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Type IL cement use in precast, prestressed concrete

■ This article reviews the impact of limestone on cement hydration and strength gain and discusses the fresh, mechanical, and durability properties of concrete containing Type IL cement.

■ Strategies are also suggested to help precast, prestressed concrete producers make the switch to Type IL cement.

Portland cement used in precast, prestressed concrete construction has evolved considerably since the Walnut Lane Memorial Bridge opened in 1951 as the first prestressed concrete beam bridge built in the United States. Changes have included increases in cement fineness and minimum compressive strength, modifications to chemical composition, and inclusion of processing additions.[1] These changes are a result of improvements in scientific knowledge of the cement reactions, improved control over the manufacturing process, and changes in market expectations about performance.

Portland cement will likely continue to evolve in response to economic, regulatory, and technological changes. The current drive for changes in portland cement manufacturing primarily comes from the desire to reduce its carbon footprint. Globally, large quantities of portland cement are used; as a result, use of this material contributes 5% to 8% of human-generated carbon dioxide (CO_2) emissions.[2–3] Government regulation, carbon taxes, and shareholder and client demands to reduce CO_2 are causing the cement industry to take action. Specific examples of these market forces affecting the cement industry include the following:

- Carbon taxes: Carbon taxes in the European Union have greatly increased the cost to produce cement, incentivizing cement companies to cut costs through more efficient and less carbon-intensive manufacturing processes. The European Union has also introduced a carbon border adjustment plan, which imposes tariffs on imported products manufactured through carbon-intensive methods. Canada uses a federal system of carbon taxes and cap and trade allowances except in those provinces that have developed their own carbon-reduction programs.

- Carbon-reduction pledges: Most U.S. cement plants are owned by foreign multinational corporations. These companies are members of the Global Cement and Concrete Association, which has developed a road map to net-zero carbon concrete by 2050.[4] In addition, in 2021, the Portland Cement Association released a similar road map to net carbon neutrality for the U.S. cement and concrete industry.[5] The participating companies have pledged to meet greenhouse-gas-reduction targets in the road map in response to government and shareholder pressure. These targets apply companywide, even if the cement plant is not located in an area with a carbon tax.

- Government policies and regulations: Local, regional, and state agencies are beginning to implement policies and regulations regarding embodied carbon. The first jurisdiction to implement carbon limits into building codes was Marin County, Calif.[6] The embodied CO_2 limits required by the county for high-early-strength concrete used in precast, prestressed concrete applications allow for 30% higher embodied carbon dioxide equivalent (CO_2e) per cubic meter compared with standard mixtures. Other local jurisdictions and states have followed similar approaches to those used in Marin County to implement carbon limits.

- Owner demands: Many owners, including government agencies, large developers, and private corporations such as Amazon, are now demanding that their construction projects use low-carbon concrete.[7] The U.S. General Services Administration has begun requiring third-party-verified environmental product declarations that include greenhouse gas emissions and embodied carbon limits for most projects based on the compressive strength and type of concrete used, as shown in **Table 1**.[8–9] These embodied carbon limits represent a 20% reduction from nationwide industry average embodied carbon values.[10] Because about one-third of all concrete in the United States is bought by state and local governments,[11] government project requirements in the United States can change the industry.

Background on Type IL cement

One of the simplest ways for cement companies to reduce their carbon footprint while maintaining similar performance is to intergrind raw limestone with the cement clinker when manufacturing cement. Cements containing ground raw limestone fines have been used successfully in construction for nearly 60 years with excellent performance. Cements containing more than 5% ground raw limestone fines are referred to as portland-limestone cements (PLCs).

The compositions and properties of cements containing limestone fines have been standardized by multiple agencies worldwide. Cements containing limestone fines have been allowed in the German specifications since 1965 and the French specifications since 1979.[12–13] The specifications in the United Kingdom, Europe, South Africa, and Singapore allow limestone addition levels of 21% to 35% in CEM II/B cement.[13] The Canadian Standards Association first allowed up to 5% limestone fines in portland cement in 1983 and in 2008 started allowing up to 15% interground limestone in some cements.[14]

Limestone fines have been allowed by ASTM International and used in cements in the United States for about two decades. Cements containing up to 5% limestone fines were first allowed in ASTM C150[15] cements in 2004. Using the ASTM C1157[16] performance specification, cement with up to 15% limestone has been used in states such as Colorado and Utah since about 2006.

Type IL cement is a type of PLC that meets the specific composition and property limits of ASTM C595.[17] Type IL PLCs, which have a limit of 15% limestone, were added to the ASTM C595 blended cement specification in 2012 along with

Table 1. General Services Administration concrete embodied carbon limits

Specified compressive strength f'_c, psi	Maximum global warming potential limits for GSA low-embodied-carbon concrete, kilograms of carbon dioxide equivalent (CO_2e) per cubic meter		
	Standard mixture	High early strength	Lightweight
≤2499	242	314	462
2500–3499	306	398	462
3500–4499	346	450	501
4500–5499	385	500	540
5500–6499	404	526	n/a
≥6500	414	524	n/a

Note: n/a = not applicable. 1 psi = 6.895 kPa. Source: General Services Administration (2022).

