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Properties of mortar according to substitution rate of ferro-nickel slag powder

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Abstract: This study analyzes the properties of cement mortar according to the substitution of fine ferro-nickel slag powder in various types of fine aggregate, with the aim of recycling industrial waste. When using a ferro-nickel slag powder as the admixture of cement mortar, it is determined that substitution rates of 30% and higher are unsuitable for use as mortar. In order to solve this problem, it is believed that it is necessary to explore means to improve the initial strength degradation that results when fine ferro-nickel slag powder is mixed. Furthermore, the differences in carbon dioxide reduction according to fine ferro-nickel slag powder substitution rates were found to be minimal, and it is thought that additional performance analysis is necessary.
Keywords: *Cement mortar, CO_2 reduction performance, Ferro-nickel slag, Recycled aggregate, XRF*

1. Introduction

Carbon neutrality is a major challenge for the construction industry. The construction industry is implementing a policy to recycle industrial waste by using at least 40% recycled aggregate when mixing concrete on site. Therefore, as a means of simultaneously improving industrial waste recycling rates and reducing cement usage, studies are being carried out into the use of ferro-nickel slag, of which two million tons are created annually and which has carbon dioxide capture properties.

Disposal of ferro-nickel slag costs approximately USD 20 per ton, amounting to approximately USD 40 million annually. This cost of industrial waste disposal is consistently being cited as a problem. Therefore, using ferro-nickel slag as a substitute for cement has the potential to reduce industrial waste disposal costs, reduce carbon dioxide emissions through reduction of cement production, and capitalize on the carbon dioxide capturing ability of ferro-nickel slag. However, concrete made using ferro-nickel slag have very low ferro-nickel slag substitution rates and are unable to exhibit the required initial strength. Appropriate solutions to these problems must be explored [1, 2, 3].

Therefore, the object of the present study is to improve ferro-nickel slag substitution rates and low initial strength by using fine ferro-nickel powder, thereby reducing cement usage. Furthermore, with the aim of maximizing recycling of industrial waste, the performance of fine aggregates will be compared using recycled aggregate and silica sand.

2. Experimental plan and method

2.1. Experimental plan

Mixtures of silica sand and recycled fine aggregate with ordinary portland cement were tested to determine appropriate fine ferro-nickel slag powder substitution rates for each type of fine aggregate. W/B was fixed at 75%, and the fine ferro-nickel slag powder substitution rate was tested at five levels 0, 10, 20, 30, 40 (%). The test items measured were CO_2 reduction using a chamber, compressive strength, and XRF. The specimens were water-cured at a temperature of 20±2℃, and the bending and compressive strength were measured at 3, 7, and 28(days). The test factors are given in Table 1.

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Table 1.
Experimental factors and level.

Experimental factor	Experimental level	Remarks
Binder	OPC1), FNS2)	2
Fine aggregate	Silica sand, Recycled sand	2
Binder : Fine aggregate	1 : 3	1
FNS	0, 10, 20, 30, 40 (%)	5
W/B	75 %	1
Curing condition	Underwater curing (20±2)℃	1
Experiment items	Compressive strength, CO_2 adsorption, XRF	3

Note: 1) OPC: Ordinary portland cement, 2) FNS: Ferro-nickel slag

2.2. Using materials
2.2.1. Ferro-nickel slag

According to the standard KS F 2527 "Aggregate for concrete," ferro-nickel slag is molten slag generated simultaneously with ferronickel in a furnace, then rapidly chilled using air or water or slowly cooled in air.

2.2.2. Silica sand

According to KS D 2120 "Sand and silica sand for molding", silica sand is a sand rich in quartz powder. Silica sand prepared by crushing quartzite is called artificial silica sand, and silica sand harvested from beaches and lakes is called natural silica sand. Sand grains with high quartz content and a round shape are preferred for molding. Natural sand whose primary component is quartz, i.e. silicate (SiO_2), was used for the test.

2.2.3. Recycled sand

According to KS F 2573 "Recycled aggregate for concrete ", recycled sand is produced using concrete or from waste concrete used in various concrete products. The particle size and collection method of recycled sand were identical to those of natural silica sand. The recycled sand was relatively light compared to natural silica sand, at 2.51g/cm^3 versus 2.61g/cm^3.

2.3. Experimental method
2.3.1. Compressive strength

For compressive strength testing, specimens of 40×40×160(mm) were used in accordance with KS L 5105. The strength was measured on days 3, 7, and 28.

