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Mathematical approach to application of industrial wastes in clay brick production—Part II: Optimization

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Abstract

The effects of organic and inorganic waste sludges, coal dust, fly and landfill ashes, soybean crust, sawdust, sunflower flakes and their ash addition to representative heavy clay were investigated. Changes introduced to shaping moist (SM), shrinkage (ΔSk) and weight loss (ΔGk) in Bigot's curve critical point, and plasticity coefficient (PC) by Pfefferkorn were studied. The highest sensitivity to drying showed samples with coal dust addition, while the greatest plasticity and shaping moist was detected in samples with 50 wt% of fly and landfill ashes.

The influence of waste material used, its' content and also firing temperature were independent parameters that influenced compressive strength, water absorption, firing shrinkage, weight loss during firing and volume mass as dependent parameters. Second order polynomial mathematical models predicted fired products characteristics, and were later used to determine the optimum conditions by Response Surface Method (RSM), coupled with Fuzzy Synthetic Evaluation algorithm (FSE), using trapezoidal function. The choice of the parameters optimal interval that characterized fired products (water absorption, compressive strength, weight loss during firing, firing shrinkage and volume mass), depended on a final usage of the raw material in heavy clay brick industry. The optimization results showed that sunflower hulls, wood sawdust, soybean husks and saturation sludge are best to be used in solid bricks production. Coal dust, landfill ashes and neutralization (inorganic) sludges are best to be used in hollow bricks production. Sunflower hulls ash can be added in higher quantity to heavy clay to produce blocks or in lower quantity in roof tiles. Fly ashes addition of 50 wt% allows roof tiles production. The optimal temperature for solid bricks and hollow blocks production is found to be 900–950 °C.

Keywords: Industrial wastes; Heavy clay industry; Properties prediction; Process optimization

1. Introduction

Constant and intensive growth of industrial production leads to a decrease in available capacity of the natural sources of raw materials, while, as a side effect, large quantities of waste or unused by-products occur. Many organic and inorganic materials may be used in clay brick industry, as a correct environmental solution to the disposal of a wide range of solid wastes. These materials improve brick porosity, while decreasing drying time and firing energy consumption [1]. This way, reduction of primary raw material plasticity and fired product's volume mass, compressive strength and thermal conductivity occur. It is, thus, very important to find the optimal mixture which would give the satisfying quality of the products, and, at the same time, be environment friendly.

Waste materials which can be used in brick industry can be of organic, inorganic or mixed nature [2]. During firing of the product containing organic secondary raw materials it is recommended that retention at a temperature of 600 °C is 2 h, for the complete combustion [3]. Problem that should be taken into account is the content of organic residues of flue gases [4]. Light-weight elements for building are characterized by a very significant primary porosity of ceramic masses, which together with the system cavities ensures very favorable thermo-technical characteristics. In addition, these elements can be

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produced in larger formats maintaining sufficiently high compressive strength. The presence of organic material in the clay can cause occurrence of black nuclei, unless there was a complete combustion of organic carbon during firing. Factors influencing this phenomenon are high content of organic matter as well as vitrification, which may block the combustion inside the matrix. Entering the combustible components generally reduces drying time and heat release decreases the amount of energy required for the firing process. Also, high energy can cause deformation of firing curve and a high-speed warm-up can cause destruction of products, followed by a danger that the energy released in the kiln can be impossible to control [5]. Inorganic additives create fewer problems to the environment, but can negatively alter plasticity of clay and increase the amount of shaping moist [6]. Also, microelements can introduce problems if they are leachable out of fired product [7].

Each particular case of brick production initiation requires preliminary examinations and definition of the optimal raw materials mixture and technological parameters. All the above mentioned aspects must be taken into account so the products can fulfill EN standards demands. For example, lowering clay minerals content in raw materials by adding sand is the cheapest way to reduce necessary shaping moist, and therefore the energy spent to dry the products [8]. Such an effect is also introduced by adding secondary raw materials, since it lowers fine fraction content.

