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Research article

Reuse of ultrafine mineral wool production waste in the manufacture of refractory concrete

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ABSTRACT

The paper deals with the mineral wool production waste (cupola dust - CD), presents CD characterization and aims to reuse CD in production of refractory concrete with calcium aluminate cement. The study of CD covers its chemical, phase and thermal analyses along with the morphological study and determination of particles size distribution. Zeta-potential, electrical conductivity and pH values of CD suspension are presented in the paper as well. Commercial microsilica additive in refractory concrete has been replaced with cupola dust. Compositions of refractory concrete have been prepared by incorporating 1%, 2% and 3% of CD. The bulk density, ultrasonic wave velocity, cold crushing strength and thermal shock resistance of the created refractory concrete have been determined. Based on experimental results, it has been found that cupola dust may be used for the production of refractory concrete. The environmental impact related to the CD reuse in refractory concrete production has been evaluated as well.

1. Introduction

In 2008, industrial waste accounted for around 55% of waste generated in the EU-27 (Euro. Comm., 2010). According to European Union legislation, 50% of industrial waste has to be prepared for reuse, recycled or recovered by 2020. The main objective is to avoid waste generation (De la Paz, 2014). Material recycling is seen as the best solution for waste treatment, followed by energy recovery and disposal as the least favourable option (Meinander et al., 2012). Mineral wool manufacturing process is also accompanied by the creation of waste and byproducts, consisting of mineral wool offcuts, filters sediments and spinning waste of mineral wool melt (Kizinievič et al., 2014). Estimated annual mineral wool waste volumes in EU27 countries in 2020 are ~2.5 million tons per year (Väntsi and Kärki, 2014). The economic viability of waste recycling has to be evaluated case by case, as there are many locally unique factors such as transportation costs, recycling costs, landfill charges, labor costs and environmental costs (Duran et al., 2006; Yuan et al., 2011). Currently there are two major options for recycling offcuts and spinning waste, consisting mostly of mineral wool fibres and small particles of unfiberised melt. First, it is possible to return the waste material directly into the mineral wool manufacturing process (Paroc-WIM; Müller et al., 2009). This may however cause problems when a shaft furnace is used to melt the raw materials. Waste may be also returned to the production cycle with previous briquetting, when the waste is pressed (ETBPP, 1998). Waste of mineral wool can be used as a raw material in other products; several publications on ceramics and concretes are available in a field. Thus, Kizinievič et al. (2014) have found that centrifugation waste of mineral wool melt (CMWW), consisting of 60–70% of under fibred melt particles and 30–40% of mineral wool fibers, can be used for the production of ceramic products.

The reuse of mineral wool waste as a substitute for cement-based composites may be perspective direction developing effective recycling technologies. In general, cement-based composites consist of aggregates bound by particular binder, where waste particles, depending on their chemical composition, could be applied in products of different types as a coarse, fine or ultra-fine filler depending on the waste particles size. A number of researches demonstrates successive replacing of natural aggregates in

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concretes by various types waste (Stefanidou et al., 2014; Guedes et al., 2013; Naik and Kumar, 2003). Cheng et al. (2011) have showed that ground rock wool waste with particles size distribution ranging from 17 to 250 μm can be used as coarse and fine aggregates replacement in pozzolanic products with improving main product properties.

Filters sediments, called also cupola dust (further – CD), from mineral wool manufacturing have an ultra-small size and thus are not easily recyclable. Based on results of investigation of Portland cement pastes containing CD, Žvironaitė et al. (2011) propose its good suitability for slag containing cements. Present work aims to evaluate the possibility to use CD as ultra-fine aggregate for refractory concretes, based on calcium aluminate cement (CAC). Currently there are different options to the introduction of ultra-fine fillers (Luz et al., 2015; Shiri et al., 2014; Kuznetsov et al., 2010; Antonovič et al., 2010) in refractory concrete. Microsilica is one of the most widely used ultra-fine additives for refractory concretes enhancing its density and improving the performance due to its pozzolanic activity and nano-size. CD is the waste of the mineral wool manufacturing process, which accumulates in the filters. Differently from other mineral wool wastes, for the moment, no suitable recycling or reuse program is proposed for CD, which could significantly reduce CD waste accumulation. The possible risk of CD disposal or storage is firstly related to its chemistry. The main aim in this study is replacing microsilica in CAC refractory concrete with ultrafine waste of mineral wool manufacturing – cupola dust. The specific method proposed in this work is suitable from both the ecological, technological and economical points of views. This research focuses on CD characterization and includes evaluating the properties of refractory concrete containing cupola dust.

2. Materials and methods

2.1. Materials

Calcium aluminate cement (further – *CAC*) ISTRA 40 produced by CALUCEM; content of Al_2O_3 40%; main mineral phase: CA; minor mineral phases: C_4AF, C_2AS, $C_{12}A_7$ (where C denotes CaO, A – Al_2O_3, F – Fe_2O_3 and S – SiO_2); refractoriness: 1270 °C. Specific surface by Blaine method of 3000 cm^2/g and bulk density of 1200 kg/m^3 have been determined.

