

The Quality Status of Aggregate for Domestic Ready-mixed Concrete and the Effect of Aggregate Quality in Concrete

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Abstract

This research examined the effect of the quality of aggregate on concrete workability and compressive strength through an investigation into regional aggregate used in domestic ready mixed concrete plants. Through the research, it was found that aggregate for ready mixed concrete shows poor quality overall. The main factor of deterioration in the quality of the concrete is the particle size of fine aggregate and fine particle content in coarse aggregate. The quality of aggregate significantly influences concrete's workability, which is defined based on 0.08mm passage related with powder and absorption. In addition, poor aggregate quality leads to increased water content in concrete to secure workability, which is related with a decline in the compressive strength and durability of concrete.

Keywords : aggregate, quality status, fineness, water absorptance, 0.08mm passage

1. Introduction

With the exception of some special cases, any aggregate used in a ready-mixed concrete factory in Korea must satisfy both/either the criteria of KS F 2526 Concrete Aggregate and/or KS F 2527 Crushed Aggregate for Concrete. However, the government's aggregate supply plan was prepared after forecasting the construction industry outlook and profitability, without considering aggregate quality. For this reason, the aggregate that actually satisfies the criteria of KS is extremely lacking when considering the government's aggregate supply plan[1,2,3]. The aggregate with good quality can be obtained from some sea sand collected from adjacent seas or crushed sand

produced in a factory condition where filling powder can be eliminated, and coarse aggregate is no exception[4].

The amount of aggregate in the government supply plan is presented to meet the demands, but the actual amount of quality aggregate is believed to be very short in supply. Furthermore, as the collection of aggregate is restricted due to recent environmental problems, the lack of quality aggregate is expected to become more serious in the future. As a result, the quality of aggregate used for ready-mixed concrete should be examined, and based on this a management plan for concrete quality should be urgently presented[5,6].

On this background, aggregate used to mix in ready-mixed concrete in Korea was collected by region in this study, and the current state of the quality of aggregates collected was analyzed in compliance with KS. In addition, aggregates were divided based on the items that show a great quality difference between aggregates, and the effect of the aggregate

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quality on flowability and compressive strength development of concrete was scrutinized to propose fundamental data for a quality management method for deteriorated aggregate quality used in ready-mix concrete factories in Korea.

2. Literature review and methodology

2.1 Literature review

As shown in Figure 1, a total of 32 ready-mix concrete factories were selected by region in the first step, and the aggregate samples used in the factories were collected. The quality of the samples was evaluated based on KS quality criteria. In addition, the quality of aggregate samples was evaluated as indicated in Table 1 at the second step, and then the quality of fine and coarse aggregate samples was divided into four grades by the items that greatly differ in quality between aggregate samples, and the physical properties and compressive strength of fresh concrete specimens with a mix proportion and workability were evaluated to examine the effect of aggregate quality on the physical properties of concrete.

In the first step, the density of the oven-dry condition of aggregate, water absorption, wear rate, grain shape judgment percentage of absolute volume, 0.08mm passage, NaCl content, and fineness modulus were evaluated based on KS F 2526 and KS F 2527. In addition, the unit water content of concrete specimens was evaluated to meet slump, air content, compressive strength and the same constructability in compliance with KS at the second step.

2.2 Materials and mix proportion

As indicated in Table 2, of the materials used to examine the effect of aggregate quality on concrete, the 1st class Ordinary Portland Cement, the 2nd class fly ash and the 3rd class furnace slag powder were used as a binder as described in Table 2. As indicated

in Tables 3 and 4, four different types of fine and coarse aggregates that are different in 0.08mm passage and absorption that are expected to have a great impact on the physical properties of concrete were selected and used. In addition, the mix proportion used in this experiment is indicated in Table 5, and the aggregate was applied to be rather different depending on its density. When the mix proportion was set, a general water reducer was employed as an admixture, and the unit water content was set to be high at 190kg/m³ to make it easy to examine the influence of aggregate quality.

