

Some Basics About Substituting Pozzolans for Portland Cement in Concrete

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Background

Major impacts to keep in mind:

- We use concrete as a material second only to water.
- For every ton of cement produced approximately one to one and a quarter tons of carbon dioxide are produced.
- It takes approximately 3200lbs. of raw material to create 2000lbs of cement.

So:

Using waste materials such as blast furnace slag and flyash as pozzolanic substitutes for Portland cement can result in significant greenhouse gas emission reductions.

The goal, then, is to specify blended cements or innovative cement technologies that either significantly increase hydraulic efficiency, or directly replace Portland cement with pozzolans according to ASTM blended cement Types I-V or using ASTM C 1157-98(a). Specifying up to 70% pozzolan in the cement blend is possible. Increasing hydraulic efficiency of the Portland cement to over 90% by increasing grinding or using new technologies such as Energetically Modified Cement is also possible.

Useful definitions for blended cement discussion:

Ground Granulated Blast Furnace Slag (GGBFS)- A processed waste product of iron and steel production in blast furnaces, usable as a pozzolan.

<i>Blended cement-</i>	Cement with a fixed percentage of pozzolans replacing the Portland cement clinker portion of the cement mix. Blended cement is usually understood as cement that is blended by a cement manufacturer rather than a ready-mix supplier.
<i>Cement-</i>	The binder in concrete.
<i>Cementitious-</i>	To have the qualities and properties of cement.
<i>Clinker-</i>	The main ingredient in Portland cement manufactured largely from limestone, clay and a variety of minerals and metals at high temperatures.
<i>Concrete-</i>	A mixture of gravel, broken stone, other particles and water in a cement or mortar mix.
<i>Fly ash-</i>	The ashen by-product of burning coal. It is a well-known pozzolan (also known as coal ash).
<i>Hydraulic cement-</i>	The most common type of cement, known for its ability to dry underwater (definition: ASTM C 219).
<i>Portland cement-</i>	Any of five basic types of cement that are composed of approximately 95% cement clinker and ground with gypsum and talc.
<i>Pozzolan-</i>	A mineral admixture that acts as a supplement to “standard” Portland cement hydration products to create additional binder in a concrete mix.
<i>Ready-mix Facility-</i>	A manufacturing facility where cement is blended with other minerals, water, and aggregate to create concrete.
<i>Rice Hull Ash-</i>	The ashen by-product of burning rice hulls and a highly practical pozzolan.

Silica Fume- An extremely fine powdered waste product of the silicon metal industry and a well known pozzolan.

Table 1 shows some useful information on the current state of the cement market. Please note that as consumption increases U.S. imports have decreased, domestic shipments have stabilized and imports have increased. This means that our work can have greater impact by decreasing significant embodied energy in foreign shipments.

Table 1: U.S. Cement Industry Consumption – Thousands of Metric Tons

Year	Portland Cement	Masonry Cement	Total	Cements Exports	Cement Imports	Total Shipments - Domestic Producers
1996	87,416	3,399	90,815	461	11,999	79,411
1997	92,708	3,458	96,166	519	13,814	82,978
1998	99,151	3,961	103,112	322	18,278	85,417
1999	104,943	4,416	109,359	315	22,862	86,933

Detailed Environmental Impacts of Portland Cement

The major environmental impacts of Portland cement include energy used during production of clinker, the production of GHG, both from energy use and the calcination process, and the impact of mining and resource depletion.

Manufacturing Portland cement is one of the most energy intensive processes of any industrial manufacturing process. The extreme heat required to operate kilns creates a significant demand for energy. Approximately 6 million BTUs are required to produce 1 ton of Portland cement.

Over the past several years, process changes and techniques have been introduced to improve efficiency in kiln operation and reduce energy demand. Two of the most significant process changes include the conversion to dry kiln processing and the burning of waste in cement kilns. 90 million tons of coal were burned and 68 thousand tons of waste were burned for cement production in 1997ⁱ

It is generally thought that the burning of waste such as rubber tires is well suited for cement production since the high heat required for kiln temperatures burns “clean.” But this use of resources makes sense only from a solid waste materials perspective. Many of the resources burned today may become valuable as feedstock for new and existing environmental technologies. A long term

materials strategy should be considered as waste becomes more attractive as fuel for cement.

During the manufacturing of Portland cement, GHGs are generated and released through two mechanisms: 1) fossil fuel burning for energy consumption by the kiln and 2) the calcination process of clinker production. For every ton of Portland cement produced, between 1ton and 1.25 tons of CO₂ are released in to the atmosphere.

