Properties of Artificial Stone According To Replacement Ratio of Binder

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Abstract. Because of the increased demand for interior space improvement as well as the exterior and structural performance of buildings as a result of the increase in older houses, artificial stone materials with low unit price, favorable material supply and demand, lightweight, and excellent thermal insulation performance are needed. In this study, the organic and inorganic binders were substituted for the excellent properties of the artificial stone. The following are the results: 70 percent of blast furnace slag was chosen as a binder among the artificial stone materials that meet the flexural strength criterion of 4Mpa or more for KS F 4035 terrazzo plate, showing roughly 60% the performance compared to organic binders and superior results compared to other binders. In addition, with respect to aggregate, recycled aggregate did not satisfy the flexural strength standard of artificial stone, and showed superior strength when mixed with natural aggregate than basalt wasterock. Blast furnace slag replacement rate of 70% and natural aggregate replacement rate of 70%, were chosen as the optimal combination because both satisfied the standard flexural strength and attendance rate of artificial stone and yielded the best results.

Keywords: Artificial stone, Blast furnace slag, Fly ash, Magnesium oxide, Alkaline activator

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1. Introduction

With the advent of the 4th industrial revolution, the Korea Energy Agency, the Ministry of Land, Infrastructure, and Transport, and the Ministry of Trade, Industry and Energy implemented the mandatory zero-energy building in 2020, emphasizing the importance of carbon emission reduction, energy-saving and efficiency(Jung, 2019). As a result, of the government`s ongoing implementation of the energy-saving strategy for buildings, the performance required for building materials while constructing a structure has increased, and the passive, zero-energy building has increased. The need for building exterior insulation was highlighted as the mandatory zero-energy building program expanded. Although the relevance of external insulation finishing materials (dry-bit method) has grown, fire safety has become a concern. In 2015, a fire in an Uijeongbu apartment sparked interest in the fire safety of finishing materials. The external wall dry bit structure was identified as a problem in the spread of the flame. Due to the limitation of the organic insulation, the flame that started on the first floor spread widely along the exterior wall, causing victims and deaths due to smoke and toxic gas. Accordingly, the importance of fire safety is highlighted, and the demand for inorganic insulation materials for external insulation is developing. As inorganic insulation materials, panels and blocks are generally manufactured based on ALC, and most are widely used as temporary walls and insulation materials(Lim, 2018; Lim, 2019). However, since a high-temperature and high-pressure curing process is necessary, production and manufacturing expenses are high. As a result, there is an issue with the economic burden being high, and the amount of CO_2 generated in the process of machine use is increasing. In addition, inorganic insulation materials are vulnerable to moisture, such as mold growth due to condensation. As a result, problems such as fire accidents caused by insulation materials and mold caused by moisture are becoming social and environmental problems, and environmental problems that require solutions. Currently, it is necessary to develop a new insulation material to compensate for the fire risk of organic insulation materials and the moisture vulnerability and economic feasibility of inorganic insulation materials. Moreover, in Korea, research on CLC and insulation materials using organic and inorganic materials is insufficient. Therefore, this study intends to secure non-combustibility and thermal insulation properties and improve workability and economic feasibility through manufacturing techniques and product development of artificial stone grafted with organic/inorganic composite insulation materials. Accordingly, it is expected that the market for finishing materials will expand further as the demand for finishing materials increases. Insulation materials attached to exterior wall finishing materials require fire resistance, and CLC is an ultra-light inorganic product and has incombustibility, so it is attracting attention as an alternative to organic insulation materials (extrusion insulation board, etc.) that are vulnerable to fire. Compared to ALC (Autoclaved Lightweight Concrete), which is a commonly used lightweight aerated concrete, CLC is economical because it does not require autoclave curing, which is a high-temperature and high-pressure curing method. In addition, the non-combustible material can compensate for the disadvantages of the organic heat insulating material used in the past(Lim, 2019; Lim, 2019).

2. Experimental plan

This is the first year of research into artificial stone products that incorporate organic/inorganic composite insulation materials. The physical properties of artificial stone (flexural strength, compressive strength, density, and water absorption) are evaluated according to the substitution rate for each organic/inorganic binder in order to produce artificial stone and evaluate its performance as an exterior wall finishing material. After selecting the optimal mixture through the comparison of the derived data, the physical properties of the artificial stone are analyzed according to the substitution rate for each type of aggregate to select the binder and aggregate for the artificial stone production and derive the appropriate substitution rate.

