RESEARCH ON MANUFACTURING OF PRECAST CONCRETE HOLLOW WALL PANELS USING THERMOELECTRIC ASH AND SLAG AS REPLACEMENTS FOR NATURAL AGGREGATES

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DOI: https://doi.org/10.59382/pro.intl.con-ibst.2023.ses2-15

ABSTRACT: Precast concrete hollow wall panels have emerged as a compelling choice in the construction industry because of their lightweight characteristics, which effectively mitigate structural burdens, coupled with their commendable acoustic and thermal insulation properties. Additionally, their expedited construction process provides a significant advantage over labor-intensive brick wall alternatives.

It is noteworthy that the production of these precast concrete panels heavily relies on the utilization of natural aggregates, a practice that has raised concerns, particularly in light of the progressively dwindling reserves of sand resources within our country. Concurrently, there is an escalating volume of ash slag emissions from coal-burning thermal power plants in Vietnam. Therefore, research endeavors aimed at exploring alternative materials, specifically the incorporation of thermal power ash and slag wastes into concrete production for the manufacturing of precast hollow wall panels, assume a dual significance-both from a scientific and practical perspective. These initiatives not only alleviate the strain on our natural aggregate resources but also offer a sustainable solution for managing thermal power wastes, thereby carrying substantial environmental and societal implications.

This article presents empirical findings derived from a comprehensive investigation into the integration of thermoelectric ash and slag as substitutes for natural aggregates, encompassing replacement ratios ranging from 70% to 100%, within the production processes of precast concrete hollow wall panels, employing extrusion technology. The results unequivocally demonstrate that with a replacement rate of up to 100% of aggregates with thermoelectric ash and slag, the quality of wall panels using thermoelectric ash slag completely meets the technical requirements according to TCVN 11524:2016 "Wall panels hollow precast concrete using extrusion technology" for use in construction projects.

1. INTRODUCTION

In conjunction with the ongoing industrialization of the construction sector and the increasing mechanization of construction and assembly methods, prefabricated hollow wall panel products have emerged as a significant development. Hollow wall panels, characterized by hollow voids running along their height or length, are a distinct category of prefabricated structural components. These panels can be fabricated using either conventional concrete or lightweight concrete. The classification of hollow wall panels is based on several criteria, including their intended use and their resistance to impacts. Specifically, they can be categorized into groups such as regular hollow wall panels and soundproof hollow wall panels, with impact resistance levels designated as C1, C2, and C3. The historical exploration of the production and utilization of hollow wall panels dates back to the early 20th century, with pioneering efforts in European countries such as Belgium (1914), Russia (1916), England (1921), and France (1926). In Vietnam, the production and adoption of hollow wall panels began in 2015 with the introduction of these panels by Xuan Mai Concrete Company. Prefabricated hollow wall panels can be manufactured based on two fundamental principles: extrusion technology, which relies on stationary forming equipment, and the principle of moving forming equipment.

Hollow wall panels have traditionally been manufactured using conventional materials, including sand, cement, chemical additives, and water. However, in contemporary times characterized by rapid developments in construction and transportation projects, the scarcity of natural resources such as sand, gravel, and crushed stone is becoming increasingly pronounced. Simultaneously, driven by the escalating demand for electricity, the volume of ash and slag discharged from coal-burning thermal power plants is on the rise.

According to data compiled from prominent corporations like Vietnam Electricity (EVN), Vietnam Petroleum (PVN), Vietnam Coal - Mineral Industry (TKV), and various other thermal power plants, the nation currently hosts 29 operational coal-fired thermal power plants. In 2021, the aggregate output of ash and slag discharged from thermal power plants across the country exceeded 16 million tons. This figure is anticipated to reach approximately 29 million tons by 2025, resulting in an estimated cumulative total of around 250 million tons. Despite this substantial surge in the production of thermal power ash and slag, its rate of reuse remains relatively low. In many facilities, nearly 100% of ash and slag is consigned to landfills, lacking effective strategies for utilization. Consequently, this practice has given rise to environmental pollution and storage-related issues.

Therefore, to address these two pressing concerns, conducting research on the substitution of natural aggregates with thermoelectric ash slag in wall panel production is highly pertinent. This approach not only offers a timely solution to the challenges at hand but also aligns with the nation's commitment to green and sustainable development policies.

