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Recycling of crushed stone powder as a partial replacement for silica powder in extruded cement panels

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HIGHLIGHTS

- The synthesis of tobermorite is largely related to strength development.
- The optimized C/S mole ratio to substitute silica powder is 0.87.
- The curing procedures require pre-curing, atmosphere steam curing and autoclave curing.
- The key mechanism of durability performance is whether stable crystal of tobermorite forms.

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ABSTRACT

The continuously increasing amount of crushed stone powder normally coming from the production of crushed aggregates or sawing stone has led to an increase in the waste disposal costs or instances of improper disposal. In this study, the effective methodology to increase the utilization of crushed stone powder was studied by considering CaO/SiO_2 mole ratio in mix design. The hydrothermal reaction to synthesis tobermorite related to strength development was also considered to improve rigidity in hardened cement. The results showed the optimized C/S mole ratio is 0.87 and a valid method for curing conditions relating to hardened cement was desired to be acquired by 2 h of pre-curing, 4 h of atmosphere steam curing (65 °C) and 4 h of autoclave curing (180 °C, 10 atm). The extruded panels satisfied all performance requirements relating to fire resistance as well as sound insulation and can have a possible application to building materials. The main findings of this investigation revealed that the stable crystal formation of tobermorite by the hydrothermal synthesis reaction affects the most important mechanism in hardened cement and mix design by considering C/S mole rate in addition to the analysis of microstructures promotes the recycling of crushed stone powder for building materials.

1. Introduction

Recently, a system of recycling resources was widely accepted in the area of construction materials to maximize resource saving by recycling waste resources. Crushed stone powder coming from production of crushed aggregates or sawing stone is mostly buried or fragmentarily recycled through construction fill materials and structural backfill materials [1–3]. Therefore, the establishment of a resource recycling system is definitely required to use 100% of materials in their life cycle from the step of waste generation to practical use, not temporary recycling. Although multidirectional study for environmentally friendly treatment of crushed stone powder as well as recycling is now in progress, alternative suggestions are currently inadequate and require a more effectual alternative with a high efficiency treatment method to prompt a realistic recycling of it. A lot of research has been done trying to find out the methods for recycling by using waste materials, including stone sludge or powder, as construction materials [1,4,5,6,2,7–11]. Research has also been conducted to reduce drawbacks such as dry shrinkage and micro-cracks to maintain high performance when these materials are applied to concrete materials. One of the biggest disadvantages in the practical use of crushed stone powder (either concrete or cementitious materials) is the moisture content, which significantly reduces strength development and dry shrinkage during curing causes the lack of dense microstructure formation.

The utilization of hydrothermal reactions can be the solution to make up for these weak points. This reaction means that high water temperature and high water pressure are involved in the chemical reaction and it is called hydrothermal synthesis when

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specific materials are synthesized from the reaction. The main mechanism for strength improvement by hydrothermal synthesis comes from the synthesis of calcium silicate. The calcium silicates are made from the reaction between lime and silicate and largely depend on the CaO/SiO2 mole ratio, temperature, pressure and time [12–15]. Tobermorite crystallized from synthesis mechanisms in microstructure play an important role in the development of strength. The crushed stone powder analyzed in this study consists of 50–60% of SiO2 and 10–20% of AlO2, which can cause the crystallization of tobermorite through hydrothermal synthesis with reactions of CaO in cement. Furthermore, higher strength development can be obtained from the various combination of curing methods.

This paper has tried to use crushed stone powder to replace existing materials as well as hydrothermal synthesis reactions to generate the required performance. Also, various curing methods, such as pre-curing, atmosphere steam curing, and autoclave curing were considered to draw the most effective curing environments. Those various methods accelerate the crystallization of tobermorite through the combined reactions among SiO_2, AlO_2 and cement components by considering C/S mole ratio From the findings of the optimized conditions the extruding cement panels were made and evaluated by performing physical and mechanical property tests as well as fire-resistance and sound insulation tests to confirm their effective utilization as building materials.

2. Property of replacement materials

2.1. Physical property

In this study, the crushed stone powder produced from a stone factory which is located in Yang-ju region, Gyeonggi, Korea was used after removing some moisture by employing a filter press to solidify it. Various analyses were performed for understanding physical property of the crushed stone powder. First, particle size analysis of the crushed stone powder as shown in Fig. 1 was completed for the prediction of physical changes when replacing silica powder, which is an important component when it is combined with cement when producing an extruded cement mixture. Also, the particle size value comparison between the crushed stone powder and the silica powder was represented in Table 1.

Second, absorption tests for both the silica powder and the crushed stone powder were performed. The crushed stone powder (5.23%) as mentioned in the introduction showed greater absorption than the silica fume (3.54%). Third, the specific gravity of materials used in this study was calculated as follows: cement (3.15); crushed stone powder (2.71); silica powder (3.09); sand (2.65); silica fume (2.27). Fourth, particle shapes were visualized by using a Scanning Electron Microscope (SEM). Fig. 2 shows the geometry of the crushed stone powder and silica powder at ×2000 magnification. The stone powders are regularly distributed with sizes of 5–7 μm with angulated shape while the silica powders normally consist of 4–15 μm sizes with relatively irregular shapes. Those small particle sizes in the mixture significantly affect the fluidity of the cement matrix during the mixing procedure. In other word, the relatively irregular shape of the crushed stone powder compared to the silica powder means that the reduction in the fluidity should be considered when different types of components are designed to make a uniform mixture.

