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Properties of Recycled Polymer Concrete Using Crushed Polymer Concrete as an Aggregate

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ABSTRACT

Recently polymer concrete is produced and used as precast products in various ways. As the demand for polymer concrete increases, the problem of waste treatment arises. Polymer concrete cannot be expected to be naturally decomposed due to strong resistance to corrosion. In this perspective, we need to research on recycling polymer concrete waste. Therefore, this study aims at reducing environmental burden by recycling aggregate gained from smashing bad polymer concrete products in producing polymer concrete. The experiments in this study include compressive, flexural, and splitting tensile strength, elasticity rank, and Poisson ratio. The results of these experiments were compared with the existing results of experiments on polymer concrete. The results showed changes within the range of significance level 1% so it is confirmed that it is sufficiently worthy to recycle.

INTRODUCTION

Polymer concrete and mortar has higher compressive, flexural, and splitting tensile strength compared to general cement concrete and mortar and is excellent in durability including chemical resistance and freezing and thawing resistance. However, the expensive price of resin has hindered application of polymer concrete to buildings. Nevertheless, in order to solve such problems of binding materials of polymer concrete, there have been on-going studies on replacement of resin with recycled waste plastic [Rebeiz 1994, Jo 2006]. Currently, polymer concrete is widely used for manufacturing products for electricity and communication facility, water supply, agricultural irrigation facilities [Yeon 2007, Ohama 2007, Fowler 2007]. *Likewise, as the range of application of polymer concrete is broad and the demand for the concrete increases, the amount of production also rises whereas the treatment of waste occurred additionally to manufacturing products becomes a big problem.* Polymer concrete is difficult to expect natural degradation because of strong resistance on corrosion, and it also costs a lot to treat as waste. From this perspective, it is urgent to plan measures to recycle waste polymer concrete. Therefore, this study attempts to use smashed polymer concrete and mortar as coarse aggregate for polymer concrete in order to examine the possibility of recycling of waste polymer concrete and mortar created additionally in producing products in a factory. In addition, by differing the granularity of coarse aggregate, testing objects were manufactured and since this study identified such characteristics experimentally, it reports the results here.

MATERIALS AND METHOD

Used materials.

In this study, unsaturated polyester resin is used as a binding material and is the ortho type added with hardening accelerator in a series of cobalt. In addition, for improvement of the process, low hardening and durability, methyl methacrylate (MMA) is used and a mixture of 70 mass % of unsaturated polyester resin and 30 mass % of MMA monomer is used.

On the other hand, since unsaturated polyester (UP) resin causes contraction when hardening, shrinkage reducing admixtures that thermoplastic polystyrene is melted in styrene monomer is used. Additionally, in order to control hardening reaction of unsaturated polyester resin and working life, methyl ethyl ketone peroxide and dimethylaniline were added. Physical features of UP resin, MMA monomer and shrinkage reducing admixtures used in this study are illustrated in the following Table 1.

Filling materials are used to reduce the amount of using resin per volume unit by recharging an aperture between binding materials and aggregates. In this study, by considering working effects of polymer concrete, as a filling material, ground calcium carbonate is used, which was the size of a particle 1-30 μm, the degree of powder 2500-3000 cm^2/g, and moisture contained below 0.1%. The physical and chemical features of the ground calcium carbonate used in this experiment is shown in the following Table 2.

Table 1. Physical Properties of Materials for Binder System

UP resin			
Density (g/cm^3, 20°C)	Viscosity (mPa·s, 20°C)	Acid value	Styrene content (%)
1.13	300	20.0	40.0
MMA monomer			
Density (g/cm^3, 20°C)	Viscosity (mPa·s, 20°C)	Molecular weight (g/mol)	Appearance
0.94	0.56	100	Transparent
Shrinkage-reducing agent			
Density (g/cm^3, 20°C)	Viscosity (mPa·s, 20°C)	Nonvolatile content (%)	Appearance
1.11	3100 - 4100	34 - 38	Transparent

Table 2. Physical and Chemical Properties of Heavy Calcium Carbonate

Physical properties					
Density (g/cc)	Absorption (cc/g)	Water content (%)	pH	Mean grain size (μm)	Retained percentage of 325 mesh sieve
0.75	0.20	<0.1	8.8	13	0.03
Chemical component					
CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	Ignition loss
53.7	0.25	0.09	2.23	0.66	42.4

