

Unconfined Compressive Strength of Soil-Cement Pavement with Recycled Red Mud

레드머드가 첨가된 흙-시멘트 포장의 일축압축강도

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ABSTRACT : The unconfined compressive strength of soil-cement mixed with red mud, an industrial by-product of alumina production, was investigated in the laboratory. The investigation involved laboratory tests under the various conditions such as red mud content, cement content, fly ash content and ratio of soil replacement with sands. The unconfined compressive strength tests were performed at 7, 14 and 21 days after specimen preparation. Results of the study show that the unconfined compressive strength increased as red mud and fly ash content decreased and cement content increased. Increasing the soil replacement ratio with sands had an insignificant effect on compressive strength because the soil had a similar particle size as the replacement sands.

Keywords : Unconfined compressive strength, Soil-cement, Red mud, Fly ash

요 지 : 알루미늄 제조 시 발생하는 산업부산물인 Red mud가 첨가된 흙-시멘트 포장 재료를 개발하기 위하여 일축압축강도시험을 수행하였으며 Red mud 함유율, 시멘트 함유율, Fly ash 대체 비율 및 모래의 대체 비율이 일축압축강도에 미치는 영향을 검토하기 위하여 양생기간 7일, 14일 및 21일에 대한 공시체를 제작하였다. 시험결과, Red mud와 Fly ash 함유량이 감소할수록 시멘트 함유량이 증가할수록 일축압축강도는 증가하였고, 화강풍화잔류토를 사용할 경우 모래의 대체 비율에 따른 일축압축강도에 미치는 영향은 없는 것으로 나타났다.

주요어 : 일축압축강도, 흙-시멘트, 적니(赤泥), 플라이 애쉬

1. Introduction

Asphalt and concrete pavements are commonly used in road and highway construction with their high strength material properties. However, in places where high strength is not necessary, such as roads for light vehicles, walking paths, parking lots and the roads to cultural assets, soil-cement pavement may be used. Soil-cement pavement is a mixture of soil, cement, and water, and its primary advantages are economy and environment (Kim et al., 2002; PCA, 1978). Because a pavement of soil-cement is not very attractive, artificial pigment is often added to make it appear more natural (Ju et al., 2003). Red mud is an industrial by-product material formed during production of alumina when the bauxite ore is subjected to caustic leaching. About 100,000 tons of red mud are produced per year from an aluminium factory in South Korea and its

disposal is a major problem for this industry (Jeong, 2004; Kim, 2003). Therefore soil-cement pavement mixed with recycled red mud could be a beneficial use of this waste material. In this study, the unconfined compressive strength of soil-cement with red mud was investigated with the various ratios of red mud, cement, fly ash, and the ratio of soil replaced with sand.

2. Materials

2.1 Soil

Two samples of weathered granite residual soils gathered from Andong-si, Kyungsangbuk-do, S. Korea were used to develop specimens of soil-cement with red mud. The results of sieve analysis tests on samples are shown in Fig. 1. Scanning electron microscope(SEM) photographs of the

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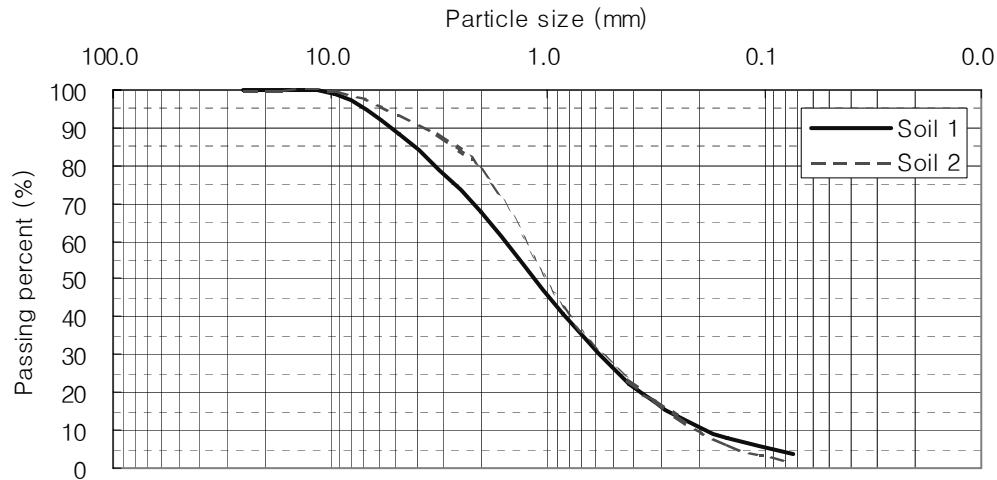


Fig. 1. Particle size distribution curve of soils

soils are shown Fig. 2 and 3.

