

Evaluation on the Fluidity and Strength of Recycled Aggregate Concrete with High Quality Fly Ash as Industrial Byproduct

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Abstract: This study aims to improve the mechanical function of recycled aggregate concrete that applied high-quality fly ash, which presents relatively stable quality by maintaining loss ignition below 1% by eliminating combustible carbon and obtained following results. As a result of the test according to the changes in high-quality fly ash ratio, as the ratio of high-quality fly ash increased, the liquidity enhanced. From the results of strength development of recycled aggregate concrete, compressive strength increased with increasing age and, when high quality fly ash is added, the Pozzolan reaction indicates a high strength increase even after 91 days of age. On the other hand, the reason why compressive strength is reduced due to replacement of recycled aggregates is that the properties of the recycled aggregate itself are lower than those of the natural aggregate, and it is judged that destruction occurs first at the surface prior to destruction of aggregates or mortar. Compressive strength according to the replacement rate of high quality fly ash tends to increase almost linearly. If high quality fly ash is used in recycled aggregate concrete, it is deemed that up to 28 days, the filling effect by the addition of high quality fly ash and the strength enhancement by the Pozzolan reaction is also exerted in 91 days.

Keywords: Loss of Ignition, High Quality Fly Ash, Recycled Aggregate, Mechanical Property, Rheology

1. Introduction

Waste concrete, a lump of concrete generated by dismantling or renovating works, has increased over the years, and interest and research on recycling the recycled aggregate that currently occupies most of the waste concrete is actively underway. Recycled aggregate has received much attention in terms of its function as an alternative aggregate, resource recycling and environmental protection, but its use is limited due to the limitations of the aggregate itself. However, most recycled aggregates are less than 2.0 densities and have an absorption rate of more than 10% and cannot be used in concrete structures in practice without further treatment of the performance enhancement of the properties. For this reason, many research and methods to improve the quality of recycled

aggregate have been proposed, but research and methods that satisfy both quality and economic feasibility are still lacking. In the case of concrete with recycled aggregate, it is necessary to secure enough data on not only the strength but also the durability degradation, i.e. shrinkage, freeze and alkali aggregate reactions. [1-5]

Generally, fly ash is an industrial byproduct that is emitted from thermal power plants and particles are spherical particles, so improvement of liquidity and material separation resistance is expected when mixed with concrete. However, it is also pointed out the disadvantage of managing the properties of concrete as the anthracite contained in the fly ash shows the variation in air mass since it adsorbs AE agent, etc. Against this backdrop, high-quality carbon-free fly ash, which has recently reduced its anthracite to less than 1 percent, has been developed and is

being studied. [6-11]

Previous research has shown that the mechanical performance of concrete using recycled aggregate can be supplemented and improved by the pozzolan reaction using a pozzolanic material, and the use of fly ash as a pozzolanic material can be mentioned representative. Fly ash improves liquidity and resistance of material separation when mixed with concrete, however, it is also pointed out that the unburned coal included in the fly ash shows a change in air mass because it adsorbs AE agent, and thus makes it difficult to control the quality of concrete. [12-14]

Against this background, high quality fly ash (HqFA) has been developed and researched and applied recently, and HqFA provides relatively stable quality from the decrease of ignition loss by removing the unburned coal lower than 1%. Therefore, the purpose of this study is to improve the mechanical performance of recycled aggregate concrete by using high quality fly ash. [15-17]

2. Used Materials and Mixture

2.1. Main Used Materials

The recycled aggregate applied in this study is a low quality aggregate obtained by first treating the lump of waste concrete generated during the dismantling of the concrete structure with crushers. Currently, recycled aggregates are of low quality and high quality aggregate obtained by performing high level processing such as secondary and tertiary processing. [8]

However, if a higher order is carried out, the quality of the aggregate itself is improved, but the purpose of using the basic recycled aggregate is halved due to the deterioration of a lot of energy and economics in the manufacturing process. For this reason, in this study, it was planned to use low grade recycled aggregate obtained from simple primary treatment. Table 1 shows the properties of coarse aggregates used in this study. One type of natural aggregate and three types of recycled aggregate were used, and recycled aggregate was used separately according to the criteria of JIS A 5021. [12]

Table 1. Properties of used coarse aggregates.

