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≫ **연구논문** ≪

저강도 고유동 충전재의 성능에 미치는 광미 전처리의 영향

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Effect of Pretreatment of Mine Tailings on the Performance of Controlled Low Strength Materials

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요 약

광산 부산물인 광미를 건설용으로 대량활용하기 위해서는 내부의 중금속을 제거하기 위한 전처리가 필요하다. 본 연구에서는 전처리 된 광미를 필러(Filler)로 혼입한 저강도 고유동 충전재(Controlled low strength material, CLSM)의 성능에 대해 실험적으로 평가하였다. 전처리가 충전재의 저 성능에 미치는 영향을 평가하기 위해서 전처리 되지 않은 광미 이외에도 고주파 가열 처리, 고주파 가열 후 자력선별 처리한 광미를 실험에 사용하였다. 시멘트의 혼입량은 광미 질량의 10%, 20%, 30%로 설정하였다. 배합설계한 모든 충전재는 미국 콘크리트학회의ACI Committee 229에서 제시한 유동성 200 mm 이상 및 강도 0.3-8.3 MPa의 기준을 만족하는 동시에 최종 침하량은 1% 이하임을 확인하였다.

주제어 : 광미, 저강도 고유동 충전재, 고주파가열, 자력선별, 유동성, 침하량, 압축강도

Abstract

For the massive recycling of mine tailings, which are an inorganic by-product of mining process, in the field of civil engineering, pretreatments to extract heavy metals are required. This study focuses on the use of pre-treated tailings as substitute fillers for controlled low-strength material (CLSM). As a comparative study, untreated tailing, microwave-treated tailing and magnetic separated with microwaved tailing were used in this study. Cement contents amounting to 10%, 20% and 30% by the weight of the tailings were designed. Both compressive strength and flowability for all types of mixture were satisfied with the requirements of the American Concrete Institute (ACI) Committee 229, i.e., 0.3-8.3 MPa of compressive strength and longer than 200 mm flowability. Furthermore, all mixtures showed settlements less than 1% by volume of the mix.

Key words : Tailing, Controlled low-strength material (CLSM), Microwave, Magnetic separation, Flowability, Settlement, Compressive strength

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1. Introduction

Substantial research has been conducted with regard to the controlled low strength materials (CLSM). There is considerable advancement in areas related to the CLSM, such as mix proportion, material design, cost reduction, standardization for test method, and applications$^{1-3)}$. The American Concrete Institute (ACI) Committee 299 summarized a common and clear understanding for CLSM and published a report in 1994$^{4)}$. The technical report defined CLSM as a cementitious material with a compressive strength of 8.3MPa and less, and it can be referred to as, flowablefill, soil cement slurry, and controlled density fill. The primary application area of CLSM is in backfills, replacing selected soil fill materials. However, CLSM has a potential for many other applications, such as a pavement section for road construction and a structural backfill$^{4)}$. CLSM is generally defined a mixture of water, cement, aggregates, and supplementary cementitious materials (SCM) such as fly ash and slag. The purpose of this research is to show a way for the use of a recycling material, with environmental benefits, as a substitute supplementary material in the production of CLSM.

Many studies have been conducted by using various SCMs for the production of CLSM, aiming for cost reduction, improvement of quality, and novel production method, as well as the stabilization of heavy metals. Tikalsky et al. successfully incorporated foundry sand with the goal of evaluating the engineering properties of CLSM$^{5)}$. In addition, a study was conducted by Lianxiang et al. on the effect of aggregate types on the water demand and compressive strength of CLSM, to understand properties of the CLSM and to develop a formula for the estimation of the compressive strength development$^{6)}$. Charles et al. used cement kiln dust, which is a contributor to air pollution, as a binder in CLSM$^{7)}$. Shah successfully substituted aggregates and cement with quarry fines, fly ash, and synthetic gypsum to reduce the cost for production$^{8)}$. Kim et al. analyzed engineering properties and leaching behavior of arsenic-rich mine tailings without any initial pretreatment to use it as a filler for CLSM production, and the result showed that it is a capable filler material for CLSM production$^{9)}$. However, the present study differ from the Kim et al. that the present study focus on the effect of pretreated tailings capability as a filler in CLSM production.

This study focuses on the effect of pre-treated mine tailings used as substitute fillers on engineering performances of CLSM. Pretreatment measures such as microwaving and magnetic separation were used to remove toxic heavy metals plus organic compounds present in the tailings and to reduce the metallic impurities, respectively$^{10,11)}$. The feasibility of CLSM was evaluated based on the engineering properties including flowability, settlement, and compressive strength.