2.3.2. CO_2 Adsorption

The reduction of carbon dioxide was measured using the small chamber method proposed by Hanbat National University [4]. Measurements were carried out over 12 hours, measuring the change in carbon dioxide concentration every hour.

2.3.3. XRF

A specimen prepared in accordance with KS M 0043 was ground to a particle diameter of 75 ㎛ or less using grinder to prepare the specimens. Fluorescence spectroscopy was used to analyze components.

3. Experimental result and analysis

3.1. Compressive strength

Figure 1 and Figure 2 are graphs showing compressive strength measurements of mortar made using natural silica sand and recycled aggregate, varying fine ferro-nickel slag powder substitution rates. The results show that the compressive strength of mortar made from natural silica and recycled aggregate tends to decrease as the ferro-nickel slag substitution rate increases. In addition, the mortar prepared using natural silica sand and recycled aggregate reached the 7-day and 28-day strength standards of masonry mortar as given in KS L 5220 「Dry ready mixed cement mortar」 up to substitution rates of 20%. At substitution rates of 30% and 40%, whereas the 28-day strength standard was reached, but the 7-day strength standard was not reached.

The mortar prepared using silica sand and the mortar prepared using recycled aggregate exhibited a difference in the compressive strength of approximately 2-3MPa. As was the case with differences in flexural strength, the difference in compressive strength is determined to be a result of differences in internal porosity.

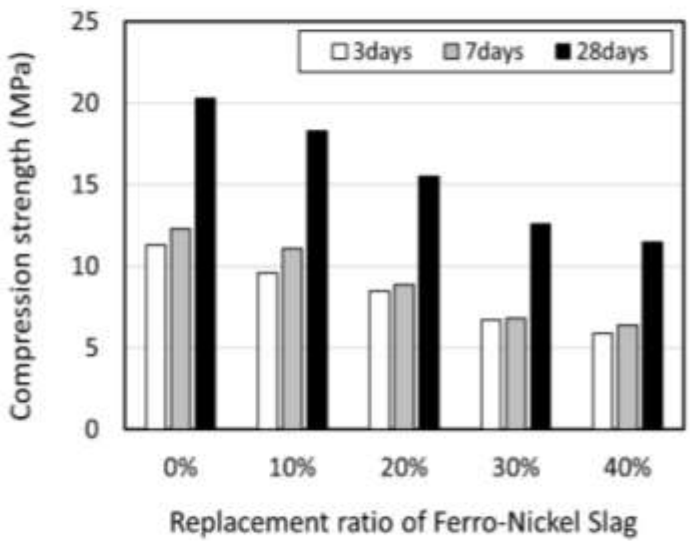

Figure 1.
Compressive strength (Silica sand).

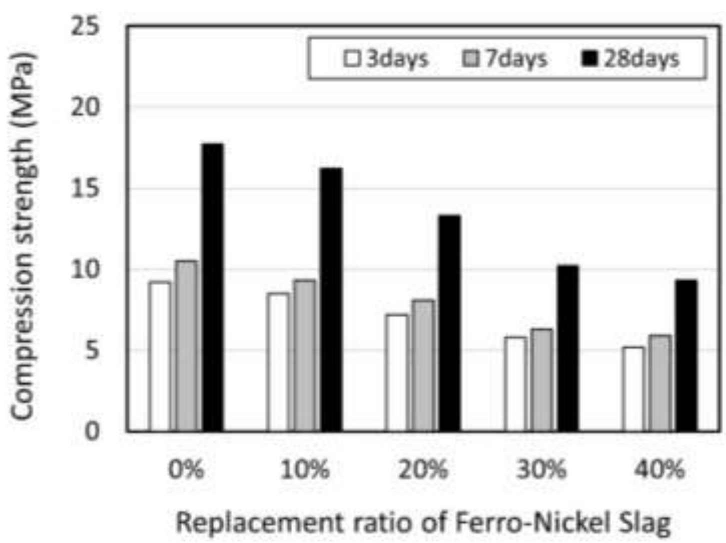

Figure 2.
Compressive strength (Recycled sand).

