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Mechanical Properties of Artificial Stone Based on Mixing Ratio Using Waste Resources†

YONGJIN YOO, SANGSOO LEE* and HAYOUNG SONG

Department of Architectural Engineering, Hanbat National University, Daejeon 302-72, Republic of Korea

*Corresponding author: Fax: +82 42 8211590; E-mail: sslee111@hanbat.ac.kr

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The environmental problems have recently aggravated due to global warming caused by greenhouse gas emissions. Furthermore, environmental damage and resource depletion have worsened by reckless collection of aggregates and limestone, which are the raw materials for cement. In addition, the extrusion molding in stone production process causes gas emission, degradation of performance, fire resistance and durability problems, making it urgent to reduce the use of cement and push forward the research into substitutes. In this study, we set the mixing ratio to 70 % for waste resources (waste glass, waste porcelain) and 80 % for exterior materials. The related items of test are flexural strength, density, water absorption ratio, rate of aggregate on the surface, *etc*.

Keywords: Magnesia phosphate complex, Waste glass, Waste porcelain, Artificial stone, Rate of aggergate on the surface.

INTRODUCTION

The environmental problems have recently aggravated amidst global warming caused by greenhouse gas emissions. Furthermore, environmental damage and resource depletion have worsened by reckless collection of aggregates and limestone which are the raw materials for cement. Under those circumstances, efforts have been to mitigate related problems. In order to resolve the problems in artificial stone, terrazzo floor materials and deluxe tiles, such as ultraviolet degradation, water resistance, durability and cost-effectiveness problems, it is necessary to develop carbon, environment-friendly artificial stone that can mitigate the problems of existing artificial stone. Therefore, this study is intended to examine mechanical properties of artificial stone through the mixture of magnesia phosphate composite (MPC) and fly-ash by using the waste glass and waste porcelain which are the natural substitutes for aggregates as part of countermeasures against environmental contamination and resource depletion arising from the use of artificial stone.

EXPERIMENTAL

Regarding the level and factors of this experiment, the mixing ratio for waste glass (WG), waste porcelain (WP), WGP (waste glass + waste porcelain) was 70 % for interior materials and 80 % for external materials (Table-1). Magnesia and fly-ash were used as binders and the fly-ash was substituted 10 wt. % based on magnesia 1,000 g. Moreover, the maximum dimension of waste porcelain and waste glass was 15 mm while the W/B was fixed at 49 %. 5 % boric acid (retarder) was mixed in view of workability.

TABLE-1
EXPERIMENTAL FACTORS AND LEVELS

Experimental factor		Level	
Type		Interior material	Exterior material
Mixing ratio (%)	WG	70	80
	WP		
	WGP		
	MPC	30	20
FA		10 %	
WG, WP Max		15 mm	
W/B		49 %	
B		5 %	
Assessment items	Density, water absorption, rate of aggergate on the surface, compressive strength, flexural strength		

Material: This binders used in this study were magnesium (MgO), fly-ash (FA), waste glass (WG), waste porcelain (WP), first potassium phosphate, boric acid(B), *etc*. Their compositions are given in Table-2. The waste glass[1] used in this experiment was produced by domestic 'S' company and made mainly from SiO_2 and CaO. This waste glass contains Na_2O and Al_2O_3 and had a density[2] of 2.04 g/cm^3. Moreover, the transparent glass bottles were used which underwent particle size adjustment process after being crushed. Meanwhile, the

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TABLE-2
BINDERS AND THEIR COMPOSITIONS

Materials	Chemical components (%)						
	SiO_2	Al_2O_3	MgO	CaO	Fe_2O_3	SO_3	K_2O
MgO	3.14	0.52	93.30	2.06	0.60	0.11	–
FA	54.38	21.50	1.89	10.83	5.16	1.29	–
WG	69.83	2.00	1.22	17.85	1.08	0.12	2.25
WP	69.46	18.90	0.41	3.32	0.39	0.22	5.19

waste porcelain used in this experiment[3] was produced by domestic 'Y' company and made mainly from SiO_2. This waste porcelain[4] contained Al_2O_3, K_2O and CaO and had a density of 2.39 g/cm^3. Furthermore, this waste porcelain underwent particle size adjustment process after being crushed in the same way as the waste glass.

Procedure: Regarding the mixing method used in this experiment, the magnesia, fly-ash, first potassium phosphate and then boric acid were put into a spiral blender and mixed dry at 35 rpm for 120 sec. Then, the mixing water was fed into and mixed at 45 rpm for 60 sec and the waste glass and waste porcelain were fed into and mixed at 45 rpm for 60 sec and discharged when a total of 240 sec were reached. In addition, for the production of test specimen, magnesia and potassium phosphate were mixed at a ratio of 2:1.

