 DOI: 10.35382/TVUJS.15.6.2025.150

NEW ENERGY SAVING AND ENVIRONMENTALLY FRIENDLY BUILDING MATERIAL TECHNOLOGY FROM ASH WASTE FROM THERMAL POWER PLANT

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Abstract – *This article analyzes the utilization of coal-fired power plant ash and slag as a sustainable construction material by synthesizing domestic and international data. The research results indicate that a large volume of ash and slag remains unutilized, while their application in construction still faces limitations in standards and environmental impact assessments. The study focuses on the potential of new material technologies to conserve energy, mitigate emissions, and efficiently recycle waste. Additionally, the research proposes development directions to improve standards and enhance the effective use of ash and slag in sustainable construction.*

Keywords: coal ash utilization, energy saving, environmental impact reduction, sustainable construction materials.

I. INTRODUCTION

New material technology (NMT) in construction is a groundbreaking field, representing the trend of modernization and optimization in the global construction industry. Advances in materials science have created new materials with superior properties, helping to improve the quality, performance, and sustainability of buildings [1]. Developed from advanced scientific research and high technology, these materials solve the challenges of durability, safety, and environmental protection. New materials include composites, self-healing materials, nanomaterials, biomaterials, and green materials, with improved properties such as durability, weight, weather resistance, heat insulation, sound insulation, and aesthetics. Composite materials such as carbon fiber and fiberglass are highly durable and lightweight, which reduces both load and cost. Meanwhile, self-healing concrete repairs cracks on itself, extending the life of the structure and reducing maintenance costs. Nanomaterials enhance mechanical and chemical properties, exhibit anticorrosion properties, and provide good heat and sound insulation. Bio-based and recycled materials, such as thermoplastics, bioplastics, and recycled waste products, reduce waste, use renewable resources, promoting sustainability [2].

NMT in construction not only marks a significant step forward in the construction industry but also contributes to the sustainable development of humanity. With the research and discovery of outstanding technical, economic, and environmental features, new technologies and materials in the future will contribute to fundamentally changing the way building and managing projects towards a sustainable and environmentally friendly future [3]. Therefore, continuing to research, develop, and apply these materials will be necessary to solve current challenges and open up new opportunities for the construction industry and society.

Currently, in several countries, including Vietnam, the system of thermal power plants (Figure 1) is a main source of energy supply [4], and at the same time, it is also the source of a large amount of industrial waste [5], causing a great impact on the ecological environment. The main types of waste from thermal plants are fly ash, bottom ash (Figure 2), and desulfurized gypsum (FGD gypsum). Instead of spending a huge amount of money to process waste, modern technology has recycled it into new building

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Received date: 3 July 2024; Revised date: 5 November 2024; Accepted date: 3 December 2024

materials with economic, energy, environmental, and development benefits.

Presently regarded as a byproduct of burning coal in thermal power plants, fly ash has enormous potential for use in the manufacturing of cement and concrete. Fly ash is frequently used in place of cement in concrete to reduce the overall cement content needed and enhance the mechanical quality of concrete, including durability, water resistance, impact resistance, and other attributes. In addition, substituting fly ash for cement contributes to the conservation of natural resources and the reduction of CO_2 emissions associated with the cement manufacturing process [6].

Fig. 1: Duyen Hai 1 Thermal Power Plant [5]

Fig. 2: Ash and slag dump [7]

In Vietnam, coal slag is currently used as road base material and brick and tile production (Figure 3). Coal slag partially replaces raw materials in brick production, minimizing the amount of natural clay exploited and saving raw materials. Products from coal slag also demonstrate good mechanical properties, ensuring quality and durability for construction projects [8].

Fly ash with unburnt carbon content is actively promoted for mixing with raw materials in the plant (Figure 4) and fed into the rotary kiln during the cement production process to reduce coal consumption in cement manufacturing [9]. Moreover, the combination of fly ash and slag for producing unburnt bricks is entirely feasible, while the cost is reduced by 16–21% compared to using crushed stone and natural sand as raw materials. Unburnt bricks made from fly ash and slag are shown in Figure 5.

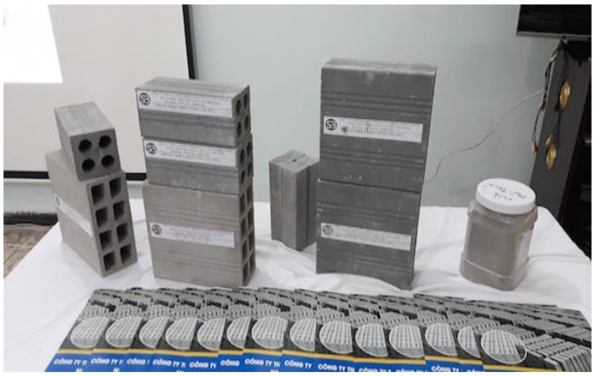


Fig. 3: Unburnt bricks produced from ash and slag [8]

Fly ash in Vietnam has been studied for use as a cement replacement in concrete production [10]. Figure 6 illustrates the slump test process of concrete using fly ash, and the consumption of fly ash by enterprises has been rapidly increasing [11]. Figure 7 depicts a road inside the Duyen Hai Thermal Power Plant being filled with fly ash.

