Research article

Effective Utilization of Ceramic Powders for Concrete Pavement

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Abstract The effective utilization of industrial wastes has been becoming the urgent problem for the establishment of the recycling society. Especially, there are many kinds of the powders-formed industrial wastes, and studies on the utilization of them have been conducted individually and widely. The powders which do not have activity are often used as a filler of asphalt pavement, but its supply has been already saturated in Japan. Therefore, the methods to use them as the aggregate of concrete pavement is also studied. When the approach method is established, it will help the reduction of the environmental load in the infrastructure development of the field of agriculture. In this study, authors focused on the powder exhausted in the manufacturing process of the ceramic product. This ceramic powder (CP for short) is one of the powders-formed industrial wastes which don't have activity. A process of the abrasion is necessary in the production of the ceramic product. On this occasion, ceramic fines are produced as sludge-formed drainage. Under the present condition, the drainage is dried by the sun and solidified by the addition of cement. It is disposed as the industrial waste in the state, and effective utilization has been expected. In this paper, CP was investigated to be used effectively as the substitute of fine aggregate. A part of JIS standard sand was replaced to CP by volume, being based on the mix proportion in the strength test of cements. The maximum replacing ratio was established experimentally from the viewpoint of fresh properties such as mortar flow test and setting time test and strength properties. The shrinkage properties was also obtained by the test of length change of mortar with dial gauge.

Keywords ceramic powder, concrete pavement, workability, strength, drying shrinkage

INTRODUCTION

The effective utilization of the industrial waste becomes the urgent problem in the establishment of the recycling society (Sogo et al., 2013). Especially, the powders-formed industrial waste exist for having many kinds, and a study on utilization is conducted individually and widely (Malhotra et al., 2005; Matsuo et al., 2007; Hosokawa et al., 2014). The powders which do not have activity are often used as a filler of asphalt pavement, but its supply is already saturated in Japan. Then, the methods to use them for aggregate of the concrete pavement is also studied. When the approach method is established, it helps the reduction of the environmental load in the infrastructure development of the field of agriculture. In this paper, authors focused on the powders exhausted in the manufacturing process of the ceramic product (CP). CP is one of the powders-formed industrial waste which does not have activity. A process of the abrasion is necessary in the production of the ceramic product. On this occasion, ceramic fines are produced as sludge-formed drainage. Under the present condition, the drainage is dried by the sun and solidified by the addition of the cement. It is disposed as the industrial waste in the state, and effective utilization is expected.

Giving attention to studies on CP, Sakagami clarified the applicability as segregation control material in the high slump concrete by replacing a part of the cement with CP (Sakagami et al., 2003). They were concerned about strength decreasing and suggested aggregate replacement not cement replacement.

In this study, CP was investigated to be used effectively as the substitute of fine aggregate. A part of JIS standard sand was replaced to CP by volume, based on the mix proportion in the strength test of cements. The maximum replacing ratio was acquired experimentally from the viewpoint of fresh properties such as mortar flow test and setting time test (JIS A 1147) and strength properties. The shrinkage properties was also obtained by the test of length change of mortar with dial gauge (JIS A 1129-3).

METHODOLOGY

1. Materials and Basic Properties

CP was dried by furnace drying to the absolute dry condition. And CP which passed 0.15mm sieve was used to unify the particle size. Table 1 shows the ingredient analysis of CP, and the Aluminum proportion is the most. The main materials were ordinary Portland cement (bulk density is 3.15 g/cm^3) as binder, the city water as mixing water and JIS standard sand (bulk density is 2.64 g/cm^3, water absorption is 0.42%) and CP (density in absolutely dry condition is 3.71 g/cm^3, non-sphere) as fine aggregate. High performance AE water reducing agent was used, and its effect was confirmed.

