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Research Article

PRELIMINARY RESULTS OF STUDY ON THE INFLUENCE OF CURING TEMPERATURE ON THE COMPRESSIVE STRENGTH OF FLY ASH CONCRETE

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ABSTRACT

The global infrastructure expansion is propelling the construction sector towards increased cement usage. However, cement production reduces natural resources and affects the living environment by emitting significant greenhouse gases. Reusing industrial waste in construction materials should be considered to promote sustainable construction practices. This study evaluated the possibility of replacing cement with fly ash in civil concrete to increase the efficient use of natural resources and minimise environmental impact. The study proposes varying the proportion of fly ash in the concrete mix (ranging from 0% to 40%) and examining its effect on the final compressive strength of low-calcium fly ash concrete (FAC) under high-temperature curing conditions. Evaluation parameters include mass loss under dry conditions, wet and dry densities, and the maximum compressive strength attained to assess the durability of FAC. Preliminary results indicate that curing FAC specimens at 70°C enhances compressive strength. Furthermore, FAC demonstrates marginally higher wet density than traditional concrete, highlighting its versatility as a construction material. The study recommends prioritising FAC usage in projects exposed to sunlight, considering its cost-effectiveness and environmental advantages. These initial insights provide valuable experimental data for advancing FAC utilisation in residential construction.

Keywords: compressive strength; concrete; fly ash; green concrete; mineral additives; thermal curing

1. Introduction

Developing countries like Vietnam, India, China, Malaysia, and many others are producing a large amount of fly ash (FA) through thermal power plants to meet the electricity demand for economic and social development. According to the third-quarter report of the

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Industrial Safety and Environmental Technology Department (Ministry of Industry and Trade, 2023), Vietnam currently has about 33 coal-fired thermal power plants, including ten plants using circulating fluidised bed (CFB) boiler technology with low-quality domestic coal and 23 plants using pulverised coal (PC) technology with higher-quality domestic coal, with a total capacity of 27,264 MW. Despite research efforts and progress in fly ash utilisation, the amount of fly ash and slag emissions from thermal power plants remains significant, estimated at over 16 million tons per year. In comparison, consumption only reaches over 14 million tons per year (accounting for over 87% of emissions and increasing significantly over the years). Besides, about 48.4 million tons of accumulated fly ash over the years (Ministry of Industry and Trade, 2021; Government Office, 2021). The issue of emitting a large amount of fly ash poses a challenge to effective management. Therefore, the Ministry of Industry and Trade is developing the implementation plan for the National Power Development Plan for the period 2021-2030, with a vision to 2050, focusing on developing renewable energy sources to fulfil the commitment of achieving net-zero emissions by 2050 (Government Office, 2023).

Concrete is the most robust construction material used in most construction projects (Bondar et al., 2013). However, the use of cementitious materials like cement in conventional concrete is causing undesirable environmental impacts, with cement production alone contributing about 7% of global carbon dioxide emissions (Celik et al., 2014). In this context, it is necessary to find alternative solutions to minimize the use of cement in concrete and enhance the beneficial consumption of fly ash. Geopolymer concrete (GPC) is an alkali-activated cementitious material with good performance and high environmental friendliness (Bhikshma et al., 2012; Vora & Dave, 2013) that can address this issue. Geopolymer is a new environmentally friendly binder material formed through chemical reactions between alkalis and aluminosilicates, such as fly ash (Amarnath et al., 2012; Sarker et al., 2013), granulated blast furnace slag (Liu et al., 2016), and metakaolin (calcined clay) (Li et al., 2018). Any raw materials rich in Silicon (Si) and Aluminum (Al) can be used to produce GPC with proven advantages such as cost-effectiveness, low energy consumption, thermal stability, workability, durability, and especially environmental friendliness due to containing little to no Portland cement (Davidovits, 1993; Shehata et al., 2021). Among these, GPC using fly ash waste produces fly ash concrete (FAC) that helps reduce emissions and contributes to managing the rapidly increasing fly ash volume. In FAC, a geopolymer mixture formed from fly ash and alkali binds coarse and fine aggregates together to create concrete (Bhikshma et al., 2012). Class F fly ash (FA acid) with a calcium content below 15% is considered most suitable for use in GPC because it contains a high proportion of Silicon and Aluminum (Amarnath et al., 2012). Recent studies have shown that using GPC can reduce greenhouse gas emissions by 25-70%, depending on the composition and ratio of the mixture (Shehata et al., 2021).

