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A Study on the Physical Characteristic and Environment Evaluation of Yellow Loess Mortar with Slaked Lime and Cement

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Abstract

Yellow loess is receiving substantial interest as a possible eco-friendly construction material. The advantages of yellow loess are its high heat absorption capacity, auto-purification properties, antibiotic properties, and infrared ray emission capability. Also, it is known to have various benefits, such as deodorizing, sanitizing, and adsorbing. However, due to low compressive strength and low shrinkage cracking resistance of loess, modern architecture is not actively pursued. Recently, various studies have been conducted to control the drying shrinkage of loess and improve mechanical strength by using various admixtures, but the environmental characteristics are not taken into consideration. Studies on yellow loess must be made on the physical characteristics as well as environmentally friendly characteristics.

The purpose of this study is to examine the physical performance and environmental performance when ordinary Portland cement (OPC) or slacked lime (SL) is added to enhance the physical properties of yellow loess.

The results indicate that the moisture controlling ability of the yellow loess mortar was decreasing when the OPC or SL is mixed, as the pores are blocked by the formation of the hydrate. And the emission of NH_3 from yellow loess mortar with OPC and SL occurred by the chemical reaction of NH_4^+ adsorbed into the yellow loess and alkali produced by the hydration of OPC and SL. But the compressive strength of the yellow loess mortar was increased as the content of SL and OPC increases. This is because aplite, which affects the strength improvement, was formed by reacting CaO and $Ca(OH)_2$ components of OPC and SL with silica components of yellow loess.

Keywords: Yellow loss, Admixture, OPC, Slacked lime, Humidity-controlling, Compressive strength

INTRODUCTION

Korea suffered from a serious housing shortage due to the increasing concentration of urban populations and changes in the formation of generations as it achieved rapid economic growth. In 1970, the government actively encouraged housing supply activities, such as row houses and apartments, and thus, the use of concrete increased due to the building's rise and size [1].

Concrete is the most widely used construction material in the world due to its low cost, high availability, and simple constructability [2]. However, cement concrete and additives can release ammonia and volatile organic compounds, increasing indoor air pollution and damaging the human body, according to studies [3-5].

In terms of health issues, there have been fervent public outcries over illnesses associated with concrete structures, such as sick building syndrome, dermatitis, allergic diseases, and atopic skin diseases, and public interest in healthy housing with eco-friendly materials has also increased sharply [2,6].

In Korea, yellow loess has been known as a healthy material traditionally, and in everyday life it has been used in various fields [7]. Yellow loess is the primary clay created by the weathering of rocks and is reddish yellow residual soil that is similar to kaolin mineralogically [8,9]. Although the exact amount of yellow loess reserves is not reported, it is estimated that yellow loess covers 15–20% of the surface of the Korean Peninsula [8]. The main advantages of yellow loess are its high heat absorption capacity, auto-purification properties, antibiotic properties, and infrared ray emission capability [10]. Also, it is known to have various benefits, such as deodorizing, sanitizing, and adsorbing [11-14].

Clay-based materials show high moisture storage capacity through surface adsorption and capillary condensation effects in the hygroscopic domain. Such phenomena coupled with moisture transport inside the porous structure are stated to offer a regulation capacity of the indoor air humidity [15], improving comfort for occupants [16-18]. So, Yellow loess is receiving substantial interest as a possible eco-friendly construction material and is the subject of much industry research [6,10,19-21]

However the development of yellow loess has not been actively pursued in modern constructions and the material has not been utilized in modern buildings due to its low compressive strength and low dry shrinkage crack resistant capacity [2]. Previous research has used cement or other additives in yellow loess to control the dry shrinkage of yellow loess and to increase its compressive strength, which has reduced the beneficial properties of yellow loess [22].

There is not enough research to examine both the physical and environmental performance of yellow loess.

The objective of this study is to examine the physical performance and environmental performance when cement or slacked lime is added to enhance the physical properties of yellow loess, and to provide basic data for the study to facilitate the use of yellow loess.

