EVALUATION OF PROPERTIES OF CONTROLLED LOW-STRENGTH MATERIAL PRODUCED USING TERNARY MIXTURE OF WASTE RED MUD, SLAG AND PORTLAND CEMENT

ĐÁNH GIÁ CÁC TÍNH CHẤT CỦA VẬT LIỆU CƯỜNG ĐỘ THẤP CÓ KIỂM SOÁT ĐƯỢC SẢN XUẤT TỪ HỖN HỢP PHẾ THẢI ĐẤT ĐỎ, TRO XỈ VÀ XI MĂNG

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Abstract - The primary aim of the present study is to evaluate the properties of the controlled low-strength material (CLSM), which is produced using a ternary mixture of red mud (RM), slag, and a small amount of cement. The CLSM samples are prepared with various weight ratios of RM-to-slag (95/0, 85/10, 75/20, and 65/30) and a constant content of 5% cement. Properties of the CLSM are checked at both fresh and hardened stages, including flow ability, setting time, and compressive strength. Additionally, microstructural properties of the CLSM are examined using a scanning electron microscope. Test results show that properties of the CLSM mixtures are acceptable for the job site application. Analysis of the optimal mixture is further conducted based on the test results. Thus, the CLSM sample incorporating 75% RM, 20% slag, and 5% cement exhibits good physical-microstructural characteristics that conform well to the standard requirements.

Key words - Controlled low-strength material; red mud; slag; setting time; flow ability; compressive strength

Tóm tắt - Nghiên cứu này nhằm đánh giá các tính chất của vật liệu cường độ thấp có kiểm soát (controlled low-strength material - CLSM) được sản xuất từ hỗn hợp đất đỏ, tro xỉ và một lượng nhỏ xi măng. Các mẫu CLSM được chuẩn bị với các tỉ lệ đất đỏ/ tro xỉ khác nhau (95/0, 85/10, 75/20 và 65/30) cùng một lượng cố định 5% xi măng. Các tính chất của cả hỗn hợp CLSM tươi và các mẫu CLSM đóng cứng gồm khả năng chảy, thời gian ninh kết và cường độ chịu nén đều được kiểm tra. Hơn nữa, các đặc điểm về vi cấu trúc của các mẫu CLSM cũng được xem xét thông qua kính hiển vi điện tử. Kết quả kiểm tra cho thấy tất cả các tính chất của CLSM đều thích hợp cho ứng dụng ngoài thực tế. Phân tích cấp phối tối ưu cũng được thực hiện dựa trên các kết quả đạt được. Từ đó, mẫu CLSM chứa 75% đất đỏ, 20% tro xỉ và 5% xi măng có các đặc điểm tốt về tính chất vật lý và vi cấu trúc, thỏa mãn các yêu cầu của tiêu chuẩn.

Từ khóa - vật liệu cường độ thấp có kiểm soát; đất đỏ; tro xỉ; thời gian ninh kết; khả năng chảy; cường độ chịu nén

1. Introduction

Controlled low-strength material (CLSM), one of the well-known materials with self-compacting, high-flow ability, and low strength characteristics, is used primarily as an alternative to compacted fill in the backfill application [1]. The American Concrete Institute (ACI) has suggested a specific compressive strength value of ≤ 8.3 MPa for a CLSM at 28 days [2]. In real practice, the strength of the CLSM is designed according to each specific application. In case of temporary construction, for example, low-strength levels of 0.5–2.0 MPa are suggested for future excavation. However, a normal strength value of about 0.7 MPa is required for most current backfill applications [3, 4].

