Influence of Dried Concrete Sludge on the Properties of Hardened Cement Paste

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Abstract

This paper presents the research into the effect of dried concrete sludge on the properties of fresh and hardened cement paste. Concrete washout slurry was also investigated which accumulates in concrete plants. Concrete washout slurry is being created from regenerated water, which have too big density to use it in fresh concrete mixes. Cement paste mixtures were made from cement, superplasticiser, water and dried concrete sludge. Cement in the mixture was replaced by concrete sludge at 0 % – 30 %. The chemical, mineral compositions and particle size distribution of the dried concrete sludge was determined. The slump of the cement paste with different content of dried concrete sludge was measured. The density, the compressive and flexural strengths of hardened cement paste containing different amounts of dried concrete sludge were tested. The tests revealed that both technological and mechanical properties of the specimens deteriorated with the increase of dried sludge content. The test results suggest that the replacement of cement by dried concrete sludge has a negative effect on mechanical properties of hardened cement paste. A slight strength decrease observed in specimens where 5 % of cement was replaced with dried concrete sludge suggests that the replacement of cement at 5 % is appropriate and could be passible.

Keywords: concrete waste, concrete sludge, hardened cement paste

1. Introduction

The volumes of standard ready-mixed concrete used in the construction industry have increased and the demand for ready-mixed concrete is likely to grow with increasing construction output. At present concrete is the second most consumable man-made material in the world (Gursel et al., 2014). The increasing amount of concrete used has a negative impact on our environment and poses ecological challenges. These negative factors are related to cement, the production of which is particularly harmful to the environment. Cement manufacturing employs huge amounts of natural raw materials and releases large amounts of CO2 into the environment (Najim et al., 2014). The cement industry ranks second by the amount of emitted greenhouse gases worldwide, which cause global warming, and account for 5%–8% of the world's CO2 emissions (Scrivener & Kirkpatrick, 2008). To reduce the negative environmental impact of the cement industry scientists around the world are looking for materials that could displace cement in part or in full. Application of waste for partial replacement of cement is one of the useful ways that could further contribute to the cleaner environment.

Some waste materials, such as blast furnace slag or fly ash, are already widely used in the production of composite cements. There is also considerable information in the literature on ternary blended cements. There is evidence that the use of additional cement-based materials in certain proportions can improve the mechanical strength of cement pastes (Ghrici et al., 2007). Concrete sludge generated in concrete plants could be used as a substitute cement-based material. This waste material generated from the washout of concrete mixer trucks upon their return from construction sites. The concrete mix can be left in the mixer trucks overnight if set retarders are added (Lobo et al., 1995; Paolini & Khurana, 1998), but usually the residue is washed out or poured into settling tanks. Researchers estimated (Orsi, 1994; Borger et al., 1994) that 9-cubic-meter concrete mixer trucks return approx. 200–400 kg of plastic concrete mix to the plants by the end of the work day. The returned mix is diluted with a large volume of water and poured into a concrete segregation plant where the aggregates are separated and washed out, and the water with suspended particles is discharged into settling tanks. Depending on the volumes of materials used in the concrete, about 70 % of the aggregates can be recovered, while the remaining 30 % do not wash out and remain in the slurry (Xuan et al., 2018).

There were attempts to use concrete sludge in other industries too. Researchers (Schoon et al., 2013) proposed to use concrete sludge in Portland clinker manufacture, but the process was too complicated due to unstable chemical composition of concrete washout slurry. Other researchers (Cerema, 2016) proposed to use concrete sludge as recycled aggregate in road building, even though the permitted leaching limits were exceeded. The possibility of using concrete sludge as a cement-based material for stabilising foundations and road construction was investigated (Zhang & Fujiwara, 2007). The use of concrete sludge was also attempted in the production of glass ceramic components (Tian et al., 2007).

Researchers (Ferriz-Papi, 2014) describe a number of ways for using recycled products from the concrete mix returned to the mixing plant. The reported test results show that the basic properties of concretes improved when sand was replaced with dried concrete sludge. It is also possible to use higher volumes of washout water in the production of concrete mixtures if the sand content in concrete mixes is adjusted according to the water density.

Dried concrete sludge was also used to replace limestone filler (Audo et al., 2016). Deteriorated workability and technological properties of fresh mixes were the two main drawbacks observed in that research. For this reason, a higher amount of superplasticizer was required, and the compressive strength values varied considerably over a wide range, from -30 % to +17%.