Table 3. Grain Size of Coarse Aggregates

Types	Kinds of aggregate	Symbol	Size (mm)
Normal polymer concrete	Crushed coarse aggregate	CA(9-13)	5.0-10.0
Recycled polymer concrete	Crushed waste polymer concrete	PC(5-9)	5.0-9.0
		PC(9-13)	9.0-13.0
	Crushed waste polymer mortar	PM(5-9)	5.0-9.0
		PM(9-13)	9.0-13.0

Aggregate used in the polymer concrete as coarse aggregate are silica rubble, polymer concrete smash, and polymer mortar smash aggregates and for fine aggregate, silica is used. When aggregate absorbs water, it weakens the binding power between the binding materials and aggregates so that the strength of polymer concrete is reduced. As a result, aggregates require to be dried until the percentage of water content becomes below 0.25 %. Therefore, aggregates were used after drying in 110±5 ℃ for 24 hours and freezing to make its percentage of water content 0.1%. However, polymer concrete revival aggregates did not undergo heating dry because it is very disadvantaged in heating dry and its water absorption rate is significantly low. Granularity by aggregate type used in manufacturing polymer concrete is as following Table 3 and Photo 1 shows the actual condition of these aggregate.

Methods of Experiment.

The combination ratio of polymer concrete is illustrated in Table 3 and according to KS F 2419 (Standard test method making polyester resin concrete specimens for strength test), specimens were produced. The specimens used in the experiment are five types in total, and the types of coarse aggregate and granularity is a variable. The items of measurement are workability, setting shrinkage, compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, and Poisson's ratio, and the experiments were conducted according to KS F 2402 (Method of test for slump of concrete), KS F 2481(Method of test for compressive strength of polyester resin concrete), KS F 2482(Method of test for flexural strength of polyester resin concrete), KS F 2480 (Method of test for splitting tensile strength of polyester resin concrete), and KS F 2438(Testing method for static modulus of elasticity and Poisson's ratio in compression of cylindrical concrete specimens).

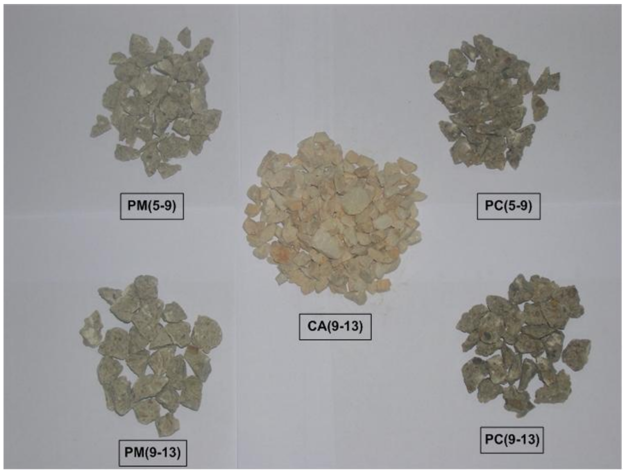

Photo 1. Shape of Aggregate

Table 3. Mix Proportion for Polymer Concrete

Mix proportions (%) (mass fraction)					Binder content (%) (mass fraction)	Binder to filler ratio (mass fraction)
Binder	Filler	Coarse aggregate	Fine aggregate (≤5 mm)	Fine aggregate (≤0.8 mm)		
UP-MMA system	Ground calcium carbonate	Crushed aggregate (Five types)	Crushed sand	Crushed sand		
9.0	18.0	43.8	14.6	14.6	9.0	1.0 : 2.0

