Feasibility Study of Using Clay Bricks Made from Municipal Solid Waste Incinerator (MSWI) Fly Ash

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Abstract. This study deals with the effect of MSWI (municipal solid waste incinerator) fly ash on fired clay bricks. Initially, the MSWI fly ash was characterized by its chemical composition and morphology. Different ratios of the MSWI fly ash (0, 2.5, 5.0 and 7.5 % by mass) were added to the clay brick. Clay brick samples were heated on 1000 °C temperatures for 1 h. The clay brick properties of the resultant material then determined, including shrinkage (after drying, after firing), density, water absorption, effective porosity and total open porosity and compressive strength. Toxicity Characteristic Leaching Procedure tests were also conducted. The results indicate that the heavy metal, chloride and sulphate concentrations in the leachates met the current regulatory thresholds (Waste Directive 2003/33/EC). Increasing the amount of MSWI fly ash resulted in an increase in the water absorption and a decrease in the compressive strength of the MSWI fly ash clay bricks. The addition of MSWI fly ash to the mixture reduced the degree of firing shrinkage. The effects of MSWI fly ash addition on the durability (frost resistance) of the clay bricks were investigated. This indicates that MSWI fly ash is indeed suitable for the partial replacement of the clay in the bricks.

1. Introduction
Thousands of millions of tons of municipal solid waste are produced every year. Waste management and utilization strategies are the major concerns in many countries. Incineration is a common technique for treating waste, as it can reduce waste mass and volume, as well as providing recovery of energy from waste to generate electricity. Generally, municipal solid waste incineration (MSWI) produces two main types of ash, which can be grouped as non-hazardous bottom ashes and non-hazardous fly ashes.

Reclamation of MSWI fly ash has been progressing positively in different research areas and, through many applications, this material has been turned into useful building construction materials.

Fly ash from MSW incineration (MSWI) is a complex mixture of various minerals and heavy metals [1-4]. MSWI fly ashes are classified as hazardous wastes (European waste catalogue, code 1 01 12 [5], and therefore require special handling. Most fly ash from MSW incineration goes to special landfill.
One waste material which has potential recycling as a clay brick additive is MSWI fly ash. In Lithuania, approximately 12 ton of MSWI fly ash was made in 2018. A number of researchers have investigated the use of MSWI fly ash in the clay brick industry [6-11]. However, there is still a need to relate the effect of MSWI fly ash on compressive strength, porosity, shrinkage characteristics and environmental toxicity of fired clay brick.

In this research, the effects due to the use of MSWI fly ash were investigated in laboratory, and physical-mechanical properties and environmental toxicity were discussed.

2. Methods and raw materials
The clay used in this study was a typical clay for making clay bricks from a well-known local area. Chemical analyses of the clay and MSWI fly ash were carried out using X-ray fluorescence technical. The chemical composition of the clay materials is given in Table 1. The mineralogical composition of the clay and MSWI fly ash were achieved using an X-ray diffractometer technique (XRD, Dron-7, Russian). The major crystalline phases found that in the clay, there were quartz, mico clay, kaolinite and feldspar and in MSWI fly ash they found calcium chloride, calcite, potassium calcium chloride, halite, sylvite, anhydrite.

| Chemical composition of clay | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | K₂O | Na₂O | L.O.I. |
|------------------------------|------|-------|-------|-----|-----|-----|------|-------|
| Clay                         | 51.43| 20.54 | 7.44  | 4.26| 3.07| 3.3 | 0.42 | 9.54  |

The chemical composition of MSWI fly ash is given in Figure 1. The major components observed in the MSWI fly ash were CaO (45.17 %) and chloride (KCl, MgCl₂, NaCl) (19.01%). The next most components were Na₂O (2.65 %), K₂O (3.52 %), MgO (1.15 %), Al₂O₃ (1.08 %). High concentrations of heavy metals were observed in the fly ash samples: As (13.8 mg/kg), Pb (1987 mg/kg), Cd (83.4 mg/kg), Cr (50.5 mg/kg), Cu (625 mg/kg), Ni (12.2 mg/kg), Hg (10.4 mg/kg), Zn (10209 mg/kg), Ba (237 mg/kg), Sn (367 mg/kg), Co (5.99 mg/kg), Sr (239 mg/kg).
In order to compare the clay brick (A - 0 % MSWI fly ash) and bricks made of clay and MSWI fly ash (B - 2.5 %, C - 5.0 % and D - 7.5 % fly ash), each batch of specimens was mixed in a porcelain ball mill to ensure homogenous mixing. In normal brick production, however, normal mixing would be sufficient to save time and cost. Then, 20–25% of water was added and mixed to obtain a plastic condition of the mixture.

Soft-mud clay bricks with a dimension of 50 mm × 50 mm × 50 mm were formed using brick hand melding. The clay brick specimens were air-dried at the room temperature (20–25 °C) for 24 h, and then dried over at 110 ± 5 °C for another 48 h to remove water content. The green specimens were fired at the temperature of 1000 °C. The time taken to reach the required temperature was 10 h and the specimens were kept at this temperature for 1 h.

