



Review

A review on use of limestone powder in cement-based materials: Mechanism, hydration and microstructures

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HIGHLIGHTS

- The action mechanism of limestone powder includes four effects.
- The physical effect of limestone powder depends on its particle size and amount.
- The chemical effect of limestone powder relies on the alumina content.

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ABSTRACT

Limestone powder (LS) has been widely used in cement-based materials; and reportedly, can influence their properties by filler, nucleation, dilution and chemical effects. The action mechanism of LS mainly depends on its particle size and amount. The filler effect of LS refines the microstructure and reduces the porosity of cement-based materials. Its nucleation effect accelerates the hydration of C_3S , increases the amount of hydration products and reduces the porosity of cement-based materials at early ages. Its dilution effect reduces the hydration peak of C_3S , decreases the amount of hydration products and increases the porosity of cement-based materials. Its chemical effect promotes the appearance of third hydration peak, forms carboaluminate and reduces the porosity of cement-based materials.

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1. Introduction

According to data from the U.S. Geological Survey (USGS) in 2017, the world production of Portland cement was approximately 4.2 billion tons [1]. Production of 1 ton of cement clinker generates approximately 0.87 ton of carbon dioxide [2]. Thus, production of cement significantly increases the global carbon dioxide emissions. Incorporation of supplementary cementitious materials (SCMs) is an effective way to reduce the use of cement clinker and carbon dioxide emissions. Moreover, the incorporation of SCMs would not be detrimental to the mechanical properties and even enhances the durability of the resulting concrete with a proper mix design [3–5].

Limestone powder is a by-product of the limestone quarry, and it has been used in cement-based materials for many years. In 1938, Bessey [6] first reported that CaCO_3 could react with cement to form calcium-carboaluminate. The formation of calcium-carboaluminate was influenced by the amount and fineness of LS, but it had little effect on the compressive strength of mixtures [7]. In 1948, Deniels [8] claimed that the incorporation of LS increased the compressive strength of concrete. Its filler effect was later confirmed by an expert committee in Norwegian government [9]. In 1976, Soroka and Setter [10] reported the accelerating effect of LS on hydration of cement due to its nucleation effect. Subsequently, a great number of studies were conducted on incorporation of LS in cement-based materials. It is now well-documented that the presence of LS can promote the precipitation of C-S-H and accelerate the hydration of cement [7]. The effects of LS on the workability [11], strength [12–14], dimensional stability [15,16] and durability [17,18] of concrete were also investigated.

Based on extensive research on application of LS in cement, the European standard first introduced and defined Portland-limestone cement in 1987, and allowed replacing Portland cement with $15 \pm 5\%$ LS [19]. In 2000, the European standard (EN 197-1) defined different type of Portland cement blends with LS [20], and the allowable replacement level increased to 35% [20]. In 2008, the Canadian standard (CSA A3001-08 [21]) also introduced Portland-limestone cement with LS contents below 15% of total binder. Subsequently, Portland-limestone cement was designated as GUL (general use limestone cement) in CSA A3001-10 [22]. In 2012, ASTM C595 [23] also introduced Portland-limestone cement with LS up to 15%.

Many researchers have conducted studies on LS in cement-based materials. This paper reviews the action mechanisms, hydration and microstructures of cement-based materials containing LS. The aim of this review is to summarize previous research progress and to suggest some needs for future studies.

2. Action mechanism of limestone powder in cement-based materials

Different mechanisms were used to explain the action mechanism of LS in cement-based materials. Some scholars [24–26] divided the action mechanism of LS in cement-based materials into

two broad mechanisms of filler effect (including filler effect, nucleation effect and dilution effect) and chemical effect, while other specified filler effect, nucleation effect, dilution effect and chemical effect as distinctive mechanisms [27–30]. Thus, it is necessary to clarify the action mechanisms of LS in cement-based materials before discussing the effects of LS on the hydration and microstructure of cement-based materials. In order to define the action mechanisms of LS in cement-based materials, in this paper, they are classified as filler effect, nucleation effect, dilution effect and chemical effect.

2.1. Origin of limestone powder

Limestone powder is crushed and ground from natural limestone. Belsazar Hacquet [31] first distinguished limestone from dolomite as sedimentary rock. Limestone is mainly composed of skeletal fragment of organisms. Calcite, aragonite, vaterite and amorphous calcium carbonate are the available forms of mineral composition of limestone. Limestone can be formed from marine organisms, lacustrine [32] and evaporite depositional environments [33,34]. It can also be formed from chemical precipitation of calcite or aragonite. Based on the method of formation, LS could be crystalline, clastic, granular or massive.

2.2. Filler effect

The filler effect of LS is mainly related to its particle size. The calculated packing density of mixtures containing cement, slag and LS is illustrated in Fig. 1 [25]. It can be seen from Fig. 1(a) that the packing density of mixtures is lower when the particle size of LS is coarser or comparable to Portland cement, whereas the packing density is higher when the particle size of LS is finer than that of cement as shown in Fig. 1(b). Therefore, if the particle size of LS is finer than cement particle, incorporation of LS will fill the voids between cement particles and improve the particle size distribution and finally increase the packing density of cement-based materials [35]. As a result, the incorporation of LS reduced the water requirement of concrete and increased the compressive strength and durability of concrete [24]. Although the incorporation of fine LS could fill the void between cement particle, the incorporation of LS will reduce the flowability of cement-based materials if the particle size of LS was too small since its specific surface area was high. The flowability of UHPC decreased by 27% when 3% nanolimestone was incorporated into UHPC [36].

2.3. Nucleation effect

Since Soroka and Setter [10] first introduced the nucleation effect of LS, many researchers have confirmed that fine LS provides nucleation sites for hydration products to precipitate [37], accelerates the hydration reaction [38], and improves the hydration degree of cement [24]. It was reported that the enhanced precipitation of C-S-H on the surface of LS was due to similarity between

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