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Characteristics of compressive strength according to the content of fine aggregate replacement beads

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ABSTRACT

Recently, concrete industry is concentrating on researches regarding on alternative aggregates to solve the two major problems of depletion of natural resources and environmental pollution. In this study, the potential use of glass, plastic, and steel beads as an aggregates substitute was reviewed, and the compressive strength and fracture mode of concrete according to the material substitution ratio (0%, 5%, 15%, 30%, and 50%) was investigated through experimental tests. Each material seems to have optimal mixing ratios that give maximum compressive strength, and although it was slightly different depending on each mixing ratio, in general, the compressive strength decreased in the order of steel, glass, and plastic.

1. INTRODUCTION

1.1 Background and Purpose of the Study

Concrete has been widely used around the world compared to other materials because it has advantages of economy and durability since its development a long time ago. However, aggregates, one of the main materials of concrete, are limited in quantity because they are natural resources. In addition, a lot of carbon dioxide is emitted during the manufacturing process, which is the main cause of environmental pollution. To solve this problem, research was conducted on the processing of waste concrete again and the use of it as a recycled aggregate. Recently, research has been conducted on the use of materials that have excellent physical properties, such as waste plastic and waste glass from factories, but are not properly recycled as aggregates for concrete. In previous studies using plastics, which are highly recyclable, as alternative aggregates, strength showed a tendency to decrease according to the mixing ratio of plastics (Ibrahim A., 2020). Therefore, this study intends to examine the use of beads according to material characteristics by conducting an experimental study to confirm the characteristics of concrete by replacing fine aggregates with glass, plastic, and steel beads.

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1.2 Research Trends

Kim (2007) conducted a study to evaluate the basic properties of concrete mixed with furnace-slab fine powder and waste-glass fine powder based on experimental studies using cement and furnace-slag fine powder and fly ash. In the compressive strength test, the compressive strength decreased regardless of age due to the increased ratio of WGP (Waste Glass Fine Powder). However, 91 days of age showed a compression strength expression ratio, which showed a great effect on improving long-term expression performance.

Yi (2020) evaluated basic properties by incorporating 30% of mixed plastic waste aggregates (MPWA) and low-density polyethylene waste aggregates (PPWA) for fine aggregate replacement. Waste plastics tended to decrease in compressive strength compared to PLAIN subjects regardless of type, and increased compressive strength of MPWA and PPWA mixed specimens.

Eu (2020) conducted a study to evaluate the mechanical properties and alkali silica reaction of high-strength mortar to examine the suitability of using waste glass as recycled aggregate. In the case of mixing waste glass from high-strength concrete and mortar, the strength showed a tendency to decrease as the mixing ratio increased. The reduction ratio was lower than that of the general strength mortar, but the difference was not significant. In addition, it is confirmed that ASR is generated more at high strength, so it is difficult to use waste glass at high strength, and it is likely that it can be used as a recycled aggregate when properly mixed at normal strength.

Through previous studies, it was confirmed that waste glass, waste plastic, and recycled aggregate are suitable for replacing aggregate, but it is difficult to generalize the reduction in strength because the process of recycling waste is different. Therefore, in this study, the strength behavior of concrete according to the replacement ratio of pure materials (glass, plastic, steel, etc.) was confirmed and used in future research on alternative materials for aggregate.

2. EXPERIMENT AND METHOD

2.1 Materials and Mix Design

The concrete used in this study was formulated considering the volume of fine aggregate and the density of the material. Table. 1 shows the characteristics of the beads used in the experiment. The PLAIN specimen formulations and mixing ratios used in the experiment are shown in Table. 2. In addition, the size of the specimen was produced as a cylindrical specimen of 100 (Φ) × 200 mm, molded after casting 1-day, underwater curing at 20 ± 2 °C, and the compressive strength was measured through a UTM tester.

Table. 1 Beads Properties

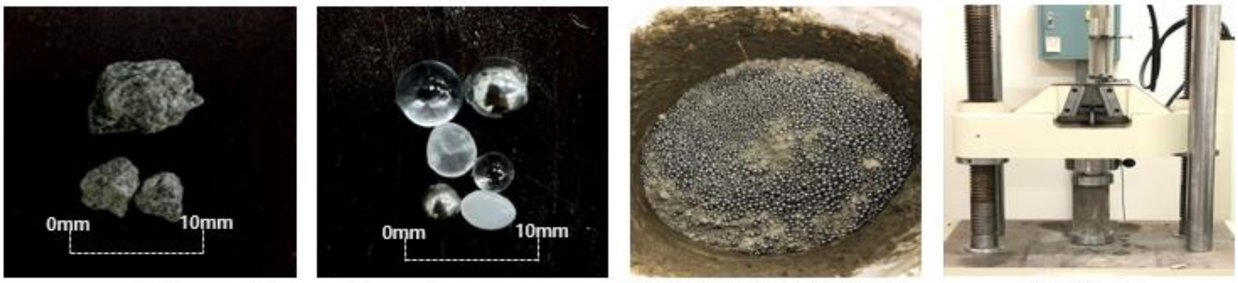
	Plastic (Polypropylene)	Glass	Steel (Stainless Steel)
Density (g/㎤)	0.92	2.5	7.93
Shape	white, elongated	limpidity, sphere	grey, sphere

