

EFFECT OF HIGH FLY ASH CONTENT ON ENGINEERING PROPERTIES OF RECYCLED AGGREGATE CONCRETE BASED ON ALKALI-ACTIVATED SLAG-FLY ASH

ẢNH HƯỞNG CỦA LƯỢNG LỚN TRO BAY ĐẾN ĐẶC TÍNH KỸ THUẬT CỦA BÊ TÔNG LÀM TỪ CỐT LIỆU TÁI CHẾ DỰA TRÊN PHƯƠNG PHÁP KIỂM KÍCH HOẠT XỈ LÒ CAO-TRO BAY

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Abstract - The aim of this study is to evaluate the effect of fly ash on the properties of fresh and hardened recycled aggregate concrete based on alkali-activated slag. The aggregate of concrete mixtures was prepared with partial replacement of recycled aggregate, which was collected from construction demolish waste. Meanwhile, the binder created by the alkali-activated slag with different replacement levels of fly ash (30%-50%), which was activated by a solution from sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Experimental results show compressive strength of concrete samples ranges from 26.5 to 36 MPa at 28 age days. Using FA helps improving the workability of concrete, however, the high level of FA replaced ground granulated blast furnace slag (GGBFS) also causes a negative influence on hardened properties such as strength, ultrasonic pulse velocity (UPV), electrical resistivity (ER).

Key words - alkali-activated slag; fly ash; compressive strength; electrical resistivity; UPV

Tóm tắt - Nghiên cứu này nhằm mục đích đánh giá ảnh hưởng của tro bay lên đặc tính kỹ thuật của bê tông làm từ cốt liệu tái chế dựa trên phương pháp kiểm kích hoạt xỉ thép. Cốt liệu được chuẩn bị từ cốt liệu tái chế của công trình đã sụp đổ thay thế một phần cho cốt liệu tự nhiên. Trong khi chất kết dính được làm từ phương pháp kiểm kích hoạt xỉ thép với sự thay thế một phần của tro bay từ 30%-50%, hỗn hợp này được kích hoạt bằng dung dịch xút có nồng độ cao và natri silicat để làm chất kết dính cho bê tông. Kết quả chỉ ra cường độ chịu nén của bê tông đạt được từ 26.5 đến 36 MPa tại 28 ngày. Độ sụt và độ chảy của bê tông được cải thiện khi sử dụng tro bay để thay thế một phần cho xỉ thép, tuy nhiên, việc sử dụng hàm lượng lớn tro bay gây nên ảnh hưởng tiêu cực cho những đặc tính của bê tông như cường độ, vận tốc xung siêu âm, điện trở suất bê mặt.

Từ khóa - vật liệu kiểm kích hoạt; tro bay; cường độ nén; điện trở suất bề mặt; vận tốc xung siêu âm

1. Introduction

Annually, a huge amount of demolished construction waste is generated all over the world which causes the environment impacts. Therefore, the reuse of waste concrete has been received attention from researches and industrial construction instead of landfill. Waste concrete can be used to produce the recycled aggregate (RA), which has been consider as a potential substitute for natural aggregate. However, RA is illustrated with high water absorption, lower density, larger porosity and higher impurities content [1, 2], which cause negative effects on the concrete properties. Many studies have found the worse workability of concrete using RA due to high water absorption and the particle shape of RA [3]. Bravo et. al illustrated that high level replacement of RA led to the lower compressive strength and elastic modulus of concrete samples [4]. Another study pointed out that higher chloride penetration was related to increase RA content [5].

Generally, Portland cement (PC) was used in concrete production based on its excellent performance and quality. However, the cement-manufacturing process causes many environmental impacts due to large CO_2 emissions [6]. Therefore, taking into account the concept of sustainable development requires improvement of the current cement production process as well as making other cement production greener than the conventional Portland cement. The alkali-activated slag (AAS) was considered as green cement that incorporates waste material like ground granulated blast furnace slag (GGBFS) and fly ash (FA) with

lower cost than PC. AAS exhibited early high compressive strength, good resistance to sulfate or acid attack and low chloride penetration [7, 8]. However, AAS also presented high drying shrinkage, fast setting time and crack matrix. In order to activate the AAS, alkaline solution could be prepared by means of sodium silicate, sodium hydroxide, sodium carbonate or their combination [9, 10].

The purpose of this study is to evaluate the effect of high volume of FA on the performance of AAS concrete that was produced with demolished construction waste as aggregate. The binder was prepared from GGBFS and partial replacement of FA of 30%, 40% and 50% by weight. These mixtures were activated by the alkaline solution including sodium hydroxide and sodium silicate according to modulus ratio of $\text{SiO}_2/\text{Na}_2\text{O}$ of 0.6 and sodium oxide (Na_2O) concentration at 4% of the weight of cementitious materials. Fresh properties of concrete were analyzed through unit weight, slump and slump flow tests, while compressive strength, ultrasonic pulse velocity (UPV), electrical resistivity (ER) were measured to evaluate the hardened properties of concrete.

