Particularities of the structure of ceramic tiles and building bricks, obtained using high amount of incinerator bottom ash

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Introduction

Last decades several industrial and urban wastes become appropriate raw materials for bricks and tiles production. This gives possibility for recycling and inertization of different residues, which disposal otherwise can create several problems. One of widely studded wastes are the bottom ashes from Municipal Solid Waste Incinerators (MSWA). The present work also is related to this topic. It is a part of long-term collaboration between Institute of Physical Chemistry, Bulgarian Academy of Sciences and Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia (Italy), which is based on the synthesise of various ceramic and glass-ceramics material using high amount of MSWA. The definite aim of present communication are some features of the structure of ceramic tiles and building bricks, which are consequence of the specific phase formation processes, going on during the heat-treatment. These structures explained the improved mechanical characteristics of obtained specimens.

Experimental

By mixing 60 wt% Municipal Solid Waste Incinerators bottom ash (MSWA) with 40 % industrial clay a ceramic with the following composition is obtained (in wt %): SiO_2 - 42.2, TiO_2 -0.8, Al_2O_3 - 25.8 2, Fe_2O_3 -7.9, CaO – 14.4, MgO - 2.1, K_2O - 1.1, Na_2O - 1.6, others – 2.7. In order to decrease the thermal losses during sintering and thus a part of the firing shrinkage MSWA was preliminary heated for 2 h at 600 ºC to burn the organic residues. The “green” ceramic samples were prepared after homogenization with 6-7 % water and pressing at 40 MPa. The sintering behaviour and the phase formations were studied by optical dilatometry and hot-stage XRD, respectively. The structure of ceramics and crystal composition were observed by SEM-EDS.

Results and discussion

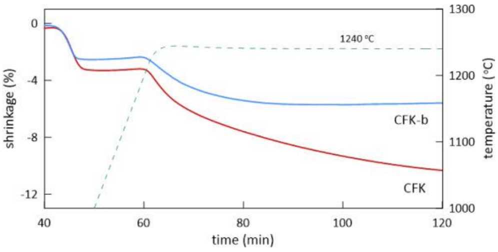

Fig.1 Dilatometric sintering plots

Fig. 1 shows the dilatometric sintering plots for 1 h at 1240 ºC of the new ceramic with, CFK-b, and without, CFK, preliminary burnout of the bottom ash.

It is evident that this initial heat-treatment of MSWA improves the sintering: in CFK-b the densification completes for only ~30 min at shrinkage of 5 %, while in CFK the sintering continues after 1 h and shrinkage of 10 %.

The sintering plots highlight that two separated densification regions can be distinguished. The first is at 900-1000 ºC, when a shrinkage of 2-3 % is reached, while during the second, starting at about 1200 ºC, the sintering process re-starts.

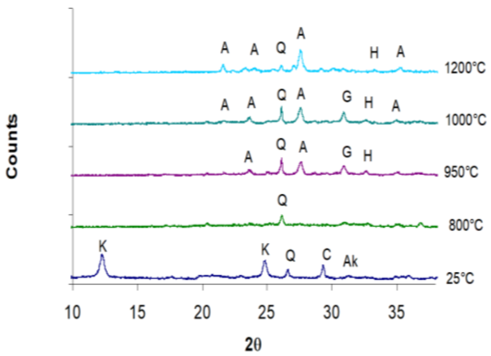

Fig. 2 HS-XRD results

Fig. 2 summarises HS-XRD patterns of CFK at different temperatures. In the initial batch are presented quartz (Q), limestone (C) and some akermanite (Ak), which are the main phases in MSWA, as well as kaolinite (K) from the clay. At 800 ºC, after decarbonisation of C and dehydration of K, only quartz is identified. At 950-1000 ºC reactions between meta-kaolinite and MSWA products starts, which leads to formation of anortihite (A), gehlenite (G) and some hematite (H). This phase formation inhibits the preliminary low temperature densification. At 1200 ºC melting of the residual quartz and transformation of gehlenite into anorthite begins.

As a result, the only crystal phase, formed after sintering at 1240-1250 ºC becomes anorthite.

The evolution of anorthite is highlighted in Fig. 3. At 1000 and 1100 ºC, the crystals are tiny and not well shaped and the sintering process is in initial stage. However, in the final ceramics (3-c) the crystal are bigger and with regular hexagonal habitus. In addition, the sintering is completed and samples with near zero open porosity and about 16-18 vol. % closed porosity are formed.

