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The use of limestone to replace physical filler of quartz powder in UHPFRC

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Abstract

One of the key features of ultra-high performance fiber-reinforced concrete (UHPFRC) is the inclusion of quartz powder (QP) as a filler to optimize granular packing. However, QP has not been compared against limestone powder (LP) in terms of the filler effects such as hydration characteristics, strength development, and autogenous shrinkage of the concrete. In this study, the effectiveness of LP as a filler is evaluated against that of QP in order to verify its potential for use as a new functional and human-friendly filler in UHPFRC. For this purpose, five types of fillers consisting of similar-sized QP and LP were designed while maintaining the same water-to-cement (w/c) and superplasticizer-to-cement (sppl/c) ratios. The early age strength increased by up to 12% depending on the LP content, due to the filler effect which accelerates cement hydration by providing a preferential surface for nucleation. However, the LP only acted as an inert filler, like QP; it did not participate in the formation of additional hydration products as confirmed by conducted analytical experiments. Although the 28-day strength was 4%-7% lower than that of the classical UHPFRC containing QP, the 91-day strength was 1%-4% higher. The early age shrinkage was also accelerated by the filler effect of the LP, but its duration was shortened in proportion to the LP content.

Keywords: filler effect; limestone powder; UHPFRC; cement hydration; autogenous shrinkage

1. Introduction

There has been an increasing interest in the use of limestone powder (LP) for the sustainable development and utilization of Portland cement (PC)-based construction materials. This interest has been motivated by the advantages associated with the use of LP, such as low price, homogeneous composition, abundant reserves, ease of quality control, and worldwide availability [1-3]. LP has been used as a functional filler to accelerate cement hydration as well as to improve the workability and fresh properties of concretes [4-6]. Due to the filler effect, LP accelerates the initial hydration of PC by providing additional surfaces for the nucleation and growth of the hydration products [6-11]. Furthermore, LP aids the formation of stable AFm-carbonate equivalents (such as hemi- and/or monocarboaluminate phases), although it has no pozzolanic properties and possesses very weak reactivity [2, 7, 9, 11, 12]. This increases the volume of the hydration products, leading to a decrease in the porosity and an increase in the strength [2, 11, 13]. As a result, the use of LP in concretes has contributed to a reduction in the overall consumption of PC [9]. Additionally, LP can be used economically as a mineral plasticizer to make self-compacting concrete (SCC) by facilitating a reduction in the requirement for polycarboxylate ether (PCE)-based superplasticizer (sppl) [1, 9, 14].

The positive effects (that is, hydration and lubrication effects) of LP are more pronounced in concretes with low water-to-cement (w/c) ratios [2, 14, 15]; such concretes are characterized as containing large amounts of unhydrated cement and PCE-based sppl [16, 17]. In particular, ultra-high performance fiber-reinforced concrete (UHPFRC), which was developed by optimization of the granular mixture, has an extremely low w/c ratio and a high superplasticizer-to-cement (sppl/c) ratio [18-20]. To reduce both the high demand for PC (of around 800 kg/m^3) and the unhydrated cement content (of hundreds of kg/m^3) in the concrete [21, 22], a reasonable method for replacing a proportion of the PC with LP has recently been proposed [23, 24]. Strictly speaking, this method has been applied only to ultra-high performance concrete (UHPC) that does not contain steel fibers, and even then, conflicting results have been reported. Yu et al. [23] showed a decrease in compressive strength at 28 and 91 days when