Improving the Strength and Engineering Properties of Alkali-Activated Slag –Rice Husk Ash Paste at the Early Ages with Addition of Various Magnesium Oxide Content

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***Abstract*—The aim of this study is to evaluate the effect of MgO on alkali-activated slag- rice husk ash paste. The mixtures were prepared with GGBFS replaced with10% RHA and modified by 2.5%, 5% and 7.5% MgO. Then these mixtures were compared to the reference mixture (without RHA and MgO content). The properties of paste were tested by flow, compressive strength, thermal conductivity and UPV analysis. In terms of finding, using RHA and MgO remarkably reduced the workability of AASR paste. In additions, the mere use of 10% RHA slightly reduced the strength of paste. However, adding MgO significantly accelerated the hydration of AASR samples in the early age and improved the strength and engineering properties of AASR paste samples.**

Key words*—rice husk *ash, Magnesium oxide, compressive strength, Engineering properties, alkali-activated slag

I. INTRODUCTION

Alkali-activated slag (AAS) was considered as an alternative binder to Ordinary Portland cement (OPC) to reduce the CO_2 emissions as well as reuse the waste materials. AAS was used in some construction projects in China and the former Soviet Union many years ago [1]. AAS binder was produced with ground granulated blast furnace slag (GGBFS) with different alkaline solutions. Generally, the alkaline solutions were used such as sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3), sodium carbonate or combinations between them. Comparing with traditional OPC, the use of AAS could achieve some benefits: early high compressive strength, good properties in sulfate or acid environments [2, 3]. However, AAS paste also faced some problems, namely fast setting time, high drying shrinkage or some micro-cracking. Moreover, AAS paste with finer slag performed the crack under water curing condition due to the high expansion of hydrotacile-like phase (Ht) [4].

The use of some by-products to modify the AAS was conducted in many papers. However, the application of rice husk ash (RHA) in alkali-activated materials was limited due to the high water absorption and the stable crystallize phase of components [5, 6], which affected the workability and the strength of AAM samples. RHA was collected from the burning process in steam boiler with high temperature. The properties of RHA mainly depended on the burning temperatures and particle size distribution [7]. Some studies illustrated that RHA was natural porous particle with large surface area with the main composition of crystalline silica phase. Therefore, it delayed the hydration reaction and influenced the

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engineering properties of cement paste in the early age days [6].

The purpose of this study was to prevent the cracks of AAS samples with the partial replacement of 10% RHA to the GGBFS. Furthermore, MgO was added with various levels at 2.5%, 5% and 7.5% by total weight of solid to improve the early age properties of AAS-RHA samples (AASR). The flow, compressive strength, ultrasonic pulse velocity (UPV) and thermal conductivity analysis were conducted to test the strength and engineering properties of AASR sample at different ages of curing.

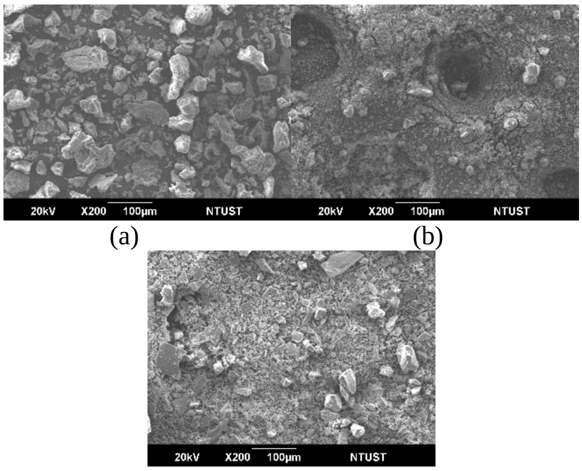
II. Details Experimental

A Materials

TABLE I. Physical Properties and Chemical Compositions of Raw Materials

Items		GGBFS	RHA	MgO
Physical properties	Specific gravity	2.98	2.18	2.91
	Mean particle size (µm)	14.56	17.40	5.60
	Specific surface area (m^2/g)	1.44	1.101	2.12
Chemical composition (wt.%)	SiO_2	33.39	95.60	8.34
	Al_2O_3	14.39	-	-
	Fe_2O_3	0.19	0.24	0.14
	CaO	41.08	0.70	0.42
	MgO	7.22	-	90.40
	SO_3	0.11	0.15	0.7
	TiO_2	0.5	0.02	-
	K_2O	0.60	2.66	-
	Others	2.52	0.63	-