Type IT, which permits up to 15% limestone combined with a supplementary cementitious material (SCM) such as fly ash or slag cement. The amount of limestone fines added to the cement is given in parentheses following the cement type. For example, Type IL(11) designates an ASTM C595 cement with 11% limestone fines. Limestone used in Type IL cements must have a calcium carbonate content of at least 40% and a total calcium carbonate plus magnesium carbonate content greater than 70%.[17]

Use of limestone fines can result in CO_2 savings of 10% on average, which would be the equivalent of 8.1 million metric tons (8.9 tons) of CO_2 per year if all U.S. cement plants used limestone fines. ASTM C595 added a high early strength (HE) designation to Type IL cement in 2021 with the same 1-day and 3-day strength requirements as Type III cement (1740 and 3480 psi [12 and 24 MPa]) in ASTM C109[18] mortar cubes, respectively). Type IL(HE) could be used as a replacement for the Type III cement commonly used in precast concrete applications.

Plants typically make Type IL cements with a 1-day strength equivalent to that of the ASTM C150 cement that the plant makes from the same clinker. To accomplish this, the Type IL cement is typically ground to achieve an approximately 100 m^2/kg higher Blaine fineness than the companion ASTM C150 Type I or Type III cement.[19] The cement needs to be finer because the softer limestone is preferentially ground, making the limestone particles smaller than the clinker particles. To achieve a 1-day strength similar to that of the ASTM C150 cement made from the same clinker, the cement clinker for Type IL cement must be ground to the same particle size as the limestone; the equivalency of the particle sizes is confirmed by the same percentage of total particles being retained on a no. 325 sieve (45 μm sieve) for the ASTM C150 cement as for the Type IL cement.[19–20]

Since 2021, many U.S. cement plants have either switched from producing ASTM C150 cement to producing ASTM C595 Type IL cement or announced that they are switching.[21–22] In some local markets, ASTM C150 cement is no longer available, and it is expected that in the near future, ASTM C150 cement will either not be present in the U.S. market or only available in very limited locations. As a result, concrete producers will have to redesign their mixtures to use Type IL cements.

Limestone reactions in cement

Limestone fines in cement are often mistakenly considered to be inert fillers that do not provide much benefit to strength development. This false notion has led some precasters to be hesitant to use Type IL cement. While most strength from cement hydration results from calcium silicates (C_3S and C_2S in the cement), some calcium carbonate fines react chemically with aluminate phases (such as C_3A) in the cement to form carboaluminate hydrates. These phases are good space fillers in concrete, resulting in a decrease in porosity and increase in strength with 3% to 5% limestone fines.[23] **Figure 1** illustrates this effect for one type of cement tested by Ramezanianpour and Hooton.[24] The very small ground limestone particles also serve as nucleation sites that accelerate hydration of the cement, improving early strength development.[25] These benefits have limits: whereas small additions of limestone fines provide an increase in strength relative to that of a portland cement without any limestone fines, large proportions of limestone may increase the porosity and reduce the strength of the concrete. Typically, a PLC with 15% to 25% limestone content achieves the same 28-day strength as the same source of cement without any limestone, with some variability in strength because of differences in the cement and limestone chemical and physical properties.[13]

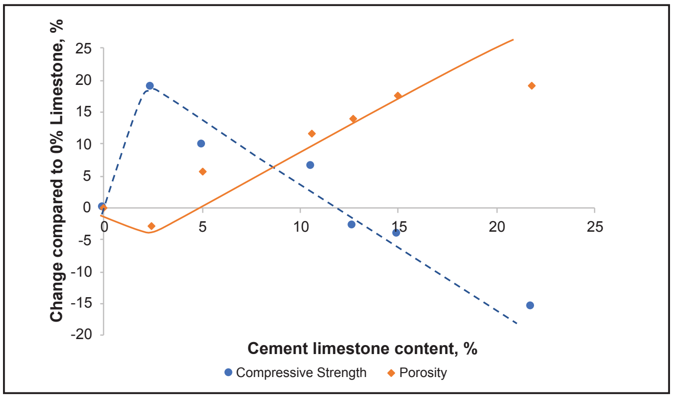

Figure 1. Effect of limestone content on strength and porosity for one cement. Source: Ramezanianpour and Hooton (2014).

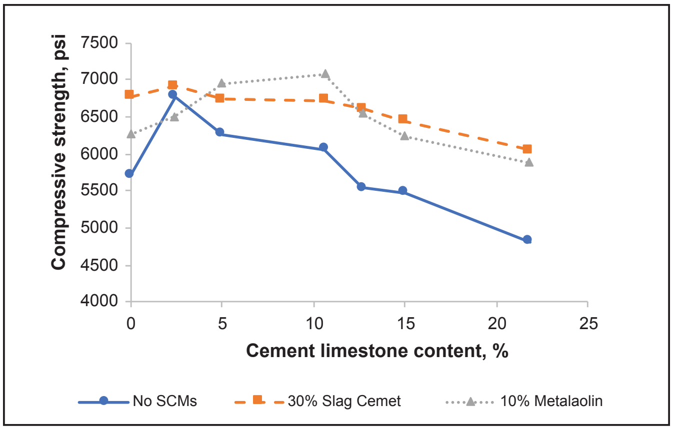

Figure 2. Association of limestone content in cement with 28-day compressive strength of mortar with and without supplementary cementitious material. Note: 1 psi = 6.895 kPa. Source: Ramezanianpour and Hooton (2014).

There is also no need to reduce the proportions of SCMs used in concrete mixtures when switching to Type IL cement. SCMs with high alumina content such as slag, metakaolin, and fly ashes also react with the limestone fines to increase strength and durability.[24–30] **Figure 2** illustrates the benefits of using SCMs with high alumina content with cements that contain limestone fines. The reaction of limestone fines with SCMs that have high alumina content can even allow for higher SCM replacement levels that further improve sustainability and durability while still meeting 28-day strength requirements.