Fuel consumption accounts for approximately 50% to 60% of CO₂ production while calcination accounts for the other 50% to 40%.ⁱⁱ

Eventhough most of the natural resources used in Portland cement are generally in ample supply, the extraction of them is not environmentally benign. Open pit mining of limestone, marl (cement rock), coral, clay, shale, sand and sandstone, just to mention a few raise impact issues of dust, local stream nutrification and other mineral run-off.

Every ton of cement (2000 lbs) requires between 3,200 and 3,500 pounds of raw materials. Much of the difference can be attributed to CO₂ gassification during calcination of clinker.

The CO₂ is easily measurable while the mining impact of 90 million tons of coal and 120 to 135 million tons of non-fuel raw materials is difficult to quantify. However, it should be noted that the use of waste pozzolans such as fly ash and blast furnace slag in blended cement as partial replacement of Portland cement, offer clear environmental advantages since they do not require heat , production of clinker calcinations, or mining of any sort.

Blended Cement

In general, a blended cement is any interground or blended mixture of Portland cement, pozzolan, or other additives. Blending can be done at both cement plants and concrete ready-mix facilities. Once clinker has been ground, it can be mixed in a number of different places. Ready-mix plants usually have a silo for storage of Portland cement, and various silos or storage for sand, gravel and other ingredients that comprise concrete. The concrete manufacturer is capable

of blending any specified mix of Portland cement, pozzolans, etc. just as the cement manufacturer is.

And yet, the product mixed by the ready-mix facility is not what is typically referred to as blended cement. This confusing fact is representative of a market issue that will be played out as demand for blended cements increase. Ready-mix providers will fight for market share since they will be able to provide blended cement.

In the meantime, there are reasons for the distinction between purchased blended cements from a cement company and cements that are blended by concrete manufacturers:

- The cement industry is monitored and product quality assurance is carefully controlled.
- Blended cements mixed at a cement plant are often proprietary blends.
- The ready-mix process is not monitored and surveyed with similar scrutiny as the cement industry.
- A cement blended in a ready-mix facility are not usually proprietary.

For these reasons, and for purposes of understanding the market in order to encourage innovative blended cement technologies, *blended cement will mean only cement that is pre-packaged and sold as a blended product from a cement manufacturer.*

Types of Blended Cements

Technically, blended cement can be any type of cement that is capable of binding concrete. There are even blended cements that contain no Portland cement – although they are used infrequently and only under very specialized situations.

The American Society of Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) have published prescriptive standards (ASTM C595-98 and AASHTO M240-94) to define five classes of blended cements and prescribe limiting percentages of materials in each.

1. Type IS
 - Blends of Portland cement and blast furnace slag.
 - Blast furnace slag content is between 25% and 70% by weight
 - Can be used for general construction
 - Air entrainment, moderate sulfate resistance, or moderate heat of hydration may be specified by adding the suffixes A, MS or MH
2. Type IP and Type P
 - Blends of Portland cement and pozzolans
 - Pozzolans can include blending of a variety of pozzolans and often includes blending with Type IS
 - Pozzolan content is between 15% and 40% by weight
 - Can be used for general construction
 - Type IP may be alternatively specified with A, MS or MH suffixes
 - Type P may be alternatively specified with low heat of hydration, LH, MS or A suffixes
3. Type I (PM)
 - Pozzolan modified Portland cement
 - Can be used for general construction
 - Blend of Portland cement or Type IS with pozzolan
 - Pozzolan content less than 15% by weight
 - Alternative specifications include A, MS or MH
4. Type S
 - A blend of ground granulated blast-furnace slag and or Portland cement and/or hydrated limeSlag cement
 - Not used alone in structural concrete
 - Minimum slag content of 70% by weight
 - Alternative specifications include A for air entrainment
5. Type I (SM)
 - A blend of finely ground blast-furnace slag and Portland cement
 - Can be used for general construction
 - Slag content less than 25% by weight
 - Alternative specifications include A, MS or MH

ASTM has also published a Standard Performance Specification for Hydraulic Cement (ASTM C 1157-98a) which contains performance requirements with no restrictions on the composition of the cement or its constituents. The

specification classifies cement by type based on specific requirements for general use, high early strength, resistance to sulfate attack, and heat of hydration.

Despite the less restrictive nature of this specification, it has gained only limited use by those who specify construction with cement and concrete. One possible explanation for its limited use is the natural human reluctance to divert from well-known, "standard" procedures. The issue of specifications will be discussed further in this report in the section addressing market barriers.

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ⁱ VanOss Table 6

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