Kind	Notation	Rank	Density (g/cm ³)	Absorption (%)	Remark
Natural aggregate	NA	-	2.67	0.5	G _{max} = 25mm
	RA1	H	2.30	3.5	JIS A 5021
Recycled aggregate	RA2	M	2.25	5.0	JIS A 5021
	RA3	L	2.22	6.8	JIS A 5021

Table 2 shows the properties of other materials used in this study. Fly ash used high quality and general fly-ash to consider the effects of different types. Cement is usually used in ordinary portland cement, and admixture used a polyacrylic type AE reducing agent.

Table 2. Properties of used materials.

Materials	Kinds	Properties
Fly ash	High quality	Loss of ignition: 0.5% Specific area:4,300cm ² /g
	Normal	Loss of ignition: 2.5% Specific area:3,800cm ² /g
Cement	OPC	Density: 3.15g/cm ³
Fine aggregate	River sand	Density: 2.65g/cm ³ Absorption: 1.85% F. M: 2.99
AE agent	Superplasticizer (Polycarbon acid)	Density: 1.1g/cm ³

2.2. Mix

The combination and details of the test specimens produced in this study are shown in Table 3. There are four types of aggregate used in the test, three types of cyclic aggregate and one type of general aggregate.

The replacement rate of recycled aggregates was considered at 30 percent, the standard replacement rate proposed in the specification. And these 30% and 50% was used which are known to be the maximum number of mixed uses in existing indoor tests. The mixing rate of high quality fly ash changed to 0%, 10%, and 20%, considering existing research results.

From this, concrete was constructed according to the ratio of natural aggregate, type of recycled aggregate, and high quality fly ash, and physical and mechanical properties were evaluated then. Meanwhile, the W/B ratio of the manufactured concrete was constant at 50 percent, referring to the preceding study results. and the total numbers of test

specimens are 7 types and 21 kinds. The design strength of concrete was 27MPa, the target slump was 150±10mm, and the target air content was 4.5±0.5%.

3. Experimental Results and Considerations

3.1. Liquidity Evaluation

1) Influence of fly ash types

Firstly, a total of seven types of test specimen were manufactured using each of the three types of plain, high quality fly ash, and general fly ash to examine the effects of each type of fly ash, and the measured results of the slump test are shown in Table 4. The W/B ratio and the exchange rate of fly ash are identical to 50% and 20%, considering the general arrangement of concrete specimens.

From the results, regardless of the type of fly ash, it was found that the mixing of fly ash compared to the plain specimen was

effective in the fluidity of the concrete. Fly ash is a round sphere of particle structure, and this is believed to cause ball-bearing action to increase fluidity between particle structures. The results showed that the plain concrete had a slump of 155mm.

For the specimen of HqFA1, it was most effective, with an approximate improvement of 1.31 times the fluidity at 197mm. In the case of specimen, NoFA3, the lowest value was shown, but the introduction of all fly ash was effective, with an improvement of around 20%. However, by type of fly ash, high quality fly ash was more effective in improving liquidity than ordinary fly ash, and this is judged to be related to the quality of the manufacturing process. This means that high quality fly ash has a lower ignition loss and a higher density than normal fly ash. It is believed that the use of

high-quality fly ash with low ignition loss reduces the adsorption of AE, and that normal fly ash with low density increases the volume of concrete molecules. For this reason, this effect is believed to be due to the increased surface area of water-absorbing molecules.

2) Influence of the mixing ratio of high quality fly ash

In this study, among the factors that may appear in the fresh concrete considering liquidity in the conditions under which the use of fly ash can occur, change of slump is measured and the results are shown in Figure 1-4.

From the results, the slump value of concrete using recycled aggregate was reduced compared to that of concrete using natural aggregate, and the higher the replacement rate of high quality fly ash, the higher the liquidity.

Table 3. Notation and combination of specimens.

Kinds	Notation	W/B (%)	Replacement ratio of R·A (%)	Replacement ratio of HqFA (%)
NAC : Natural Aggregate Only	NAC-0-0			0
	NAC-0-10	50	0	10
	NAC-0-20			20
	RAC1-30-0			0
	RAC1-30-10	50	30	10
	RAC1-30-20			20
	RAC1-50-0			0
	RAC1-50-10	50	50	10
	RAC1-50-20			20
	RAC2-30-0			0
RAC : Natural Aggregate + Recycled Aggregate	RAC2-30-10	50	30	10
	RAC2-30-20			20
	RAC2-50-0			0
	RAC2-50-10	50	50	10
	RAC2-50-20			20
	RAC3-30-0			0
	RAC3-30-10	50	30	10
	RAC3-30-20			20
	RAC3-50-0			0
	RAC3-50-10	50	50	10
RAC3-50-20			20	

Table 4. Results of slump test according to the kinds of fly ash.