In addition to environmental concerns, the sustainability and durability of FAC are crucial considerations for meeting technical construction criteria. Evaluating the performance of FAC at high temperatures is necessary when considering its sustainability and durability, especially in tropical areas with high summer temperatures. Recent studies have observed the behavior of GPC, which is reported to have high strength and maintain normal strength when exposed to high temperatures (Raju et al., 2021). Previous studies have shown that incorporating fly ash in concrete can improve mechanical properties and delay strength through the slow hydration process (secondary hydration) (Golewski, 2018). Curing conditions, especially the curing temperature of GPC, strongly influence its compressive strength (Zhang et al., 2018). Higher curing temperatures accelerate the hydration process in the concrete mixture and enhance compressive strength. Concrete temperature is also limited to 70°C during hydration to avoid water loss (Li et al., 2017). If the temperature during this process is too high, it will cause the concrete strength to develop rapidly in the early stage and increase less in the later stage, leading to reduced structural strength. Curing by steam or hot air at temperatures ranging from 60°C to 90°C for 24 hours is recommended to achieve higher compressive strength for GPC (Ramezanianpour et al., 2013; Sun et al., 2018). Furthermore, thermally treated GPC has better resistance to sulfate attack and minimizes surface degradation (Bhikshma et al., 2012). The performance of GPC is improved due to its lower calcium content compared to using Portland cement in conventional concrete (Singh et al., 2013). Some studies have shown that the rate of compressive strength growth of FAC is better when cured at high temperatures (Ho et al., 2003; Khoury, 1992; Mengxiao et al., 2015). According to the recommendation of the American Society of Civil Engineers (ASCE), using fly ash in GPC achieves the best performance when cured at temperatures of 80-90°C (Nagral et al., 2014). Several other studies have evaluated the influence of curing temperature on the compressive properties of fly ash-based concrete (Azzahran Abdullah et al., 2018; Nagalia et al., 2016; Vora & Dave, 2013). Specifically, a study (Nagalia et al., 2016) measured the compressive strength of fly ash concrete after 7 days of curing at temperatures ranging from 46 to 70°C. Azzahran Abdullah et al. (2018) investigated the compressive strength after 7 days and 28 days of curing at 60°C. In summary, the results concluded that FAC achieves better compressive performance when cured at high temperatures. However, the suitable temperature and the degree of strength enhancement vary depending on the quantity and class of substituted fly ash. Few studies have been conducted to observe the influence of high-temperature curing on the final compressive strength of FAC. Domestic literature has almost not indicated, to our knowledge, the scarcity of experimental data on the effect of curing temperature on the final compressive strength of FAC. The main purpose of this study is to evaluate the compressive load capacity of FAC with different fly ash replacement ratios towards Mac 400 commonly used for residential construction with compressive relationships after high-temperature curing and compressive relationships after curing in room temperature conditions.

2. Material and methods

2.1. Material

The alternative cementitious material to Portland cement is fly ash (FA) with low calcium content (Class F), sourced from a coal-fired thermal power plant in Binh Thuan, Vietnam. It is a waste product generated when coal is burned in power plants as shown in Figure 1a. FA is a complex material with its composition and mineral content depending on various factors such as coal type, combustion environment, burner technology, and collection method. The chemical composition of FA is typically determined using chemical techniques according to TCVN8262:2009 standards. Details of the chemical composition of the FA class in Binh Thuan used in this study have been analyzed in our initial report. ASTM standards have identified FA as either a standalone material (ASTM C618, 2022) or as a cementitious component (ASTM C595/C595M, 2021). According to these standards, class F FA, primarily formed by burning bituminous and anthracite coal, has been predominantly used. When using Class F FA blended with Portland cement, standards set requirements limiting the maximum Calcium oxide content to 18%, (SiO_2+Al_2O_3+Fe_2O_3) values > 50%, SO_3 < 5%, loss on ignition < 6%, fineness < 34%, and the strength activity index relative to Portland cement after 28 days must be greater than 75%. Physical properties such as particle size, bulk density, and surface area of FA are also provided for reference in Table 1 (Balamohan et al., 2024). It has a specific gravity of 2.63 g cm^{-3} and a surface area of 2.27 m^2 g^{-1}. According to the study, the average particle size of FA is 45.7 µm, and the most common class of FA particle is spherical, as shown in Figure 1b.

Table 1. *Physical properties of cement and fly ash materials (Balamohan et al., 2024)*

Material	Cement	Class C FA	Class F FA
D10 (10-6m)	1.96	4.39	1.88
D50 (10-6m)	12.29	46.91	10.09
D90 (10-6m)	36.54	164.65	33.15
Density (g.cm-3)	3.04	2.26	2.63
Surface area (m2g-1)	1.34	1.61	2.27

The type of cement Insee PCB40 is defined in standard EN 197–1:2011 (British European Standards Specifications, 2011), which is common in the market for civil construction materials. Naturally available silica sand with fine particle size, used as fine aggregate, and blue stone used in floor construction with a particle size of 1× 2 cm are used as coarse aggregate. The main component of sand is SiO_2. Physical properties such as particle size, bulk density, and surface area of the cement are also provided for reference in Table 1 (Balamohan et al., 2024). A quantity of fine powder Sikacrete additive (< 0.1 µm) of type pp1 is used for the FAC samples.