In recent years, studies on the production CLSM using various sources of waste materials and on the application of the CLSM have been conducted by many researchers in the world. Katz and Kovler [3] investigated the possibility of using cement kiln dust (CKD), coal fly ash, coal bottom ash, asphalt dust, and quarry waste to produce CLSM. Their results showed that all of the CLSM samples exhibited good properties with 25–50 wt.% dust contents. Moreover, the samples containing fly ash (FA) and CKD showed better properties than other samples due to pozzolanic and cementing potential of the FA and CKD. Türkel [4] studied the long-term compressive strength, water absorption, and extraction procedure toxicity characteristics of the CLSM produced using class-C fly ash, crushed limestone sand, and a small amount of pozzolanic cement. Test results showed that the CLSM samples exhibited a good flowability and low compressive strength levels of 1.2 – 2.8 MPa after a year. Nataraja and Nalanda [5] evaluated the performance of CLSM derived from FA, rice husk ash (RHA), and quarry dust. Their results supported the successful application of these materials in CLSM. The 28-day compressive strength values of the CLSM samples ranged from 0.05 MPa to 4.2 MPa. Do and Kim [6] investigated the engineering properties of CLSM containing red mud (RM), ponded ash, FA, and ordinary Portland cement (OPC). Their results showed that all of the CLSM samples conformed well to the requirements of ACI 229 [2] in terms of flowability, bleeding rate, initial setting time, corrosivity, and compressive strength. They also found that the incorporation of RM affected all of the engineering properties of the CLSM significantly. Horiguchi et al. [7] studied the applicability of CLSM produced using incinerated sewage sludge ash, crushed-stone powder, and FA. They reported that the desired strength and flowability of the CLSM could be obtained with careful consideration of mix design. Their results also demonstrated a great potential of applying such solid wastes in CLSM. Taha et al. [8] evaluated properties of CLSM developed from OPC, copper slag, cement by-pass dust, and incinerator ash. Their results proved that it was possible to produce the CLSM samples from such solid wastes with good properties that met the standard requirements. In addition, curing conditions were found to have significant effects on the compressive strength of the CLSM.

Since the information regarding the use of blended red mud, slag, and OPC for producing CLSM is limited in the literature, the present study aims to evaluate the properties of both fresh and hardened CLSM in order to evaluate the possible application of this blended material in producing

CLSM. Moreover, microstructure observation and optimal mixture analysis are also conducted in this investigation.

2. Experimental programs

2.1. Material properties

Various proportions of RM-slag-OPC blends are used to prepare the CLSM samples for this investigation. The RM used in this study is sourced from China, whereas the slag and OPC are sourced from Taiwan. Both RM and slag are the waste materials of alumina and steel industries, respectively. These materials are collected and directly recycled without any pre-treatment process in order to obtain cost-effectiveness. It is noted that all of the raw materials used are in dry form. These raw materials are checked of both physical and chemical properties prior to use, with the results are shown in Table 1 and Table 2, respectively. High concentrations of silicon dioxide, aluminum oxide, and calcium oxide are detected in all of the raw materials. A high percentage of sodium oxide is found in RM, whereas a large amount of magnesium oxide is found in both slag and OPC. In addition, Figure 1 shows the scanning electron microscope (SEM) images of the raw materials. It can be seen clearly that RM comprised of particles with partially round- and angular-shaped, whereas slag comprises particles with an irregular-shaped. Moreover, the mean particle size of slag was finer than that of RM and OPC (Table 2). Thus, the hydration rate of slag would be greater than that of RM.

Table 1. *Physical properties of raw materials*

Physical properties	RM	Slag	OPC
Specific gravity	2.72	2.92	3.15
Mean particle size (μm)	9.1	8.8	19.1
Specific surface area (m^2/g)	1.59	1.68	1.11

Table 2. *Chemical composition of raw materials*

Chemical composition (wt.%)	RM	Slag	OPC
SiO_2	21.0	39.1	12.5
Al_2O_3	22.0	13.0	4.6
SO_3	0.4	1.9	1.7
CaO	6.2	37.5	68.8
MgO	1.3	7.1	5.8
Na_2O	10.5	-	-
Others	2.3	2.0	3.3

2.2. Ingredient proportions

In the present study, the same amount of OPC (5%) is mixed with various amounts of RM and slag (RM/slag ratios of 95/0, 85/10, 75/20, and 65/30) to prepare the CLSM samples. In addition, a constant water-to-binder (w/b) ratio of 0.45 is used for all CLSM mixtures. Thus, the mixture proportions (by weight of materials) used in the CLSM are presented in Table 3.

Table 3. *CLSM ingredient proportions*

Mixture	w/b	Material proportions (kg/m^3)			
		RM	Slag	OPC	Water
R95S00	0.45	1165.4	0.0	61.3	552.1
R85S10	0.45	1046.0	123.1	61.5	553.8
R75S20	0.45	925.9	246.9	61.6	555.5
R65S30	0.45	804.9	371.4	61.9	557.2