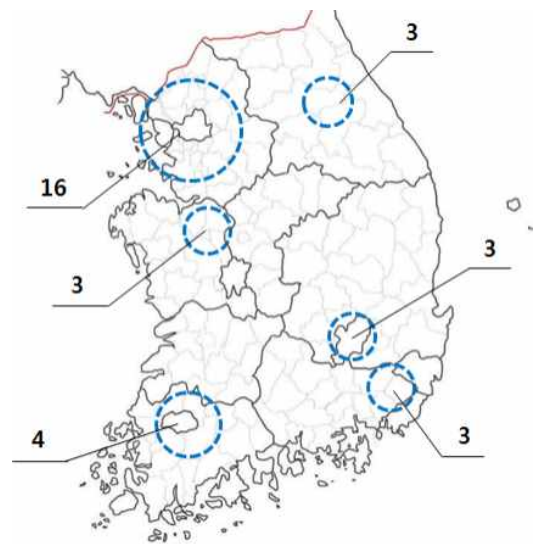


Figure 1. Area of aggregate collection

Table 1. Experiment design

Step	Factors	Levels
1	Investigation of aggregate quality	<ul style="list-style-type: none"> ▪ Ready-mixed concrete plants : 32 ▪ Fine aggregate : 40 types Coarse aggregate : 33 types
2	Effect of aggregate quality	<ul style="list-style-type: none"> ▪ Quality grade : 4 levels ▪ Condition : 2 levels <ul style="list-style-type: none"> - Same mix proportion - Same workability

Table 2. Physical properties of used binder

Type	Properties
Cement	<ul style="list-style-type: none"> Type 1 (KS L 5201) Density 3.15g/cm³, Blain 3,322cm²/g
BFS	<ul style="list-style-type: none"> Type 3 (KS F 2563) Density 2.90g/cm³, Blain 4,592cm²/g
FA	<ul style="list-style-type: none"> Type 2 (KS L 5405) Density 2.14g/cm³, Blain 3,964cm²/g

※ BFS : Ground Granulated Blast Furnace Slag, FA : Fly Ash

Table 3. Physical properties of used aggregate

Item	Fine aggregate				Coarse aggregate			
	A	B	C	D	A	B	C	D
F.M.	2.60	2.92	3.33	3.31	6.84	6.86	6.87	6.69
0.08mm passage (%)	1.13	2.20	2.65	4.59	0.28	0.92	1.36	1.56
Density (g/cm ³)	2.56	2.57	2.52	2.50	2.63	2.67	2.71	2.57
Water absorbance (%)	1.19	1.29	2.29	3.03	0.60	0.72	0.82	1.09
Solid Volume (%)	56.8	55.9	54.8	53.8	55.4	54.3	54.2	56.3
Wear rate (%)	-	-	-	-	15.3	18.2	22.0	17.6
NaCl (%)	0.03	-	-	-	-	-	-	-

※ F.M. : Fineness Modulus, □ : Sub-Quality of KS F 2526

Table 4. Shape of used aggregate









Kinds	A	B	C	D
Fine agg.				
Coarse agg.				

Table 5. Mix proportion of concrete

W/B (%)	S/a (%)	Unit weight (kg/m ³)					
		W	OPC	BFS	FA	S	G
57.6	49.0	190	230	50	50	835	869

※ W:Water, OPC:Ordinary Portland Cement, S:Sand, G:Gravel

3. Review results and analysis

3.1 Current state of aggregate quality

3.1.1 Quality of fine aggregate

When fine aggregates were evaluated for the 40

aggregate samples collected from 32 ready-mix concrete factories by region, only 9 samples were shown to satisfy all the quality criteria of KS F 2526 and KS F 2527. By fine aggregate type, 5 out of 29 crushed sand samples and 4 out of 11 sea sand samples met the criteria of KS, which indicates that the overall quality of crushed sand is low.

By specific item, the density in the oven-dry condition of aggregate was 2.5–2.6 as shown in Figure 2, and there were 4 samples that did not satisfy the criteria.