MATERIALS AND METHODS

Materials:

(1) Cement and Slacked lime

Ordinary Portland Cement as specified in KS L 5201 (Portland cement, 2006) was used in the manufacture of all concrete. Initial and final setting times of the cement were 2h 30min and 3h 30 min, respectively. Its blaine specific surface area was 3250cm^2/g. Slacked lime was applied as alkali activator and its chemical composition is given in Table 1.

(2) Yellow loess powder

Yellow loess powder (325mesh) was selected from soil in Kochang in Korea.

Table 1: Chemical properties of law materials

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO
Yellow loess	60.27	21.07	6.27	0.13	2.55	0.81
OPC	21.57	4.49	4.33	60.43	1.27	3.12
SL	-	0.19	0.12	65.88	-	1.03

PRODUCTION OF SPECIMENS

(1) Mixing ratio

Ten specimens were prepared by mixing different proportions of yellow loess, SL and OPC, as shown in Table 2.

When producing yellow loess mortar specimens by adding only water to yellow loess powder, their water ratio was 40% like the cement mortar specimens.

Table 2: Mix proportions of yellow loess mortar

	Loess(g)	OPC(g)	SL(g)	Water(g)
H100	1000	-	-	400
H95C5	950	50	-	400
H95C10	900	100	-	400
H80C20	800	200	-	400
H95L5	950	-	50	400
H90L10	900	-	100	400
H80L20	800	-	200	400
C20L5	750	200	50	400
C20L10	700	200	100	400
C20L20	600	200	200	400

(2) Manufacturing of Specimens

Compressive specimens were cast into a mold of dimensions 50 × 50 × 50 mm to measure the physical properties of the mortars. The specimens were left in a constant temperature and humidity chamber (20 ± 2 ℃, 60 ± 10%). And the specimens used for the moisture-controlling experiment and the ammonia gas detecting experiment were produced in 130 × 155 × 40mm. However, only 100 × 100mm of a specimen was exposed, while the remaining area was sealed with aluminum foil and aluminum tape.

Figure 1: Yellow loess mortar specimen for compressive strength and moisture controlling experiment

EXPERIMENTAL METHOD

(1) Flow table test for fresh yellow loess mortars

The flow value of the yellow loess mortar was measured by means of a flow test, as shown below, in accordance with KS L 5105 [23], using the flow table specified in KS L 5111 [24]. The upper part of the flow table was first carefully and cleanly wiped, and a plate was placed in the center of the flow table. About 2.5-cm-thick layers of colored mortar were then placed in the plate, followed by tamping 20 times with a tamper. After filling the flow mold with mortar and tamping it as in the first layer, the plate was lifted smoothly and immediately to allow the mortar to flow down the table 25 times for 15s at a height of 1.27 cm. The diameter of the mortar was measured in the lower part four times at the same interval, and the flow value was expressed as an average of these measurements.

Figure 2: Table flow test of yellow loess mortar

(2) Compressive strength test for yellow loess mortars

Three cubic specimens of 50mm sides were used for each age. Specimens produced from fresh mortar were demolded after 24 hours, and were then cured in a constant temperature (20 ± 2℃) and humidity (60 ± 10% RH) chamber for 3, 7, 28 and 182 days. The compressive strength of each specimen was determined using KS f 2405 [25]. Compressive strength measurements were carried out using Shimadzu UH-100A with a capacity of 100ton at a loading rate of 0.2 ton/s.

(3) Assessment of moisture controlling ability

The specimens were dried at a temperature of 105 ℃ for 24 hours. Then, after the specimens at the absolute dry condition were placed inside the thermo-hygrostat, their weight change was measured once per day (every 24 hours). When the weight of a specimen stopped increasing, it was defined as the maximum moisture absorption condition. The maximum moisture absorption quantity was calculated by converting the difference between the weight of a specimen at the maximum moisture absorption condition and the absolute dry specific gravity into a value per a unit size (cm^2). The specimen at the maximum moisture absorption condition was left inside a chamber at a temperature of 25 ℃ and at RH 25% (see Table 3, Figure 3). When the weight stopped decreasing at a constant weight, it was defined as the maximum moisture desorption condition. The maximum moisture desorption quantity was calculated by converting the difference in weight between the maximum moisture absorption condition and the maximum moisture desorption condition into a value per a unit sixe (cm^2).