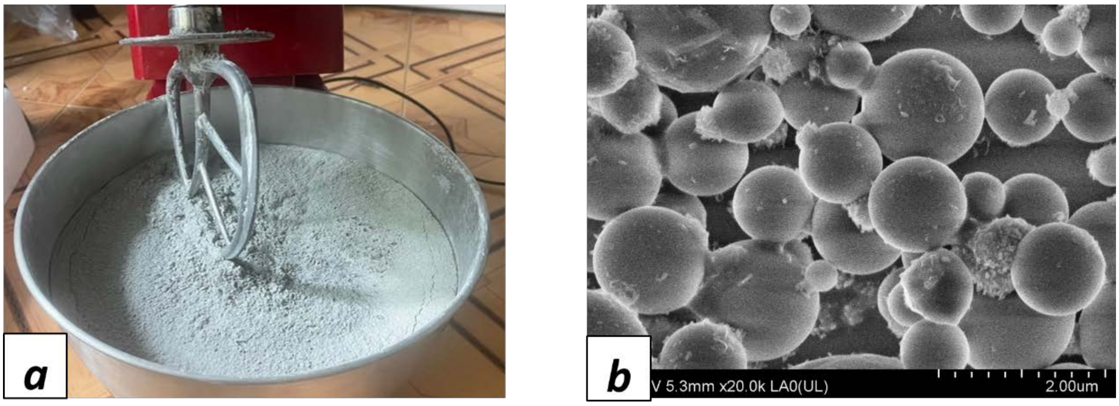

Figure 1. *Fly ash:* ***(a)*** *Fine FA,* ***(b)*** *FESEM of FA particle*

2.2. Procedure for sampling

Table 2 presents the mixing ratios of concrete samples aimed at Mac 400 for use in high-strength civil concrete, which can be used for main columns, ceilings, and walls. The experimental variable is the amount of FA chosen to replace Portland cement (CM) in FAC at levels of 10%, 20%, 30%, and 40%, denoted as FAC10, FAC20, FAC30, and FAC40 respectively, and the control sample without FA is FAC0. The FAC sample preparation process includes the sieving of sand and construction stones. These materials are washed, dried, and accurately weighed with a ratio of aggregates (sand and stones) to binders (CM and FA) of 4.5. Binders and additives are dry-mixed for three minutes using a powder mixer in the laboratory to enhance homogeneity in the sample matrix. The total mass of binders remains constant at 5.93kg for each batch of three identical samples. The water/binder ratio is fixed at 0.48, and the additive/binder ratio is 0.05.

The concrete mixing from the prepared materials uses a laboratory concrete mixer to produce a wet FAC mixture (see Figure 2a). For the mixing process, all dry materials are mixed inside the machine for 5 minutes in the order of adding sand, binder, and stones with the machine's rotation set at 270 revolutions, then water is added, and mixing continues for another 180 revolutions until a homogeneous wet mixture is obtained. The wet concrete is poured into molds of dimensions of 150 mm × 150 mm × 150 mm to create cuboid-shaped sample blocks. Wet samples are poured into molds filled in two layers, and each layer is vibrated for approximately 30 seconds using a specialised vibrating table. The samples, along with the molds, are covered with plastic film to retain moisture immediately after casting under ambient conditions for 24 hours. A batch of three identical samples is heat-cured at 70°C for about 48 hours, while another batch is maintained at room temperature for approximately 72 hours, as these are the necessary durations to ensure the concrete samples achieve structural hardness (Bondar et al., 2013). After 48 or 72 hours, the molds are removed, and the samples are maintained under normal controlled conditions until the 28-day testing period according to the national standard TCVN 3118:2022 (see Figure 2b).

Table 2. *The mix design ratio calculated for 1 m^3 and wet density for Fly ash concrete specimens of M400 grade*

Mixture	Density (g cm^{-3})	Details for the mix design ratio with water to an aggregate ratio of 0,48				
		Cement (kg)	Fly ash (kg)	River sand (kg)	Stone 1×2 cm (kg)	Sikacrete (kg)
FAC0	2.48	436.6	0.0	577.2	1383.8	21.7
FAC10	2.51	392.9	43.7	577.2	1383.8	21.7
FAC20	2.52	349.3	87.7	577.2	1383.8	21.7
FAC30	2.50	305.6	131.0	577.2	1383.8	21.7
FAC40	2.52	262.0	174.6	577.2	1383.8	21.7

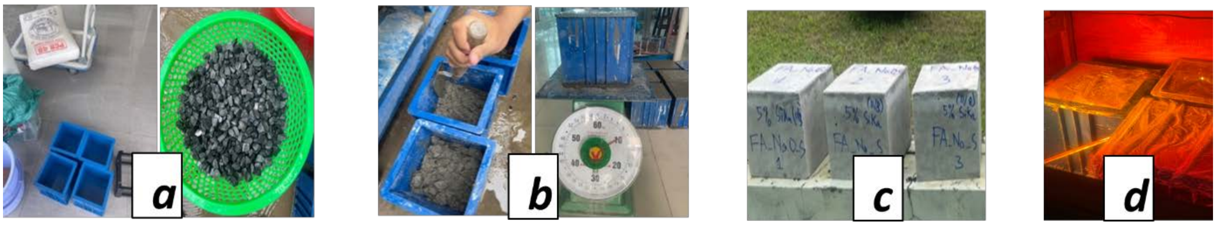

Figure 2. *Casting and curing of fly ash concrete:* ***(a)*** *Material preparation* ***(b)*** *Casting of cubes* ***(c)*** *Unmoulded cubes after ambient curing period* ***(d)*** *Heat-treated cubes*