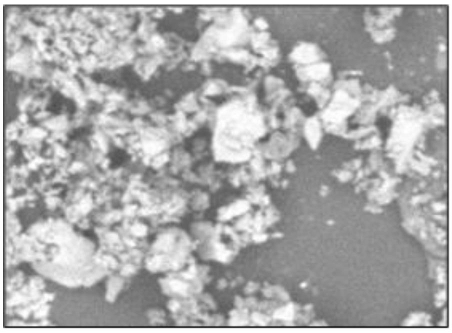

Photo. 1 Ceramic powder (3000 times)

Table 1 X-ray Diffraction Analysis of CP

Element	Al	Si	Ca	Mg	Cu
(%)	89.2	6.6	1.1	1.0	0.5
K	Ni	Mn	Na	Fe	Others
0.4	0.4	0.3	0.2	0.2	0.2

Table 2 shows the mix proportion of mortar. Unit volume water and unit volume cement was constant. Mixing was carried out following JIS R 5201, physical testing method for cement. Namely, after the mixing of water and cement for 30 seconds, the fine aggregates were added and mixed for another 30 seconds. After 90 second stop, they were mixed for 60 seconds again.

Air content was measured just after mixing, and setting test and bleeding test were conducted, each according to JIS A 1128, JIS A 1147 and JIS A 1123. In JIS A 1128, the air amount of mortar is able to be measured by the device such as Photo.2. In JIS A 1147, the increase of penetration resistance by time can be obtained by inserting of the bar into mortar as Photo.3. The time when the penetration resistance was to 3.5 N/mm^2 is determined as the initial setting, and that of 28.0 N/mm^2 is determined as the final setting. In JIS A 1123, the water floating on the surface of the mortar is absorbed in a filler directly, and the weights is measured as the bleeding (see Photo.4). The test specimens were prisms, and the dimensions were 40*40*160 mm. Strength test was conducted at the curing age of 3, 7, 28 and 91 days.

Table 2 Mix Proportion of Mortar (Base)

No.	W/C (%)	*CP (%)	**SR (%)	Unit Weight (kg/m^3)					Fresh & Strength	Shrinkage
				W	C	S	CP	SR		
S0	50	0	0	256	512	1536	0	0	○	
S5	50	5	0	256	512	1458	108	0	○	
S10	50	10	0	256	512	1381	216	0	○	
S15	50	15	0	256	512	1305	324	0	○	
S15H1	50	15	1	256	512	1305	324	10		○
S15H2	50	15	2	256	512	1305	324	20		○
S20	50	20	0	256	512	1228	431	0	○	
S25	50	25	0	256	512	1151	539	0	○	

*CP: Ceramic replacing ratio by volume
**SR: Shrinkage reducing agent, 1 means the standard usage