Fresh properties

The effect of Type IL cement on the fresh properties of concrete depends on the fineness of the cement and the amount of limestone it contains. However, the variations in fresh properties observed in concrete mixtures that use different Type IL cements tend to be similar to the variations noted when comparing concrete mixtures that use Type I/II cements from different plants. Concrete producers can make adjustments to accommodate any small differences in the workability or setting time in the same way that they normally make adjustments when changing between different sources of ASTM C150 cements.

Concrete workability

Concrete workability is a function of the solid packing fraction (inverse of water content), particle shape and texture, particle size distribution, and particle surface area. As mentioned, Type IL cement is ground slightly finer than Type I cement, which leads to small differences in workability. Better particle packing from the smaller limestone particles can provide some mitigation for the higher water demand normally associated with higher fineness; as a result, the workability of a concrete mixture containing Type IL cement is only slightly different from that of a concrete mixture containing ASTM C150 cement made with the same clinker. When an ASTM C595 Type IL cement is ground to give similar strength gain to an ASTM C150 cement made with the same clinker, the overall differences in concrete workability can be, though not always, minor enough that they are not a concern when switching from ASTM C150 to ASTM C595 Type IL cement.[31] **Figure 3** shows that for the same clinker, large increases in cement surface area generally result in reduced slump and workability.[28] This is the same effect on workability that would be expected when increasing the fineness of a cement to make a Type I cement into a Type III cement.

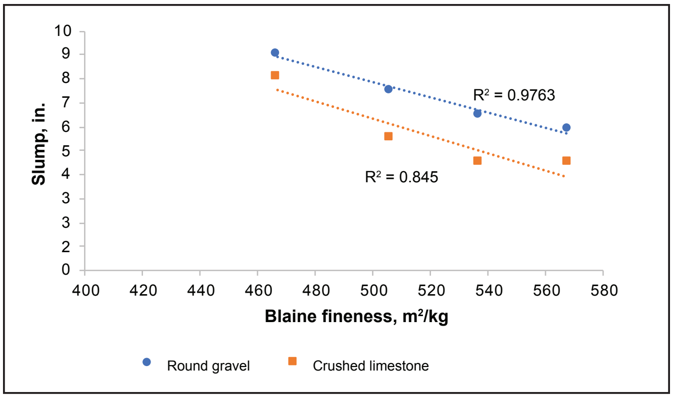

Figure 3. Effect of Type IL cement fineness on slump for concrete made with the same clinker and approximately 10% interground limestone fines. Note: 1 in. = 25.4 mm. Source: Data from Hansen et al. (2020).

Setting time

The presence of a higher number of fine limestone particles has been reported in some cases to contribute to a small reduction in setting time. The higher the cement fineness was, the larger the reduction in setting time typically experienced.[32] This finding may be explained by the nucleation effect of the small limestone particles accelerating cement hydration. A study that used ASTM C1753, *Standard Practice for Evaluating Early Hydration of Hydraulic Cementitious Mixtures Using Thermal Measurements*,[33] to examine the setting time of Type IL cements found that when limestone fines were used, the setting time was higher in some cases and lower in others. Overall, the investigators found that limestone fines had no statistically significant effect on the setting time.[34]

Air content

When the air-entraining admixture additions are the same, concrete made with Type IL cement typically has similar or slightly lower air content than concrete made with ASTM C150 cement.[14, 34–35] This difference is almost always within 1%, with most comparisons showing air contents within the margin of error specified in ASTM C231.[36] Even in cases where the air content of concrete made with Type IL cement was slightly lower than that of concrete made with ASTM C150 cement, no differences were seen in the air-void-spacing factor.[14] If there is a concern because the air entrainment decreases slightly when an ASTM C595 Type IL cement is used instead of an ASTM C150 cement, a small increase in the air-entraining dosage can increase the air content in the concrete. The compatibility between the Type IL cement and the air-entraining admixtures should be confirmed.

Mechanical properties

Compressive strength

In most ASTM C150 cements, limestone fines already make up 3% to 5% of all content, with the limestone fines acting to decrease concrete porosity and consequently increase concrete strength. Higher levels of limestone in the cement will further increase concrete strength to a point; then, with all other things being equal, the 28-day compressive strength of concrete will typically decrease from the peak with additional limestone additions (Fig. 1). However, when cement producers optimize the fineness and calcium sulfate content of Type IL cements, mortar compressive strengths on mill test reports for the ASTM C150 cement and Type IL cement will likely be similar.

Elgalhud et al. analyzed data from 171 publications to compare the compressive strengths of concrete made with PLC and concrete made with portland cement without added limestone.[13] The analysis showed that on average, concrete with a limestone content of 17.5% had a compressive strength similar to that of concrete made with portland cement. This average finding is based on tests of many cements; results in specific cases will vary based on the clinker used to make the cement.

Increasing the fineness of cement can significantly increase the cement's early-age strength. To make Type III cement, most cement plants grind the same clinker that is used for their Type I/II cement to a greater fineness and use a slightly higher proportion of calcium sulfate to control setting time. The same principle applies to cement containing limestone fines, as shown in **Fig. 4**. In some cases, Type IL cement can be ground finer, with the content of gypsum optimized for the finer grind, to produce Type IL(HE) cement.

