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The influence of mullite wool waste on the properties of concrete and ceramics

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HIGHLIGHTS

- Utilizing of mullite wool waste.
- Effect on the structure.
- Strength characteristics.

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ABSTRACT

The influence of technogenic waste (burned and unburned mullite wool) on the properties of cement concrete as well as the influence of unburned mullite wool on the properties of ceramics are analysed in the paper. For the purpose of research, the part of sand in a cement concrete (2%, 4%, 6%, 8%, 10%) was replaced by a mullite wool waste. When 10% of the burned mullite wool waste was used the compressive strength of concrete increased by 7.7% after 7 days, and by 3.2% after 28 days. When 8% of the unburned mullite wool waste was used the compressive strength of concrete decreased by 3.4% after 7 days, and by 12.2% after 28 days. The ceramic samples were made from 4 different formation mixtures, in which the amount of unburned mullite wool waste was 0%, 5%, 10% and 15% (the amounts of quartz sand were replaced with waste). The samples were burned at the temperatures of 1050 °C and 1080 °C, keeping them at these temperatures for 4 h. The experimental results showed that the application of mullite wool waste in the manufacture of ceramic products is beneficial because of its positive impact on ceramic properties and the possibility to avoid overloading landfill sites. At the optimum burning temperature of 1080 °C, the significantly higher frost resistance, compressive strength and lower water absorption of ceramics is obtained.

1. Introduction

The mullite wool waste forms during the production of thermal insulation material. This thermal insulation material is used in industrial thermal equipment, for example, in the manufacture of electric and gas stoves, gas furnaces. It might also be applied for insulation works in boiler rooms or for insulation of different boilers, reactors, turbines, generators or cable lines, passing closely to the heat sources. In the foundry industry, these thermal insulation panels are used for futeration of buckets or to seal the apertures of casting machines. They are also used to build fire screens. The panels must have precise dimensions. The sawing and grinding of the panels lead to large amounts of waste. The waste forms during two stages of production: before burning and after burning.

Our previous research [1] presented the analysis of the influence of burned mullite wool waste on the properties of ceramics. It showed the most rapid water absorption and settlement in the ceramic samples without waste additive, while slower water absorption was noticed for the samples with 10% of waste additive. However, after three days the values of water absorption were almost equal. The estimated average frost resistance (when samples were burned at the temperature of 1080 °C) varied from 220 cycles (for the samples without waste additive) to 440 cycles (for the samples with 10% of mullite wool waste). The mullite wool waste is decreasing the density of a ceramic body, its structural inhomogeneity and the rate of capillary absorption and it increases significantly the compressive strength. Taking into account frost resistance and compressive strength, the optimum quantity of the waste in a formation mixture is 10%, when the samples are

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burned at the temperature of 1080 °C [1]. In the other study [2] it was determined, that the optimum quantity of the waste in the production of frost resistant ceramics under the maximum burning temperature of 1050 °C is 5%. To obtain stronger ceramic products, 15% of the burned mullite wool waste should be added. In that case the compressive strength would be 23 MPa. However, the estimated frost resistance of such ceramic body would be only 65 cycles.

The unburned mullite wool waste was used only in the research of expanded clay concrete [2]. The investigations showed that the additive of unburned mullite wool waste decreases frost resistance and density of samples, and increases their water absorption. Replacing 10% of the cement with the unburned mullite wool waste almost does not change the compressive strength. This waste can be used for expanded clay concrete wall blocks and masonry, protected from the aggressive impact of environment [2].

Mullite ($3Al_2O_3{\cdot}2SiO_2$) and mullite ceramics are widely used in many fields because of their excellent mechanical properties, high melting points (1830 °C), low coefficients of thermal expansion ($4.5 \times 10^{-6}\,K^{-1}$), excellent creep resistance, good chemical stability, and resistance to high temperatures [3–5]. The authors [5] revealed that the content of mullite grows with an increase in the sintering temperature from 1100 °C to 1500 °C. The other researchers [6] state that the density of mullite is 3.2 g/cm^3, and the strength about 200 MPa. Alumina-mullite ceramics with a low content of glass phase may have a high potential for armour and wear resistance applications if these ceramics have an optimal ratio between two major crystalline phases and, therefore, a remarkable level of physical properties [7]. The unburned mullite wool used in our studies was characterized by a relatively large amount of glass phase.