The same researchers (Audo et al., 2018) also studied sludge from concrete mix manufacturers and found that the sludge contained a high proportion of cement particles and a low proportion of sand particles. The sludge described in their paper contained 9.7 % of cement, 38.7 % of sand and 11.6 % of limestone filler.

There were attempts to substitute cement or sand with concrete washout slurry; however, the drop in compressive strength was observed and appropriate substitution proportions were not determined (Pistili & Peterson, 1975). Possibilities to use concrete sludge in concrete block manufacture were also investigated (Hossain et al., 2017). The experiments focused on the variation of cement content in batch of the blocks and aggregate content in another batch. All blocks made of different compositions of concrete mix complied with applicable requirements.

2. Materials and methods of testing

Cement CEM I 42,5 R complying with LST EN 197-1 and dried concrete sludge, obtained through the washing process of left over concrete and separating it from coarse aggregates, were used. The physical properties of dried concrete sludge are given in Table 1 and the chemical composition of the sludge is given in Table 2.

Table 1. Properties of dried concrete sludge.

Properties	Dried concrete sludge
Specific surface area, m/g^2	316
Particle density, kg/m^3	2774
Bulk density, kg/m^3	826

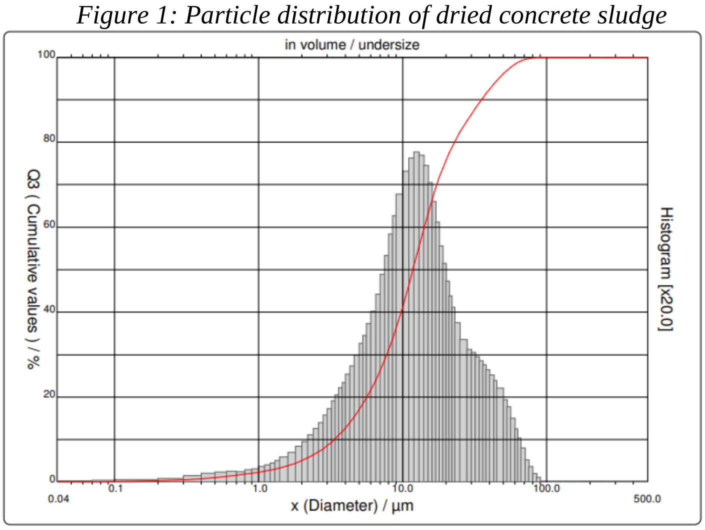
Table 2: Chemical composition of dried concrete sludge.

Chemical composition of concrete sludge, %											
CaO	SiO_2	AlO_{23}	SO_3	FeO_{23}	MgO	$_2KO$	$_2PO_5$	TiO_2	SrO	MnO	Cl
40.9	14.9	3.14	2.40	2.37	2.26	0.89	0.38	0.21	0.06	0.04	0.03

The specific surface area and particle size distribution of the dried concrete sludge particles were determined by using a Cilas 1090 LD particle size analyser (dry dispersion) in the range of 0.01 µm to 500 µm, using air as a carrier. The particles were dispersed by ultrasonication until 12 % distribution of the material in the medium was achieved. The measurement time was 60 s. The standard operating system *Fraunhöfer* was used.

The granulometric analysis of the dried concrete sludge showed that the prevailing average particle size of the dried concrete sludge used was 15.85 µm.10 % of the particles were smaller than 3.35 µm and 10 % were larger than 35.31 µm. Figure 1 shows the particle distribution of the dried concrete sludge.

Figure 1: Particle distribution of dried concrete sludge



X-ray diffraction analysis was done on *BRUKER AXS D8 ADVANCE* diffractometer with the following test parameters: CuK radiation, Ni filter, detector step 0.02°, intensity measuring span 0.5 s, the anode voltage U = 40 kV, and the amperage I = 40 mA. The accuracy of the X-ray diffraction analysis was 2θ = 0,01 º.

X-ray fluorescence analysis was performed on a Bruker X-ray S8 Tiger WD spectrometer. A rhodium (Rh) tube was used, with anode voltage Ua up to 60 kV and amperage I up to 130 mA. The specimens were measured under helium atmosphere. The measurements were done using the SPECTRA Plus QUANT EXPRESS method. The microstructure of the concrete sludge was analysed using a scanning electron microscope (SEM) workstation Helios NanoLab 650.

Hardened cement paste specimens were prepared from cement, superplasticiser, water and dried concrete sludge. All materials were dosed by weight. A mechanical mixer was used for mixing. The cement was first mixed with water and superplasticiser and afterwards an appropriate quantity of dried concrete sludge was added.

