

Communication

Replacement of “coarse” cement particles by inert fillers in low w/c ratio concretes

II. Experimental validation

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Abstract

It has been suggested that in low water-to-cement ratio (w/c) concretes, the “coarser” cement particles could be replaced by an “inert” filler with little loss in performance in terms of hydration and strength development. This communication presents the results of an experimental study conducted to validate this hypothesis, using a coarse limestone filler and a classified cement. The cement and limestone powders were both classified with a cutoff diameter of about 30 μm . The coarse limestone was then blended with the fine cement, and water-to-solids ratio=0.3 pastes and mortars were prepared to compare to reference (original cement powder) systems. The results for chemical shrinkage for the pastes were consistent with a simple dilution of the cement by the limestone and also with the results predicted by the CEMHYD3D hydration model. In mortars, the predicted compressive strength loss in the filled system at 7 days was consistent with model predictions, and furthermore, at 56 days, no detectable difference in strength was measured. Thus, this study further supports the idea that coarse limestones could be used to replace equivalent size cement particles in low w/c concretes with little loss in hydration and strength performance.

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Keywords: Blended cements; Compressive strength; Hydration; Modeling; Particle size distribution**1. Introduction**

As the construction industry adapts to a global marketplace and growing environmental regulations, the efficient usage of materials and energy becomes evermore important. Many years ago [1] and much more recently [2], it has been suggested that in low water-to-cement (w/c) ratio concretes, some cement could be saved by replacing the “coarser” cement particles with relatively inert fillers, such as ground sand [1] or limestone powder [2]. The addition of limestone powder to cement is a common practice in Europe but is not yet commonplace

in the U.S. The most recent version of the ASTM C150-04 standard specification for Portland cement [3] now permits limestone additions up to 5%. Computer simulations have suggested that this replacement can be made in low w/c ratio concretes, with little if any detrimental effects on performance in terms of hydration and compressive strength development [2]. This communication presents the results of a preliminary experimental study conducted to directly verify this hypothesis. Further support for this concept can be found in the recent work of Bonavetti et al. [4] who studied an ordinary Portland cement and two interground limestone cements in pastes and concretes at a variety of water-to-cementitious materials ratios and showed little loss in 28-day strength for the blended systems. In the study to be presented here, the coarser cement particles are manually replaced

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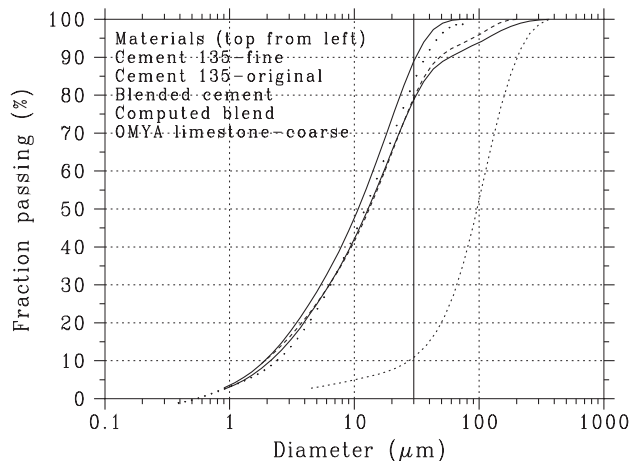


Fig. 1. Measured particle size distributions for materials used in this study.

by similarly sized limestone as opposed to intergrinding the two materials.

2. Experimental and modeling approach

Studies were conducted utilizing Cement and Concrete Reference Laboratory cement sample 135 [5] and a commercially available white limestone powder obtained from OMYA.¹ The two powders were particle size separated using an alpine air classifier with a cutoff size of approximately 30 μm . The fine fraction of the cement (predominantly below 30 μm) was blended with the coarse fraction of the limestone (predominantly above 30 μm) in a v-blender to prepare a blended system with 15% limestone by volume (assuming specific gravities of 2.71 for the limestone and 3.2 for the cement). A 15% by volume replacement level was chosen based on previous computer simulations [2] that suggested this to be the maximum replacement level for a $w/c=0.3$ system without compromising performance. The particle size distributions (PSDs) of the original and fine cements, the coarse limestone and the blended system were measured using laser diffraction techniques. The cumulative PSDs so obtained are shown in Fig. 1, along with the calculated distribution for the blended system based on its volumetric/mass proportions. It can be observed in Fig. 1 that the separation was basically successful, with only 10% of the particles being finer or coarser than the 30 μm cutoff for the limestone and cement powders, respectively.

