SCA SLAG CEMENT ASSOCIATION

Information Sheets

30: Slag Cement and Portland Limestone Cement in Concrete

Importance

- In Portland Cement Concrete (PCC), about 96% of the CO_2 emissions, and roughly 85% of the embodied energy come from cement alone. (r.6). Since 1972, cement plants have already reduced their CO_2 emissions by over 40%. With such efficient equipment operating at cement plants, additional methods of reducing CO_2 associated with cement production are needed, and one way to do that is by decreasing the amount of clinker in cement. Effective ways of doing this are to replace some of the clinker content with ground limestone or supplementary cementitious materials (SCMs) to produce blended cements. This includes Portland-limestone cements (PLCs, or ASTM C595 Type IL), portland-slag cements (ASTM C595 Type IS), portland-pozzolan cements (ASTM C595 Type IP), and ternary blended cements (ASTM C595 Type IT).

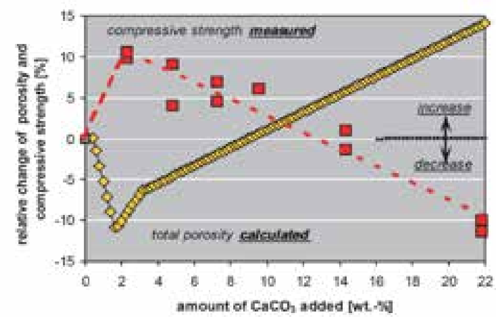
PLC: The Basics

- PLC is made from the same components as portland cement but contains up to 12% more ground limestone. PLCs (Type IL) have to meet the same setting times and strength development as the portland cement (ASTM C150 Type I) that it replaces. Type IL cement provides about a 10% reduction in CO2 emissions from cement plants and reduces the carbon footprint of concrete by up to an additional 10% without impacting performance or durability.

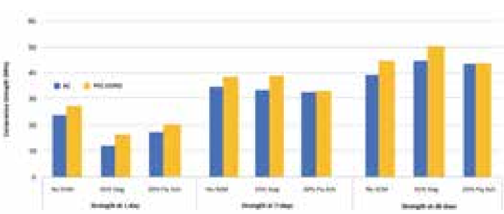
Performance Properties

When properly optimized, PLCs that contain up to 15% limestone can contribute to the properties of the cement.

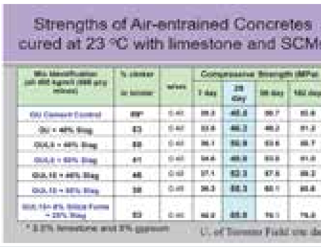
- Compressive Strength & Relative Porosity
    - The early-age performance of slag cement concrete with Type IL cement has been found to be equal to or better than the same portland cement without slag cement. (Note that the slag component can be added as an SCM or as part of a Type IT blended cement.)
    - The Blaine Fineness of Type IL cement is higher than that of Type I. With limestone being a softer material than cement clinker, Type IL cement is typically ground finer than Type I to maintain the same strength performance. Limestone helps by improving hydration through nucleation, allowing cement gel more locations to start forming and potentially accelerating the rate of hydration. Limestone also produces better particle packing and increased carbo-aluminate formation. The carbo-aluminate formation fills in pores which, in turn, increases the strength of the material.
    - Figure 1 illustrates the effect that the addition of limestone has on the relative change of porosity and compressive strength of concrete.
    - Optimum compressive strength and lowest porosity are reached at about 3-4% limestone addition. As limestone addition reaches 12-14%, the strength and porosity return to values roughly the same as portland cement without any limestone addition.
    - Alumina in slag can react with more of the finely divided limestone in Type IL cement to form additional carbo-aluminate hydrates that result in reduced porosity and increased strength of concrete.
    - Figure 2 shows the early age compressive strength development of PC and PLC mixes with and without SCMs. In this example, the addition of 20% fly ash to PLC produces a 28-day compressive strength almost identical to a 20% fly ash mix with PC. To contrast, the addition of slag at 35% to PLC produces a greater 28-day compressive strength than its equivalent PC concrete.
    - Figure 3 compares the 28-day compressive strength of regular portland cement, portland cement with slag, and PLC with slag. Figure utilizes Canadian concrete standards, where the term GU (General Use) can be used interchangeably with the United States PC. (R.1)
    - Portland-limestone cement with slag produces higher compressive strengths than regular portland cement with the same percentage of slag replacement.
- Durability
    - One way to assess the durability of a particular concrete mix is by performing a Rapid Chloride Permeability Test (RCPT). This test measures the amount of electrical charge passed through a concrete specimen. Lower levels of charge passed, in Coulombs, indicates a higher resistance to chloride ion penetration.