Together with SCMs such as slag cement or metakaolin, Type IL cements can provide increased strength compared with what would be expected from an ASTM C150 cement, as shown in **Fig. 5**. This is because the Al_2O_3 in the SCM can react chemically with the limestone fines to produce hydration products that add to strength. SCMs with high Al_2O_3 contents, such as slag cement and metakaolin, are able to provide this synergistic reaction and increase strength. Ramezanianpour and Hooton found that mortar made with slag contents up to 30% with up to 15% interground limestone had 28- and 56-day strengths similar to those of mortar made with a Type I/II cement without limestone.[24]

Flexural strength

Flexural strengths of mortar and concrete made with Type IL cement are similar to those made with ASTM C150 cement. Barrett et al. found that the flexural strength of concrete made with Type IL cement was on average 3% higher than the control made with an ASTM C150 cement.[37] All of the results were significantly higher than those predicted by Eq. (19.2.3.1) in the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*[38] for the modulus of rupture. Another study found that the flexural strength of mortar containing cement with limestone fines was between 5% lower and 13% higher than the equivalent mortar made with a Type II or Type V cement.[34]

Elastic modulus

The effect of limestone fines use on concrete elastic modulus is typically negligible as long as the limestone content is below the 15% limit allowed by ASTM.[37,39] The elastic modulus of concrete is primarily a function of the type and quantity of aggregate used as well as the water–cementitious material ratio *w/cm* of the paste fraction; therefore, as long as the type, quantity, and gradation of aggregate are not changed, any differences in elastic modulus should be smaller than the expected scatter in the modulus of elasticity measurements.

Shrinkage, creep, and prestress losses

To design prestressed concrete products, designers need to know the expected concrete prestress losses from elastic shortening, shrinkage, creep and relaxation, friction, and anchorage set. The differences in these properties stemming from the use of Type IL cement are very small or negligible;

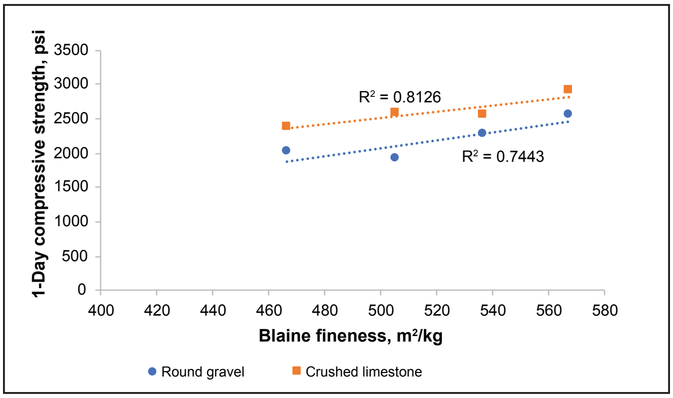

Figure 4. One-day compressive strength for concrete made using a 0.43 water–cementitious material ratio and Type IL cement with different degrees of fineness made from the same clinker and approximately 10% limestone fines. Note: 1 psi = 6.895 kPa. Source: Data from Hansen et al. (2020).

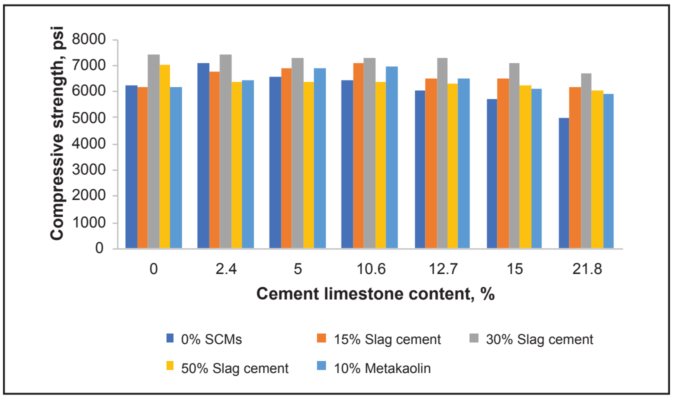

Figure 5. Fifty-six-day compressive strength of mortar containing slag or limestone and increasing amounts of limestone fines. Note: SCMs = supplementary cementitious material. Note: 1 psi = 6.895 kPa. Source: Data from Ramezanianpour and Hooton (2014).

therefore, the prediction equations used for concrete with ASTM C150 cement should also be applicable to concrete with Type IL cement.

In several studies comparing the autogenous and drying shrinkage of concrete made with ASTM C150 cement with that of Type IL cement ground to give equivalent strength as its companion ASTM C150 cement made with the same clinker, investigators found that the amounts of shrinkage were similar.[34,40-43] Bharadwaj et al. found that the amounts of shrinkage for ASTM C150 cement and cement with 15% interground limestone fines were not statistically different.[34] In that study, specimens made with portland cement were compared with specimens in which 10% of the portland cement had been replaced by limestone fines. Compared with the portland cement specimens, the PLC specimens showed small increases in shrinkage up to 14 days; at 28 days, the amounts of shrinkage in the two types of specimens were similar.

