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Optimum Mix Proportion for Recycling Waste Foundry Sand as Fine Aggregate in Concrete

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ABSTRACT

The amount of the waste foundry sand(WFS) produced in Korea is over 700,000 ton per year, but most WFS buries itself and only 5~6% of total WFS is recycled in the way of mixing as fine aggregate for construction materials. A by-product, WFS produced from a foundry may affect our environmental contamination if it is discharged without proper waste disposal in Korea. Therefore in this study, we performed the fundamental research about specific gravity, absorption, grading curve, finesse modulus of WFS, different aggregates and the flow and the compressive strength of mortar with WFS replaced as fine aggregate, the workability and compressive strength of concrete with WFS as fine aggregate aimed at the specified strength of 270 kgf/cm^2, and then optimum mix proportion of concrete was determined

Keywords : waste foundry sand, environmental contamination, recycling concrete

1. Introduction

The development of automobile, vessel, railroad, and machine industry leads increase of foundry production used as their components, which cause a by-product, waste foundry sand (WFS). The amount of the total WFS produced in Korea is over 700,000 ton per year, but most WFS buries itself and only 5~6% WFS is recycled as fine aggregate in construction materials.

So, it is necessary for most WFS to research other ways which can be used in a higher value added product. On the other hand, the study on recycling it as fine aggregate in concrete or green sand has been in progress in America since 1970 and in Japan since 1980. In the case of Japan, only 1.7% WFS buries itself and the rest of it is recycled in diverse methods; 86% of it as green sand and 12% of it as a fine aggregate in concrete.

In this study, first of all, not only the quality of WFS(specific gravity, absorption, finesse modulus, percentage of solids etc.) but also these of different fine aggregates are investigated.

Into the bargain fundamental properties of mortar with WFS replaced as fine aggregate is examined, and several types of concrete aimed at the specified strength of 270 kgf/cm^2 were mixed with washed seashore sand in which salt was removed, crushed sand and WFS, and then optimum mix proportion of concrete was determined. Moreover, basic properties such as air contents, workability and slump of the fresh concrete with WFS were tested and compared with those of the concrete mixed without WFS. In addition, both compressive strength of hardened concrete at each ages and tensile strength of it at the age of 28 days were measured and discussed.

2. Materials

2.1 Cement and Waste Foundry Sand

Ordinary portland cement (OPC), and CO_2-type waste foundry sand have the chemical compositions and physical properties as shown in Table 1. While in here chemical compositions of WFS is silica of 84.3%, CaO, 0.85%, is a small quantity and Na_2O keeps within bounds 1.01%.

2.2 Aggregates

Washed seashore coarse sand (WCS), washed seashore medium sand (WMS) in which salt was removed, crushed sand (CRS), and WFS were used as fine aggregates and coarse aggregate is G_{max} 25mm. The physical properties of these aggregates are shown in Table 2.

3. Mixture

3.1 Mortar

The mortar mixtures, in which WFS is replaced with fine aggregates (WCS, WMS, CRS) from 0% to 100% respectively are mixed. In addition, flow values and flow loss ratios are tested, and compressive strength is also measured at the age of 3, 7 and 28 days respectively. Mix proportion of mortar is shown in Table 3.

3.2 Concrete

In concrete mixtures, design strength was from 240kg/cm^2 to 270kg/cm^2 and target slump was 12±1.5cm. The concrete specimens, in which WFS is replaced with fine aggregates at the rate of 0, 25, 50, 75, and 100% are

Table 1. Chemical Compositions and Physical Properties of Cement and WFS

Types \ Items	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	SO_3 (%)	Ig. Loss (%)	Specific Gravity	Surface Area (cm^2/g)
OPC	21.95	6.59	2.81	60.10	3.32	-	2.11	2.58	3.15	3,112cm^2/g
WFS	84.30	5.95	0.42	0.85	0.16	1.01	-	5.61	2.60	-

