, some of the mineralised and stabilised bulk solid waste can be used as artificial aggregate. Aggregates can be directly substituted for some building materials, such as natural sand and gravel in the subgrade layer and ordinary concrete, to achieve resource substitution and sustainable use of resources. Mineralised products can also absorb CO_2 in construction materials and convert waste into new building materials [4]. Some industrial alkaline waste residues can also promote the carbonation reaction to improve efficiency, thus avoiding traditional mining and broadening or flexibly expanding the range of options for engineering, environment and economy benefits [5]. CCS has been optimised to address the cost problem, and now it can be used for CO_2 utilisation and long-term carbon sequestration through mineral carbonation. However, the long-term stability has not been verified, and further experiments are needed to determine whether the sequestration in building materials is permanent [4]. Ecological Glass is a kind of building exterior cladding. It has a small size, is energy-efficient, environmentally friendly, and can block some

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ultraviolet (UV) and infrared (IR) rays. It can keep out the heat outside in summer and prevent heat loss from indoors in winter to maintain a stable warm temperature indoors [6]. These energy-saving materials can be used in combination with low-carbon materials and building materials that actively absorb carbon to reduce the carbon emissions from buildings and thus address the problems of high CCS costs and energy consumption. Ecological glass is recyclable and can therefore be used to promote green development. Green and environmentally friendly materials can meet the requirements of green building development and improve the external appearance of buildings at the same time. Such materials can reduce energy consumption and decrease solid waste; thus, they promote the low-carbon development of the construction industry. These materials can reduce the lifecycle carbon emissions from building construction and operation.

2.2. Renewable and recycled materials

Renewable and recycled materials can reduce embodied carbon emissions by decreasing dependence on virgin resources and improving resource efficiency [7]. These materials have strong corrosion resistance and a long service life. Whether it is the reduction in resource needs due to the lightweight nature of aluminum-magnesium composite materials at the source, the decrease in carbon emissions during transportation due to lower density per unit weight, the reduction in construction time and thus the decrease in carbon emissions and energy consumption due to the assembly performance of the materials, Biobased building materials are sustainable and can also reduce cost issues. Some raw materials are photosynthetic plants, which can both sequester carbon dioxide and reduce it at the source. Some building materials can also improve the strength of concrete and extend the lifespan of buildings [8]. These types of building materials passively absorb carbon due to the materials themselves, while CCS technology actively absorbs carbon. The two different forms of carbon reduction methods thus form a complementary relationship. Compared to CCS, the scope of renewable materials is broader, and they consume less cost and resources, filling some of the shortcomings of CCS technology and methods such as the reuse of construction waste can offset carbon emissions and convert them into useful materials, which also provides further solutions for the dual carbon plan [9, 10].

2.3. Adsorptive materials

• Some porous materials can exhibit adsorption properties, with certain pore structures capable of fixing and adsorbing CO2. Additionally, some modifiers (mainly including acids, bases, metals, and amines) can be used to modify the adsorbent, creating more active sites on the adsorbent surface and enhancing For example, porous concrete structures are loose and porous, but thru the modification of porous concrete materials, zeolite porous concrete can be made, which not only improves filtration and adsorption but also helps to achieve ecological balance [11]. Mixing some porous materials with concrete can effectively improve carbon adsorption efficiency. Compared with conventional CO_2 capture processes, adsorptive building materials may reduce energy consumption during capture and provide additional application scenarios. However, the hydrophilicity of zeolites can reduce the amount of CO_2 adsorbed under humid conditions, which has a certain impact on their adsorption properties in environmental contexts [12]. Biomass porous materials can also adsorb CO_2 thru physical adsorption, chemical adsorption, and the synergistic effect of physical and chemical adsorption. Physical and chemical activation can increase the surface area and adsorption performance, thereby enhancing efficiency. Doping with heteroatoms can increase adsorption capacity, and template methods can precisely Agricultural and forestry residues, as primary raw

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materials, reflect cost control [13]. However, achieving suitability for large-scale utilization, economic viability, and environmental sustainability still requires ongoing research. Amine-containing porous organic polymer materials have improved adsorption capacity, selectivity, and adsorption amount, and under certain conditions, they can maintain the carbon dioxide adsorption capacity of POPs in humid environments [14]. However, the stability of amine-based materials, their large-scale production feasibility, and processing performance still require further investigation. These approaches can enhance CO_2 capture efficiency and reduce the associated energy and economic costs. The integration of these materials with CCS-related strategies provides additional pathways for improving carbon reduction performance and promoting the development of low-carbon emission reduction technologies. Table1 describes Comparison of CO_2 Interaction Mechanisms and Relationships with CCS among Green Decorative Materials, Renewable Materials, and Adsorptive Materials

Table 1. Comparison of CO_2 interaction mechanisms and relationships with CCS among green decorative materials, renewable materials, and adsorptive materials