Figure 3: Humidity control Chamber and precision balance

(4) Detecting NH_3 from yellow loess mortar

The environmental chamber sampling system used in this study was especially designed and consists mainly of a $0.02m^3$ stainless steel environmental chamber. And for detecting NH_3, a comparative analysis was carried out in accordance with KS standards [27].

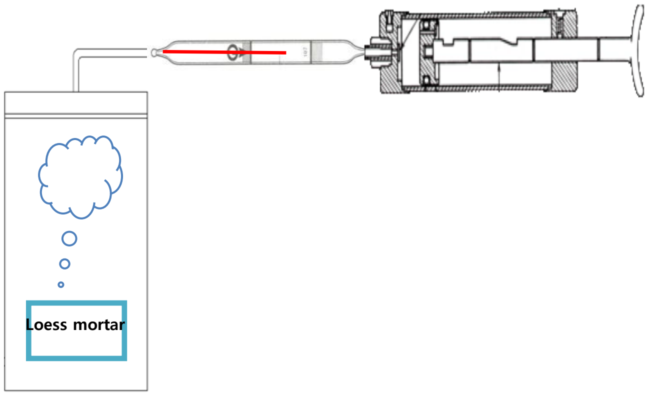


Figure 4: Detecting NH_3 using detector tube

Table.3. Composition of moisture controlling ability experiment [26]

	Moisture absorption process	Moisture desorption process
Specimen condition before experiment	Absolute dry condition	Maximum moisture absorption condition
Temperature	25℃	25℃
Humidity	RH 98%	RH 25%
Measurement Interval	daily (every 24 hours)	daily (every 24 hours)

RESULTS & DISCUSSION

Analysis of material characteristics

(1) Composition of yellow loess

Yellow loess is formed when the surface layer of Kaolinte, a residual clay, becomes oxidized and weathered. It is comprised of silica, alumina, limestone, iron, magnesium, sodium and calcium. The crystalline structure of yellow loess has a lamellar crystal form which is made up with tetrahedral silica and octahedral alumina at the composition ratio of 1:1, which form a double layer structure

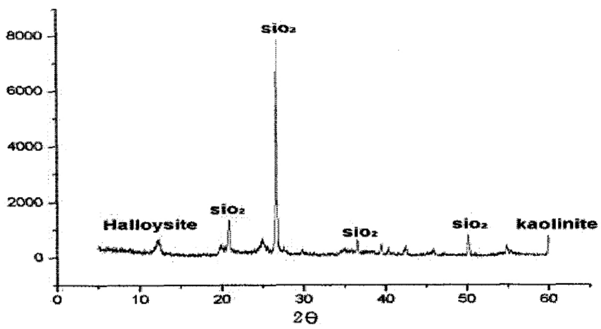
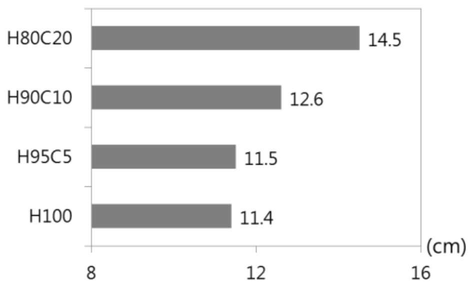


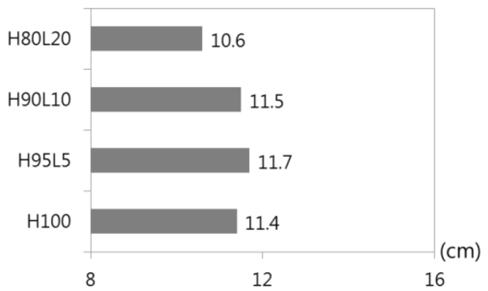
Figure 5: XRD pattern of yellow loess

(2) Table flow

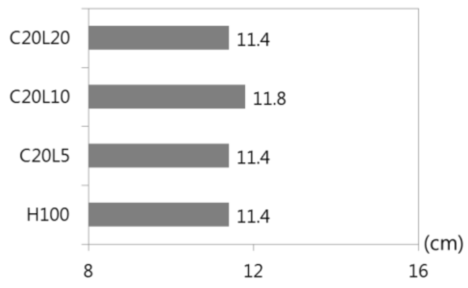
Figure 6 shows flow properties of specimen according to the replacement rate of the OPC, SL. The analysis of the data showed that flow value increased with replacement rate of the OPC but flow decreased with replacement rate of the SL.



