Calcium Aluminate Technology and Its Application in Refractory Shotcrete

by Mark W. Fitzgerald, Joseph Talley, and Charles W. Alt

The use of calcium aluminate cement as the binder in refractory systems in general, and refractory shotcretes in particular, is widely known and well documented. A lesser-known approach to high-performance refractory shotcrete involves the use of calcium aluminate aggregates along with the calcium aluminate cement. The addition of this unique aggregate imparts enhanced properties to shotcretes, enabling them to endure the toughest of industrial environments.

Typical slag pit application in the steel industry.

Temperature-related problems in the steel industry.

There are two processes used to manufacture calcium aluminates: sintering and fusion. It is the fusion process that can be employed to produce calcium aluminate aggregates. In the fusion process, where large reverberatory furnaces are fed with precise amounts of the two fundamental raw materials, bauxite and limestone, a molten bath of calcium aluminate is formed. Once cooled, the raw calcium aluminate will disaggregate into large angular pieces of extremely hard and dense material that, when properly crushed and sized, make an excellent aggregate with unique properties well-suited to demanding industrial applications for refractory shotcretes. Aggregates made by fusion are well-known for their high strength and very low porosity.

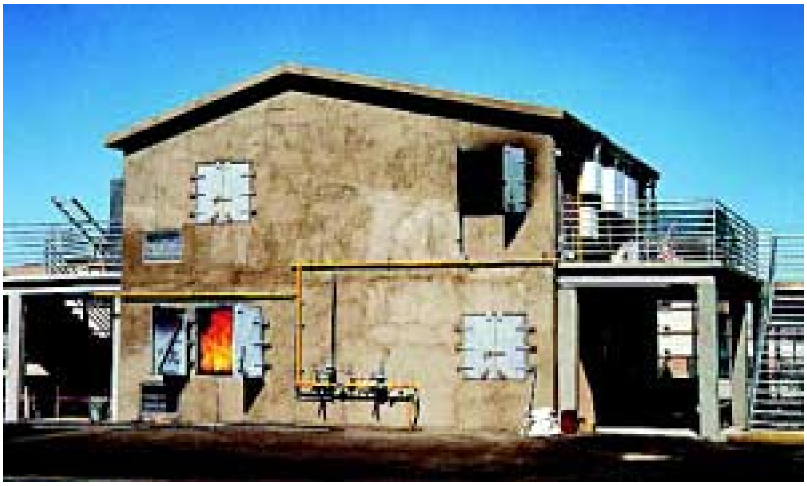
When suitably proportioned in shotcretes or conventional concretes, the mixtures of calcium aluminate cement and calcium aluminate aggregate, or pure calcium aluminate systems, will provide high-early strength, high-ultimate strength, outstanding resistance to heat and thermal shock (to 2000 °F [1100 °C]), and very good abrasion resistance. In these mixtures, the paste-to-aggregate bonding is both mechanical, as well as chemical, and this unique affinity between aggregate and cement provides many of the enhanced properties of the systems.

In the traditional high-temperature industry (iron, steel, and aluminum), refractory shotcretes based on pure calcium aluminate systems have been used for rehabilitating and protecting coke wharves, slag pits, drossing areas, and mill scale flumes. Each of these applications relies on the material's ability to gain strength quickly, resist heat and thermal shock, and withstand repeated mechanical abuse and abrasion. Most industrial applications of these materials have carried the additional constraint of requiring a return to service in 24 hours or less, and pure calcium aluminate systems are capable of delivering over 7500 psi (51 MPa) within 24 hours.