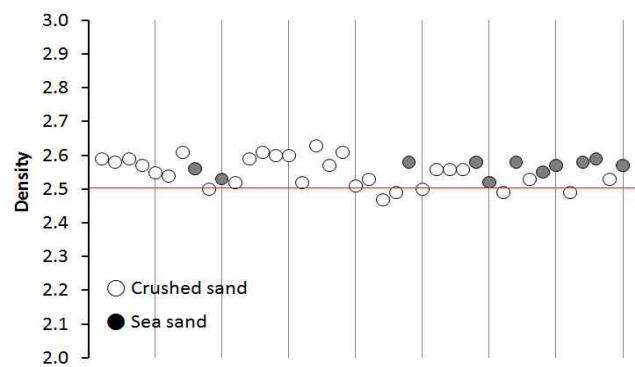


Figure 2. Density of fine aggregate

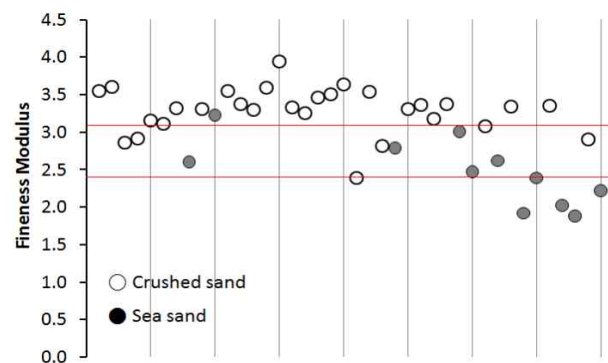


Figure 3. Fineness modulus of fine aggregate

In terms of fineness modulus, 27 samples were 2.3–3.1, most of which are out of the range of fineness modulus effective to provide the physical properties of concrete as shown in Figure 3. Of all the crushed sand, only 7 samples were shown to be within the appropriate range of fineness modulus. More specifi-

cally, most of the crushed sand samples had fineness modulus beyond 3.1, while most of the sea sand samples had fineness modulus less than 2.3, which did not meet the quality criteria. This implies that the grain size of aggregate became greater due to insufficient crushing of the sand and faulty set-up of the screen, and the grain size of sea sand became smaller because it was supplied from EEZ[7].

Figure 4 shows the results of 0.08mm passage. All the samples meet 0.7% of the criteria for crushed sand specified in KS F 2527, but 8 samples did not meet 3.0% of the aggregate criteria for concrete specified in KS F 2526. In terms of the grain shape judgment percentage of absolute volume that shows the shape of concrete, there were 6 samples that did not satisfy the criteria set out in KS, as shown in Figure 5.

