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PROPERTIES OF CONCRETE WITH THE CALCINED LOW-KAOLINITE CLAY AS A PARTIAL CEMENT REPLACEMENT

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Abstract

Properties of concrete containing the ground calcined low-kaolinite clay was experimentally studied. Clay, calcined at 900 and 1000°C, was used as a partial replacement of cement at dosage of 20 % by the weight of cement. Tests performed on concrete samples include the consistency, air content, compressive strength and flexural strength. The experimental results show a moderate decrease in slump, as well as in compressive and flexural strength comparing to concrete containing only cement CEM I as a binder. Better results were obtained with concrete containing clay calcined at 1000°C. Further research is needed to determine the optimal dosage of calcined clay in concrete, as well as the optimal temperature of clay calcination.

Keywords: *low-kaolinite clay, calcination, cement replacement, concrete properties*

1. INTRODUCTION

Cement is the main ingredient in concrete, and the cement industry is one of the leading emitters of greenhouse gases. For the production of one ton of cement, nearly a ton of carbon dioxide is released into the atmosphere [1]. Typical substitute materials for cement, fly ash, and granulated blast furnace slag, are becoming scarce in the EU countries due to the green transition. Ever stricter restrictions regarding the CO_2 emissions in the cement industry have led to the need to find the alternative replacement materials for cement [2]. One of the interesting possibilities is the use of calcined clay for this purpose. The thermal treatment of kaolin clay at temperature of 700 – 850 °C yields a product known as metakaolin. Metakaolin, thanks to its high reactivity and particle fineness, is a very reactive mineral additive for the cement composites [3,4]. However, given that kaolin clay is a high-value raw material, used to obtain more sophisticated ceramic products, and that its reserves are limited, in most cases it is not rational to use metakaolin for the production of cement composites. On the other hand, there are many clay deposits in Europe with a lower content of kaolin and other clay minerals. So far, these clays have only been used to a small extent, and the possibility of their application in the production of cement and concrete is being intensively investigated [1,2]. This paper presents the results of a study on the possibility of using the calcined clay from the "Bilalovac" deposit in Kiseljak, Bosnia and Herzegovina, as a mineral additive for concrete.

2. EXPERIMENTAL

2.1 Calcined clay

Clay from the exploitation field of the former factory of refractory materials at the locality “Bilalovac” (Kiseljak, B&H) was used in this study. The chemical composition of clay is shown in Table 1. Loss on ignition was determined gravimetrically after heating samples at 900 °C. The content of SiO_2 was also determined gravimetrically, while the content of Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, K_2O, Na_2O, and MnO after dissolving with acid, was determined on a Perkin Elmer atomic absorption spectrometer. Chemical analysis indicates the presence of clay minerals, quartz and possibly feldspar. Relatively low loss on ignition indicates a lower content of clay minerals.

Table 1. *Chemical composition of raw clay*

Component	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	MnO	K_2O	Na_2O	ZnO	LOI
Percentage (%)	63.60	22.30	2.04	0.95	0.006	0.76	0.008	4.66	0.50	0.016	4.98

The mineralogical composition of the clay was assessed qualitatively, using a simultaneous differential thermal and thermogravimetric analysis (DTA/TG), and X-ray diffraction analysis (XRD). The DTA/TG analysis was conducted on a Netzsch STA 409 CD instrument. The clay sample was heated in a nitrogen atmosphere from room temperature to 1200˚C, at a heating rate of 10°C/min. The test results are shown in Figure 1, where, in addition to the DTA and TG curves, the differential thermogravimetric (DTG) curve is also shown.