Table 1: Experimental factors and levels

Experimental factors	Experiment levels					
Binder	OPC, MgO	OPC, BFS	OPC, FA	OPC, S738P	OPC, VAE RDB	5
W/B	40%					1
Aggregate mixing ratio	70 (wt %)					1
Replacement ratio of Binder	0, 10, 30, 50, 70 (wt %)					5
Curing condition	Temp. 20±2℃, Hum. 60±5%					1
Experimental item	Flexural strength, Compressive strength, Density, Absorption ratio					4

1)OPC : Ordinary Portland Cement 2)MgO : Magnesium oxide 3)BFS : Blast furnace slag 4)FA : Fly ash 5)S738P : Anti-sag polymer 6)VAE RDP : Cement mortar reinforcement polymer

2.1. Materials

A polymer for improving concrete construction and an inorganic binder with excellent self-bonding ability were utilized to test the properties of artificial stone according to organic and inorganic binder.

- **Organic Binder (S738P, VAE RDP)**

Polymers used for construction are classified into acrylic, VAE, and SBR based on their components. Liquid dispersion is used in various paints, adhesion, coating, primer, waterproofing, flooring, repair materials, textile, wood, iron plate, concrete, etc. Powdered resin is a product in powder form according to the quality control, construction equipment, and logistics system of the construction site, and is used in various cement mixture products such as construction adhesives, flooring materials, finishing materials, waterproofing agents, and repair materials. S738P used in this experiment has good flowability in powder form and is effective in improving fluidity.

VAE Redispersible Powder (RDP) is a fine powder prepared from vinyl acetate-ethylene copolymer base, and it is easily dispersed in water to form a stable emulsion. It is easy to handle and store because it has added powder properties that flow easily to the original EVA emulsion properties. Mixing dried mixtures such as cement, sand, and aggregate at the factory and RDP powder results in uniform and reliable performance on the job site. It can also be mixed with cement and plaster or used as a sole binder in other dry mix formulations. It improves the adhesion, flexibility, abrasion resistance, and workability of products sold in the form of various dry powders, including thin-set mortar, tile adhesive, grout finish plaster, and trowel compound.

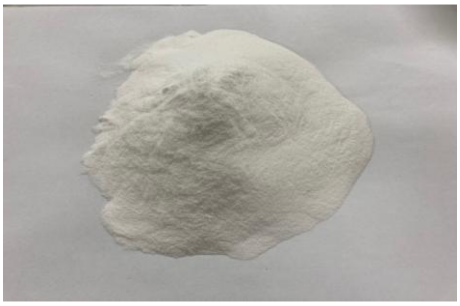


Fig. 1: S738P

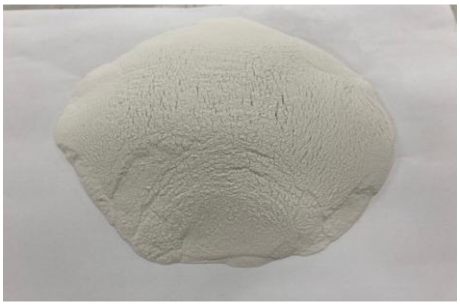


Fig. 2: VAE RDP

- **Inorganic Binder (OPC, MgO, BFS)**

As for the cement, type 1 ordinary Portland cement of domestic S company was used, and ordinary Portland cement has lime, silica, alumina, and iron oxide as main components.

Magnesium oxide is made by separating carbon dioxide by heating and sintering magnesite because high-purity magnesium oxide cannot be produced in the natural state, and magnesia with different characteristics is produced depending on the sintering temperature. The calcination temperature affects the crystal size and specific surface area of MgO, and thus the expansion performance of MgO is changed. Magnesium oxide includes dead burned magnesia fired at 1,400°C or higher, hard burned magnesia fired at 1,000-1,400°C, and light burned magnesia fired at 400-1,000°C depending on the firing temperature. The higher the calcination temperature, the lower the hydration reaction rate. In this study, light magnesia was used as well as potassium monophosphate as an alkaline activator potassium monophosphate as an alkaline activator(Lim, 2018; Song, 2019).