The classification properties of the two soils are shown in Table 1. According to the unified soil classification system, both soils are classified as SM, and two soils are quite similar index and compaction properties.

2.2 Red mud

In this study, samples of red mud were gathered from the factory in S. Korea and the type of red mud used is locally known as SP (scarlet powder). The red mud is shown in Fig. 4 (a) and SEM photograph of red mud is shown in Fig. 4 (b). The chemical composition and physical properties of red mud are shown in Table 2.

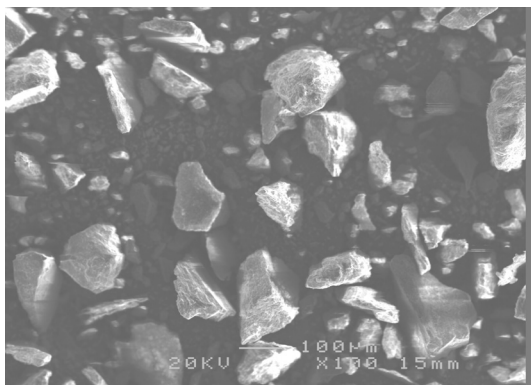


Fig. 2. SEM photograph of Soil 1 (X100)

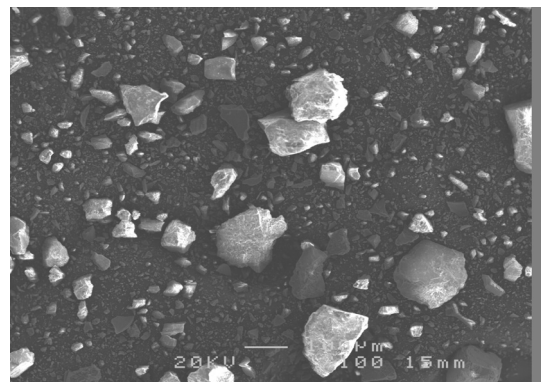


Fig. 3. SEM photograph of Soil 2 (X100)

Table 1. Properties of soils

Soil	USCS	Specific gravity	LL (%)	PI (%)	#200 Passing (%)	C_u	C_c	γ_{dmax} (t/m^3)	OMC (%)
1	SM	2.54	20.5	2.1	3.5	7.9	1.2	1.972	9.5
2	SM	2.65	21.0	5.4	1.3	6.1	1.2	1.880	12.0

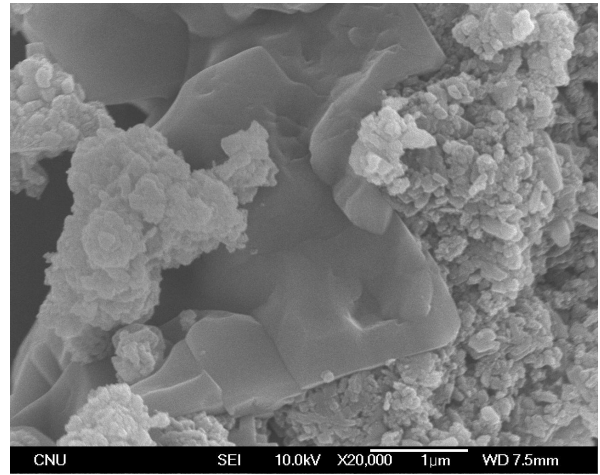
3. Laboratory test procedures

3.1 Mixture condition

In this study, various percentages of red mud and the replacement ratio of sands, fly ash, and cement content were used to make soil-cement mixtures with red mud. Compressive strength tests were performed on specimens having 7, 14 and 28 days curing time, respectively. Table 3 shows the mixture conditions for laboratory tests with different cement and red mud ratios. The objective was to see the effect on strength of cement and red mud content. The mixture conditions for soil replacement with sands and cement replacement with fly ash are shown in Tables 4 and 5.