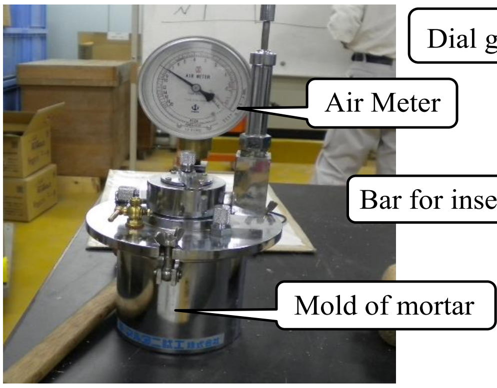

Photo. 2 Measurement of air amount

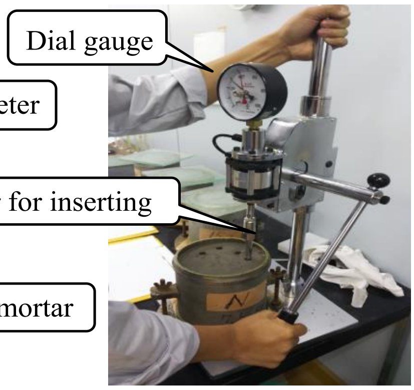

Photo. 3 Measurement of setting time

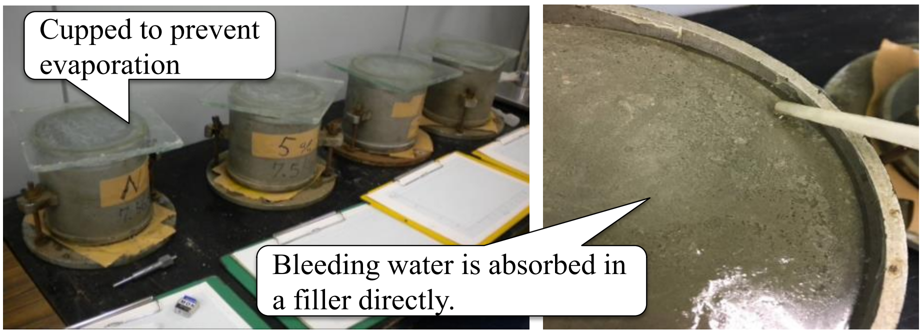

Photo. 4 Measurement of the amount of bleeding water

2. Methods of Measurement for Length Change

Table 2 also shows the mix proportions in the length change test. "S" means the replacing ratio to CP. Based on S0 which is the mix proportion of the cement strength test, a part of fine aggregate was replaced by volume to CP. "H" means the amount of shrinkage reducing agent, which main ingredient is glycol ether. "1" means the standard amount and "2" means twice as much. This agent was used and the effect was confirmed in the mix proportion of 15% of replacing ratio of CP.

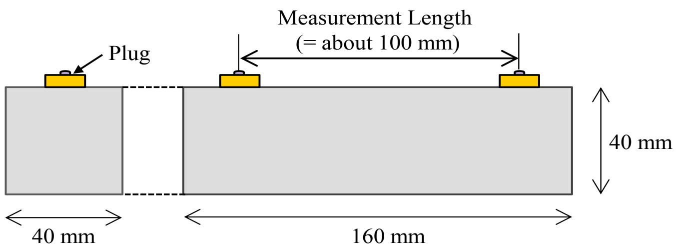

Fig. 1 Specimen size and position of the plugs for length change test

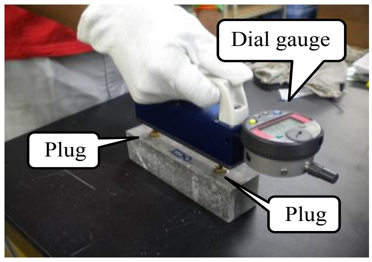

Photo. 5 Length change test

The test specimens were prisms, and the dimensions were 40*40*160 mm as same as basic tests (see Fig.1). 3 specimens were made by every mix proportion. They were demolded on the next day of casting, and had begun to be dried after 28 days standard curing. The environmental condition of drying in draft chamber was the room temperature of 20 degrees Celsius and the humidity of 60%. The length change test was conducted according to JIS B 7503 (see Photo.5).

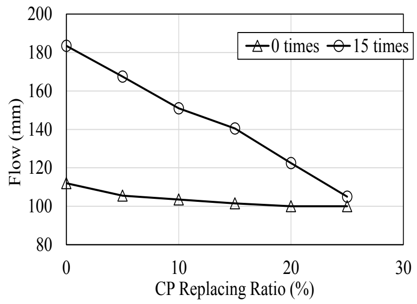

Fig. 2 Relationship between CP replacing ratio and mortar

RESULTS AND DISCUSSION

Figure 2 shows the relationship between CP replacing ratio and mortar flow. As the replacing ratio increase, the mortar flow decreases. Especially, when the replacing ratio exceeded 15%, workability decreased remarkably, which is out of practical use. Because a particle size of CP is extremely smaller than JIS standard sand, and surface area ratio is big, the adsorption water increased, which could be estimated as the factor that the workability decreased.

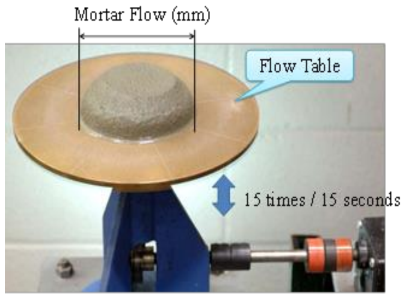

Photo. 6 Measurement of mortar flow

Figure 3 shows the result of the bleeding test. When the replacing ratio exceeded 10%, almost none of bleeding occurred. Even at 5% of CP replacing ratio, bleeding became about a one-third of basic mix proportion. This would be because the surface of CP which particle size is very small absorbed water like flow test. From the above, CP decreases the bleeding, but workability extremely decreases when CP replacing ratio exceed 10%.