BFS is defined as dry pulverization of crushed blast furnace slag or the addition of gypsum to it according to KS F 2563 "fine blast furnace slag powder for concrete". The fine blast furnace slag powder used in this experiment was a domestic S company product, and a fine blast furnace slag powder having a density of 2.91 g/cm^3 and a fineness of 4,464 cm^2/g was used. The alkaline activator used is NaOH(Park, 2002; S, 2007).



Fig. 3: OPC **Fig. 4: MgO** **Fig. 5: BFS**

2.2. Experimental methods

- **Flexural and compressive strength**

For the flexural strength test method, a 40×40×160 (㎣) specimen was used. To reduce the error of the test, prepare three specimens, measure the strength at 3, 7, and 28 days of age and compare them. For the compressive strength test method, a specimen 50×50×50 (㎣) was used in accordance with 'KS L 5105' (Lee, 2021; Lee, 2020).

- **Density and Absorption ratio**

To measure the density and water absorption, a test specimen was prepared using 40 × 40 × 160 (㎣). In order to measure the water absorption, the cured specimen is demolded, dried in a dryer for 24 hours, and then the weight is measured(Lee, 2021; Kim, 2021; Park, 2019).

- **Attendance ratio**

In accordance with KS F 4035, two diagonal lines are drawn on the surface of an artificial stone 300 × 300 × 45 (mm), and then, for each straight line, the dimension of the part where the straight line passes over the aggregate is 0.5 as shown in the figure below. It is read in mm, calculated according to the formula, and expressed as the average value(Kim, 2021).

3. Experimental result and analysis

For the optimal mixing of inorganic binders, magnesium oxide, blast furnace slag, and fly ash were selected as binders to produce artificial stone, and the physical properties were analyzed through flexural strength, compressive strength, density, and water absorption tests. In addition, an organic artificial stone was manufactured using polymer-based S738P and VAE RDB as binders, and the performance of the inorganic binder and the organic binder was compared through the same test. Blast furnace as a binder shows superior results compared to other binders by expressing 66.2% of S738P replacement rate of 30%, the lowest density among artificial stone materials that satisfy the flexural strength standard of KS F 4035 terrazzo plate of 4MPa or more, and 67.7% of the lowest water absorption rate of VAE RDB replacement rate of 30%. Slag 70% was selected(Cho, 2022; Hong, 2021).

