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Eco-friendly fired clay brick manufactured with agricultural solid waste

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ABSTRACT

Green building materials have attracted attention recently due to sustainability issues. Agricultural waste used as alternative raw materials in the manufacturing of building products, fired clay bricks in particular, is an innovative way of waste utilisation. Large quantities of waste are produced in grain processing. New ways of utilising this waste are required for solving this problem. The main objective of this study is to investigate the effects of agricultural solid waste (oat husk and barley husk and middlings) on the physical and mechanical properties and porosity of fired clay bricks. Brick moulding compounds were prepared by adding 5%, 10% and 20% of oat husk or barley husk and middlings and fired at 900 °C and 1000 °C temperature, keeping them at the highest temperature for 1 h. Oat husk, barley husk and middlings incinerate at 500 °C temperature, thus forming a porous structure in the clay body. The addition of 5–10% of oat husk or barley husk and middlings into brick moulding compound produces eco-friendly fired clay brick having the density of 1300–1800 kg/m^3, compressive strength of 3.3–9.5 MPa, total open porosity of 34–49%, water absorption 14–28%. Oat husk or barley husk and middlings reduce the compressive strength of eco-friendly fired clay brick.

1. Introduction

Eco-friendly building materials are gaining popularity and this industry is growing rapidly. The main factors influencing the growing popularity of eco-friendly building materials are as follows: environmental regulations, impact on the environment and human health, decarbonisation objectives and utilisation of materials at the end of the life-cycle. Fired clay bricks is one of the oldest and the most ecological building material as it is made of natural raw materials, namely clay, sand and water. Such products have high density, compressive strength, resistance to freeze–thaw cycles, and low water absorption values. Various combustible materials, which incinerate during firing, can be added to brick moulding compounds to obtain products of lighter weight, higher porosity and with low heat transfer coefficient [1].

Combustible agents form pores in clay brick [2], consequently, they change the structure of a product. Depending on

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the amount of combustible agent added and the highest temperature, mechanical properties of clay brick may considerably decrease [1].

Authors [3] suggest adding 10% of olive mill waste in clay brick and burn it at 950 °C temperature. The density of such products is 1.45 g/cm^3, thermal conductivity – 0.436 W/mK, compressive strength – 10 MPa, porosity – 47%. Other authors [4] claim that up to 5% of processed waste tea improve physical–mechanical properties of clay brick that is burn at 900 °C temperature, and the lower amount of additive negatively affects the strength properties.

Natural grain by-products can be used as combustible agents [5–7]. Authors [5] state that under addition of 10% of rice husk, the density and compressive strength of the products deteriorate, water absorption increases.

Grain processing generates a lot of by-products, such as husks, mixtures of husk and middlings, etc. During grain threshing season the mill may generate up to 4–5 tons of husks and up to 2–3 tons of hull and middlings mixture. Modern facilities usually use grain processing waste (humidity $< 10\%$) as biofuel for boiler rooms [8,9]. Smaller companies, however, do not have such possibilities and incur high waste transportation and landfill costs. In terms of economy, the most beneficial approach is to use grain processing waste as animal feed. Unfortunately, stale or rotten grain processing by-products cannot be used to this end.

Agricultural solid waste incinerated in boiler rooms generates large amounts of ash that must be utilised. Chemical composition and characteristics of this ash differ depending on the region where crops, used as agricultural solid waste, were grown and also on the firing temperature. It was found [10,11] that clay bricks produced from clay containing rice husk ash additive, fired at 1000 °C temperature and conditioned for 4 h have higher firing shrinkage and compressive strength. The bricks are recommended for load-bearing walls. Other authors [12] argue that in order to obtain high performance clay brick products, the firing temperature must be increased to 1050 °C, whereas the optimum rice husk ash content is up to 30%. Authors [6] say that the optimum rice husk ash content in the ceramic body may not exceed 2%. The density of such products reaches 1.68 g/cm^3, the compressive strength is 6.2 MPa, and water absorption is 15.2%. Higher content of ash has a negative effect on the strength properties of ceramic products. Authors [13,14] tested the effect of sugarcane bagasse ash and propose to add it at 10%. Other authors [15] state that sugarcane bagasse ash can be increased up to 20%. The firing temperature must be at least 1000 °C. In temperatures above 1000 °C, the ash reacts in the liquid phase and causes the formation of new phases (mullite and cristobalite).

Agricultural solid waste can be used as combustible additives that may have a positive effect on the ceramic body's properties depending on the origin and characteristics of the additive, content in the mix and the firing temperature of the clay body. Tests conducted by researchers [5] proved that up to 10% of combustible rice husk can be added to the clay brick mix in order to meet the requirements of standard EN 772-1. The strength of such clay bricks ranges between 7 and 10 MPa. Some authors [7] argue that up to 50% of rice husk can be added to the clay brick mix. Authors [16] found that 5% of grape and cherry seed additive has a better effect on physical and mechanical properties of the ceramic body compared to wood sawdust additive.

Secondary research showed that the use of organic grain waste in the manufacturing of ceramic products is well examined, but the effect of agricultural solid waste on the final properties of ceramic products differs depending on the crop harvesting region, grain properties, the properties of core materials (clay, sand), firing temperature and additive content in the mix. There is also a great variety of agricultural solid waste.

In the context of recycling, the present study focuses on using agricultural solid waste (oat hulls, barley husk and meal mixture) in clay brick compounds for civil construction. Although the ceramic industry is highly promising for the final disposal of solid wastes, little is known about the reuse of agricultural solid waste (oat husk, barley husk and middlings) in clay ceramics.

The main objective of this study is to investigate the effects of agricultural solid waste (oat husk and barley husk and middlings) additives on physical and mechanical properties and porosity of fired clay bricks.

2. Materials and methods

The experiments were done with clay of low melting point, sand, and oat and barley processing by-products: oat husk, and barley husk and middlings.

At first the components were dry-mixed and afterwards they were wetted to the humidity required for moulding (20–25%). Plasticity is an important parameter in clay brick manufacturing. Insufficient plasticity may cause heterogeneities of the moulding mass and result in weaker mechanical properties. Tests revealed that higher content of OH and BHM additives increase the water demand to obtain the moulding compound of adequate plasticity. The reason is high water absorption of organic components. $70 \times 70 \times 70$ mm specimens were formed from the moulding compound. 12 specimens were made out of each moulding compound. 6 specimens were fired at 900 °C temperature and 6 specimens were fired at 1000 °C temperature. The compositions of the moulding compounds are shown in Table 1. The specimens were kept for three weeks under natural laboratory conditions; afterwards they were dried to the constant mass at 105 ± 5 °C temperature. Dried specimens were fired at 900 °C and 1000 °C temperatures and conditioned for 1 h at the highest firing temperature.

The block diagram below (Fig. 1) illustrates the methodology followed in the manufacturing of clay bricks (brick specimens) containing agricultural solid waste.

The chemical composition of the raw material used in laboratory tests was analysed by applying the classical chemical analysis methods for silicate materials and by using energy-dispersive detector (INCA PENTA FET 3, Oxford Instruments, Co., UK). The compressive strength of the ceramic body was measured following the procedure described in LST EN 772-1:2003, net dry density was measured according to LST EN 772-13:2003, water absorption (W_h) according to EN 772-21:2011, initial rate of absorption according to LST EN 772-11:2011. The effective and total porosity of