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RECYCLING AND ITS USE IN CONCRETE WASTE PROCESSING BY HIGH-SPEED MILLING

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Abstract. This article discusses the possibility of recycling of concrete waste using the high-speed milling method. The resulting of milling is micronize old concrete. Used old concrete was created by crushing of old concrete, which served as a structural concrete for the construction of a supporting column. Two level of milling process was used to recycle old concrete. The main use of waste is the possibility of partial replacement of commonly used binder and microfillers in concrete. For this reason, properties as particle size distribution, dynamic modulus of elasticity, flexural strength and compressive strength were observed. The aim is to replace as much cement as possible while maintaining mechanical properties.

Keywords: Micronized old concrete, high-speed mill, cement pastes, mechanical properties.

1. Introduction

Amount of produced waste increases with new concrete structures per year. Most of the concrete waste is recycled, approximately 10 - 20 wt. % of old concrete is stored in landfills [1]. This waste is largely contaminated and can not be used. The most common way of recycling is to reuse old concrete in the form of aggregate to new concrete. First, the reinforcement is removed and then concrete is crushed into fractions. New waste is generated during crushing. This waste is composed of particles sized from 0-1 mm. This waste is not used in new concrete because it increases the water content of the concrete recipe and thus also increases the shrinkage and reduces the mechanical properties [2–4]. Waste generated during recycling contains most of the old cement matrix. It is already hydrated cement, which also contains a part of unhydrated clinker because during hydration the water does not reach the center of the clinker minerals and thus the hydration is stopped. The amount of unhydrated clinker is about 10 % in the old matrix [5]. Amount of unhydrated clinker directly depends on the age of concrete, its use, and quality. Using the high-speed milling method, these unhydrated clinker centers can be uncovered and mechanically activated. Recycled concrete can act as a microfiller and binder in the future composite [6–8]. The process of high-speed milling uses the principle that has been known for thousands of years. It is the rotation of friction elements between which the milled material passes. This process has been enhanced by the use of patented friction elements (teeth, pins) at LAVARIS Ltd. and the use of high milling speed [9]. However, this process becomes very energy-intensive and thus creates an economic burden for recycling. For this reason, it is necessary to optimize the milling process and thereby economically improve the recycling process using high-speed milling [10].

2. Materials and samples

Experimental work deals with cement pastes, where part of cement was replaced with micronized concrete powder. Micronized old concrete was formed by micronization of old concrete. It was old structural concrete used for the load-bearing structure, directly for the columns of the old engine factory. Two levels of milling were used to recycle old concrete. For the experiment, fractions from 0 to 1 mm were used and it contained a large amount of the old cement matrix (OC). At the first level of the milling process, patented teeth with a diameter of 400 mm were used as the milling element. The result was a micronized old concrete (MOC A), which was taken from two places directly behind the mill (MOC A _1) or behind the filter (MOC A _2). At the second level of the milling process, patented pins with a diameter of 300 mm were used as the milling element. The result was finer micronized old concrete powder (MOC B), which was, as in the previous case, taken from the recycling line in two places, behind the mill (MOC B _1), or behind the filter (MOC B _2). Collection points and the entire recycling line can be seen in Figure 1. Individual grain curves are shown in Figure 2. It is clear from results that in the case of recycled MOC A _2, MOC B _1 and MOC B _2 we get a finer material than the used cement. This effect can also be seen in the Table 1, where these three micronized old concretes had the highest specific surface area and therefore the possible future activity.