(1) OPC mixed



(2) SL mixed



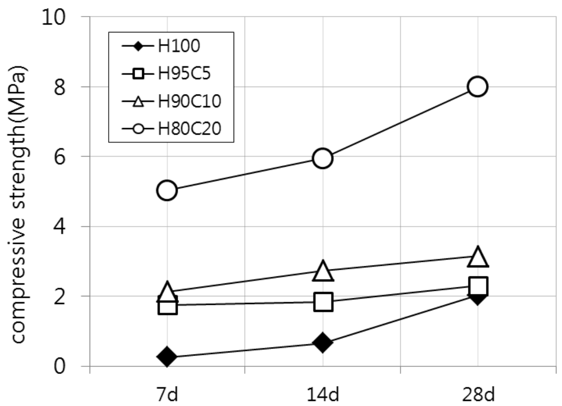
(3) OPC and SL mixed

Figure 6: Flow of yellow loess mortar with OPC and SL

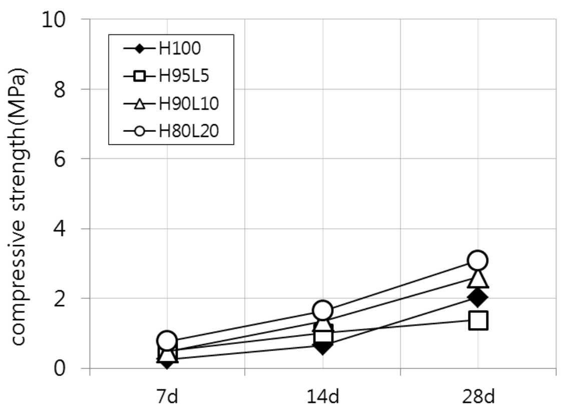
If a fine particle binder (SL) is added to mortar, the larger water demand generally results in a decrease in compactness and increase in porosity; this explains the decrease in elastic modulus obtained as a function of the percentage of fine material in aggregate substitution [28].

(3) Compressive strength

To investigate the effect of yellow loess admixture on the compressive strength of mortar, OPC and SL were prepared.



(1) OPC mixed



(2) SL mixed

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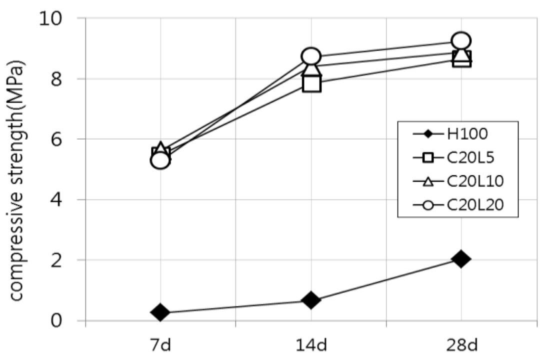