2. Materials and test methods

2.1. Material properties

In this study, class F fly ash and ground granulated blast furnace slag from the local company in Taiwan were used to produce the alkali-activated binder. The physical properties and chemical compositions of these materials were shown in Table 1. Besides, the binder was activated by alkaline

solution with a combination of sodium silicate (with SiO_2 : 25.7%; Na_2O : 8.26%; H_2O : 66.4%) and high purity sodium hydroxide NaOH (>98%). The local tap water was used for extra water mixture. The waste from demolished construction was processed and used as recycled fine and coarse aggregate according to ASTM C33 standard [11]. The natural fine and coarse aggregates were imported from Mainland China. The Fig. 1 showed that RA highly contained old mortar, brick and impurities, so it presented higher water absorption and lower specific gravity comparing with natural aggregates as shown in Table 2.



a. RFA

b. RCA

Figure 1. Recycled aggregate

Table 1. Physical and chemical properties of raw materials

Items		FA	GGBFS
Physical properties	Specific gravity	2.08	2.98
	Mean particle size (μm)	21.8	14.56
Chemical composition (%)	SiO_2	63.9	33.39
	Al_2O_3	20.0	14.39
	Fe_2O_3	6.64	0.19
	CaO	3.84	41.08
	MgO	1.25	7.22
	K_2O	1.08	0.6
	Others	1.68	3.13

2.2. Experimental programs

Table 2. Physical properties of the aggregate

Items	Water absorption (%)	Specific gravity (g/cm^3)
Natural fine aggregate (NFA)	10	2.32
Natural coarse aggregate (NCA)	7.34	2.41
Recycled fine aggregate (RFA)	1.4	2.6
Recycled coarse aggregate (RCA)	1.0	2.64

Various FA levels of 30%, 40% and 50% were used to replace GGBFS to produce the alkali-activated materials. The alkaline solution is a combination of sodium hydroxide and sodium silicate with ratio of $\text{SiO}_2/\text{Na}_2\text{O}$ at 0.6 and the percentage of Na_2O at 4% of total weight binder. The water to binder was fixed at 0.38. In this study, the fine aggregate was prepared from the combination between recycled fine aggregate (RFA) and natural fine aggregate (NFA) with volume ratio of 3:7, while the recycled coarse aggregate (RCA) was used with 40% of natural coarse aggregate (NCA) by volume. The volume of paste was fixed at 35% and the amount of sand was used at 55% of total aggregate. The detailed mix proportion was shown in Table 3.

The property of fresh alkali-activated slag-FA (AASF) recycled concrete was measured by slump cone. The 100x200 mm cylinder specimens were prepared for

compressive strength, ultrasonic pulse velocity (UPV) and electrical resistivity (ER) tests. These samples were demoulded after 24 hours of curing in the mold at ambient condition of $27 \pm 2^\circ\text{C}$ and delivered to water tank at temperature of $25 \pm 2^\circ\text{C}$ for compressive strength and ER test. Other samples were moved to curing chamber at temperature of $25 \pm 2^\circ\text{C}$ and 60% humidity for UPV analysis. The compressive strength was conducted according to ASTM C39 [12], the UPV test was measured following to ASTM C597 [13], while ER was tested by concrete electrical resistivity meter of CNS Company in UK.

Table 3. Mix-proportion for the preparation of concrete samples

Mixtures	Concrete ingredient proportion (kg/m^3)						
	Sand	Coarse	GGBFS	FA	Na_2SiO_3	NaOH	Water
M5CF30	861	704	296	127	39	104	109
M5CF30	861	704	250	167	39	103	108
M5CF30	861	704	205	205	38	101	107

3. Results and discussion

3.1. Fresh properties of AASF recycled concrete

The fresh properties of AASF recycled concrete were shown in Table 4. The results illustrated that a higher FA level replaced GGBFS, the better slump and slump flow of AASF recycle concrete. These results were supported with previous studies that used FA to increase the workability of fresh concrete and FA was considered as a mineral water reducer [14]. Nguyen et al. showed that using higher FA content reduced the amount of superplasticizer (SP) to achieve the same slump and slump flow of high strength self-compacting concrete [15]. Besides, increasing the FA level reduced the unit weight of AASF recycled concrete due to lower specific gravity compared to GGBFS as shown in Table 1.

Table 4. Fresh properties of AASF recycled concrete

Mixtures	Unit weight (kg/m^3)	Slump (mm)	Flow (mm)
M5CF30	2292	170	270
M5CF40	2288	185	285
M5CF50	2283	210	315

3.2. Compressive strength development

The most important property of concrete is compressive strength, which plays a major role of general quality control of concrete. Figure 1 presented the compressive strength of AASF recycled concrete up to 28 days of curing. After 28 days of curing, compressive strength ranged from 26 to 36 MPa with various FA levels. The compressive strength increased continuously along with an increase in the curing time due to long-term reaction of those components. It was contributed by the hydration products of alkali-activated slag with fly ash such as C-S-H gel, hydrotacile-like phase. Using higher levels of FA caused negative effects on the compressive strength of AASF recycled concrete because of slow reaction of FA particle. Saha illustrated that using the partial replacement of FA to cement caused the decrease in compressive strength in the early age days, but in later age days, due to the pozzolanic reaction of FA, the compressive strength of concrete increased with FA content up to 30% [16].