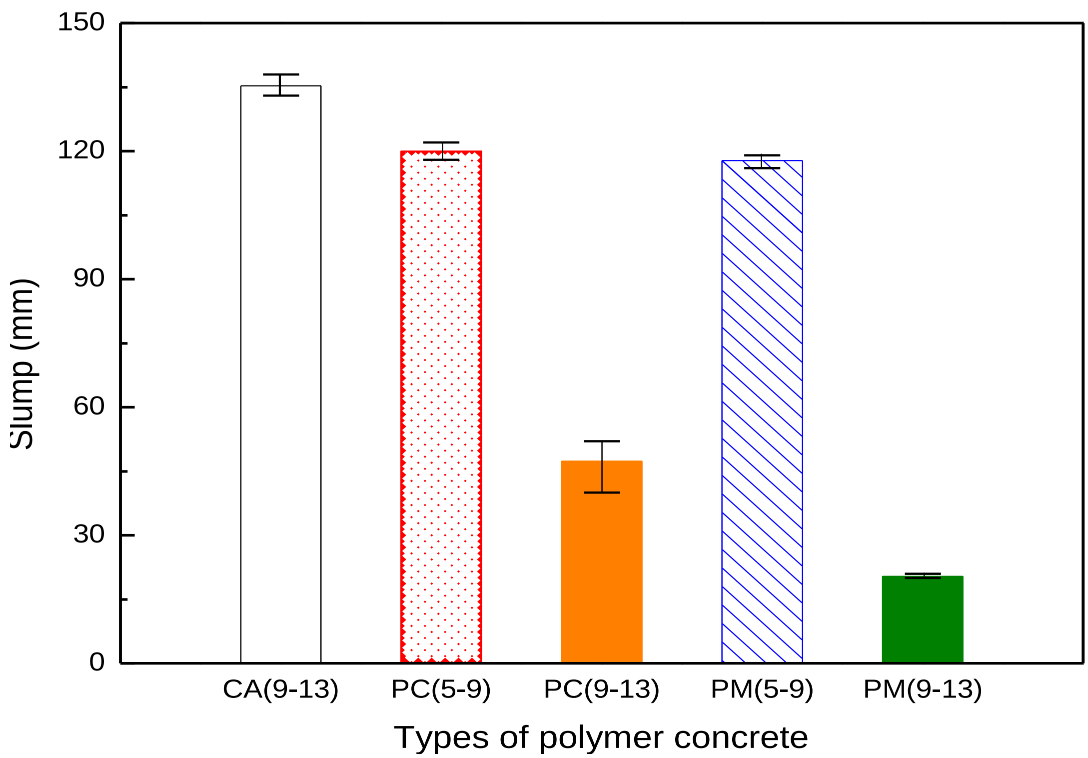

Fig. 1. Comparison of Slump

RESULTS AND DISCUSSION

Workability.

The workability of polymer concrete is largely affected by mainly the viscosity and amount of the main element of binding material, which is fluid polymer. In addition, shape and granularity of aggregate is another large influence on the workability [Yeon 2003]. In regard to the value of slump of polymer concrete that is used in this experiment, normal polymer concrete showed the highest value; regardless of the type of recycled polymer concrete, the lower granularity is, the higher the value is. This shows the same characteristic as the normal cement concrete, which means that when the granularity of aggregate is bigger, the workability becomes bad. Since the aggregate for recycled polymer concrete has sharp corners, even if the granularity is the same, it is considered that workability is still bad.

Setting shrinkage.

Setting shrinkage is regarded as an important characteristic because it affects strength and durability of polymer concrete. In addition, in the case of polymer concrete, if the added amount of shrinkage reducing admixtures increases, the amount of shrinkage reduces but it causes reduction of strength and is less economical [Ohama 1979, Demura 1983]. Therefore, in this study, setting shrinkage was measured by using the amount of shrinkage reducing admixtures of 0, 5, and 10 mass % by using Ohama-Demura method; the size of the specimen was 7×7×32 cm. When measuring, the temperature was 25±2 ℃, and the change of its length was measured after adding hardener with 10 minute intervals in the first three hours and 30 minute intervals in the next 21 hours.