In this study GGBFS, RHA and MgO were used as powder materials. While, GGBFS and MgO were collected from the local company in Taiwan, the RHA was imported from Vietnam. Table 1 exhibited the physical properties and chemical composition of raw materials. The SEM images and XRD analysis of raw materials were shown in Fig. 1 and 2, respectively. As shown in Fig.1, RHA particles showed the high porosity, while the GGBFS and MgO show the angular shapes. On the other hand, the XRD analysis result presented well crystallize phase cristobalite and magnesium with RHA and MgO, respectively, while GGBFS showed the amorphous material. The activator solution was prepared with sodium silicate (with SiO_2: 25.7%; Na_2O: 8.26%; H_2O: 66.04%) and highly-purity (>98%) sodium hydroxide (NaOH). The local tap water was used for extra water.



(a) (b) (c)

Figure 1. SEM image of raw materials (a) RHA, (b) MgO, (c) GGBFS

B Experimental Methods

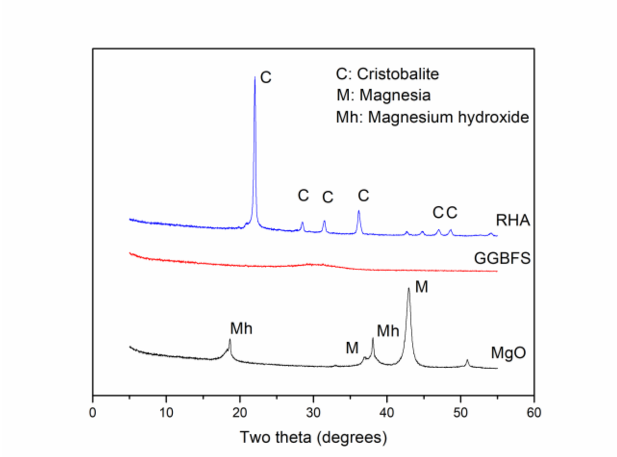


Figure 2. XRD patterns of raw materials

In this study, the alkali-activated slag and RHA (AASR) were prepared with 10% RHA replace to GGBFS and this mixture was modified with various adding MgO, 2.5%, 5% and 7.5%. The results were compared with reference mixture with 100% GGBFS. The AASR samples were activated by alkaline solution with the SiO_2/Na_2O ratio fixed at 0.4 and a concentration of Na_2O of 4% of total binder weight. The water to binder was fixed at 0.4 for all of mixtures. The NaOH was prepared with 10M and the mix proportion was clearly presented in table 2. Firstly, the alkaline solution was mixed in 2 mins to dissolve these components. For casting, the MgO was dissolved in the water in 2 mins, and then GGBFS was added in 2 mins. Finally, the alkaline solution was added and mixed in 3 mins to achieve the homogeneous fresh paste. The flow of paste was tested after casting and the fresh paste was poured into the 50x50x50mm cubic molds for compressive strength and the cylinder 50x100mm for UPV and thermal conductivity tests. A thin film was covered the surface paste to prevent the water evaporation and curing in ambient condition with 50 ±5% humidity and 27±2^{o}C.

After 24 hours, the samples were demoulded and delivered to water container at 25±1°C for compressive strength and chamber with 50 ± 5% humidity and temperature at 25±2°C for thermal conductivity and UPV test.

The flow test was conducted by the flow table. The compressive strength was conducted at 1, 7, 14 and 28 days of curing according to ASTM C109, while the UPV and thermal conductivity were measured following the ASTM C518 and C597, respectively.