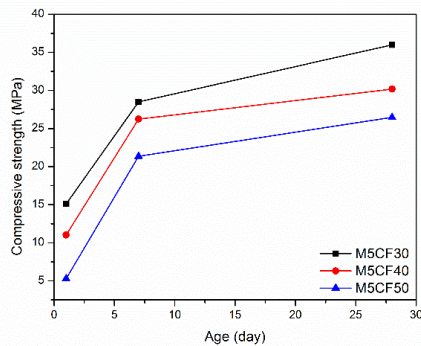


Figure 2. Compressive strength AASF recycled concrete

3.3. Ultrasonic pulse velocity (UPV)

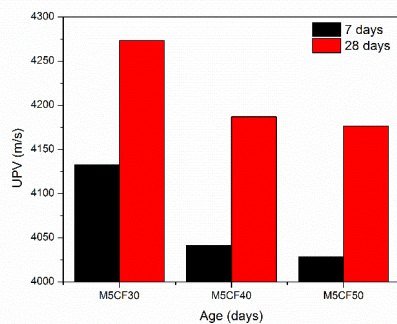


Figure 3. UPV value of AASF recycled concrete

Ultrasonic pulse velocity is one of indirect factors performing durability and compressive strength of concrete samples. In this study, UPV test was measured at 7 and 28 age days of curing and the results were shown in Fig. 3. The UPV values of all samples were greater than 3660 m/s. As reported in Fig. 3, the UPV values subsequently increased with curing times and at 28 days of curing, the concrete samples showed the UPV values of range of 4176 to 4273.5 m/s. Therefore, these concrete samples exhibited good durability according to Malhotra [17]. Additionally, increasing the FA content caused a decrease in the UPV values of concrete samples. Moreover, the relationship between compressive strength and UPV values of concrete samples was analyzed by a linear regression and shown in Fig. 4. The results showed higher UPV values that presented greater compressive strength of the concrete samples.

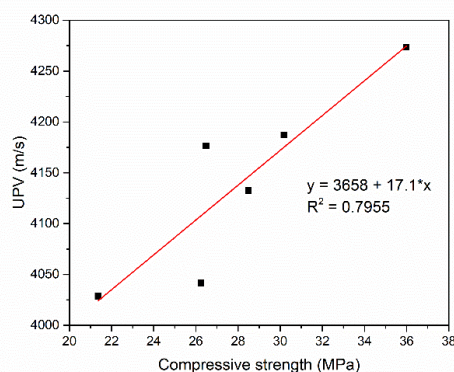


Figure 4. the relationship between compressive strength and UPV of concrete samples

3.4. Electrical resistivity (ER)

Electrical resistivity is another factor which can be used to indicate the durability of concrete samples. The dense concrete is related to low corrosion as well as high electrical resistance of concrete samples. Previous studies recommended that the ER value of high performance concrete is greater than 20 KΩ-cm [18]. In this study, ER test was conducted at 7 and 28 days of curing and the results showed that the ER values grow with concrete age through the hydration reaction of those components. As seen in Fig. 5, all of ER values of concrete samples after 28 days were higher than 20 KΩ-cm and achieved the range of 42.6 to 55 KΩ-cm with the FA content from 30% to 50%.

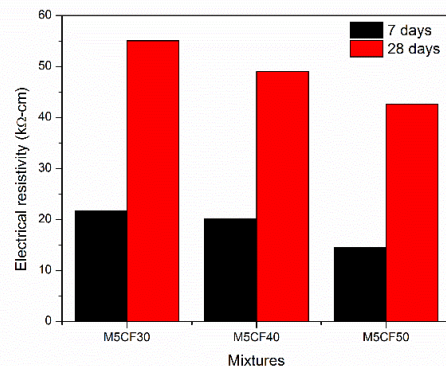


Figure 5. ER value of AASF recycled concrete

4. Conclusions

The following conclusions can be drawn from this research:

- Using FA to replace GGBFS improves the workability and reduces the unit weight of alkali-activated slag-fly ash recycled aggregate concrete.
- The compressive strength of recycled aggregate concrete ranged from 26 to 36 MPa at 28 days of curing. The compressive strength value reduced with increasing fly ash level.
- The high volume of fly ash content caused an decrease in UPV and ER of concrete samples. Both UPV and ER values increased along with curing time and after 28 days of curing, these values are higher than 3660 m/s and 20 KΩ-cm, respectively. They indicate good durability of alkali-activated slag-fly ash recycled aggregate concrete.

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