Figure 1. Thermal power plant and ash slag emissions

Currently, there is a dearth of global research and applications concerning the utilization of thermoelectric ash and slag to replace natural aggregates in wall panel production. However, existing research and practical applications involving the use of thermoelectric ash and slag to replace natural aggregates in concrete suggest its suitability for wall panel production. An illustrative study conducted by Norhaiza Ghazali and colleagues [1] investigated the use of ash and slag to replace sand in concrete. Various replacement ratios were explored, including 0%, 20%, 50%, 75%, and 100% bottom ash replacing sand, alongside 20% fly ash replacing conventional Portland cement. The findings reveal that an increase in bottom ash content leads to reduced workability in concrete. At 28 days, all concrete samples displayed comparable performance in terms of physical and mechanical properties such as compressive, bending, and tensile strength. However, at 91 and 180 days, concrete samples containing 75% bottom ash and 20% fly ash exhibited significantly higher tensile and flexural strengths compared to control samples. Additionally, concrete mixtures incorporating 50%, 75%, and 100% bottom ash and 20% fly ash demonstrated lower drying shrinkage than control concrete samples.

In their study [2], Mahdi Rafieizonooz and colleagues explored the substitution of sand with thermoelectric bottom ash in concrete, alongside a 20% replacement of cement with fly ash. Results indicated that increasing the bottom ash content reduced workability. However, compressive, flexural, and tensile strengths at 28 days showed minimal change. Remarkably, at 91 and 180 days, concrete samples containing 75% bottom ash and 20% fly ash exhibited significantly higher flexural and tensile strengths. Siddique and colleagues [3] investigated the mechanical properties of concrete with partial fine aggregate (sand) replacement by type F fly ash, ranging from 10% to 50%. Their findings revealed a proportional relationship between compressive strength and fly ash content. Flexural strength and elastic modulus improved compared to the control concrete, but workability decreased. Cadersa and colleagues [4] explored using untreated bottom ash to replace fine aggregate in concrete, ranging from 20% to 80%. Increased bottom ash content led to reduced concrete volume, lower compressive and flexural strengths, and volume reduction over time.. Basheer and colleagues [5] replaced natural sand with thermoelectric bottom ash at varying ratios, resulting in decreased compressive strength and dry shrinkage as bottom ash content increased. However, workability remained similar to control concrete, and drying shrinkage increased with over 30% bottom ash replacement.

Figure 2. Products using thermoelectric ash slag aggregates

In Vietnam, thermal power ash slag is primarily used as a mineral additive in cement and concrete production, as well as for leveling materials. However, research on substituting ash and slag for natural aggregates is limited and faces constraints. Most studies involve processed thermoelectric fly ash, incurring high costs and time consumption, or they are confined to laboratory-scale experiments with limited scope and evaluation of product properties [6][7][8].

Contemporary research focusing on replacing natural aggregates with thermoelectric ash and slag in concrete wall panel production not only offers a solution to depleting resources but also addresses the significant ash and slag wastes in Vietnam today.

2. MATERIALS

The raw materials employed in this research comprised Nghi Son Cement PCB40, crushed sand, ash slag from the Hai Phong thermal power plant, water, and a drycast water-reducing additive from Sika company. The specific properties of these materials are outlined below:

2.1. Cement

The Physical properties of Nghi Son cement PCB40 used in the study are presented in Table 1.

Table 1. Phbysical properties of Nghi Son cement PCB40

Nº	Characteristics	Unit	Value
1	Fineness, by Blaine method	cm^2/g	3.350
2	Standard consistency	%	28.5
3	Setting time		
	Initial	Min	118
	Final	Min	185
4	Compessive strength		
	3 days	MPa	30.8
	28 days	MPa	52.1
5	Soundness, by Le-chatelier's method	mm	0,0

2.2. Crushed sand

The fine crushed stone (CS) originated from the province of Ha Nam, with D_{max} < 10 mm. Physical properties and grain size of the CS are shown in Table 2.