Table 2. Physical Properties of Aggregates

Types \ Items	Specific Gravity	Absorption (%)	Finesse Modulus	Unit Weight (kg/m^3)	Percentage of Solids (%)	Abrasion Value (%)
WFS	2.60	2.30	2.43	1,537	55.0	-
WCS	2.60	0.78	3.44	1,653	56.4	-
WMS	2.61	0.63	2.63	1,597	56.2	-
CRS	2.55	1.88	3.03	1,656	55.7	-
Coarse Aggregate	2.65	0.78	6.51	1,741	64.9	28.6

Table 3. Mix proportion of mortar

Types \ Items	Flow and strength	Flow loss ratio
WCS+WFS	WFS 0 WFS25 WFS40 WFS55 WFS70 WFS85 WFS100	WFS 0 WFS10 WFS30 WFS50
WMS+WFS	〃	〃
CRS+WFS	〃	〃

respectively mixed. Then compressive strength values are measured at the age of 7, and 28 days. Mix proportion of concrete is shown in table 4.

4. Results and Discussion

4.1 Characteristics of WFS and fine aggregates

4.1.1 SEM of WFS and fine aggregates

The particle shapes of WFS and different fine aggregates are compared in images in the scanned photomicrographs from electron microscope. They are shown in fig 1.

Fig 1 shows that particle shapes of WFS is smaller than different particles and more or less single sized aggregate.

The order of particle size is WCS > WMS > CRS > WFS.

4.1.2 Grading analysis of WFS and fine aggregates

As you know in fig 2, finesse modulus of WFS is 2.43 that is a smaller than different fine aggregates. This value is a range of 2.3~3.1 that is generally used in concrete. But fig 1 shows that grading curve of WFS is deviated from standard grading curve. Therefore, the grading of WFS is controlled to make up for smaller finesse modulus of WFS by WCS, WMS, and CRS which is higher than particle of WFS.

4.1.3 Quality of WFS and different fine aggregates

According to Table 2 while specific gravity of WFS is 2.60, which is a range of usual fine aggregate used for concrete, absorption 2.30 of WFS is very higher than that of natural fine aggregates. On the other hand, fig 3 shows organic impurity test results of WFS, WCS, WMS, and CRS.

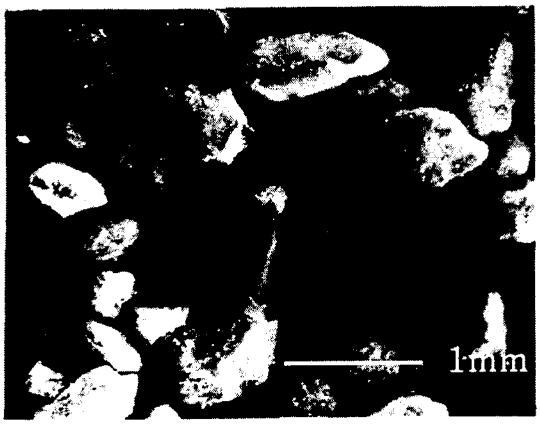
In this fig it is difficult to infer degree of organic impurity. However, when color by organic impurity test