2.3. Method for measuring compressive strength

The setup for compressive strength testing and the test samples after undergoing compressive strength testing are depicted in Figures 3a and 3c, respectively. The formula for calculating the compressive strength of the concrete samples is computed by the ratio of the maximum compressive force that the compression machine can record during the sample's crushing process and the cross-sectional area of the concrete sample:

$$CS(MPa) = \frac{CF_{max}(kN)}{CSA(m^2)} \quad (1)$$

where CS is compressive strength, CF_{max} is maximum compressive force, and CSA is cross-section area.

Firstly, the testing machine is turned on, and the testing program is initiated. Next, the concrete sample block is cleaned on the surface, and the pressure-bearing surface of the sample is ensured to be flat. Test parameters (sample size, curing age) are adjusted, the maximum compressive strength value is set at 100 MPa, and the pressing speed is adjusted to ensure stability and safety during testing. The compression process begins, and the machine operates so that the upper platen gently contacts the top surface of the sample. The load is increased continuously at a constant speed of 0.6 ± 0.2 MPa s^{-1} until the sample block is crushed. The sample's loading time until failure is less than 30 seconds. The failure load of the sample is the maximum load achieved, and the maximum force value of the sample is recorded at the end of the test. Finally, similar samples are grouped, and a serial number is assigned to each sample group for data analysis. Suppose the difference between the maximum force value and the minimum force value of the three measurements does not exceed 15% of the average value. In that case, the average value is accepted as the measured value.

Figure 3. *Testing the compressive strength of fly ash mixed concrete:*
(a) *Concrete Strength Testing Machine,* ***(b)*** *FAC, and* ***(c)*** *FAC blocks after testing*

3. Results and discussion

3.1. Wet density

The surface of the FAC blocks did not change much when subjected to heat curing, and the wet bulk density of the FAC samples was determined using the method of measuring mass and calculating volume with precise scales and measuring tools. The results are presented in Table 2. An increase in wet bulk density with the addition of FA was observed, but this increase was not significant. The highest was observed in the FAC40 sample, replacing 40% FA and increasing by about 1.6% compared to the FAC0 sample without FA. The FAC30 sample was also observed to not strictly follow the law of increasing with the amount of FA added, but it still showed a wet bulk density of 2.50 g cm^{-3}, higher than the FAC0 sample at 2.48 g cm^{-3}. Although FA class F has a lighter density than CM, as referenced in Table 1, this increased density capability may be due to the refinement of the FAC porous system, thanks to the smaller spherical particle size compared to CM. Another reason could be the higher water absorption capacity of FA class F compared to CM (Nagalia et al., 2016), which affected the bonding between the constituent components in FAC. Furthermore, these are just preliminary experimental results we obtained, and the sample size is not large enough to increase the reliability of the wet density increase law when adding FA to concrete. Further studies with larger sample sizes and more detailed FA replacement ratios are needed to clearly observe this changing law.

3.2. Calculating the final compressive strength

The results of determining the compressive strength for concrete samples maintained at room temperature and 70°C for 28 days of the concrete mixtures are presented in Figure 4, showing the maximum increase in compressive strength of concrete after 28 days depending on the ratio of CM replaced by FA at water to binder ratio of 0.48. Overall, the change in compressive strength of the FACs under both regular and heat maintenance compared to the reference sample FAC0 was insignificant, with a slight decrease observed at replacement ratios below 30% and an increase in the 30 to 40% range. All the FAC M400 samples in this study met the expected compressive strength values according to the compressive strength requirements for commonly used M400 civil construction concrete. Heat-maintained FAC samples always exhibited higher compressive load-bearing capacities than regular maintenance FAC samples. This result suggests that moderate heat has helped enhance the hydration process during the curing of FAC. Specifically, the variation in results for the FAC samples compared to the reference FAC0 sample under regular maintenance ranged from a decrease of 10.9% to an increase of 4.4%. Specifically, when the FA content was 10% and 20%, the compressive strength of the concrete decreased by 10.9% and 6.7%, respectively. The compressive strength improved when the replacement ratio of FA was 30% and 40%, with corresponding increases of 9.8% and 4.4%. According to our research, although the particle morphology of FA is fine and spherical, potentially filling voids in the concrete better than CM, its large surface area leads to a higher water absorption capacity, reducing compressive strength, especially at low water/binder ratios (Nagalia et al., 2016). With the selected water/binder ratio, FA content from 30 to 40% positively influenced the compressive strength of concrete, indicating the best filling effect achieved at the replacement ratios being investigated. Lower replacement ratios resulted in a slight decrease in compressive strength, possibly because the FA content was insufficient to achieve effective filling compared to water absorption effects. A similar changing law was observed for heat-maintained FAC samples at 70°C but with higher compressive strength after 28 days. The corresponding range of changes from 10 to 40% for heat maintenance was a decrease of 4.5% to an increase of 8.8%, with only the FAC10 sample (10% FA) showing a reduction in compressive strength of 4.5%.

