COLD CLIMATE HOUSING RESEARCH CENTER

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Promoting and advancing the development of healthy, durable and sustainable shelter for Alaskans and other circumpolar people.

Substantially Superior Cements

An Introduction to Magnesium Phosphate Cements (MPCs) and Geopolymers

Cole Sonafrank, CCHRC

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Introduction

For the last century, "cement" and "concrete" have implied Portland cement and Portland cement mixed with sand and aggregate. Other types of cement have been used for thousands of years, but Portland cement has predominated since the late 1800s. Beginning in the last decade, Portland cement has more frequently been referred to it as Ordinary Portland Cement (OPC) because the addition of other materials into cement mixes has improved the resulting concrete properties dramatically; such modified Portland cements are not the subject here.

Two completely different classes of cements chemically unrelated to Portland cement are gaining international attention and increased commercial investment—Magnesium Phosphate Cements (MPCs) and geopolymers. The United States and European interest in these cements initially centered on nuclear waste containment, but their properties promise potential uses far exceeding those of traditional cements. CCHRC has only recently begun investigating these materials. This Snapshot is not an endorsement of either material for any specific application, nor of any commercially available product. At this point CCHRC can only say that they appear to be worthy of further investigation, which the organization has undertaken.

Importance

Ordinary Portland Cement is far from perfect, yet, our present civilization was built with it. While having many benefits, making Portland cement "standard" has not been without environmental and structural consequences.

Environmental consequences include increased human production of the green house gas carbon dioxide (CO2) by 6–8%. To produce one ton of OPC it takes over 400 lbs of coal (or the BTU equivalent) and releases one ton of CO2 into the atmosphere. Incidentally, another 1% of U.S. energy consumption goes into producing Gypsum-based drywall releasing another 25 billion pounds of CO2 annually. Efforts to meet the increasing demand for cement and its high rate of fuel consumption more economically include burning tires and wastes as a cheaper substitute for diesel, coal or gas. Many maintain that the resultant air pollution issues have been less than ideally managed.

In 2006, approximately 100 million tons of Portland cement was produced in the United States and over 1 billion tons in China. The total 2006 world-wide production was about 2.5 billion tons. Annual demand continues to increase.

Structural consequences have resulted from Portland cement's problematic properties. For example, OPC does not hold up well in salty environments and tends to slowly corrode away the steel used to reinforce it. Tremendous research and development has occurred to overcome its problems and modern cements are much improved. However, the roads, bridges and buildings in the United States are aging. Many are approaching 40 years old and were not built using modern materials. How to repair and remediate the problems of our nation's deteriorating concrete infrastructure is a major concern. Other properties such as water absorption and significant expansion and contraction, have proven to be relatively easy to work around. Still, they have had an indelible impact upon design and engineering practices and lead to expensive remedies if not handled appropriately.

Related Topics:

Website

- http://www.cchrc.org/product-testing

Cold Climate Housing and Research Center, PO 82489; Fairbanks, AK 99708;
Phone: (907) 457-3454, Fax: (907) 457-3456; info@cchrc.org

Magnesium phosphate cements and geopolymers are gaining a foothold in the global cement market because their physical properties are most useful in the areas where OPC's properties are limiting. They are stronger, lighter, more durable, more stable and impervious to water. The production of MPCs requires far less energy and releases about 75% less CO2 than the production of OPC. The figures for geopolymers are more variable due to a greater range of usable components but their production is generally stated to be about 75% more efficient than OPC's.

What are MPCs & geopolymers used for?

To compete against the giant OPC industry, geopolymers and MPC's in the U.S. are taking two main approaches in their marketing. The first is to address niche markets where the superior properties make the economics clearly beneficial. Examples include refractory applications, pre-cast building panels, fire-proof insulation and wall panels, road repair, bridge reinforcement, and many others. The second marketing approach is to undertake individual projects such as large housing developments where the rapid set time reduces labor costs; sea walls and other retention walls to provide stability in adverse environments; and radioactive and other hazardous waste containment which require properties not available in Portland cements, especially their imperviousness and chemical stability.

What are these materials like to work with?

In some ways working with MPCs and geopolymers is similar to working with other cements. The primary components are dry powders. They are mixed with liquids comprised mostly of water and placed by pouring, spraying and/or troweling into or onto their intended form and allowed to cure. The cement binder may also be mixed with a full range of sands, fillers, aggregates and reinforcing materials to form stuccos, mortars and concretes. One major difference is that they cure much more rapidly than Portland-based cements. Depending upon the mix design and application they can be made to cure in a matter of seconds which can be beneficial when spraying. Usually their set times range between several minutes and a few hours. Therefore, they are not mixed at a batch plant and delivered in a redi-mix truck. At first glance this may seem a fatal flaw. However, their ability to form a strong chemical bond with previously placed material, combined with their negligible coefficient of expansion and processes designed specifically for the material can make the rapid cure times economically and structurally advantageous.

