Waste Management 60 (2017) 230–246

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Review

Utilization of inorganic industrial wastes in producing construction ceramics. Review of Russian experience for the years 2000–2015

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ARTICLE INFO

Article history:
Received 15 February 2016
Revised 15 October 2016
Accepted 4 November 2016
Available online 12 November 2016

Keywords:
Industrial wastes
Construction ceramics
Ceramic brick
Ceramic raw material
Clay

ABSTRACT

This paper analyzes the significant scientific publications worldwide for the last 15 years concerning construction ceramics (predominantly brick) made with various inorganic industrial wastes added to the ceramic raw material for the improvement of properties and for eco-friendly disposal. The information gap resulting from the lack of mentions of the Russian publications on this subject in English-language reviews is filled. The paper includes brief summaries of 34 dissertations and 29 patents issued in Russia since 2000. The waste additives described in these summaries are grouped by origin type (mining industry waste, ore enrichment waste, metallurgical waste, sludge, ashes, cullet, large-capacity building wastes and waste from various chemical production processes) with the ceramic mixture compositions, molding and firing conditions, final strength, water absorption and other parameters of the final ceramic samples reported. Russian scientists have expanded the nomenclature of each group of wastes significantly upon addition to the list described in English-language reviews for 2000–2015. References to the recent Russian developments in the field of ecological management in ceramic industry are provided.

Contents

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http://dx.doi.org/10.1016/j.wasman.2016.11.008
0956-053X/

1. Introduction

The utilization of various industrial and agricultural wastes in the industry of construction ceramics is a hot topic. It is interesting to both the enterprises producing waste and the producers of ceramic brick, stone, tile, and so on. On the one hand, the high-temperature 900–1100 °C firing of ceramics makes it possible to neutralize and reliably store in a body of ceramics many types of waste, and on the other hand, such additives to clay raw materials make it possible to increase the product quality. For example, agricultural waste in the form of a peel of seeds is used as the burning-out additive to form porosity in a ceramic brick, thereby improving the heat-insulating properties of the brick. Industrial wastes may contain mineral substances that increase the strength of ceramics, provide an interesting color, optimize water absorption and frost resistance, or reduce energy consumption on firing. Skillful management in this sphere can solve a number of important problems: (1) utilizing waste without damaging the environment, (2) improving the quality and extension of ceramic products through the use of local waste, and (3) establishing new ceramic enterprises considering the properties of local raw sources of clay and waste.

However, establishing such cooperation among enterprises is an uncommon task for management, due to the high sensitivity of ceramic technologies to structure of ceramic mixtures. Therefore, the use of different additives in clay, as a rule, requires preliminary scientific and technological study, for example, as presented in publications (Menezes et al., 2005; El-Mahllawy, 2008; Chen et al., 2011; Lingling et al., 2005; Dondi et al., 2002, 2009; Shih et al., 2004; Machado et al., 2011; Caroline et al., 2009; Loryuenyong et al., 2009). The results of similar studies conducted more recently are discussed in review articles (Mymrin et al., 2014; Muñoz Velasco et al., 2014; Bories et al., 2014; Zhang, 2013; Raut et al., 2011; Vieira and Monteiro, 2009).

Information on the types of waste that have already been successfully introduced into ceramic production, how they affect the consumer properties of construction ceramics, what types of clays were modified by the waste in what quantities and in what state the waste was introduced into a ceramic mixture is valuable for managers in this sphere. Unfortunately, the English-language review articles cited almost completely lack the data on this subject from Russian-language publications. However, in the last 15 years, special attention has been paid in Russia to the management of waste in the ceramic industry, as confirmed by tens of PhDs and doctoral dissertations and a large number of patents for inventions. The general state of affairs in the Russian ceramic industry, which is under active development, is now described in Information and reference book on the best available technologies (2015).

The purpose of this review is to fill the information gap regarding the use of inorganic industrial wastes in the production of construction ceramic materials, particularly brick. Close attention is paid to references to the relevant dissertations defended in Russia since 2000. These dissertations are readily available on the Internet and contain complete lists of the articles published by the authors. The claims of the patents on this subject issued during this period in the Russian Federation are also presented. Thus, the world development of ceramics technology using industrial inorganic wastes during the last 15 years is reviewed, and the contribution of Russian investigators is noted.

2. Characterization of ceramic samples

In the Russian Federation, brick quality is estimated based on the criteria provided by the state standard (Russian Standard 530-2012). In many respects, it coincides with the standards of other states and regulates the requirements for the geometrical parameters of a product and its physical properties. Regarding the characteristics of the ceramic material itself, it makes sense to consider first its strength and water absorption. Density, heat conductivity, the initial speed of water absorption by a basic surface and acid resistance are also important characteristics, but they are of secondary importance. Therefore, many published laboratory studies of new ceramic materials contain only tests of strength and water absorption. According to (Russian Standard 530-2012), each of such tests requires a ceramic sample of a specific shape and size. For example, the compression test requires a cubic sample of not less than 40 × 40 × 40 mm. The compression strength of products is calculated by the formula $R_{compr} = P/S$, where P – maximum loading reached during the test; S – cross-section area of a sample (without deduction of the void area), which is calculated as the arithmetic mean of the upper and lower surface areas.

To measure the flexural strength R_{flex}, a solid brick is required. $R_{flex} = 3Pl/2bh^2$, where P – maximum loading reached during the test; l – distance between axes of supports; b – sample width; h – sample height in the middle of a flight without the leveling layer. However, in a number of publications, the samples described are tiny compared to a real brick. Certainly, the data obtained for them can characterize the ceramic material properties, but they cannot be used directly for the evaluation of a full-scale brick made of the material.

It is also important to note that the influence of the waste additive on the final ceramic material depends strongly on the properties of the clay. We will provide results from recent Russian doctoral dissertations (Yatsenko, 2015; Stolboushkin, 2015) to illustrate this effect. Table 1 and Fig. 1 show the influence of mineralizing additives, which are components of industrial wastes, on the color of a brick.

As a rule, laboratories use firing in electric furnaces in an air atmosphere, while plants use gas furnaces with an atmosphere of the products of natural gas combustion. The chemical composition of the atmosphere influences the ceramic sintering process and the properties of the final product. According to (Yatsenko, 2015), the regulation of the oxidation-reduction properties of the gas environment in the furnace makes it possible to obtain bright and dark tones in a ceramic brick from the clay raw materials modified by industrial wastes (see Table 2).

Therefore, the data given below regarding the use of waste should be considered only as a reference point for developing similar industrial technology based on local clay raw materials and energy sources.

The external properties of ceramics and their hidden physical/mechanical properties are defined by the internal microscopic structure. Images characterizing the interaction of crystallites in the ceramics modified by waste are shown in Fig. 2. The chemical and mineral compositions of such crystallites at different stages of firing are determined by X-ray spectral analysis, dilatometry, differential thermal analysis and other methods. All of them are available in the arsenal of Russian scientists and are applied when developing production technologies for ceramic products with