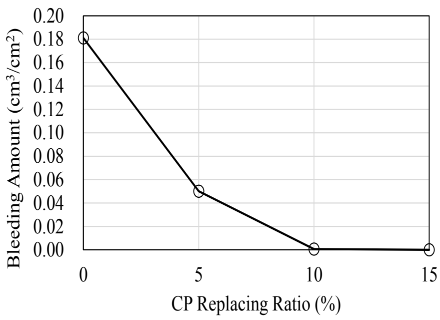

Fig. 3 Result of bleeding test

Figure 4 shows the result of the air content test. When CP was mixed, the air content increased obviously. The air content represented the maximum value at 5% of CP replacing ratio, and had a tendency to decrease at 10 and 15% of CP replacing ratio. Generally, when the amount of powders increases, the air content increases. In this study, there was too much quantity of particles, and the mortar was too dry condition, that caused the difficulty of air entraining.

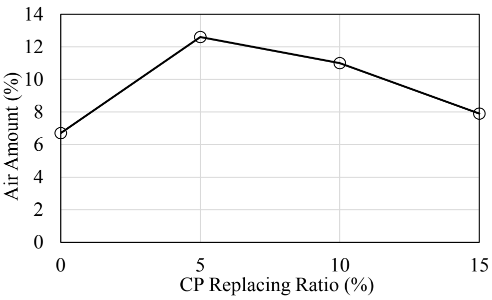

Fig. 4 Relationship between CP replacing ratio and air amount

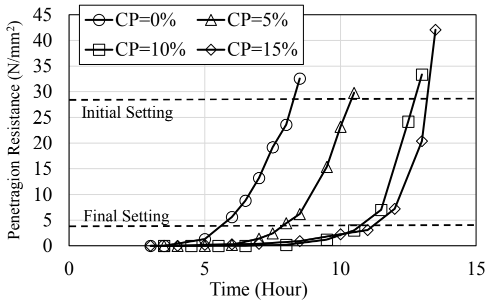

Fig. 5 Result of setting test

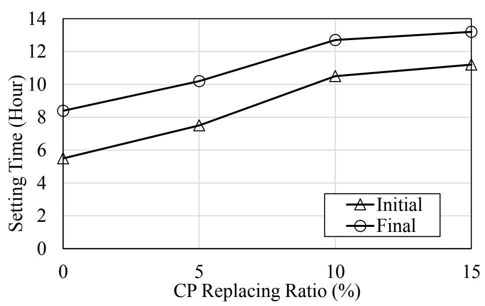

Fig. 6 Relationship between CP replacing ratio and setting time

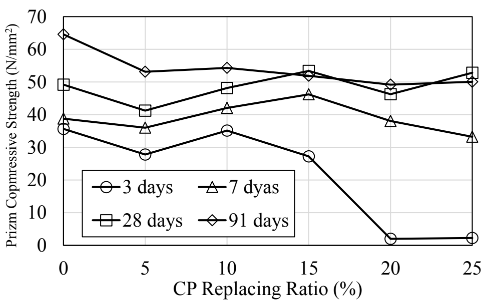

Fig. 7 Relationship between CP replacing ratio and prizm compressive strength

Figures 5 and 6 show the results of setting test. Retardation of setting of 2 hours in S5, 5 hours in S10 and 5.7 hours in S15, in comparison with the initial setting time of S0 (5.5 hours). And retardation of setting of 1.8 hours in S5, 4.3 hours in S10 and 4.8 hours in S15, in comparison with the final setting time of S0 (8.4 hours). In addition, time from initial setting time to final setting time decreased with the increase of replacing ratio, and the difference between S0 and S15 was approximately 0.9 hours. From the above, it was confirmed that CP delays the setting time of concrete.

Figure 7 shows the results of cubic compressive strength test. At 3 day material age, although the strength did not decrease with until 15% of CP replacing ratio, strength decreased remarkably with after 20% of CP replacing ratio. After 7 day material age, regardless of CP replacing ratio, it was confirmed that the strength development was approximately equal to plain mortar.