RESULTS AND DISCUSSION

Density, water absorption ratio and rate of aggregate on the surface: For the interior materials, WG 70 % had a density of 2.3 g/cm^3 and water absorption ratio of 6.8 % suggests that the density and water absorption ratio were the lowest. For the exterior materials, WG 80 % had the density of 2.1 g/cm^3 and water absorption ratio of 4.0 % suggests that the density and water absorption ratio were the lowest.

In overall way, interior materials fell within the standard absorption range of 5 to 18 % specified in "KS L 1001 porcelain quality" and the exterior materials showed a water absorption ratio of 3 to 5 % which fell within the proper range (Fig. 1). This is attributed to the fact that higher density makes pores filled between binders and smooth waste materials(waste glass, waste porcelain) which in turn makes the test piece dense and therefore reduces water absorption ratio.

The rate of aggregate on the surface was 50.7 %, the lowest, in interior material WP 70 %, while rate of aggregate on the surface was 65.0 %, the highest, in exterior material WGP 80 %. The rate of aggregate on the surface increased gradually in the order of WP, WG, WGP and exhibited similar tendency in exterior materials as in interior materials. In addition, reference value 50 %, specified in "KS F 4035 Precast terrazzo", was met (Fig. 1). As the quantity of waste materials (waste glass, waste porcelain) increases, the distribution becomes proper and the dimension of portion of artificial stone's two(2) diagonal lines passing over the waste glass becomes larger, making the rate of aggregate on the surface increase (Fig. 2).