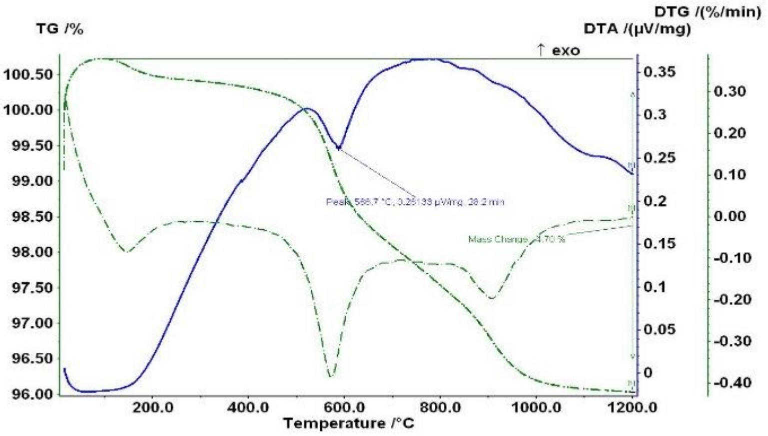

Figure 1. *DTA/TG curves of clay*

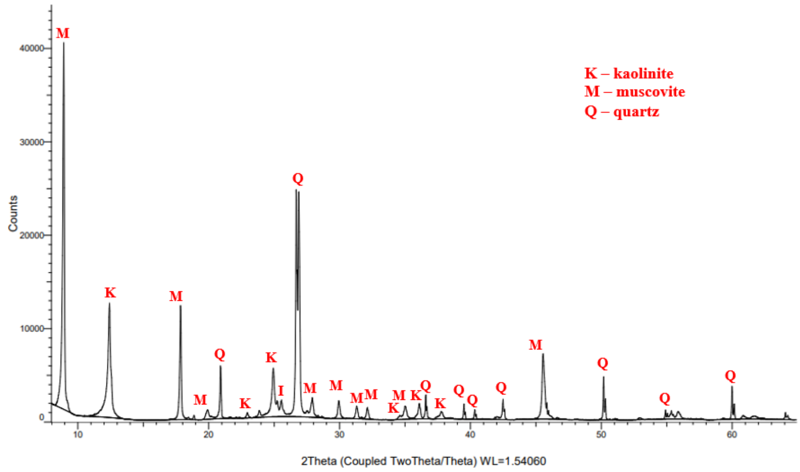

Figure 2. *XRD difractogram of clay*

An endothermic peak at around 587°C can be seen at the DTA curve, while a significant mass loss in the temperature range between 500 and 650°C is registered at the TG and DTG curves. This corresponds with the presence of kaolinite in clay. A change in the DTG curve in the interval 100 - 150°C, which refers to the removal of water molecules located in the interlayer space of clay minerals, as well as free water, absorbed from the atmosphere. The DTG curve also shows a mass loss at around 900°C, which could correspond to the decomposition of illite or muscovite minerals, whose presence is confirmed by the increased K_2O content in the chemical analysis. An XRD diffractometer of the Brucker D8 Endeavor type was used for the X-ray diffraction analysis, and the results are graphically presented as a function of intensity the diffraction maxima on diffraction angle. The diffractogram of studied clay. presented in Figure 2, confirms that this clay is composed of quartz, muscovite and/or illite and kaolinite.

Before calcination, clay was dried, ground, and sieved through a 1 mm sieve. Then, the amount of water needed to achieve the standard consistency was added to the clay, and cylinder-shaped samples of 40 mm height and 33 mm diameter were prepared. A half of samples was calcined at 900°C, and the other at 1000°C. For about 20 hours, samples were gradually heated to the maximum temperature where they were kept for two hours. After calcination, samples were rapidly cooled in water at room temperature, dried, and ground in the laboratory mill. The specific surface area (SSA) of grounded calcined clay was about 5500 cm^2/g.

2.2 Concrete

The three concrete mixes were made for the experimental investigation. The reference mix contained only cement as a binder, and in the second and third mixes, 20 wt. % cement was replaced with ground calcined clay. Composition of the concrete mixes is given in Table 2.

Table 2. *Composition of concrete mixes*

Concrete component		Reference concrete	Concrete with clay calcined at 900°C	Concrete with clay calcined at 1000°C
Cement (kg/m^3)		350	280	280
Calcined clay (kg/m^3)		-	70	70
Water (kg/m^3)		195	195	195
High-range water reducer admixture (kg/m^3)		1.5	1.5	1.5
Aggregate (kg/m^3)	0 - 4 mm	918	918	918
	4 - 8 mm	214	214	214
	8 - 16 mm	588	588	588

The cement used in this study was the Ordinary Portland Cement (OPC) CEM I 52.5 N with a specific surface area of 3500 cm^2/g. A polycarboxylic ether-based high-range water-reducing admixture is used to improve the workability of concrete mixtures. The crushed limestone aggregate with a maximum grain size of 16 mm and tap water were used for preparation the concrete mixes. After mixing, the slump test was carried out on each mix according to the EN 12350-2 [5], and the air content of fresh concrete mixes in accordance with the EN 12350-7 [6].