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3.2. CO_2 Adsorption

Figure 3 and Figure 4 are graphs analyzing the carbon dioxide reduction rates of mortar made using silica sand and recycled aggregate, varying fine ferro-nickel slag powder substitution rates. In the case of mortar made of silica sand, the carbon dioxide reduction performance tends to improve as the fine ferro-nickel slag powder substitution rate increases. This is determined to be due to the chemical reaction of magnesium oxide (MgO), one of the components of ferro-nickel slag, with atmospheric carbon dioxide. This reaction produces magnesium carbonate, which captures nearby carbon dioxide.

In the case of the mortar made from recycled aggregate, the carbon dioxide reduction performance tends to improve as the fine ferro-nickel slag powder substitution rate increases. The performance was higher than the mortar using natural silica sand. This is determined to be because the internal porosity of mortar prepared with recycled aggregate is greater than that of mortar prepared with natural silica sand.

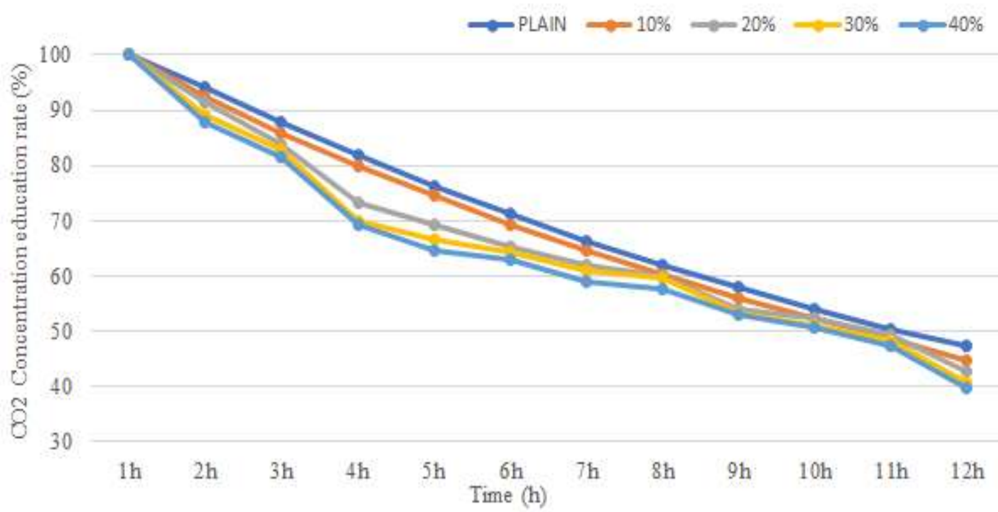

Figure 3.
CO_2 Concentration reduction (Silica sand).

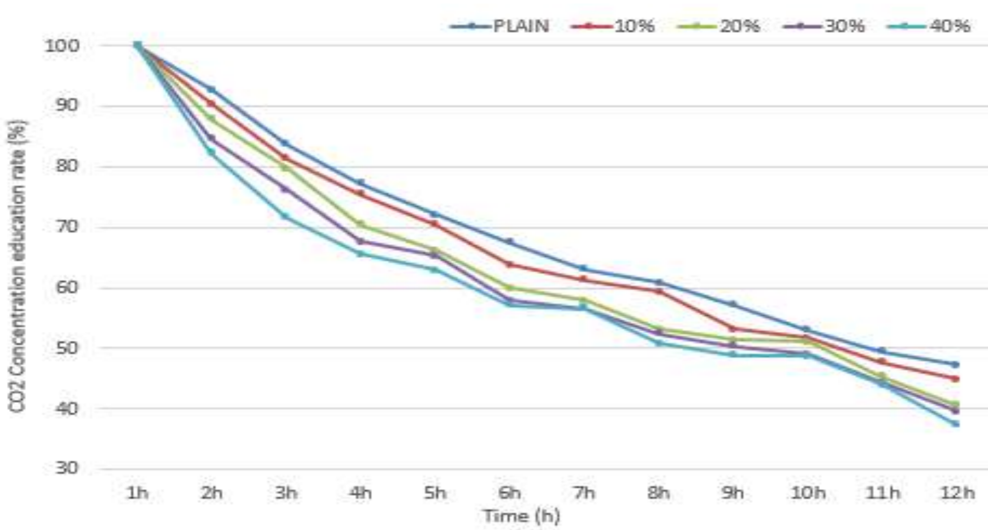

Figure 4.
CO_2 Concentration reduction (Recycled sand).