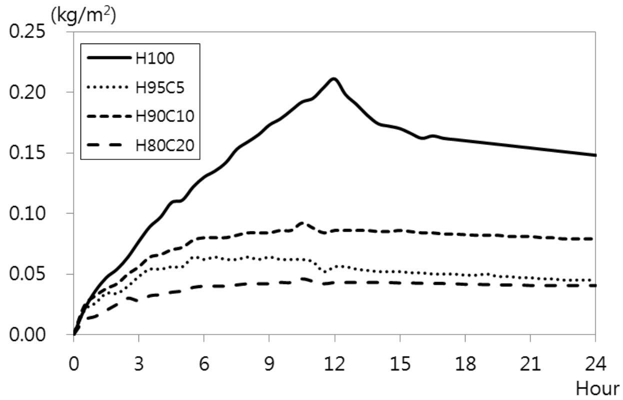
(3) OPC and SL mixed

Figure 7: Compressive strength of mortar with OPC and SL

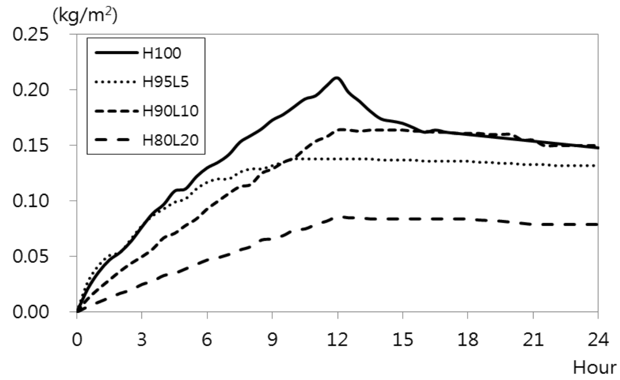
Figure 7(1), (2) shows the compressive strength of yellow loess specimen according to the different type of admixture mixing ratio. The compressive strength of the mortar with 20% OPC was 393.4% greater than that of the normal yellow loess specimen (H100) at 28 d. However the specimen with 20% SL was 151.9% greater than of H100. Figure 7(3) showed the compressive strength of yellow loess mortar mixed with 20% cement and 5, 10 and 20% lime, respectively. The strength incensement after 7 days was higher than that of yellow loess mortar mixed with OPC, SL separately. And the compressive strength of all the specimens exceeded 8MPa. It was concluded that the production of Aplite ($3CaO \cdot 2SiO_2 \cdot 3H_2O$), which is a product that affects the strength development of CaO and $Ca(OH)_2$ components of OPC and SL reacted with the silica component of yellow loess. But as the mixing ratio of lime increased, the strength tended to increase, but the difference was small.

(4) Moisture controlling ability

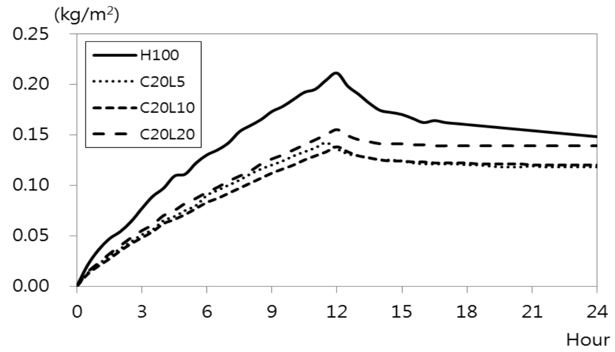
To analyze the moisture controlling ability of the yellow loess mortar with OPC and SL, the specimens in the absolute dry condition were exposed to moisture at a RH of 98% in the thermal-hygrostat, and their mass continued to be measured until they reached the point of a constant weight. The results of mass measurement are as follows. {KS 규격}



(1) OPC mixed



(2) SL mixed



(3) OPC and SL mixed

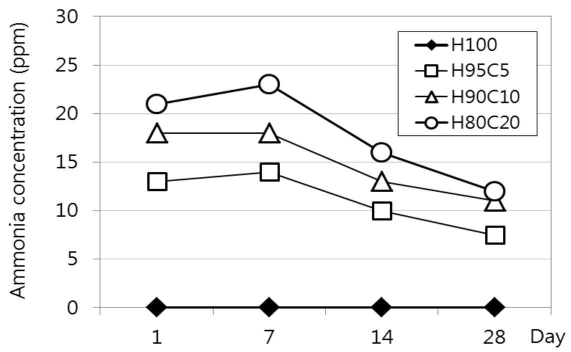
Figure 8: Moisture controlling ability of yellow loess mortar