The compositions of hardened cement paste specimens are given in the Table 3. Different batches of the specimens were made by replacing cement with dried concrete sludge and thus reducing the cement content in the mix. The quantities of water and superplasticizer were kept the same in all specimens.

Table 3. Mixing proportion of hardened cement paste

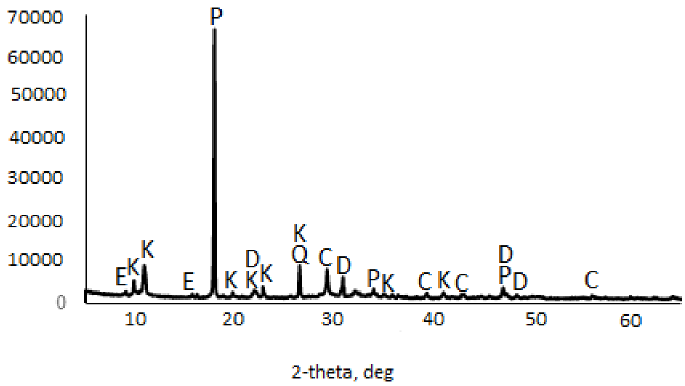
Batches	1	2	3	4	5	6	7
Cement, %	100	95	90	85	80	75	70
Water, %	100						
Chemical admixture, %	0.40						
Dried concrete sludge, %	0	5	10	15	20	25	30
w/c	0.35						

The main properties of the specimens were determined by reference to the relevant standards. The slump of the mixtures was determined according to LST EN 123-505:2019, the density of hardened cement paste according to LST EN 12390-7:2019, the compressive strength according to LST EN 12390-3:2019, and the flexural strength according to LST EN 12390-5:2019.

3. Research results and discussion

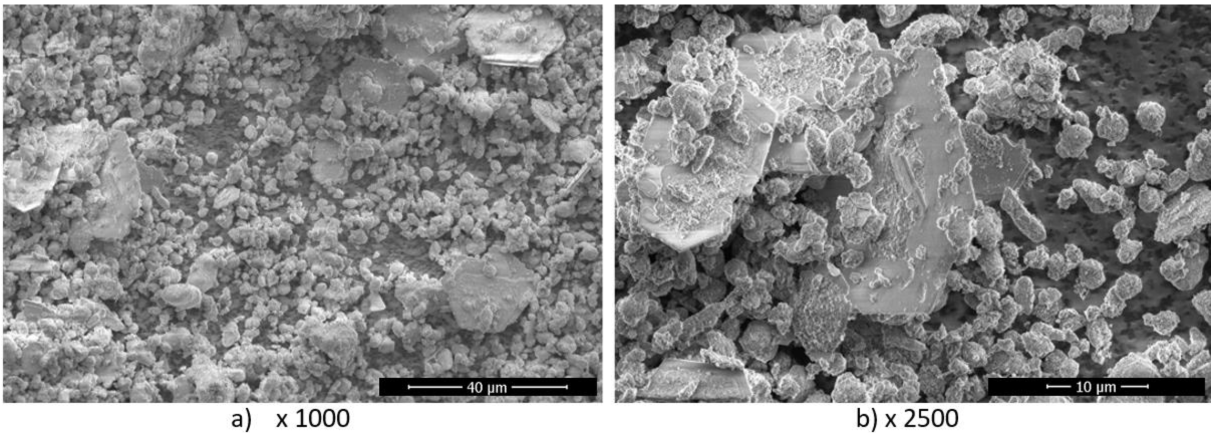
The X-ray structure analysis of the dried concrete sludge is shown in Figure 2. The sludge mainly contained calcite, 36 %; other minerals detected were: portlandite, 16 %, dolomite, 14 %, quartz, 11 %, larnite, 10.7 %, kuzelite, 7.6 % and ettringite, 3.8 %.