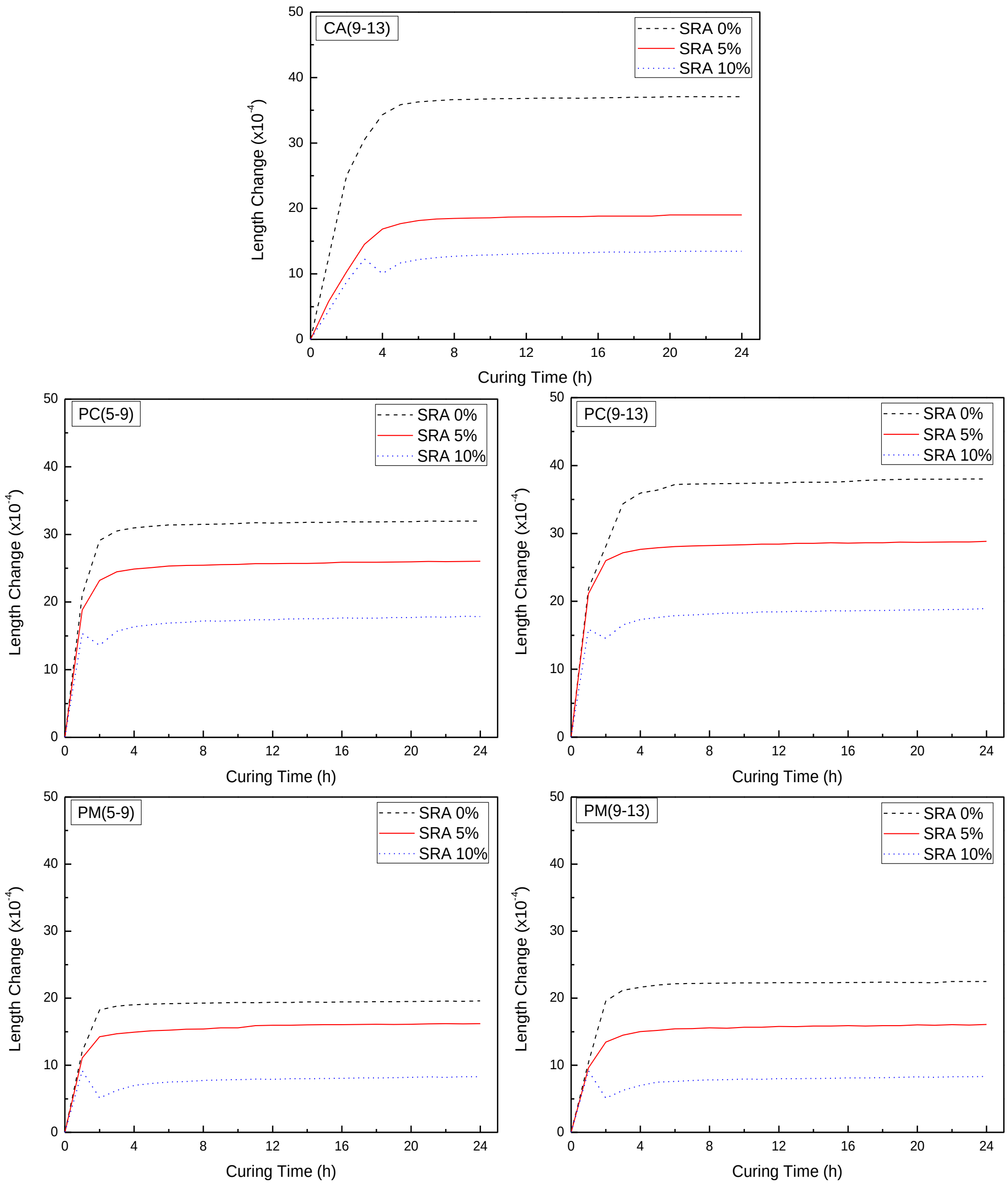

Fig. 2. Setting Shrinkage

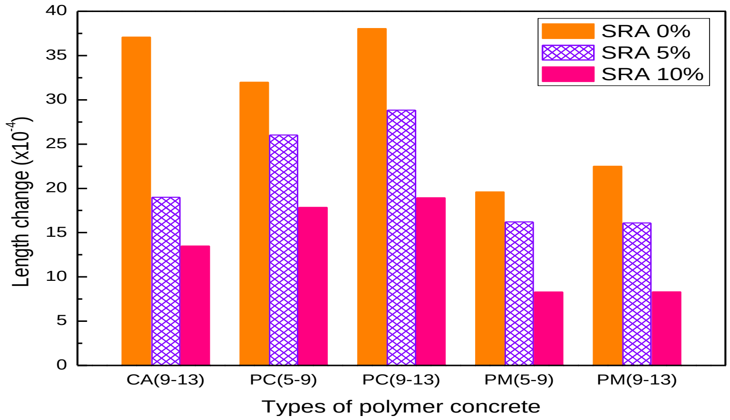

Fig. 3. Comparison of Setting Shrinkage

The result of the experiment on setting shrinkage is shown in Figure 2 and Figure 3. They illustrate the amount of shrinkage when the amount of shrinkage reducing admixtures was 0, 5, and 10% mass, respectively. When CA (9-13) is the standard, length change was significant with 32% in the case of PC(5-9) and 40% in the case of PC(9-13), and PM(5-9) and PM(9-13) showed a relatively low value of 35%. The cause of such results is assumed that in the case of waste polymer mortar, unified hardened resin occupied large portion of granularity of aggregates shaped in an unified form.

Strength.

The results of experiments on compressive strength of polymer concrete is illustrated in Figure 4. As seen in the results, the compressive strength is 88-90 MPa in CA(9-13), 79-89 MPa in PC(5-9), 86-87 MPa in PC(9-13), 92-95 MPa in PM(5-9), and 83-88 MPa in PM(9-13). There was not a big difference in strength between normal polymer concrete and recycled polymer concrete. Here, PC(5-9) showed slightly low compressive strength and PM(5-9) slightly higher, but this is a change within the 1% of significant level [$F(4, 10; 0.01) = 5.99 > 3.72$].