Fig. 4: Fly ash in cement manufacturing [9]

Fig. 5: Fly ash in unburnt brick production [9]

Fig. 6: Fly ash in concrete manufacturing

II. RESEARCH METHODS

This study employed a systematic literature review method, integrated with AI-assisted data screening and synthesis, to ensure a comprehensive and efficient analysis of existing research and to identify strengths, limitations, and gaps for further investigation. The synthesized findings provided insights into emerging trends and feasible directions for developing sustainable and energy-efficient coal ash utilization technologies applicable to the Vietnamese context. The process of identifying and filtering relevant literature is illustrated in Figure 8.

In the initial stage, to guarantee the study's objectivity and correctness, a total of 338 documents (78 Vietnamese sources and 260 International sources) sourced from various rep-

Fig. 7: Using ash and slag to install road base inside Duyen Hai Thermal Power Plant [11]

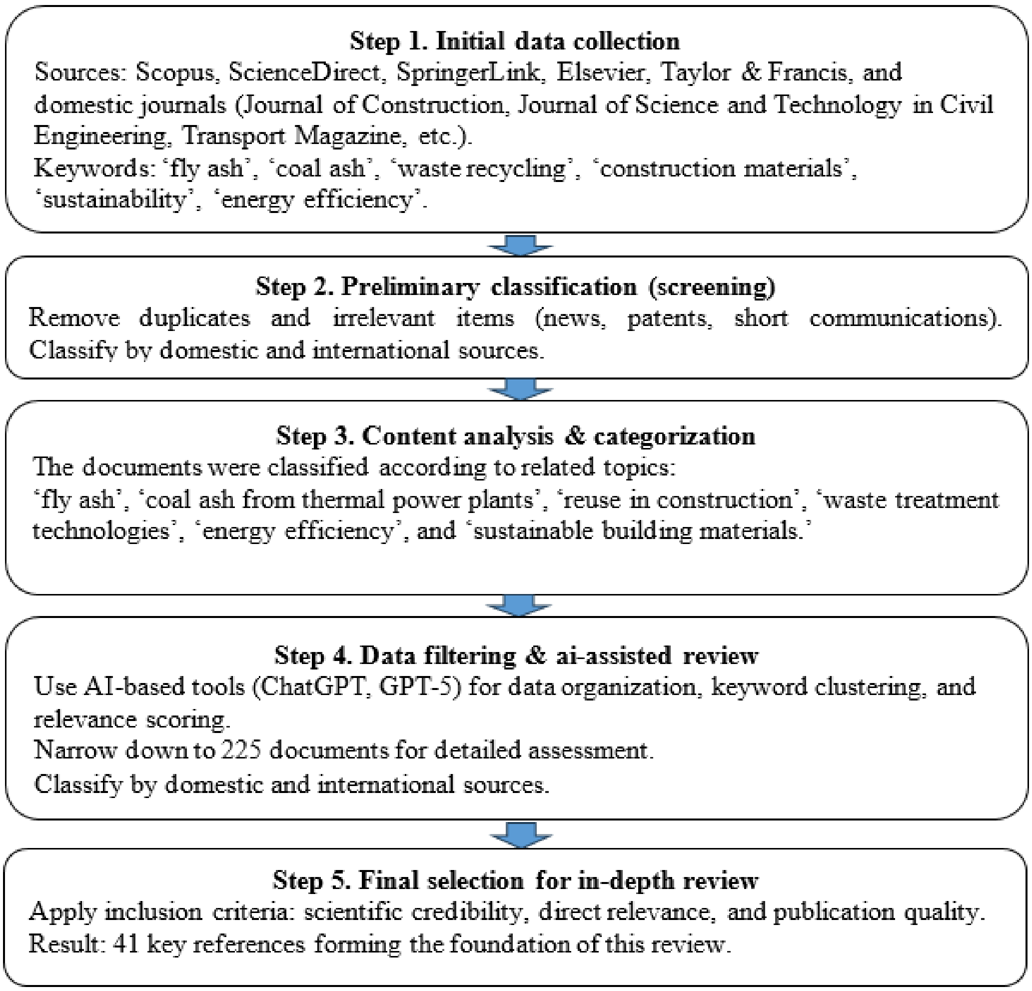


Fig. 8: Process of literature collection, screening, and AI-assisted synthesis

Source: Proposed by the Authors in 2024

utable academic sources, including international databases (Scopus, ScienceDirect, SpringerLink, Elsevier, Taylor & Francis) and domestic sources (Journal of Construction, Journal of Science and Technology in Civil Engineering, Transport Magazine, etc., as well as scientific reports, specialized theses, books and Vietnamese Standards) were collected.

