Effect of fine recycled aggregates on the properties of non-cement blended materials

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Abstract. In this study, the different proportions of co-fired fly ash and ground granulated blast-furnace slag were used to fully replace the cement as non-cement blended materials in a fixed water-cement ratio. The recycled fine aggregates were replaced with natural fine aggregates as 10%, 20%, 30%, 40% and 50%. The flowability, compressive strength, water absorption and scanning electron microscope observations were used as the engineered indices by adding different proportions of recycled fine aggregates. The test results indicated that the fluidity cannot be measured normally due to the increase in the proportion of recycled fine aggregates due to its higher absorbability. In the compressive strength test, the compressive strength decreased accordingly as the recycled fine aggregates increased due to the interface structure and the performance of recycled aggregates. The fine aggregates and other blended materials had poor cementation properties, resulting in a tendency for their compressive strength to decrease. However, the compressive strength can be controlled above 35 MPa of the green non-cement blended materials containing 20% recycled aggregates.

1 Introduction

Concrete is a mixture of cementitious materials, aggregate, and water. Aggregate occupies over half of the concrete volume, which means that the quality of the aggregate largely determines many of the properties of the resulting concrete. Most of the fine and coarse aggregates in Taiwan are obtained via river dredging, sand and gravel mining, and importation. Approximately 90 million tons of fine and coarse aggregates are consumed in Taiwan every year. Continuing efforts to improve the infrastructure of the country mean that the demand for ready-mixed concrete is also growing swiftly, further increasing the consumption of aggregate to levels that cannot be maintained indefinitely. Replacing some of the natural aggregates with recycled aggregates can have economic benefits and help to protect the environment.

For Civil Engineering, most buildings are erected using cement, the production of which creates massive amounts of CO_2, the leading culprit of the greenhouse effect [1-2]. To mitigate the greenhouse effect, governments should focus on devising effective measures to

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reduce greenhouse gas emissions. Cutting down on cement use would not only reduce CO_2 emissions and slow down the greenhouse effect but also promote energy conservation. Portland cement is one of the primary materials used in construction. An investigation report in 2000 [3] revealed that an average of 0.87 kg of CO_2 is emitted for every kilogram of cement produced and that the cement manufacturing industry contributes to 7 % of global CO_2 emissions [4]. Development of a complete replacement of cement using effective fly ash or slag formulas enables a decrease in the production costs of concrete as well as decreases environmental impact. This is achieved through energy conservation, carbon reduction, and optimization of waste recycling [5].

In order to reduce the impact of global warming, we also hope to obtain sustainable materials in civil construction. Therefore, the industrial by-products produced by material processing are gradually developed into usable building materials in industrial development. Many by-products can also be used and become a usable material after processing. In Taiwan, the research and development of recycled aggregates and recycled concrete are driven by the incisive increase in the use of natural aggregates from rivers, coupled with the ban on the use of natural aggregates, which often results in a shortage of aggregate sources. A large volume of concrete waste accumulated after the structure is demolished can be used as recycled aggregates to reduce the use of natural raw materials [6-9]. This study is aimed to examine the effect of fine recycled aggregates on the properties of non-cement blended materials without using the alkali activator. Green non-cement mortar specimens with water-quenched blast-furnace slag (ggbs) and co-fired fly ash from circulating fluidized bed combustion were mixed to compare the compressive strength and absorption via scanning electron microscopes (SEM) observation.

2 Materials and test procedures

Co-fired fly ash used in this study had a fineness of 2800 cm^2/g and specific gravity of 2.73. Its chemical composition was 29.47 % SiO_2, 35.54% CaO, 19.27% Al_2O_3 and 3.49 % Fe_2O_3. ggbs had a fineness of 5860 cm^2/g and specific gravity of 2.88. Its chemical composition was 33.68 % SiO_2, 40.24% CaO, 14.37% Al_2O_3 and 0.29 % Fe_2O_3. The specific gravity, water absorption rate, and fineness modulus of the fine recycled aggregates were 2.61, 8.20%, and 3.66, respectively. Control mix design (water/blended ratio is 0.45) consisted of water (250.0 kg/m^3), ggbs (197.1 kg/m^3), co-fired fly ash (295.7 kg/m^3), fine aggregates (1355.2 kg/m^3) and superplasticizer (9.9 kg/m^3), respectively. The substitution ratio for recycled fine aggregates to natural fine aggregates was used as 10%, 20%, 30%, 40% and 50%. Flowability was measured in accordance with ASTM C230. Compressive strength was measured in accordance with ASTM C109. Absorption was conducted in accordance with ASTM C642 and SEM observations were conducted in accordance with ASTM C1723.