The rate and total amount of shrinkage in Type IL cement can vary, depending on the cement fineness, limestone fineness, and limestone content.[42,44] As in ASTM C150 cements, finer grinds in Type IL cement increase the amount of autogenous and drying shrinkage.[45-46] Some SCMs with high alumina content, such as slag, can react synergistically with the limestone to increase shrinkage by up to 8%. However, that is not considered to be a large increase in shrinkage; it is within expected experimental scatter, and it is less of an increase in shrinkage than would be expected from a 1% increase in paste content.[47]

The conclusions presented in the literature on the effects of limestone fines on concrete creep are not unanimous. Alunno-Rossetti and Curcio fount that creep was about 16% higher in concrete made using a cement with 20% limestone fines than in concrete made with cement without limestone fines.[40] Sait also found that the concrete creep increased as the limestone fines content increased.[48] Those findings conflict with findings from other studies, which concluded that little to no difference, or even a decrease in creep, was associated with the use of cement containing limestone fines.[49]

Shalan compared the prestress losses for beams made with Georgia Department of Transportation (GDOT) Class AAA concrete with either a Type I/II cement or a Type IL cement.[50] The mixtures tested had 800 lb/yd^3 (475 kg/m^3) of cement, a water-cement ratio of 0.32, 1890 lb/yd^3 (1120 kg/m^3) of granite coarse aggregate, and 1096 lb/yd^3 (650 kg/m^3) of natural sand. Shalan found that the anchorage seating losses for both types of prestressed beams were similar; the elastic shortening was slightly higher for the beams made with Type IL cement because the elastic modulus was 5% lower for that mixture; and the time-dependent losses were 16% lower for the beams made with Type IL cement. Overall, the prestress losses for the two types of beams were similar to or slightly lower than the losses predicted by the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[51]

Bond

The bond properties of Type IL cement to steel have been found to be very similar to those of ASTM C150 Type I/II cement. Shalan[50] used the Mustafa large block pullout test[52] to compare strand bond for concrete specimens made with Type IL cement or Type I/II cement. The concrete in the study met the GDOT Class AAA concrete requirements with a *w/cm* of 0.32 and 800 lb/yd^3 (475 kg/m^3) of cement, and the strand load-displacement curves during pull-out testing showed that the two types of concrete had the same bond to the steel.[50] Whereas the AASHTO LRFD specifications[51] use transfer lengths of 60 times the strand diameter for design, the measured transfer lengths in this study were much shorter. Results from the beam tests in that study showed that the two specimen types behaved similarly. Measured development lengths in the study were more than 55% shorter than the lengths predicted by the AASHTO LRFD specifications.

Durability of concrete made with Type IL cement

Concrete made with Type IL cement has similar durability properties to that of concrete made with Type I cement from the same clinker. Variations in concrete durability when switching from Type I to Type IL cement are similar to those experienced when changing from one Type I cement to another, with some small synergies seen when SCMs with high alumina content are used.

Resistance to freezing and thawing

Thomas and Hooton[14] reported ASTM C666[53] durability factors and ASTM C672[54] scaling mass losses for 0.40 and 0.45 *w/cm* concretes made with both Type I and Type IL cement, with and without partial replacements by ASTM C618[55] Class F fly ash or slag. These data are shown in **Table 2**, along with strength and ASTM C1202[56] rapid chloride permeability test data.

Resistance to chloride ingress

The ASTM C1202 test[56] is often used as a rapid index of concrete's resistance to chloride penetration. Concretes containing SCMs typically have much lower Coulomb values because SCMs reduce the connectivity of the pores in concrete. **Figure 6** shows that changing from Type I/II cement to PLC has no significant impact on Coulomb values.[14]

Bharadwaj et al.[47] used the ASTM C1556 test methodology[57] to measure chloride ingress profiles in concrete made with Type I/II and Type IL cements and found no difference in the penetration of chloride.

Corrosion resistance

Bharadwaj et al. performed corrosion tests on portland cement and PLC systems.[34] Using the OC_{crit} test, which measures the critical chloride content C_{crit} required to initiate corrosion, the

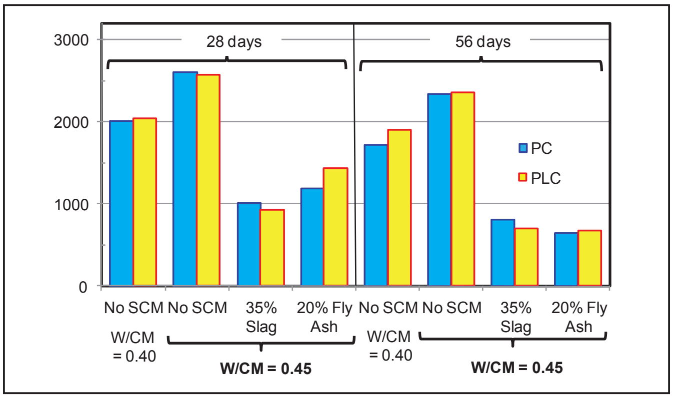

Figure 6. Rapid chloride permeability results from ASTM C1202 testing with and without supplementary cementitious material. Note: PC = portland cement; PLC = portland-limestone cement; *w/cm* = water–cementitious material ratio. Source: Thomas and Hooton (2010).