The blended system was used to prepare cement pastes and mortars with a water-to-solids ratio (w/s) of 0.3. Control mixtures were also prepared using the original cement 135

powder. For the pastes, to assess hydration rates, chemical shrinkage measurements [6] were executed for a period of 10 days. The maximum expanded uncertainty [7] in the calculated chemical shrinkage has been previously estimated [6] to be 0.001 ml/g, assuming a coverage factor of 2 [7]. For the mortars, compressive strength cubes were prepared according to ASTM C109 specifications [3] but with a $w/s=0.3$. Their compressive strengths were evaluated after 7 and 56 days of curing in a tank of lime-saturated water. Three cubes were tested for each mixture at each age. The mixture proportions for the mortars are provided in Table 1. All curing and measurements were conducted at a temperature of 25 $^{\circ}\text{C}$.

All simulations were conducted using version 2.0 of the NIST CEMHYD3D program [6,8] and the Virtual Cement and Concrete Testing Laboratory web-based interface [9]. Three-dimensional starting microstructures with $w/s=0.3$ were created based on the measured PSDs and phase compositions of cement 135 [5] and the blended system. The starting microstructures were then hydrated using the CEMHYD3D codes and the calculated chemical shrinkage and compressive strength developments compared to the experimental data. In the model, compressive strengths were calculated based on Power's gel-space ratio concept [6,10] with a strength prefactor of 123.5 MPa for the mortar cubes. Power's gel-space ratio for strength prediction has been applied successfully in the past to limestone blended cements [4]. While limestone is not extremely reactive, its slow conversion to a monocarboaluminate phase ($\text{AFmc}-(\text{CaO})_3(\text{Al}_2\text{O}_3)-\text{CaCO}_3-11\text{H}_2\text{O}$) [11,12] was included in the reactions present in the updated CEMHYD3D codes.

3. Results and discussion

The measured chemical shrinkages for the two cement pastes are provided in Fig. 2. From the figure, it can be seen that the limestone is basically functioning as a simple dilutant in terms of the observed chemical shrinkage, as the normalized chemical shrinkage for the blended system is basically identical to that of the original cement. No indication of a significant acceleration or retardation or significant reactivity of the limestone is indicated by the chemical shrinkage results. This is consistent with the majority of the results present in the literature, as summarized by Hawkins et al. [13]. As shown in Fig. 3, the CEMHYD3D model provides a good fit to the

Table 1
Mixture proportions for mortars for strength testing

Material	Mass (g)
Cement 135 or blended system	1035.6
Water	301.2
Graded sand	1910.6
Water-reducing admixture (ASTM C494 Type A [3]; naphthalene sulfonate-based)	15.69

¹ Certain commercial materials and equipment are identified in this paper to specify the materials used and the procedures employed. In no case does such identification imply endorsement by the National Institute of Standards and Technology, nor does it indicate that the products are necessarily the best available for the purpose.

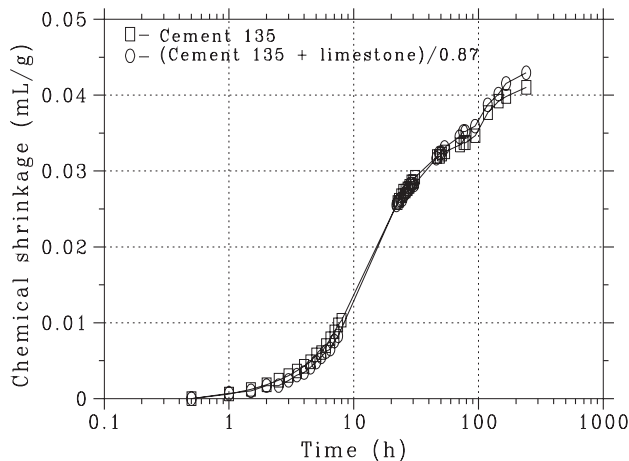


Fig. 2. Measured chemical shrinkage for cement pastes with $w/s=0.3$ for CCRL cement 135 and blended system (normalized by cement mass fraction).

experimental chemical shrinkage data for the blended system. A similarly good fit (not shown) was obtained for the base cement 135 system.