- **Case of S738P**

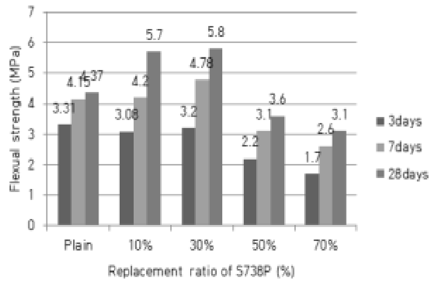


Fig. 6: Flexural strength

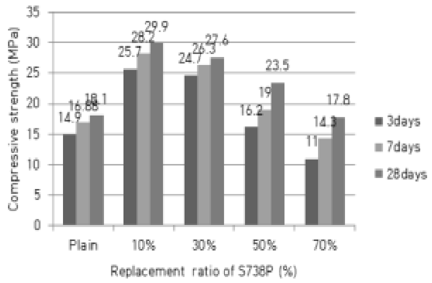


Fig. 7: Compressive strength

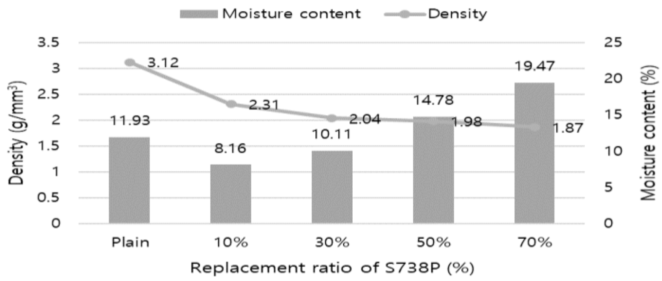


Fig. 8: Density and Absorption

- **Case of VAE RDB**

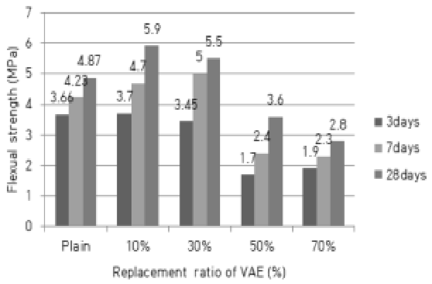


Fig.9: Flexural strength

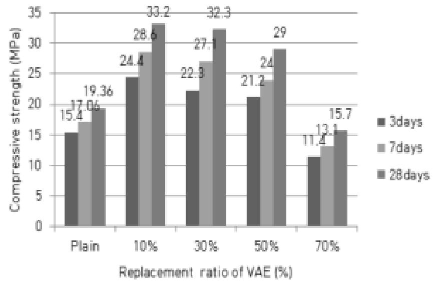


Fig. 10: Compressive strength

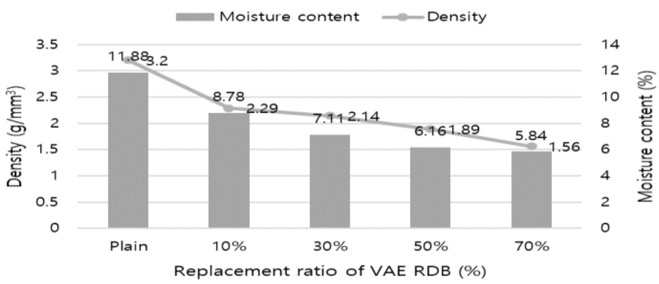


Fig. 11: Density and Absorption

- **Case of MgO**

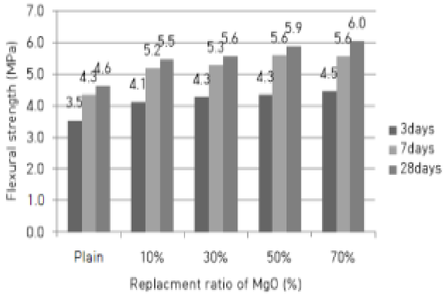


Fig. 12: Flexural strength

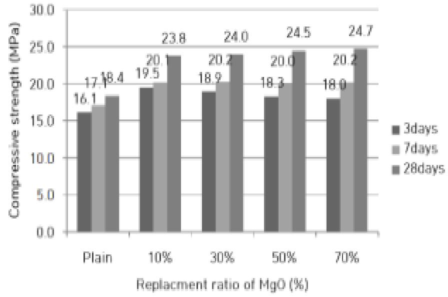


Fig. 13: Compressive strength

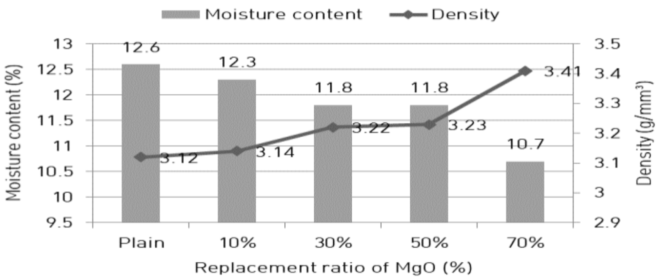


Fig. 14: Density and Absorption

- **Case of BFS**

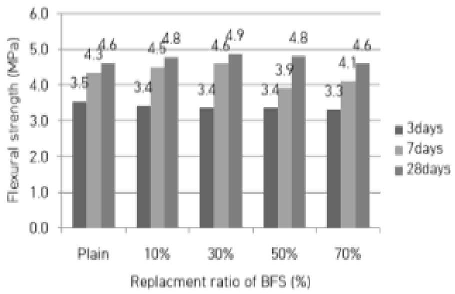


Fig. 15: Flexural strength

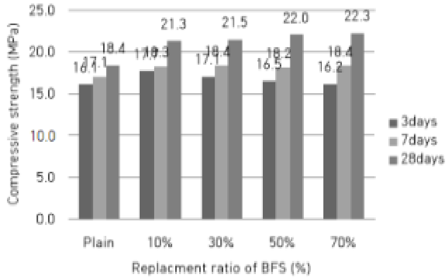


Fig. 16: Compressive strength

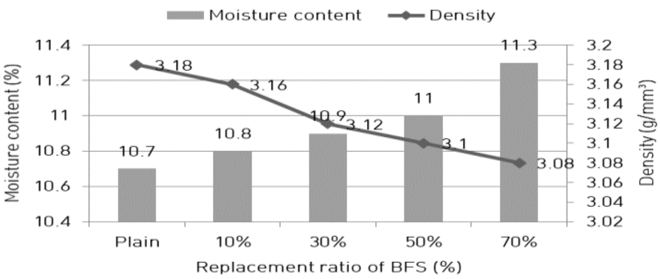


Fig. 17: Density and Absorption

• **Case of FA**

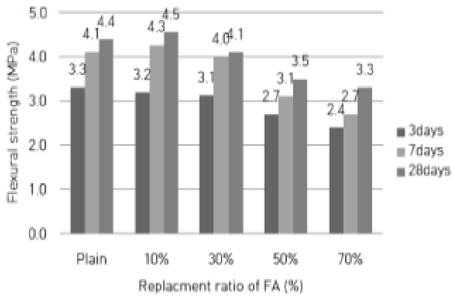


Fig. 18: Flexural strength

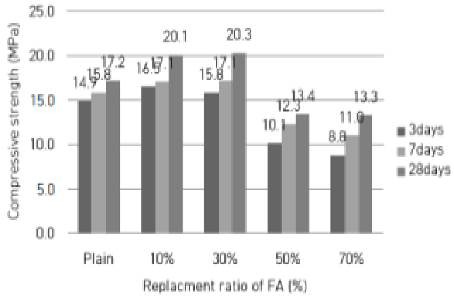


Fig. 19: Compressive strength

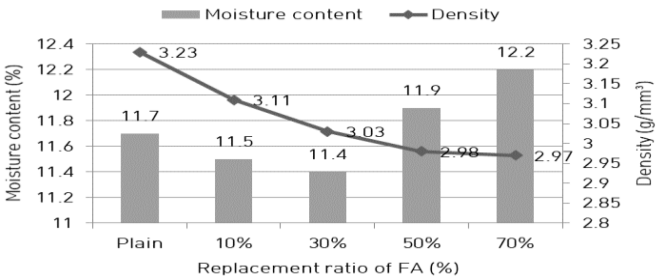
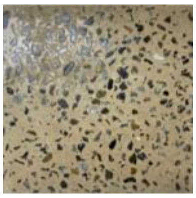
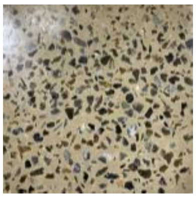
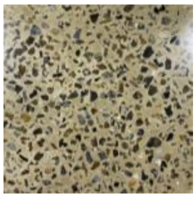
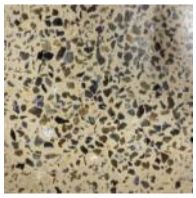


Fig. 20: Density and Absorption

• **Attendance ratio by natural aggregate replacement rate of artificial stone using blast furnace slag (70%) as a binder (KS F 4035)**

When aggregates are mixed, the results show that the substitution rate of 70% to 50% or more of the attendance rate of KS F 4035 is satisfied. Therefore, in the subsequent strength test of artificial stone according to the type of aggregate, the aggregate substitution rate variable was set to 70% and 80%.

Table 2: Attendance ratio according to aggregate replacement rate

Replacement of aggregate (%)	50	60	70	80
				
Attendance ratio (%)	43	47	52	54

• Analysis of the physical properties of artificial stone according to the type of aggregate (natural aggregate, recycled aggregate, basalt waste-rock)

Based on the results of previous experiments, strength tests were conducted based on the 70% and 80% aggregate replacement rates for the blast furnace slag replacement rate of 70%. Recycled aggregate did not satisfy the flexural strength standard of artificial stone, and natural aggregate and basalt waste-rock showed similar results but showed excellent strength when mixed with natural aggregate. Blast furnace slag replacement rate of 70% and natural aggregate replacement rate of 70%, which satisfied the standard flexural strength and attendance rate of artificial stone, and derived the best values, were selected as the optimal combination.

