Influence of thermal treated concrete demolition waste on the properties of expanded perlite mortar

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Strategies for reducing raw material consumption, reusing waste, and lowering CO_2 emissions have been developed to achieve the European Union's sustainable and circular economy goals. This article presents the properties of expanded perlite mortar with thermal-treated material (TTM). The TTM was prepared by heating demolition concrete waste (particles under 125 µm) at 550°C for 3 hours. At this temperature, the decarbonization does not occur. Using TTM can minimize the negative environmental effects of demolished concrete landfills and the demand for natural resources used in cement manufacturing. Commercial cement CEM II/A-LL 42.5R was substituted by 10%, and 30% TTM. By substituting CEM II/A-LL 42.5R (reference) by TTM, cement aqueous suspension pH and Ca^{2+} concentration generally decreased for all measurements (2 hours, 6 hours, 24 hours, 4 days, and 7 days). After 2 hours, the pH value was 12.42 for reference and decreased to 12.27 for 30% TTM. The concentration of Ca^{2+} estimated by complexometric titration was 20% lower in suspension with 30% TTM in comparison to reference, for 2 hours. The mortars have cement: expanded perlite volume ratio of 1:3 and consistency 140 mm…200 mm. The density of hardened mortars was about 1500 kg/m^3. At 7 days, the compressive strength of reference was 20.5 MPa compared to 12 MPa for mortar with 30%TTM. A significant decrease in flexural strength for mortar with 30% RC was observed. Due to its properties, expanded perlite mortar is a good thermal insulation material.

1. Introduction

Over one-third of the waste produced in the European Union is classified as construction and demolition waste (https://environment.ec.europa.eu/topics/waste-and-recycling/construction-and-demolition-waste_en). It is made up of many different materials, including bricks, concrete, wood, glass, metals, and plastic. At the moment, some demolition waste is effectively processed to create recycled rubble and sand, which are utilized as aggregates in road construction (Menegaki and Damigos, 2018). A rising number of researchers are also interested in investigating the potential of utilizing these wastes as components of cementitious materials or aggregates to produce mortar and concrete that is durable and high-strength (Chandru et al (2023), Rodriguez-Morales et al (2024)). Research on the use of CDW as a substitute for cement is promising for EU member states due to the limited availability of traditional supplementary cementitious materials including fly ash, granulated blast furnace slag, and natural pozzolans. Furthermore, research on the characteristics of concrete after a fire has demonstrated that concrete that has become weak due to high temperatures can partially restore its mechanical properties and rehydrate after coming into touch with water (Alonso and Fernandez (2004)). The literature contains many studies of hydration and properties of cement pastes calcined at different temperatures (Bogas et al (2022), Xu et al (2022), Tokareva et al. (2023)). This paper shows the results of a study regarding the properties of expanded perlite mortars with thermal-treated concrete demolition waste.

2. Material and methods

In the study, the following materials were: Portland cement type CEM II/A-LL 42.5R, thermally treated material, and expanded perlite sizes smaller than 2 mm, type IZO-PER 2 (producer Procema Perlit SRL). The thermal-treated material was obtained by calcinating concrete demolition waste (under 125 µm) at 550°C for 3 hours and cooling in the oven to room temperature (Nabertherm N11/H). The water was added to mortars in order to obtain a plastic mortar (consistency between 140 mm and 200 mm). The mortars with TTM had a water/cement ratio higher than the reference, according to the increased quantity of water required for the standard consistency of TTM (paste).

TTM partially substituted cement into mortars (10%, and 30%). The reference mortar contains 100% cement type CEM II/A-LL 42.5R. The influence of TTM on the pH and Ca^{2+} ions content in aqueous suspension was assessed. The pH was measured with a Jenway 3540 pH meter. The CaO content in the solution was calculated based on the complexometric titration method. The mortars have a cement: expanded perlite volume ratio of 1:3. The consistency, density, mechanical strength, and thermal conductivity of mortars were studied. The mortars were poured into prismatic molds 40x40x160 mm for mechanical strength testing and demolded after 24 hours. The samples were cured at 20°C and a relative humidity of 95±5% until testing time. The compressive strength was tested with a WPM hydraulic machine. The thermal conductivity was determined using a Heat Transfer Service Unit for Building and Insulating Materials, type H111N.

3. Results and discussion

3.1 The assessment of pH and Ca^{2+} concentration in aqueous suspensions

In order to obtain information regarding the evolution of the hydration process, suspensions with a cement/water ratio of 1/50 were prepared and mixed for 7 days with GFL 3040 equipment. At 2h, 6h, 24h, 96h, and 168h the pH and content of CaO in solution were measured. The results show that pH decreased with increasing in TTM content by up to 50%. The values were in the range of 12.36 … 12.83 for 10% TTM and 12.23 … 12.76 for 50% TTM, compared to reference 12.43 … 12.83. The values of the concentration of Ca^{2+} (CaO), in the solution, are correlated with the degree of hydrolysis of the calcium silicates from cement and the evolution of the formation of hydrated compounds. The evolution of the CaO content in the liquid phase is discontinuous. The CaO content increases up to 24 hours as a consequence of the hydration of the calcium silicates in the Portland cement. After this term, after reaching a concentration probably corresponding to supersaturation, the Ca^{2+} concentration starts to decrease as a result of the precipitation of calcium hydroxide and other hydro compounds. The concentration of CaO had the lowest value when cement was substituted 50% by TTM.

3.2 The properties of mortars

The consistency of mortar was tested by the flow table method (SR EN 1015-3: 2001) corresponding to a plastic consistency (140-200mm). No bleeding was observed.

The density of 28-day mortar slightly decreased when cement was substituted by TTM due to TTM's lower density than reference cement. All the mortars had a density under 1500 kg/m^3.

The flexural strengths decreased with increasing in TTM content up to 30%. At 7 days, the compressive strength of reference was 20.5 MPa compared to 12 MPa for mortar with 30%TTM. Compressive strength at 28 days reduced significantly when cement was substituted by 30%TTM. The compressive strength of mortars with TTM was lower than the reference. These results corroborated with CaO content in solution and X-ray diffraction analysis are supported by the absence of key phases in concrete waste for the thermal activation process, namely portlandite, and ettringite.

The thermal conductivity of mortars showed a decrease of λ-value (12%) when cement was substituted by TTM, probably due to a higher porosity of mortars.

4. Conclusions

The partial substitution of cement by TTM obtained from the thermal treatment of concrete demolition waste decreased the content of CaO in the solution. The mortars with perlite and cement partially substituted by TTM were stable, and the value of consistency corresponds to a plastic mortar. Increasing TTM content decreased mechanical strengths at 7 and 28 days. The λ-values of mortars with TTM were lower than the reference.

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