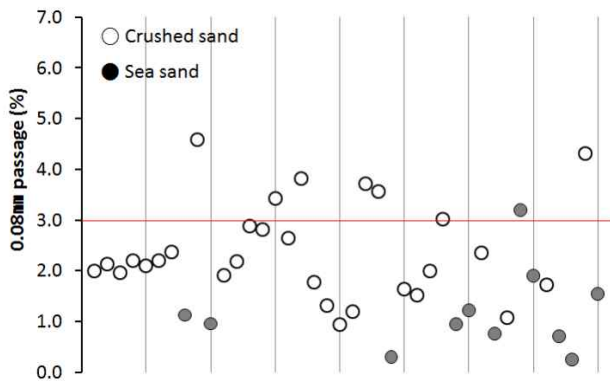


Figure 4. 0.08mm passage of fine aggregate

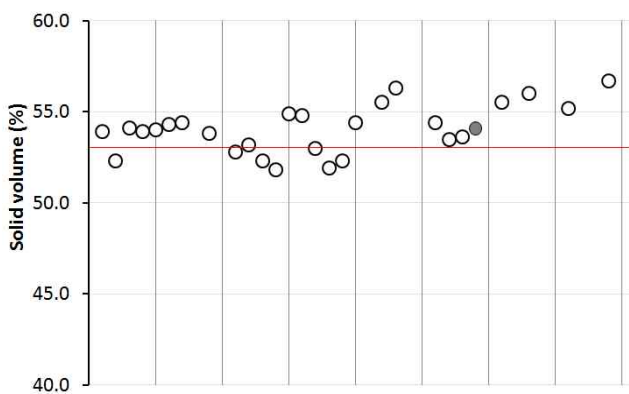


Figure 5. Solid volume of fine aggregate

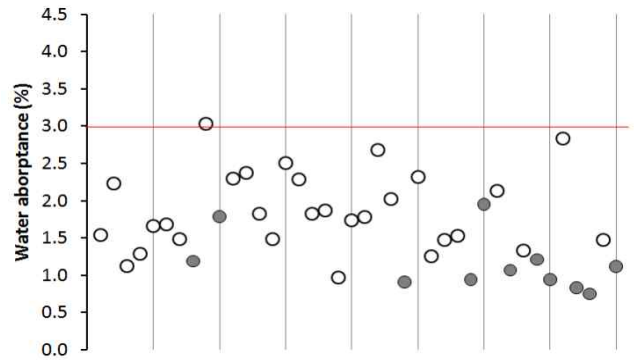


Figure 6. Water absorption of fine aggregate

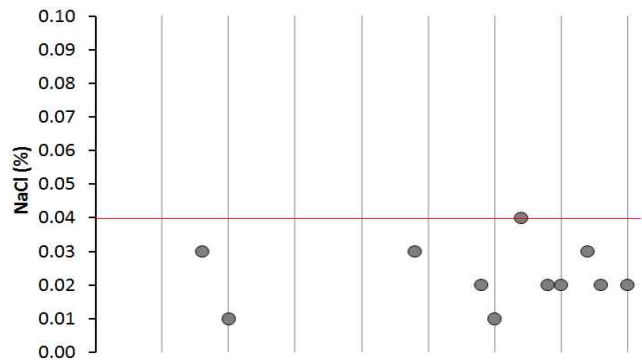


Figure 7. NaCl content of fine aggregate

On the other hand, in terms of the absorption, which is highly correlated with the properties and durability of concrete, there was one sample that did not satisfy the KS criteria as indicated in Figure 6, but the absorption of most of the crushed sand samples ranged between 1.5%–3.0%, which indicates that there are many aggregate samples with relatively good absorption.

Figure 7 shows the results of the analysis of NaCl content of sea sand, which is related with durability of concrete, based on which it was found that there was one sample that did not satisfy the quality in terms of NaCl content that has a direct relation with items of acceptance inspection of fresh concrete.

As described above, it was revealed that overall quality problems with fine aggregate were related with the grain size on the basis of KS. As mentioned earlier, this implies that collecting sea sand is limited,

and to meet the demands of aggregate low quality aggregates is applied without any limit.

3.1.2 Quality of coarse aggregate

All of the 33 samples collected from 32 ready-mixed concrete factories were crushed gravel, and only 7 samples satisfied all the criteria specified in KS F 2527.

In terms of the density in the oven-dry condition of aggregate, most of the samples were within the range between 2.55 and 2.70, as shown in Figure 8, all of which met the KS criteria. In terms of fineness modulus with which the grain size can be expressed, all the samples, as shown in Figure 9, satisfied the range between 6.0 and 8.0, which is appropriate for coarse aggregate. They were evaluated to have relatively better quality compared with fine aggregate. However, in terms of 0.08mm passage, which is related with the content of hazardous materials including clay powder, there were 19 samples that did not meet the KS criterion of 1.0%, which accounted for 60% of all.

