INFLUENCE OF FLY ASH AND GROUND GRANULATED BLAST FURNACE SLAG ON PROPERTIES OF CONCRETE

Hoang Quoc Gia[1]

Abstract: *This work proposes an experimental program for characterizing the mechanical properties of concrete using fly ash (FA) and ground granulated blast furnace slag (GGBFS). The testing procedure bases on two experiments: compressive strength and temperature rise and was performed on three types of binder i) fly ash cement (PCFA) which was ordinary portland cement partially substituted with fly ash by 30%; ii) slag cement (PCBS) containing GGBFS at a replacement ratio of 65%, and iii) ternary blended cement (PCFABS) which was fly ash cement (PCFA) partially replaced with GGBFS at 55%. It has been shown that using a combination of fly ash and GGBFS in concrete can improve compressive strength and reduce the temperature as compared with other types of binder.*

Keywords: Concrete, fly ash, ground granulated blast furnace slag, strength, temperature rise.

1. INTRODUCTION

Fly ash is produced, in massive amounts, as a waste material of burning fossil fuel (coal combustion) for the thermal generation of electricity. In fact, about 900 million tons of fly ash were emitted annually over the world and around 30-40% of them are utilized variously, including cement and concrete manufacturing. The use of fly ash in portland cement concrete brings many benefits and improves concrete performance in both the fresh and hardened state. Specifically, it improves the workability of plastic concrete and the strength, durability of hardened concrete. Also, the use of fly ash can minimize the cost, i.e, when fly ash is added to concrete, the amount of portland cement may be reduced.

Using fly ash in mass concrete, however, has also some disadvantages and problems. While the main benefit of fly ash is decreasing the permeability of concrete at a low cost but the permeability probably increases if we use poor quality fly ash. Adding fly ash into concrete slows the setting time of concrete that might be considered as a disadvantage; however, it could be a benefit by reducing the thermal stress. Slow set and low early strength need to be considered as non-consequences of using fly ash. In fact, in most cases, the high- fineness and low-carbon fly ash will result in high early strength. Sometimes, additional lime, an accelerator, or a superplasticizer will be needed. Also, fly ash can be mixed with a small amount of condensed silica fume to improve the setting time or early-strength properties.

In Vietnam, nowadays it is estimated that the amount of fly ash generated from thermal power plants is up to 12 million tons/year. Therefore, fly ash would be a great threat to the environment due to its components of dust and toxic if there is no action to handle and recycle it effectively. In addition, it also put pressure on the annual demand for storage area. It can be noted that fly ash is a big issue; as a result, the Prime Minister has also issued Decision No. 1696 / QD-TTg on some solutions to treat ash of thermal power plants as raw materials.

Ground granulated blast-furnace slag, GGBFS, is a by-product of iron in blast-furnace. It consists mostly of molten calcium silicate and aluminosilicate, which must regularly be extracted from the blast furnace. The chemical compositions of GGBFS rely on the raw

[1] *Bộ môn Vật liệu Xây dựng, Đại học Thủy lợi*

materials used in iron processing, similar to fly ash, the physical characteristics rely on the cooling mechanism used to cool down the molten materials. When used in portland cement, GGBFS offers many advantages over unmodified portland cement: Increased sulfate resistance, alkali-silica reaction resistance; Decreased permeability; Increased long-term strength. Before using GGBFS as a portland cement replacement, several precautions must be realized. Instead of raising the water content, an admixture is needed to improve workability. Setting time is significantly delayed by around 20 minutes, and early compressive strengths are reduced. The enhanced drying shrinkage is also caused by GGBFS. When using this or any other alternative cementing material with portland cement, it is necessary to create trial mixtures to ensure proper proportioning for the desired properties.

In this work, we studied the properties of concrete (the strength, temperature rise) using different contents of fly ash and ground granulated blast-furnace slag. The experimental program was carried out on several mix design of concrete, with W/B ratio change from 0.4 to 0.6.

2. MATERIALS AND MIX DESIGN

2.1. Materials

All concrete of the study is prepared with an Ordinary Portland Cement **PC40**, according to the standard TCVN 2682:2009. Table 1 presents the main chemical and physical properties of the cement.

Table 1. Properties of ordinary Portland cement

Composition	**Value**	**Unit**
SiO_2	20.8	%
Al_2O_3	4.6	%
Fe_2O_3	2.4	%
CaO	65.1	%
MgO	2.0	%
SO_3	3.4	%
K_2O	0.86	%
Na_2O	0.11	%
Cl^-	0.06	%
Na_2O equivalent	0.67	%
Physical and mechanical properties		
3 days compressive strength	23	MPa
28 days compressive strength	45	MPa
Blaine specific surface area	3200	cm²/g
Density	3.14	g/cm^3
Water demand for standard paste	29	%
Final setting time	2.45	hh.mm

Fly ash (FA) used in this study had a density of 2.62 g/cm^3 and fineness of 3300 cm²/g; ground granulated blast-furnace slag (BS) had a density of 2.91 g/cm^3 and fineness of 4464 cm²/g. The chemical properties of used materials are shown in table 2.