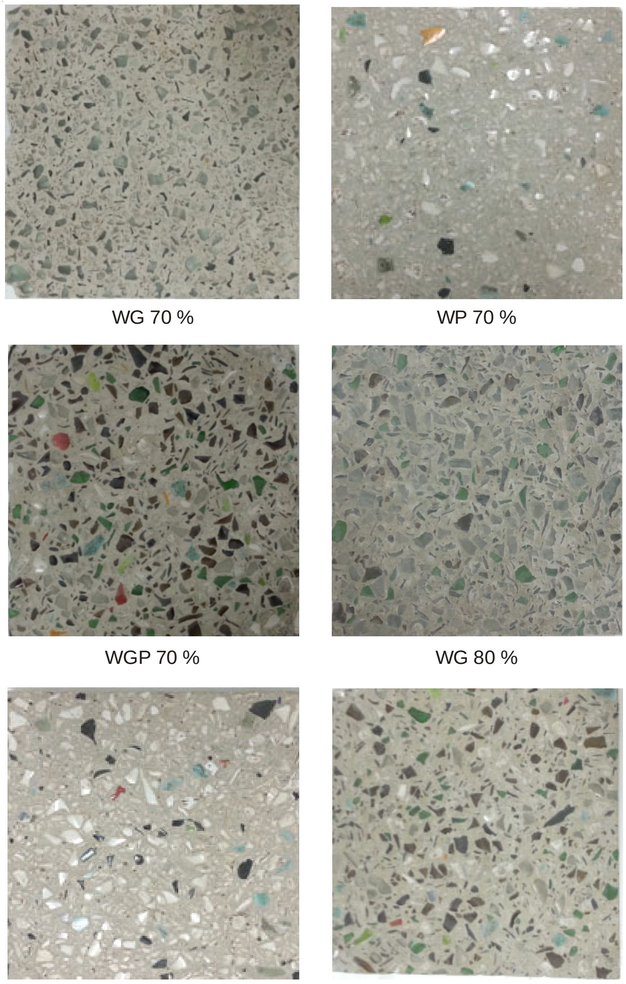

Fig. 2. Surface variation of the artificial stone

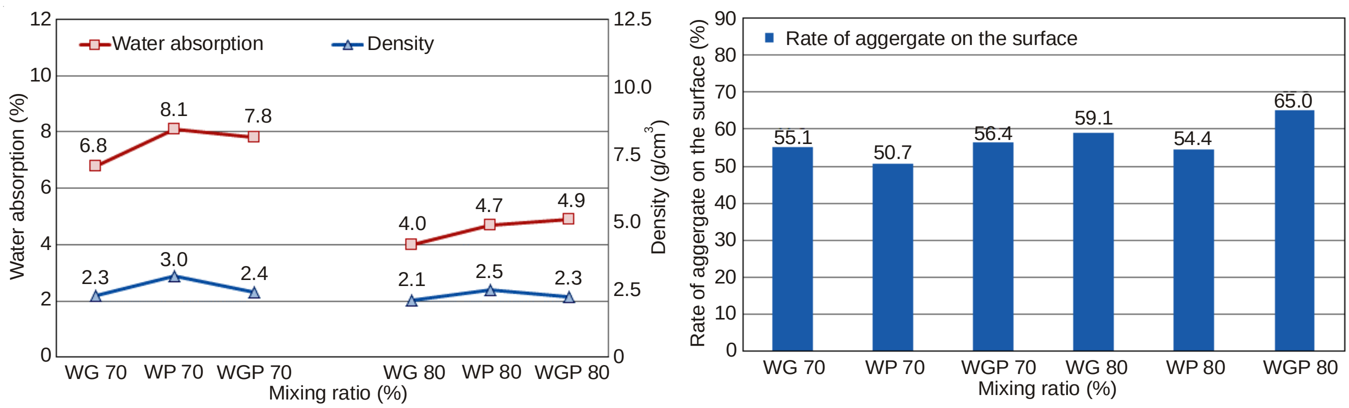

Fig. 1. Water absorption, density and rate of aggregate on the surface

Compressive strength and flexural strength: In overall way, compressive strength was the lowest in WG 70 % and was in the order of WP 70 % and WGP 70 %. For the interior materials, compressive strength was 16.5 MPa in WG 70 %, 16.7 MPa in WP 70 % and 19.8MPa in WGP 70 % at the age of 7 days. For the exterior materials, compressive strength was 24.5 MPa in WG 80 %, 24.5 MPa in WP 80 % and 24.2 MPa in WGP 80 % (Fig. 3), suggesting that the compressive strength was higher when the waste glass and waste porcelain were mixed, compared to when they were used separately. The flexural strength corresponded to the reference value 5 MPa as specified in "KS F 4035 precast terrazzo". At the age of 7 days, the flexural strength was considered to exceed the KS reference value.

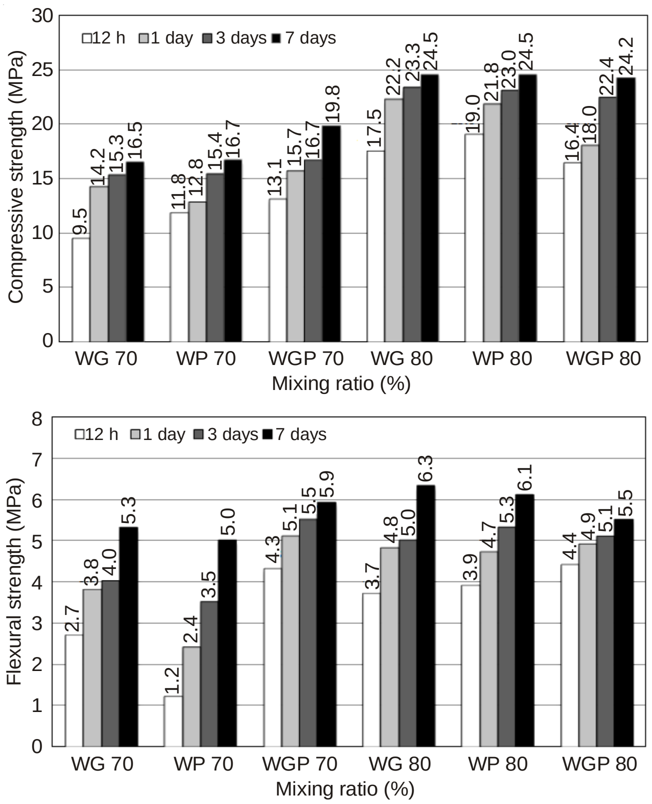

Fig. 3. Compressive strength and flexural strength

The flexural strength was the highest when the mixing ratio was exterior material WG 80 % at the age of 7 days, *i.e.* when the ratio of magnesia phosphate composite and waste glass was 20:80. In addition, the flexural strength was the lowest in WP 70 %. That is considered attributable to an increase in the area of continuous adhesion with binders due to overall 'pore filling effect' of artificial stone based on particle size distribution and optimum particle mixing ratio of waste glass, thereby increasing the flexural strength and strength value.

Conclusions

In this study, we mixed the magnesia phosphate composite and fly-ash to apply waste resources (waste glass, waste porcelain) in order to determine physical properties of eco-friendly artificial stone. The results are as follows:

• The density of exterior materials and interior materials based on the mixing ratio of waste resources was found to conform to the standard of "KS L 1001 porcelain quality" in overall way.

The rate of aggregate on the surface of all interior materials satisfied the standard reference value of "KS F 4035 Precast Terrazzo" and the flexural strength showed flexural strength ratio for the reference value 5 MPa. In overall way, the flexural strength is considered to meet or exceed the KS reference value. The flexural strength was the highest in interior material WGP 70 %, exterior material WG 80 % and WP 80 % at the age of 7 days.

• The results of experiment suggested that the WGP 70 % (*i.e.*, waste glass-waste porcelain mixing ratio of 70 % & magnesia phosphate 30 %) led to the most excellent strength. For the exterior materials, WGP 80 % (*i.e.*, waste glass-waste porcelain mixing ratio of 80 % & magnesia phosphate 2 %) was found to lead to the most excellent strength.

Those results are expected to provide useful data related to artificial stone. As they conform to KS quality standards for artificial stone, they may be used in case of additional review in the period ahead.

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