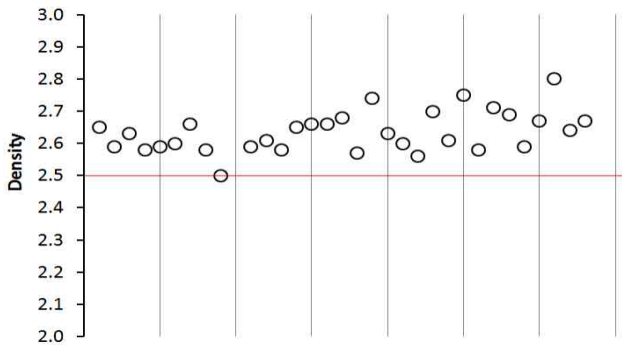


Figure 8. Density of coarse aggregate

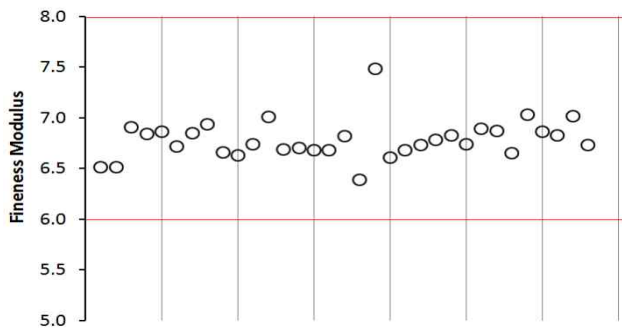


Figure 9. Fineness modulus of coarse aggregate

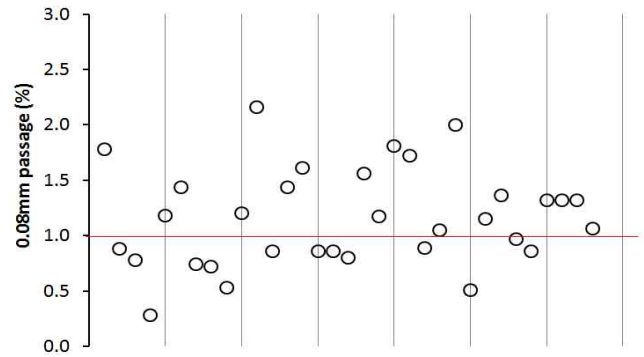


Figure 10. 0.08mm passage of coarse aggregate

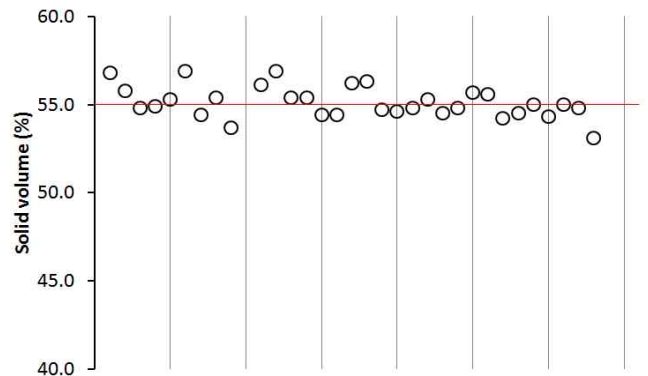


Figure 11. Solid volume of coarse aggregate

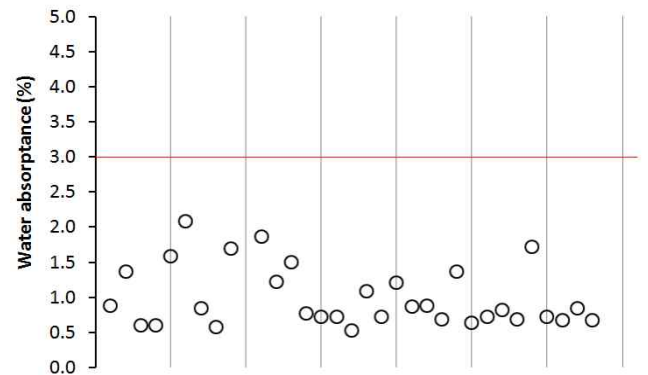


Figure 12. Water absorption of coarse aggregate

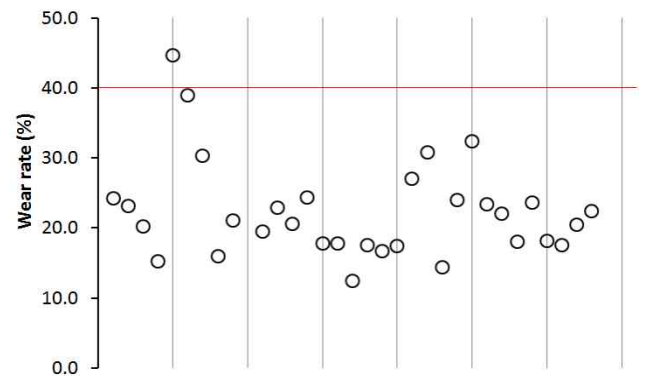


Figure 13. Wear rate of coarse aggregate

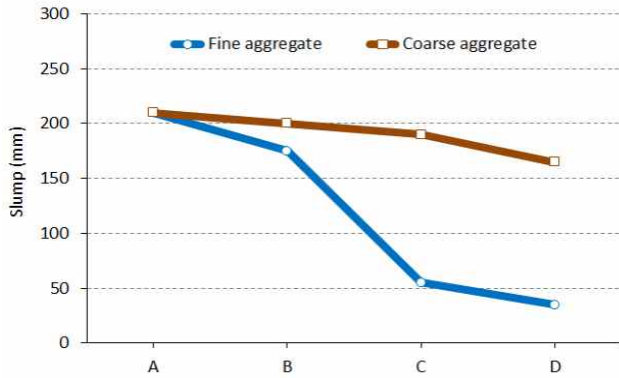


Figure 14. Slump by change of aggregate quality (Same mix proportion)

This implies that the collection of aggregate from rocky mountain has recently been limited, that the blasting rock generated at construction sites has been increasingly used as the ore of crushed gravel; nonetheless, the crushed gravel was not washed sufficiently in the process of the projection. For this reason, it would be important to manage the fine powder on the surface as part of the quality control of coarse aggregate.

Figure 11 shows the grain shape judgment percentage of absolute volume of crushed gravel, and there were 13 samples that did not meet higher than 55.0% of the KS criteria. The average of grain shape judgment percentage was shown as 55.1%, which is the bottom line of the KS criteria. In terms of absorption, all the samples met less than 3.0% of the KS criteria, some of which exceeded 2.0%, but overall samples were between 0.5%~1.0%, which proved to be good in absorption. In Figure 13, the evaluation results of wear rate are shown, and with the exception of one sample, all the samples satisfied less than 40% of the KS criteria.