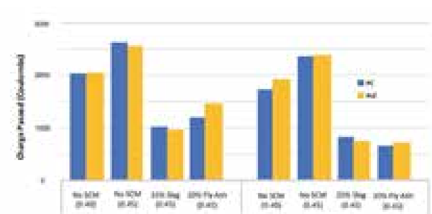
[Figrue 1 (r.5)]



[Figure 2 (r.4)]



(Figure 3)



[Figure 4 (r.4)]

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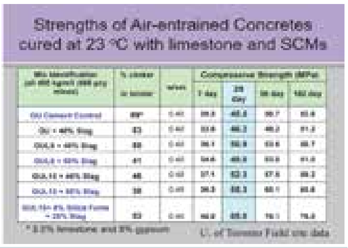
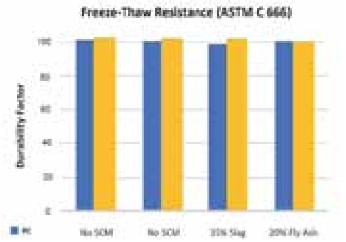
- Figure 4 illustrates that with or without any SCMs, PC concrete and PLC concrete both provide similar resistances to the penetration of chloride ions. The addition of slag reduces the penetration in both PC and PLC concrete.
- Thomas, M.D., Hooton, D., Cail, K., Smith, B.A., Wal, J.D., & Kazanis, K.G. (2010). Field Trials of Concretes Produced with Portland Limestone Cement: New CSA cement type performs well in an aggressive environment. *Concrete Internationa*l, 32, 35-41.

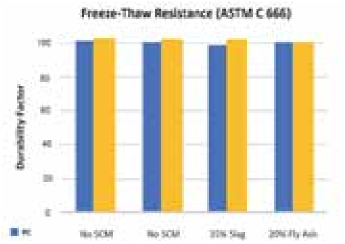
- Drying Shrinkage
  - Figure 5 (r.1). Figure utilizes Canadian concrete standards, where the term GU (General Use) can be used interchangeably with the United States PC.
  - For concrete mixtures with 0.4 w/cm, the drying shrinkage of PC was largely unaffected by the addition of limestone in PLC mixes. The addition of slag to both PC and PLC mixes reduced the early age drying shrinkage, but by 2 years demonstrated little to no difference.
- Alkali-Silica Reaction
  - There are no significant differences from PC to PLC regarding the expansion of mortar bars and concrete prisms with alkali-silica reactive aggregates. Recent data from Caltrans showed slight reductions in C441 mortar bar expansions with PLC compared to PC from the same plant. PLC on its own without any SCMs is unlikely to prevent ASR, whereas Type IS, Type IP, or Type IT blended cements may be able to. re has been no observed difference in the level of SCMs needed to mitigate the expansion. The best way to prevent deleterious expansion due to ASR is to utilize the appropriate amount of SCMs for the aggregate, alkali loading, and exposure of the mix.
- Freeze-Thaw Performance
  - Freeze-thaw performance was tested using PLC at 12%. Figure 6 shows that the addition of 12% limestone has little to no impact on the Durability Factor of a concrete mix. This relationship holds true with or without slag or fly ash.
- Sulfate Exposure
  - While some early published papers indicated a potential concern for an increased risk of low-temperature thaumasite sulfate attack, extensive long-term tests on concretes have shown that Type IL cement and slag cement combinations are as resistant to sulfate attack as Type I cement-slag cement combinations and can be more resistant than equivalent w/cm concretes made with Type V cements to both the ettringite and thaumasite forms of degradation. (r.3)
  - The University of Toronto produced a sulfate-resistance testing program where 53 concrete mixtures were tested and continually monitored for over 5 years. Mixes with 40% and 50% slag cement were tested with portland-limestone cements. The tests showed that without supplementary cementitious materials, all of the concrete prisms (whether Type I, or Type IL) showed severe surface damage in both Na_2SO_4 and $MgSO_4$ and at both 15,000 and 1500 ppm [SO_4]
  - Concrete prisms with SCMs that showed no signs of sulfate deterioration include the 40% and 50% slag cement mixtures, 25 slag+10MK, 25slag+6SF, and 8% SF mixes made with either Type I or Type IL(15%) cements. The effect of w/cm (0.40 vs 0.50) was no different for Type IL-SCM concretes than for Type I-SCM concretes.



(Figure 5)



(Figure 6 r.4)



(Figure 7 r.4)

References

1. *University of Toronto Field Site Data (2016)*, Referenced in ACI webinar; Performance of Slag Cement with Portland Limestone Cement in Concrete, Professor Doug Hooton.
2. Hooton, R. D., and Thomas, M. D. A., *Sulfate Resistance of Mortar and Concrete Produced with Portland-Limestone Cement and Supplementary Cementing Materials: Recommendation for CSA A3000, SN3285b*, Portland Cement Association, Skokie, Illinois, USA, 2016, 28 pages.
3. *2016 PCA Report*
4. *Thomas & Hooton 2010* – presentation Thomas & Hooton 2010 – Thomas, M.D., Hooton, D., Cail, K., Smith, B.A., Wal, J.D., & Kazanis, K.G. (2010). Field Trials of Concretes Produced with Portland Limestone Cement: New CSA cement type performs well in an aggressive environment. *Concrete International*, 32, 35-41
5. *Performances of Limestone Modified Portland Cement and Concrete*, D. Herfort; L. Courard; Y. Villagran, University of Liege, 2016
   - https://orbi.uliege.be/bitstream/2268/200184/1/Report%20on%20the%20performance%20of%20Portland%20limestone%20cements%20in%20concrete_20160401.pdf
6. *PCA, Third Quarter 2006 Survey of Portland Cement by User Group*, PCA, November 2006