Figure 8(1), (2) shows the results of the moisture controlling ability of yellow loess mortar with OPC and SL separately. According to the results, the H100 specimens showed a remarkable increase in terms of absorption and desorption quantities compared to the yellow loess mortar with OPC and SL. The moisture controlling ability of the specimens showed no difference according to the mixing ratio of OPC and SL, but showed the lower moisture absorption / desorption value when OPC or SL were mixed. And all types of yellow loess mortar showed less moisture desorption than moisture absorption. Generally, yellow loess is known to have excellent air permeability because it has a special structure such as a honeycomb shape in which the pore is half of the total volume. When the cement or lime is mixed, the pores are blocked by the formation of the hydrate, thereby reducing the permeability. Figure 8(3) showed the Moisture controlling ability of yellow loess mortar mixed with 20% cement and 5, 10 and 20% SL, respectively. All the specimens showed higher humidity control ability than yellow loess mortar with OPC and SL separately. As the mixing ratio of SL increased, the amount of moisture absorption increased

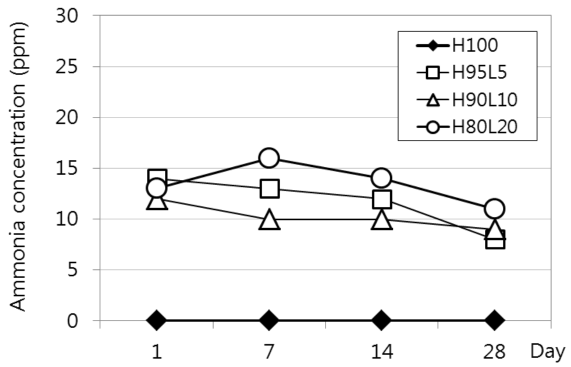
(5) Emission of ammonia from yellow loess mortar

Figure 9 shows the concentration of NH_3 released from yellow loess mortar with OPC and SL in the environmental chamber using a detector tube method. It can be seen from Figure 9 that the concentration of NH_3 of the H80C20 using OPC 20% is about 23ppm, which was more than 1.6 times that of the H95C5 using OPC 5%.

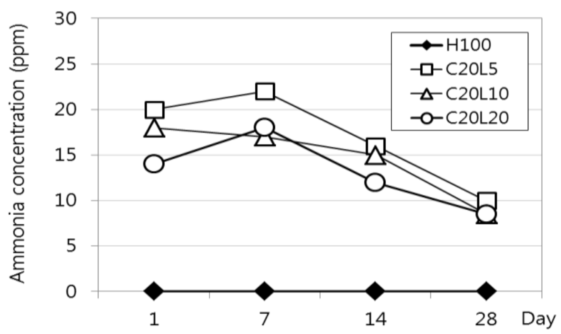
In general, NH_4^+ in soil is released into the atmosphere by the chemical reaction of NH_4^+ and alkali (OH^-) and this is called ammonia volatilization [29]. On the same principle, the emission of NH_3 from yellow loess mortar with OPC and SL occurs by the chemical reaction of NH_4^+ adsorbed into the yellow loess and alkali produced by the hydration of OPC and SL.



(1) OPC proportion



(2) SL proportion



(3) OPC and SL proportion

Figure 9: Concentration of NH_3 of yellow loess mortar

CONCLUSION

1) The flow value increased with the OPC replacement rate, but the flow value decreased with the SL replacement rate. This is due to the high water demand for SL, which leads to decrease compactness and increased porosity.

2) The CaO and $Ca(OH)_2$ components of cement and lime react with the silica of the yellow loess and produce Aplite ($3CaO \cdot 2SiO_2 \cdot 3H_2O$) which affects the strength development. The compressive strength of the yellow loess mortar was increased as the content of lime and cement increases. Especially, the specimens mixed with OPC and SL showed high strength overall.

3) The moisture controlling ability of the yellow loess mortar showed no difference according to the mixing ratio of OPC and SL, but showed the lower moisture absorption / desorption value when OPC or SL were mixed. Because when the cement or lime is mixed, the pores are blocked by the formation of the hydrate

4) The emission of NH_3 from yellow loess mortar with OPC and SL occurs by the chemical reaction of NH_4^+ adsorbed into the yellow loess and alkali produced by the hydration of OPC and SL. And the NH_3 concentration of the yellow loess mortar with 20% OPC was 24ppm/day at 7 days.

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