Table 4. Mix proportion of concrete

Types \ Items		W/C	S/a	Unit Weight (kg/m³)							
				W	C	S			G	WR (Cυ%)	AE (Cυ%)
						WFS	WCS	WMS			
WCS	WFS0	45	43.9	186	413	0	764	-	976	0.5	0.0065
	WFS25		42.9	186	413	191	573	-	1016	σ	0.0065
	WFS50		42.4	186	413	382	382	-	1036	σ	0.0075
	WFS75		40.7	196	436	544	181	-	1056	σ	0.0100
	WFS100		39.0	196	436	700	0	-	1095	σ	0.0150
	WFS0	50	46.4	160	320	0	845	-	976	σ	0.0050
	WFS25		44.2	160	320	202	604	-	1016	σ	0.0060
	WFS50		43.2	160	320	394	394	-	1036	σ	0.0080
	WFS75		42.1	168	336	575	192	-	1056	σ	0.0110
	WFS100		39.9	168	336	727	0	-	1095	σ	0.0130
WMS	WFS0	45	37.9	179	398	0	-	650	1064	Cυ0.5	0.005
	WFS25		37.1	181	402	158	-	475	1072	σ	0.005
	WFS50		36.1	184	409	305	-	305	1080	σ	0.005
	WFS75		34.6	190	422	431	-	144	1087	σ	0.005
	WFS100		32.7	198	440	531	-	0	1095	σ	0.005
	WFS0	50	40.1	172	344	0	-	713	1064	σ	0.005
	WFS25		39.4	174	348	174	-	522	1072	σ	0.005
	WFS50		37.1	186	372	318	-	318	1080	σ	0.005
	WFS75		35.6	192	384	451	-	451	1087	σ	0.075
	WFS100		33.8	200	400	559	-	559	1095	σ	0.075

(a) SEM of WFS (×20 magnifications)

(b) SEM of WCS (×20 magnifications)



(c) SEM of WMS (×20 magnifications)

(d) SEM of CRS (×20 magnifications)

Fig 1. SEM of fine aggregates

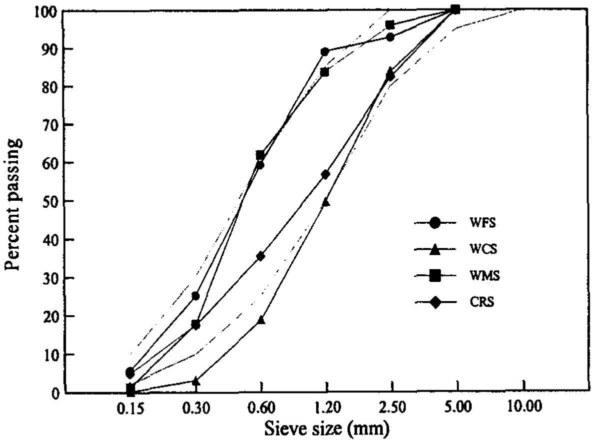


Fig 2. Grading curve of WFS and fine aggregates

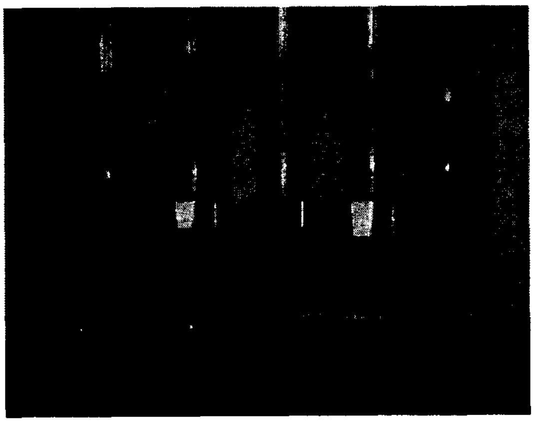


Fig 3. Organic impurity of WFS and fine aggregates

result of WFS is compared to reference color, the color of the supernatant liquid shows lighter yellow than reference standard color solution. Hence, WFS is affirmed usability as fine aggregate for concrete

4.2 Properties of Mortar

Prior to using WFS as fine aggregate for concrete is replaced with different fine aggregates (WCS, WMS, and CRS) at the ratio of 25, 40, 55, 70, 85 and 100% to measure properties of mortar.

Fig 4 and fig 5 show flow values and compressive strength of mortar according to replacement ratio of WFS respectively. Flow values of mortar is very highly decreased with increasing the replacement ratio of WFS regardless of types of fine aggregates.

In other words, the reason that flow values of mortar is very highly decreased with increasing the replacement ratio of WFS is due to inappropriate size distribution, finesse modulus, and particle shape of WFS compared to WCS, WMS, and CRS. Moreover fig 4 shows compressive strength of mortar at the age of 3, 7, and 28 days.

