Effect of Duyen Hai 3 thermal power plant fly ash on the compressive strength development of cement mortar over time

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ABSTRACT

This study investigates the effect of fly ash (FA) from Duyen Hai 3 Thermal Power Plant on the compressive strength development of cement mortar over time. Mortar mixes were prepared with FA replacing cement at 0%, 5%, 10%, 15%, and 20% by weight. Compressive strength was evaluated at 3, 7, 28, and 56 days of curing. At 3 and 7 days, the mix containing 5% FA achieved the highest strength, while replacement levels of ≥10% led to reduced early strength. At 28 and 56 days, the 10% FA mix attained the highest strength, surpassing the control mix, attributed to the effective pozzolanic reaction. The 15% replacement level showed strength comparable to the control, whereas 20% replacement resulted in significant strength reduction at all ages. Duyen Hai 3 FA, characterized by high reactive oxide content, appropriate fineness, and low loss on ignition, contributed to the formation of additional C-S-H gel and pore filling in the mortar matrix.

Keywords: *Compressive strength, pozzolanic reaction, fly ash, cement mortar*

1. INTRODUCTION

In the context of sustainable development, the construction industry is facing a dual challenge: meeting the increasing demand for building materials while simultaneously minimizing adverse environmental impacts. One promising approach is the partial replacement of cement with reactive mineral admixtures, particularly FA - a by product generated from coal combustion in thermal power plants. The incorporation of FA not only reduces greenhouse gas emissions associated with clinker production but also contributes to the management of industrial solid waste, thereby promoting a circular economy in the construction sector [1][2].

FA is a fine particulate material rich in silica (SiO_2), alumina (Al_2O_3) and iron oxides (Fe_2O_3), capable of undergoing pozzolanic reactions with the hydration products of Portland cement - particularly $Ca(OH)_2$, to form secondary C-S-H gel, which is the primary phase contributing to the strength and durability of cementitious materials [3]. However, the performance of FA is strongly influenced by its chemical composition, particle size distribution, loss on ignition (LOI), as well as curing conditions and the cement replacement level [4][5]. García [6] reported that although FA may reduce early-age compressive strength, it can significantly improve long-term strength and durability when used at appropriate dosages and with suitable FA characteristics.

In Vietnam, millions of tons of FA are discharged annually from coal-fired power plants, and many sources in the Mekong Delta region remain underutilized. A typical example is the FA produced by the Duyen Hai 3 Thermal Power Plant in Vinh Long Province. This FA is classified as Class F according to TCVN 10302:2014 [7], indicating its high potential for use as a mineral admixture in cement and mortar. Although numerous studies have investigated the effects of FA on the properties of concrete and mortar, research specifically focusing on FA from Duyen Hai 3, particularly its influence on the time-dependent development of mortar strength, remains limited. In construction practice, mortar plays a crucial role in plastering and bonding applications, requiring adequate strength at both early and later ages. Therefore, evaluating the effect of cement replacement levels with FA on compressive strength over time is essential to support its practical application.

Based on these practical considerations, this study was conducted to assess the influence of various replacement levels of Duyen Hai 3 FA (5%, 10%, 15%, and 20%) on the compressive strength development of cement mortar at ages of 3, 7, 28, and 56 days. The findings provide a scientific basis for proposing an optimal FA replacement ratio in construction mortar, contributing to the development of sustainable and environmentally friendly building materials.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1. Materials

2.1.1. Cement

In this study, the authors used Hà Tiên PCB40 cement, and the experimental results are presented in Table 1.

Table 1: Physical and Mechanical Properties of Hà Tiên PCB40 Cement

Characteristic	Testing Methods	Test result
1. Specific gravity (g/cm^3)	TCVN 4030-2003	3.10
2. Consistency (%)	TCVN 6017-2015	28.8
3. Setting time Initial (minutes) Final (minutes)	TCVN 6017-2015	 139’ 3h45’
4. Soundness (Lechatelier method) (mm)	TCVN 6017-2015	0.71
5. Fineness, retained 0.09 mm (%)	TCVN 4030-2003	6.50
6. Compressive strength (MPa) 3 days 28 days	TCVN 6016-2011	 22.20 44.0

2.1.2. Fine aggregate

The fine aggregate used in this study is natural river sand with a fineness modulus of 1.8. The particle size distribution test results of the sand are shown in Figure 1.

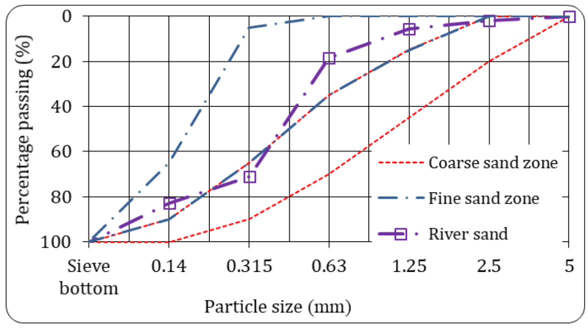

Figure 1. Particle size distribution of river sand

2.1.3. Fly ash

The FA used in this study was obtained from the Duyen Hai 3 Thermal Power Plant in Vinh Long Province (Figure 2), and its test results are presented in Table 2. These results indicate that the FA corresponds to Class F FA according to the classification specified in TCVN 10302:2014 [7]. The technical requirements for Class F FA according to TCVN 10302:2014, along with the test results of the FA used in this study, are also provided in Table 2.