3 Results and discussion

3.1 Flowability

The flowability of non-cement blended materials containing various recycled fine aggregates is summarized in Tables 1 and 2. Due to the higher water absorbability of the recycled fine aggregates, different water demands had a significant effect on the flowability. For the water demand of 211.9 kg/m^3, the flowability was about 30% when the recycled fine aggregates were replaced from 0 to 30%; however, the flowability was almost 0% when the recycled fine aggregates were replaced up to 40 and 50%. When water demand was 250.0 kg/m^3, the flowability can be controlled at 110±5% for all mixes. In order to achieve the target of workability, water demand was changed to meet the flowability controlled at 110% ± 5%. Water used in the original design was 211.9 kg/m^3, and the water-cement ratio was 0.43. When water demand was increased to 250.0 kg/m^3, the corresponding water-cement ratio was 0.51. Therefore, the specimens had better quality and workability by increasing water demand. The subsequent tests were performed with a water-cement ratio of 0.51. In addition, different percentages of recycled aggregates in non-cement blended materials had no negative impact on flowability, which is consistent with the previous study [10].

Table 1. Flow test results of specimens (water-cement ratio = 0.43)

Test results (mm)	Mix no.					
	C6R0	C6R1	C6R2	C6R3	C6R4	C6R5
1	135	150	130	135	95	-
2	135	148	125	135	93	-
3	137	145	130	130	90	-
4	134	140	128	125	90	-
Average	135	146	128	131	92	-
Flowability (%)	35.3	45.8	28.3	31.3	-	-

Table 2. Flow test results of specimens (water-cement ratio = 0.51)

Test results (mm)	Mix no.					
	C6R0	C6R1	C6R2	C6R3	C6R4	C6R5
1	210	210	210	209	210	205
2	210	209	215	215	206	205
3	205	212	209	213	209	204
4	205	213	210	205	214	203
Average	208	211	211	211	210	204
Flowability (%)	107.5	111.0	111.0	110.5	109.8	104.3

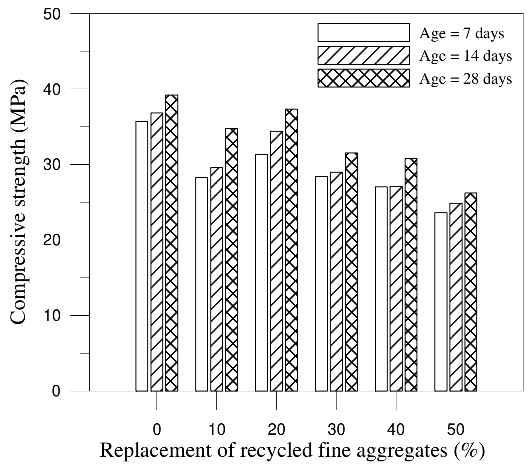


Fig. 1. Compressive strength histograms.

3.2 Compressive strength

The test results of compressive strength are shown in Figure 1. The test results found that at the same curing age, the compressive strength decreased with the increase of the replacement of the recycled fine aggregates. When the replacement of recycled aggregates exceeded 30%, the compressive strength tended to decrease significantly. This is because the recycled aggregates were more deformable than natural aggregates under compression. Hence, the strength of the recycled aggregates was lower than that of natural aggregates [11]. The fine aggregates and other blended materials had poor cementation properties, resulting in a tendency for their compressive strength to decrease. However, the compressive strength can be controlled above 35 MPa of the green non-cement blended materials containing 20% recycled aggregates.