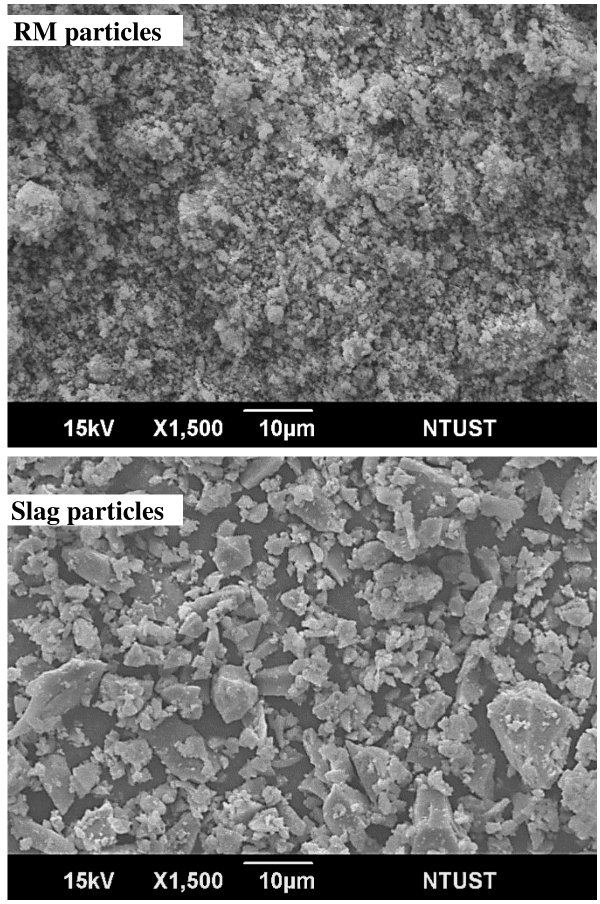

Figure 1. *SEM micrographs of RM and slag particles*

2.3. Samples preparation and test methods

All of the raw materials are prepared and mixed in a laboratory mixer, followed by mixing water. Right after mixing, the fresh CLSM mixture is checked for flow ability and setting time following the guidelines of ASTM D6103 [9] and ASTM C403 [10], respectively. After that, the CLSM samples with dimensions of 50×50×50 mm are prepared for the test of compressive strength. These samples are cured at room temperature until the testing ages. The compressive strength test is performed at the sample ages of 1, 7, and 28 days in accordance with ASTM C109 [11]. The reported result is the average strength value of three samples from each mixture. In addition, broken pieces of the 28-day-old CLSM samples that are taken right after the compressive strength test are soaked in alcohol to stop hydration and then examined using a SEM.

3. Results and discussion

3.1. Flow ability of fresh CLSM mixture

Table 4 shows the results of flow ability measurement of fresh CLSM. The ASTM D6103 [9] has suggested a common flow ability value of greater than 150 mm, which is acceptable for job site work. Thus, all of the fresh CLSM produced in this study has good flow ability performance, with the measured values ranging from 185 to 205 mm. The results shown in Table 4 indicate that the incorporation of more slag reduces flow ability of the mixture. This is because of the combined effect of both the irregular shape of slag particles, which inhibits the lubricant effect and the very fine slag particles with a high specific surface area, which absorbs more water on the particle surfaces and in internal pores, leading to a loss in flow ability of the fresh CLSM. This behavior is supported by Hwang and Huynh [12].

Table 4. *Flow ability and setting time of fresh CLSM mixtures*

Mixture	Flow ability (mm)	IS (hour)	FS (hour)
R95S00	205	-	-
R85S10	200	8.6	13.7
R75S20	190	7.8	12.7
R65S30	185	7.3	11.1

Note: *"-" indicates the samples did not set within 24 hours; IS = Initial setting time; FS =Final setting time.*

3.2. Setting time

The IS and FS of the fresh CLSM are measured and reported in Table 4. The designation for setting time of the CLSM is based on its specific applications. For example, the required IS for backfills application suggested by ACI 229 [2] is normally about 4 hours and about 20–35 minutes in some special cases. In the off-urban area, the IS of the fresh CLSM may be longer than 4 hours. In addition, the requirement for FS of the fresh CLSM is ≤ 24 hours in most of the cases. As can be seen from Table 4 that the IS and FS of the fresh CLSM mixtures range from 7.3 to 8.6 hours and from 11.1 to 13.7 hours, respectively. This study also finds that the CLSM mixture containing more slag registers a shorter setting time, while the slag-free CLSM mixture does not harden within 24 hours. As aforementioned, the inclusion of more slag accelerates the hydration rate, shortening the setting time of the fresh CLSM mixture. This is in good agreement with the results that were previously reported by Nath and Sarker [13]. Therefore, the R95S00 mixture cannot be used to produce the CLSM due to its delay in setting time.

3.3. Compressive strength

The compressive strength development of the CLSM samples is presented in Figure 2. As shown, the strength keeps increasing with the curing time, which is attributable to the continuous hydration process between the materials with both cementing and pozzolanic characteristics [14]. The R95S00 samples with no slag inclusion do not harden within 24 h, thus their strength values are not measured.