As described above, most of the coarse aggregate samples examined in this study met the quality criteria, but the quality problems were remarkably related with fine powder, like clay powder. As mentioned previously, this may be related with the problems

such as the ore for the production of coarse aggregate and production method.

3.2 Changes in concrete depending on aggregate quality

3.2.1 Effect on properties of concrete at a mix proportion

Of the aggregate samples evaluated for quality in the first step, 4 aggregate samples that were found to have differences in quality based on the KS criteria were selected for fine and coarse aggregate, respectively, and their properties were examined. The quality was categorized from A(good) to D(bad) in the order of A,B,C, and D, and when experimenting to determine the effect of fine aggregate, fine aggregate A was used, and when experimenting to determine the effect of coarse aggregate, coarse aggregate A was used.

Figure 14 shows the changes in slump by aggregate quality. When it comes to the quality of aggregate samples selected for this research, the quality of fine aggregate had a greater influence on slump than that of coarse aggregate. Figure 15 shows changes in slump by aggregate quality, and Figures 16 and 17 show grain size distribution of the aggregate samples. From the Figures it is revealed that the quality items that had a similar tendency with the concrete slump measured were 0.08mm passage, absorption, grain shape judgment percentage and grain size distribution for fine aggregate, while for coarse aggregate they were 0.08mm passage, absorption and grain size distribution. With these results, the factors such as the amount of fine powder, 0.08mm passage that is related with absorption, and grain size of aggregate were found to have an effect on the rapid decrease in slump of fine aggregate[8,9]. For coarse aggregate, the decrease in slump was relatively smaller compared with fine aggregate, but the causes

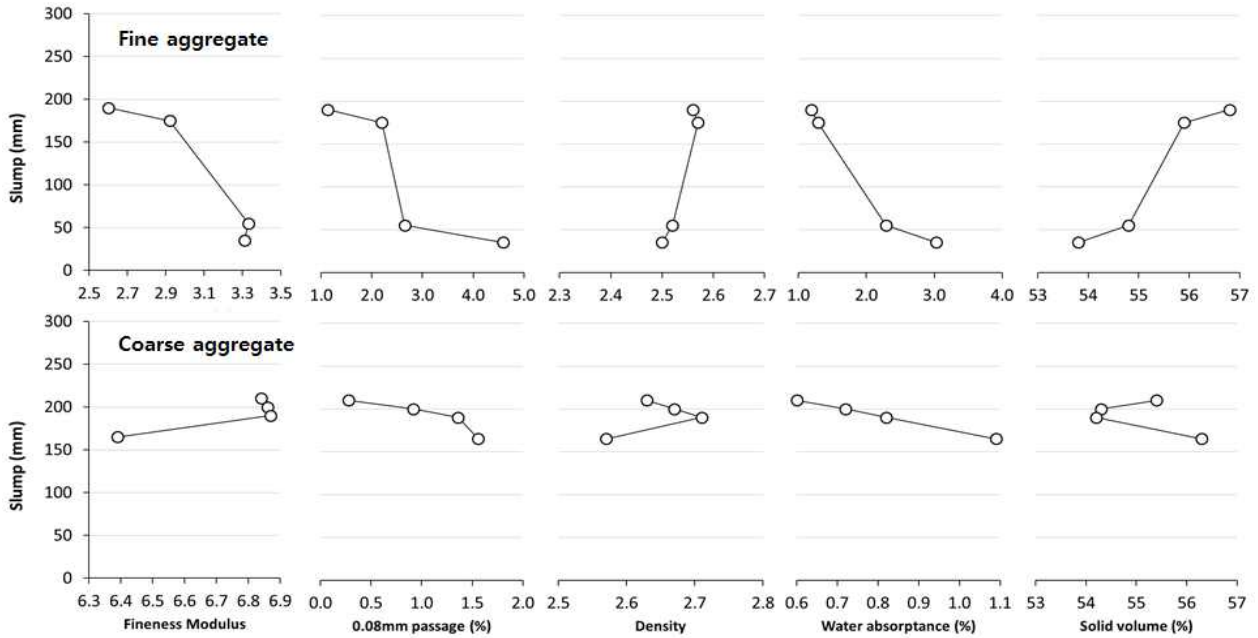


Figure 15. Slump by change of aggregate quality items (Same mix proportion)

of a decrease in slump can be interpreted as being that the aggregate with lower quality had more clay powder and it could have a high 0.08mm passage, and showed a discontinuous grain size distribution due to an increase in fine grains.