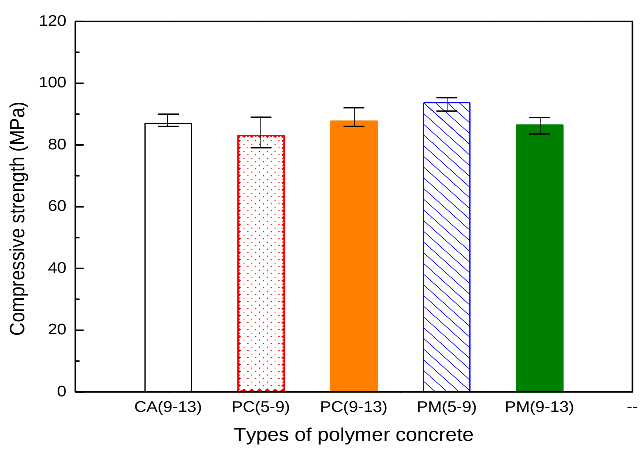

Fig. 4. Comparison of Compressive Strength

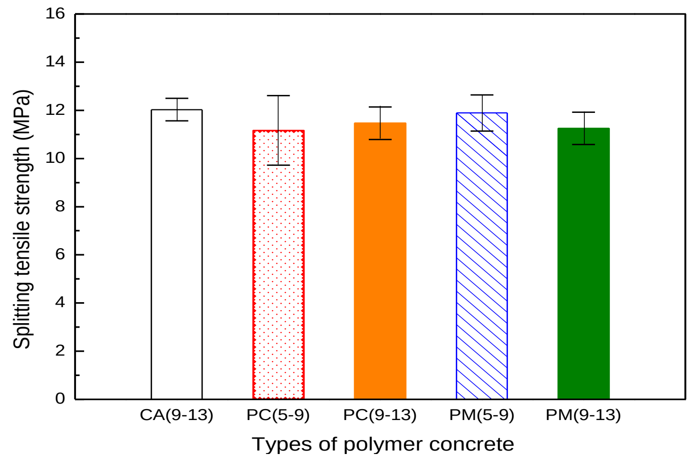

Fig. 5. Comparison of Splitting Tensile Strength

Meanwhile, coarse aggregate with waste polymer mortar smash tends to have slightly higher compressive strength than the aggregate using waste polymer concrete smash. This is assumed because waste polymer mortar aggregate is finer and has better attachment power than polymer concrete aggregate.

Splitting tensile strength is shown in Figure 5. In terms of splitting tensile strength, 11.6-12.5 MPa in CA(9-13), 9.7-12.6 MPa in PC(5-9), 10.8-12.1 MPa in PC(9-13), 11.1-12.6 MPa in PM(5-9), 10.6-11.9 MPa in PM(9-13), and there were slightly significant difference between the minimum strength and maximum strength. However, that difference is within 1% of the significant level [$F(4, 10 ; 0.01) = 5.99 > 0.59$], which shows that splitting tensile strength is not significantly lower than normal polymer concrete.

