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Ultrasound effects on zeolite synthesis from fly ash. A mini review

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Abstract

In this short review, effects of ultrasound treatment on the synthesis of zeolite from fly ash are analyzed. Zeolites can be synthesized using various processes and among these, because of reducing incubation time, the application of ultrasound treatment has been received great attention in the last few years. Moreover, literature data indicate that sonication also improves crystallinity of the synthesized zeolites. The most important mechanism enhancing crystallization is the ultrasonic cavitation, i.e., the growth and explosive collapse of microscopic bubbles.

Keywords: Zeolite; Ultrasound; Fly ash.

1. Introduction

Zeolites are hydrated aluminosilicate minerals and fly ash is a waste material produced by coal combustion in thermal powder plant.

Zeolites can be formed from fly ash using various processes and, among these, conventional (e.g., Shih, & Chang, 1996; Querol et al., 2001; Tanaka et al., 2003) and pre-fused hydrothermal methods (e.g., Shigemoto et al., 1993; Berkgaut & Singer, 1996; Rayalu et al., 2000) are widely used. In the last few years, because of reducing incubation time as well as incubation temperature, the application of ultrasound method for minerals synthesis has been received great attention (Park et al., 2001; Wu et al., 2006; Wang et al., 2008; Askari et al., 2013; Bukhari et al., 2015). The most important mechanism happening

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in sonocrystallization is the acoustic cavitation, that is the growth and explosive collapse of microscopic bubbles. As far zeolites synthesis from fly ash, the ultrasonic energy acting on the amorphous components of the waste material and affecting depolymerization-polymerization equilibria (Hagenson et al., 1998) improves the formation of the mineral. This action leads to Al-Si enrichment which influences the nucleation rate of crystalline phases with effects on the newly-formed zeolite size. Moreover, the cavitation bubbles caused by sonication act as nuclei for crystal growth and disrupt nuclei already laid down in the medium (Wu et al., 2006), thereby increasing the number of the nuclei involved. This facilitates the synthesis of zeolite at a lower temperature (Azizi & Yousefpour, 2010; Belviso et al., 2011; 2013).

This short paper reviews the current state in the application of ultrasonic method for the transformation of fly ash, a waste material, into zeolites.

2. Fly ash and zeolites

Coal-based power generation produces large amount of fly ash every year thus representing the most abundant coal combustion by-product. Although coal fly ash is partly used in concrete and cement manufacturing due to its well-known pozzolanic reactivity (Larosa, 1992), more than half percent of the production is disposed of in landfills because it finds no other application. Over the last few years fly ash has been gaining ground in finding solutions to environmental problems or it has being used for the synthesis of zeolites. However, this waste material cannot be properly used, both in cement manufacturing and in environmental application, without an in-depth knowledge of its mineralogical and chemical characteristics. So far there have been many literature data dealing with the morphological, mineralogical and chemical characterization of fly ash using different techniques such as scanning electron microscopy (SEM) (Sokol et al., 2000; Vassilev et al., 2004; Kutchko & Kim, 2006), thermal analysis (TG/DTA) (Sarbak & Kramer-Wachowiak, 2001; Majchrzak-Kuceba & Nowak, 2004), fast Fourier spectroscopy (FTIR) (Vempati et al.1994) and X-ray powder diffraction (XRD) (van Roode et al., 1987; McCarthy & Solem,1991; Ward & French, 2006).

The major chemical constituent of fly ash are influenced by the properties of coal be burned as well as combustion method (Ahmaruzzaman., 2010; Zacco, 2014) whereas its morphology is mainly characterized by particles predominantly spherical in shape (Fig. 1). This waste material is formed mainly of amorphous aluminosilicate, and minor amounts of quartz, mullite, hematite, magnetite and carbon (Hower et al., 1999; Sokol et al., 2000; Hall &Livingston, 2002; Mishra et al., 2003; Koukouzas et al., 2006; Belviso et al., 2009; 2010).

The abundance of amorphous aluminosilicate glass, which is the prevalent reactive phase, is what makes fly ash an important source material in zeolites synthesis.

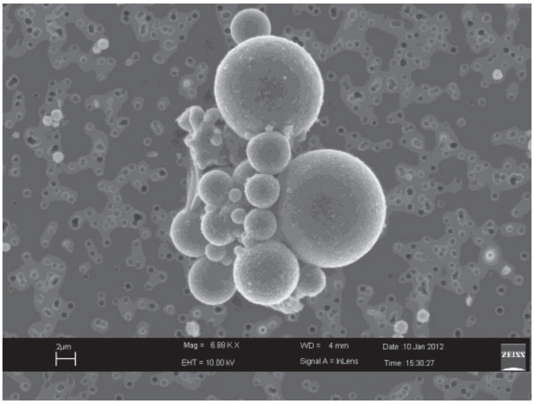

Fig. 1. SEM images of typical fly ash shape.