(a) Red mud



(b) SEM photograph of red mud (×20,000)

Fig. 4. Red mud and SEM photograph of red mud

Table 2. Chemical composition and physical properties of red mud

Type of red mud	(a) Chemical composition (%)						
	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	TiO ₂	CaO	Na ₂ O	Other
SP(Scarlet Powder)	40~45	15~20	5~7	6~8	7~10	4~7	3~23

Type of red mud	(b) Physical properties		
	Water content (%)	pH	Average particle size
SP(Scarlet Powder)	10~15	12	6~10µm

Table 3. Mixture conditions for laboratory tests with cement and red mud ratio

Case	Ratio (%)			Weight of Soil (g)
	W/C	Cement/Soil	Cement/Red mud	
A1	191	10	10	3,105
A2	127	15	10	2,970
A3	96	20	10	2,700
A4	191	10	15	3,105
A5	127	15	15	2,970
A6	96	20	15	2,700
A7	191	10	20	3,105
A8	127	15	20	2,970
A9	96	20	20	2,700

Table 4. Mixture conditions for soil replacement with sands

Case	Ratio (%)			Soil : Sand	Weight of Soil (g)
	W/C	Cement/Soil	Cement/Red mud		
B1	191	10	10	2 : 1	2,070
B2	191	10	10	1 : 1	1,553
B3	127	15	10	2 : 1	1,980
B4	127	15	10	1 : 1	1,485
B5	96	20	10	2 : 1	1,800
B6	96	20	10	1 : 1	1,350

Table 5. Mixture conditions for cement replacement with fly ash

Case	Ratio (%)			Weight of Soil (g)
	(Cement+Fly ash)/Soil	Red mud/Cement	Fly ash/Cement	
C1	10	10	0	3,105
C2	10	10	10	3,105
C3	10	10	20	3,105
C4	10	10	30	3,105
C5	10	15	0	3,105
C6	10	15	10	3,105
C7	10	15	20	3,105
C8	10	15	30	3,105
C9	10	20	0	3,105
C10	10	20	10	3,105
C11	10	20	20	3,105
C12	10	20	30	3,105

This part of the investigation was made in order to investigate the effect of soil replacement with sands and for cement replacement with fly ash on long term strength. The ratios of soil replacement with sands were 50 and 100% and the ratios of cement replacement with fly ash were 10, 20 and 30% in the laboratory test.

3.2 Specimens

The specimens were prepared and cured in the same way soil-cement compression and flexure test specimens are prepared in the laboratory (KS F 2329). Three specimens were prepared and tested to get an average value for each mixture condition, and the specimens were cured under submerged condition with water. Diameter of samples for the unconfined compressive strength tests was 5cm and height of samples was 10cm. Compressive strength was performed using an UTM according to KS F 2328.

4. Test results and discussion

4.1 Unconfined compression strength with red mud content

Fig. 5, 6, and 7 show the relationship of unconfined compressive strength and curing time for the specimens having different red mud contents. It was found that the compressive strength increased with increased curing time. The variation of unconfined compressive strength with red mud content is shown in Fig. 8. Note that the unconfined

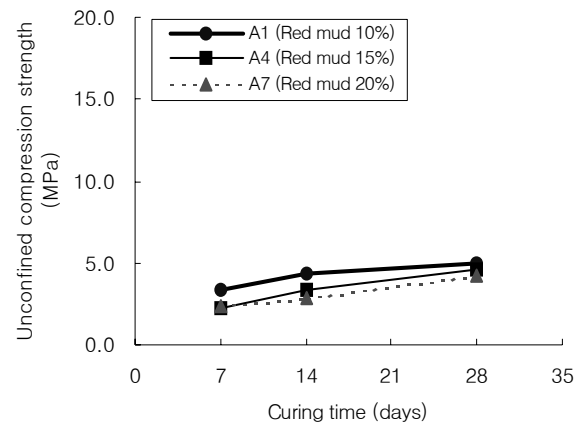


Fig. 5. The relationship of unconfined compressive strength with curing time (cement 10%)