3.3 Absorption

An absorption test was used to observe the compactness of the non-cement blended mortar specimens. From the results in Figure 2, it was shown that the absorption decreased as the age and the replacement of recycled aggregates increased, mainly because the microstructures of specimens were dense and compact. The pores in microstructures became smaller and the absorption tended to decrease. The cementing pastes on the surface of the recycled fine aggregates can be hydrated with cementless blended materials, which helps to increase the degree of compactness without external force, thereby reducing absorption. However, some specimens had the opposite trend of absorption because the surface of the mortar specimens ruptured, causing the internal pores and cracks to form a weak connection surface, which increased absorption.

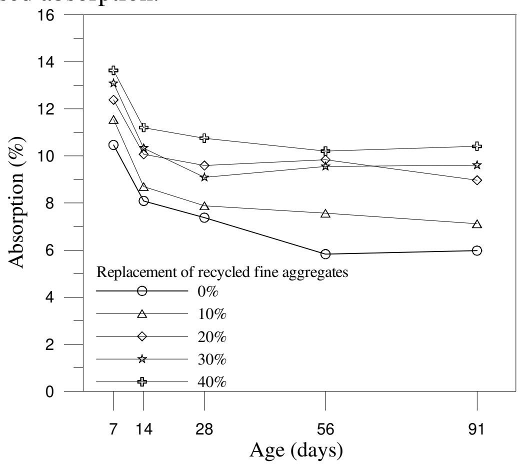
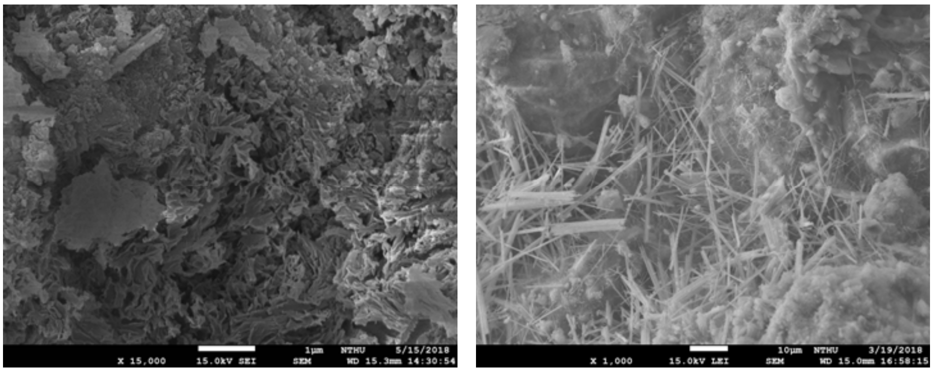


Fig. 2. Absorption development curves.