Figure 2. Fly ash used in the experiment

Table 2. Technical Properties of Duyen Hai 3 FA

Indicator	Result (%)	Requirement according to TCVN 10302:2014 [7]
Total content of $SiO_2 + Al_2O_3 + Fe_2O_3$, % by mass	88.5	≥ 70%
Sulfur content, sulfur compounds converted to SO_3, % by mass	1	≤ 3%
Loss on ignition (LOI), % by mass	0.7	≤ 12%
Residue on 45µm sieve, % by mass	13	≤ 25%

The FA used in this study was collected from the Duyen Hai 3 Thermal Power Plant and was characterized for its basic physical and chemical properties in accordance with TCVN 10302:2014. The total content of SiO_2, Al_2O_3 and Fe_2O_3 reached 88.5% by mass, significantly higher than the minimum requirement of 70%. This indicates that the material belongs to Class F pozzolanic FA with high reactivity. The high proportion of these oxides provides a solid basis for the pozzolanic reaction to develop strongly at later ages, thereby contributing to the improvement in compressive strength of mortar over time.

The sulfur content (expressed as SO_3) was 1%, which is considerably lower than the maximum allowable limit of 3% specified by the standard. This ensures that the FA does not pose a risk of increasing sulfate attack or adversely affecting the volume stability of cementitious mortar.

The measured LOI was 0.7%, indicating that the amount of unburnt carbon in the FA is very low. The FA with such a low LOI is generally more uniform and stable, exerting minimal influence on cement hydration and demonstrating good compatibility with chemical admixtures.

In addition, the residue on the 45 μm sieve was 13%, well below the limit of 25% prescribed by TCVN 10302:2014. This reveals that the FA possesses relatively good fineness, which enhances its dispersion in the mixture and allows it to act as a micro-filler to fill voids, thereby improving the density and compactness of the mortar.

2.2. Experimental Methods

To evaluate the effect of FA sourced from the Duyen Hai 3 Thermal Power Plant on the development of compressive strength in cement mortar, a set of three prism specimens with dimensions of 40 × 40 × 160 mm was prepared and tested at the ages of 3, 7, 28, and 56 days. The mix proportions were designed based on TCVN 6016:2011 [8]. According to this standard, standard ISO sand with a relatively coarse particle size is used together with 225 g of water per batch. However, in the present study, river sand with a fineness modulus of 1.8 was employed, which is generally finer than the ISO standard sand. Due to its higher water absorption, a water dosage of 245 g was adopted instead of the specified 225 g to ensure better workability during specimen casting. The replacement levels of FA investigated in this study were 5%, 10%, 15%, and 20% by mass of cement; in addition, a control mixture without FA was prepared for comparison. The detailed mix proportions of all mixtures are presented in Table 3.

Table 3: Mortar mix composition with FA (g)

% FA by cement	Cement	FA	Sand	Water
0	450	0	1350	245
5	450	22.5	1350	245
10	450	45	1350	245
15	450	67.5	1350	245
20	450	90	1350	245

The mortar was mixed using a mechanical mixer and compacted in molds by means of a standard jolting apparatus (Figure 3). The mixing procedure began with blending water with the cement and FA mixture for 30 seconds, followed by the gradual addition of sand and mixing continued until a homogeneous mixture was achieved. After casting, the specimens were cured in molds under ambient laboratory conditions for 24 hours, then demolded and submerged in water until the designated testing ages.

The compressive strength was determined in two stages: first, the specimens were subjected to flexural loading until failure (Figure 4a); subsequently, the two broken halves were used for compressive testing (Figure 4b). The compressive strength value reported for each mixture is the average of six specimens. All tests were conducted in accordance with TCVN 3121-11:2003 [9].

(a) Mixer (b) Jolting apparatus

Figure 3. Equipment

(a) bending test (b) compression test

Figure 4. Flexural Failure Test and Compressive Strength Determination

3. RESULTS AND DISCUSSION

The compressive strength development of cement mortar incorporating FA from the Duyen Hai 3 Thermal Power Plant at the ages of 3, 7, 28, and 56 days, corresponding to FA replacement levels ranging from 0% to 20% by mass of cement, is illustrated in Figure 5. In general, the compressive strength of all mixtures increased over time, reflecting the continuous progression of cement hydration and the pozzolanic reaction. However, the degree of strength improvement varied significantly depending on the percentage of FA replacement.

At 3 days, the compressive strength increased when 5% FA was used, achieving a higher value than that of the control mixture (0% FA). However, as the replacement level increased to 10–20%, the strength gradually decreased. This indicates that the primary role of FA at the early stage is related to the filler effect and the provision of nucleation sites for hydration products, particularly at low replacement levels (5%). At higher dosages, the reduction in cement content results in fewer early hydration products, thereby negatively affecting early-age strength.

