Production of green low-carbon mortar containing recycled calcined clay from the tile factory and ground granulated blast furnace slag

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ABSTRACT

To mitigate environmental impacts and increase energy efficiency in the cement production process, alternative materials to clinker are now used in cement, allowing for the production of a larger amount of composite cement with identical properties from a certain amount of clinker produced by the cement factory. This is achieved through the appropriate combination of low-carbon and environmentally friendly materials. The aim is to produce cement that not only uses accessible resources but also reduces carbon emissions. In this study, recycled minerals (recycled clay (RC) and ground granulated blast-furnace slag (GG)), calcined clay (CC), and limestone (LS) powder were used as partial replacements for cement/clinker to create low-carbon cement. The properties of fresh mortar and compressive strength tests were considered. Accordingly, 16 mix designs were prepared, including 5 mortar mix designs containing CC, LS powder, and recycled materials as a cement replacement, and 9 mix designs containing CC, LS powder, and recycled materials as a clinker powder replacement, along with two reference mixes. The results showed that the compressive strength of the mixes containing RC at different ages was similar to that of mixes containing CC. Based on the results, the compressive strength of the mixes containing RC and LS with 30% replacement decreased by about 20% compared to the reference mix. Meanwhile, the reduction in compressive strength of the 35% replacement mixes containing recycled minerals was less than 10%.

KEYWORDS

Calcined clay; recycled; green mortar; low-carbon cement; ground granulated blast-furnace slag.

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1. Introduction

Cement is by far the most widely used manufactured material due to its compatibility, low cost, and the availability of raw materials [1]. The mass production of cement accounts for nearly 8% of human-made global carbon emissions [2, 3]. Nowadays, various supplementary cementitious materials (SCMs), such as natural pozzolans like clay, LS, or hydrated lime [4, 5], and artificial pozzolans like GG [6], are used to partially replace cement in order to reduce environmental impacts and achieve concrete sustainability. CC and LS powder have been introduced as SCMs due to their pozzolanic properties after being calcined at temperatures between 550 and 950°C and their filler effect, respectively [7, 8]. The literature reports that the compressive strength development of samples containing CC and LS powder was better compared to the reference sample [9, 10]. In some studies, low-kaolinite clays such as calcined kaolin waste and ceramic waste have been proposed as partial cement replacements for the production of low-carbon cement [11, 12].

Although numerous studies have been conducted on the production of low-carbon cement containing CC and LS powder, RC from biscuit grinding in tile factories has not yet been used as a SCMs in cement production. Furthermore, no study has been carried out to combine RC with LS powder or other recycled materials. Therefore, the aim of this study is to investigate the effect of recycled mineral materials (RC and GG) as partial cement replacements on compressive strength and to analyze their growth and development trends.

2. Methodology

In this study, CC, LS powder, and recycled mineral materials including GG and RC for the production of low-carbon cement have been introduced as complementary cement materials. The clays were calcined at 850°C for 1 hour. RC was considered as recycled calcined clay and was used without calcination process in the mixing design. After combining the powder materials, the mortar compressive specimens were made with a ratio of water-to-binder of 0.44 and sand-to-binder of 2.0 and were kept in a water chamber for processing until the ages of 3, 14, and 28 days. After curing processing, the compressive strength test was performed on the mortar specimens and the average of the obtained results was presented as the final result.

3. Results and Discussion

Compressive strength results are presented in Figure 1. The results of 20% substitution show that by reducing the RC content and increasing the GG content, the 3-day compressive strength has decreased and its 28-day compressive strength has increased. By examining the results of the mortar containing the same content of RC and GG ($K_{80}RC_{10}GG_{10}$), it can be seen that the compressive strength is acceptably similar to the reference mortar (K_{100}). This result can be attributed to the improvement of cement paste porosity due to the formation of secondary C-S-H gel due to suitable pozzolanic reactions of RC and GG, as well as the effect of morphology and particle size distribution of additives. Similarly, the results of 35% replacement also showed that adding GG and combining it with RC can lead to an increase in the long-term strength of the mortar.