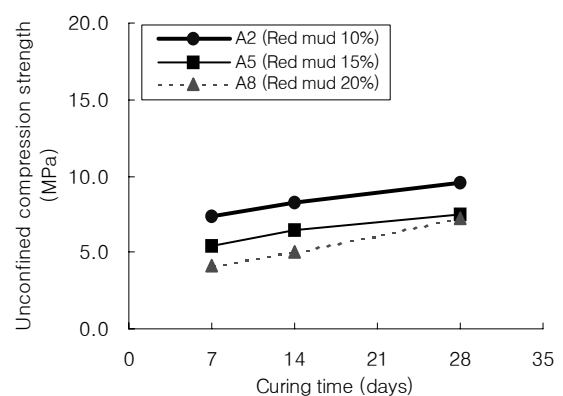


Fig. 6. The relationship of unconfined compressive strength with curing time (cement 15%)

compression strength slightly decreased with an increasing content of red mud.

Fig. 8 shows the relationship of unconfined compressive strength for the specimens having 28 days curing time and

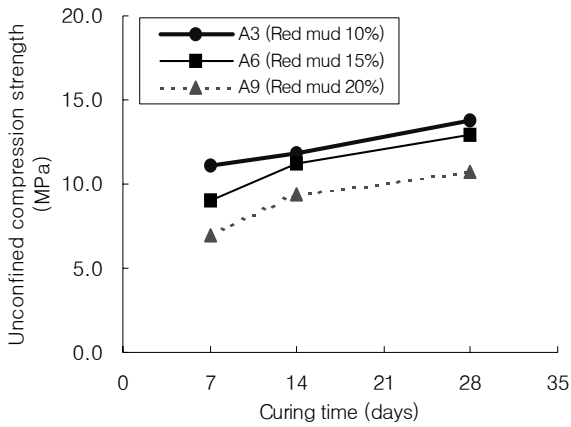


Fig. 7. The relationship of unconfined compressive strength with curing time (cement 20%)

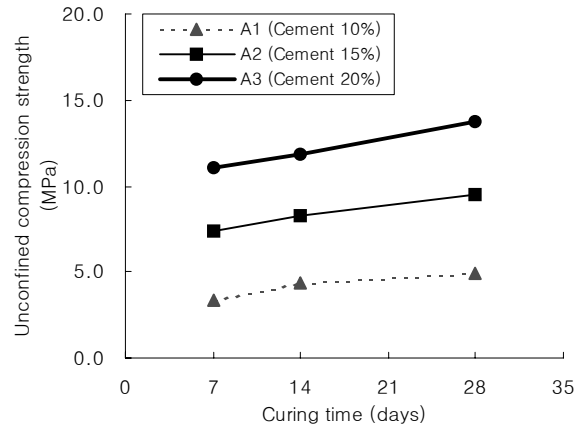


Fig. 9. The relationship of unconfined compressive strength with curing time (red mud 10%)

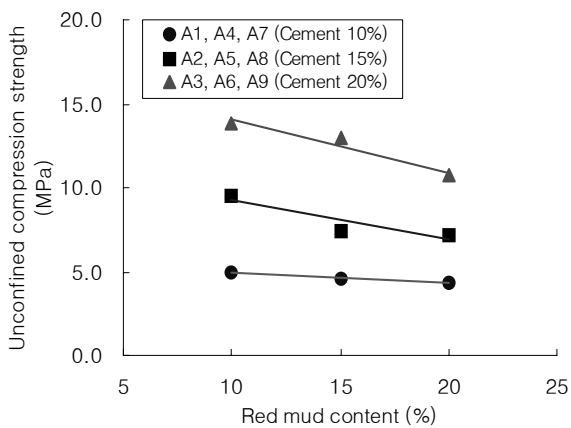


Fig. 8. The relationship of unconfined compressive strength with red mud content

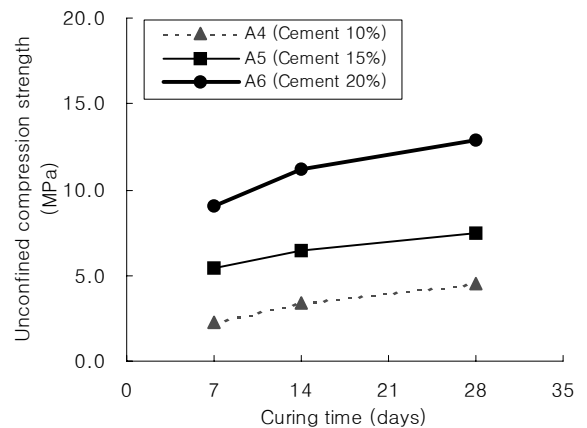


Fig. 10. The relationship of unconfined compressive strength with curing time (red mud 15%)