Table 2. Concrete mixture proportions and durability test results

	Series B						Series C	
w/cm	0.45						0.40	
SCM	No SCM		35% slag		20% fly ash		No SCM	
Proportions, kg/m³								
PC	354	-	230	-	286	-	409	-
PLC	-	358	-	231	-	287	-	413
Slag	-	-	125	125	-	-	-	-
Fly ash	-	-	-	-	72	71	-	-
Water	159	161	160	160	161	161	164	165
Proportions, lb/yd³								
PC	597	-	388	-	482	-	689	-
PLC	-	603	-	389	-	484	-	696
Slag	-	-	211	211	-	-	-	-
Fly ash	-	-	-	-	121	120	-	-
Water	268	271	270	270	271	271	276	278
Air, %	6.2	5.3	6.0	5.6	5.2	5.0	6.2	5.4
Slump, mm	120	120	110	110	130	110	130	115
Slump, in.	4.75	4.75	4.25	4.25	5.00	4.25	5.00	4.50
Set time, min.	340	290	380	345	425	345	395	355
Strength, MPa								
1 day	23.2	27.0	11.7	15.9	16.9	19.2	30.6	33.5
7 days	34.0	38.0	32.8	38.1	31.8	32.6	45.6	48.8
28 days	39.4	44.8	44.9	50.4	43.4	43.6	54.6	57.3
56 days	43.4	47.5	48.9	53.0	50.8	49.3	58.5	60.6
Strength, psi								
1 day	3365	3916	1697	2306	2451	2785	4438	4859
7 days	4931	5511	4757	5526	4612	4728	6614	7078
28 days	5714	6498	6512	7310	6295	6324	7919	8311
56 days	6295	6889	7092	7687	7368	7150	8485	8789
Durability factor,* %	101	102	98	101	100	100	101	102
Scaling mass,† g/m²	52	113	520	368	189	516	61	48
Scaling mass,† oz/yd²	1.52	3.31	15.22	10.77	5.53	15.10	1.79	1.40
RCPT,‡ coulombs								
28 days	2610	2571	1016	925	1184	1433	2017	2048
56 days	2344	2354	807	708	639	678	1716	1900

Source: Thomas and Hooton (2010).

Note: PC = portland cement; PLC = portland-limestone cement; RCPT = rapid chloride permeability test; SCM = supplementary cementitious material; *w/cm* = water–cementitious material ratio.

* Durability factor after 300 freezing-and-thawing cycles per ASTM C666 procedure A.

† Mass loss after 50 freezing and thawing cycles ponded with salt solution per ASTM C672 salt scaling test.

‡ Charged passed after 6 hours per ASTM C1202 rapid chloride permeability test.

investigators concluded that there was no significant difference in corrosion initiation times between the portland cement and PLC systems. Compared with no fly ash, the addition of 25% fly ash with either cement lengthened the time until corrosion initiation. The investigators also performed ASTM G109 corrosion tests[58] and showed that the total charge passed until corrosion initiated were similar for the two cement types.

Resistance to sulfate attack

Hooton and Thomas conducted long-term exposure studies to compare the sulfate resistance of concrete made with PLC with or without SCMs versus concrete made with Type V cement or Type I/II cement combined with SCMs.[59] Over 50 mixtures of air-entrained concretes were cast and exposed to variable temperatures ranging from 37°F to 61°F (3°C to 16°C) in outdoor exposure in 15,000 parts per million sodium and magnesium sulfate solutions. After 3 to 5 years of exposure, the results demonstrated that for concretes made at the same *w/cm* and using sufficient SCMs to prevent or minimize sulfate attack, the use of PLC had no impact on sulfate resistance. Also, the mixtures containing SCMs using either Type IL or Type I/II cement were more resistant to sulfate attack than were concretes made with Type V cement alone. **Tables 3** and **4** present visual damage ratings from Hooton and Thomas's study for concretes with and without slag cement and with or without fly ash, respectively, after long-term sulfate exposure. Recent unpublished test results after 10 to 12 years of exposure are in agreement with the earlier findings.

In a California Department of Transportation (Caltrans) investigation that used ASTM C1012[60] mortar bar tests, Bharadwaj et al. found that "the presence of all SCM(s) reduced expansions significantly compared to the control (with no SCM)."[34] The investigators also found that in the presence of SCMs, PLC mixtures "performed similar to, if not better than" comparable portland cement mixtures. The investigators concluded that "Caltrans can use their current SCM mixtures as is with ASTM C150 Type II or V clinker that is then interground or interblended with PLC up to 15% limestone and expect similar external sulfate resistance to ASTM C150 Type II or V cements with no or very low amounts of interground/interblended limestone."

Resistance to alkali-aggregate reaction

Figure 7 shows that PLC made from the same clinker as Type I/II cement has no consistent impact on alkali–silica reaction expansions, regardless of the test method used.[14]

Making Type IL work for your plant

Before a plant begins to use Type IL cement, trial mixtures should be made to confirm the concrete properties, just as would be done when changing any cement source.

If your plant normally uses Type I/II cement for the manufacture of precast concrete products, it may be able to substitute Type IL cement and achieve the same set times and early-strength development without any changes to the mixture design other than minor adjustments to the admixture type or dosages. Many concrete plants have made the change to Type IL cement, with the concrete achieving high strength-gain rates and plant workers not noticing a difference in performance.

Figures 8 and **9** offer examples of plant data comparing strengths of concrete mixtures containing Type I/II or Type IL cements.[61] While plant A (Fig. 8) obtained higher early

Table 3. Visual damage ratings of 0.40 *w/cm* air-entrained concretes with and without slag cement exposed to 15,000 ppm SO_4 (as Na_2SO_4) in outdoor exposure for up to 90 months/7.5 years

Cementitious material			Exposure period, months				
Cement type	Limestone, %	Slag, %	12	24	36	54	90
HS	0	0	Undamaged	Minor	Moderate	Severe	Severe
GU	0	0	Severe	Severe	Severe	Severe	Severe
PLC9	9	0	Severe	Severe	Severe	Severe	Severe
PLC15	15	0	Severe	Severe	Severe	Severe	Severe
GU	0	40	Undamaged	Minor	Minor	Minor	Moderate
PLC9	9	40	Undamaged	Minor	Minor	Minor	Moderate
PLC15	15	40	Undamaged	Undamaged	Undamaged	Minor	Moderate

Source: Hooton and Thomas (2016).