During the preliminary classification (screening), duplicate entries and irrelevant materials – such as news articles, patents, and short communications – were systematically removed. The remaining items were then categorized based on their origin, distinguishing between domestic and international sources. This step determines their advantages and disadvantages, and suggests appropriate avenues for subsequent steps.

Content analysis and categorization focused on organizing the screened documents by thematic relevance. These categories included topics such as 'fly ash', 'coal ash from thermal power plants', 'reuse in construction', 'waste treatment technologies', 'energy efficiency', and 'sustainable building materials'. This classification enables a clearer understanding of the research landscape and supports targeted analysis in later stages.

To enhance the efficiency and accuracy of the review process, data filtering and AI-assisted tools were utilized. These tools assisted in organizing the data, clustering keywords, and scoring the relevance of each document. The documents continued to be classified by domestic and international sources. The dataset was narrowed down to a focused selection of 225 documents, prepared for detailed assessment and analysis.

In the last step, final selection for in-depth review, documents were evaluated based on strict inclusion criteria, including scientific credibility, direct relevance to the research topic, and overall publication quality to ensure the highest quality of sources. Through this selection process, a total of 41 key references were identified. These findings proposed directions for future research to develop sustainable coal ash treatment technologies that meet practical demands.

III. RESULTS AND DISCUSSION

A. Analyzing the current state of research

Domestic research

Research into the use and recycling of waste products as construction materials is currently extremely necessary. With the rapid development of society, especially in the construction industry, the demand for construction materials is increasing; however, traditional raw materials such as stone, sand, and cement are increasingly scarce. Finding and developing alternative materials not only has high practical significance but also meets urgent needs in the construction industry. In detail, by the end of 2021, Vietnam will have 29 coal-fired power plants operating and, on average, releasing 15 + 18 million tons of ash and slag are released into the environment each year. These thermal power plants have a total capacity of nearly 22,000 MW, reaching approximately 35.5% of the total electricity in the entire system [12]. In recent years, with the efforts of the electricity industry and the drastic direction from the Prime Minister and relevant ministries, a series of related decisions have been issued to promote the rapid treatment of ash and slag waste. The government is paying close attention to promoting the treatment and use of ash, slag, and gypsum from thermal power plants, chemicals, and fertilizers as raw materials for construction material production [13–15]. Coal-fired thermal power plants of Vietnam Electricity (EVN) achieved a consumption rate of 33% in 2015, increasing to 94% in 2021, and there are directive documents from the competent authorities approving the project to promote the treatment and use of ash, slag, and gypsum from thermal power plants, chemical plants, and fertilizers as production materials and construction materials in construction projects. However, a large amount of ash and slag still needs to be processed [16]. Particularly in Tra Vinh Province, with the operation of four thermal power plants, it consumes more than seven million tons of coal/year and emits more than 500,000 tons of ash and slag per year [17], presented in Table 1.

Table 1: Wattage of thermal power plants in Vietnam

Factory name	Wattage (MW)	Year of commercial operation
Pha Lai 1	440	1983–1986
Pha Lai 2	600	2002–2003
Na Duong	110	2005
Cao Ngan	110	2007
Cam Pha 1	330	2010
Son Dong	220	2010
Uong Bi expanded	300	2011
Quang Ninh 1	600	2011
Hai Phong 1	600	2011
Cam Pha 2	330	2011
Mao Khe	440	2012
Uong Bi expansion 2	330	2013
Nghi Son 1	600	2013
Quang Ninh 2	600	2014
Hai Phong 2	600	2014
Vung Ang 1	1,200	2014–2015
Vinh Tan 2	1,244	2015
Duyen Hai 1	1,245	2015
An Khanh	120	2015
Mong Duong 2 (BOT)	1,242	2015
Duyen Hai 3	1,245	2016
Mong Duong 1	1,080	2016
Vinh Tan 4	1,200	2017
Thai Binh 1	600	2017
Thang Long	620	2018
Vinh Tan 1 (BOT)	1,200	2018

Source: Vietnam Electricity [17]

The treatment and consumption of ash, slag, and gypsum face numerous challenges and obstacles. In Vietnam (as of 31 May 2023), there are 32 thermal power, fertilizer, and chemical plants with a total remaining amount of ash, slag, and gypsum of 48,739,986 tons, of which the North, Central, and the South have about 30,651,872 tons, 14,075,739 tons, and 4,012,375 tons, respectively [18]. Many units must reduce storage area and spending costs to support the transportation of ash and slag. Due to the combustion technology and fuel, factories have low-quality ash and slag that will be used as additives for cement and concrete, leading to a limited consumption market, especially for circulating fluidized bed factories. According to TKV Group (National Coal and Mineral Industries Group–Vinacomin), by the end of October 2023, the total amount of ash and slag remaining in the dumps of thermal power plants under the corporation is about 12,444,994 tons (dry ash and slag).