2. Experimental Method

2.1. Materials used

Three types of solid materials were used in the experiment: mine tailing, natural river sand, and type I Portland cement. The specific gravity and water absorption ratio of the sand used in this study were 2.6 and 0.83%, respectively. The tailing was obtained from the Sun-Shin mine in the Jeolla-Namdo province of South Korea. Since the mining target element was gold (Au), mine tailings generated from the mine site had a fine particle size$^{12)}$. The tailings used in this study were in three different forms. The first one is its raw form, without any change from its site condition; in other words, it was directly used in raw form without any treatment, and it is named as raw tailing (RT) throughout the paper.

The second form is microwaved tailing (MT). Microwave treatment uses high-frequency radiations, which generate polar molecules in a material to produce thermal energy without direct use of thermal treatment as a primary heating mechanism$^{11)}$. Heavy metals like arsenic (As) in the tailing exist in the form of arsenopyrite (FeAsS) and pyrite (FeS_2)$^{11)}$. During the microwave treatment processes the arsenopyrite is decomposed by high heat above 1000℃ within 10 min to As gas and AsS gas, and is liberated$^{10,11)}$. The liberated toxic gases from the tailings were captured by an additional instrument used to capture the toxic gases inside the devise. As given in Table 1, the tailings loss of ignition (LOI)

Table 1. The chemical compositions of mine tailings

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI
Raw tailing (RT)	79.53	9.52	3.22	0.16	0.64	0.51	0.72	3.24	0.52	0.06	2.46
Microwaved tailing (MT)	80.6	9.33	3.99	0.15	0.66	0.42	0.64	3.57	0.60	0.05	0.15
Microwaved with magnetic separation tailing (MMT)	83.23	10.11	0.12	0.14	0.61	0.38	0.73	3.88	0.01	0.01	0.19

shows a reduction after the microwave process.

The last form is microwaved with magnetic separation tailing (MMT). For the pre-treatment, the tailing was microwaved, and then a magnetic separation took place. Microwaving process was identical to the MT and the magnetic separation was applied to remove metallic impurities[10,13)].

Table 1 shows chemical compositions of the tailings used in this study. The chemical compositions were measured by X-ray fluorescence (XRF), using RIX-2000 (manufactured by Rigaku Inc., Japan). The major components were silica, alumina, ferrite, and potassium oxide in both the raw and microwaved forms. The composition of ferrite decreased after magnetic separation took place.

The crystalline nature of the tailing was investigated by X-ray diffraction (XRD), using X'Pert^3 Pro MRD (manufacture by PANalytical, Netherlands). Fig. 1 shows that the tailing has a silica (SiO_2) based mineral ore, mainly containing quartz, hedenbergite ($CaFeSi_2O_6$), muscovite ($KAl_2(AlSi_3O_{10})(F,OH)_2$) and anorthite ($CaAl_2SI_2O_8$). In addition, As-oriented trace element was detected, arsenopyrite [FeAsS]. Ti was also detected as a form of titanite ($CaTiSiO_5$).

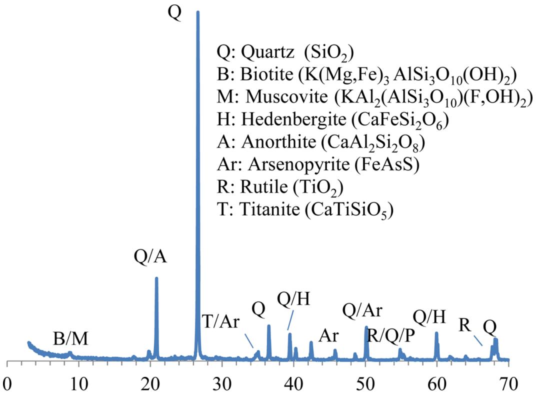

Fig. 1. X-ray diffraction (XRD) spectra of tailing.

A particle size distribution of the tailings and cement was analyzed by using a Beckman Coulter-LS230 laser diffraction particle size analyzer. A standard sieve analysis was performed for the natural sand. Fig. 2 shows the particle size distributions of the sand and tailings. Note that the MMT has fineness similar to that of MT.

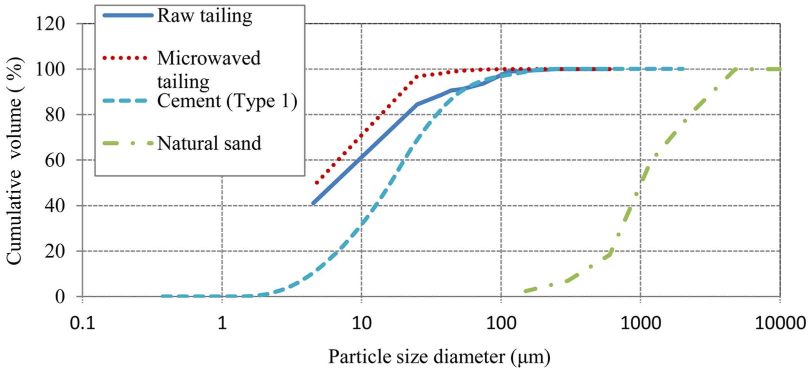

Fig. 2. Particle size distribution (PSD) of solid materials.