Note: The Canadian Standards Association (CSA) general use hydraulic cement (GU) (Type I) and portland limestone cement (PLC) clinkers contained >11% C_3A. CSA high-sulphate-resistant (HS) hydraulic cements are equivalent to Type V cements. PLC9 contained 9% interground limestone, and PLC15 contained 15% interground limestone. *w/cm* = water–cementitious material ratio.

Table 4. Visual damage ratings of 0.40 *w/cm* air-entrained concretes with and without fly ash exposed to 15,000 ppm SO_4 (as Na_2SO_4) in outdoor exposure for up to 70 months/5.8 years

Cementitious material			Exposure period, months			
Cement type	Limestone, %	Fly ash, %	8	21	33	70
HS 2	0	0	Undamaged	Undamaged	Minor	Minor/moderate
HS 3	0	0	Undamaged	Undamaged	Minor	Minor
PLC10.5	10.5	0	Minor	Moderate	Severe	Severe
PLC10.5	10.5	25	Undamaged	Undamaged	Undamaged	Minor
PLC10.5	10.5	35	Undamaged	Undamaged	Undamaged	Undamaged
PLC10.5	10.5	40	Undamaged	Undamaged	Undamaged	Minor
PLC10.5	10.5	50	Undamaged	Undamaged	Undamaged	Undamaged

Source: Hooton and Thomas (2016).

Note: The Canadian Standards Association (CSA) general use hydraulic cement (GU) (Type I) and portland limestone cement (PLC) clinkers contained >11% C_3A. CSA high-sulphate-resistant (HS) hydraulic cements are equivalent to Type V cements. PLC9 contained 9% interground limestone, and PLC15 contained 15% interground limestone. *w/cm* = water–cementitious material ratio.

strengths with the Type IL cement, plant C (Fig. 9) saw lower strengths. These differences are similar to what you would expect if you changed cement suppliers or plants, and they can be managed with small changes in the air entrainment or water-reducing admixture dosage. It was also reported that the elastic modulus and splitting tensile strength of concretes made with Type I/II and Type IL cements (both fine and coarse ground) were statistically similar, so the concrete made with Type IL cement should not cause any new problems with camber or cracking.

If your plant uses Type I/II cement combined with SCMs such as fly ash or slag cement, you may see modestly improved early strengths when switching to Type IL cement. This improvement results from the reaction of the aluminates in these SCMs with the carbonate from the limestone to form additional carboaluminate hydrates that fill in porosity, in addition to the normal formation of calcium silicate hydrates. In this case, a direct substitution of Type I/II cement by Type IL cement may be possible with only small tweaks in admixture dosage, with the potential for small reductions in cementitious content.

If your plant currently uses Type III cement, it could possibly substitute in a Type IL(HE) cement with little effect on concrete set times and early strength gain. Although we are not aware of any cement producers making a Type IL(HE) cement, some producers may in the future consider making a Type IL(HE) cement that meets the same strength requirements as a Type III cement. The Blaine fineness of Type IL cement is higher than Type I/II, but that is due to the additional fineness from intergrinding with the softer limestone; therefore, the fineness of Type IL cement is not equivalent to the high fineness associated with Type III cement. A Type IL(HE) cement must be ground much finer than a Type IL cement

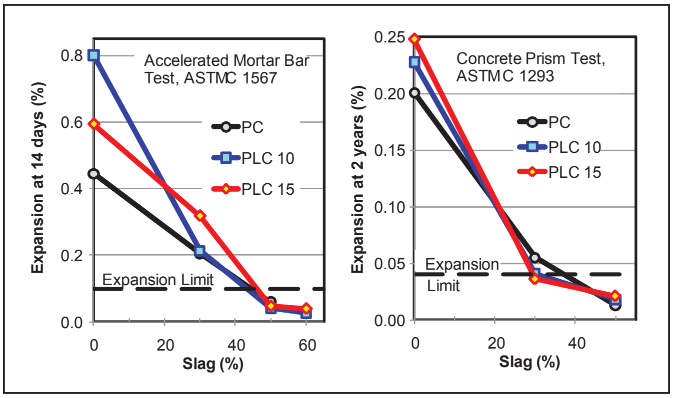

Figure 7. Expansion of mortar bars and concrete prisms containing alkali-silica reactive aggregate. Note: PC = portland cement; PLC = portland-limestone cement. PLC 10 contained 10% interground limestone and PLC 15 contained 15% interground limestone. Source: Thomas and Hooton (2010).

to meet the early-age strength requirements of ASTM C595. This fineness requirement could limit the cement plant production if the plant does not have spare grinding capacity, and that could make it difficult to produce Type IL(HE) cement economically. Talk to your cement producer to see if they have the grinding capacity available to make a Type IL(HE) cement and what their plans may be.