Kinds	Specimen	Slump (mm)
Plain	PCFA-0	155
	HqFA1	197
High quality FA	HqFA2	193
	HqFA3	195
	NoFA1	192
Normal FA	NoFA2	190
	NoFA3	188

For natural aggregate concrete, compared to recycled aggregate concrete, increased liquidity due to the addition of high quality fly ash was relatively low, however, the results were enhanced by the increase in the mixing rate.

For recycled aggregate Concrete, the higher the absorption rate of recycled aggregate, the less the fluidity, and the higher the replacement rate of recycled aggregate, the greater the

reduction rate. Comparison of maximum slump reduction without high quality fly ash compared to natural aggregate concrete specimen, NAC-0 and recycled aggregate concrete test RAC3-50-0, about 40 percent of the slump was different.

For the specimen, RAC3-50-20 with 20% of high quality fly ash added to the specimen, RAC3-50-0, the value of the slump is approximately equivalent to the reference plane test specimen. Therefore, the use of high quality fly ash is effectively determined to prevent the liquid degradation of low quality recycled aggregate concrete.

Meanwhile, the measured air content in the specimen ranges from 4.3 to 5.3%, and the target air content is satisfied in all the specimens.

3.2. Compressive Strength Results

1) Strength Development of Recycled Aggregate Concrete

The results of the compressive strength tests according to

each age tested in this study are shown in Figure 5 to Figure 7. The specimens for compressive strength manufactured according to target slumps, and only changes

in the replacement rate of recycled aggregates and the mixing rate of high quality fly ash were adjusted to be variables.

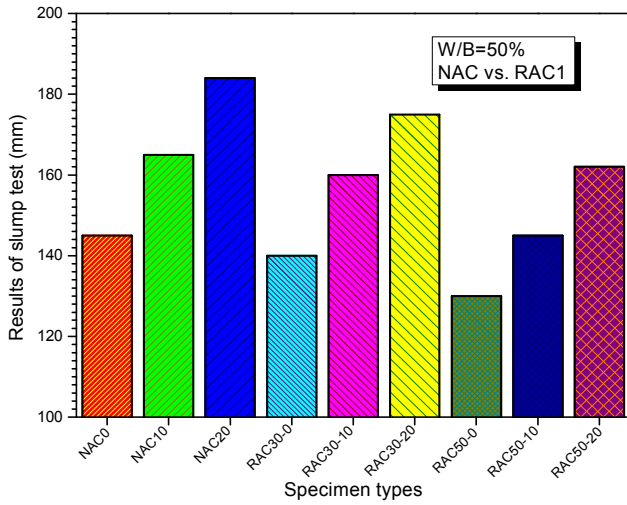


Figure 1. Results of slump test (NAC vs. RAC1).

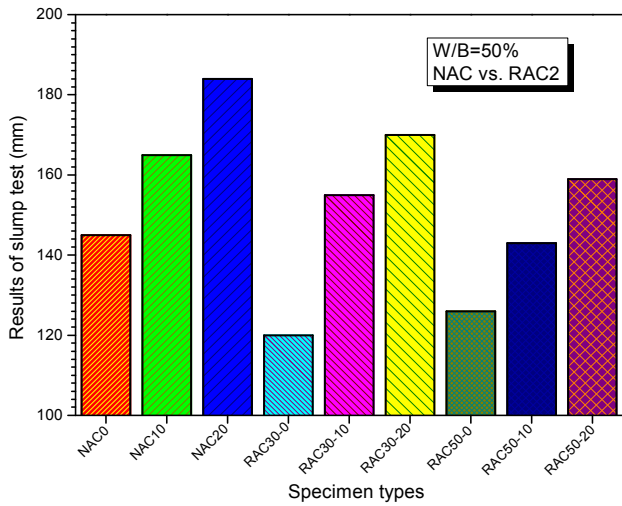


Figure 2. Results of slump test (NAC vs. RAC2).