Figure 9 shows the simulation results of Koplitz et al. [18] on the concentration level of $PM_{2.5}\mu m$ emitted from coal-fired thermal power plants in Vietnam today (Figure 9(a)) and forecast for 2030 (Figure 9(b)) according to the data from the Electricity Master Plan VII [19]. According to EVN data, the proportion of electricity output from coal burning is expected to rise from approximately 33.4% in 2015 to 49.3% in 2020 and further to 53.2% by 2030 [4].

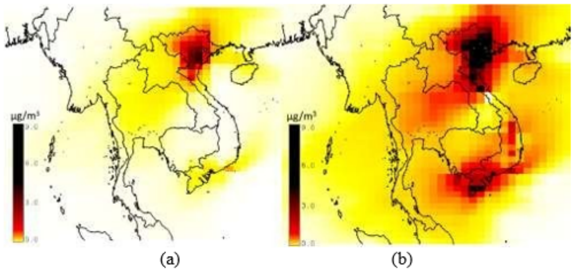


Fig. 9: Concentration level of $PM_{2.5}$ μm in Vietnam today (a) and forecast for 2030 (b) [18]

Abroad research

Globally, Southeast Asia has a high population density and rapid economic development, with growing electricity demand mainly from coal. Coal emissions are predicted to triple by 2030, especially in Indonesia and Vietnam, to 2.6 Tg SO_2 and 2.6 Tg NO_x annually. Simulations show a significant increase in air pollution, with $PM_{2.5}$ increasing by 11 $\mu g/m^3$ in Northern Vietnam and ozone increasing by 15 ppb in Indonesia. It is estimated that there are 19,880 deaths per year due to coal emissions in Southeast Asia, rising to 69,660 by 2030, of which 9,000 are in China. With China's coal emissions decreasing, cross-border pollution from Southeast Asia has become a more serious problem [20]. By using the GEOS-Chem model, a new plant-specific inventory of baseline coal SO_2, NO_x, and $PM_{2.5}$ emissions in 2011 was obtained across countries (Table 2).

Plant location and capacity information is based on the Platts Utilities Data Institute and World Power Plant Database [20]. The location of the factory, plant-specific emissions estimates, and parameter values are shown. The approach proposed in this study to estimate pollutant emissions at each facility is described in Figure 10.

According to the WHO [20], Japan has a very low average $PM_{2.5}$ value, only 13 $\mu g/m^3$, while India reaches 62 $\mu g/m^3$. Within Southeast Asia, Indonesia and Malaysia have low average $PM_{2.5}$ concentrations (14 and 15 $\mu g/m^3$), and Thailand and Vietnam have higher concentrations (22 and 23 $\mu g/m^3$). Specific countries such as Brunei, Canada, Norway, and Portugal have very low average $PM_{2.5}$ concentrations (less than 10 $\mu g/m^3$), while countries such as Saudi Arabia (108 $\mu g/m^3$) and Bangladesh (84 $\mu g/m^3$) possess extremely high values. In urban areas, these concentrations are even higher. This is an overview of global air quality through the $PM_{2.5}$ index, to which Vietnam also needs attention. Specifically, $PM_{2.5}$ in urban and rural areas of countries is presented in Table 3 [20].

In other countries, according to data from the 2013 World Coal Ash Conference, cited by Dinh Quoc Dan et al. [21], the rate of coal ash used for backfilling in Europe is 18.98%, in India is 6.4% for road embankment and 12.6% for leveling. In the United States, more than 11% of coal ash is used for backfilling, while in Japan this

Table 2: Emissions from coal-fired power plants in 2011 and forecasts to 2030 in countries

Number of plants			SO_2		NO_X		$PM_{2.5}$	
Nation	**2011**	**2030**	**2011**	**2030**	**2011**	**2030**	**2011**	**2030**
Cambodia	1	6	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Indonesia	147	323	0.29	0.90	0.29	0.88	0.03	0.05
Japan	160	172	0.10	0.12	0.10	0.12	< 0.01	< 0.01
Laos	0	3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Malaysia	18	26	0.05	0.07	0.07	0.11	< 0.01	< 0.01
Myanmar	3	16	0.01	0.30	< 0.01	0.18	< 0.01	0.01
Philippines	30	77	0.07	0.19	0.08	0.25	< 0.01	0.01
South Korea	97	123	0.06	0.10	0.08	0.12	< 0.01	< 0.01
Taiwan	71	81	0.03	0.04	0.05	0.06	< 0.01	< 0.01
Thailand	37	48	0.14	0.20	0.11	0.15	0.01	0.01
Vietnam	38	133	0.09	0.63	0.08	0.69	0.01	0.07
Total	602	1,008	0.84	2.60	0.86	2.63	0.06	0.16