Zeolites (Fig. 2) are microporous crystalline hydrated aluminosilicates characterised by a three-dimensional network of tetrahedral (Si, Al)O_4 units that form a system of interconnected pores. The aluminium ion produces a net negative charge, which is balanced by the presence of an extra cation in the framework. The framework structures of zeolites are listened in the publication of Atlas of Zeolite Framework Types and at each structures is assigned a code by the commission of International Zeolite Association (Berlocher et al., 2007).

Due to their similar structure and physicochemical properties, synthetic zeolites have replaced natural zeolites in a variety of applications. Literature data indicate that zeolites can be synthesized using several raw material such as clay minerals (Gualtieri et al., 1997; Mezni et al., 2011; Jiang et al., 2012; Belviso et al., 2013; 2015; Musyoka et al., 2014;), other minerals (e.g. Le Van Mao et al., 1989; Saada et al., 2009), waste materials (Yang and Yang, 1998; Prasetyoko D. et al., 2006; Belviso et al. 2009; 2010a; 2012a; 2015, Ng et al., 2015) or different pure precursors (e.g. Mintova et al., 2003 and references therein).

The physiochemical properties of zeolites are factors determining their performances in a number of applications ranging from environment (e.g., Belviso et al., 2010b; 2012b; 2014 Can et al., 2010; Medina et al. 2010; Visa et al. 2012) to enzymatic model and catalysis (e.g., Cejka & Mintova, 2007; Lanzafame et al., 2012; Van Speybroeck et al., 2014).

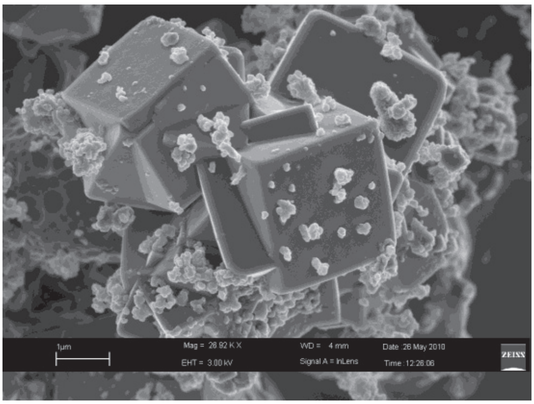

Fig. 2. SEM images of synthetic zeolites.

3. Brief literature review on conversion of fly ash to zeolite by sonication

As compared to the conventional hydrothermal method, the ultrasonic processes provides an efficient way for reduce the crystallization time and temperature as well as to improve the crystallinity of the final products (Park et al., 2001; Adac et al., 2005; Belviso et al., 2011; 2013). Moreover, a comparison of conventional and ultrasonic hydrothermal method indicates that zeolites synthesized after sonication are smaller (Belviso et al., 2011; 2013). According to the mechanism described before, in fact, sonication accelerates the reaction between solid reactants and liquid due to the easy formation of radicals responsible for a rapid crystallization of zeolites after a controlled nucleation stage (Askari et al., 2013; Mintova et al., 2013).

As far zeolite synthesis from fly ash, recent literature data display that A-type and X-type zeolite, as well as hydroxysodalite, have been synthesized from coal fly ash both using ultrasonic assisted hydrothermal method and ultrasonic energy irradiated directly into the reaction mixtures.

Musyoka et al. (2011) converted fly ash in zeolite A with fusion followed by ultrasound assisted hydrothermal conversion and the authors showed that sonication for 40 min prior to hydrothermal synthesis reduced the synthesis time of zeolite A from 2 h to 1 h enhancing crystallization. In our previous works (Belviso et al., 2011) it was demonstrated that the application of 1 hour ultrasonic treatment before the hydrothermal incubation facilitated the formation of zeolite X at a lower temperature using different sample of fly ashes. The data were also confirmed using seawater during the hydrothermal process (Belviso et al., 2013). Moreover, the results showed that as consequence of sonication with seawater, K and Na induced the formation of zeolite domains that served as templates for the crystallization and growth of ZK-5 zeolite and sodalite at lower temperatures. Finally, Woolard et al. (2002) changed fly ash from South Africa power plant to hydroxysodalite displaying that treatment time considerably decreased introducing ultrasonic energy.

Bukhari et al. (2016), instead, reported zeolitization process from fly ash using the ultrasonic probe irradiating energy directly into reaction solution. The authors showed that with this method the zeolitization time drastically decreased and pure single crystalline phase formed at lower temperature.

4. Conclusions and outlook

This mini review reports a brief literature data about the synthesis of zeolite from fly ash using ultrasonic treatments showing the great promise of sonication energy in fast and efficient conversion of a waste material in useful products.

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