Table. 2 Standard Mix Ratio (kg/㎥)

	Cement	Water	Coarse Aggregates	Fine Aggregates
PLAIN	384	179	1039	695

2.2 Specimen Production and Test Method

The maximum dimensions of coarse aggregates were mixed with 10mm and 5mm aggregates 1:1 using 10mm suitable for sample size. Beads were used as aggregates to replace fine aggregates, and 5mm and 3mm were mixed 1:1 to make the fine aggregate classification standard of 5mm the maximum aggregate. The mixing ratios of all samples are shown in Table. 3 below.



(a) Aggregates used in specimen (b) Mixed with Steel Beads (c) UTM Test

Fig. 1 Image of Specimen and Experiment

Table. 3 Mix Ratio (kg/㎥)

Specimen	W/C (%)	Coarse Aggregates	Fine Aggregates	Beads (g)	
				3mm	5mm
PBA5	50	1.79	1.14	9.66	9.66
PBA15			1.02	28.97	28.97
PBA30			0.84	57.94	57.94
PBA50			0.60	96.57	96.57
GBA5			1.14	26.24	26.24
GBA15			1.02	78.73	78.73
GBA30			0.84	157.45	157.45
GBA50			0.60	262.42	262.42
SBA5			1.14	81.68	83.40
SBA15			1.02	245.03	250.20
SBA30			0.84	490.06	500.39
SBA50			0.60	816.76	833.99

* *PBA(Plastic Beads Aggregate)*
GBA(Glass Beads Aggregate)
SBA(Steel Beads Aggregate)

The experiment was conducted to compare the compressive strength for each material according to their mixing ratios. (0%, 5%, 15%, 30%, and 50%) Two identical specimens were prepared for each mixing ratios based on previous studies, and the standard deviation and compressive strength were compared.

3. RESULTS

3.1 Results of Compressive Strength

Specimens for comparison of compressive strength by material and SBA5, 15, 30, and 50% specimens were all underwater curing for 28 days. The compressive strength test results for each material and mixing ratio are summarized in the Table. 4 and Fig. 2, 3.