Source: World Health Organization [20]

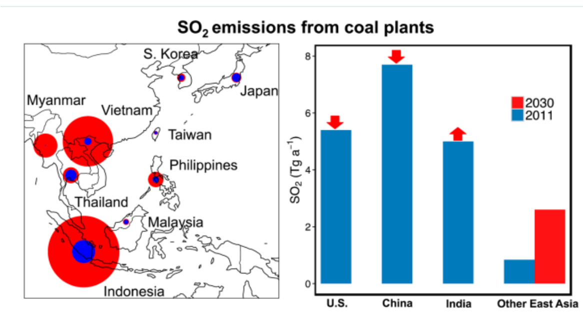


Fig. 10: SO_2 emissions from coal in 2011 and forecast for 2030 [20]

Table 3: Annual average of $PM_{2.5}$ in 2012 with lower and higher values adjusted for population density and model

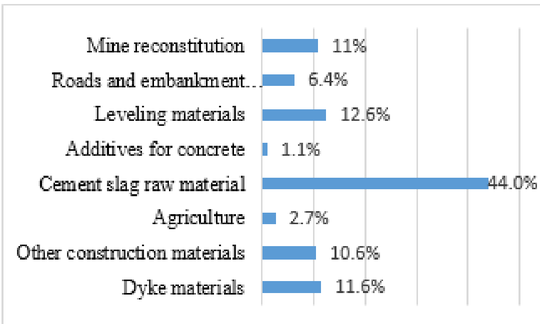
Nation	$PM_{2.5}$ ($\mu g/m^3$) Rural and Urban			$PM_{2.5}$ ($\mu g/m^3$) Urban		
	Medium level	Low level	High level	Medium level	Low level	High level
Cambodia	23	7	75	25	6	69
China	54	37	80	59	42	84
India	62	41	95	66	45	97
Indonesia	14	9	23	18	11	28
Japan	13	8	19	13	9	19
Laos	27	9	76	34	10	106
Malaysia	15	9	24	17	10	26
Philippines	22	14	35	27	17	43
Thailand	25	16	37	27	19	38
Vietnam	26	15	43	28	17	45

Source: World Health Organization [20]

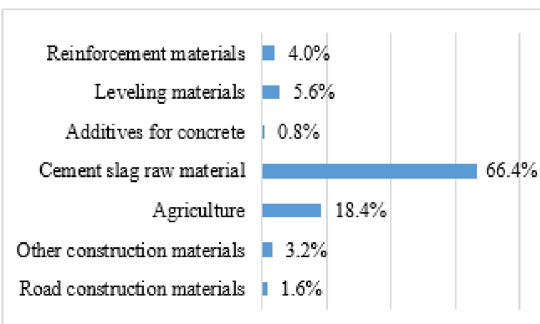
proportion is the lowest, only 5.6%, as shown in Figure 11. However, it can be affirmed that ash thermal power is used in significant quantities for backfilling in these countries. Thus, continuing to research and develop technology to handle ash and slag materials from thermal power plants is necessary in general and in Vietnam.

B. Notable experimental results

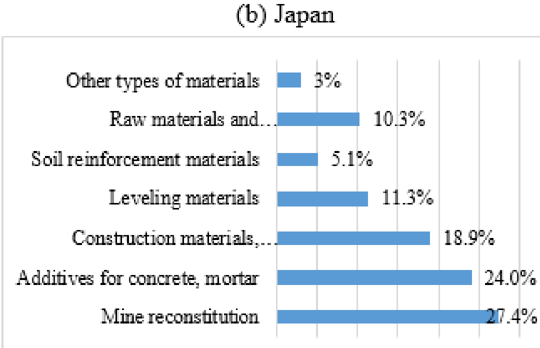
In recent years, the use of fly ash for producing concrete with ecological considerations, as well as the potential to utilize large quantities of ashes and related materials, has garnered significant interest from scientists. Therefore, the experimental method in the laboratory has attracted significant interest from scientists and has yielded many valuable results. Mocharla et al. [22] conducted a life cycle assessment study on high-volume fly ash concrete mixtures incorporating sand and steel slag. Their findings indicated that structural strength remained high when 50% of the cement and natural sand were replaced with fly ash and sand slag, which are waste byproducts from the primary steelmaking industry. Similarly, Du et al. [23] investigated the development of eco-efficient high-volume fly ash mortar based on a central



(a) United States



(b) Japan



(c) India

Fig. 11: Ash and slag reuse rate in the United States, Japan, and India

Source: Compiled and modified by the Authors from Dinh Quoc Dan et al. [21]

mix design. The optimal mix design of high-volume fly ash (HVFA) mortar ensures comparable strength while significantly lowering CO_2 intensity (CO_2 emissions per unit of compressive strength) by up to 17.57%. In this study, the HVFA composite mortar containing 67% fly ash, 5% limestone powder, no asphalt emulsion, and a w/cm ratio of 0.25 demonstrated a compressive strength of 39.2 MPa after 28 days and a tensile strength of 3.3 MPa at the same age. Another study by Kosivtsov et al. [24] focused on ash and slag, where the author identified valuable components such as iron slag with an iron content of 51–52%, precious metal concentrates (gold, platinum, palladium), and hollow aluminosilicate microspheres, which reduce the amount of adsorbed and chemically bound water by 1%. Consequently, ash and slag are commonly used as raw materials for producing construction materials, cement, and silicate foam. The incorporation of ash and slag waste into industrial processes is thus one of the most efficient methods of conserving resources.