Figure 2: Dried concrete sludge X-ray; C – calcite ($CaCO_3$); P – portlandite ($Ca(OH)_2$); D – dolomite ($CaMg(CO_3)_2$); Q – quartz (SiO_2); K – kuzelite ($Ca_2Al(SO_4)_{0.5}(OH)_6*3H_2O$); E – $Ca_6Al_2(SO_4)_3(OH)_{12}*32H_2O$)



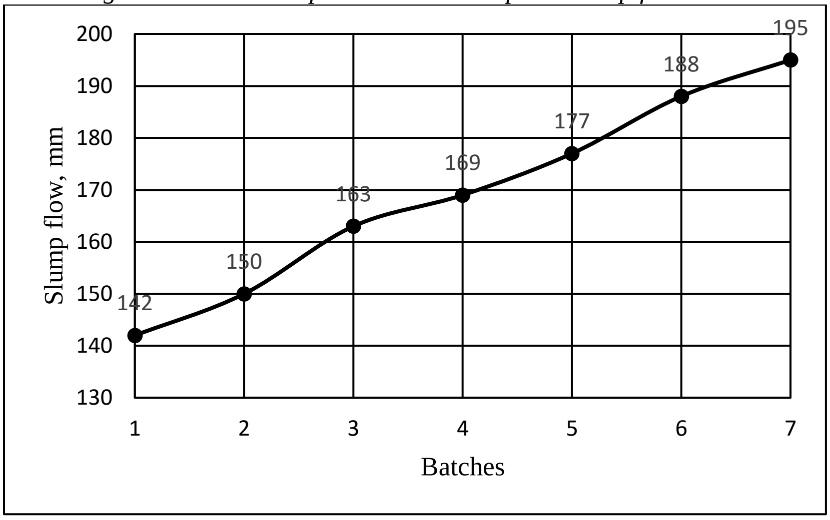
The microstructure of the dried concrete sludge is shown in Figure 3. The microstructure image obtained show that the dried concrete sludge is composed of round crystals and pentagonal plates. The pentagonal plates are portlandite crystals.

Figure 3 Microstructure of the dried concrete sludge: a) magnification x1000 b) magnification x2500



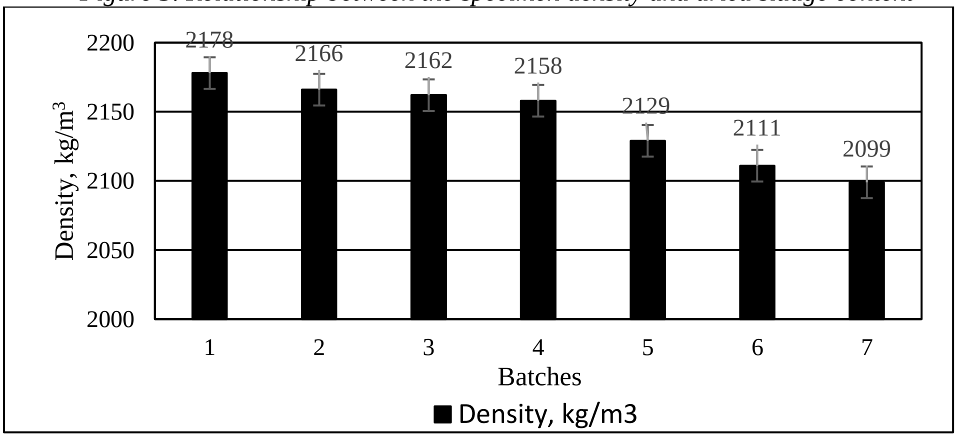
The slump flow tests of the cement paste showed an increase in the flowability of the mixes. The graphic representation of slump relationship is given in Figure 4. The slump flow increased with a higher content of dried concrete sludge replacing cement in the mix. A 53 mm increase of the slump flow was observed when 30 % of cement was replaced by dried concrete sludge. The reasons for this increase in the final diameter may be the dilution effect and a lower water absorption rate of the dried concrete washout slurry and reduced plasticizer demand in the mixture.

Figure 4: Relationship between cement paste slump flow and the amount of concrete sludge