Compressive strength of mortar is decreased with increasing the replacement ratio of WFS regardless of types of fine aggregates at the same like flow values.

That reason is that quality of fine aggregate mixed with WFS is decreased with increasing replacement ratio of WFS.

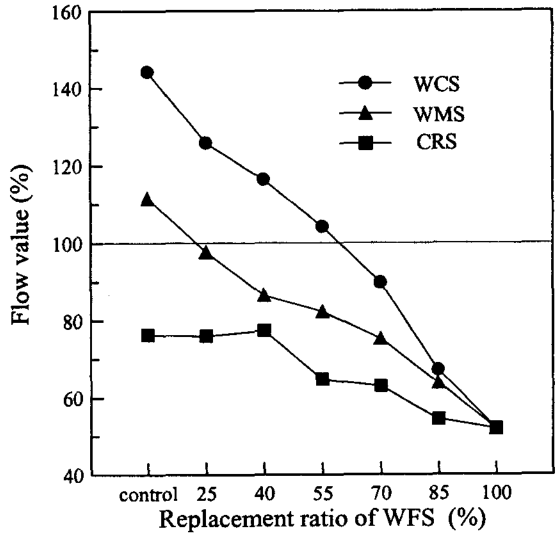


Fig 4. Flow values of mortar according to replacementratio of WFS

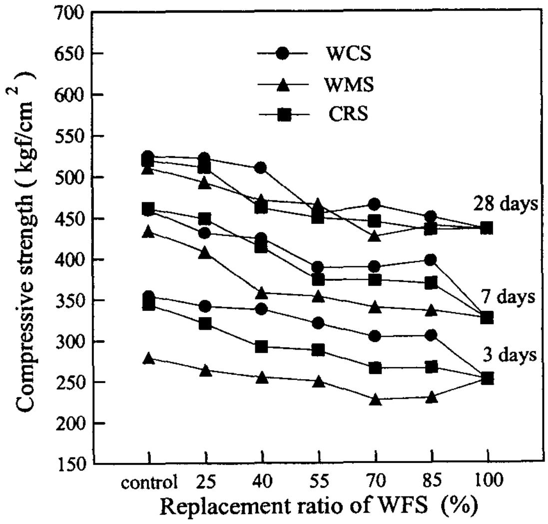


Fig 5. Compressive strength of mortar according to replacement ratio of WFS

4.3 Properties of Concrete

On the basis of properties of mortar with WFS, WCS, and WMS were chosen as fine aggregate. Designed slump and air content of recycling concrete replaced fine aggregate for WFS, WCS and WMS are 12ρ1.5 cm and 4.5ρ1%.

Unit water content and AE admixture content of concrete are shown in fig 6 In this figure unit water content and AE admixture content of concrete are increased with increasing replacement ratio of WFS regardless of types of fine aggregates respectively.

In case of replacing WFS for WMS, to coordinate at the same slump and air content need to be more unit water content and AE admixture content than those in case of replacing WFS for WCS.

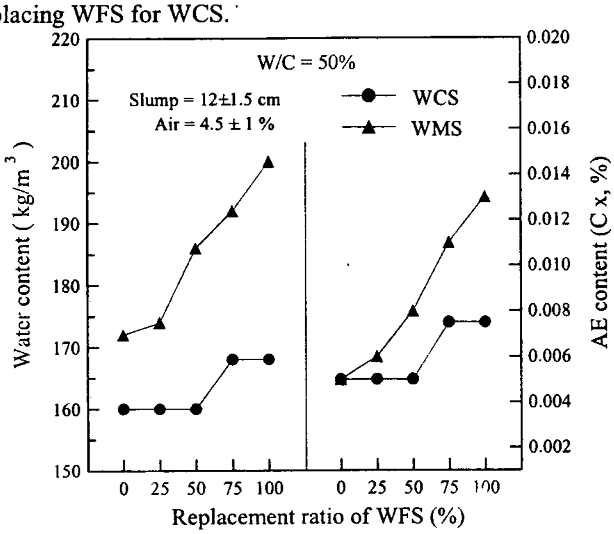


Fig 6. Water and AE agent content according to the replacement ratio of WFS

According to the case of WFS it is thought that WFS need to be more unit water content and AE agent content than those in case of replacing WFS for WCS, WMS at the same slump and air content because of poor grading distribution and containing small particle.