Shrinkage was determined by direct measurement of specimen length before and after firing. The linear drying shrinkage and the total linear shrinkage were measured and compared to the length before shrinkage in accordance with equations:

\[ L = \frac{L_0 - L_1}{L_0} \times 100 \% \] (1)
\[ L = \frac{L_0 - L_2}{L_0} \times 100 \% \] (2)

where: \( L_0 \) – the distance between indentations on the formed sample, mm; \( L_1 \) – the distance between indentations on the dry sample, mm; \( L_2 \) – the distance between indentations on the burnt sample, mm

The compressive strengths of specimens were measured in accordance with LST EN 772-1:2011, density accordance with LST EN 772-13:2003, water absorption accordance with LST EN 771-21:2011. Effective porosity and total open porosity, relative thickness of pore and capillary walls are determined in accordance with the methodology [12]. The reported results of all tests were the average of 6 samples.

3. Results and discussions

The bricks in this research were manufactured from clay and MSWI fly ash. The properties of fired clay bricks are shown in Figure 2 a) and b). The investigated and reported physical and mechanical properties are drying and firing shrinkage, water absorption, density, effective and total open porosity, relative thickness of pore and capillary walls and compressive strength.

The results showed that shrinkage occurred in the fired clay brick with MSWI fly ash additions (B, C, D) were in the range of 8.5–9.4%. The control fired clay brick (A) have firing shrinkage of 11.2 %.

As the density of the clay brick decreases, its strength also decreases, while its water absorption increases. The density of clay bricks was proportional to the quantity of MSWI fly ash added in the mixture. The bulk density of the clay bricks decreased with an increase in the amount of MSWI fly ash. As a result, the densities of clay bricks containing MSWI fly ash were in the range of 1.60–1.80 g/cm3 (Figure 2 b). The density is related to water absorption and porosity of clay bricks.

Water absorption is an important factor for the durability (frost resistance) of clay bricks. When water infiltrates brick, it decreases the frost resistance of clay brick. The water absorptions of clay
bricks with MSWI fly ash additions were in the range of 15.5–22.3 %. The control fired that the clay brick (A) have a water absorption of 9.5 %.

Water absorption is indirectly proportional to effective and total open porosity. The study showed that the effective and total open porosity of clay bricks depended on the amount of MSWI fly ash addition. The highest effective and total open porosity were 34.0 % and 39.8 % with 7.5 % MSWI fly ash addition, and the lowest were 18.0 % (effective porosity) and 23.0 % (total open porosity) with 0 % of MSWI fly ash addition.

In this study, the result indicated that the strength of clay bricks greatly depended on the amount of MSWI fly ash addition. A decrease in compressive strength was due to the increase in porosity and decrease in density. The results revealed that the compressive strengths were in the ranges of 18.0–27.0 MPa when MSWI fly ash addition increased from 2.5 % to 7.5 %.

**Figure 2.** Shrinkage, effective and total open porosity, compressive strength of clay brick
Fly ash from municipal solid wastes (MSW) incinerators in Lithuania contains a large number of toxic materials (heavy metals). MSWI Fly ash in Lithuania has a high chlorine concentration. The leachate of heavy metals, chloride and sulphate from the clay brick are present in Figure 3.

The MSWI fly ash used in the experiment contains 19.02 % chloride. Chloride content in sintered bricks was relatively high (higher than 800 mg/kg when 5.0-7.5 % MSWI fly ash was added). Sulphate content in sintered bricks was very high (higher than 6000 mg/kg when 5.0-7.5 % MSWI fly ash was added). The sulphate was found to have an obvious influence on the performance of the bricks (resulting efflorescence surface appearance) when over 5.0 % MSWI fly ash was added while making the bricks (Figure 3c).

Leaching toxicity analysis showed that leaching concentrations of Cr and Ni exceeded the standard inert limit (Figure 3a and b). Cd, Pb, Cu and Zn leaching results from sintered clay bricks were far lower than the limit inert value, and thus, heavy metals were stabilized in the strengthened matrixes of clay brick through the sintering process.

![Bar chart showing leaching concentrations of Cr, Cd, Pb, Cu, and Zn in clay bricks.](chart.png)
4. Conclusions

The physical and mechanical properties, environmental toxicity of clay bricks with MSWI fly ash addition were studied. The results showed that the compressive strength of clay bricks decreased with increases in MSWI fly ash addition from 2.5 to 7.5 wt.%. The values of effective and total open porosity and water absorption of bricks also increased with increases in MSWI fly ash addition.

The optimum MSWI fly ash content 2.5 wt. %, and resulted in clay bricks with decrease compressive strength, and an increase in effective and total open porosity, compared to those of normal clay bricks fired at 1000 °C. The study also revealed that the clay bricks containing 2.5 % MSWI fly ash do not exceed the limit values of inert substances, according to the Waste Directive 2003/33/EC.

The 2.5 % MSWI fly ash could, thus, be used in the clay brick industry.
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