At 7 days, a similar trend was observed. The mixture containing 5% FA continued to exhibit the highest strength, suggesting that an appropriate replacement level of Duyen Hai 3 FA can contribute positively at early ages due to its fineness and high reactive oxide content. However, when the replacement level reached 10% or more, the compressive strength decreased, as the pozzolanic reaction had not yet become dominant at this age, while a significant portion of cement clinker had already been replaced.

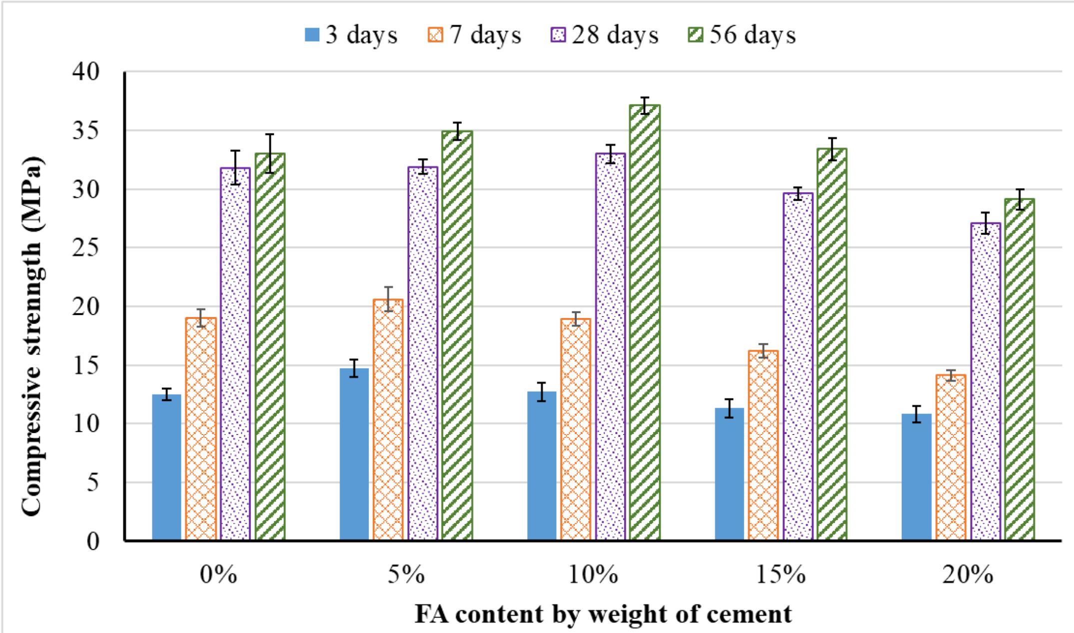

Figure 5. Compressive strength of mortar at different ages with various FA replacement levels

Notably, at 28 days, the mixture containing 10% FA achieved the highest compressive strength among all replacement levels, even surpassing the control sample. This result indicates that the pozzolanic reactivity of the Duyen Hai 3 FA becomes more pronounced after 28 days, as the reactive oxides in the FA react with $Ca(OH)_2$ generated from cement hydration to form additional C-S-H gel, thereby enhancing strength. This confirms the effectiveness of a 10% replacement level in improving mechanical performance at medium ages.

At 56 days, this superiority was maintained in the 10% FA mixture, which continued to exhibit the highest compressive strength. The mixtures containing 5% and 15% FA also reached values comparable to or higher than the control sample, whereas the 20% replacement mixture recorded the lowest results. This demonstrates that an excessively high FA content can lead to a reduction in mechanical properties due to insufficient early cementitious material, even though the pozzolanic reaction continues to develop over time. In contrast, replacement levels of 5-10% effectively take advantage of both mechanisms: cement hydration and the pozzolanic reaction.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the experimental findings regarding the effect of FA from the Duyen Hai 3 Thermal Power Plant on the time-dependent compressive strength development of cement mortar, the following conclusions and recommendations can be drawn:

The Duyen Hai 3 FA fully satisfies the technical requirements specified in TCVN 10302:2014 for Class F pozzolanic admixtures. Its chemical and physical characteristics indicate good pozzolanic reactivity and high potential for application in mortar and concrete production.

The replacement of cement with Duyen Hai 3 FA influences the compressive strength of mortar depending on the replacement level and curing age. A 5-10% replacement results in improved compressive strength at 28 and 56 days due to enhanced pozzolanic activity. A 15% replacement provides strength values comparable to the control mixture, whereas a 20% replacement leads to a noticeable reduction in strength at all ages. Therefore, the optimal replacement level is recommended to be within 5-10% to ensure long-term strength and sustainable performance.

Further studies are required to evaluate other properties of mortar and concrete incorporating this FA, such as durability, permeability resistance, shrinkage, and sulfate attack resistance, in order to establish a more comprehensive scientific database and support practical applications in construction engineering.

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