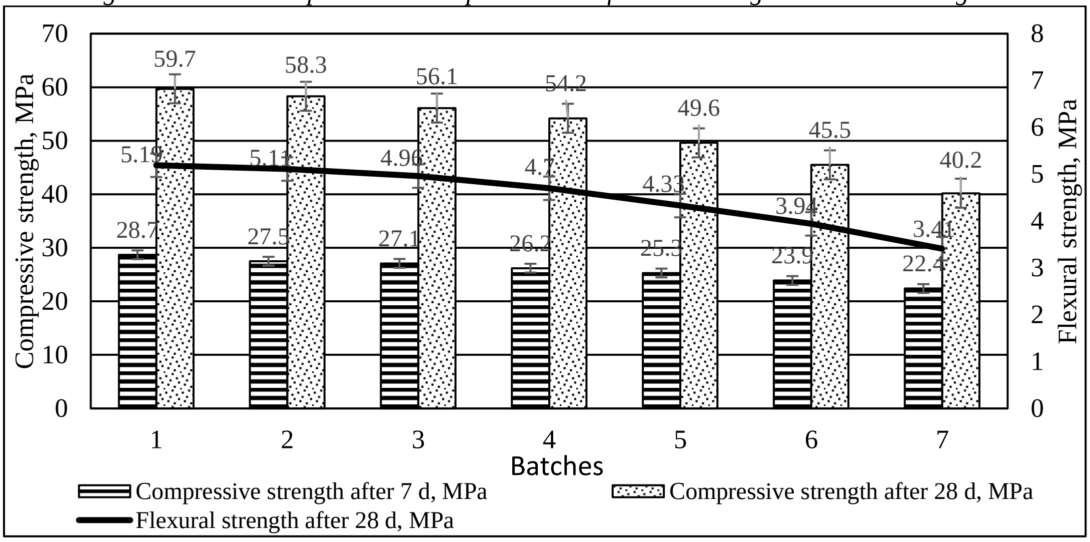
The density of the mixed specimens showed a tendency to decrease with increasing dried concrete sludge content. The density dependence diagram is shown in Figure 5. A decrease in density stability was observed when up to 15 % cement was replaced with dried concrete sludge. The density decreased by 12 kg/m^3 at 5 % replacement, by 16 kg/m^3 at 10 % replacement and by 20 kg/m^3 at 15 % replacement. A steeper decrease in density was observed in the specimens containing more than 15 % of dried concrete sludge, while the lowest density value of 79 kg/m^3 was recorded in the specimens where 30 % of cement was replaced with the sludge.

Figure 5. Relationship between the specimen density and dried sludge content



The compressive strength of the specimens was determined after 7 and 28 days of curing and the flexural strength was tested only after 28 days of curing. The strength results correlate with the obtained density results. The strength values decreased in proportion to the dried concrete sludge content in the specimens. The strength decrease, although not sharp, was already observed after 7 days with compressive strength difference of 22 % between the control specimen and the specimen with the highest content (30 %) of dried concrete sludge. The difference in strengths after the full curing period was even greater. After 28 days of curing, the strength of the specimen containing 30 % of dried concrete sludge decreased by 32 %. The strength of the specimens where only 5 % of cement was replaced with sludge decreased insignificantly, only 1.4 MPa, compared to the control specimen. A 2 % decrease in flexural strength was recorded in the specimens with the lowest amount (5 %) of dried concrete sludge and a 35 % decrease was observed in the specimens where 30 % of cement was replaced with dried concrete sludge.

Figure 6. Relationship between compressive and flexural strengths and dried sludge content



Conclusion

Dry concrete sludge increases the slump of cement paste. The more cement was replaced by dry concrete sludge in the mixes, the more the slump of the mixes increased. The slump from the control mixture increased by 37%.

The obtained sample density results showed that the drier concrete sludge was added to the mixes, the lower the sample density. Compared to the control sample, the densities of the samples with up to 15% cement dry concrete sludge were slightly lower. The density decreased by 12 kg/m^3 at 5 % replacement, by 16 kg/m^3 at 10 % replacement and by 20 kg/m^3 at 15 % replacement. A steeper decrease in density was observed in the specimens containing more than 15 % of dried concrete sludge, while the lowest density value of 79 kg/m^3 was recorded in the specimens where 30 % of cement was replaced with the sludge.

The strength results correlate with the obtained density results. The strength values decreased in proportion to the dried concrete sludge content in the specimens. The strength decrease, although not sharp, was already observed after 7 days, after the full curing period was even greater. After 28 days of curing, the strength of the specimen containing 30 % of dried concrete sludge decreased by 32 %. The strength of the specimens where only 5 % of cement was replaced with sludge decreased insignificantly, only 1.4 MPa. A decrease in flexural strength was recorded in all specimens, bet with the lowest amount (5 %) of dried concrete sludge, the decrease was insignificant.

The test results suggest that the replacement of cement by dried concrete sludge has a negative effect on mechanical properties of hardened cement paste. A slight strength decrease observed

in specimens where 5 % of cement was replaced with dried concrete sludge suggests that the replacement of cement at 5 % is viable.
Replacing more than 5% of the cement with dry concrete sludge starts to further deteriorate the properties of the cement stone. The slump of the cement paste is significantly reduced, which impairs the workability of the mixture. With the addition of more than 5% of dry concrete sludge, the density, compressive and flexural strength of the specimens start to decrease significantly.

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