A scientific report by Pham Huy Khang [25] presented the latest research on fly ash in Vietnam in traffic construction, especially in motorways and airports. Currently, the largest thermal power plants in the country are emitting large amounts of fly ash, and utilizing this material not only helps solve economic problems but also minimizes environmental problems, which cannot be evaluated in terms of money. Nguyen Thanh Sang et al. [26–28] have conducted many studies on fly ash as a substitute for binders and aggregates in construction. The articles revolve around the physical properties, durability, applicability, and necessity of using this material in construction. Moreover, using fly ash as a new construction material contributes positively to environmental protection and sustainable development. Nguyen Thi Thu Nga [29] studied fly ash and bottom slag from the Vung Ang 1 Thermal Power Plant as materials for rural road construction. The author conducted many experiments, showing that using fly ash and bottom slag in road construction is feasible. When used for rural roads, the materials all meet the standards and can fully meet the technical requirements for construction materials [30, 31]. The road using fly ash as the main material is shown in Figure 12 and Figure 13.

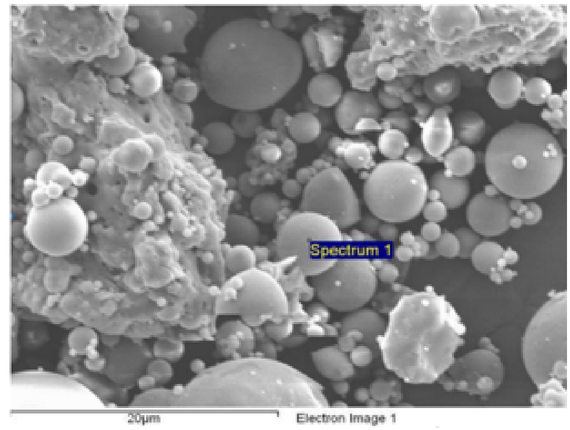
Fig. 12: Urban roads using fly ash and bottom slag materials [30]

Fig. 13: Rural roads using fly ash and bottom slag materials [31]

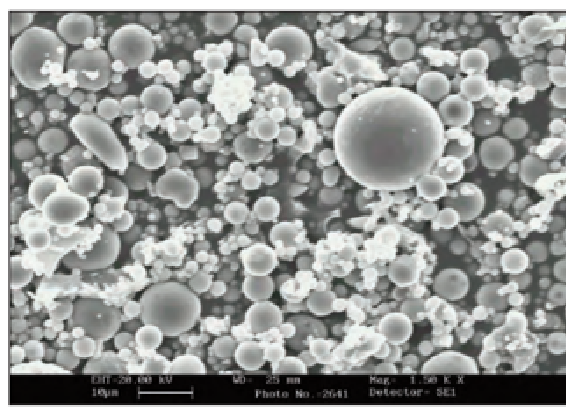
In a research project of the Ministry of Construction of Vietnam [32], fly ash replacing cement is combined with sea sand to create a mixture of materials to reinforce weak soil foundations in coastal and island projects. According to the study's findings, the fly ash-rich pavement concrete, the K95 backfill soil layer, and the K98 backfill soil layer have nothing to do with the cement, sand, and fly ash mixture used to create typical soil cement piles. The study category examines the economic efficiency in more depth; however, for regular cement concrete materials, the cost will be 20–30% less than for concrete with the same strength level. However, the K98 backfill material needs to be very high.