Mathematical optimization of brick production has recently become practice. For example, a few studies are conducted to optimize insulation abilities by designing number and place of voids in the brick structure, mostly by finite volume method [9–12], whereas one study only shows admixtures of heavy clay and industrial waste [13]. Optimization of the most suitable product form and firing temperature, together with heavy clay raw materials chemical composition, trapezoidal membership function is used [14,15]. Also, mathematical methods are performed in order to optimize fuel/air use in tunnel kiln in production of bricks with addition of low calorific value coal [16]. Since the literature on mathematical optimization of production and waste additions in brick industry is very limited, further research and development is necessary [17].

This study is based on mathematical optimization of different brick products by separate using of various industrial wastes. The main aim of this research was to determine the optimum process conditions (regarding firing temperature, choice of waste and its' quantity) and to find the best possible use of certain waste material in brick production. On the basis of Response Surface Method (RSM), results presented in Part I of this paper, Fuzzy Synthetic Evaluation algorithm (FSE), using trapezoidal function, is used in optimization. Raw mixture changes of technological characteristics are accompanied by: shaping moist, plasticity of used masses for extrusion forming, shrinkage and sensitivity to drying. The porosity changing effect is determined by water absorption and volume mass of fired products. Also, compressive strength, weight loss during firing and firing shrinkage were included in the optimization process. In this way, the influence of organic and inorganic industrial wastes addition on heavy clay products shaping, drying and firing is determined.

2. Materials and methods

All the samples used, laboratory products prepared and testing methods are described in the first part of this paper. Eleven types of waste materials, which origin and usage reasons were described in detail in Part I, were mixed in the starting representative heavy clay in order to prepare twenty-four samples:

1. Two samples of sludges remained from hot-dip galvanizing industry in Ćuprija (Serbia) after waste water neutralization (added by 3 wt% to gain samples S1 and S3, and 6 wt% in samples S2 and S4),
2. Sludge remained from hot-dip galvanizing industry in Stalać (Serbia) after waste water neutralization (added in 5 and 10 wt% quantities to gain samples S5 and S6),
3. Coal dust remained after washing of coal in industrial tanks in Vreoci, Serbia (added in 3 and 6 wt% to gain samples CD1 and CD2),
4. Coal dust remained after washing of coal in industrial tanks in Obrenovac, Serbia (added in 3 and 6 wt% to gain samples CD3 and CD4),
5. Fly ashes remained in thermal power plant in Obrenovac, Serbia (added in 50 wt% to gain samples FA1, FA2, FA3, FA4 and FA5),
6. Landfill bottom ashes remained in thermal power plant in Obrenovac, Serbia (added in 50 wt% to gain samples LA1, LA2, LA3, and LA4),
7. Soybean crust (6 wt% in sample S) from edible oil factory in Zrenjanin (Serbia),
8. Wooden sawdust (2.5 wt% in sample WS) from Vojvodina,
9. Sunflower hulls from edible oil factory in Zrenjanin, Serbia (added in 5 and 10 wt% to gain samples SF1 and SF2),
10. Sunflower hulls ash from edible oil factory in Zrenjanin, Serbia (added in 5 and 10 wt% to gain samples SFA1 and SFA2), and
11. Saturation sludge from sugar factory in Crvenka, Serbia (added in 5 and 10 wt% to gain samples SS1 and SS2).

Plasticity coefficient according to Pfefferkorn (PC) and susceptibility to drying by Bigot (ΔSk and ΔGk) are also determined and analyzed together with shaping moist (SM) [18]. Also, properties of the fired samples presented in Part I of this paper, are used in optimization (water absorption of tiles—WAT, water absorption of hollow bricks—WAB, water absorption of solid cubes—WAC, compressive strength of hollow blocks—CSB, compressive strength of solid cubes—CSC, weight loss during firing of tiles—WLFT, blocks—WLFB and cubes—WLFC, then firing shrinkage—FS and volume mass of cubes—VMC).