red mud content. The slopes of compressive strength are 0.65, 2.38 and 3.16. Therefore, the decrease of compressive strength with increasing red mud content is greater with increasing cement content.

4.2 Unconfined compression strength with cement content

Fig. 9, 10, and 11 show the relationship of unconfined compressive strength and curing time with variation of red mud content. From the results, the compressive strength increases with increasing curing time. The trend of compressive strength increase with increasing cement content ratios are greater than that with red mud content ratios. Fig. 12 shows the variation of unconfined compressive strength with cement content for soil mixtures with red mud. As the content of cement increases, the unconfined compressive strength increases.

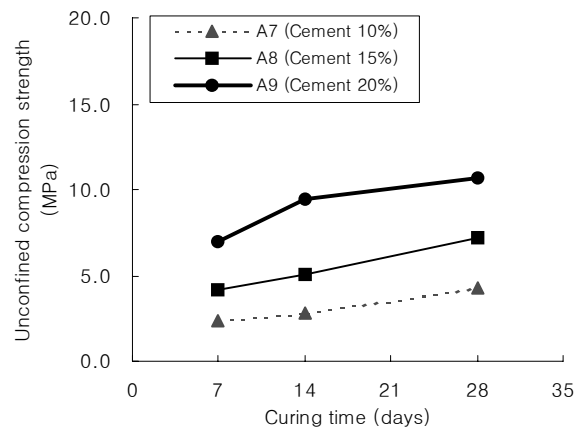


Fig. 11. The relationship of unconfined compressive strength with curing time (red mud 20%)

4.3 Unconfined compression strength with fly ash content

Fig. 13, 14, and 15 show the relationship of unconfined compressive strength and curing time with fly ash content.

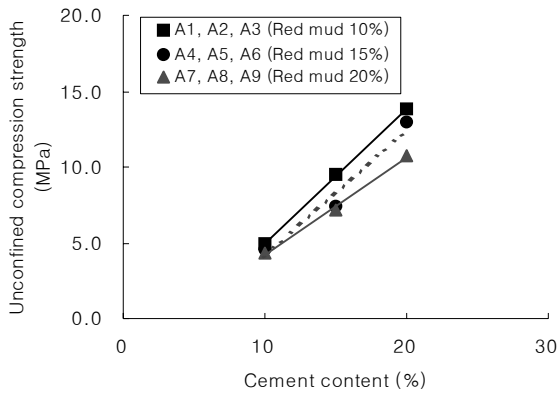


Fig. 12. The relationship of unconfined compressive strength with cement content

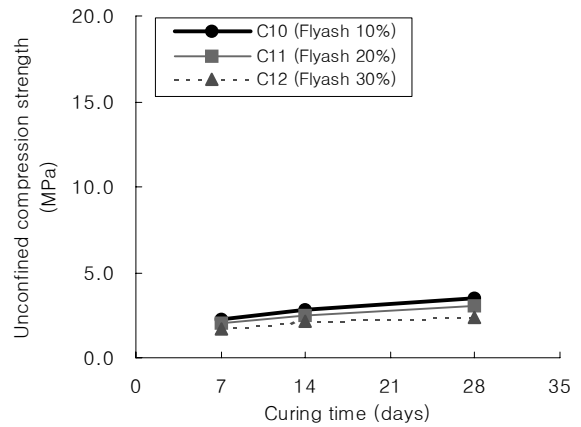


Fig. 15. The relationship of unconfined compressive strength with curing time (red mud 20%)

