Cement & Concrete Composites 44 (2013) 41–49

Contents lists available at SciVerse ScienceDirect

Cement & Concrete Composites

journal homepage: www.elsevier.com/locate/cemconcomp

Jet mill grinding of portland cement, limestone, and fly ash: Impact on particle size, hydration rate, and strength

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ARTICLE INFO

Article history:
Received 14 July 2012
Received in revised form 12 February 2013
Accepted 24 March 2013
Available online 15 April 2013

Keywords:
Jet mill grinding
Grinding
Blended cement
Fly ash
Limestone
Fineness

ABSTRACT

While the majority of commercial ordinary portland cement (OPC) is ground using a ball mill or a vertical roller mill, other industries have shown that jet mill grinding can be an alternative approach for grinding materials. This paper investigates the potential application of jet mill grinding for two systems. The first system is a blend of OPC and 15% limestone, and the second system is a blend of OPC and 40% fly ash. It was observed that when jet mill grinding is used, the average particle size of the powders is decreased to approximately 4 μm or less with a narrower particle size distribution than that achieved using ball milling. In addition to evaluating the size and shape of the particles obtained from the jet mill grinding process, this paper focuses on evaluating, using isothermal calorimetry, the effect these changes in particle size and distribution have on the extent and rate of hydration as well as their effect on the compressive strength of cement pastes or mortars.

This study also investigated differences between inter-grinding and blending separately ground materials to form an OPC/limestone mixture. Both inter-ground and separately ground OPC/limestone mortars demonstrated an accelerated hydration at early ages accompanied by an increase in early age strength. This appears to be primarily due to the increased surface area of the finer particles that provides more available surface for the hydration reaction. The inter-grinding appeared to be more effective than grinding the materials separately because an improved graded particle size distribution was obtained. The inter-ground OPC/limestone mixture shows accelerated initial hydration at water to powder ratios (w/p, where powder = cement + limestone) of 0.50 and 0.35 when compared with the samples before grinding. At the lower w/p of 0.35, the OPC/limestone mixture appears much more efficient. In the OPC/fly ash mixture, jet mill grinding also accelerates the rate of hydration and strength development.

1. Introduction

Several different techniques are available to control the fineness of cement-based materials. These include a series of non-destructive approaches (i.e., sieving [1–3], air classifying [2], or magnetic-extraction [3] methods) as well as destructive approaches (i.e., mechanical grinding methods [3–12]). The cement industry typically uses ball-mill grinding as the preferred method to reduce the size of clinker in cement manufacturing [3–9]. Vertical roller mill grinding [13] is being increasingly used. Roller milling [14] and airflow milling [15] have also been used to grind cements with the particle gradation and shape change dependent on the specific milling procedure. Research described in this paper examines the use of an alternative milling method, jet mill grinding, and in particular, the effects that changes in particle size and distribution resulting from jet mill grinding have on the extent and rate of hydration.

Jet mill grinding works by using multiple air jets or air streams to accelerate cement (or fly ash and limestone) particles from a very low velocity to the sonic velocity range. As collisions occur between cement and/or supplementary cement particles, the cement and any supplementary cementitious materials are ground. Jet mill grinding has been used in other industries as a method to modulate the particle size distribution [16–24]. When the jet mill is compared to the ball mill, the jet mill is able to grind materials to a smaller particle size (1–10 μm) with a narrower particle size distribution [5]. The fluidity of jet mill ground cement/limestone mixture and shape of cement particles have been examined

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http://dx.doi.org/10.1016/j.cemconcomp.2013.03.023

[5], and it was found that after jet mill grinding, the fluidity of OPC/limestone pastes increased. The jet mill ground particles showed similar dimensions in orthogonal directions. Furthermore, when ball milling is used, the final product may be contaminated with fragments of the ball-milling media that are ground off or broken off during the milling process. Phase transitions may also occur in the material due to heat generated in the grinding process. This can be avoided with jet milling because the material being ground is itself the milling media, and minimal additional heat will be generated during the process because of the cooling effect of the jets [25]. The jet mill grinding process also has the capability to produce blended powders since multiple streams of material can be introduced into the jet mill simultaneously [26].

The potential for using jet-mill processing may be of particular interest now due to the growing interest in reducing the clinker content per ton of cement as a method to reduce CO_2 production. Blended cements that incorporate mineral powders are being increasingly developed due to their economic and environmental protection benefits [3]. In addition to the benefit of reducing CO_2 production, the use of cement/limestone or fly ash blends can improve performance [27]. For example, finer fly ash may improve mechanical properties and the hydration reaction without sacrificing workability [1–3,6–9,27,28]. Limestone fines have also been found to be effective in accelerating the rate of hydration or helping to control viscosity for self-consolidating concrete [5,10–12,27,29–31]. The jet milling approach may even open up the possibility of using previously land-filled materials as supplemental materials since regrinding may make these materials more chemically active.