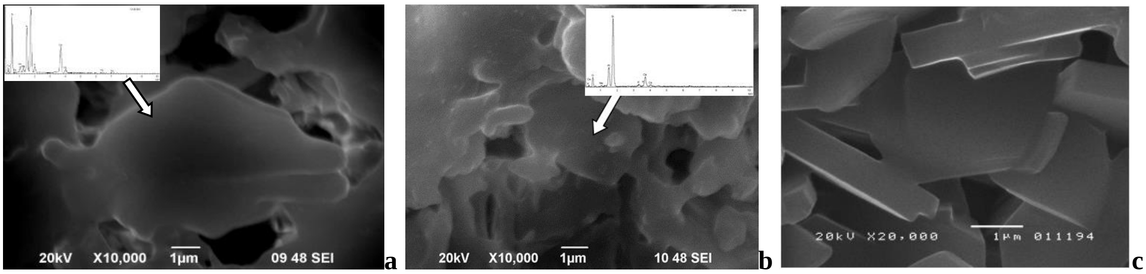

Fig. 3 SEM-EDS images showing anorthite formation at 1000 ºC (a), 1100 ºC (b) and 1240 ºC (c)

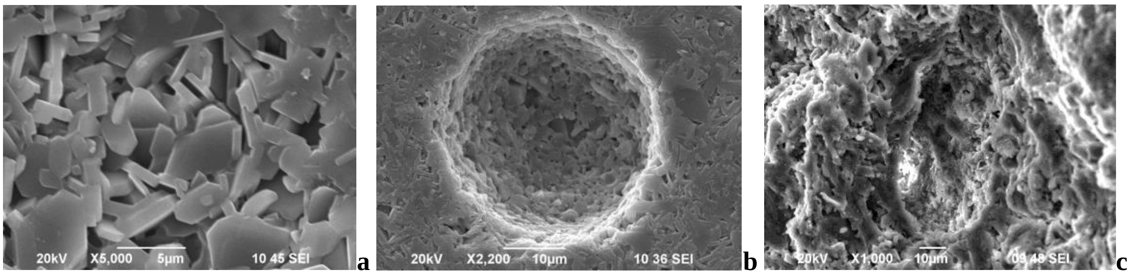

Fig. 4 SEM images of surface (a) and fracture (b) of ceramic, sintered at 1240 ºC, and fracture of "brick" sample, sintered at 1000 ºC (c)

The well sintered surface of the sample and the untypical for a traditional ceramic high crystallinity is demonstrated in Fig. 4-a, while a characteristic closed pore is shown in Fig. 4-b. It can be noted that the pores also are characterised with a rough poly-crystalline surface, instead of the smooth one, observed in the traditional ceramics tiles. This difference is explained by a phase formation process, taking place at the cooling step, which increases the final crystallinity to 45-50 wt % and the porosity with 2-3 %. For a comparison, in the porcelain stoneware tiles the crystallinity usually is 30-35 % and the crystal phases are mullite and residual quartz. Due to its increased crystallinity the new ceramic is also characterized by very good mechanical properties: bending strength of 50-55 MPa, Young's modulus of 50 GPa and Mohs hardness of 8.

Fig. 1 elucidate that between 1000 and 1200 ºC no shrinkage (i.e. densification of the sample) takes place. At the same time, Fig. 2 demonstrates that the anorthite crystals are formed yet at 1000 ºC, which is confirmed by the SEM-EDS observations (Fig. 3).

This means that, during a low-cost treatment (5–10 min at about 1000 °C), some densification, accompanied by and intensive re-crystallisation reactions between the meta-kaolinite and the phases from MSWA, carried out.

The measured values for compressive strength (55-65 MPa), linear shrinkage (2-3 %), water absorption (13-15 %) and bulk density (1,9-2,0 g/cm^3) of samples, heat-treated at such regime, are in good agreement with the requirements for building bricks.

This is another possibility to use the bottom ashes from Municipal Solid Waste Incinerators as raw material for a high volume ceramic manufacture.

Conclusions

The phase compositions and structure of ceramic, obtained by mixing 60 wt% MSWA with 40 % industrial clay, sintered above 1200 ºC, are different from ones of the traditional tiling ceramics. The main crystal phase, instead quartz and mullite, is anorthite. In addition, due to the crystallization at cooling, amount of the residual vitreous phase is inferior and the surface, fracture and even the pores are characterized by regular fine polycrystalline structure. The open porosity is negligible, while the closes is 16-18 vol %.

If a short thermal cycle at ~1000 ºC is performed, samples with 2-3 % shrinkage, 1.9-2.0 g/cm^3 density, 12-13% water absorption can be also synthesised. These values correspond to the standards for traditional clay bricks, which however are produced at significantly longer thermal cycle. The short thermal treatment is explained by fast formation of anortithe as a result of reaction between metakaolinite and bottom ash.

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