Table 2. Physical properties and grain size of fine crushed stone

Nº	Characteristics	Unit	Value
1	Density	g/cm^3	2.68
2	Bulk density	kg/m^3	1510
3	Grain size (retained by a sieve with apertures of)		
	10 mm	%	0
	5 mm	%	20.5
	2.5 mm	%	53.6
	1.25 mm	%	64.9
	0.63 mm	%	75.4
	0.315 mm	%	84.9
	0.14 mm	%	95.6

2.3. Fly Ash

Fly ash used for making concrete is a material originating from Hai Phong thermal power plant. The physical properties of the fly ash are shown in Table 3.

Table 3. The physical properties of the fly ash

Nº	Characteristics	Unit	Value
1	Density	g/cm^3	2,1
2	Bulk density	kg/m^3	870
3	Fineness		
3.1	Retained by sieve 0.09	%	8.3
3.2	Retained by sieve 0.045	%	17.4
4	Fineness, by Blaine method	%	1930
5	Activity index	%	
5.1	7 days	%	80.5
5.2	28 days	%	92.6

2.4. Bottom slag

Bottom ash used in this research also derived from Hai Phong thermal power plant. The mechanical properties and grain composition of the bottom ash are shown in Table 4.

Table 4. Physical properties and grain size of the bottom ash

Nº	Characteristics	Unit	Value
1	Density	g/cm^3	2,25
2	Bulk density	kg/m^3	950
3	Content of mud, dust, clay	%	0,72
4	Water absorption	%	2.9
5	Grain size (retained by a sieve with apertures of)		
	20 mm	%	0.83
	10 mm	%	5.36
	5 mm	%	21.2
	2.5 mm	%	46.8
	1.25 mm	%	55.22
	0.63 mm	%	62.25
	0.315 mm	%	67.38
	0.14 mm	%	85.9

Water used to mix concrete in this research was domestic water, which meets the requirements of TCVN 4506:2012 "Water for mixing concrete and mortar - Technical requirements".

The chemical admixture used for the study was a mixture of Lignosulfonate and surfactant which is widely used for no-slump or dry concretes at present.

3. MIX PROPORTIONS

The mix proportions were established following the absolute volume principle, with a cement content of 380 kg. The ratio between fly ash and bottom slag was consistently maintained at 60:40. Natural aggregate replacement rates were designated at 0%, 70%, 80%, and 100% using ashes. These selected mix proportions, refined through laboratory testing, were later applied in practical production within the factory setting. Comprehensive details of the experimental mix can be found in Table 5.

Table 5. Mix proportions for trial mixes

Nº	Composition	Ash slag content (%)	CS (kg)	Cement (kg)	Fly ash (kg)	Bottom slag (kg)	Admixture (litre)	Water (litre)
1	C380.TX0	0	1880	380	0	0	3.8	120
2	C380.TX70	70	511	380	715	477	3.8	226
3	C380.TX80	80	326	380	785	523	3.8	251
4	C380.TX100	100	0	380	885	592	3.8	257

4. FABRICATION OF PRECAST CONCRETE HOLLOW WALL PANELS USING EXTRUSION TECHNOLOGY

In this study, precast hollow wall panels were produced using a Weiler extruder principle technology, which operates on the principle of moving forming equipment. This technology contributes to achieving a solid density in the concrete, allowing for a product porosity ratio of up to 50%. Dry concrete mix (0mm slump concrete) was used, resulting in cost savings for both production and transportation, and a reduction in excess concrete due to product finishing, leading to a notable decrease of 40-50% in production costs. The technical parameters and details of the wall panel extrusion machine can be found in Figure 3.

Figure 3. Technology parameters and hollow wall panel extrusion machine

Figure 4. Fabrication of precast concrete hollow wall panels using extrusion technology

5. RESULTS AND DISCUSSION

5.1. Effect of the amount of thermal ash slag used on the amount of water and concrete mixing time to make wall panels

The influence of the amount of thermal power ash slag on the amount of water and concrete mixing time in the wall panel production process is shown in Table 6.