Microsilica (*MS*) RW-Füller produced by RW silicium GmbH: ultrafine powder containing 96 ± 1.5% of SiO_2. Colour varies from light to dark grey. Bulk density 300 kg/m^3 has been determined.

Cupola dust (*CD*): ultrafine waste from the production of mineral wool. Bulk density 200 kg/m^3 has been determined.

Chamotte aggregate BOS125 produced by Tabex-Ozmo: content of $Al_2O_3 \geq 29\%$; fractions ≤ 5 mm.

Dispersive chamotte SZM1 produced by Tabex-Ozmo: fractions 0–0.5 mm.

Polycarboxilate deflocculant Castament FS30 produced by BASF.

Water. Suspensions were prepared with distilled water, concrete – with drinking water.

2.2. Methods

X-ray Fluorescence spectroscopy (XRF) was performed by on a Bruker X-ray S8 Tiger WD spectrometer equipped with a Rh tube with energy of up to 60 keV. Powder samples were measured in Helium atmosphere and data were analysed with Spectra Plus Quant Express standard less software.

The phase analyses have been done on SmantLab (Rigaku) X-ray diffractometer, using Cu-Kα (λ = 0.1541837 nm) radiation. PDF-4+ (2013) database for crystal compounds was used during the analysis of X-ray diffraction patterns.

The differential thermal analysis (DTA) of CD powders has been carried out with the use of LINSEIS STA PT-1600 equipment. ~50 mg of CD powder was placed in alumina crucible and during non-isothermal experiment was heated in nitrogen from ambient temperature up to 1050 °C; the heating rate was 10 °C/min. The temperature difference between sample and reference, inert in this thermal cycle, was recorded and plotted against heating temperature.

The morphological analysis has been performed by Scanning Electron Microscope (SEM) JSM-7600F (JEOL).

For investigating the electrical conductivity and pH of the suspensions, the device MPC227 of the company METTLER TOLEDO (the electrode InLab 730, conductivity range 0.00–1000 mS/cm, pH range 0.00–14.00) has been used. The solid-water ratio of 1:10 was constant; the solutions of suspensions were made by dissolving 5 g of MS or CD in 500 g of water. Test temperature 20 ± 1 °C.

The particle size distribution and zeta-potential values of suspensions have been analysed by means of dynamic scattering technique. The samples of MS and CD were dispersed in deionized water (1 mg per 1 ml) at 25 °C and investigated by means of Malvern ZETA SIZER NANO device with using of helium-neon laser (4 mW, 633 nm wave length).

For ultrasonic and mechanical investigation, the mix of refractory concrete was prepared in a special mixer of forced mixing of the Hobart type with the capacity of 5 l. First, dry components of the mixture were mixed for 2 min, then the water, making 3/4 of the total water content, was poured into the dry mixture and mixed for 2 min (56 rpm), and, finally, the remaining water was poured and mixed further for 3 min. The temperature during samples preparation and component temperature during mixing was 20 ± 1 °C.

Physical and mechanical properties were determined on prism-shaped samples of sizes 70 × 70 × 70 mm and 40 × 40 × 160 mm. The samples have been formed under slight vibration and then were covered with polyethylene sheet and hardened 72 h in normal curing at 20 ± 1 °C. After 72 h of curing, the samples were transferred into electric drying furnace and stored there for 48 h at 105 ± 5 °C. Dried samples were fired at 800 °C and 1000 °C temperatures in an electronic controller furnace. Firing regime includes: heating from 20 °C to 800 °C or 1000 °C temperature with heating rate 5 °C/h; holding at the highest temperature for 5 h; cooling from 800 °C or 1000 °C till 20 °C under cooling rate of 60 °C/h.

The ultrasonic pulse velocity was measured by the device Pundit 7 (Schleibinger Geräte GmbH) using two 54-kHz standard cylindrical transducers (transmitter and receiver). The transducers were pressed against the samples at two strictly opposite points. Vaseline was used to insure a good contact. The ultrasonic wave velocity (UWV) in m/s was calculated by the equation $(S/t)\cdot 10^6$, where S is distance in meters and t is time in microseconds.

Cold crushing strength (CCS) tests were performed with "ALPHA 3-3000 S" compression testing maschine (FORM + TEST Seidner & Co. GmbH) and the arithmetic averages of the three individual measurements are presented in the work.

Thermal shock resistance test has been carried out on samples of size 160 × 40 × 40 mm. The test included heating of samples and their further cooling in water-cooled panels. Firstly, samples were placed in the heated furnace (800 °C) and kept there within 40 min to provide uniform cross-section heating up to 800 °C. Then, heated samples were placed between two water-cooled panels and kept there within 30 min, until samples temperature reached 20 ± 1 °C. Such a heating/cooling was continued for 7 cycles and the UWV of the samples was determined after 3 and 7 cycles.

The conventional tests have been carried out in compliance of these standards: LST EN 196-6:2010, LST EN ISO 1927-1:2012, LST