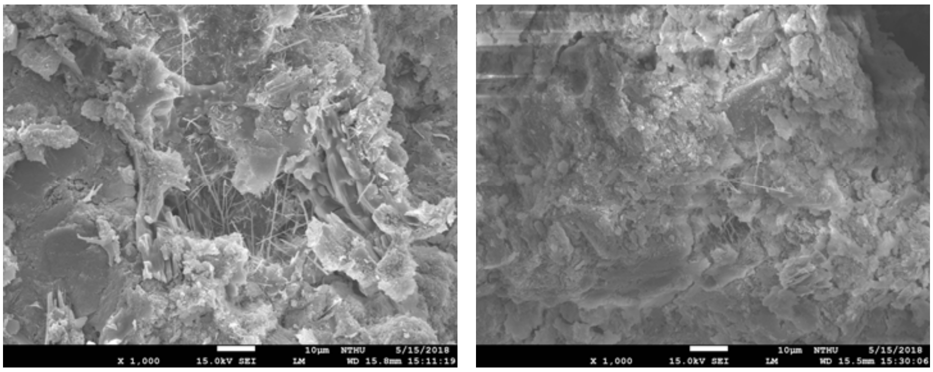
3.4 SEM observations

The SEM photos of the water-cement ratio of 0.43 and 0.51 at 28 days are shown in Figures 3(a) and 3(b), respectively. It can be seen that the cementation status of the specimens at the water-cement ratio of 0.51 was better than that of the water-cement ratio of 0.43. It can be found that the microstructures of the specimens were relatively more uniform and denser, so it can achieve improved workability and compressive strength. Figure 4(a) is the SEM image for the replacement of 10% recycled aggregates. It can be found that the specimen had better compactness. Figures 4(b) to 4(e) are SEM images of 20, 30, 40 and 50% replacement of recycled aggregates, respectively. Among them, in high substitution amounts, it can be found that the microstructures of the specimen were relatively loose, and the porosity of the internal microstructures reflected the increase of absorption. Besides, the C-S-H and C-A-S-H colloids can be observed in those SEM photos and the pores were mostly filled, resulting in reduced absorption. The microstructures of the specimen can also be observed with some needle-shaped ettringite (AFt) and hexagonal-flake hydrates as petal-like hydrated calcium aluminate (AFm). It indicated that the mixtures containing ggbs and co-fired fly ash can be produced with a more complete hydration reaction and enhanced higher compressive strength.

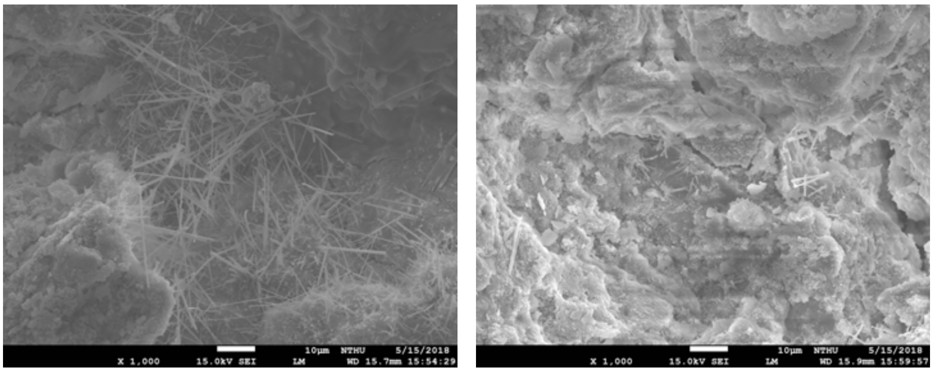


(a) specimen for water-cement ratio of 0.51 (b) specimen for water-cement ratio of 0.43

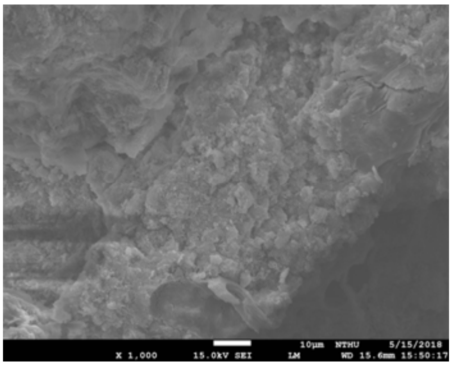
Fig. 3. SEM photo for non-cement blended specimens at the age of 28 days.



(a) 10% recycled aggregates (b) 20% recycled aggregates



(c) 30% recycled aggregates (d) 40% recycled aggregates



(e) 50% recycled aggregates

Fig. 4. SEM photo for non-cement blended specimens containing various amounts of recycled fine aggregates at the age of 28 days.

4 Conclusions

For the same flowability (210 mm), the compressive strength decreased and absorption increased as the replacement ratio of fine aggregates increased. Compressive strength of non-cement blended materials containing 20% recycled fine aggregates can reach the target strength of 37 MPa, which constitutes 95% of control non-cement blended specimens. SEM micrographs verified that the development in compressive strength obtained from the C-S-H and C-A-S-H colloids produced by $Ca(OH)_2$, SiO_2, and Al_2O_3, made the structure denser and resulted in its greater strength. Using this new green non-cement blended composites without the alkali activator in construction materials can be regarded as an innovative material to save natural resources.

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