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The origin of the pozzolanic activity of calcined clay minerals: A comparison between kaolinite, illite and montmorillonite

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1. Introduction

Calcined kaolinite, or metakaolin, has been well studied in recent years and has proven to have very good pozzolanic properties [1,2]. Its potentially beneficial use in concrete has been well established; for example, it has been shown that the replacement of cement by 5%–10% of metakaolin can drastically improve the mechanical properties of concrete, as well as its durability [3,4]. However, the origin of the pozzolanic properties of calcined kaolinites, in contrast to other clay minerals, is not well understood.

Crystallography has helped a lot in understanding the effects of thermal treatment on the structure of clay minerals. Brindley [5] laid the groundwork in this field by investigating the kaolinite–mullite reaction series back in 1959. He used ²⁷Al NMR to suggest a semicrystalline structure for metakaolin. Around 30 years later, Mackenzie [6] proposed a revised structure including only 4- and 6-coordinated Al, but Rocha and Klinowski [7] confirmed the occurrence of 5coordinated aluminium in the structure based on previous work on aluminosilicates [8,9]. Although much of the interest with NMR has been focused on kaolinite transformations, some papers also report some findings on the thermal behaviour of illite [10] and montmorillonite [11].

In parallel, research in cement and concrete has looked at the pozzolanic properties of various calcined clay minerals by mixing them with lime or cement [i.e. 12,13]. It was concluded that kaolinite was the most reactive type of clay. Many of these works also looked at

ABSTRACT

This paper investigates the decomposition of three clayey structures (kaolinite, illite and montmorillonite) when thermally treated at 600 °C and 800 °C and the effect of this treatment on their pozzolanic activity in cementitious materials. Raw and calcined clay minerals were characterized by the XRF, XRD, ²⁷Al NMR, DTG and BET techniques. Cement pastes and mortars were produced with a 30% substitution by calcined clay minerals. The pozzolanic activity and the degree of hydration of the clinker component were monitored on pastes using DTG and BSE-IA, respectively. Compressive strength and sorptivity properties were assessed on standard mortars. It was shown that kaolinite, due to the amount and location of OH groups in its structure, has a different decomposition process than illite or montmorillonite, which results in an important loss of crystallinity. This explains its enhanced pozzolanic activity compared to other calcined clay–cement blends. © 2010 Published by Elsevier Ltd.

the influence of calcinations parameters such as time and temperature on the final properties of the blends, aiming at optimizing the pozzolanic reactivity of metakaolin for potential industrial applications [14,15]. However, little effort has been put into linking the pozzolanic reactivity of calcined clay minerals to the decomposition process.

This paper investigates three types of clay minerals commonly found in the earth's crust: kaolinite, illite and montmorillonite. The aim is to compare the decomposition mechanisms of these structures and see how they influence the pozzolanic properties of the materials when mixed with cement. The work includes the characterization of the clay structures before and after calcination, a study of the pozzolanic activity of calcined clay minerals–cement blends and the assessment of the mechanical and sorptivity properties on mortars.

2. Materials and methods

Kaolinite, illite and montmorillonite, referred to as standards clay minerals, were purchased from Ward's Natural Science [16] and were used as received. These clay minerals are natural materials that cannot be considered pure minerals as they contain some impurities such as quartz, feldspars or other clay types in minor amounts. Their structure and ideal formulas are presented in Fig. 1. Aluminosilicate minerals are formed by the stacking of layers composed of alternating tetrahedral and octahedral sheets [17]. In the case of kaolinite, because its layer is formed of two sheets only, two distinct interlayer surfaces coexist: one with aluminate groups and one with silicate groups. The adjacent layers are linked by hydrogen bonding involving aluminol (Al–OH) and siloxane (Si–O) groups. These bonding forces mean kaolin is a nonswelling clay [18]. Also, in the plane of atoms

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