The cubes, 100×100×100 mm, and beams, 100×100×400 mm, were prepared for testing the hardened concrete properties. All specimens were demolded after 24 hours and then stored in water at temperature of 20°C until tests were conducted. The compressive strength of the cubes was measured following the procedure described in the norms EN 12390- 3 [7] in 2, 7, 14, 28, 56 and 90 days. The flexural strength test was carried out on the beams according to the norm EN 12390- 5 [8] at 2, 28 and 90 days.

3. RESULTS AND DISCUSION

The results of consistency and air content tests of fresh concrete are shown in Table 3. The slump reduction, observed in the mixes containing calcined clay, is explained by the fact that the specific surface area of calcined clay particles is larger than that of cement, and it absorbs more water thus reducing the amount of water needed for fluidity of the concrete mixture.

Table 3. *Slump and air content of fresh concrete mixes*

Property	Reference concrete	Concrete with clay calcined at 900°C	Concrete with clay calcined at 1000°C
Slump (mm)	210	195	185
Air Content (%)	2.0	1.8	1.6

The results of compressive and flexural tests of hardened concrete are shown in Figures 3 and 4. The results show that both compressive and flexural strength significantly decrease with the addition of calcined clay. The strength loss is lower in concrete containing clay calcined at 1000 °C. Later-age compressive strength of concrete containing clay calcined at 1000 °C is only 5 - 10 % lower than the strength of concrete with only the Portland cement CEM I as a binder.

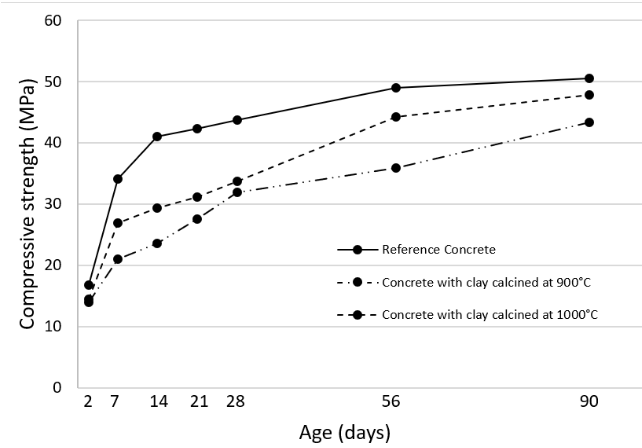

Figure 3. *Compressive strength of concrete*

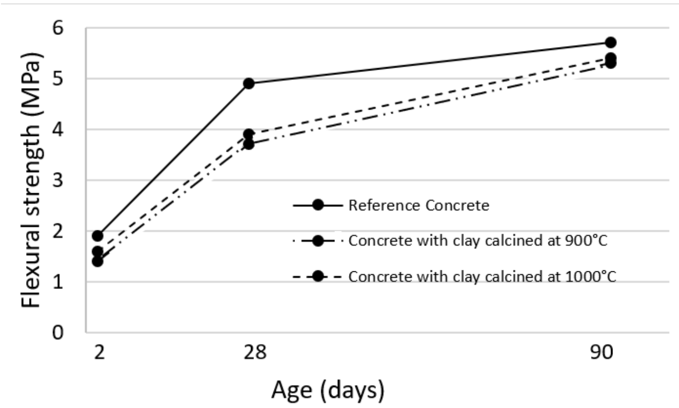

Figure 4. *Flexural strength of concrete*

4. CONCLUSION

Based on the test results, it can be concluded that the replacement of Portland cement with ground calcined clay by 20 wt. % leads to a slight decrease in fresh concrete slump, while the air void content has not been significantly affected by the calcined clay addition. The compressive and flexural strength of concrete also decreased. The decrease in strength is lower in concrete containing clay calcined at 1000°C than in concrete with clay calcined at 900°C. Further research is needed to determine the optimal dosage of calcined clay in concrete, as well as the optimal temperature of clay calcination.

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