Chau Truong Linh et al. [33] researched and analyzed the use of ash and slag at Duyen Hai Thermal Power Plant. The untreated coal slag and fly ash mixture of the Duyen Hai Thermal Power Plant was reinforced with cement to manufacture foundation materials and road surface structures in Tra Vinh Province. The physical and mechanical properties, such as compressive strength, splitting strength, shear strength, cohesive force, angle of internal friction, California bearing ratio, standard compaction, and elastic modulus, were studied in laboratory experiments. The results showed that this mixture achieved strength levels II and III according to national standards [34, 35]. The elastic modulus in the field and the laboratory was also similar. Moreover, a mixture with a 2% to 8% cement content can be used as a roadbed under high-class roads A1 and A2. Research helps create new sources of materials for infrastructure construction in Tra Vinh Province, minimize environmental pollution, save land area used as a coal slag and fly ash waste dump at Duyen Hai Thermal Power Plant, and ensure sustainable development. Pham Thanh Tung et al. [36] continued to study the use of fly ash from the Duyen Hai Thermal Plant as soil piles to reinforce the weak soil infrastructure of the new urban area project east of Mau Than Street, Tra Vinh City, Tra Vinh Province. The authors introduced some results on fly ash content and pile diameter when reinforcing and treating weak soil through modeling with Plaxis software for pile diameters D400, D500, and D600 corresponding to the following fly ash content 35%, 40%, and 45%, respectively, from which the displacement and stress values can be determined. The study serves as a basis for selecting pile size, fly ash content, and arranging structural solutions for weak soil. Chau Truong Linh et al. [37] combined untreated coal slag and fly ash at Duyen Hai Thermal Power Plant and lime as the foundation and pavement structure in Tra Vinh Province. The study analyzed the strength indexes of the mixture of untreated coal slag, fly ash, and lime as the pavement structure base material by simulating the behavior of materials and soil in several different cases. The authors conducted compaction experiments with five different mixes, including a mixture of coal slag and fly ash, and started curing, then tested at 7, 14, 28, 56, and 90 days of age. The compressive strength, splitting strength, and elastic modulus tests all achieved good results. The results showed that the use of ash combined with other additives can be used as type II crushed stone aggregate roadbed material as a base layer under the pavement structure (cement content > 4%). In addition, when further studying this material mixture, the results showed that the mass ratio of 50% coal slag, 42–46% fly ash, and 4–6% cement is considered the most reasonable mix when making a foundation under the pavement, dam, or dike body. In addition, the authors suggested conducting more related experiments and using the ASTM 4874-2014 standard for evaluation.

Several basic properties of ash and slag have been researched. Fly ash is a waste product of the electricity production process from coal-fired power furnaces. The shape of fly ash is shown in Figure 14. The surface area of fly ash varies from 2,000 cm^2/gram to 6,800 cm^2/gram and is usually spherical, with dimensions ranging from 0.5 μm to 300 μm, with dry porous mass from 450 kg/m^3 to 700 kg/m^3 and specific gravity from 1,800 kg/m^3 to 2,300 kg/m^3. With current coal-burning techniques, fly ash can completely contain unburned coal particles and have an unknown shape. Bottom slag is also a waste product originating from the same source as fly ash. Bottom slag is coarser and larger particles than fly ash, a non-burning component collected at the bottom of the furnace, usually in the form of lumps or granules in size from 0.125 mm to 2 mm, dry volume from 700 kg/m^3 to 900 kg/m^3, and specific gravity from 2,000 kg/m^3 to 2,600 kg/m^3. Normally, fly ash accounts for about 80%–90%, while slag accounts for only about 10%–20% [38, 39].



a) SEM micrograph of fly ash particles [38]



b) Typical fly ash particles [39]

Fig. 14: Microscopic image of fly ash

The Green Innovation and Development Centre (GreenID) [40] has shown the typical chemical composition of fly ash produced from different types of coal. Barnes [39] reported the influence of technological changes and several other factors on ash production and its characteristics. Table 4 shows the normal range of chemical composition for fly ash generated from various coal sources.

The physical properties of fly ash and coal slag of Quang Binh Thermal Power Plant were

Table 4: Typical chemical composition range of fly ash produced from different types of coal, weight%

Ingredients	Bituminous coal	Semi-bituminous coal	Ligneous coal
SiO_2	20–60	40–60	15–45
Al_2O_3	5–35	20–30	10–25
Fe_2O_3	10–40	4–10	4–15
CaO	1–12	5–30	15–40
MgO	0–5	1–6	3–10
SO_3	0–4	0–2	0–10
Na_2O	0–4	0–2	0–6
K_2O	0–3	0–4	0–4
Burning loss (free carbon)	0–15	0–3	0–5

Source: American Coal Ash Association, cited by Barnes [39]

determined by experiment, and the results are given in Table 5 [21].