Although some of the physical properties of the cured materials are similar, the MPCs and geopolymers chemical properties are altogether different. MPCs are composed of a reactive form of magnesium oxide (MgO), which is a fine white to tan powder. This is combined with a

Comparison of Typical Physical Characteristics (special mix designs will yield different results)

	OPC	MPCs	Geopolymers
Compressive Strength in psi (typical)	3,000 - 7,000	8,000 - 12,000	7,000 - 16,000
Bending Tensile Strength in psi	250 - 1,000	900 - 1,700	300 - 2,900
pH Tolerance	6.5 - 14	3 to 11	3 to 14
Salt Tolerant (continuous exposure)	No	Yes	Yes
Max. Structural Temperature	$1,500^0$ F	$2,000^0$ - $2,700^0$ F	$2,000^0$ - $2,700^0$ F
Curing Time (demolding)	1 - 2 days	10 min - 2 hrs	3 hrs - 3 days
Curing Time (high strength)	28 days	1-3 days	3 days
Curing Temperature Range	5^0 - 420^0 F	-10^0 - 160^0 F	50^0 - 200^0 F
Bonds Strongly to Itself	No	Yes	Yes
Bonds to Reinforcement	No	Yes	Yes
Shrinks Upon Drying	Yes	No	No
Coefficient of Thermal Expansion	0.000012	0.00000017	~ 0.000001
Absorbs Water	Yes	No	No
Foamable	Yes	Yes	Yes

phosphate and water. Various phosphate formulations, most of them common agricultural fertilizers, are used. For some applications where off-gassing is not a problem (such as road repair) ammonium phosphate is suitable, but use of magnesium phosphate or potassium phosphate is more common. Depending upon the application, the phosphate can be combined as a dry powder with the MgO as well as other additives and/or reinforcing fibers. This can then be mixed with local sand, fillers and aggregates at the job site. The inclusion of some salt in the mix does not cause problems, so beach sand and non-potable water is usable.

Geopolymers can be made from a diverse range of raw materials. What they have in common is the predominance of aluminum oxide, in the form of reactive alumina, and silicon dioxide. Commonly used materials of this type are metakaolin (calcined kaolin), fly ash and other by-products of high temperature industrial processes (e.g. blast furnace slag). The dry aluminosilicate powder is combined with a strong alkali solution to form the cement binder paste. A combination of sodium hydroxide (lye), sodium silicate (waterglass) and clean water is usual. Until it cures, the cement is highly caustic, like Portland cement only more so. Additional care must be taken to handle it safely. Clean sands, fillers, aggregates and reinforcing materials can also be included. Many such mixes require additional heat for the alumina and silica to polymerize into long amorphous chains. Other mixes will cure to full strength at room temperatures. Thus, commercial marketing of geopolymers to date appears largely limited to pre-cast products.

Key points of interest

Aside from the important environmental concerns, especially as they relate to global warming, the products have many compelling points of interest such as improvements in fire safety. The MPC's tolerance of impurities makes it of special interest where clean water and washed aggregates are expensive. The potential for making high quality construction material using primarily locally produced and presently wasted by-products of Alaskan coal could be of notable economic and environmental benefit to Alaska, as well as the export markets of Usibelli coal. The applications for foam made from Portland-based cements are continuing to become more widespread and numerous. Stronger and lighter foams made using these alternative

A Grancrete & foam sandwich

A Lithistone precast MPC sink & counter using colored glass aggregate

Some samples of geopolymers with various compositions.

cements could lead to superior insulation products as well as foam filled composite structural components. The ability to bond strongly to most materials including themselves may have profound implications to building and fabrication processes and products.

Some commercial U.S. manufacturers

This is not an exhaustive list of U.S. manufacturers providing or making products with MPCs and geopolymers. Some of these manufacturers also work with related cements made using other metallic oxides such as those of calcium, aluminum, iron, or zinc as well as other chemical bonds such as oxychloride or sulphate, which are not covered by this Snapshot. Some others preferred not to be listed. Inclusion in this list does not imply any endorsement of these companies or their products:

- *www.grancrete.net*
- *www.ceralith.com*
- *www.bindancorp.com*
- *www.lithistone.net*
- *www.seriousmaterials.com*

It is common for researchers and manufacturers to claim that these materials are superior in every way to ordinary Portland cement and most modified Portland-based cements. While this claim appears to have merit with regard to physical characteristics, it ignores the practical issues of compatibility with existing production facilities, commercial availability, standards, and necessary training and dissemination of knowledge, among others. Therefore, while it is conceivable that alternative cements could someday entirely replace Portland-based cements, they are currently available only in certain niche markets. Which applications obtain the capital investment required to make the transition into a larger marketplace and what new applications will emerge are fascinating aspects of investigating these products.

CCHRC's focus

We are working in close collaboration with faculty from the University of Alaska Fairbanks' Institute of Northern Engineering (INE) on this and other projects. INE's main focus is on fundamental material science and how the materials' properties are affected by the cold. CCHRC's focus is on investigating potential applications of these materials, especially to cold climate construction. We are anxious to discuss possibilities for collaboration with builders, manufacturers and entrepreneurs who may be interested in working with CCHRC on product development and testing.

This is a photo of Air Krete (http://www.airkrete.net) being foamed into a stud cavity. Air Krete is a magnesium oxychloride-based insulation commercially available since 1984. MPCs and geopolymers can be foamed in several ways suggesting a range of possible uses including stronger and more adhesive insulations.