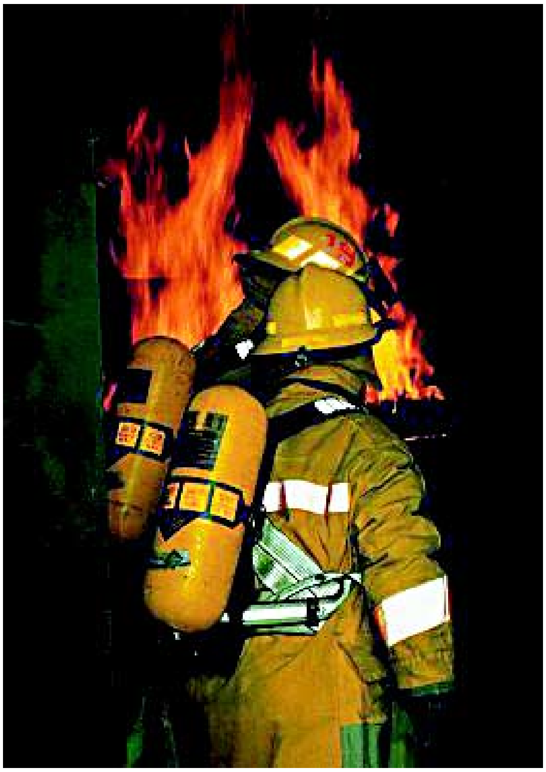
Another application for pure calcium aluminate shotcrete is in the lining of fire training structures. These cast-in-place or block-constructed buildings are used by firefighters for live-fire training purposes. Typically, large amounts of combustible materials such as wooden pallets or bales of hay are stacked and soaked with fuel oil prior to ignition. Once ablaze, temperatures exceeding 1800 °F (980 °C) are not uncommon. To further test the integrity of the structures, firefighting trainees then quickly douse the flames with high-pressure water streams, resulting in extreme thermal shock. Conventional concretes or shotcretes are unable to withstand this type of repeated thermal abuse. Pure calcium aluminate shotcretes have proven to be a reliable means of protecting these structures and are commonly used.

Beyond its applications as a refractory material for industry, pure calcium aluminate technology has been used to rehabilitate dam spillways and structures affected by biogenic corrosion, such as manholes and pipes.

For most application schemes, preparation involves the removal of existing deteriorated material, a thorough cleaning of the affected areas to remove surface laitance, and the setting of an appropriate mechanical anchoring scheme, such as wire mesh or V-clip-type anchors. Anchoring can be critical in certain applications, and in extremely high service temperature environments, a stainless steel anchoring system is recommended. Typical anchor types, spacing, and configurations are explained in detail in ACI 547R, *Refractory Concrete*. For any application involving thermal conditions, a minimum thickness of 4 in. (100 mm) of pure calcium aluminate material is generally required. If extreme abrasion is present with high service temperatures, gunite materials can be manufactured to include the addition of 1.5 to 3.0% steel fibers. The service temperature will govern the choice of the anchor material. According to ACI 547R, "Carbon steel can be used for anchor



A burn facility in the fire-training industry.



Trainees in action.

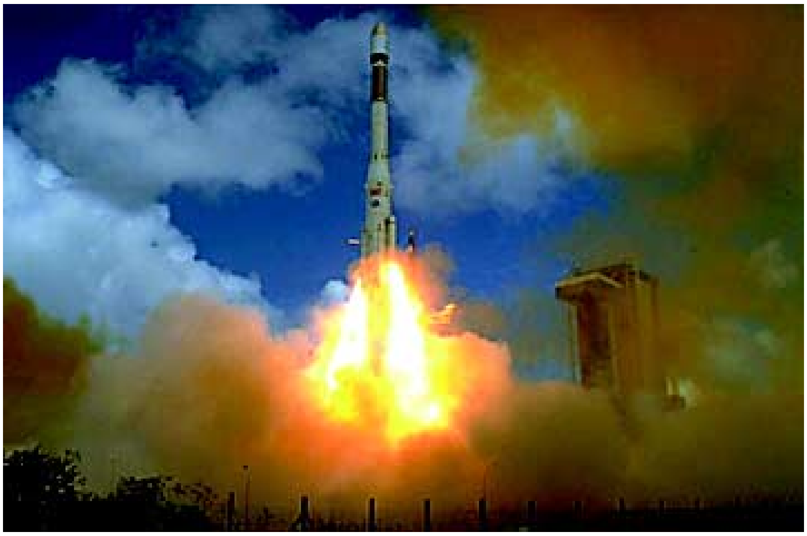
Dam spillway application.