Table 2. Chemical components of FA and BS

Materials	Chemical components (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
BS	34.39	14.47	0.63	41.67	6.49	0.36	1.2
FA	54.38	21.50	5.16	10.80	1.89	-	-

A new generation modified polycarboxylate is used as a superplasticizer allowing efficient dispersion of cement particles and improving grout's flowability for an extended duration. Table 3 presents the main properties of this superplasticizer.

Table 3. Main properties of superplasticizer

Properties	**Value**	**Unit**
Density	1.08 ± 0.02	g/cm^3
pH	6± 2	
Cl^-	< 0.1	%
Na_2O equivalent	< 2	%
Dry material content	20 ± 1.5	%

2.2. Mix design of concrete

In the experiments, three types of binders were used:

- **Fly ash cement** (PCFA) which was ordinary Portland cement partially substituted with fly ash by 30%;

- **Slag cement** (PCBS) containing GGBFS at a replacement ratio of 65 %;

- **Ternary blended cement** (PCFABS) which was fly ash cement partially replaced with GGBFS at 55%.

Each form of the binder was measured at three different ratios of water to binder (W/B): 0.4, 0.5, and 0.6. In all cases, the water content was 160 kg/m^3, independent of W/B. The amounts of superplasticizer were modified to achieve a target slump of 12 cm. Table 4 shows the design mix proportion of concretes.

Table 4. Concrete mix proportions

Binder types (Symbols)	W/B	Unit weight (kg/m^3)						SP
		W	FA	OPC	BS	S	G	(ml)
FA30 cement (PCFA)	0.4	160	120	280	-	760	1005	2600
BS65 cement (PCBS)			-	140	260	790		
Ternary blended cement (PCFABS)			54	126	220	770		
FA30 cement (PCFA)	0.5	160	96	224	-	780	1050	2600
BS65 cement (PCBS)			-	112	208	800		
Ternary blended cement (PCFABS)			43	100	177	790		
FA30 cement (PCFA)	0.6	160	80	187	-	808	1080	2200
BS65 cement (PCBS)			-	93	174	813		
Ternary blended cement (PCFABS)			36	84	147	810		

3. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, we will illustrate some experimental results of the mechanical properties of concrete. The compressive strength of concrete was measured in accordance with TCVN 3118:1993, using 150-mm cubic specimens. Each specimen was cured in water for 28 days at 27^{0}C.

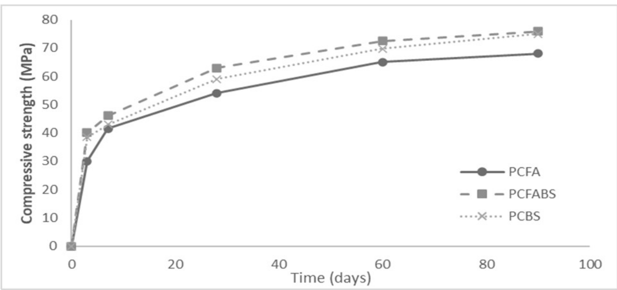

Figure 1. Compressive strength as a function of time

As shown in figure 1, cubic compressive strength at 28 days of concretes with the same W/B ratio (0.4) was the highest with PCFABS cement and lowest in the case of PCFA (about 10% lower). It is important to highlight the fact that the difference in the compressive strength of concrete use ternary blended cement PCFABS and slag cement PCBS is very small, especially at long age.

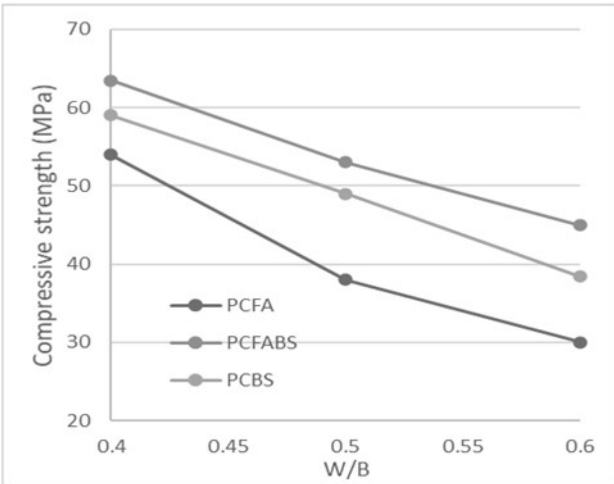

Figure 2. Compressive strength at age of 28 days as a function of W/B

Figure 2 shows the relationship between compressive strength and water to binder ratio (W/B) at the ages of 28 days. From the results, it is clear that the compressive strength decreases with higher W/B ratio. The results of the experiment found clear support for the strong influence of binder content on the properties of concrete. Our results also demonstrated that the compressive strength of PCFA was smaller than those of PCBS and PCFABS as comparing the same W/B, with the difference being larger at higher W/B. For all W/B ratios studies, concrete used ternary blended cement presented the highest strength.