Table 5: Physical characteristics of fly ash and slag

No.	Physical characteristics	Ash	Slag	Ash and slag
1	Grain composition %			
	+ Clay particles < 0.005	2.2	-	4 (1.80–9.80)
	+ Dust particles 0.005–0.05	53.9	28.1	51.6 (32.1–70.3)
	+ Smooth 0.005–0.01	14.6	6.8	11.2 (3.8–17.6)
	+ Coarse 0.01–0.05	39.3	21.3	39.6 (28.3–53.3)
	+ Sand grains 0.05–2	43.9	56.8	48.7 (26.6–71.6)
	- Smooth 0.05–0.1	42.8	16.4	30.1 (4.1–46.5)
	- Small 0.1–0.25	0.6	13.1	6.3 (1.1–16.5)
	- Average 0.25–0.5	0.3	8.3	5.5 (0.3–18.8)
	- Large 0.5–1	0.1	7.7	4.3 (0.1–18.3)
	- Coarse 1–2	0.1	11.3	4.7 (0.2–26.4)
2	Characteristics of particle distribution			
	+ Coefficient of uniformity Cu	7.2	20	8.1 (3.8–13.1)
	+ Grading coefficient Cs	0.8	0.7	0.9 (0.7–1.0)
3	Grain volume g/cm^3	2.42	2.01	2.53 (2.35–2.69)
4	Dry volume mass g/cm^3			
	+The tightest state	1.44	1.44	1.27 (1.06–1.81)
	+The most porous state	0.95	1.01	1.01 (0.65–1.41)
5	Empty coefficient			
	+The tightest state	0.40	0.68	0.84 (0.46–1.34)
	+The most porous state	1.12	1.40	1.66 (0.82–2.62)
6	Permeability coefficient. 10^{-3} cm/s			2.19–3.18

Source: Modified by the Authors from Dinh Quoc Dan et al. [21]

National Standard (TCVN) 12249:2018 [41] provides general requirements for coal-fired thermal power plant ash as filling material for construction, traffic, and technical infrastructure. However, the type of ash used is not a hazardous waste to ensure environmental safety and meet the load-bearing capacity.

IV. CONCLUSION

A. Promoting technologies to recycle waste into construction materials

Nowadays, recycling industrial waste into building materials not only helps to reduce environmental pollution but also optimizes the use of resources. Recycling technology has opened new opportunities in the production of environmentally friendly, energy-saving materials, especially from ash and other waste sources. Several typical applications for turning waste into sustainable building products are proposed, such as manufacturing unburnt bricks from ash and slag. The bricks can help reduce clay exploitation and CO_2 emissions, save energy, and be environmentally friendly because it does not go through the heating stage. Lightweight concrete produced from fly ash helps to reduce concrete volume but still ensures strength and durability, and is suitable for constructions that need to reduce the load.

Several other proposals include creating a new mixture by replacing part of the clinker with ash and slag in cement production to reduce the amount of clinker, CO_2 emissions, and energy consumption during the production process, or ash and slag can be used to produce composite materials. Ash is combined with polymers or other binders to create composites, which are widely used today (to make plywood, panels, or other products). With the emergence of many advanced technologies, ash and slag can completely replace part or all traditional materials, such as cement, sand, and stone, to produce concrete slabs, block bricks, and the like. This new production technology has the potential to make the most of industrial waste sources that pollute the environment.

B. Applying new techniques and technologies to reduce emissions and save energy

In the industrial production process, recycling and waste management are essential to minimize negative impacts on the environment. Advanced technologies for recycling and reusing industrial waste are applied to turn ash and slag into valuable, sustainable, and environmentally friendly construction materials. First, waste heat management systems manage and reuse waste heat from the production process to dry ash and slag, helping to save energy, reduce humidity, and improve output product quality. Second, plasma technology converts ash and slag into high-value building materials, such as fiberglass or fire-resistant. This technology helps reduce harmful gas emissions. By applying wet ash and slag treatment, ash and slag are washed and cleaned before use to remove toxic impurities and improve ash and slag quality. Third, carbonization technology turns ash and slag into valuable products such as activated carbon or filter material, minimizing the amount of ash and slag released into the environment. Geo-polymer technology creates new building materials that are highly durable, heat-resistant, and environmentally friendly, and can replace traditional materials. Last, it is possible to build a system that combines classification and recycling at the source, which reduces transportation costs greatly and avoids environmental pollution due to storing and transporting ash and slag while also creating other products. The construction products meet the requirements of sustainable development and are environmentally friendly.

C. Recommendations

Using ash and slag waste from thermal power plants to make construction materials is a feasible solution and brings many significant benefits both economically and environmentally. Research and practice have demonstrated that ash and slag can be recycled into various types of construction materials, including unburnt bricks, mixed cement, lightweight concrete, composite materials, and block bricks. These solutions help reduce dependence on traditional raw materials, save energy, and reduce CO_2 emissions, contributing to environmental protection.

New technologies and methods, such as wet ash and slag treatment, plasma technology, waste heat management systems, carbonization technology, and geopolymer, promise to improve ash and slag recycling efficiency and create new high-value products. These technologies help improve the quality of output products, reduce harmful emissions, and make the production process more sustainable.

Although there have been many studies related to the use of ash and slag waste in construction materials, there is still a lack of specific instructions and evidence of toxicity affecting children's health, people, and creatures on Earth.

To maximize the potential of using ash and slag from thermal power plants in the production of energy-saving and environmentally friendly construction materials, it is necessary to synchronously implement several tasks, such as strengthening applied research, developing advanced recycling technology, enhancing education to raise people's awareness, and implementing support policies to encourage the recycling of by-products from industrial production.

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