Figure 18 shows changes in compressive strength based on aggregate quality at 3 days and at 28 days. In the fine aggregate samples, the compressive strength of fine aggregate A was relatively high at 3 days but the compressive strength of all the fine aggregate samples selected was shown to be similar at 28 days regardless of aggregate quality. Based on the results, the quality of fine aggregate was not shown to have a great impact on compressive strength within the quality range of this research when a mix proportion was applied[10]. The compressive strength of coarse aggregate D was relatively lower at 3 days, but this difference was not significant, while the comprehensive strength of coarse aggregate C was relatively higher but that of coarse aggregate D was lower at 28 days.

Considering the results of the evaluation of the

physical properties of coarse aggregate samples employed in this study, they are believed to have been affected by the density in the oven-dry condition of aggregate. However, under the same mix proportion condition, the composition of cement paste was identical, and the compressive strength of aggregate itself did not have a great effect within the general strength range, on which basis it is found that aggregate quality did not greatly affect compressive strength.

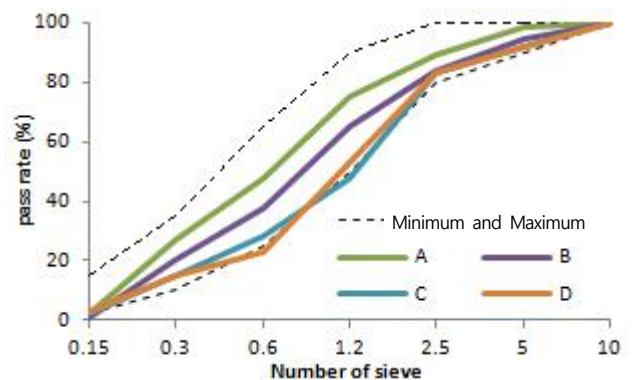


Figure 16. Particle size distribution of fine aggregate

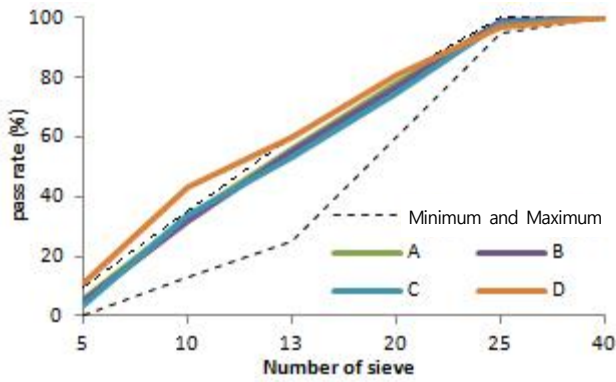


Figure 17. Particle size distribution of coarse aggregate

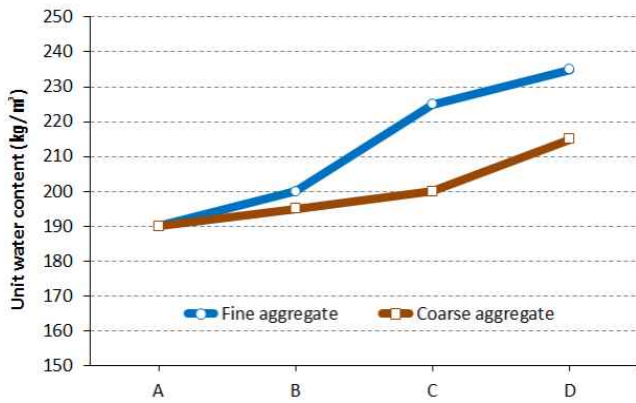


Figure 18. Unit water content by change of aggregate quality (Same workability)