The compressive strength results are provided in Fig. 4. The CEMHYD3D predicted values for the 7-day strength lie well within the precision of the experimentally measured values. At 56 days, there is more deviation between model and experiment, but more importantly, experimentally, there is no observed strength difference between the original and the blended systems, as both achieved average compressive strengths of nearly 100 MPa. The extra hydration achieved in the blended system at later ages due to its effectively higher w/c ratio appears to be sufficient to compensate for the reduction in cement content [2,4]. It would be expected that the two systems have basically equivalent amounts of capillary porosity at later ages (and, thus, equivalent strengths according to Power's gel-space ratio theory).

It is important to note the criticality of replacing the coarse cement particles with limestone. If one was to replace

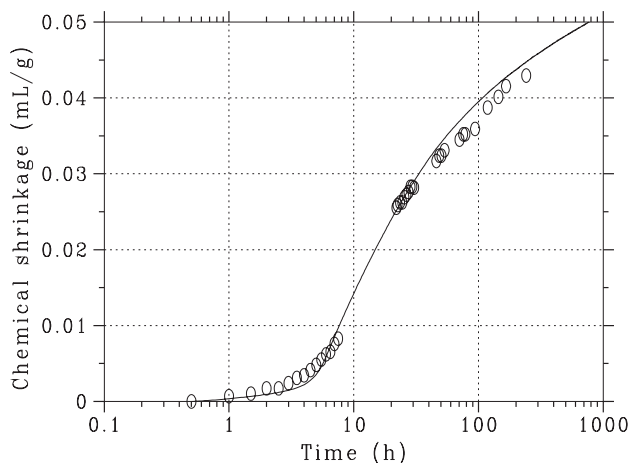


Fig. 3. Measured (O) and model (solid line) chemical shrinkage (per mass of cement) for blended system with $w/s=0.3$ cured under saturated conditions at 25 °C.

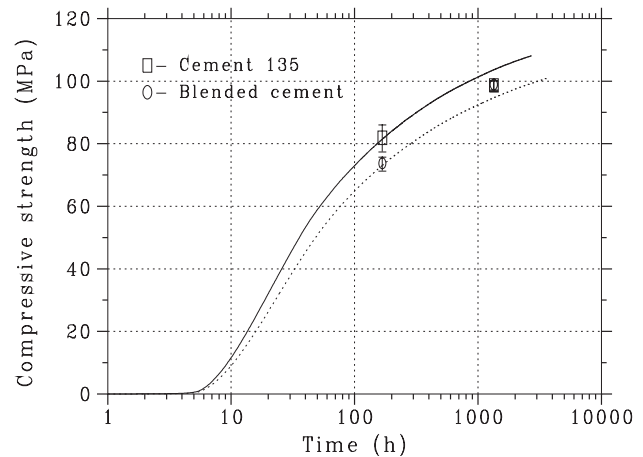


Fig. 4. Measured (\square and \circ) and model (lines) compressive strength development for original cement (solid line) and blended system (dashed line) mortars with $w/s=0.3$ cured under saturated conditions at 25 °C. Error bars indicate plus or minus one standard deviation in the experimentally measured values.

the finer cement particles instead, the computer simulation results suggest that a significant reduction in achieved hydration and compressive strength development would be obtained in the equivalent (limestone volume fraction of 15%) blended system. Naturally, this is because it is the finer cement particles that make the largest contribution to hydration and strength development, particularly at early ages [1,10]. Intergrinding of the limestone and cement will likely arrive at an intermediate between the coarse limestone/fine cement and fine limestone/coarse cement systems. The studies conducted by Bonavetti et al. [4] have in fact indicated that the higher fineness often produced in interground limestone blended cements, along with their higher effective w/c ratio, may result in systems whose performance in terms of hydration and strength is basically equivalent to the original (lower fineness) cement. Whether the limestone is interground or directly replaces the coarser cement particles, the usage of cement is reduced, with concurrent ecological and economical advantages. However, the advantage of classification and replacement over intergrinding could be in a cost and energy savings inasmuch as no energy will be expended in further grinding of the coarse limestone.

4. Conclusions

This preliminary experimental study has indicated the feasibility of replacing only the coarser cement particles in a high-performance (low w/s) mortar or concrete by an inert filler to conserve cement. Although the concept was investigated by Wig [1] almost 100 years ago, few if any direct applications of the concept have been found. While adding limestone to cement to achieve cost savings is a common practice in many parts of the world, the judicious replacement of coarse cement particles by similarly sized

limestone may provide equivalent economic incentives with little or no reduction in long-term quality.

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