Figure 8 shows the results of bending strength test. It was able to be confirmed that the strength development was low in the case of high replacing ratio of CP in 3 day material age, and the strength development could be obtained in every replacing ratio after 7 days material age as same as compressive strength. Figure 9 shows the change of shrinkage strain with time. In all specimens in which fine aggregate was replaced with CP, the shrinkage strain increased in comparison with plain specimen. And as CP replacing ratio increased, the shrinkage strain also had a tendency to increase. In S15H2 which used shrinkage reducing agent, it could be improved to the same degree as S0, and in S15H2 it was improved to degree more than S5.

Figure 10 shows the change rate of weight with time. The change rate of weight among S10 to S25 did not have the evident difference. The performance was improved in all the specimen using the shrinkage reducing agent in comparison with plain specimen. However, CP replacing ratio and the change rate of weight did not have the proportion relations. It is a future problem to elucidate the reason. Fig.11 shows the change rate of specific strain with time. Here, the specific strain is the value that divided the shrinkage strain by the amount of evaporated water, which could be considered to be a resistant index for drying shrinkage. It is confirmed that the hardness has an influence on the length change also from this figure.

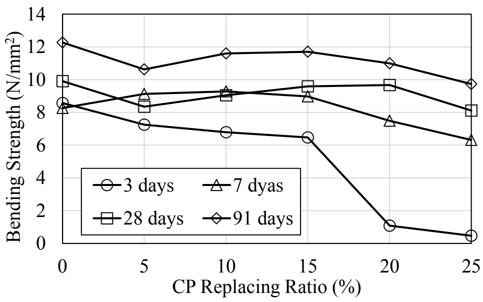

Fig. 8 Relationship between CP replacing ratio and bending strength

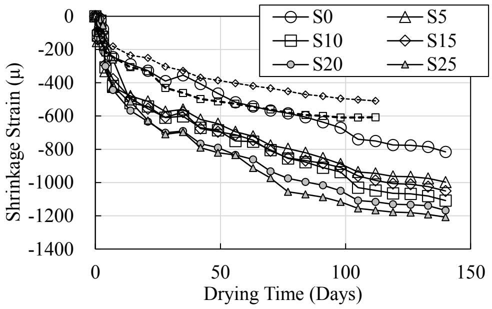

Fig. 9 Change of shrinkage strain with time

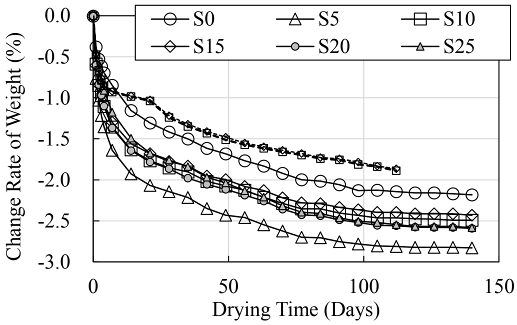

Fig. 10 Change rate of weight with time

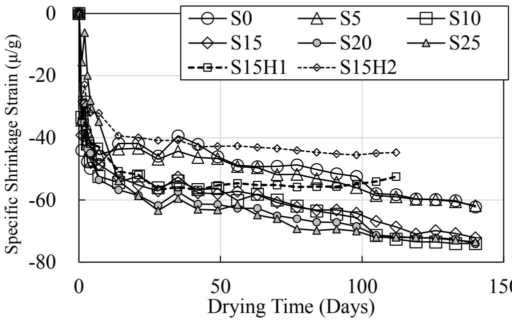

Fig. 11 Change rate of unit strain with time

CONCLUSION

1. When CP was mixed, the air content increased obviously and the bleeding decreased and the setting time delayed.
2. When CP replacing ratio is high, the strength in early age is small, but the strength does not decrease within 25% of CP replacing ratio after 7 days of curing age.
3. Without water reducing agent and so on, most adequate CP replacing ratio is 15%, considering workability altogether.
4. Shrinkage strain have a tendency to increase with CP replacing ratio, but shrinkage reducing agent is effective as measures, and the improvement effect is proportional to its mixing amount.

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