



Of Geopolymers, Pyramids And Homes

A White Paper

The Research Group of Dr. Michel Barsoum
Drexel University
Philadelphia, PA, USA
January 2006



Email: barsoumw@drexel.edu Phone: (215) 895-2338
Website: www.materials.drexel.edu/pyramids/
Address: Dept. of Materials Science and Engineering, Drexel University
3141 Chestnut Street, Philadelphia PA, 19104, USA



Historical discovery rarely leads directly to modern technology. The pyramids, however, have provided insight into the development of an affordable and sustainable building material. Through rigorous academic treatment, we have learned from the past to build a brighter future. Geopolymer concrete is environmentally friendly, inexpensive, and robust. We propose to develop this technology and use it to benefit the world, especially developing communities.

The Great Pyramid of Giza is one of the most impressive constructs of humankind. Until the erection of the Eiffel Tower, The Great Pyramid was the tallest building on earth. It has outlived all of the other wonders of the ancient world and for millennia, has captivated the imaginations and hearts of countless generations. Currently, it is believed that the pyramids were constructed by carving limestone blocks – some of which are massive - from local quarries, hauling them and hoisting them via ramps, into place. While at first blush this theory sounds plausible, it cannot explain some very basic facts about the construction process, not the least of which is how to get the ramps to the top of the pyramids. In the mid-1980s, Davidovits¹ proposed that the pyramids were cast in situ using granular limestone aggregate and an alkali aluminosilicate-based binder that he named a geopolymer. Hard evidence for this idea, however, remained elusive until our very recent paper² in which we present compelling microstructural evidence that supports his idea in *part*. Based on our work, it now appears that the glue that held the limestone aggregate together is not an alkali aluminosilicate-based binder, but more simply, an amorphous silica binder. Also, in disagreement with Davidovits, we do not believe that the entirety of the pyramids are cast; only select critical parts such as the outer and inner casings, and most probably the upper echelons.

According to Davidovits these materials are made by starting with a high-pH solution into which a silicate mineral such as clay is dissolved. Once the limestone aggregate is added and some of the water evaporates, a polycondensation reaction occurs, wherein a geologic glue is formed that acts as a binder. The final product is indistinguishable by eye from naturally occurring limestone, and can be used in all of the same applications as modern concrete.³

As noted above, according to Davidovits, the pyramid samples should have contained sodium and aluminum in the binding phase. We found only silicon dioxide and calcium silicates in our cementing phases. The implication is that the ancient Egyptians did not start with clay, as proposed by Davidovits, but with diatomaceous earth. Diatomaceous earth (DE) is a naturally occurring, soft, chalk-like sedimentary rock that is easily crumbled into a fine powder. It consists of fossilized remains of diatoms, a type of hard-shelled algae. Experimentally we found that the advantages of starting with DE, as compared to clay, has a much faster dissolution and reaction rate of the former. One of the keys to the entire process of geopolymerization is the dissolution of silica.

This knowledge leads to our basic premise: Could this simple and inexpensive 4500 year old technology be redeveloped for use today? We believe the answer to be a resounding yes. Research groups around the world, including our own, are well on their way to producing a geopolymer cement to rival the industry standard Portland Cement (PC) in compressive strength and cost.

¹ J. Davidovits, "X-rays analysis and XRD of Casing Stones from the Pyramids of Egypt, and the Limestone of Associated Quarries", David, R.A. (ed.), Science in Egyptology Symposia, Manchester U Press, Manchester, UK 511-520, (1986).

² M. W. Barsoum, A. Ganguly and G. Hug, "Microstructural Evidence for Reconstituted Limestone Blocks in the Great Pyramids of Egypt", J. Amer. Cer. Soc., 89, 3788-3796 (2006).

³ B. V. Rangan, Ch. 26 in Concrete Construction Engin. Handbook, Ed. E. G. Nawy, 2nd Ed., CRC Press, NY, 2007.

Geopolymers have several key advantages. First, they clearly can survive nearly five millennia. Second, geopolymer cement produces 90% less CO₂ than PC. To make the latter, limestone containing some silica is heated to 1450 °C. Thus CO₂ is produced twice: CO₂ derived from decarbonation of limestone, and CO₂ from kiln fuel combustion. The PC industry is thus a major producer of carbon dioxide, a greenhouse gas. For every ton of cement made, roughly a ton of gas is released into the atmosphere. In 2004 alone, the PC industry worldwide released more than 2 billion tons of CO₂ into the atmosphere. By 2010, that number is projected to grow to 2.8 billion tons. Geopolymers, on the other hand, use roughly 90% less lime, and therefore release roughly 90% less greenhouse gases.

Third, geopolymer concrete would be inexpensive all over the world. The raw materials used to produce geopolymer cement are ubiquitous in the Earth's crust. The materials require little pre-processing, no high temperatures, and a simple mixing process. Furthermore, this concrete is almost indistinguishable from natural stone and thus aesthetically pleasing.

Over the past two years, we have focused the development of our geopolymers towards one specific goal: to create a limestone-based concrete that can be used in place of Portland Cement-based concrete with the strictures that it: i) be composed of naturally occurring and easily obtainable reactants such as DE and limestone and ii) cure at room temperature and/or temperatures less than 100 °C. The primary reason for this is simple: in many developing communities, PC, the key component of modern concrete, is either too expensive for widespread use and/or the infrastructure for its distribution is not present. The secondary reason is that this green, sustainable, aesthetic, inexpensive technology could find widespread use in developed nations all over the globe for buildings, roads, and more.

In the last two years we have made great progress towards our goal. We now can make reconstituted limestone starting with sodium hydroxide, limestone powder, DE and a small amount of lime. The samples, cured at 90 °C, result in stone with compressive stresses >20 MPa and can survive submersion in water for 2 months before their properties degrade. We are currently working on a third generation – the first generation did not survive more than a day in water – that we hope will bring us closer to our goal. The work to date has been unfunded, however, and we are now seeking funding to accelerate the project, reach our objective and commence a worldwide campaign to disseminate our knowledge, especially to Sub-Saharan Africa and other places where robust and sustainable shelter is lacking.

According to a United Nations Task Force, “Science, technology, and innovation underpin every one of the Millennium Development Goals” such as health, education, and deliverance from poverty⁴. The Ancient Egyptians used a unique chemistry to create what ranks as one of humankind's greatest architectural achievements. Today, once this chemistry is rediscovered, we believe it can be used to combat the lack of adequate housing in much of the developing world. Our research is backed by a solid knowledge base and already shows great promise. With continued research, we hope to reach the day, in the not too distant future, when people of all nations and circumstances can build robust homes and infrastructure *themselves*, from nothing more than the right kind of “dirt,” water, and the knowledge gained from our work. That the resulting structures would use a green and highly sustainable technology is an added benefit.

For more information about the pyramids, their mode of construction, and Geopolymers, visit: www.materials.drexel.edu/pyramids/

⁴ “Innovation: Applying Knowledge In Development,” Millennium Project, Earthscan, 2005.