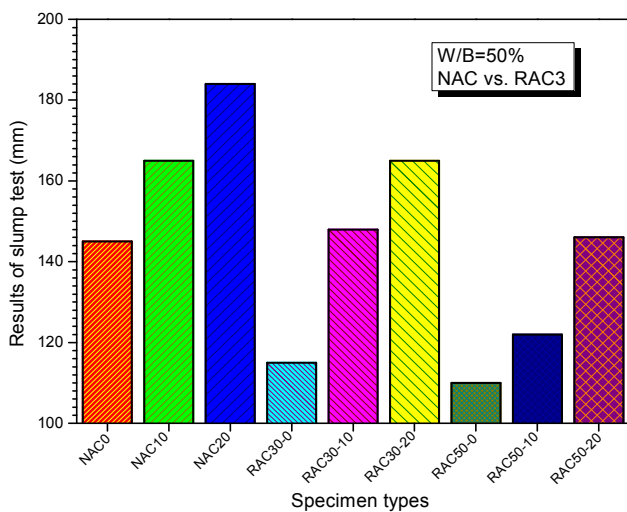


Figure 3. Results of slump test (NAC vs. RAC3).

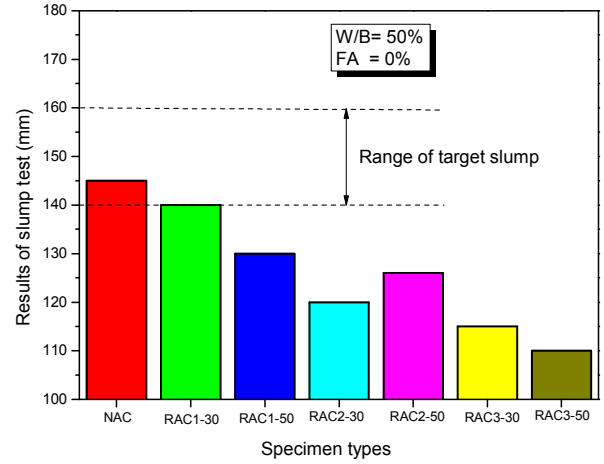


Figure 4. Comparison results of slump test for null-additive of HqFA.

From the results, the compressive strength of all specimens increased with increasing age. If high quality fly ash is added, in a pozzolan reaction, the strength has increased significantly even after 91 days. If high quality fly ash is mixed, the compressive strength for 28 days was about 80% to 90% of the plain concrete, but on the 91 days, the strength increased 1.15 times.

For recycled aggregate Concrete, depending on the quality of the recycled aggregate, compared to the criteria specimen, NAC-0-0, which is a natural aggregate concrete, it was in the range of 50% to 80% on the 28 days, but it was approximately 65% to 100% on the 91 days, therefore the effects of high quality fly ash have been identified.

On the other hand, the reason why compressive strength is reduced due to replacement rate of recycled aggregates is that the properties of the recycled aggregate itself are lower than those of the natural aggregate, rather, the adhesion of the recycled aggregate interface is inferior to that of the natural aggregate, it is judged that destruction occurs first in the surface. before the destruction of aggregates or mortar.

2) Effect on the quality of recycled aggregate

All the recycled aggregate used in this study are of three types, and this product is selected according to the quality standards of recycled aggregate. Generally, several factors are mentioned that affect the quality of aggregates, but the most important factors are specific gravity and absorption rate. Recycled aggregate has a lower specific gravity and a significantly higher absorption rate than natural aggregates, making it unsuitable as a structural material. For this study, while natural aggregates have a specific gravity of 2.67 and absorbance of 0.5%, recycled aggregates have a specific gravity of 2.2 to 2.3, and absorbency of 4 to 7 percent.

From the results of compressive strength, at 28 days, compared to the strength of natural aggregate concrete, the strength of recycled aggregate concrete, which has been replaced by 30% with recycled aggregate concrete, was found to be around 80% of the strength of natural aggregate concrete and which has been replaced by 50% with recycled

aggregate concrete, was found to be around 50% of the strength of natural aggregate concrete. The compressive strength test shows that the strength reduction rates shown in Figure 5 through Figure 7 are almost linear. Therefore, concrete that utilizes recycled aggregate needs to improve its quality, such as its compressive strength, and the use of high quality fly ash suggested in this study is considered as a method of improving its compressive strength after 91 days.

