Limestone Cement in Shotcrete

By Jonathan E. Dongell

Today, the use of supplemental cementitious material (SCM) (fly ash, microsilica, or slag) with portland cement is commonplace. The advantages range from ease of pumping and application to increased rheology and durability. Recently, ultra-fine (micro-fine) limestone "filler" additions, beyond the amounts used as a grinding aid, are being introduced into cements produced in the United States. Many countries allow limestone replacement for certain types of cement. Some countries allow as much as 35% replacement for "general purpose" cement.[1] Replacing a portion of the cement with limestone fines produces a more energy-efficient product and lessens greenhouse gases, but the challenge is to do so "while succeeding in maintaining the fundamental characteristics of hydraulic cement."[2] Perhaps a better goal is to do so while maintaining or improving the fundamental characteristics of the "parent" portland cement; in other words, producing cement that is "green" without sacrificing the performance, characteristics, and durability of the "parent" cement.

In the United States, several ASTM Standards,[3-5] ACI Codes,[6,7] and guides regulate the composition of limestone fines and its usage in concrete mixture designs. However, current ASTM Standards do not require that limestone fineness be fine enough to ensure a similar performance to that of the "parent" portland cement (or "optimizing" the fineness). Instead, current standards focus on requiring a minimum strength, which is designed to ensure that limestone cement performs its primary function as a hydraulic cement binder. Limestone additions that are not "optimized," or ground finer as the limestone replacement increases, can increase permeability and sorptivity, reduce abrasion resistance, and have a higher water demand; thus, producing an overall loss in durability when compared to using portland cement alone.[8-12]

It seems logical that if "optimizing" fineness is an essential factor in producing limestone cement with similar or equivalent properties to the parent portland cement, more stringent fineness requirements should be mandated. Exceptions to the optimized fineness requirement could be made for tertiary blends or blended cements that incorporate combinations of pozzolan and limestone filler, or where an equivalent performance can be demonstrated. Unfortunately, existing standards and codes do not provide specific requirements for this essential aspect of limestone fillers added to portland cement. Until they do, shotcrete companies should consider the following information.

Cement companies cannot be expected to produce cement that is ideal for every usage. For shotcrete, the applicator must ensure that the concrete mixtures with limestone cement produce the specific characteristics and properties of the in-place material that provides the required serviceability and durability in the service environment. It is recommended that prior to using limestone cements in the field, various mixture designs incorporating limestone cement be produced for lab testing. These should then be shot on a number of test panels to ensure the mixture produces an acceptable end product and to familiarize the field crew with the unique material characteristics and workability traits.

Use in Dry, Nonaggressive Exposures

There are significant advantages and disadvantages that should be considered when using limestone cement in relatively dry exposures. In general, increased amounts of optimized micro-fine limestone—up to 15% replacement of the cement—have been shown to slightly improve certain characteristics and properties of portland cement, including increased rheological performance (pumping, placing, and finishing ability); decreased water demand; and decreased drying shrinkage. Therefore, a shotcrete placement where

Table 1: Current allowable limestone limits in cement

Current cement standard specifications	Maximum Allowable
ASTM C150	Up to 5%
ASTM C595	From 5 to 15%
ASTM C1157	No limits

little to no moisture will be present during service life, or where only a mild threat of a chemical-attack environment exists, limestone "filler" replacements up to 15% appear to be acceptable. Again, this assumes that the portland cement and limestone combination has been "optimized."

This increased durability, in which little to no water contact or only mild chemical attack is likely, is due to the fact that increasing the amount of limestone "filler" decreases the amount of cement, which, in turn, decreases the amount of calcium hydroxide normally created as cement hydrates. As the amount of calcium hydroxide decreases, chemical deterioration associated with calcium hydroxide decreases. And, while calcium carbonate formed with limestone cements is also vulnerable to certain water-contact and chemical-attack environments, it is less vulnerable than calcium hydroxide. Secondly, micro-fine limestone has been shown to densify the paste matrix (particle packing), reduce the gap—or distance between—the cement compounds and sand/aggregate (the interfacial zone), and interact with the calcium aluminate component of cement early on to form carboaluminates, which are more stable in dry, nonaggressive environments.[1,8-15]

Overall rheology (pumping, placing, and finishing ability) and workability of the material can be significantly enhanced using optimized micro-fine limestone additions, which are reported to decrease bleed, increase the adhesion of the material to the substrate, and increase cohesion of the material itself. However, the opposite affect can occur as limestone fines increase in coarseness greater than 45 microns (325 mesh). It is also significant to note that while certain workability characteristics may improve using coarser limestone fines, in general, overall durability decreases.[1,8,9,11,12,14]

Use in Wet, Chemically Aggressive Exposures

When shotcrete is placed in a constant moisture/water contact environment, or where a moderate to severe chemical attack environment exists, the overall durability of cement with limestone "filler" decreases with the increase in limestone (calcium carbonate). In such environments, the combination of calcium hydroxide and calcium carbonate becomes more susceptible to attack, and accelerated deterioration of the concrete surface exposed to such conditions is reported. Limestone additions should not be allowed where the potential for sulfate attack (as is common in wastewater treatment facilities or high sulfate soils), accelerated chloride intrusion, or corrosion of reinforcement is a potential risk. Therefore, in shotcrete structures with constant moisture/water contact or where a moderate to severe chemical attack is likely to exist, the addition of limestone "filler" above 5% is not recommended.