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3.3. XRF

Figure 5 and Figure 6 are graphs showing the results of XRF component analysis for mortar prepared using natural silica sand and recycled aggregate, respectively, varying the substitution rates of fine ferro-nickel slag powder. In the case of natural silica sand, the ratio of SiO_2 according to fine ferro-nickel slag powder substitution rates in the specimens were 47.86, 45.65, 53.92, 50.27, and 65.41 (%), respectively, accounting for the largest proportion of the mortar. MgO accounted for 1.29, 2.74, 2.85, 2.93, and 3.04 (%), respectively. It is determined that the presence of the MgO component in the fine ferro-nickel slag powder is the cause of the increase in MgO as the fine ferro-nickel slag powder substitution rate increases.

In the case of the recycled aggregate, the ratio of SiO_2 according to the fine ferro-nickel slag powder substitution rate was 35.74, 34.65, 43.92, 43.27, and 50.41 (%), respectively, accounting for the largest proportion of the mortar. The ratio of MgO was 4.39, 5.61, 5.73, 5.85, and 6.15 (%), respectively. These ratios were higher than those for the mortar made of natural silica. This is determined to be the result of the MgO content of recycled aggregate, which is higher than that of natural silica.

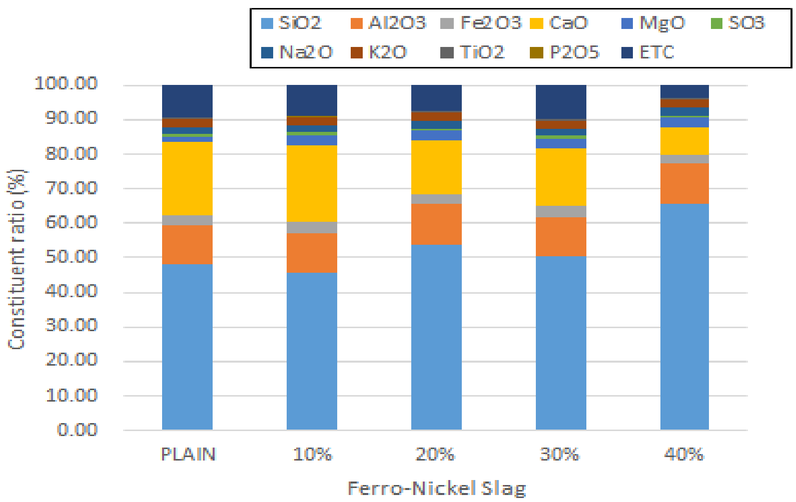

Figure 5.
XRF (Silica sand).

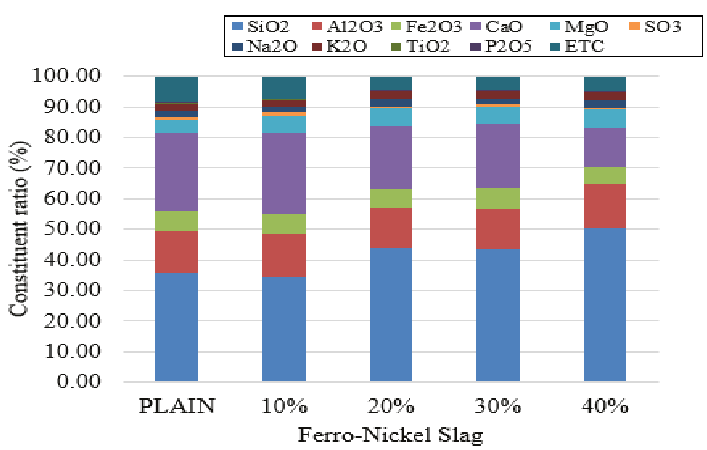

Figure 6.
XRF (Recycled sand).

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4. Conclusion

In the present study, the compressive strength, carbon dioxide reduction rate, and XRF analyses were performed to examine the basic properties of cement mortar specimens according to the fine ferro-nickel slag powder substitution rates of different fine aggregate types. When using fine ferro-nickel slag powder as an admixture for cement mortar, improved workability due to improved fluidity and reduced cement usage make the cement mortar suitable for use as low-carbon cement mortar. However, mortar with substitution rates of 30% or greater were determined not to be appropriate for use as mortar. In order to solve this problem, it is believed that it is necessary to explore means to improve the initial strength degradation that results when fine ferro-nickel slag powder is mixed. Furthermore, the differences in carbon dioxide reduction according to fine ferro-nickel slag powder substitution rates were found to be minimal, and it is thought that additional performance analysis is necessary.

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