White Paper

Understanding Ancient Geopolymers Used in Egyptian Pyramids to Modernize Contemporary Concrete Masonry

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3/27/2015

Background

Contemporary concrete masonry excels as a building material, especially in regard to compressive strength, aesthetics, and thermal mass. Despite these advantages, modern concrete masonry can also be characterized by very high embodied energies and suboptimal durability. Ancient monuments like the Great Pyramids at Giza, ingeniously built using indigenous materials, demonstrate remarkable resistance to weathering and deterioration and provide a staggering juxtaposition to many of today’s cheaply-built, ephemeral structures. The study of such ancient edifices can inform and benefit contemporary building efforts.

Many contemporary concrete materials are responsible for substantial emissions of CO₂ and relatively short lifecycles. A large portion of the masonry materials market is dominated by concrete masonry units, the manufacture of which is responsible for an estimated 8 million metric tons of CO₂ annually. The vast majority of concrete masonry’s CO₂ emissions results from the production of ordinary Portland cement (OPC), the primary binder used in modern concrete and concrete masonry. In addition to the high environmental costs associated with OPC use, the production and transportation of aggregates for the concrete industry involves environmentally damaging quarry operations and significant additional costs. Furthermore, the durability of many modern concrete masonry structures demonstrates room for improvement, with much effort in academic and professional spheres dedicated to understanding the corrosive mechanisms acting on modern concrete masonry building materials and developing means of enhancing their durability.

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3 Internal calculations from industry production data.
Contrasting the energy-intensive production and suboptimal durability of modern concrete masonry are examples of ancient masonry that demonstrate intelligent use of local resources, great ingenuity, and remarkable durability. Upending the longstanding belief that the Egyptian pyramids were constructed entirely of quarried stones, recent discoveries indicate that a significant portion of the “stones” used in the pyramids were man-made masonry blocks compacted in place using geopolymer-like binders. These concretious masonry materials are believed to have incorporated indigenous, naturally-occurring pozzolanic materials, hydrated limestone and other alkaline media, and bear many resemblances to modern geopolymer concretes. Geopolymer concretes differ from ordinary concretes in that they utilize unique, amorphous stabilizers consisting of a combination of alkaline solution and solid aluminosilicate materials rather than relying on ordinary Portland cement (OPC) as a binder. Geopolymer stabilizers, recently rediscovered, have generated enormous interest because of their potential to reduce the environmental impact and improve the durability and mechanical properties of contemporary concrete by means of reduced processing requirements and superior mechanical performance. Ancient Egyptian builders are believed to have developed and implemented novel processing and manufacturing techniques that were instrumental in producing high-quality, low embodied-energy masonry materials that have demonstrated remarkable durability for upwards of 4,000 years.

**Egyptian Pyramids**

The enigmatic nature of the ancient Egyptian pyramids has been the source of much speculation for centuries. The nearly inconceivable scale of construction, together with the rudimentary nature of then present manufacturing technology, has long proved a subject of great fascination and deliberation. Historically, it has been assumed that virtually all of the materials used to build the pyramids were carved stone (or ashlar), implying that a mind-numbing amount of manual labor was involved in their construction. Over the past several decades, many of these assumptions have been questioned by scientific investigation, yielding insights that can be fruitfully applied to contemporary building efforts.

Joseph Davidovits, a renowned building materials researcher and the father of modern geopolymerization, is responsible for significant pioneering theories concerning the techniques used in the construction of the Egyptian pyramids. In 1974, Davidovits posited that many of the “stones” used in the construction of the pyramids are actually man-made masonry blocks that were compacted in place in temporary formworks and that utilized advanced, geopolymer-like binders. Davidovits suggests that ancient Egyptian chemists, including the famed Imhotep, combined lime and natron salts to create a type of caustic soda, a key ingredient in their early brand of geopolymer. As in modern geopolymerization reactions, the introduction of alkaline media (caustic soda, for example) to aluminosilicate materials (pozzolanic ash and clay in this case) precipitated a strong chemical reaction that catalyzed the integration of silica and alumina products. These reactions resulted in the formation of strong, cement-like, C-A-S-H binders with exceptional performance properties.