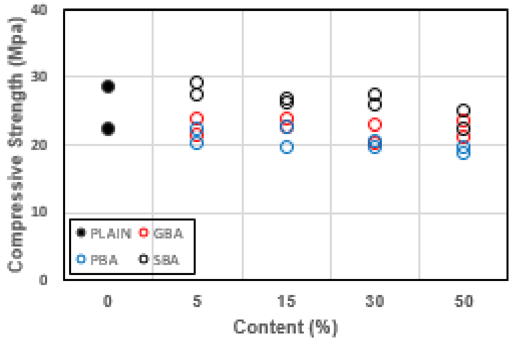


Fig. 2 Compressive Strength by Mix Rat

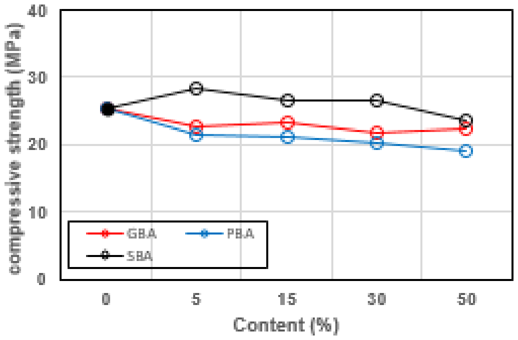


Fig. 3 Average Compressive Strength

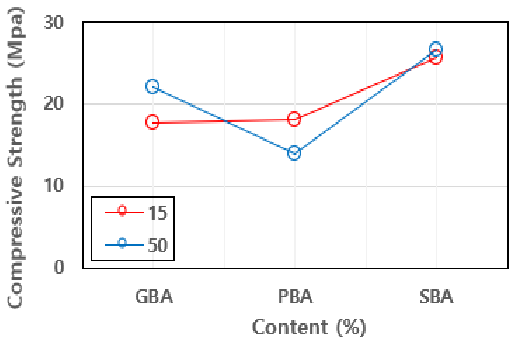


Fig. 4 Compressive Strength by material

Table. 4 Compressive Strength

Fig. 2 and 3 is a graph summarizing all the compressive strengths and average

Specimen	Compressive Strength (MPa)			Standard Deviation	Number
	Max.	Min.	Avg.		
PLAIN	28.5	22.2	25.35	3.47	2
GBA5	23.9	21.5	22.7	1.29	
GBA15	23.9	22.5	23.2	0.75	
GBA30	23.1	20.2	21.65	1.57	
GBA50	23.5	21	22.25	1.36	
PBA5	22.4	20.2	21.3	1.17	
PBA15	22.5	19.6	21.05	1.65	
PBA30	20.5	19.7	20.1	0.46	
PBA50	19.7	18.7	19.2	0.55	
SBA5	29.3	27.3	28.3	1.0	
SBA15	26.8	26.2	26.5	0.3	
SBA30	27.3	25.8	26.5	0.7	
SBA50	24.9	22.3	23.6	1.3	

compressive strengths of the specimens by mixing ratio, and Fig. 4 shows the compressive strength values for each material.

In the case of GBA specimens, the averaged compressive strengths according to the mixing ratios and the average values of GBA5 and GBA50 are 22.7 MPa and 22.3 MPa. This value is about 19% smaller than that of reference specimen.

In the case of PBA specimens, unlike GBA and SBA, the strength of the specimens with a 50% mixing ratio showed lower compressive strength for each material, and the difference in strength between the two specimens was 23%, which is similar to that of GBA. In PBA specimen case, the greater the replacement ratio, the lower the compressive strength.

It can be seen from Fig. 4 that the strength of the GBA specimen shows a decrease according to the mixing ratio in the same way as the PBA. In the compressive strength of each material, the same as GBA, the 50% mixing ratio is 26.46MPa, which is larger, but the strength difference is 3%, so the strength difference according to the mixing ratio is insignificant. However, in both experiments, the strength was greater than that of GBA and PBA, and the strength was higher than PLAIN up to 30% of the mixing ratio.

3.3 Cross Section of Specimen

In a specimen with a mixing ratio of 15% and 30%, it was completely split and destroyed. Below Fig. 5 shows the failure mode of the specimens.

Fig. 5 Failure Mode of Specimen

In addition, the PBA50 and SBA50 specimens exhibited a phenomenon in which the outer surface fell off rather than split. In the case of plastic, it was confirmed that the surface was smooth and the adhesion to the cement paste was very low, so that it was split, and the inner beads fell at the same time.

3.4 Discussion

In the case of glass beads, the compressive strength of GBA50 is larger than that of GBA15. However, there was little difference in compressive strength according to the mixing ratio. And, unlike previous studies in which the strength decreases according to the mixing ratio (Drzymała T, 2020), it shows almost the same average strength as PLAIN. It is judged that the glass beads of the same composition as the fine aggregate are playing the role of the fine aggregate.

In the case of plastic beads, the same results were obtained in both the compressive strength by material and compressive strength by mixing ratio. Also, as in previous studies using waste plastics, the strength of beads showed a tendency to decrease according to the mixing ratio (Lee, 2020). It is thought that the low density also influenced the decrease in strength.

In the experiment, the steel beads recorded much higher strength than GBA and PBA. In addition, the strength of all specimens except for SBA50 was higher than the average strength of the PLAIN specimen, 25.4 MPa. However, like PBA, the strength of the steel beads also decreases with increasing mixing ratio. It is considered that the strength decreases as the mixing ratio increases, despite the increase in strength due to material properties because the steel bead is hollow and has voids inside.

4. CONCLUSION

In this study, the following conclusions were obtained by analyzing the compressive strength characteristics according to the mixing ratio by replacing glass, plastic, and steel beads with fine aggregates.

- Glass beads have the same main components as fine aggregates. Therefore, it was found that the difference in strength according to the mixing ratio was not large compared to PLAIN when mixed with concrete. This seems to be a material characteristic of glass, and it is judged that it acts as an aggregate like fine aggregate.

- When plastic beads are mixed, the strength tends to decrease as the mixing ratio increases, as shown in the previous research results. This is due to material separation due to low strength and low density due to decreased adhesion between plastic beads and cement paste.

- In case of mixing steel beads, the highest strength was recorded in all specimens. This appears to be a material property due to the high density and showed higher average strength than the PLAIN specimen. However, the SBA also showed the same pattern as the PBA specimen, in which the strength decreased according to the mixing ratio. This is judged to be a decrease in strength due to internal voids apart from an increase in strength according to the material characteristics of the steel beads.

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