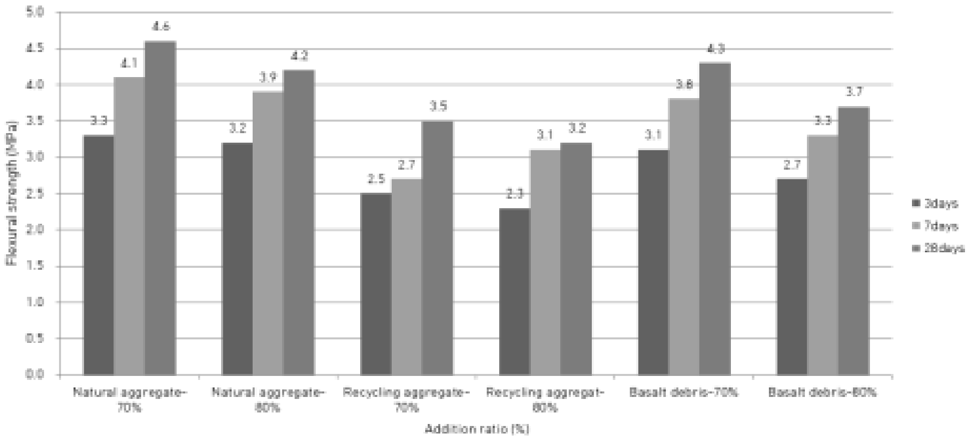


Fig. 21: Flexural strength

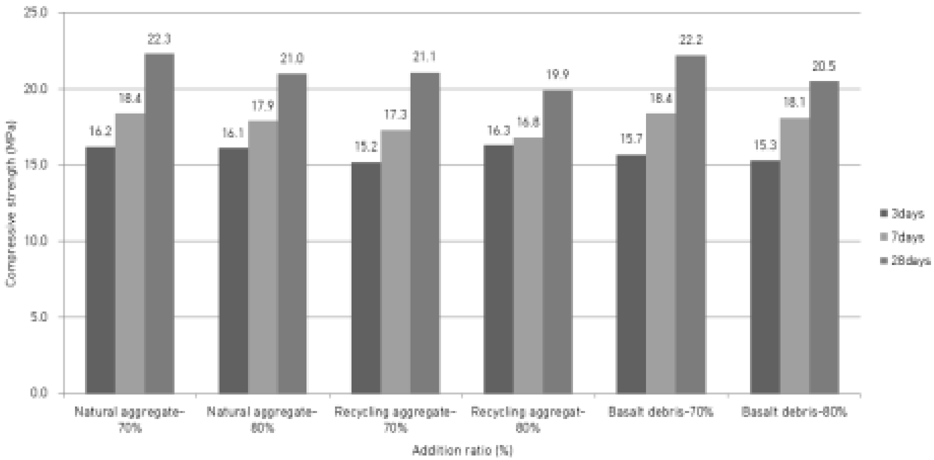


Fig. 22: Compressive strength

4. Conclusion

In this study, artificial stone materials for each type of binder were manufactured and tested to serve as benchmark data for future research on the production of lightweight and thermally insulating artificial stone grafted with CLC. S738P and VAE RDP were replaced with organic binders and blast furnace slag, fly ash, and magnesium oxide was replaced with inorganic binders. The result of the study are as follows:

1. In terms of strength, artificial stones using organic binders show higher values than artificial stones using other inorganic binders. It can be seen that, because of the high viscosity of the polymer, the polymer composite has higher compressive, tensile, and flexural strength than general concrete, so even artificial stone has high self-strength(Pyeon, 2019). Among inorganic binders based on flexural strength, the highest values are shown when magnesium oxide is 70%, blast furnace slag is 50%, and fly ash is 10%, respectively.
2. Density shows similar values except for VAE RDP. In terms of moisture content, magnesium oxide and fly ash show relatively high values at 11% compared to blast furnace slag.
3. In the attendance rate part, aggregate replacement rates of 70 and 80 (%) are considered appropriate because the results satisfy the KS standard (50%) from 70% or more of aggregate mixing, and cracks and strength degradation occur at 80%.
4. As a result of the comparative experiment on the type of aggregate, recycled aggregate did not satisfy the flexural strength standard (4MPa) of KS artificial stone, and the best results were obtained when natural aggregate was mixed.

Therefore, 70% replacement rate of blast furnace slag and 70% of natural aggregate replacement rate were selected as the optimal formulation for this study. It is anticipated that the findings of this study will help to solve the problem of securing insulation and fire resistance performance of exterior wall finishing materials as well as provide basic data for the future development of organic/inorganic composite insulation materials.

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