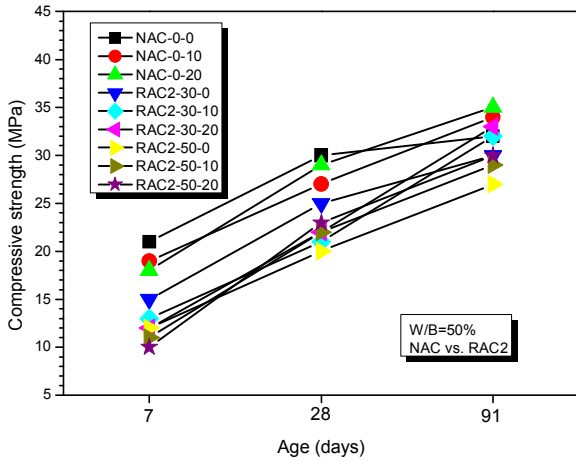


Figure 5. Results of compressive strength (NAC vs. RAC1).

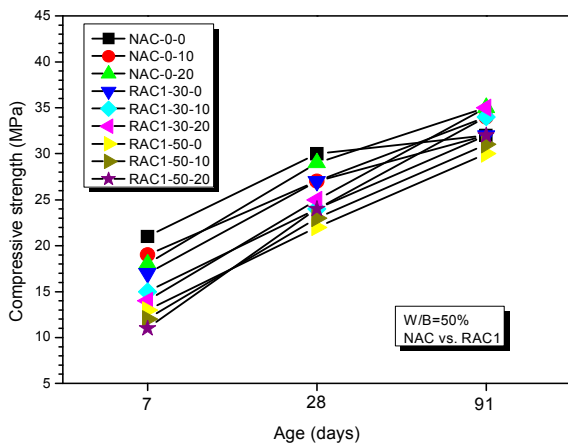


Figure 6. Results of compressive strength (NAC vs. RAC2).

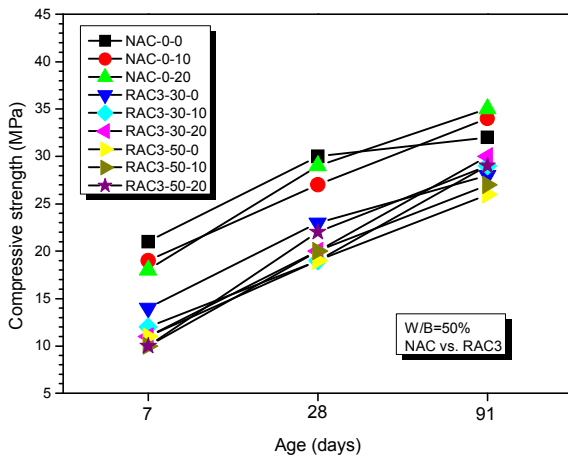


Figure 7. Results of compressive strength (NAC vs. RAC3).

3) Effect on mixing of high quality fly ash

The effect of using high quality fly ash for recycled aggregate concrete was showed Figure 8 to Figure10. From the results, compressive strength due to increase in replacement rate of high quality fly ash tends to increase almost linearly. The trend also stood out according to age. The compressive strength for 91 days, when compared with the results of plain concrete, concrete with 10% of high quality fly ash improved its strength by up to 20%, while concrete with 20% of high quality fly ash improved its strength by up to 35 percent.

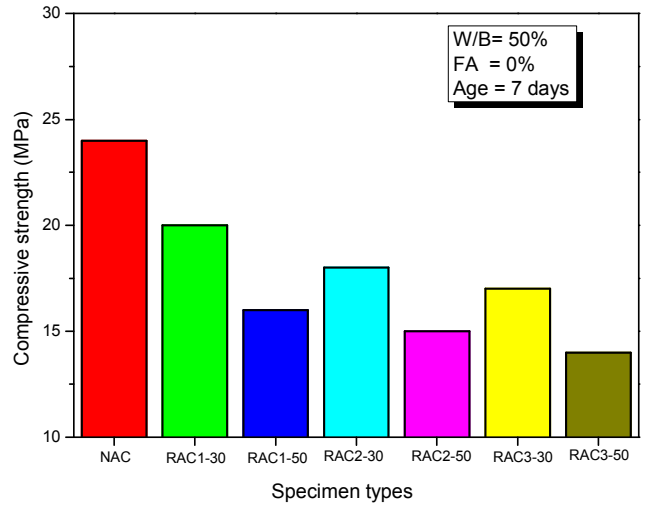


Figure 8. Comparison results of compressive strength for null-additive of HqFA (age: 7 days).