The normalized compressive results show that the growth of compressive strength of mortar containing RC at the ages of 0-3 days is higher than the reference mortar (Figure 2). According to the figure, increasing the GG content and decreasing the RC content in the mortar has caused an increase in the compressive strength of the samples at older ages (3-28 days). So that using the same content of RC and GG in the mortars had the highest pozzolanic activity at the ages of 3-14 days.

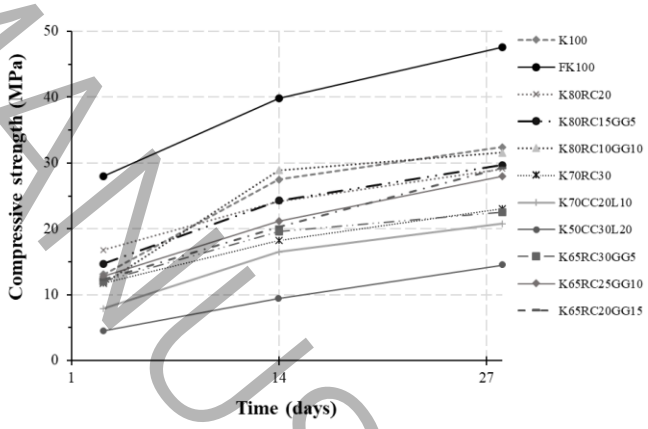


Figure 1. Compressive strength of clinker-based mortar samples

Based on Figure 3, almost all the mortars containing RC had an acceptable performance compared to the reference mortar. So that the difference in the compressive strength of low-carbon mortar with the reference mortar at an early age is less than 10%. As mentioned, the same combination of RC and GG has obtained an acceptable performance in 20% replacement of clinker, which according to the figure of the difference in compressive strength at the age of 28 days has reached below 4%. Finally, by comparing the results

of $K_{65}RC_{20}GG_{15}$ and $K_{65}RC_{25}GG_{10}$, it was observed that the appropriate combination of recycled materials can reduce the difference in compressive strength by 10-15 compared to the reference mortar.

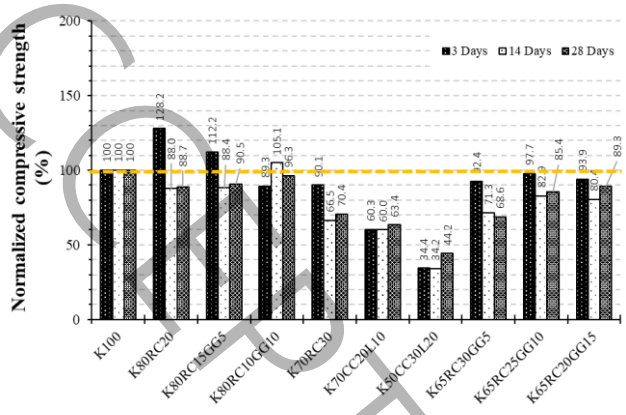
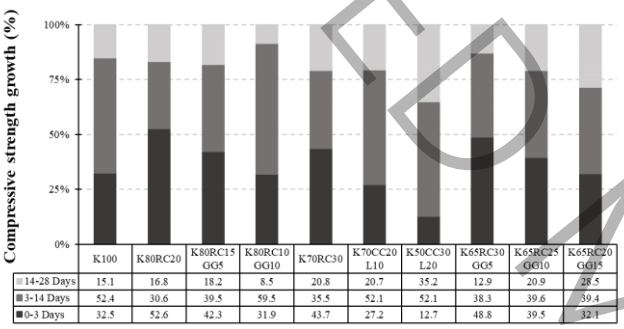