When W/C is 45 and 50%, compressive strength of concrete according to replacement ratio of WFS show in fig.7 and fig.8. In these figures compressive strength of concrete with WFS and WCS as fine aggregates are to some degree higher than that of concrete with WFS and WMS as fine aggregates without regard to W/C, ages and replacement ratio of WFS.

In particular, when W/C is 50%, considered in the result of workability and compressive strength of concrete with WFS as fine aggregate, it is estimated that an appropriate replacement ratio of WFS is within the range of 30 ~ 50%.

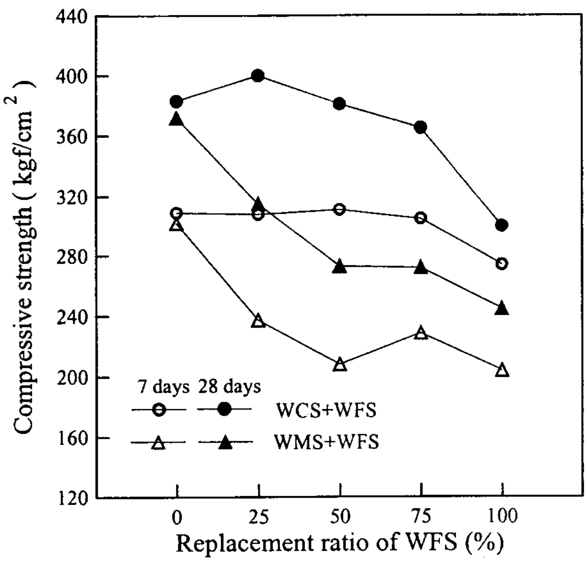


Fig 7. Compressive strength according to the replacement ratio of WFS (W/C=45%)

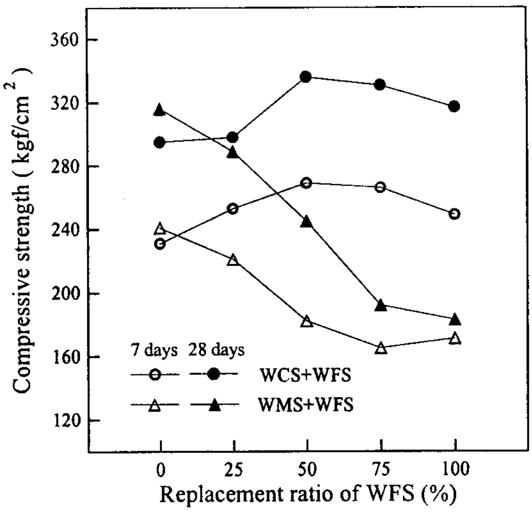


Fig 8. Compressive strength according to the replacement ratio of WFS (W/C=50%)

5. Conclusion

(1) As the specific gravity and absorption of WFS are each 2.60 and 2.30%. Absorption of WFS is higher than other natural aggregates. In the test result of organic impurity, WFS shown as deep yellow color is little lighter color than that of standard solution.

(2) Flow values and compressive strength of mortar according to replacement ratio of WFS are decreased with increasing the replacement ratio of WFS regardless of types of fine aggregates. Because it's due to inappropriate grading curve, finesse modulus, particle shape of WFS compared to WCS, WMS, CRS.

(3) To make good designed slump and air content of concrete with WFS demands water content and AE admixture, because of grading curve containing with fine powder.

(4) In case of replacing WFS for WCS as fine aggregate, the highest compressive strength is shown in replacement ratio of WFS 50% and suitable replacement ratio is within the range of 30~50%.

6. References

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