Cement pastes were made up of 70 wt. % of Port-

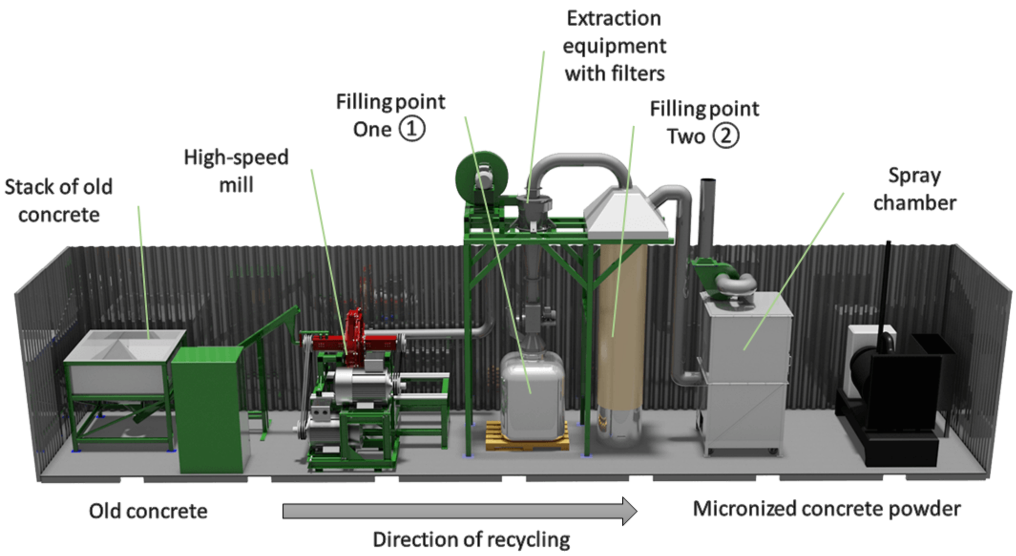

Figure 1. Recycling line with individual components and filing points.

Sample	Density of matrix [kg/m^3]	Specific surface area [m^2/kg]	Grain size		
			Dx (10) [µm]	Dx (50) [µm]	Dx (90) [µm]
CEM	3104	380	1.07	12.8	44.1
OC	2418	58	38.3	355	752
MOC A_1	2489	144	7.77	75.3	267
MOC A_2	2495	736	1.19	10.6	39.2
MOC B_1	2592	860	0.793	5.95	18.9
MOC B_2	2612	1351	0.551	3.04	11.5

Table 1. Characterization of grains of used materials.

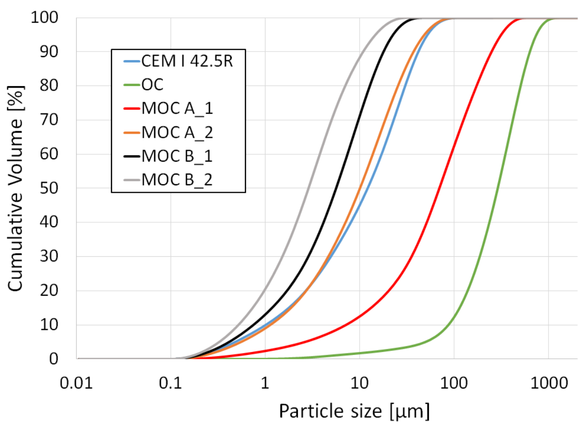

Figure 2. Partical size distribution curve of used materials.

land cement CEM I 42.5 R Radotin (CEM) and the remaining 30 wt. % formed a differently micronized old concrete. The resulting micronized old concrete differed the particle size and the milling time with each other. Four different micronized old concretes were tested, which were then compared with the two reference mixtures. The first reference mixture was made up of Portland cement only and the second reference mixture was made up of Portland cement and the non-milled old concrete (fraction of 0-1 mm). The water-binder ratio was set to w / b = 0.4 in all cases (Table 2). Six beams of 40 × 40 × 160 mm were produced from each mixture. They were stored in a water bath with 100 % humidity and air temperature 23 ± 3 ° C for 28 days. The size of grains affected the workability of mixtures (Table 2). The workability was measured by the cone spill method after 15 impulses. The cone spill was not measured on the mixture with non-milled old concrete because the mixture was too fluid.

3. Experimental methods

The resulting activation of the old unhydrated clinker was measured by the indirect method using the mechanical properties of the resulting cement paste. Set of parameters describing the mechanical properties of the resulting cement paste was chosen for this purpose, namely the dynamic shear modulus, the dynamic modulus of elasticity, the flexural strength and the compressive strength. The dynamic shear modulus and dynamic modulus of elasticity were measured by the non-destructive method - the resonance method. The advantage of a non-destructive measurement was that the property was traced over time. In our case,

Mixtures	Composition			Workability [mm]	Bulk density [kg/m^3]
	Cement [wt. %]	Old concrete [wt. %]	Water ratio		
CEM	100	0	0.40	280	2030 ± 2
CEM + OC	70	30	0.40	-	2028 ± 15
CEM + MOC A_1	70	30	0.40	290	1989 ± 11
CEM + MOC A_2	70	30	0.40	227	1930 ± 3
CEM +MOC B_1	70	30	0.40	225	1944 ± 8
CEM + MOC B_2	70	30	0.40	139	1993 ± 36

TABLE 2. Composition of the individual set/mixtures.