The authors [8] examined different methods of synthesizing mullite from clay. They determined that in case the Algerian kaolinite was used the mullite formed at 1550 °C. In the studies of ceramics often the additives with higher amounts of Al_2O_3 and SiO_2 are used in order to obtain mullite. The researchers [9] examined ceramics made with foam-gelcasting, using $CaCO_3$, SiO_2, Al_2O_3-ά. They determined that the produced mullite highly influences the microstructure and properties of ceramics. The compressive strength changed from 4.2 to 30.9 MPa. Other researches [10,11] used fly ash. The authors [10] discovered that when ceramics comprising mullite, sillimanite and quartz is burned at 1200 °C the mullite, cristobalite and ά-Al_2O_3 form. However, when the temperature is increased to 1400 °C and kept constant for 2 h, only mullite is obtained. In addition, the other authors [11] also state that only mullite is produced when ceramic samples are burned at the temperature of 1400 °C.

The studies of ceramics often include the analysis of technogenic raw material (catalyst) of oil industry, which is rich in Al_2O_3 (68.85–85.25%). Such studies were also performed by the scientists [12,13]. They burned the ceramic samples with this waste and determined that mullite already forms at the temperature of 1100 °C.

A number of different wastes are used for concrete mixtures: crushed ceramic bricks [14–16], plastic waste [17], crushed glass [18], waste from mines [19] etc.

The authors [20] state that carbon fibres might be classified into three groups: long 1.5–2.6 mm, average 0.25–1.5 mm and fine 38 μ–0.25 mm. The fibres distribute unevenly in the sample of porous concrete. Adding carbon fibre to the aerated concrete mixture, the V/K ratio has to be increased. However, the fluidity of a formation mixture still decreases in proportion to the fibre amount. Adding more than 0.4% of the fibre makes the samples almost impossible to form as the formation mixture is fluid and the fibres cannot be distributed evenly in a formation mixture. The fibres increase significantly the strength of porous concrete. A small amount of this additive (0.05%) makes the porous concrete stronger even by 13.6%. Increasing the amount of this additive up to 0.2%, the compressive strength increases 1.45 times. This is explained by the arrangement of newly formed derivatives in the hollows of fibres and the even distribution of fibres in the structure of porous concrete.

Sinica [21] analysed porous concrete with synthetic fibre (length of fibres 5.2 mm, diameter 4.6–7.7 μm) and glass fibre (length of fibres 5 mm) additives. He determined that the cohesion of non-autoclaved foamed cement concrete with fibres is smaller than the fibre tearing force. When tension or bending forces are applied to cement concrete, the fibres loosen as the reinforcement material fibre itself is stronger than the cohesion between fibre and cement concrete. The reinforcement fibres change slightly the compression strength of a composite. The 0.4% additive of synthetic fibres increase the bending strength of a composite by 50%, the 0.4% additive of glass fibres increase the bending strength by 70% compared to the bending strength of a control sample.

The researchers [22,23] analysed the influence of fibre additives on the properties of autoclaved aerated concrete. The following 5 mm fibre reinforcement additives were used: (diameter 6.15 μm), polypropylene (diameter 7.5 μm), basalt wool (diameter 4.6 μm), and kaolin wool (diameter 3.3 μm). It was defined that the mineral fibres (basalt and kaolin) react chemically with the binding material and adhere very well. The 0.3% of hydrophilised fibres increased the compressive strength by 45.5%, while 0.2% of it increased the bending strength by 35.6%.

The aim of this study is to determine the influence of mullite wool waste on the properties of ceramics and concrete.

2. Raw materials and investigation methods

The following raw materials were used for concrete: composite limestone Portland cement CEM II/A-L 42.5N, conforming standard EN 197-1 requirements (its chemical and mineralogical composition is presented in Tables 1 and 2, other properties in Table 3); natural sand, conforming to standard EN 12620, with the maximum size of particles equal to 4 mm (the properties are given in Table 4, the graph of granulometric composition in Fig. 1); gravel, conforming to standard EN 12620, of 4/16 fraction (the characteristics are provided in Tables 5 and 6, the graph of granulometric composition in Fig. 2). The obtained gravel impact resistance to crushing was SZ = 24.9%, resistance to wear 13.0%.

Concrete mixtures also included superplasticiser and waste (burned and unburned mullite wool).

The used superplasticiser MC-PowerFlow 3100 conforms to the requirement of standard EN 934-2. “MC-PowerFlow” is manufactured on the basis of the newest polycarboxylate ether technology. Due to the accelerated adsorption, the effect starts immediately. The manufacturer declares that this superplasticiser is especially suitable for the manufacture of stable, non-exfoliating concrete. The used water conforms to the requirements of standard EN 1008.

The chemical composition of the mullite wool waste is presented in Table 7; the X-ray picture of the unburned mullite wool waste is shown in Fig. 3, and the one of the burned mullite wool – Fig. 4.

The X-ray of the burned mullite wool waste shown in Fig. 3 indicates, that the main mineral in the wool is M mullite $3Al_2O_3$

Table 1
Chemical composition of Portland cement.

Chemical composition, %						
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3^{2-}	Other
20.61	63.42	5.45	3.36	3.84	0.80	2.52