In contrast, the FAC20, FAC30, and FAC40 samples all showed higher compressive strength than the reference sample FAC0. This may be explained by the appropriate temperature stimulating the hydration process, mitigating the delayed hydration disadvantage of FA. Another observation was that the replacement ratio of FA made the compressive strength of FAC peak at 30% for standard maintenance samples (reaching 47.2 MPa) and 40% for heat maintenance samples (reaching 50.8 MPa). This result suggests the advantage of increasing the FA content for FAC samples when heat is maintained to achieve the best compressive strength, contributing to increased FA utilisation and reducing negative environmental impacts. These results are also consistent with previous studies.

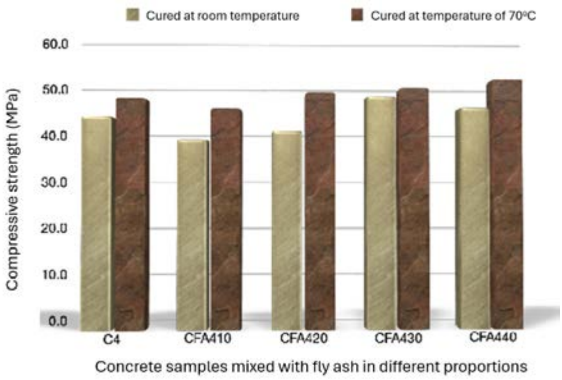

Figure 4. *Correlation between fly ash replacement ratio and compressive strength of concrete in Mac 400 in two different curing modes*

3.3. Analysis of costs and carbon dioxide emissions of FAC

Cost analysis for producing FAC was conducted based on the market prices of raw materials applied in the study. It can be observed that the cost of 1 m^3 of FAC is lower than that of conventional concrete, as presented in Table 3. The reduction in FAC costs is primarily due to the low price of fly ash, even for free. With reference prices from current construction material sources on the market, when FA is substituted for CM, costs can be reduced by up to 79% based on the amount of CM used. This calculated ratio is applied through production scale analysis in the laboratory; if produced on a larger scale, costs will decrease even further.

Carbon dioxide emission analysis for FAC with 40% FA compared to conventional concrete has been evaluated, and the results are presented in Table 4. Various components' carbon dioxide emission factors were referenced (Nayaka et al., 2018, 2019). It was found that FAC40 reduces carbon dioxide emissions by up to 90.53 kg per 1 m^3 of production compared to conventional concrete. This result becomes even more significant when combined with superplasticisers or sika additives; FA is used more in concrete.

Table 3. *Price list of fly ash concrete materials (HCMC Department of Construction, 2024; Hai Duong Province Department of Construction, 2024)*

Type of concrete	Content	Amount of material (kg)	Amount of materials used for 1m^3 (kg m^{-3})	Price (VND)/kg	Cost (VND)	Total (VND)
C4	Cement	5.9	436.6	2,040	891,000	1,192,000
	Sand	7.8	577.2	130	75,000	
	Stone	18.7	1383.8	163	226,000	
FAC440	Cement	3.5	259.0	2,040	529,000	838,200
	Fly ash	2.4	177.6	46	8,200	
	Sand	7.8	577.2	130	75,000	
	Stone	18.7	1383.8	163	226,000	

Table 4. *The CO_2 emissions for the components of Mac 400 concrete*

Type of concrete	Content	Emission rate CO_2 (Nayaka et al., 2019)	Amount of material (kg)	Amount of materials used for 1 m^3 (kg m^{-3})	CO_2 emissions per material (kg m^{-3})	Total CO_2 emissions (kg m^{-3})
C4	Cement	0.8800	5.9	436.6	384.21	455.75
	Sand	0.0139	7.8	577.2	8.02	
	Stone	0.0459	18.7	1383.8	63.52	
FAC440	Cement	0.8800	3.5	259.0	277.92	349.46
	Fly ash	0.0000	2.4	177.6	0.00	
	Sand	0.0139	7.8	577.2	8.02	
	Stone	0.0459	18.7	1383.8	63.52	

4. Conclusion

An increase in the compressive strength of fly ash concrete (FAC) was observed during the maintenance process at higher-than-normal curing temperatures (70°C). Although the increase is insignificant, it is a positive result compared to conventionally maintained concrete. Further research is needed to examine trends in compressive strength changes of FAC with different proportions of fly ash substitution and at higher maintenance temperatures, which this study has been unable to conduct due to experimental constraints.