The experimental program continued with the temperature rise test. The temperature was measured using a quasi-adiabatic sample filled with 200 mm thick expanded polystyrene for insulation, which was a 400-400-400 mm concrete cube. Using a strain meter inserted in the center of the quasi-adiabatic specimen, measurements were performed in figure 3.

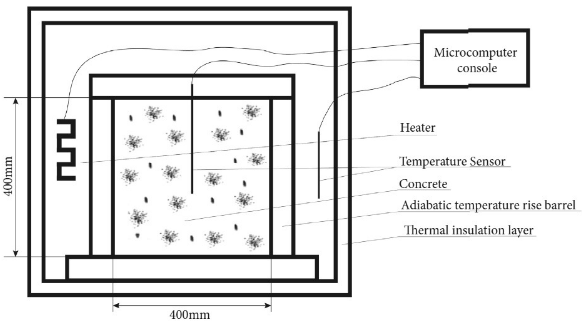

Figure 3. Temperature rise experiment

The temperature rise experiment was carried out on W/B 0.4 for all three types of the binder. The result data was presented in figure 4.

In all cases, temperature increases hit the highest value in two days from concrete placement. After that, the temperature reduces slowly. The temperature rise was the lowest with the ternary blended cement PCFABS and becoming higher with the PCFA and PCBS cement. The temperature increase of PCFA cement was lower than that of PCBS cement by about 4°C and that of ternary blended cement was lower than that of PCFA cement by about 1 °C.

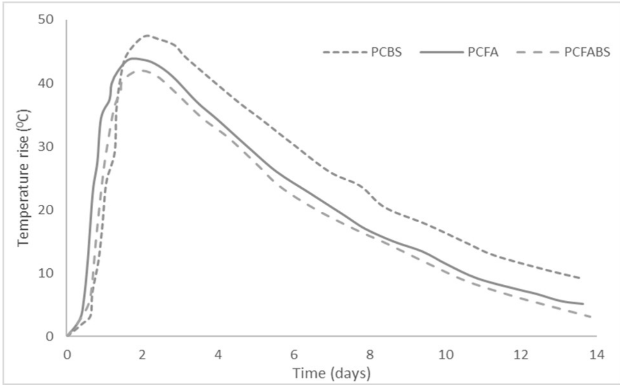

Figure 4. Temperature rises at the central part of the specimens

4. CONCLUSION

More generally, the basic findings are showing that:

1) At the same water to binder ratio, the compressive strength of concrete of cement containing 30% fly ash (PCFA) was lower than that of cement with a high amount of ground granulated blast-furnace slag (PCFABS or PCBS).

2) Compared to the slag cement containing GGBFS at a high replacement ratio of 65% (PCBS), the fly ash cement containing fly ash at a replacement ratio of 30% (PCFA) was lower in compressive strength but lower in temperature rise, indicating comparable performance at the same compressive strength.

(3) The ternary mixed cement containing both fly ash and ground granulated blast-furnace slag showed better performance (higher in compressive strength and marginally lower in temperature rise), compared to fly ash cement and slag cement.

Future research should consider the potential effects of fly ash and ground granulated blast-furnace slag on the properties of concrete more carefully, for example, the thermal cracking resistance, autogenous shrinkage, and also influence of different types of fly ash or ground granulated blast furnace slag.

REFERENCES

EN 206 -1: *Concrete - Part 1: Specification, performance, production, and conformity*

TCVN 2682:2009: *Portland cement - Specifications*

TCVN 3118:1993: *Heavyweight concrete - Method for determination of compressive strength*

No. 1696/QD-TTg: *Decision, Taking measures to treat ash, slag and gypsum from thermal power, chemical, or fertilizer plants for the production of building materials*

Tóm tắt:

ẢNH HƯỞNG CỦA TRO BAY VÀ XỈ LÒ CAO DẠNG HẠT ĐẾN TÍNH CHẤT CỦA BÊ TÔNG

Nghiên cứu này đưa ra một chương trình thí nghiệm để đánh giá tính chất cơ lý của bê tông sử dụng tro bay và xỉ lò cao dạng hạt. Có 2 chuỗi thí nghiệm bao gồm cường độ chịu nén và tăng nhiệt độ được tiến hành trên ba loại chất kết dính: i) xi măng tro bay (PCFA) được tạo bởi xi măng pooclăng thông thường thay thế bởi 30% tro bay; ii) xi măng xỉ (PCBS) có 65% xỉ lò cao dạng hạt nghiền mịn thay thế xi măng và iii) xi măng hỗn hợp 3 thành phần (PCFABS) được tạo bảo xi măng tro bay thay thế 55% bằng xỉ lò cao dạng hạt. Kết quả cho thấy sử dụng kết hợp tro bay và xỉ lò cao trong bê tông có thể cải thiện cường độ chịu nén và giảm sự tăng nhiệt độ khi so sánh với các loại chất kết dính khác (xi măng tro bay và xi măng xỉ).

Từ khóa: Bê tông, tro bay, xỉ lò cao dạng hạt, cường độ nén, sự tăng nhiệt độ.

Ngày nhận bài: 05/12/2020

Ngày chấp nhận đăng: 31/12/2020