The result of experiment on flexural strength by the type of polymer concrete is illustrated in Figure 6. In this result, the flexural strength of recycled polymer concrete tends to be slightly low compared to that of normal polymer concrete, but it also appeared within 1% of significant level [$F(4, 10 ; 0.01) = 5.99 > 1.18$]. In terms of practical use, it does not have any problem.

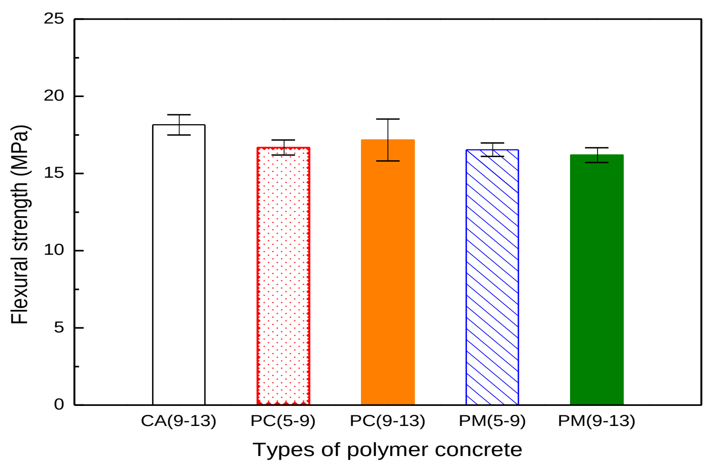

Fig. 6. Comparison of Flexural Strength

Figures 7, 8, and 9 are a comparison of strength value between normal polymer concrete and recycled polymer concrete. Compressive, splitting tensile and flexural strength did not show a significant difference compared to normal polymer concrete using crushed aggregate. This means that the reuse of recycled polymer concrete does not have any problem.