Figure 2. Normalized compressive strength of clinker-based mortar samples



	K100	K80RC20	K80RC15 GG5	K80RC10 GG10	K70RC30	K70CC20 L10	K50CC30 L20	K65RC30 GG5	K65RC25 GG10	K65RC20 GG15
14-28 Days	15.1	16.8	18.2	8.5	20.8	20.7	35.2	12.9	20.9	28.5
3-14 Days	52.4	30.6	39.5	59.5	35.5	52.1	52.1	38.3	39.6	39.4
0-3 Days	32.5	52.6	42.3	31.9	43.7	27.2	12.7	48.8	39.5	32.1

Figure 3. Compressive strength growth of clinker-based mortar samples

4. Conclusions

In this study, the feasibility of producing low-carbon mortar containing recycled materials in the country has been investigated. The most important results obtained in this research are as follows:

- The growth of initial compressive strength of mortar containing RC in replacing the clinker has been significant. On the other hand, the use of GG has increased the growth of compressive strength in the period of 14 to 28 days. The results showed that the simultaneous and optimal use of RC and GG can lead to the creation of effective low-carbon cement that has the same performance as ordinary cement. This happened due to the pozzolanic performance of RC and the microcrystalline effects of GG.

- The compressive strength of mortar containing calcined clay (both recycled and natural clay) and LS powder decreased compared to the reference mortar, and this value was less than 20%. Meanwhile, the compressive strength of mortar containing recycled minerals (RC and GG) has decreased by 10% with 35% replacement.

- Based on the results, using a maximum of 25% of RC in the combination of RC and GG can have well performance.

5. References

[1] P.K. Mehta, P. Monteiro, Concrete: microstructure, properties, and materials, (No Title), (2006).
[2] B. Sabir, S. Wild, J. Bai, Metakaolin and calcined clays as pozzolans for concrete: a review, Cement and concrete composites, 23(6) (2001) 441-454.
[3] K.L. Scrivener, A. Nonat, Hydration of cementitious materials, present and future, Cement and concrete research, 41(7) (2011) 651-665.
[4] R. Kajaste, M. Hurme, Cement industry greenhouse gas emissions–management options and abatement cost, Journal of cleaner production, 112 (2016) 4041-4052.
[5] M. Schneider, M. Romer, M. Tschudin, H. Bolio, Sustainable cement production—present and future, Cement and concrete research, 41(7) (2011) 642-650.
[6] Y. Zhao, Y. Gao, G. Chen, S. Li, A. Singh, X. Luo, C. Liu, J. Gao, H. Du, Development of low-carbon materials from GGBS and clay brick powder for 3D concrete printing, Construction and Building Materials, 383 (2023) 131232.
[7] Y. Cao, Y. Wang, Z. Zhang, Y. Ma, H. Wang, Recent progress of utilization of activated kaolinitic clay in cementitious construction materials, Composites Part B: Engineering, 211 (2021) 108636.
[8] V.M. John, B.L. Damineli, M. Quattrone, R.G. Pileggi, Fillers in cementitious materials—Experience, recent advances and future potential, Cement and Concrete Research, 114 (2018) 65-78.
[9] Y. Dhandapani, T. Sakthivel, M. Santhanam, R. Gettu, R.G. Pillai, Mechanical properties and durability performance of concretes with Limestone Calcined Clay Cement (LC3), Cement and Concrete Research, 107 (2018) 136-151.
[10] A. Ramezanianpor, A. Yadak Yaraghi, A. Zolfagharnasab, A.M. Ramezanianpour, Investigation of mechanical properties and chloride ions ingress in concretes containing calcined, Amirkabir Journal of Civil Engineering, 54(3) (2022) 1119-1132.
[11] C. Jesus, E.A. Junior, N. Braga, J.S. Junior, M.S. Barata, Coloured concrete produced from low-carbon cements: Mechanical properties, chromatic stability and sustainability, Journal of Building Engineering, 67 (2023) 106018.
[12] M. Mohit, H. Haftbaradaran, H.T. Riahi, Investigating the ternary cement containing Portland cement, ceramic waste powder, and limestone, Construction and Building Materials, 369 (2023) 130596.