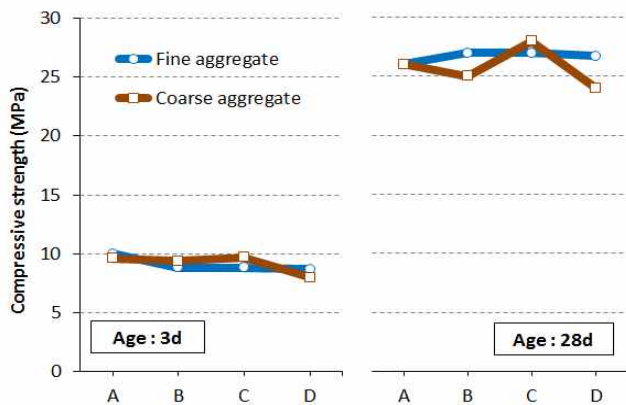


Figure 19. Strength by change of aggregate quality (Same mix proportion)

3.2.2 Effect on concrete properties at the same workability

To examine the effect of aggregate quality on the properties of concrete at the same workability, the target slump was set at 200 ± 25 mm, and water reduc-

er was fixed at 0,5% of a naphthalene admixture. The test was repeated by changing unit water content to find the water content for each aggregate that satisfies the target slump.

Figure 19 shows changes in unit water content by fine and coarse aggregate to get the target slump. With aggregate quality deteriorating, the unit water content required tended to increase. In addition, in terms of fine aggregate, unit water content had to be increased by 45kg/m^3 in aggregates A and D to secure identical workability, while in terms of coarse aggregate unit water content had to be increased by 25kg/m^3 . Based on these results, it was found that changes in quality of fine aggregate have a greater impact on the increase in unit water content to secure the same workability. This implies that fine aggregate has higher absorption and higher 0.08mm passage than coarse aggregate, so that unit water content increased greatly to secure the same workability, but the quality of coarse aggregate D was similar to that of fine aggregate A, and the unit water content did not increase greatly.

Figure 20 shows the changes in compressive strength based on aggregate quality under identical workability conditions. The lower the aggregate quality, the more the compressive strength was decreased. By aggregate, a quality difference between coarse aggregate samples did not greatly affect the compressive strength of concrete, but a quality difference between fine aggregate samples had a relatively large impact on compressive strength since the unit water content of fine aggregate increased more greatly than that of coarse aggregate. Based on these results, the quality items of aggregate related with the constructability of concrete were 0.08mm passage related with fine powder and absorption. If those items were not appropriate, the unit water content increased to secure constructability, resulting in deterioration in compressive strength and

durability. Therefore, aggregate quality management and a mix proportion application plan should be established.

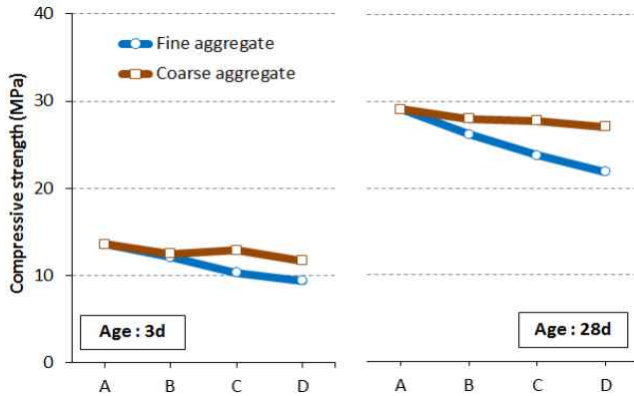


Figure 20. Strength by change of aggregate quality (Same workability)

4. Conclusion

The aggregate samples used in domestic ready-mix concrete factories were collected to understand the current state of aggregate quality and the effect of quality differences in aggregate on the constructability and compressive strength of concrete, and the findings of this study can be summarized as follows:

- 1) 23% fine aggregate samples and 21% coarse aggregate samples collected by region satisfied the KS criteria, which implies that overall quality of aggregate used for ready-mix concrete is low.
- 2) In terms of fine aggregate, most of the quality problems are related with grain size, which can result from a restriction in the collection of sea sand, and the application of low-quality aggregate without any limit to meet demands for aggregate.
- 3) In terms of coarse aggregate, its quality is relatively good, but quality problems caused by clay

powder are significant.

- 4) In the quality range of aggregate samples selected in this study, the quality of fine aggregate has a great influence on concrete slump compared with that of coarse aggregate.
- 5) It is found that under the same mix proportion conditions, aggregate quality did not greatly affect compressive strength.
- 6) Through the test by quality item, 0.08mm passage related with fine powder and absorption are found to have an effect on constructability of concrete.
- 7) Deterioration in aggregate quality brings about more mixes of concrete, and results in deterioration in compressive strength and durability, and an aggregate quality management and mix proportion plan should be established in consideration of these findings.

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