Level	Mechanism of CO_2 action	Relationship with CCS
Green and environmentally friendly decorative materials	Primarily based on chemical reactions, relying on alkaline components reacting with CO_2 to form stable carbonates.	Reduce CO_2 at the source to decrease the use of CCS technology; carbonation can directly sequester carbon, complementing and upgrading CCS. Mitigate some of the issues with CCS
Renewable materials	Using the material itself to sequester carbon in chemical reactions	Indirectly complementing traditional carbon neutrality and carbon capture technologies, it allows carbon emissions to be offset and transformed into usable materials, reducing energy loss and waste discharge.
Adsorbent materials	Chemical adsorption and physical adsorption synergy: CO_2 undergoes a chemical reaction while the porous structure provides physical adsorption channels.	Direct contact, adsorbent materials can enhance the capture rate of carbon dioxide and other substances, reducing cost consumption.

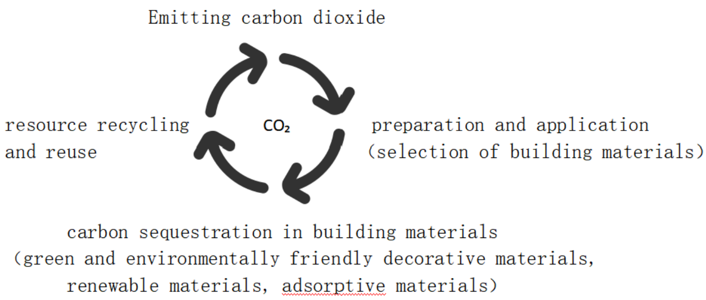

Figure 1. Cycle diagram

DOI: 10.54254/2753-7064/2026.36638

Figure1 shows that Carbon dioxide is used to select suitable building materials for carbon fixation according to different needs, and then the materials with fixed carbon are continuously reused thru resource recycling.

3. Discussion

With the increasing demand for energy conservation and carbon reduction, more attention has been paid to the development of low-carbon technologies. Traditional carbon neutrality and carbon capture technologies are too costly and carry the risk of secondary energy loss. Their broad application range makes it difficult to achieve targeted and efficient low-carbon emissions reduction. By applying green decorative materials, renewable materials, and adsorptive materials, targeted carbon reduction strategies can be developed for different application scenarios. These methods cannot completely replace the fundamental carbon capture and storage technologies, but they significantly enhance the application of these technologies. Through the application of certain green building materials, carbon sequestration can be achieved through chemical reactions such as carbonation. Compared to traditional CCS, this method improves carbon sequestration efficiency and reduces costs, thereby addressing some of the shortcomings of CCS. However, this method still has some limitations that need further verification. The use of renewable resources, such as biomass-based materials, can reduce carbon emissions through material substitution and carbon sequestration during plant growth, thereby alleviating the cost and energy pressure associated with traditional CCS technologies. The application of these materials in construction is inseparable from CCS technology itself, thus forming a complementary and supportive relationship between the two. However, some renewable materials, such as temporary wooden houses, will produce carbon emissions when they are eventually dismantled, indicating that carbon cannot be permanently stored, and different materials will have different storage time scales [15, 16]. Adsorptive materials and carbon capture and storage are directly related, as they enhance carbon dioxide capture rates and reduce cost consumption thru the synergistic effect of physical and chemical adsorption. However, under certain specific conditions, their adsorption rates may be lower than the adsorption effects in normal environments, and some stability aspects still need to be verified. These three materials can be approached from the perspectives of improvement, assistance, and mitigation. Some building materials have specific requirements for environmental conditions and can be selected based on different climates. The sources of different materials also vary, and different building materials can be selected based on the proportion of local raw materials.

4. Conclusion and outlook

In order to achieve a carbon-free and reliable energy system, it is necessary to gradually develop CCS technology, which will eventually evolve into CCUS technology. The continuous development of technology aims to achieve comprehensive decarbonization by integrating CCUS technology with renewable energy and other low-carbon technologies. CCS technology has made significant progress, but its application in the construction sector still faces challenges. The system still has some unavoidable issues. Using suitable green building materials can effectively reduce costs, energy loss, and increase efficiency, further advancing CCS technology and gradually alleviating energy-saving and carbon-reduction problems in the building sector. Currently, the use of building materials also has some limitations; it is not possible to use the same material on a large scale, and no single material can address all the issues arising from traditional CCS technologies. The experimental conditions for different materials vary significantly, making direct comparison

DOI: 10.54254/2753-7064/2026.36638

difficult. In the future, with the deep advancement of green building and energy-saving and emission-reduction goals, further research and development of green building materials will be needed, such as the development of new adsorption materials and the integrated design of building materials with CCS. This will help address some limitations of certain materials and conduct practical

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