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# Evaluation of a low temperature hardening Inorganic Phosphate Cement for high-temperature applications

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ABSTRACT

Phase and mechanical changes of Inorganic Phosphate Cement (IPC) are identified along with changes in macro properties as functions of temperature and time. In addition to amorphous phases, the presence of significant amounts of brushite and wollastonite in the reference IPC is confirmed using X-ray diffraction. The thermal behavior of IPC up to 1000 °C shows that contraction of the solid phase in IPC due to chemical transformations causes reduction in the volume of the material. Also the ongoing meta-stable calcium phosphate transformations and reactions over a long time contribute significantly to the phase instability of the material at ambient conditions. It is found that the strength of IPC increases with ageing at ambient conditions but the formation microcracks below 105 °C causes a sharp reduction in the mechanical performance of IPC. According to the results obtained by Mercury intrusion porosimetry, the pore system of the reference IPC is dominated by mesopores.


## 1. Introduction

Calcium phosphate cement is the generic term to describe chemical formulations in the chemical system that can experience a transformation from a liquid or pasty state to a solid state, and in which the end product of the reaction is a calcium phosphate. These cements consist generally of a concentrated mixture of one or several calcium phosphate powders and an aqueous solution (e.g. water), but it may also consist of a mixture of two or more solutions [1,2]. These cements have the ability to precipitate different end products (e.g. hydroxyapatite, calcium deficient apatite, brushite, etc.) after full conversion [3]. The calcium phosphate cements (CPCs) are commonly used in dentistry and orthopedic bone filling surgeries, which require extremely invasive procedures [1–6]. The discovery of CPCs has been ascribed to Brown and Chow for an abstract published in 1983 [4]. However, several authors worked with similar reactions before 1983. For example, Kingery looked at formulations based on CaO and phosphoric acid in 1950 [5]. Over the last few years, researchers at the Vrije Universiteit Brussel (VUB) have been developing a chemically bonded Inorganic Phosphate Cement (IPC) for structural and industrial applications where (accidental) and high temperatures may occur. This material is called Inorganic Phosphate Cement (IPC) and is available under the commercial brand name Vubonite [7]. IPC is a new material that sets at room temperature, with unique properties for manufacturing E-glass fiber reinforced composite materials. Such a textile reinforced cementitious composite is an interesting material in those applications where high load-bearing capacity, good temperature or fire resistance, and lightweight constructions are demanded [8]. IPC is a two-component system, consisting of a calcium silicate powder and a phosphoric acid-based solution of metal oxides. After hardening, the material's properties are similar to those of Portland cement based materials. IPC can be used in elevated temperature applications such as moulds for shaping of composites with thermoplastic matrix or post curing of thermosets. Because the IPC belongs to a novel class of room-temperature-setting chemically bonded materials with remarkable thermal, structural and rheological properties that are ideal for matrices of fibre reinforced composite materials, the main objective of this paper is to study the impact of temperature and time on its properties. The thermal and dimensional stability of the material is evaluated in order to provide an overview of the main challenges that will be encountered when using IPC in various applications. Specifically, the problems which will limit the use of IPC in structural applications will be investigated and identified, particularly those related to heat resistance and ageing. A link between mechanical properties and molecular and microstructure is looked for.

## 2. Basic chemistry of IPC

The setting reaction of IPC was described in previous work [9]. A small overview will be given here. The reaction between the Ca source wollastonite ($CaSiO_3$) and the phosphoric acid solution starts in a very

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