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Mathematical approach to application of industrial wastes in clay brick production – Part I: Testing and analysis

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Abstract

The objective of this study was to investigate utilization potential of organic and inorganic industrial wastes in clay bricks. Mineral composition of starting heavy clay sample is tested using an X-ray diffractometer. Chemical content and loss on ignition were determined in sludges, coal dust, fly and landfill ashes, soybean crust, sawdust, sunflower hulls and their ash. Different ratios of wastes were added to heavy clay, while the applied firing temperatures were in the range 850–1000 °C. The laboratory samples (tiles, solid bricks and hollow blocks) were tested by using the standard test methods. Changes in product's quality were studied in terms of relative differences to ceramic-technological parameters compared to samples without waste materials addition. It is noticed that all of the additives increased weight loss, firing shrinkage and water absorption, while decreasing compressive strength and volume mass. The greatest changes in performances were observed with addition of organic materials, whereas, among them, sunflower hulls initiated the lowest compressive strength. Inorganic additives introduced fewer changes to fired products, while fly ash caused the lowest decrease in compressive strength.

Response Surface Methodology (RSM) was applied and Second Order Polynomial models (SOP) were used to show the effects of firing temperature, waste materials addition and their quantity on characteristics of fired products. High prediction accuracy was obtained, with coefficient of determination in the range of 0.896–0.999. It was concluded that all of the analyzed materials can generally be used in building bricks by taking advantage of low cost and environmental protection, whereby thermal conductivity decreases.

Keywords: Industrial wastes; Heavy clay bricks; Response Surface Method; Second Order Polynomial models

1. Introduction

The strategy of sustainable development includes mineral raw materials usage as very important, claiming it is necessary to reduce natural ingredients and energy consumption, include waste materials, lower emitting of hazards and especially carbon dioxide, reconstruct the mines after exploitation of raw materials, etc. [1,2]. The possibility of using waste in raw material mixtures based on heavy clay is intensively explored, since traditional construction materials allow mixing without significant modifications of the manufacturing process [3–5]. The recent matter of concern is that in many parts of the world there is already a shortage of heavy clay raw materials [6], and therefore in some countries it have been even prohibited to use it in construction [7]. This concept has several benefits from a sustainability point of view, namely less energy consumption, lowering the quantity of industrial wastes, and less land use (for excavation and disposal sites). One of the most remarkable benefits is that the final products show improved properties by means of thermal insulation.

Waste materials that can be used as secondary raw materials in the brick industry can be organic, inorganic or of mixed nature. Combustible, organic remains are often used, such as: saw dust, residues from the manufacture of tobacco [8], the ash

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created by firing of rice husks [9], petroleum waste [10], oil shale [11], sewage sludge [12], etc. Secondary raw materials of mixed nature were for example: sludge from the production of recycled paper, [13], dried sludge from purification of drinking water, [9], contaminated marine and river sediments [14,15], and so on are studied. Among inorganic raw materials the possibility of applying the remains of natural stone and fly ash, metallurgical waste, residue from the production of pine, waste blocks, [14–16], municipal solid waste incineration fly ash [17], etc. Also, many interested review papers are published, among which the newest were written by Bories et al. [18] and Monteiro and Vieria [19]. But yet, no research presented the idea of using the same heavy clay raw material and many different organic and inorganic supplements, in order to compare the effects introduced to the final products, as this study presents.

Inorganic and organic sludges, coal dust, fly and landfill ashes, soybean crust, sawdust, sunflower hulls and their ash are mixed in the chosen plastic representative raw heavy clay material. Following is a brief review of previous studies related to the used secondary raw materials in the brick industry, with emphasis on the materials that were used in this study.

Neutralization sludges and coal combustion residues usage reduces environmental problems and total cost of raw material disposition. Neutralization sludges from galvanizing industry are previously proved to be usable in brick industry in our previous study [3]. The coal of pure quality is generally used in most of the power plants, and the remaining results are large amounts of fly and bottom ash of varying properties. These ashes have not been utilized effectively, though much research is done on this subject [7,20]. The possibility of using ashes as secondary raw material in heavy clay bricks is well known, so they are also included in this study. The physical and chemical properties of fly and bottom ashes may be quite variable as they are influenced by kind of coal used, then particle size, and type of coal burning process. Therefore, several of every kind of ashes was tested in this work for use in brick industry. Using the ashes as raw materials in bricks also includes advantages of saving firing energy introduced by remained carbon [20].

