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Neutralization of cement-asbestos waste by melting in an arc-resistance furnace

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ABSTRACT

The paper presents the results of research on asbestos waste disposal by the melting process. The tests were carried out in a laboratory arc-resistance electric furnace. The obtained results showed that the fibrous structure of asbestos contained in cement-asbestos waste was completely destroyed. This led to the formation of new mineral phases without dangerous properties. The melting test was conducted on raw cement-asbestos samples without any additives and with a content of mineral compounds, the aim of which was to support the melting process. The additives were selected among others on the basis of the computer simulation results carried out using FactSage database computing system. The research results indicate that the melting process of asbestos wastes is a potential and interesting method of neutralizing hazardous asbestos waste, which allows for further treatment and material recycling.

1. Introduction

Since the early 1960s, asbestos, being a cheap commercially available building material, began to lose its popularity. It was due to the discovery of asbestos harmful properties related to the specific crystal microstructure of asbestos minerals. The group of asbestos minerals includes six silicate minerals characterized by fibrous structure: chrysotile, actinolite, tremolite, anthophyllite, crocidolite – a fibrous form of riebeckite, as well as amosite – a fibrous variety of grunerite. Inhalation of asbestos fibers especially in the respirable form) may cause lethal lung diseases.

Problems related to the harmfulness and disposal of asbestos materials are well known all over the world. All asbestos minerals are considered carcinogenic and their use is restricted or banned in more than 50 countries (Secretariat, 2016; Paglietti et al., 2016). These problems are particularly acute in Poland. During a period of several years of applying commercial asbestos products, ca. 15.5 million tons of asbestos-containing materials were accumulated in Poland alone. According to the "Programme for the removal of asbestos and asbestos-containing products used on the territory of Poland", which was adopted by the Polish Government, all asbestos-containing products will have been removed by the year 2032 (Annex to the Resolution No. 39/2010, 2010). This plan is considered to be one of the priority national programs for the protection of health and the environment. In accordance with the guidelines of the programme, the only permitted and preferred method of asbestos waste neutralisation in Poland is its storage in special landfills for hazardous waste, which does not solve the problem in the long term, because the dangerous fibrous structure is still maintained. Also, there is no guarantee that secondary contamination of soil, groundwater and the local environment will not take place. Moreover, storage requires a huge amount of free space to deposit the waste which is banned from use in the future.

One of the possible solutions to the asbestos problem could be industrial neutralization of asbestos waste by destroying its fibrous structure, followed by recycling of the obtained product as a secondary raw material. According to European Directive 2008/98/EC, recycling should be the preferred method of diverse waste management.

Methods of asbestos waste disposal and recycling have been the subject of numerous studies carried out by various research centers around the world. Most of them are concentrated on investigations on a laboratory scale. There are few examples of large-scale applications in industrial plants. One of them is INERTAM-Europlasma plant in France, where plasma torch is used for the vitrification of asbestos-containing materials. The vitrification furnace is heated with three plasma torches. At 1500 °C asbestos waste reaches fusion through a thermal-chemical reaction, during which the asbestos fiber is destroyed. The product of fusion is extracted from the furnace and recycled as a base layer in road construction (Inertam Groupe Europlasma, 2016).

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A detailed description of asbestos-containing materials neutralization and further recycling ways is provided, among others, by Gualtieri (2013). Generally, methods allowing for asbestos transformation into a safe derivative material can be divided according to the initiating agent causing destruction of the fibrous form of asbestos. Therefore, possible ways of asbestos destruction include the chemical method (in which asbestos minerals can be destroyed by dissolution in aggressive agents such as bases, inorganic or organic acids) (Sugama et al., 1998; Pawelczyk et al., 2017; Turci et al., 2007; Rozalen and Huertas, 2013), the mechanochemical method (in which some of the mechanical energy is converted into heat, causing amorphization of the milled material) (Plescia et al., 2003; Colangelo et al., 2011), the biological method (in which acidic metabolites of some lichens progressively convert asbestos fibers into amorphous material) (Favero-Longo et al., 2005) as well as thermal and hydrothermal treatment (Yanagisawa et al., 2009; Anastasiadou et al., 2010). Thermal transformation in a sufficiently high temperature is the most common asbestos destruction process, which can be carried out with various heat sources, such as plasma, microwave, electric arc or resistive heating (Boccaccini et al., 2007; Leonelli et al., 2006; Kusiorowski et al., 2012; Kusiorowski et al., 2015). Destruction of asbestos occurs during thermal treatment and, depending on the final and assumed process temperature, it is associated with temperature-induced recrystallization, sintering or melting.

A process for direct thermal transformation of cement-asbestos waste has been developed by Gualtieri et al., where cement-asbestos materials are thermally treated in a tunnel kiln in the range of 1200–1300 °C. The obtained product is mainly composed of SiO_2 and CaO and has the composition of an Mg-rich clinker (Gualtieri et al., 2008; Viani et al., 2013; Gualtieri et al., 2011).