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Fossil shells, limestone aggregates, and silt were added to the mix design and compacted in-place to ensure a dense interparticle arrangement and highly-efficient stabilization.\(^7\)

Davidovits’ findings offer plausible alternative explanations to the seemingly impossible feats of construction presumed to have been performed by the ancient Egyptians. While his discoveries are still officially considered theories, numerous peer-reviewed scholarly papers have been published by reputable scientific organizations that corroborate his findings. Support for his theories is increasing in recent years as evidence continues to surface. His findings are substantiated by Linn W. Hobbs, professor of materials science at Massachusetts Institute of Technology and Michel W. Barsoum at Philadelphia’s Drexel University, among others. Barsoum’s contributions to Davidovits’ findings go beyond validation. In addition to verifying Davidovitz’s discoveries through microscopic analysis\(^8\), Barsoum has presented research describing binding methodologies likely used by Egyptian builders and potential reasons for the use of both quarried stones and cast blocks throughout different sections of the Pyramids. Despite not yet being accepted as established fact, Davidovits’ findings are astoundingly convincing, not only in favor of the construction model they posit but also in discrediting previously-assumed methods of construction through presentation of a wealth of credible evidence.\(^9\)

The incredibly-long lifetime of the Pyramids is a testament to the effectiveness of the low embodied-energy masonry construction techniques theorized to have been innovated by the ancient Egyptians. By combining indigenous pozzolanic materials with a novel caustic soda to create highly-durable, geopolymer-like binders, these innovate builders appear to have engineered complex and high-performance concretious masonry that they enhanced by compaction in temporary formworks to optimize density and mechanical properties. The structures they built have resisted weathering and deterioration for over 4,000 years, providing today’s builders with valuable tools for updating contemporary construction practices. Recent research into the exceptional performance of geopolymer stabilizers, like those used by the ancient Egyptian builders, has brought attention to the potential for these materials to offset the environmental and economic costs associated with the widespread use of OPC, and to improve the durability of modern masonry materials. In comparison to OPC stabilizers, the materials used to produce geopolymer stabilizers require less processing, reducing environmental and economic costs.\(^10,11\) The superior durability of geopolymer concretes stands to further improve the environmental profile of modern concrete masonry by extending building lifetimes. With support from the National Science Foundation, Watershed Materials is researching possibilities for expanding the range of


aluminosilicate materials that can be used as feedstocks for geopolymers, ideally targeting construction and mining waste. Watershed Materials’ research is accompanied by the parallel research from other teams seeking to develop more cost effective methods for extracting the alkali materials necessary for geopolymerization from novel sources including industrial wastes.

Watershed Materials LLC

The staff at Watershed Materials LLC is committed to finding solutions to shortcomings in modern construction materials, in part through the study of masonry construction’s rich history and the selective application of the most successful innovations of ancient builders and engineers. Watershed Materials advances technologies perfected by the ancient Egyptians including the geopolymerization of natural pozzolans and locally-sourced fines minerals. Watershed Materials integrates historic construction techniques with the industry state-of-the-art by implementing proprietary technologies and production processes including specialized C-A-S-H stabilization approaches, high-shear mixing, ultra high-pressure dynamic compression, and high-efficiency curing.

Building on the tremendous successes of Imhotep and his peers, Watershed Materials LLC is working to enhance the durability of modern masonry materials while reducing their embodied energy and environmental footprint. These benefits are realized by extending building lifetimes, increasing the use of indigenous materials and implementing low embodied-energy strategies for materials processing and stabilization.

The National Science Foundation recently funded research by Watershed Materials to study the geopolymerization of natural aluminosilicates. This research represents a significant advancement in geopolymer stabilization technologies as it focuses on utilizing commonly-occurring aluminosilicates as the source of alumina and silica in geopolymer binders rather than the energy-intensive, regionally-limited Supplementary Cementitious Materials typically used in modern geopolymer applications. This innovation has the potential to dramatically expand the range of feedstocks suitable for geopolymerization and reduce the environmental footprint and embodied energy of next-generation geopolymer stabilizers and masonry materials.
The Pyramids of Giza with modern Cairo in the background. From left to right: the great pyramid of Khufu, 481 feet; the Pyramid of Khafre 448 feet; the pyramid of Menkaure 215 feet; the pyramids of Queens. Image ©David Holt used with permission of Creative Commons license.
A gash in the side of one of the pyramids built by Senefru — the father of Khufu, who built the Great Pyramid — shows a combination of what appears to be irregularly cut quarried limestone blocks surrounded by tight jointed, cast-in-place geopolymer blocks. Image © Michel Barsoum.
A ground level block in front of the Great Pyramid of Khufu includes a irregular lip at the bottom that would have been very hard, and somewhat pointless, to carve. This lip indicates that the block was cast in place — the material in the lip having slid out under the temporary wooden mold before hardening. Barsoum analyzed a piece of material from the bottom lip and says he did not find smoking gun evidence. “The only logical conclusion is that after 5000 years, the binding phase has basically been washed away. Solution? Get samples from the core of that block. Easier said than done.” Image © Michel Barsoum

**Further Reading**

**Accessible to public:**

Barsoum, M W. “Of Geopolymers, Pyramids, and Homes” Department of Materials Science and Engineering Department of Materials Science and Engineering, Drexel University - [link](http://www.materials.drexel.edu/media/146620/geopolymerwhitepaper-barsoum.pdf)  


**Scholarly:**  