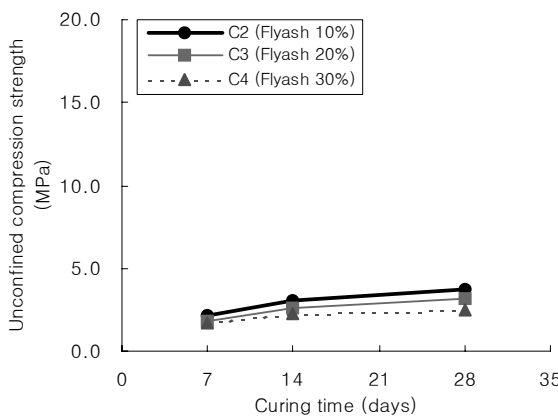


Fig. 13. The relationship of unconfined compressive strength with curing time (red mud 10%)

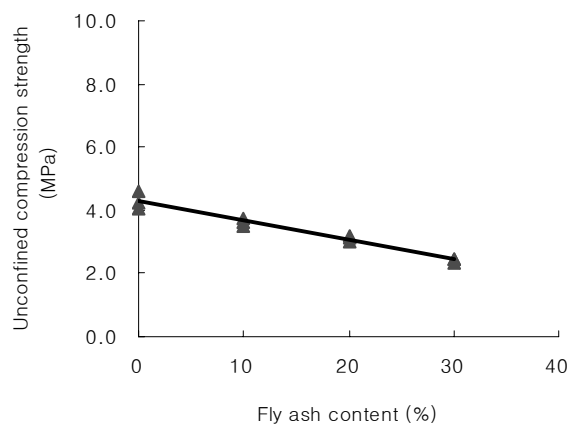


Fig. 16. The relationship of unconfined compressive strength with fly ash content

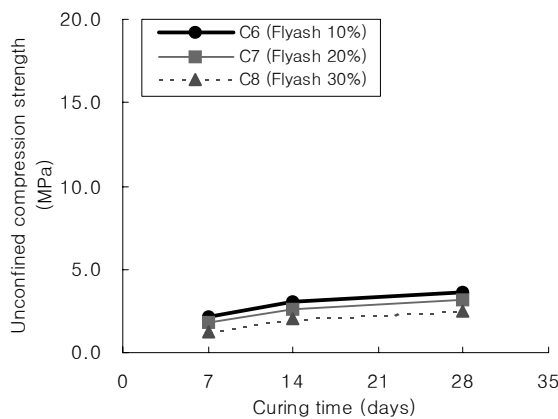


Fig. 14. The relationship of unconfined compressive strength with curing time (red mud 15%)

The unconfined compression strength decreased with increasing fly ash content and the variation of compressive strength with increasing red mud content was insignificant. Fig. 16 shows the relationship of unconfined compressive strength and fly ash content. As the fly ash content increased, the unconfined compressive strength decreased.

4.4 Effect of soil replacement with sand

Fig. 17, 18, and 19 show the relationship of unconfined compressive strength and curing time when soil was replaced with sands. The effect on compressive strength with increasing soil replacement ratio with sands was insignificant. Fig. 20 shows the unconfined compressive strength with soil versus replacement with sands. From the test results, these two samples are equivalent in strength, probably because the weathered granite residual soils (SM) have a similar particle size as the replacement sands.

5. Conclusions

In this study, unconfined compressive strength tests for soil-cement mixtures with red mud were performed in order to investigate the effects of red mud content, cement content, fly ash content, and soil replacement with sands

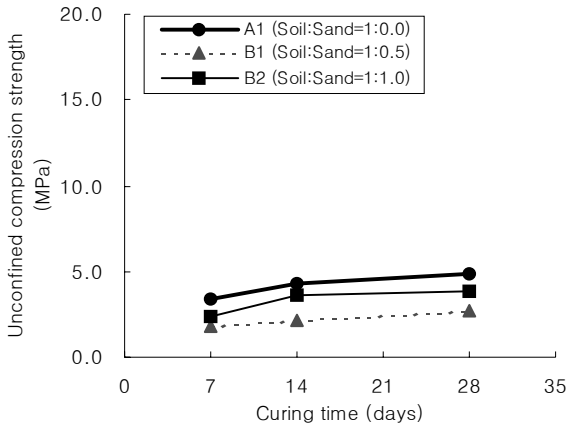


Fig. 17. The relationship of unconfined compressive strength with curing time (cement 10%)