Concrete mixture design strategies for switching to Type IL

If your plant uses Type III high-early-strength cement for some concrete products, you can expect to see a decrease in set time and early strength gain when substituting a Type IL cement. The concrete producer has several options to accelerate early strengths of concrete made with Type IL cement. These can include the following:

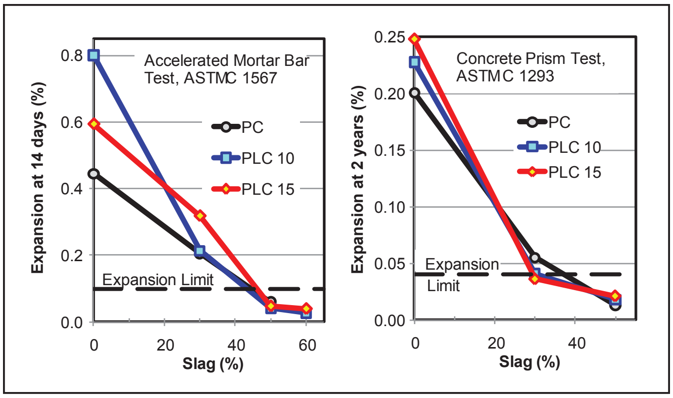

Figure 8. Concrete strength development at concrete plant A for Georgia Department of Transportation (GDOT) Class AAA concrete mixtures. Note: The GDOT specification (sections 500 and 865) minimum 18-hour and 28-day strength requirements for Class AAA concretes are shown with the dotted lines. Note: Sec. = section; min. = minimum. 1 psi = 6.895 kPa. Source: Shalan et al. (2016).

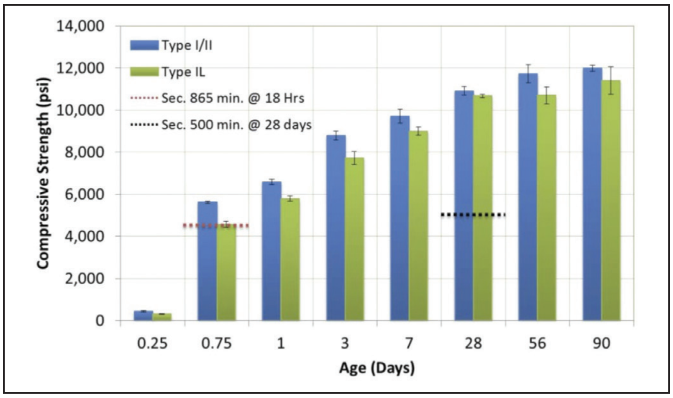

Figure 9. Concrete strength development at concrete plant C for Georgia Department of Transportation (GDOT) Class AAA concrete mixtures. Note: The GDOT specification (sections 500 and 865) minimum 18-hour and 28-day strength requirements for Class AAA concretes are shown with the dotted lines. Note: Sec. = section; min. = minimum. 1 psi = 6.895 kPa. Source : Shalan et al. (2016).

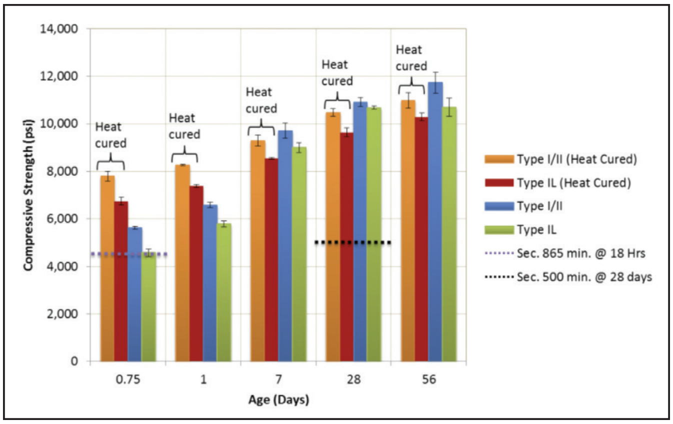

Figure 10. Concrete strength development at concrete plant C for Georgia Department of Transportation (GDOT) Class AAA concrete mixtures. Note: The GDOT specification (Sections 500 and 865) minimum 18-hour release strength requirement of 4500 psi and 28-day strength requirement of 5000 psi for Class AAA prestressed girders concretes are shown with the dotted lines. Note: Sec. = Section; min. = minimum. 1 psi = 6.895 kPa. Source: Shalan et al. (2016).

- lowering the *w/cm*
- using accelerating admixtures, such as calcium nitrite (which also acts as a corrosion inhibitor)
- raising the initial curing temperature to accelerate the chemical reactions (the cost of heating can be partially offset by the lower cost of Type IL cement relative to Type III)

Your cement producer and admixture supplier will likely want to help you make this switch and may provide assistance in making changes to the mixture design if any are needed.

Figure 10 shows findings from Shalan et al. on the impact of heat curing on concrete strengths at plant C, where concretes were heat cured for 18 hours at 140°F (60°C) or at 73°F (23°C).[58] Note that as previously shown in Fig. 9, plant C used a Type IL cement that resulted in lower concrete strengths.

Examples of precast concrete plants that have switched to Type IL cement

There are several examples of precast concrete plants that have successfully and economically made the switch to Type IL cement. In personal communications with the Cement Association of Canada in July 2022, it was reported that at least 13 precast concrete plants in Canada have switched to using Type GUL (general use limestone) cement. Orren Abrell, quality control manager of Shockey Precast in the United States, says that Shockey Precast switched to Type IL in June 2022 with no change in mixture design and very little change in admixture dosages. The strengths of Shockey's double-tee girders actually improved over those previously made with Type I/II cement from the same cement plant.

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Abstract

This article reviews the impact of limestone on cement hydration and strength gain; discusses the fresh, mechanical, and durability properties of concrete containing Type IL cement; and suggests strategies to help precast, prestressed concrete producers make the switch to Type IL cement.

Keywords

Cement hydration, limestone, strength gain, Type IL cement.

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