2.2. Test methods

As a filler, mine tailings were mixed with Type I Portland cement. The mix proportion of the tailings was fixed, while the cement content was varied in the mixture design by 10%, 20%, and 30% of the tailings weight (RT, MT and MMT). The water and sand ratio were fixed at 1.1 and 2, respectively by weight of tailing. In total, nine mix designs were used for the experiment.

An automatic mixer with a capacity of six liters was used to mix the cement, tailing and sand with water for approximately five minutes. After mixing a flowability test was conducted in accordance with ASTM D6103[14)] using a cylinder of diameter, 75 mm, and height, 150 mm. Settlement measure was taken according to ASTM C232[15)] with a small variation in the cylinder mold, which had a diameter of 85 mm and a height of 120 mm, because aggregate was not used in this experiment[9)]. A 50 mm × 50 mm × 50 mm cube mold was used to cast the compressive specimens. The test was conducted at ages of 7, 28 and 91 days to evaluate early-aged, standard, and long-term strengths respectively. Three specimens were used for each measurement. For the compressive strength test, specimens were cured by air-drying at a temperature of 20 ± 1°C and humidity of 50 ± 10%, according to ASTM C 109. The load sensitivity of the load cell of the compressive strength test was ± 10 N (± 0.039 MPa).

3. Results and Discussion

3.1. Flowability and settlement

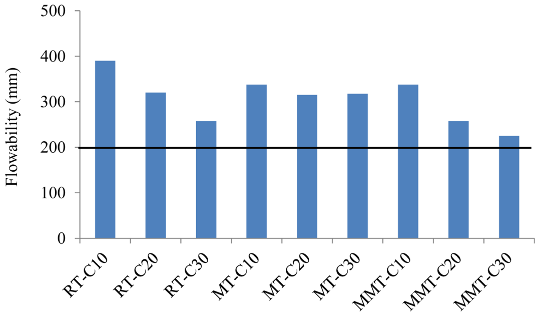

Fig. 3. Flowability of CLSM mixtures (solid line: the standard for ACI 229R-13).

Fig. 3 presents the flowability result of CLSM. The result clearly shows that all mixtures have a good flowability, longer than 200 mm, which is recommended in ACI committee report[4)]. Flowability displayed almost a linear reduction as the amount of cement in the mixture increased, especially for RT and MMT. In the case of MT, however, the reduction was insignificant. The decrease in flowability was due to the amount of cement powder increase in the mixture reducing the amount of free water available in the mixture. However, the flowability of all mixtures measured in this study was over 225 mm, which is a higher value than the ACI 229R-13 guideline requirement.

The RT showed higher flowability than the other tailings while having the same cement content. Since RT contains relatively larger particle size having a low surface area which makes RT easily flowable than the other tailings. On the other hand, even though MT and MMT have the same particle size the MMT showed lower flowability especially in case of mixtures containing cement 20% and 30%, which might be due to the agglomeration of tailings in the mixture. In over all, flowability was mainly governed by the cement content, rather than by the particle size of the tailings.

Settlement of the CLSM mixtures as a function of time is shown in Fig. 4. In all cases, settlement finished within four hours after mixing, and all mixtures showed a smooth layer without any surface crack. Most of the settlement occurred within the first two hours, and once the CLSM reached the setting point, there was no further settlement[4)]. The final settlement was less than one percent of the total volume for all mixtures, except for MT with a 30% cement mix, showing the settlement slightly over one percent, as shown in Fig. 4. Comparing the relation of settlement with tailing types and cement content, RT showed a constant settlement, while MT exhibited the highest and lowest values of settlement for 30% and 20% of cement content, respectively. In the case of MMT, a lower cement content led to a higher settlement. It can be inferred that the amount of cement in the mixture did not determine the settlement of CLSM, but rather the particle size and the specific surface area of the tailings[17)].