2. Experimental methods

Research described in this paper focuses on measuring particle size distributions obtained by jet mill grinding of two cement-based mixtures: (1) OPC/limestone and (2) OPC/fly ash, and assessing the impact of the particle size distribution on the rate of hydration (using isothermal calorimetry) and on compressive strength of standard cylinder specimens. The following section describes how the materials were prepared and tested.

2.1. Jet mill grinding

A jet mill works by using multiple air jets or air streams to accelerate particles from low velocity to a very high velocity (sonic). Collisions between particles that are induced in this high-velocity environment occur in the center of the chamber and cause the grinding. An illustration of a typical particle path of a jet mill is shown in Fig. 1a (adapted from Ref. [26]). The material is fed into the milling device through a hopper at a constant rate set by the operator. As the material is fed into the system, it passes through the jet mill. The air streams accelerate the particles causing them to collide with one another. The collision causes the particles to fracture, and thereby to reduce their size. Unlike ball milling, there is a reduced risk of contaminating the product with milling media because the material itself is the milling media. The interior walls of the chamber can also be lined with materials that are highly resistant to abrasion to minimize powder contamination [26].

A Micron-Master Jet Pulverizer jet mill (0.61 m in diameter)was used in this study to grind the materials as shown in Fig. 1a and b. The materials to be ground were blended for 60 min in a 0.19 m^2 V-blender (this step is only conducted for blends). After blending, approximately 45 kg of the pre-blended material was transferred into the hopper for jet mill grinding. The feed rate was set at 9.07 kg/h. The pressure of air feeds to the mill was 552 kPa. Once all of the material passed through the jet mill, the materials were defined as having completed one-pass of grinding.

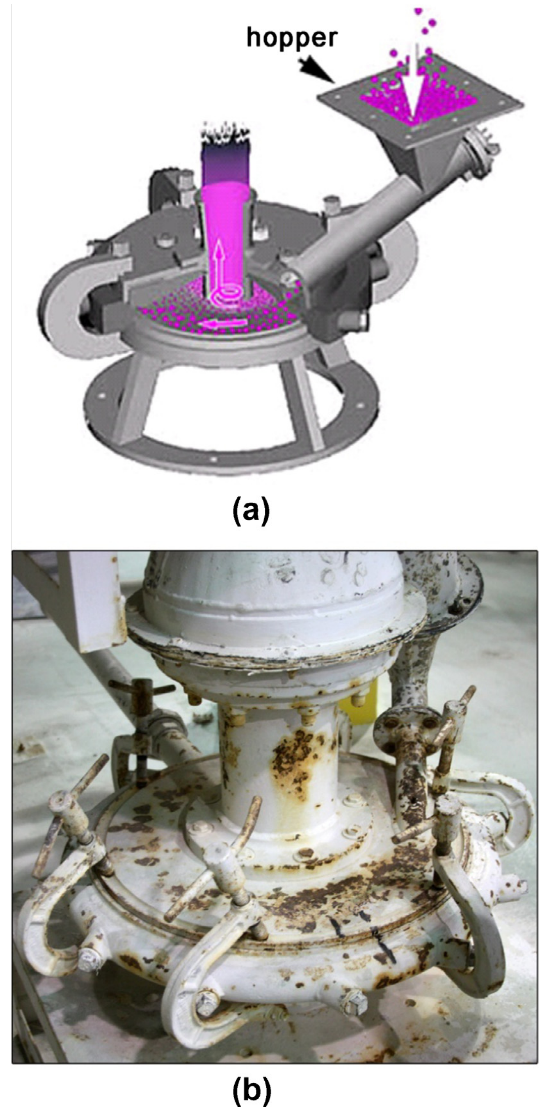

Fig. 1. (a) A conceptual illustration of a typical jet mill adapted from Ref. [26]. (b) A picture of the jet mill used to grind materials.

In this study, a maximum of three passes through the jet mill were performed to determine the appropriate grinding level for the OPC/limestone mixtures.

2.2. Constituent materials

Two samples of blended cements were investigated. One sample consisted of a blend of ordinary portland cement (OPC1) and a limestone powder. The second sample contained a different ordinary portland cement (OPC2) blended with Class C fly ash. The chemical compositions of the materials are listed in Table 1. The mineral compositions of the two cements were obtained from X-ray diffraction and the Rietveld fitting method.

The mixture proportions for the two samples are shown in Tables 2 and 3. The following notations were used: (1) C, L, and F were used to identify cement, limestone, and fly ash, respectively; (2) G in front of C, F, and L denotes a material ground by jet mill grinding; (3) the mass percentage of limestone or fly ash in each mixture was noted after C, F, and L except for cement reference (C); and (4) I and S denote whether the material was inter-ground (I) or ground separately (S). The inter-ground materials were blended and ground in the jet mill, whereas the separate-ground