Table 6. Effect of ash and slag content on technological parameters

Nº	Composition	Ash slag content (%)	Actual amount of water (litre)	Mixing time (min)
1	C320.TX0	0	90	5
2	C320.TX70	70	144	10
3	C320.TX80	80	160	10
4	C320.TX100	100	180	10

The experimental results demonstrate that when increasing the ash and slag content to produce high-quality slab products, significant changes occur in the technological parameters of water usage and concrete mixing time compared to the production of reference wall panels:

- Mixing Water Amount: Due to the substantial surface area and the prevalence of fine particles in thermoelectric ash slag, the amount of mixing water required for aggregates employing thermoelectric ash slag is notably higher, ranging from 1.6 to 2 times more than that of the control sample when increasing the ash and slag content from 70% to 100%.

- Mixing Time: To ensure the homogeneity of the concrete mixture, it is necessary to double the mixing time for aggregates using thermoelectric ash slag compared to the control sample. The primary reason behind this extended duration is the high content of fine particles and the magnetic properties of thermoelectric ash slag. During the mixing process, clumping and sticking can easily occur, making it essential to increase the mixing time for the concrete mix to achieve uniformity.

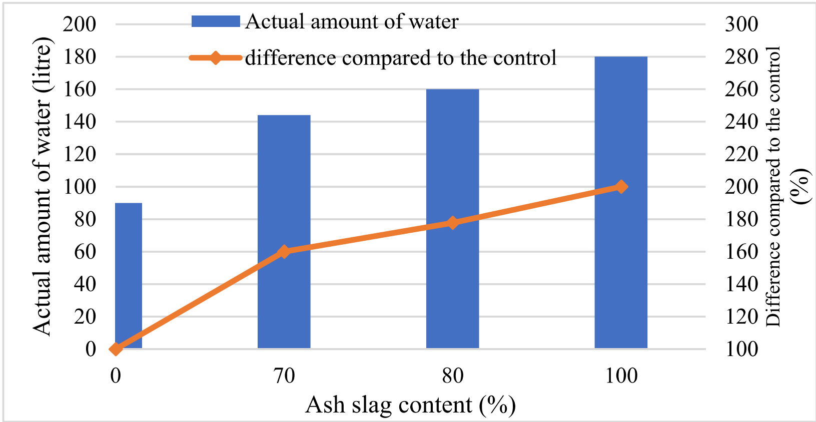

Figure 5. The amount of mixing water of concrete mix when changing the ash slag ratio

5.2. Evaluate the quality of wall panels

In order to assess the quality of wall panel products utilizing ash slag aggregates, they are evaluated in accordance with the technical requirements of TCVN 11524 - "Precast concrete hollow wall panels using extrusion technology." The evaluation results are presented in Table 7.

Table 7. Experimental results evaluating the quality of hollow wall panels

Characteristics	Mix proportions				Technical requirements according to TCVN 11524
	Control sample	70% TX	80% TX	100% TX	
Appearance and defects allowed	Qualified	Qualified	Qualified	Qualified	
Compressive strength (MPa)					
1 d	10.79	11.62	10.25	7.25	-
7 d	24.67	25.92	22.83	18.64	-
28 d	25.92	27.22	24.16	20.93	≥ 15
Porosity (%)	36.35	36.35	36.35	36.35	≥ 20
Water absorption (%)	6.2	7.5	8.2	9.8	≤ 12
Impact resistance	C1	C1	C2	C2	≥ C3
Durability of hanging heavy objects	Qualified	Qualified	Qualified	Qualified	≥ 1000 N

Based on the research results assessing the quality of wall panel products, several observations can be made:

Appearance and Defects: Wall panels incorporating thermoelectric ash slag aggregates exhibit a highly aesthetic appearance with a smooth surface. They show minimal cracking and feature relatively square shapes with fewer burrs compared to wall panels using natural aggregates. It is noteworthy that all panels meet the appearance and defect criteria stipulated by TCVN 11524.

Regarding strength, the assessment is conducted in accordance with TCVN 3118 using a 15×15×5 cm cube. The experimental results indicate that the panels' strength at 28 days meets the minimum strength requirements specified in TCVN 11524. Furthermore, when ash slag is utilized as a replacement at a rate of 70%, the results demonstrate an increase in strength, ranging from 5% to 9% compared to the control sample, dependent on the age of the experiment. However, as the replacement rate for natural aggregate increases, the concrete strength tends to decrease, declining by 20% to 32% when up to 100% thermal ash slag is used.