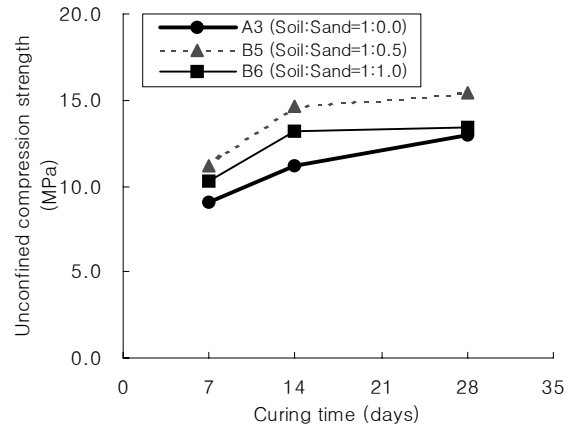


Fig. 19. The relationship of unconfined compressive strength with curing time (cement 20%)

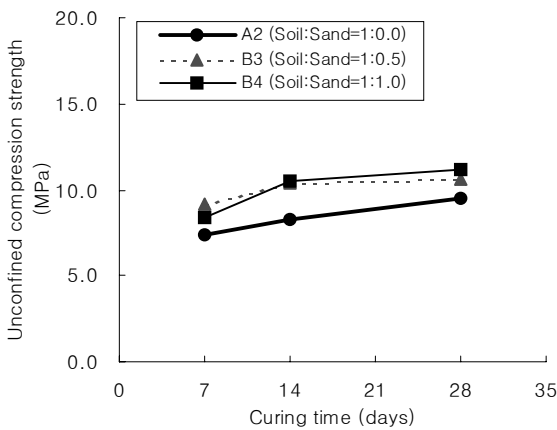


Fig. 18. The relationship of unconfined compressive strength with curing time (cement 15%)

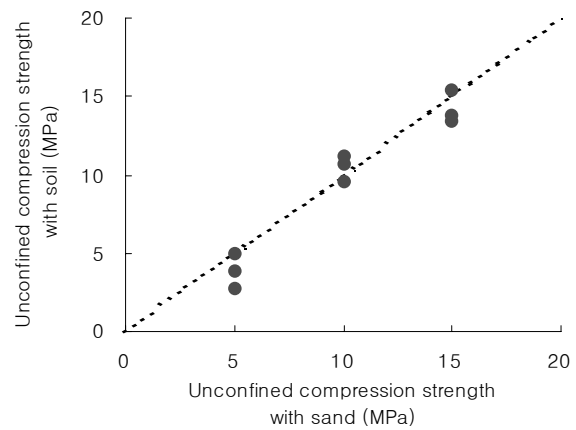


Fig. 20. Unconfined compressive strength with soil versus unconfined compressive strength with sand

on unconfined compressive strength.

From the test results, the unconfined compressive strength increased with increasing cement content and decreasing content of red mud and fly ash. As the content of red mud increased, the compressive strength slightly decreased and this tendency was more distinct with increasing cement content. Unconfined compressive strength decreased with increasing content of fly ash and the variation of compressive strength with an increasing red mud content was insignificant. Therefore, fly ash does not show an effect of increasing long term strength. Variation of compressive strength with increasing soil replacement ratio with sands was insignificant because both soils have similar particle sizes.

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REFERENCES

1. Jeong, Won-sik (2004), *Recycling of Red Mud*, Construction Technology Information, pp. 32~44.
2. Ju, Jae-Woo, Park, Jong-Beom, Ju, Jin-Young, Lee, Dong-Seob (2003), Production of Soil Mixed Pavement using Hydronium, *Journal of the Korean Society of Civil Engineers*, Vol. 23, No. 4, pp. 213~219.
3. Kim, Byoung-II, Kim, Young-Uk, Lee, Seung-Hyun (2002), Unconfined Compressive Strength of Soil Cement Mixed with NSC, *Journal of the Korean Geotechnical Society*, Vol. 18, No. 4, pp. 159~165.
4. Kim, I-Tae (2003), The Characteristic of Heavy Metals Leached from the Treated Sludge and Soil using Red Mud, *Proc. of the Korean Society of Soil and Groundwater Environment*, pp. 73~77.
5. Portland Cement Association (1978), *Soil-Cement Construction Handbook*, p. 40.

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