Finally, as a helpful guideline, several studies reported a correlation between the fineness of the cement and limestone filler based on the amount of limestone replacement. Based on these reports, it is suggested that the current accepted fineness requirement of bulk fineness of under 45 microns (approximately 325 sieve or 3000 Blaine) and finer is not alone sufficient

Table 2: Compression Strength of Market-Available White Portland Cement vs. White Limestone Cement

Sample I.D.	Type	Date	*w/cm* ratio	7-day	28-day	90-day
White cement 'A', in.	2 x 2 cube	28-Aug-09	0.50 (s)	6181	7765	n/t
White cement 'B', in.	2 x 2 cube	28-Aug-09	0.48 (s)	6529	8328	n/t
White cement 'A', in.	2 x 2 cube	26-Oct-09	0.48 (s)	6333	8143	8455
White cement 'D', in.	2 x 2 cube	26-Oct-09	0.47 (lab)	6436	9879	10116
White cement 'D', in.	2 x 2 cube	28-Aug-09	0.52 (s)	6273	7838	n/t
White cement 'D', in.	2 x 2 cube	10-Aug-10	0.54 (s)	6018	8275	8595
White cement 'A', in. with 15% limestone	2 x 2 cube	12-Jun-12	0.58 (s)	4374	5435	6096
White cement 'A', in. ('parent' cement)	2 x 2 cube	12-Jun-12	0.52 (s)	5614	6240	8211
White cement 'E', in.	2 x 2 cube	6-Sep-12	0.52 (s)	6791	7826	8499
White cement 'D', in.	2 x 2 cube	28-Aug-13	0.52 (s)	7204	9026	r/p
Whie cement 'B', in. ('parent' cement)	2 x 2 cube	27-Aug-13	0.49 (s)	6234	9936	r/p
White cement 'A', in.	2 x 2 cube	28-Aug-13	0.54 (s)	6706	8556	r/p
White cement 'B', in. with 10% limestone	2 x 2 cube	28-Aug-13	0.52 (s)	5064	9301	r/p
White cement 'F', in.	2 x 2 cube	27-Aug-13	0.54 (s)	5506	9184	r/p

Note: n/t is not tested; (s) is field versus lab *w/c*; r/p is results pending

Table 3: Rough fineness conversions for cement

Micron	Mesh	Blaine
74	200	2000
44	325	3000
37	400	3350
30	600	3600
25	710	4000
14	1410	5400
7	—	7800

Note: Some of the references in this paper refer to Blaine fineness and some refer to direct particle size analysis. This table is provided to allow a rough comparison to be made between the two methods of reporting fineness. The Blaine Fineness does not directly correlate to micron or mesh fineness.

to produce limestone cements with equal properties to portland cement. A preferable bulk fineness range for the limestone fillers to produce a limestone cement that is comparable to the "parent" cement would be 30 microns (approximately 600 sieve or 3600 Blaine) and finer for 10% limestone replacement and 15 microns (approximately1450 sieve or 5400 Blaine) and finer for 15% limestone replacement.[1,14,16,17]

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***Jonathan E. Dongell** is currently Director of Research & Development at Pebble Technologies, Scottsdale, AZ. Dongell has worked in concrete construction and with cementitious materials for over 30 years, His roles have included Technician, Superintendent, Manager, Contractor, and President. He was past president of both Whitestone Cement Company, Scottsdale, AZ (1998-2005), and Universal White Cement Co, Inc, Glendale, AZ. (1992-1998). He is a member and Past Chair of ACI Committee 524, Plastering, and is a member of ACI Committees 201, Durability of Concrete; 225, Hydraulic Cements; 232, Fly Ash and Natural Pozzolans in Concrete; 308, Curing Concrete; 350, Environmental Engineering Concrete Structures; and 555, Concrete with Recycled Materials; and is a former member of ACI 116, Terminology and Notation (discharged 2007). He currently serves on the ACI Concrete Research Council (CRC) Committee. He is a voting member on the American Shotcrete Association (ASA) Pool & Recreational Shotcrete Committee; American Society of Testing Materials (ASTM) Main Committees, and several ASTM Subcommittees, including C4.01, Cement; Lime; Gypsum; and C4.02, Concrete and Aggregates. Dongell is also the author of several books, including The Durability of Cementitious Materials in a Water Contact Environment.*