Dellisanti et al. (2009) have recently reported the vitrification process of cement-asbestos pipes, during which the waste was heated up to 1600 °C in the process of resistive heating. This treatment led to the complete melting of asbestos waste. Rapid cooling resulted in the formation of monolithic glass without any crystalline phases.

Another similar example is provided by Lázár and Carnogurská (2016), who carried out plasma high-temperature treatment of cement-asbestos mixed with fly ash. As a result of the research, asbestos fibers were transformed into the glass matrix of a new product in the form of glassy slag.

Asbestos-containing waste could also be mixed with chemical additives and heated with microwaves. An example of this neutralization method is shown by Yvon and Sharrock study (Yvon and Sharrock, 2011). Three different asbestos products (including cement-asbestos) were treated and the obtained material was recycled in a mortar. Microwave heating of the waste revealed a difference in structure between the raw samples and the products obtained after the microwave process - all the products had an amorphous vitreous nature. According to the authors, various fusion additives (like carbonates, phosphates or borates) can be used in the microwave heat treatment of asbestos waste in order to decrease the process temperature.

A slightly different approach was proposed by Osada et al. (2013). Asbestos-containing materials (5–15 wt%) were previously mixed with another primary industrial waste (85–95 wt%), like automobile shredder residue or municipal solid waste, and thermally treated in a gasification and melting shaft furnace. The temperature of the melt in the furnace was around 1500–1600 °C. TEM analysis confirmed that no asbestos fibers were detected in the solid products (slag and fly ash) or in the exhaust gas.

The aim of this research project was to perform a melting test of asbestos-containing waste in a laboratory electric arc-resistance furnace and assess the usefulness of this method as a possible way of dealing and recycling this dangerous waste. The scope of the work encompassed: (a) physicochemical characteristics of asbestos waste, (b) establishing in computer simulations which additives reduce the melting temperature, (c) carrying out the melting process in a laboratory arc-resistance furnace and (d) characterization of the obtained product.

2. Experimental

2.1. Materials characterization techniques

The subject of examination was cement-asbestos waste (commonly referred to as "eternit"). It is a material which is made from Portland cement and asbestos fibers. In Poland this waste represents the great majority of all asbestos products accumulated over several dozen years. According to the national recipes for cement-asbestos manufacture, 5–20 wt% asbestos was added to the blend, depending on the final destination of the product. The asbestos content in the cement-asbestos waste subjected to testing reached ca. 10 wt%.

A chemical analysis of samples was performed by X-ray fluorescence (XRF) using a Panalytical Magix PW-2424 spectrometer. The measurement was made according to PN-EN ISO 12677:2011 standard. The chemical analysis data was supplemented with the loss on ignition value (LOI) obtained through calcination at 1025 °C.

Mineralogical characterization of raw cement-asbestos waste and the after-melting process were carried out by powder X-ray diffraction (XRD). Analyses were conducted using a PANalytical X'pert Pro diffractometer (Cu Kα radiation, Ni filter, 40 kV, 30 mA, X'Celerator detector).

Thermogravimetric analysis (TG) combined with evolved gas analysis (EGA) was performed using an STA 409PC NETZSCH thermal analyser, which was coupled with a QMS 403C Aëolos quadrupole mass spectrometer. A total of 22 mg of samples was placed in an alumina crucible. The heating rate of the sample was 5 K min^{-1}. The tests were carried out in synthetic air atmosphere.

The raw sample of cement-asbestos as well as the treated samples were also characterized by optical light microscopy (microscope NU Carl-Zeiss Jena). Observations were made on samples in a powdered form, previously dispersed in immersion oil (n = 1.545). The measurements were taken by the TLM method (transmitted light microscopy) in a different magnification ratio, ranging from 1:250 to 1:500.

High-temperature microscopy is one of the thermal methods of analysis in which changes in the shape of a sample are measured. During the measurement so-called characteristic temperatures were determined, among which the most important are: the beginning of sintering, softening point and melting point of the cement-asbestos sample used. The measurements were performed in a high-temperature microscope (Leitz). Cube-shaped samples (dimension of edge 3 mm) of ground material were prepared for tests. The measurement was carried out in air atmosphere at the constant heating rate of 5 °K min^{-1} up to the temperature of 1500 °C.

To identify and select useful additive substances reducing the melting temperature, computer simulations in FactSage database computing system as well as refractoriness measurements were performed. Computer calculations were designed to evaluate the effectiveness of the selected additives. The simulation was based on determining the amount of liquid phase produced per 100 g of mixture (90 wt% of cement-asbestos and 10 wt% of additive) versus temperature. The value of refractoriness was also determined using the method of pyrometric cones in accordance with PN-EN 993-12 standard.