Wastes of organic nature were added to increase porosity and insulation ability of the products, while improving mechanical strength of the matrix by introducing combustion energy. For such reasons, soybean crust, wooden sawdust, sunflower hulls and their ash are used in this research, as they do not represent a great concern to the environment and are already used for other purposes. Agricultural waste application presents an innovative way to produce heavy clay bricks, but rather modest concentrations are usually added – up to 10 wt% [8,21]. Nevertheless, sunflower husks were never tested as a secondary raw material in brick industry before. Only sunflower husks ash can be found in the literature, since solid residues of biomass combustion are rarely considered to be used or recycled [22].

Waste coal dust and saturation sludge from sugar factory are produced in large quantities and often only disposed of. The brittle nature of coal causes occurrence of large quantities of coal dust during mining and transportation. As it is environmentally hazardous, especially because of possibility to explode and also its toxic nature, it is recommendable to be used as a fuel or binder, but it is never tested as a supplementary material in brick industry. In the sugar industry, as the result of processing of diffusion juice of beets after straining and alkalization with lime milk, in the first phase of gas saturation using CO_2 and later, after filtration, a sludge that contains large amounts of finely granulated calcite remains. This saturation sludge, not usable in industry, is presented in only one research work that aimed to test production possibility of facing bricks [23].

In the present research, chemical content of used materials and loss on ignition (LOI) are determined. After adequate mixing of wastes and heavy clay raw materials, and later shaping of laboratory products, firing was conducted at 850, 900, 950 and 1000 °C. The fired products quality is determined based on mechanical and ceramic-technological tests as a function of firing temperature and the shape of products. Second Order Polynomial models (SOP), with defined firing temperature and additive material concentration, were used for calculation of 10 response variables (compressive strength of blocks and cubes – *CSB* and *CSC*, water absorption of blocks, cubes and tiles – *WAB*, *WAC* and *WAT*, tiles firing shrinkage – *FS*, weight loss during firing – *WLFB*, *WLFC* and *WLFT*, and volume mass of cubes – *VMC*) on the basis of experimental results. Analysis of Variance (ANOVA) has been applied to test the effects of waste materials concentrations on fired products properties, and to compare the differences.

The main aim of this research was to determine the influence of organic and inorganic industrial wastes addition on heavy clay products quality, while using the same clayey raw material in all the mixtures, and test their usability to get light-weight products and elegantly resolve environmental problems, while spending the unwanted waste.

2. Materials and methods

2.1. Raw materials and laboratory brick samples

Heavy clay raw material, containing enough clay minerals to be used to produce roof tiles, was sampled from a brick factory in Vlasotince (Serbia). Eleven types of waste materials were mixed with starting representative heavy clay in order to prepare 24 samples (Table 1). The quantity of industrial wastes was chosen on the basis of previous research and also literature data [2,3,6–9,18,19,22,24].

After addition of chosen secondary raw materials to representative heavy clay, the masses are mixed, sufficiently moistened and left in sealed nylon begs to homogenize. Afterwards, the laboratory samples (plates $120 \times 50 \times 14$ mm^3, solid cubes $30 \times 30 \times 30$ mm^3 and hollow blocks $55.5 \times 36 \times 36$ mm^3) are extruded under vacuum in a laboratory Händle machine. The specimen bodies were dried at room temperature for 72 h, and later in a laboratory dryer the temperature is carefully raised to 105 ± 5 °C, at which the samples stayed for 24 h [3,25,26]. The firing stage was carried out in the temperature range from 850 to 1000 °C. The heating rate of the electric furnace used for firing was 1.4 °C/min up to 610 °C, and 2.5 °C/min, with 2 h soaking at the maximum temperature. Cooling was done by natural