The study investigated the wet density, compressive strength, cost advantages, and carbon dioxide emission calculations of geopolymer concrete based on fly ash with heat-cured maintenance. The results obtained are as follows:

- The wet density of FAC tends to increase with increasing fly ash content, but not significantly.
- FAC cured at higher temperatures exhibits higher compressive strength, improving mechanical properties. The amount of fly ash that can be replaced for the best compressive strength is also higher when cured at room temperature.
- FAC performs better when replacing cement in concrete mixtures with fly ash at an appropriate ratio than traditional concrete. The optimal ratio for achieved compressive strength ranges from 30 to 40%.
- Cost analysis of FAC demonstrates that it is a more economical option for concrete than conventional concrete.
- Carbon dioxide emission analysis of FAC indicates a significant reduction in emissions, making it a viable, sustainable alternative to conventional Portland cement concrete.

An essential extension is to determine the maximum risk of cancer for users of FAC, which needs to be carefully monitored.

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REFERENCES

Amarnath, Y., Rama Chandurdu, C., & Bhaskar Desai, V. (2012). Influence of fly ash replacement on strength properties of cement mortar. *International Journal of Engineering Science and Technology*, *4*(08), 3657-3665.

ASTM C595/C595M (2021). *Standard Specification for Blended Hydraulic Cements*. ASTM International, West Conshohocken, PA.

ASTM C618 (2022). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. *ASTM international, West Conshohocken, PA.*

Azzahran Abdullah, S. F., Yun-Ming, L., Al Bakri, M. M., Cheng-Yong, H., Zulkifly, K., & Hussin, K. (2018). Effect of Alkali Concentration on Fly Ash Geopolymers. *IOP Conference Series: Materials Science and Engineering*, *343*(1). https://doi.org/10.1088/1757-899X/343/1/012013

Balamohan Balakrishnan, Mehdi Maghfouri, Vahid Alimohammadi, & Iman Asadi, R. R. (2024). The acid and chloride permeability resistance of masonry cement plaster mortar incorporating high-volume fly ash content. *Journal of Building Engineering*, *86*, Article 108783. https://doi.org/10.1016/j.jobe.2024.108783

Bhikshma, V., Koti, R. M., & Srinivas, R. T. (2012). An Experimental Investigation on Properties of Geopolymer Concrete (No Cement Concrete). *Asian J. Civ. Eng*, *13*, 841-853.

Bondar, D., Lynsdale, C. J., & Milestone, N. B. (2013). Alkali-Activated Natural Pozzolan Concrete as New Construction Material. *ACI Materials Journal*, *110*(3), 331-337. https://doi.org/10.14359/51685667

British European Standards Specifications. (2011). Cement Part 1: Cement Composition, specifications and conformity criteria for common cements. *London: European Committee For Standardisation*.

Celik, K., Jackson, M. D., Mancio, M., Meral, C., Emwas, A. H., Mehta, P. K., & Monteiro, P. J. M. (2014). High-volume natural volcanic pozzolan and limestone powder as partial replacements for portland cement in self-compacting and sustainable concrete. *Cement and Concrete Composites*, *45*, 13-147. https://doi.org/10.1016/j.cemconcomp.2013.09.003

Davidovits, J. (1993). Geopolymer cement to minimize carbon-dioxde greenhouse-warming. *Ceramic Transactions* , *37*(1), 165-182. https://www.researchgate.net/publication/284682578_Geopolymer_cement_to_minimize_carbon-dioxde_greenhouse-warming

Golewski, G. L. (2018). Effect of curing time on the fracture toughness of fly ash concrete composites. *Composite Structures*, *185*(October), 105-112. https://doi.org/10.1016/j.compstruct.2017.10.090

Government Office. (2021). *Chỉ thị số 08/CT-TTg ngày 26/3/2021 của Thủ tướng Chính phủ về đẩy mạnh xử lý, sử dụng tro, xỉ, thạch cao của các nhà máy nhiệt điện, hóa chất... làm nguyên liệu* *sản xuất vật liệu xây dựng và sử dụng trong công trình xây dựng.: Vols. 08/CT-TTg*. [*Directive No. 08/CT-TTg dated March 26, 2021 of the Prime Minister on promoting the treatment and use of ash, slag, plaster of thermal power plants, chemicals... as raw materials for the production of building materials and use in construction works.: Vols. 08/CT-TTg.*]

Government Office. (2023). *Toàn văn Quyết định 500/QĐ-TTg ngày 15/5/2023 của Thủ tướng Chính phủ phê duyệt Quy hoạch phát triển điện lực quốc gia thời kỳ 2021 - 2030, tầm nhìn đến năm 2050.28. Toàn văn Quyết định 500/QĐ-TTg ngày 15/5/2023 của Thủ tướng Chính phủ phê duyệt Quy hoạch*. [*The full text of Decision 500/QD-TTg dated May 15, 2023 of the Prime Minister approving the National Electricity Development Plan for the period 2021 - 2030, with a vision to 2050.28. Full text of Decision 500/QD-TTg dated May 15, 2023 of the Prime Minister approving the Planning.*]