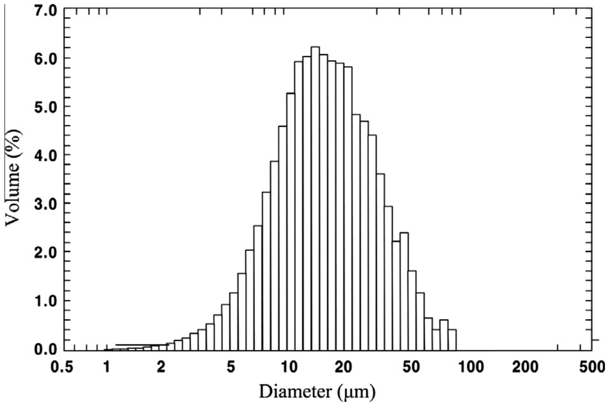

Fig. 1. Particle size distribution of crushed stone powder.

Table 1
Particle size distribution between crushed stone powder and silica powder.

Material	Mean (μm)	Standard deviation	Median (μm)
Crushed stone powder	19.13	13.72 μm (71.7%)	14.98
Silica powder	20.82	14.77 μm (70.9%)	16.69

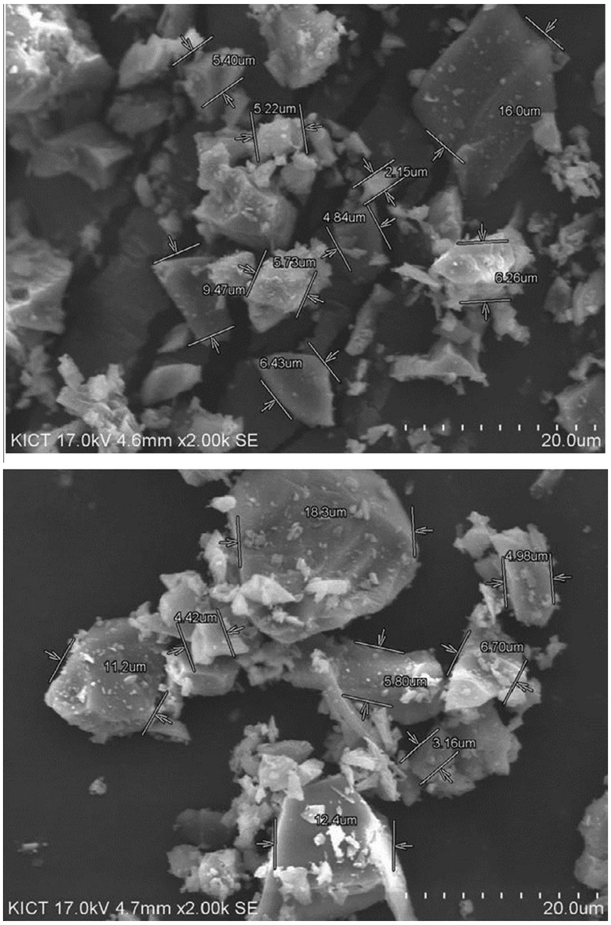

Fig. 2. Comparisons of the shape of particles: crushed stone powder (top) and silica powder (lower).

2.2. Chemical property

For mineral composition, X-ray diffraction analysis was used as shown in Fig. 3. The crushed stone powder is mainly comprised of components of Muscovite ($K_2O\cdot 3Al_2O_3\cdot 6SiO_2\cdot 2H_2O$), Albite ($Na_2O\cdot Al_2O_3\cdot 6SiO_2$), and Orthoclase ($K_2O\cdot Al_2O_3\cdot 6SiO_2$), but small amounts of Kaolinite ($Al_2O_3\cdot 2SiO_2\cdot 2H_2O$) and Calcite ($SiO_2\cdot Al_2O_3\cdot Fe_2O_3$) are also present. Quartz (α-SiO_2) peak was the greatest among various mineral organizations. Chemical compositions are represented in Table 2 by using an X-ray fluorescence analyzer. The proportion of SiO_2 in crushed stone powder was a lot less than that in silica powder and another composition, CaO, shows an even bigger difference. Therefore, those different compositions in stone powder ultimately lead to the modified mix designed by considering C/S mole rate to minimize the deviation caused by chemical combination. Other compositions, such as Al_2O_3, K_2O, CaO, Fe_2O_3 were indicated to be greater than those of silica powder. A test of Thermogravimetry–Differential Thermal Analysis (TG–DTA) was performed with a rate of 10 °C/min up to 1000 °C and test results were shown in Figs. 4 and 5. The proportion of weight reduction was −4.6% for the crushed stone powder and −0.8% for silica powder. Dehydration of free water and ettringite normally occurring within the range of 100–200 °C was not present in either of the figures. In the vicinity of 620 °C an endothermic reaction was observed for the silica powder and the crushed stone powder for 730 °C.