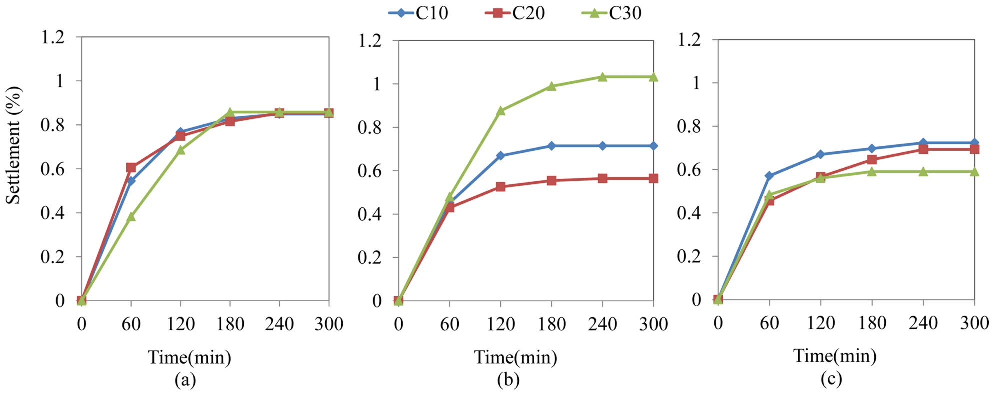

Fig. 4. Settlement of CLSM (a) Raw tailing (b) Microwaved tailing (c) Microwaved with magnetic separation.

3.2. Compressive strength

Based on the report of ACI Committee 299, CLSM should have strength lower than 8.3 MPa. Furthermore, the report has different upper limits, with 8.3 MPa being the upper limit for permanent structural fills and pavement bases, 2.1 MPa being the upper limit for most general fill applications and areas of future excavation with backhoe, and a range of 0.3-0.7 MPa for use as well-compacted soil that can be easily excavated with conventional digging equipment[4]. Fig. 5 shows that all specimens showed a compressive strength below 2.5 MPa, which indicates the capability of the CSLM for various applications and that it can be easily excavated in the future.

The compressive strength showed an increase for all specimens from 7 days to 28 days. The same result was shown from 28 days to 91 days, a consistent and significant amount of increase in strength, especially for mixtures containing 30% cement. The strength of CLSM was mainly influenced by the cement content, and it indicates a clear distinction between the mixtures containing 10%, 20% and 30% of cement content as shown in Fig. 5. A further increase of cement decreases the water to cement ratio by increasing the strength. On the other hand, the effect of the different types of mine tailing while having the same cement content was insigni-

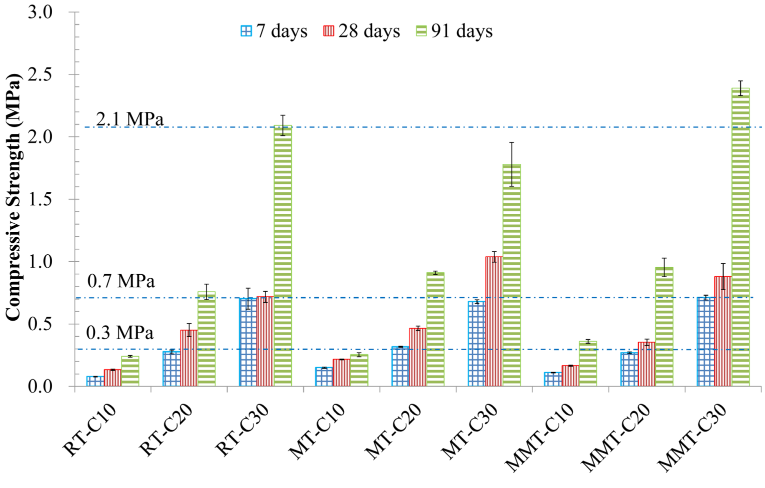

Fig. 5. Compressive strength of CLSM (centre lines: the standard range of ACI 229R-13).

ficant and difficult to be compared due to the small range difference between the values.

4. Conclusion

This research was conducted by using tailing in three different states, namely, in its original raw form, by microwaving the raw tailing, and by microwaving with magnetic separation of the raw tailing. The tailing was mixed with cement at the mix ratio of 10%, 20% and 30% by the weight of tailing, resulting in nine different mixes. From the experiment, it was shown that the effect of the type of tailings on the compressive strength, flowability, and settlement were insignificant, comparing with the effect of the cement ratio.

All mixtures fulfilled the requirements of the ACI committee 229 standards for the flowability showing significant results that is over the requirement set by the standard. The settlement in overall showed values less than one percent of the total volume for all mixtures, except for MT with 30% cement content. In addition, the compressive strength showed a reasonable value for all forms of CLSM based on the ACI Committee 229 standard and a continuous increase was recorded throughout the ages. Nearly all mixtures showed strength below 2.1 MPa except for MMT with 30% cement content. This indicates easy excavation in the future. In overall, the experimental results showed that the mine tailings have a high potential as a cementitious filler in the CLSM production for various applications.

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