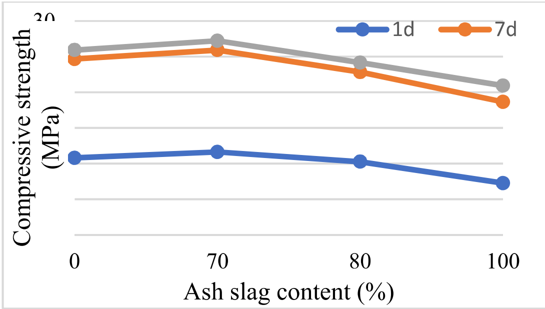

Figure 6. Graph showing the strength of wall panels with different ash slag content

Regarding impact resistance, the research results reveal that as the thermal power ash slag content increases, the impact resistance of wall panels tends to gradually decrease. With a replacement rate of 70%, the panel quality reaches the C1 level, which is equivalent to the performance of the standard mix. However, when using 100% thermal ash slag, the impact resistance of some wall panels only attains the C2 level, while some others still meet the C1 level.

Figure 7. Experiment to evaluate the impact resistance of precast concrete hollow wall panels using thermoelectric ash and slag

The decrease in impact resistance observed in this study can be attributed, in part, to adjustments in the technological parameters of the forming machine, such as pressing pressure and vibration frequency during the production process. These adjustments were made to assess the panel's shaping ability when using ash slag, leading to some wall panels with higher porosity and reduced solidity.

Water absorption in the wall panels exhibits an increase from 6.2% to 9.8% when ash content varies from 0% to 100%. Notably, the water absorption of thermoelectric ash slag exceeds that of natural aggregate. Furthermore, the incorporation of high concentrations of ash slag introduces numerous voids into the concrete structure, which subsequently contributes to the heightened water absorption in the panels.

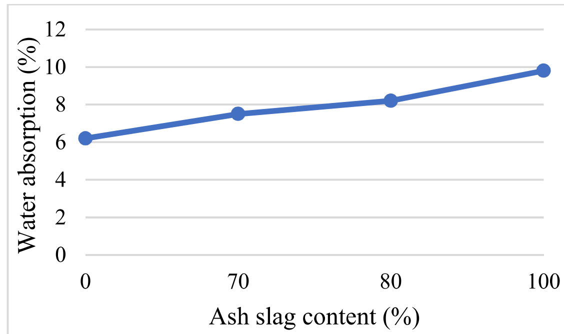

Figure 8. Graph showing water absorption of wall panels with different ash slag content

Based on the aforementioned observations and the comparative data presented in Table 7, it is evident that all three types of wall panels utilizing different ash slag concrete mixes fundamentally adhere to the technical specifications of TCVN 11524:2016. Wall panels that incorporate 70% to 100% thermoelectric ash slag as a replacement for natural aggregate exhibit the potential for extensive application in real construction projects.

6. CONCLUSIONS

Concrete containing thermoelectric ash and slag as replacements for natural aggregates demands 1.6 to 2 times more mixing water as the ash slag content increases from 70% to 100%. This necessity arises from the substantial surface area and fine particle composition of thermal power ash slag. To attain uniformity in the concrete mixture, the mixing duration for aggregates using thermoelectric ash slag had to be extended, doubling the time required compared to the control sample.

Hollow concrete wall panels, manufactured through extrusion technology employing 70% to 100% thermoelectric ash slag as a substitute for natural aggregates, adhere to the technical specifications of TCVN 11524-2016 "Precast concrete hollow wall panels using extrusion technology." Consequently, these panels hold considerable potential for widespread adoption in the construction industry. Significantly, this type of wall panel represents an environmentally conscious building material, as it effectively utilizes recycled wastes sourced from thermal power ash and slag. Moreover, it offers impressive load-bearing capacity, excellent soundproofing, and thermal insulation properties, owing to its hollow core structure, which can reach up to 36.35%.

ACKNOWLEDGMENT

This article publishes a part of research results of State-level project "Research on using thermoelectric ash and slag to replace natural aggregates in manufacture of precast concrete hollow wall panels using extrusion technology, code: ĐTĐL.CN 99/21". The research team sincerely thanks the Ministry of Science and Technology for approving this research topic.

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