Hai Duong province Department of Construction. (2024). *Công bố giá Tro xỉ nhiệt điện đốt than làm vật liệu san lấp*. [*Announcement of the price of coal-fired thermal power ash as a leveling material.*] https://Soxaydung.Haiduong.Gov.vn/vi-vn/2024/Trang/Cong-Bo-Gia-Tro-Xi-Nhiet-Dien-Dot-than-Lam-Vat-Lieu-San-Lap.Aspx

HCMC Department of Construction. (2024). *Công bố giá vật liệu xây dựng trên địa bàn Thành phố Hồ Chí Minh tháng 3/2024. [Announcement of construction material prices in Ho Chi Minh City in March 2024.]* https://Soxaydung.Hochiminhcity.Gov.vn/Web/vi/Vat-Lieu-Xay-Dung/Cong-Bo-Gia-Vat-Lieu-Xay-Dung/-/Asset_publisher/PcoYAr5aCkog/Content/Cong-Bo-Gia-Vat-Lieu-Xay-Dung-Tren-Ia-Ban-Thanh-Pho-Ho-Chi-Minh-Thang-3-2024?_com_liferay_asset_publisher_web_portlet_Asse

Ho, D. W. S., Chua, C. W., & Tam, C. T. (2003). Steam-cured concrete incorporating mineral admixtures. *Cement and Concrete Research*, *33*(4), 595-601. https://doi.org/10.1016/S0008-8846(02)01028-1

Khoury, G. A. (1992). Compressive strength of concrete at high temperatures: A reassessment. *Magazine of Concrete Research*, *44*(161), 291-309. https://doi.org/10.1680/macr.1992.44.161.291

Li, X., Bao, Y., Wu, L., Yan, Q., Ma, H., Chen, G., & Zhang, H. (2017). Thermal and mechanical properties of high-performance fiber-reinforced cementitious composites after exposure to high temperatures. *Construction and Building Materials*, *157*, 829-838. https://doi.org/10.1016/j.conbuildmat.2017.09.125

Li, Y. L., Zhao, X. L., Singh Raman, R. K., & Al-Saadi, S. (2018). Thermal and mechanical properties of alkali-activated slag paste, mortar and concrete utilising seawater and sea sand. *Construction and Building Materials*, *159*, 704-724. https://doi.org/10.1016/j.conbuildmat.2017.10.104

Liu, Z., Cai, C. S., Peng, H., & Fan, F. (2016). Experimental Study of the Geopolymeric Recycled Aggregate Concrete. *Journal of Materials in Civil Engineering*, *28*(9), 1-9. https://doi.org/10.1061/(asce)mt.1943-5533.0001584

Mengxiao, S., Qiang, W., & Zhikai, Z. (2015). Comparison of the properties between high-volume fly ash concrete and high-volume steel slag concrete under temperature matching curing condition. *Construction and Building Materials*, *98*, 649-655. https://doi.org/10.1016/j.conbuildmat.2015.08.134

Ministry of Industry and Trade. (2021). *Quyết định số 1818/QĐ-BCT ngày 20/7/2021 của Bộ trưởng Công thương về việc ban hành kế hoạch của Bộ thực hiện Chỉ thị số 08/CT-TTg.*[*Decision No. 1818/QD-BCT dated July 20, 2021 of the Minister of Industry and Trade on promulgating the Ministry's plan to implement Directive No. 08/CT-TTg.*]

Nagalia, G., Park, Y., Abolmaali, A., & Aswath, P. (2016). Compressive Strength and Microstructural Properties of Fly Ash–Based Geopolymer Concrete. *Journal of Materials in Civil Engineering*, *28*(12), 1-11. https://doi.org/10.1061/(asce)mt.1943-5533.0001656

Nagral, M. R., Ostwal, T., & Chitawadagi, M. V. (2014). Effect of curing temperature and curing hours on the properties of geo-polymer concrete. *Int. J. Comput. Eng. Res*, *4*(9), 1-11.

Nayaka, R. R., Alengaram, U. J., Jumaat, M. Z., Yusoff, S. B., & Alnahhal, M. F. (2018). High volume cement replacement by environmental friendly industrial by-product palm oil clinker powder in cement – lime masonry mortar. *Journal of Cleaner Production*, *190*, 272-284. https://doi.org/10.1016/j.jclepro.2018.03.291

Nayaka, R. R., Alengaram, U. J., Jumaat, M. Z., Yusoff, S. B., & Ganasan, R. (2019). Performance evaluation of masonry grout containing high volume of palm oil industry by-products. *Journal of Cleaner Production*, *220*, 1202-1214. https://doi.org/10.1016/j.jclepro.2019.02.134

Rahman, M. M., Law, D. W., & Patnaikuni, I. (2017). Effect of curing temperature on the properties of 100% clay-based geopolymer concrete. *Proceedings of International Structural Engineering and Construction*, *4*(1), 1-11. https://doi.org/10.14455/ISEC.res.2017.98

Raju MP, R. A. (2021). Effect of temperature on residual compressive strength of fly ash concrete. *Indian Concr J*, *75*(5), 347-350.