TABLE II. MIX PROPORTION OF AASR PASTE

Items	Ingredient (%)				Flow (cm)
	w/b	GGBFS	RHA	MgO	
R00M0	0.4	100	0	0	34
R10M0	0.4	90	10	0	33
R10M2.5	0.4	90	10	2.5	33
R10M5	0.4	90	10	5	32
R10M7.5	0.4	90	10	7.5	31

III. RESULTS AND DISCUSSION

A Flow Test

The flow values of AASR paste samples was displayed in table 2. The results showed that the 10% of RHA replacement to GGBFS caused negative effects on the workability of paste. This result came from the natural porous of RHA particle, which absorbed the water and reduced the flow of paste sample [8]. Otherwise, using MgO to modify the AASR paste also decreased the flow of AASR sample. the increase of MgO levels led to the lower flow values of AASR samples [4]. The MgO particle size was smaller than RHA and GGBFS and showed a large specific surface area, so adding MgO reformed the workability and accelerated the hydration reaction of the components to achieve the high compressive strength in the early age days [9]

B Compressive Strength

The compressive strength of AASR samples with various MgO contents are shown in Fig. 3. At 28 age days of curing, the compressive strength of all paste ranged from 39 to 45 MPa. The compressive strength of AASR paste was attributed by the hydration product such as C-S-H gel, hydrotalcite-like phase. As shown in Fig.3, the strength of paste increased along with the curing time. Without MgO content, the compressive strength of AASR paste with 10% RHA content was lower than reference mixture in all curing times. This phenomenon caused by the slow reaction of RHA particle, which was due to the stable crystallize phase SiO2 as hown on Fig.2and due to the natural porosity of RHA particle. This led to more porous structure and reduce the strength of AASR in the early ages days [10]. However, using the MgO to modify the AASR significantly increased the strength of AASR paste, especially in the early age days. At 7 days of curing, the compressive strength of AASR paste samples was higher than 5%, 11.7% and 13.6% with 2.5%, 5% and 7.5% adding MgO, respectively, comparing to reference mixture. While, R10M0 showed the strength with 1.7% lower than reference mixture. At 28 days of curing, the mixture with 7.5% MgO revealed the highest compressive strength with 6% higher than reference mixture. This can be explained by the acceleration of the hydration process of alkali-activated materials in the early days and significant improvement of the strength of AASR via adding MgO. Moreover, MgO reacted with broken Al-O and Si-O to form more hydrotalcite-like phase [10] with high voluminous, which refined the porous matrix.

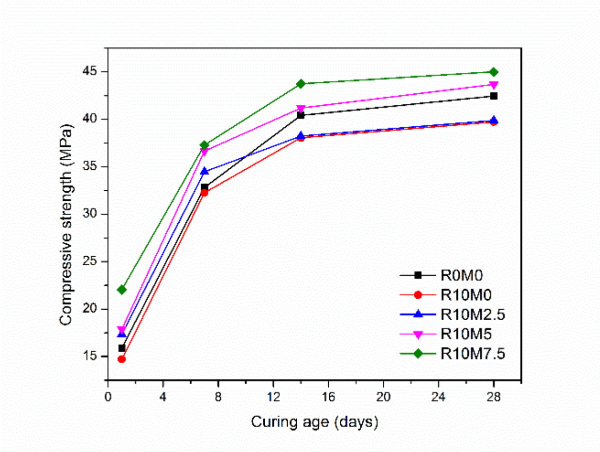


Figure 3. Compressive strength of AASR samples

C Ultrasonic pulse velocity (UPV)

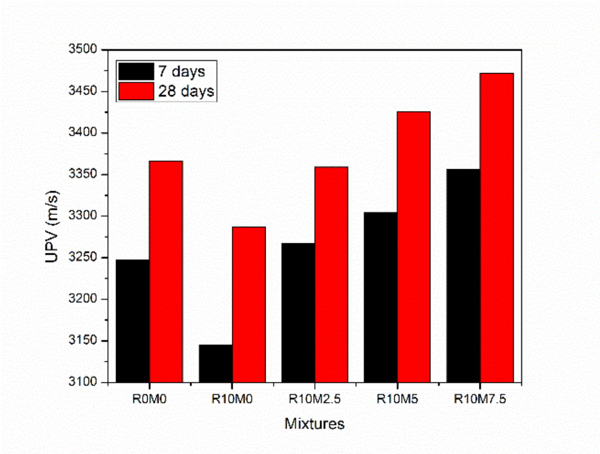


Figure 4. UPV value of AASR samples

UPV value of paste can be used to evaluate the quality of samples. In this study, UPV values of AASR samples increased with the curing time and reached the range of 3287 to 3472 m/s at 28 days of curing as shown in Fig. 4. In the same trend with compressive strength, the UPV at 28 age days presented the highest value with R10M7.5 mix. This result demonstrated the good reaction of those components to form more the hydration products and improved the compressive strength of AASR samples.