A sewer pipe installation.

temperatures up to 1000 °F (540 °C). Type 304 stainless is suitable for anchor temperatures of up to 1800 °F (980 °C) and Type 310 stainless is adequate up to 2000 °F (1100 °C)." A rebound rate of 15% on vertical surfaces is not uncommon, and overhead rebound rates can range between 20 to 30%, depending on the substrate material, anchoring scheme, and gunning technique. The inclusion of stainless steel fibers may increase these percentages slightly.

Type 304 stainless V-clips are being installed at the Nassau County Fire Service Academy.

A refractory gunite installation at the Nassau County Fire Service Academy.



The aerospace industry.

Once in place, and following the first evolution of heat at final set—normally within 2 hours—the pure calcium aluminate system is protected from plastic shrinkage cracking through the use of a moist curing scheme such as misting, wet burlap, or a heavy application of a curing compound that conforms to ASTM C 309. Twenty-four hours after placement, the system can be considered ready for service.

One example of pure calcium aluminate technology in use in the real world is at the Nassau County Fire Service Academy (NCFSA) in Bethpage, NY. This 14-acre facility is used to train firefighters from New York City and all of the surrounding areas. Beginning in 1991, the NCFSA began evaluating pure calcium aluminate technology as a means to line its existing structures to protect them from the damage of daily training exercises. Conventional refractory shotcretes had proven to be a relatively short-term solution, and following 5 years of testing the NCFSA selected a pure calcium aluminate system to line several thousand square feet of newly constructed building space constructed in 1998. The contractor that installed this material is Herman Sommer and Associates based in Newark, NJ.

Another example of high-temperature shotcrete application exists in the aerospace industry. Pure calcium aluminate technology is commonly used in areas of direct flame impingement in both private and governmental facilities. Areas where this material is used include flame buckets, deflector pads, and exhaust tunnels. These areas experience both very high service temperatures as well as significant abrasion through airborne particulates. Typically, these installations will include stainless steel fibers, as mentioned previously. These are areas where rockets and motors are developed and evaluated, or actually used in the case of Cape Canaveral. Atlantic Fire Brick and Supply Company based in Jacksonville, FL, installed pure fused calcium aluminate technology in the flame bucket area of Complex No. 37 at NASA's Cape Canaveral facility. The pure fused calcium aluminate material was installed with traditional dry-gunite equipment in early 2000.

The petrochemical industry also has its share of severe refractory applications. Pure fused calcium aluminate technology is commonly used in sulfur pit applications in this industry. This is an area with moderately high operating temperatures and a severe chemical attack coming from direct molten sulfur contact. It is also commonly used in other high-temperature petrochemical applications such as boiler foundations. Pure fused calcium aluminate technology has been widely accepted in this industry by companies such as Exxon, Texaco, Mobile, and PeMex with a history in North America dating back to the early 1990s.

In summary, we can see from the applications previously listed that calcium aluminate concretes and mortars can withstand many hostile environments that destroy normal concretes in a short period of time. Calcium aluminate compositions have been successfully adapted to the shotcrete method of installation and have proven themselves in many industrial references.

When considering an appropriate shotcrete material for refractory applications, it is important to not only consider the temperatures involved, but the other aspects of the operating environment that could lead to premature failure. These would include thermal shock, abrasion, mechanical abuse, and chemical attack. Refractory shotcretes designed around "pure" calcium aluminate systems, those containing calcium aluminate aggregates and calcium aluminate cement, will provide excellent long-term service in the aggressive environment of heavy industry. Successful applications span a wide range of industries, well beyond iron and steel, where their importance was first recognized. Future uses of these unique materials will be found by innovative contractors who are committed to the expansion of shotcrete applications in heavy industry.

For more information and references on this technology, please visit our website at www.LCAinc.com or contact a Lafarge Aluminates representative.

A petrochemical gunite installation.

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