Meanwhile, the 28-day-old CLSM samples with 10%, 20%, and 30% slag had compressive strength values of 7.4, 10.2, and 16.4 MPa, respectively. Thus, the incorporation of slag in the CLSM mixture is found to have a positive strength improvement as more slag associated with greater strength. This is attributable to a positive effect of hydration due to the pozzolanic or the cement-like characteristics of slag. Moreover, the very fine slag particles greatly contribute to enhancing the hydration rate, in which slag may act as an accelerator and improve the CLSM strength [12]. Like the general requirements for job site application of a CLSM, the 1-day and 28-day compressive strength values should be ≥ 0.7 and ≤ 8.3 MPa, respectively [2]. Thus, the strength values of the R85S10 sample fix well to these requirements. In some specific applications, however, the 28-day strength may be required to be higher than 8.3 MPa.

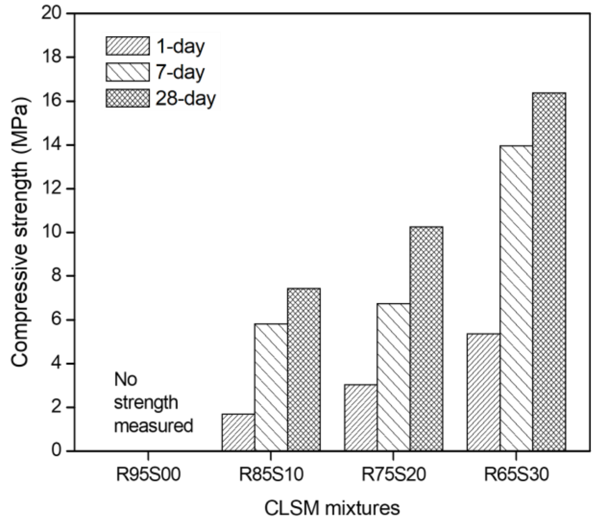

Figure 2. *Compressive strength development of the hardened CLSM samples*

3.4. Microstructure analysis

The SEM micrographs of the hardened CLSM samples are displayed in Figure 3. As shown in the figure that the R65S30 sample has a denser microstructure than the others, indicating that the incorporation of more slag improves the hydration degree and thus creates a denser microstructure with less uncompleted/ unreacted particles. This characteristic supports the improved strength of the CLSM samples as presented in Figure 2. However, a close observation on Figure 3 finds some uncompleted/ unreacted RM and slag particles and micro-cracks, indicating a not fully reaction in the system and thus negatively affecting the mechanical properties of the CLSM. This finding is in line with previous results reported by Hwang and Huynh [14].

3.5. Analyses for the most suitable mixture

With consideration of green construction and sustainable development, the use of OPC should be limited due to the negative impacts on the environment during its use and production [12]. Therefore, recycling solid waste materials (RM and slag) as an alternative to OPC in the production of CLSM is an effective way, which helps to solve the problem regarding the management of these wastes.

On the other hand, the cost of raw materials is another important consideration. So far, the cost for RM is much lower than that of slag. Thus, using more RM in CLSM mixture is found to have cost-effectiveness. The results of the present study show that the CLSM mixture incorporating 80% RM, 20% slag, and 5% OPC (R85S10) is the most suitable for the requirements as above mentioned. This mixture has a flow ability value of 200 mm, an IS of 8.6 hours, an FS of 13.7 hours, and 1-day and 28-day compressive strength values of 1.7 and 7.4 MPa, respectively.