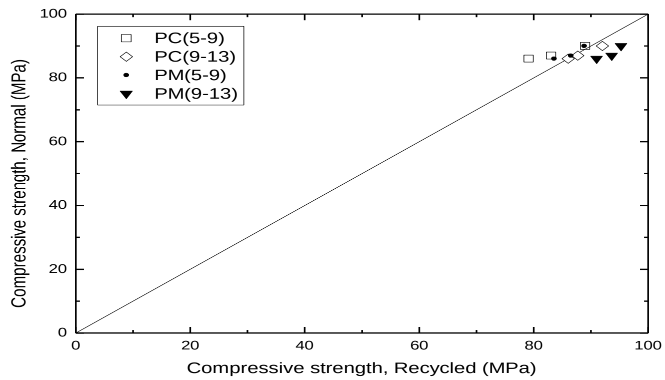

Fig. 7. Compressive Strengths of Normal versus Recycled Polymer Concrete

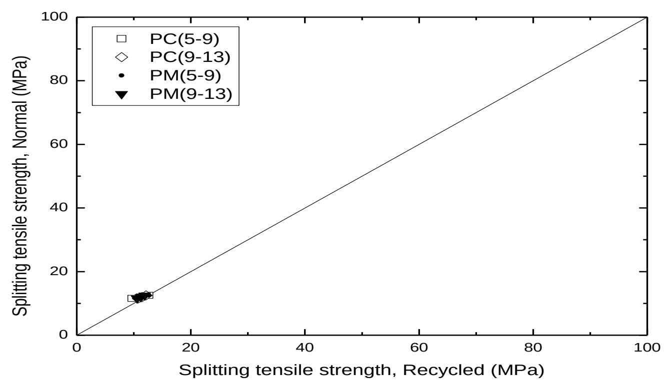

Fig. 8. Splitting Tensile Strengths of Normal versus Recycled Polymer Concrete

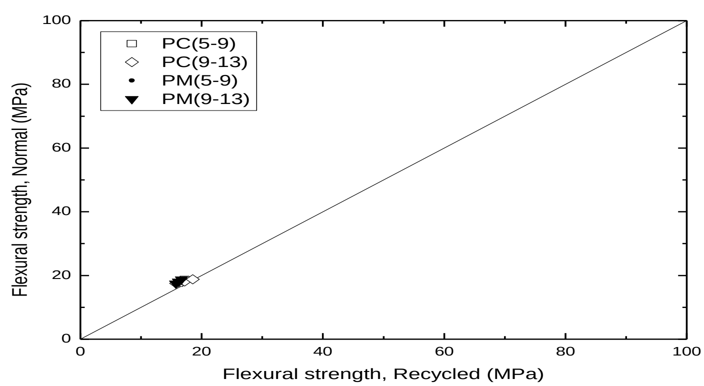

Fig. 9. Flexural Strengths of Normal versus Recycled Polymer Concrete

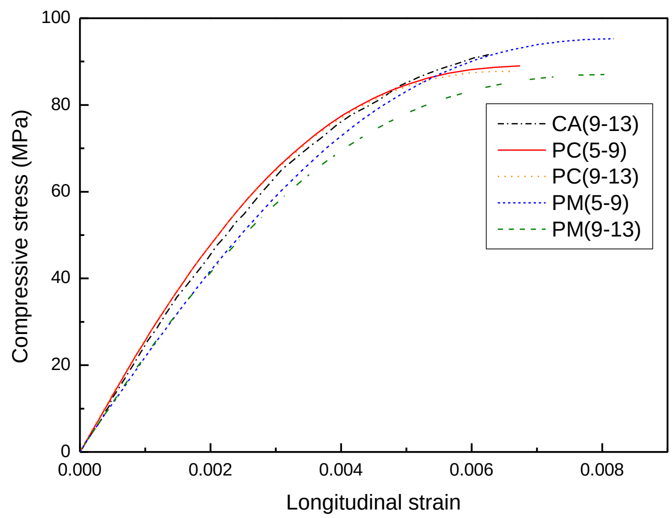

Fig. 10. Compressive Stress-Strain Curves

Modulus of elasticity and Poisson's ratio.

Figure 10 shows a curve of compressive stress-modification ratio. The modulus of elasticity is 24.11 GPa in CA(9-13) and PC(5-9) and PC(9-13) is similar with 24.15-25.07 GPa, while PM(5-9) and PM(9-13) showed slightly low values, which were 21.17 GPa and around 19.22 GPa, respectively.

The compressive and modification ratio until destroying was the highest in polymer concrete using waste polymer mortar with 0.008. Such result is because waste polymer mortar aggregate has low strength compared to that of normal crushed aggregate.

Regardless of types of aggregate, Poisson's ratio appears to be higher in aggregate with 5-9 mm small granularity as 0.24-0.26, and the Poisson's ratio of aggregate with 9-13 mm was the same as the normal polymer concrete with 0.22 [Okada 1981].

CONCLUSIONS

This study identified the possibility of recycling waste polymer concrete (mortar) generated additionally in producing products in a factory as aggregate and the results are as follows;

1. Regardless of the types of recycled polymer concrete, the smaller their granularity is the higher the value of slump is, and because of formation of sharp corners when smashing waste polymer concrete and aggregate, even if they have small granularity, in terms of workability, it appeared that they are disadvantaged.

2. On the basis of normal polymer concrete, the amount of shrinkage was high in PC(5-9) with 32% and PC(9-13) with 40% while in the case of PM(5-9) and PM(9-13), it was about 35% lower value. This is because in the case of waste polymer mortar, smashed aggregate particles were mostly occupied with hardened resin.

3. As a result of comparison and analysis of 84-93 MPa of the compressive strength of normal polymer concrete and recycled polymer concrete, 11-12 MPa of splitting tensile

strength and 16-18 MPa of flexural strength, it showed changes within 1% significance level.

4. In terms of modulus of elasticity, in the case of normal polymer concrete, it was 24.11 GPa, and in the case of waste polymer concrete rubble, it was 24.15-25.07 GPa, which was similar to the former. However, in the case of using waste polymer mortar rubble, it was 19.22-21.17 GPa, which was slightly lower. Regardless of the type of aggregate, in terms of Poisson's ratio, in the case of aggregate with small granularity of 5-9 mm, it was 0.24-0.26, which was high and 9-13 mm aggregate was 0.22, which was similar to that of normal polymer concrete.

5. Although this was limited experimental research, the results showed that crushed waste polymer concrete can be recycled for producing aggregate.

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