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Enhancement of low-cement self-compacting concrete with dolomite powder

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HIGHLIGHTS

- Dolomite powder was successfully applied for manufacturing high quality SCC.
- 28-Day compressive strength of concrete with 50% OPC reached 43.9–63.1 MPa.
- A high durability SCC with dolomite based filler could be produced.

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ABSTRACT

This study aims at exploring the benefits of using dolomite powder (DP) to improve the engineering performance of low-cement self-compacting concrete (SCC) with cementitious materials comprised of 50 wt % of ordinary Portland cement (OPC) and 50 wt% pozzolanic materials of ground granulated blast furnace slag (GGBFS/slag) and low calcium fly ash (FA). Experimental results showed that the DP addition to partially substitute for the pozzolanic materials had no impact on the setting properties of pastes with blended binder of slag and OPC while significantly improved those of the pastes with that of FA and OPC or ternary mixture of slag, FA, and OPC binder. In addition, the adjustment of DP addition to the above-mentioned three binders had successfully manufactured the self-compacting mortars (SCMs) with significant increase in the flowing ability and compressive strength, in which the DP addition of 30 wt% substituting for the total amount of pozzolanic materials resulted in the hardened mortars with highest compressive strengths after ages of 7 days. The improvement of compressive strengths of hardened SCMs can be obtained by the DP addition up to 50 wt%. The SCCs produced from the appropriate proportions of the resulting DP modified SCMs had the engineering properties mostly satisfying the technical requirements for practical concrete structures.

1. Introduction

The invention of self-compacting concrete or self-consolidating concrete (SCC) is one of the most important successes of the concrete industry, which will significantly contribute to the global development of sustainable construction materials in future. The definition of SCC itself means that the fresh mixture of concrete illustrates an adequate capacity of flowing, passing, and filling under the own weight to be applied to the structural construction with hard congestion from steel reinforcement distribution and formwork with complicated shape without any durable impacts related to segregation, blocking, and bleeding [1–3]. The application of vibration-energy-free SCC to the construction infrastructure, therefore, assures the concrete structure with the satisfactory quality almost independent of the craftsmanship of labor at constructing stages.

Actually, the curiously distinguished self-flowing performance of the SCC in comparison with the traditional concrete with consolidating vibration comes from the special ingredients of SCC mixture. In general, the proportion of SCC consists of the lower volume of coarse aggregate than that of normal concrete and fresh mortar with high deformability and suitable viscosity [3]. The laboratory research and jobsite practice on designing SCC show that the property of fresh mortar serves as an crucial factor affecting the expected performance of fresh concrete, implying

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the necessity of studying on the performance of self-compacting mortar (SCM) as suggested by the SCC founder [3] and the current case studies and practices on SCC [2,4–9]. Development of SCM design also leads to reducing the high consumption of time and cost because it avoids the loss on a great deal of labor and raw materials investigated during the trial process of SCC design [10]. In addition, studying on SCM contributes to enhancing the categories of new technology products of repair mortars normally used for construction maintenance [5].

Among the proportions of the SCC/SCM, the addition of filling powder (filler) partially substituting for ordinary Portland cement (OPC) is an ideal method making the SCC/SCM manufacture with the quadruple benefits of practice, technique, economy, and ecology. Indeed, as incorporating into SCC/SCM mixture, the filler plays an important role in modifying the flowing ability of the fresh concrete/mortar due to the optimized particles size distribution. The improvement on the viscosity of the fluid mixture with addition of the filler leads to the fresh concrete/mortar with significant improvement on resistances to bleeding and segregation. By replacing a certain quantity of OPC with the filling powder, the modified SCC/SCM significantly contributes to lower the cost of final product and flue gases emissions during OPC manufacture. Therefore, the exploration on the new fillers consisting of either reactive or inert powder with the mean size of particle smaller than 0.125 mm to be possibly applied to the SCC/SCM has been strongly encouraged. Typically, the conventional coal fly ash is one of the common pozzolanic fillers to partially replace OPC for producing SCC/SCM with excellent fresh performance and satisfactory engineering properties at the hardened state [4,11–13]. On the other hand, the utilization of the ground granulated blast furnace slag (GGBFS/slag) to partially replace OPC has been preferred for producing the SCC with lowered impacts on setting times and early strengths than those induced by using fly ash [14]. The existence of a large number of researches concentrating in the utilization of slag cement as the primary binder for SCC has been an apparent evidence proving the remarkable contribution of the slag as the pozzolanic filler to the SCC development [1,6,15–18].

On the other hand, the recycling of various industrial by-products from stone industries as one of the primary ingredients of powder fraction used in SCC/SCM has also become a researching interest. Limestone is probably the most commonly inert filler powder used to modify the engineering performance of SCC/SCM due to the global availability of such powder [19,20]. An investigation on SCC using alternative inert filler of limestone powder showed that the quarry dust with physicochemical properties similar to those of limestone could be successfully applied to SCC production with slight increase in superplasticizer addition [21]. Utilization of binary powder of limestone and quarry waste [22] or limestone and chalk powder [23] with an adjustment on the dosage of superplasticizer were proposed to produce SCC with significant reduction in the cost. The estimation on using the industrial wastes of marbles and tiles from factories to manufacture the SCC with acceptable rheological properties, mechanical performances, and durability was also reported [24–26].