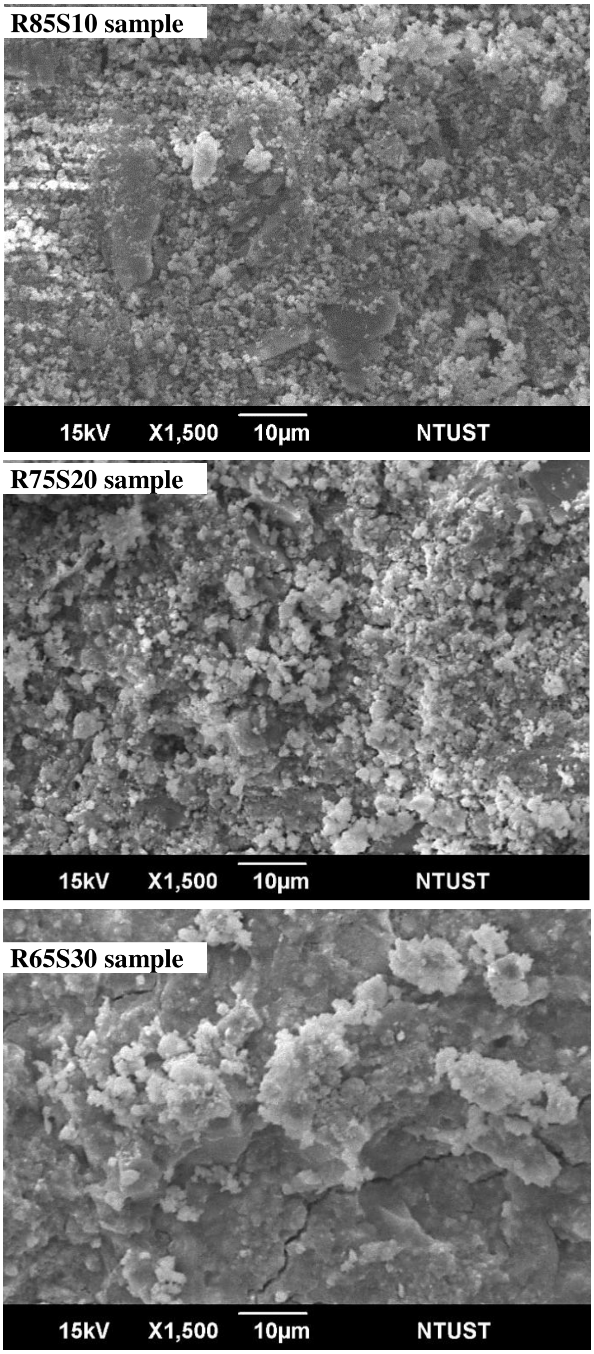

Figure 3. *SEM micrographs of the hardened CLSM samples*

4. Conclusions

The physical and microstructural properties of the CLSM produced using blended RM, slag, and OPC are evaluated in this study. The following conclusions may be drawn from the results of the experiments:

- The flow ability and setting time of the fresh CLSM decrease with the incorporation of slag in the CLSM mixtures. However, compressive strength values of the CLSM samples significantly increase with slag content.

- A denser microstructure is observed at the CLSM samples containing more slag. This finding supports the development in the strength of the CLSM.

- The CLSM samples derived from 85% RM, 10% slag, and 5% OPC have acceptable properties that meet the current specifications for job site application.

- The results of the present study demonstrate a great possibility of using RM and slag with a small amount of OPC in the production of CLSM.

REFERENCES

[1] Siddique R. Utilization of waste materials and by-products in producing controlled low-strength materials. *Resources, Conservation and Recycling*, 2009; 54: 1–8.

[2] ACI 229, *Controlled low-strength materials (CLSM): reported by ACI Committee*, 1999.

[3] Katz A., Kovler K. Utilization of industrial by-products for the production of controlled low strength materials (CLSM). *Waste Management,* 2004; 24: 501–512.

[4] Türkel S. Long-term compressive strength and some other properties of controlled low strength materials made with pozzolanic cement and class C fly ash. *Journal of Hazardous Materials*, 2006; B137: 261–266.

[5] Nataraja M.C., Nalanda Y. Performance of industrial by-products in controlled low-strength materials (CLSM). Waste Management, 2008; 28: 1168–1181.

[6] Do T.M., Kim Y.S. Engineering properties of controlled low strength materials (CLSM) incorporating red mud. *International Journal of Geo-Engineering,* 2016; 7: 1–17.

[7] Horiguchi T., Fujita R., Shimura K. Applicability of controlled low-strength materials with incinerated sewage sludge ash and crushed-stone powder. *Journal of Materials in Civil Engineering*, 2011; 23: 767–771.

[8] Taha R.A., Alnuaimi A.S., Al-Jabri K.S., Al-Harthy A.S. Evaluation of controlled low strength materials containing industrials by-products. *Building and Environment*, 2007; 42: 3366–3372.

[9] ASTM D6103, *Standard test method for flow consistency of controlled low strength material (CLSM)*, 2004.

[10] ASTM C403, *Standard test method for time of setting of concrete mixtures by penetration resistance*, 2008.

[11] ASTM C109, *Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens)*, 2016.

[12] Hwang C.L., Huynh T.P. Characteristics of alkali-activated controlled low-strength material derived from red mud-slag blends. Key Engineering Materials, 2017; 753: 343–348.

[13] Nath P., Sarker P.K. Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition. *Construction and Building Materials*, 2014; 66: 163–171.

[14] Hwang C.L., Huynh T.P. Effect of alkali-activator and rice husk ash content on strength development of fly ash and residual rice husk ash-based geopolymers. *Construction and Building Materials*, 2015; 101: 1–9.

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