Furthermore, the relationship between compressive strength and UPV values of AASR samples are shown in Fig. 5. The results showed that the linear regression was used to evaluate this relationship. With the greater UPV values, the higher compressive strength for AASR paste samples.

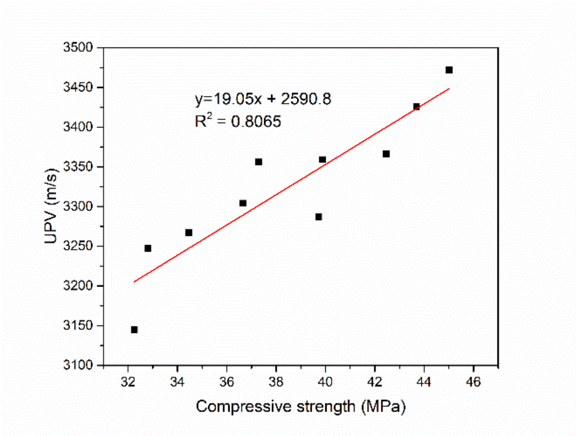


Figure 5. Relationship between UPV values and compressive strength

D Thermal Conductivity Test

Figure 6 exhibited the thermal conductivity of AASR samples at 7 and 28 age days of curing. The results indicated that increase in curing time caused the decrease of thermal conductivity of AASR paste samples [11]. Moreover, using RHA and MgO improved the thermal conductivity of AASR paste in the early age days. Because of the high water absorption of RHA particle, the AASR paste showed the high thermal conductivity than reference mixture caused by the effect of water content. Moreover, using MgO remarkably increased the thermal conductivity of AASR samples because of the highly conductive nature of MgO [12]. Nevertheless, in 28 days of curing, the mixture R10M0 showed the lowest thermal conductivity value, while all the mixtures with MgO content presented the higher thermal conductivity than reference mixture.

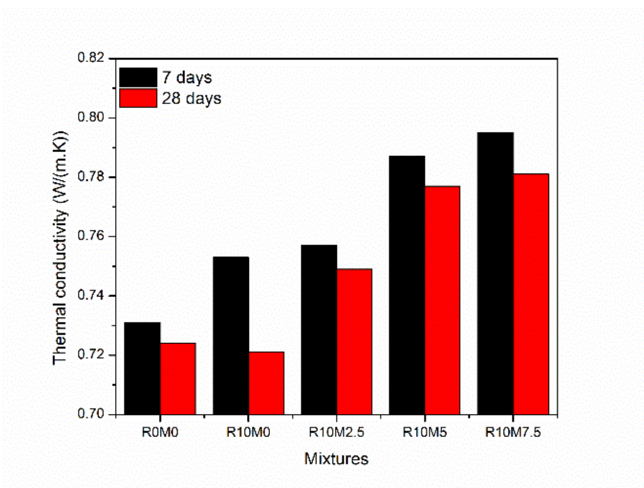


Figure 6. Thermal conductivity of AASR samples

IV. CONCLUSIONS

Based on the experimental works of the present study, the following conclusions can be drawn:

[1] Using RHA and MgO in AAS paste shows the negative effect on workability of AASR samples.

[2] The compressive strength of AASR paste is significantly affected by adding MgO. Using MgO helps accelerate the hydration process in the early age days and improve strength of AASR paste.

[3] Thermal conductivity of AASR samples are improved by adding MgO. Additionally, using RHA to replace for GGBFS remarkably increases the thermal conductivity of AASR paste in the early age days, but significantly reduces in the later age days.

[4] The UPV values show the same trend with compressive strength of AASR paste samples. Adding MgO accelerates the hydration reaction and improves the UPV value of AASR paste, while using RHA to replace for GGBFS slightly reduces the UPV values of AASR pastes up to 28 days of curing.

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