



# Geopolymers

Structure, processing,  
properties and  
industrial applications

Edited by John L. Provis and  
Jannie S. J. van Deventer

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## Geopolymers

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# Introduction to geopolymers

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**Abstract:** This introductory chapter provides a brief overview of some important aspects of geopolymer technology, in particular its historical development and the terminology by which geopolymers are described. An introduction to geopolymer technology from a scientific viewpoint is also given. The scope of this review is confined to predominantly low-calcium materials, i.e. 'traditional' alkali-aluminosilicate geopolymers, to the exclusion of alkali-activated slags and other related materials.

**Key words:** geopolymer, inorganic polymer, aluminosilicate, alkali activation.

## 1.1 History of geopolymer technology

The term 'geopolymer' was coined in the 1970s by the French scientist and engineer Prof. Joseph Davidovits, and applied to a class of solid materials synthesised by the reaction of an aluminosilicate powder with an alkaline solution (Davidovits 1982a, 1991, 2008). These materials were originally developed as a fire-resistant alternative to organic thermosetting polymers following a series of fires in Europe, and products based on this initial work have since found application as coatings for fire protection for cruise ships (Talling 2002), as a resin in high-temperature carbon-fibre composites (Lyon *et al.* 1997), in thermal protection of wooden structures (Giancaspro *et al.* 2006), as a heat-resistant adhesive (Bell *et al.* 2005, Krivenko and Kovalchuk 2007), as a monolithic refractory (Comrie and Kriven 2003, Kriven *et al.* 2004), and in various other niche applications. However, as can be seen from a brief perusal of the Table of Contents of this book, the primary application for geopolymer binders has since shifted to uses in construction. This is primarily due to the observation, first published by Wastiels *et al.* (1993), that it is possible to generate reliable, high-performance geopolymers by alkaline activation of fly ash, a by-product of coal combustion.

The synthesis of construction materials by alkaline activation of solid, non-Portland cement precursors (usually high-calcium metallurgical slags) was first demonstrated by Purdon (1940). Detailed lists of key historical references and milestones in the development of alkali-activated binders have been presented in various review papers (Malone *et al.* 1985, Krivenko 1994, Roy 1999, Krivenko 2002); the majority of these relate to the alkaline

activation of blast furnace slags, and so are beyond the scope of the current discussion. A very extensive review focussed predominantly on alkali activation of metallurgical slags has recently been published (Shi *et al.* 2006), and the reader is referred to that excellent book for information in that area. The key distinction to be made here is that the alkaline activation of slags produces a fundamentally calcium silicate hydrate-based gel (Richardson *et al.* 1994, Wang and Scrivener 1995, Shi *et al.* 2006), with silicon present mainly in one-dimensional chains and some substitution of Al for Si and Mg for Ca, whereas the geopolymer gel is a three-dimensional alkali aluminosilicate framework structure (Duxson *et al.* 2007b). The role of calcium in geopolymers is a matter still under investigation; some of the subtleties of calcium chemistry in geopolymers will be discussed throughout this book.

Much of the early published research into aluminosilicate geopolymers was published in the patent literature (for example: Davidovits 1982b, 1984), and so contains little scientific detail. Probably the most valuable documents summarising work throughout the 1980s are the proceedings of a conference (*Geopolymer '88*) held in France in 1988 (Davidovits and Orlinski 1988), and a review paper authored by Davidovits (1991). Shortly after this, Palomo and Glasser published the first detailed scientific study of metakaolin geopolymers (Palomo and Glasser 1992), followed shortly afterwards by an extremely valuable three-part series by Rahier *et al.* (1996a, 1996b, 1997). These papers laid the groundwork for both broader and deeper study of metakaolin geopolymers in the ensuing decade, in particular work by groups in Spain (Granizo and Blanco 1998, Palomo *et al.* 1999b, Alonso and Palomo 2001), New Zealand (Barbosa *et al.* 2000, Barbosa and MacKenzie 2003), Germany (Kaps and Buchwald 2002, Buchwald *et al.* 2003, Buchwald 2006), and Australia (Yip and van Deventer 2003, Duxson *et al.* 2005, Perera *et al.* 2005, Singh *et al.* 2005, Steveson and Sagoe-Crentsil 2005). The proceedings of Geopolymer conferences held in 1999 (Davidovits *et al.* 1999), 2002 (Lukey 2002) and 2005 (Davidovits 2005) also provide valuable information regarding both technical developments in the field and the worldwide growth in geopolymers research during this period. A book published recently by Davidovits (2008) also summarises a good deal of work that was only previously available in the patent literature.

Research into fly ash geopolymers has grown from the aforementioned conference paper by Wastiels *et al.* (1993) to now form the bulk of applications-oriented research in this field. Fly ash has long been used in Portland cement concretes to enhance flow and other properties (Diamond 1986, Bouzoubaâ *et al.* 1999, Manz 1999), to reduce the carbon footprint of concrete, as well as simply a means of disposing of some of the many millions of tonnes of fly ash produced worldwide each year. Additional early reports of geopolymerisation of ASTM Class F (low-calcium) fly ash were provided by a number of researchers (van Jaarsveld *et al.* 1997, 1998,