Ramezanianpour, A. A., Khazali, M. H., & Vosoughi, P. (2013). Effect of steam curing cycles on strength and durability of SCC: A case study in precast concrete. *Construction and Building Materials*, *49*, 807-813. https://doi.org/10.1016/j.conbuildmat.2013.08.040

Sarker, P. K., Haque, R., & Ramgolam, K. V. (2013). Fracture behaviour of heat cured fly ash based geopolymer concrete. *Materials and Design*, *44*, 580-586. https://doi.org/10.1016/j.matdes.2012.08.005

Shehata, N., Sayed, E. T., & Abdelkareem, M. A. (2021). Recent progress in environmentally friendly geopolymers: A review. *Science of the Total Environment*, *762*, Article 143166. https://doi.org/10.1016/j.scitotenv.2020.143166

Singh, N., Vyas, S., Pathak, R. P., Sharma, P., Mahure, N. V., & Gupta, S. L. (2013). Effect of Aggressive Chemical Environment on Durability of Green Geopolymer Concrete. *Int. J. Eng. Innov. Technol.*, *3*, 277-284.

Sun, J., Wang, Z., & Chen, Z. (2018). Hydration mechanism of composite binders containing blast furnace ferronickel slag at different curing temperatures. *Journal of Thermal Analysis and Calorimetry*, *131*(3), 2291-2301. https://doi.org/10.1007/s10973-017-6739-9

Vora, P. R., & Dave, U. V. (2013). Parametric studies on compressive strength of geopolymer concrete. *Procedia Engineering*, *51*, 210-219. https://doi.org/10.1016/j.proeng.2013.01.030

Zhang, H., Shi, X., & Wang, Q. (2018). Effect of curing condition on compressive strength of fly ash geopolymer concrete. *ACI Materials Journal*, *115*(2), 191-196. https://doi.org/10.14359/51701124

NHỮNG KẾT QUẢ BAN ĐẦU NGHIÊN CỨU ẢNH HƯỞNG CỦA NHIỆT ĐỘ ĐÓNG RẮN LÊN KHẢ NĂNG CHỊU NÉN CỦA BÊ TÔNG TRO BAY DÂN DỤNG

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TÓM TẮT

Sự tăng trưởng cơ sở hạ tầng trên toàn thế giới đang buộc ngành xây dựng hướng tới mức tiêu thụ xi măng cao. Sản xuất xi măng không chỉ tiêu thụ một lượng lớn tài nguyên thiên nhiên mà còn gây ô nhiễm môi trường do việc thải hàng tấn khí nhà kính vào khí quyển. Để tạo một môi trường xây dựng bền vững, việc tái chế chất thải công nghiệp thành vật liệu xây dựng là rất cần thiết. Nghiên cứu này hướng đến ứng dụng tro bay như một lựa chọn thay thế cho xi măng trong bê tông dân dụng, nhằm hỗ trợ tính bền vững tài nguyên thiên nhiên và môi trường sống. Nghiên cứu đề xuất thay thế một phần xi măng bằng tro bay theo các tỉ lệ khối lượng khác nhau (0, 10, 20, 30 và 40%) và quan sát hiệu ứng nhiệt độ cao trong quá trình đóng rắn đối với khả năng chịu nén sau cùng của bê tông pha tro bay (FAC) có hàm lượng calcium thấp. Các thử nghiệm bao gồm đánh giá độ mất khối lượng khi khô, mật độ khi ướt, mật độ khi khô, và quan trọng nhất là cường độ nén lớn nhất đạt được để đánh giá hiệu suất độ bền của FAC. Kết quả ban đầu cho thấy FAC đạt cường độ nén cao hơn bằng cách bảo dưỡng đóng rắn mẫu vật ở nhiệt độ 70°C. Ngoài ra, FAC cho thấy mật độ khi ướt cao hơn không đáng kể so với bê tông thông thường bảo đảm cho nó lợi thế như là một loại vật liệu xây dựng có tính linh động cao. Kết quả của nghiên cứu đề xuất FAC nên được ưu tiên sử dụng như là bê tông trong các công trình thường xuyên tiếp xúc với ánh nắng mặt trời. Các lợi ích về chi phí sản xuất và bảo vệ môi trường cũng đã được tính toán trong nghiên cứu. Những kết quả ban đầu này đóng góp dữ liệu thực nghiệm trong việc phát triển FAC cho xây dựng dân dụng, đặc biệt là trong việc gia tăng khả năng chịu nén của vật liệu bê tông.

Từ khóa: cường độ nén; bê tông; tro bay; bê tông xanh; phụ gia khoáng chất; bảo dưỡng nhiệt