In addition, the investigation concerning with the utilization of dolomite powder (DP) as the filling fraction of SCC also showed the interesting results [27]. Accordingly, the experimental observation clarified that the SCC with blended mixture of fly ash and DP (rather than the traditional limestone powder) with ratio of 3:1 illustrated the engineering properties mostly satisfying the requirements for researching practice and jobsite application. As such, the study initially drew a high potential of possibly manufacturing the commercial SCC/SCM with the utilization of the industrial by-product of DP as one of the primary fraction of filler. However, the studies exploring the potential of using such DP for concrete/mortar based advanced construction materials may have been limited to the normal workable concrete [28].

The literature review on the properties of SCC/SCM as aforementioned apparently points out the necessity of the basic awareness of SCM performance with proper filler, which can be served as a crucial indicator to predict the properties of the resultant SSC or as a new industrial product applied to repairing. Thus the exploration on the alternative filling powder such as DP suitable for SCC/SCM manufacture is also of encouraging. Therefore, the aim of the current study is to simultaneously explore the effects of DP addition on the engineering properties of both SCM and SCC with common cementitious materials comprised of varied combination of lower ordinary Portland cement (OPC), ground granulated blast furnace slag (GGBFS/slag), and low calcium coal fly ash (FA), which has not been previously presented in published literature or study cases. As a result, the goals of this study not only contribute to confirming the possible application of DP as the alternative filler other than limestone powder for SCC/SCM, but also intermediately rank the efficiency of utilization of various amounts of DP for SCC/SCM.

2. Experimental program

2.1. Materials

Type I Ordinary Portland cement (OPC) in accordance with ASTM C150 [29], ground granulated blast furnace slag (GGBFS/slag), low calcium coal fly ash (FA), and the dolomite powder (DP) supplied from China were used to comprise the powder fraction of SCC/SCM. The physicochemical properties of the powder were shown in Table 1. Accordingly, the FA illustrated the chemical composition matching the classification of ASTM C618 [30] for the Class F fly ash commonly applied as pozzolanic materials for wide fields of construction infrastructure. The DP comprised mainly the calcium and magnesium oxides, making it become well-known as an impure limestone. Natural sand with specific gravity of 2.65, water absorption of 1.0%, and finesse modulus (FM) of 2.72 was used as the fine aggregate. The coarse aggregate used in this study came from crushed stone with the maximum size of 19 mm. The specific gravity and water absorption of the coarse aggregate were 2.67 and 0.8%, respectively. For fabricating the SCM and SCC with good bonding property between the ingredients, both the fine and coarse aggregates were carefully washed before being used for mortar/concrete manufacture. The particle size distributions of the raw materials shown in Fig. 1 were used to facilitate the individual role of each solid fraction. As expected from the figure, the particle sizes of the DP mostly concentrated on the similar range to that of other powders (i.e., OPC, slag, or FA), implying the suitable application of DP as partial replacement for the fraction of pozzolanic filler. The comparison showed that the mean size of the DP was comparable to that of the FA powder but significantly smaller than that of OPC or slag powder. To control the workability of the SCM and SCC, the commercial Type G superplasticizer (SP) was adapted.

2.2. Mix proportions

The designing principle used for the proportions of SCMs/SCCs was based on the suggestion of the founder of SCC [3]. Accordingly, the performance of appropriate fresh SCM and volume ratio of coarse aggregate to total volume of solid were the crucial factors influencing on the performance of the resultant SCC. As such, in this case, the effect of the DP on the rheological properties of SCMs with each type of binder was firstly assessed to carry out the appropriate proportions of mortars with minimized consumption of time, labor, and raw materials. Such the appropriate proportions of SCMs with optimal DP addition after completing the first stage of experimental study were selected for the manufacture of resulting SCCs.

In this study, the control binders used for producing SCMs were comprised of low 50 wt% of OPC and 50 wt% of total amount of pozzolanic filler. The pozzolanic filler used in this study included plain ground granulated blast furnace slag (GGBFS/slag), plain low calcium coal fly ash (FA), or the blending mixture of both slag and FA with the weight ratio of slag:FA of 50:50. The fraction of DP varied at 0, 10, 30, 50, 70, and 100 wt% as partial replacement for the pozzolanic filler was used for the assessment of its effects on the performance of SCMs. To optimize the appropriate ingredients of SCMs with the DP addition, the volume ratio of the fine aggregate to total volume of mortar and the weight ratio of water to powder were fixed at 0.4 and 0.32, respectively. The dosage of superplasticizer (SP) was adjusted based on the expected fresh properties of the SCMs as mentioned in next subsection. The mix proportions of the SCMs are detailed in Table 2. On the other hand, the mix proportions of the SCCs with the appropriate ingredients of SCMs modified by the DP addition (to be discussed in later section) are shown in Table 3 by using the fixed