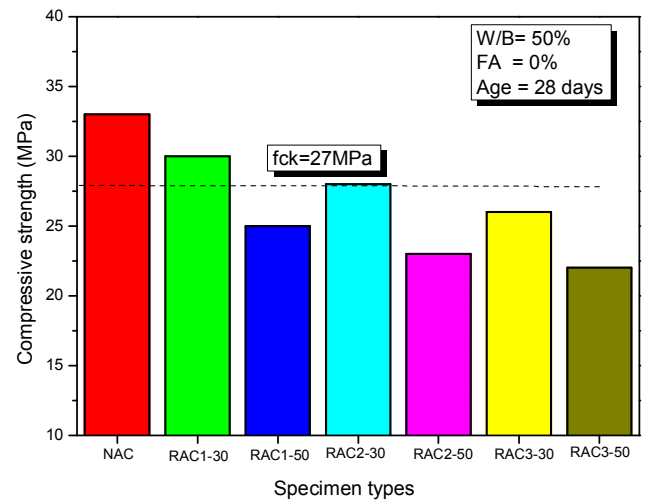


Figure 9. Comparison results of compressive strength for null-additive of HqFA (age: 28 days).

Compared the compressive strength of concrete with 20% of high quality fly ash without mixing high quality fly ash, the compressive strength ratio was up to about 100%, from this, the increase in compressive strength due to the introduction of high quality fly ash was confirmed. The growth rate was also the highest at 91 days. The growth rate of concrete using natural aggregate was around 20%, and concrete with recycled aggregate increased by about 10% on

average. So, from the above results, if high quality fly ash is used in recycled aggregate concrete, the filling effect of high quality fly ash addition is effective up to 28 days. In addition to this, in 91 days, it is judged that the strength enhancement effect caused by the Pozzolan reaction.

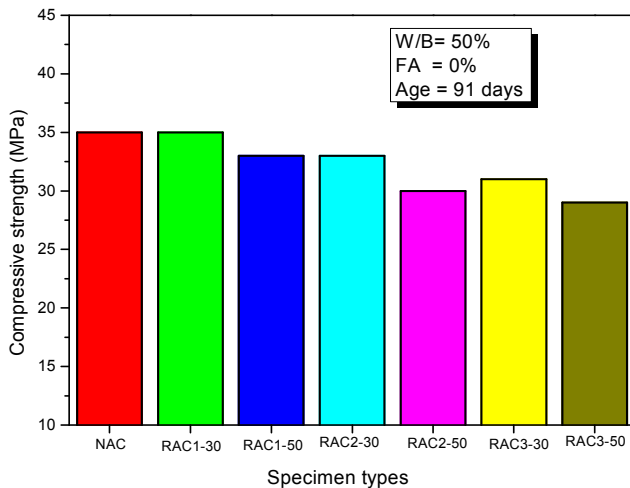


Figure 10. Comparison results of compressive strength for null-additive of HqFA (age: 91 days).

4. Conclusion

In this study, the purpose of this study was to improve the mechanical performance of recycled aggregate concrete by using high quality fly ash. Therefore, the following conclusions are obtained by evaluating the physical and mechanical properties of concrete manufactured according to changes in the mixing ratio of natural aggregate, types of recycled aggregate, and high quality fly ash.

1) After reviewing the effects of fly ash type, regardless of the type of fly ash, it was found that the mixing of fly ash is effective in the fluidity of concrete. In addition, high quality fly ash was more effective in improving liquidity than regular fly ash, which is believed to be related to the quality of the manufacturing process.

2) Results of a review on the impact of high quality fly ash, The higher the replacement rate of high quality fly ash, the better the fluidity results. In the case of recycled aggregate concrete, there was a difference of about 40% in the slump compared to plain concrete without high quality fly ash, but 20% in the case of high quality fly ash was added, the slump value was about the same as the plain concrete specimen.

3) From the results of strength development of recycled aggregate concrete, compressive strength increased with increasing age and, when high quality fly ash is added, the Pozzolan reaction indicates a high strength increase even after 91 days of age. On the other hand, the reason why compressive strength is reduced due to replacement of recycled aggregates is that the properties of the recycled aggregate itself are lower than those of the natural aggregate, and it is judged that destruction occurs first at the surface prior to destruction of aggregates or mortar.

4) Compressive strength according to the replacement rate

of high quality fly ash tends to increase almost linearly.

If high quality fly ash is used in recycled aggregate concrete, it is deemed that up to 28 days, the filling effect by the addition of high quality fly ash and the strength enhancement by the Pozzolan reaction is also exerted in 91 days.

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