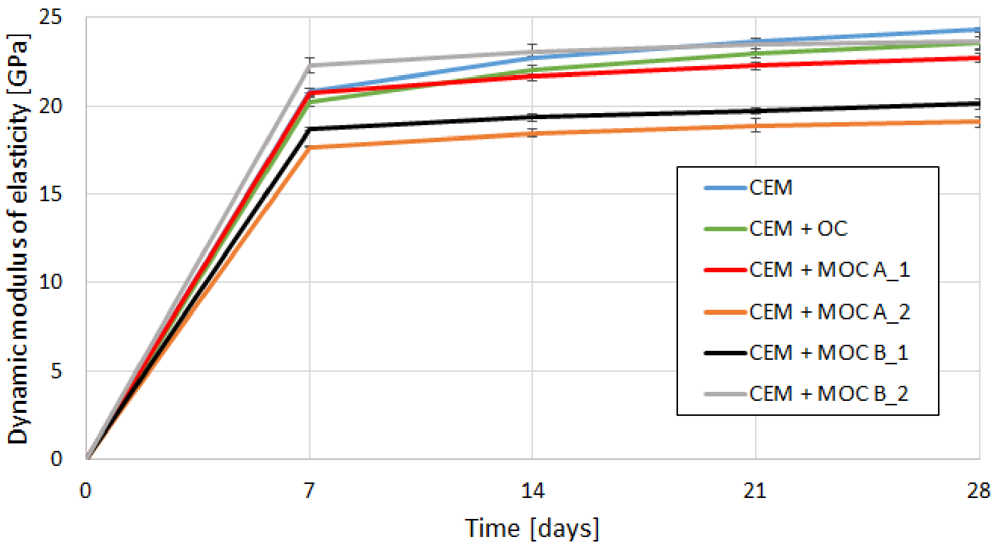

FIGURE 3. Development of dynamic modulus of elasticity.

samples were measured at 7, 14, 21 and 28 days. Dynamic modulus of elasticity was accomplished by measuring the basic longitudinal natural frequency of the samples. The acceleration transducer was located in the centre of the vertical side perpendicular to the length of the sample, and the impact hammer strikes were carried out in the middle of an opposite side. Dynamic shear modulus was measured by measuring the basic torsional natural frequency of the sample. The acceleration transducer was located in the corner of the vertical side parallel to the length of the sample, and the impact hammer strikes were carried out diagonally the opposite corner on the same side. Samples were destructively tested after 28 days of curing. First, a three-point bending test was used to determine the flexural strength of a 40 × 40 × 160 mm beams and then the compression strength was determined using a single-axis pressure test on broken halves from bending tests using the Heckert device, model FP100. The tests were controlled by shifting in the case of a three-point bend of 0.1 mm/min and the case of a pressure test of 0.3 mm/min. The distance between supports for the three-point bending test was equal to 100 mm. All of the results have been discussed below.

4. DISCUSSION

Figure 3 and 4 shows the development of the dynamic shear modulus and the dynamic modulus of elasticity. Results show a gradual increase in the dynamic modulus of elasticity between 7 and 28 days in all samples with micronized old concrete. The dynamic modulus of elasticity increased by about 2 GPa. Highest average values of the dynamic modulus of elasticity after 28 days had a sample with the finest micronized old concrete (CEM + MOC B_2) of 23.6 ± 0.5 GPa. This is 0.7 GPa less than the reference Portland cement (CEM) and 0.2 GPa more than the reference sample of a paste composed of cement and non-milled old concrete (CEM + OC). A similar trend as with the dynamic modulus of elasticity is seen in the dynamic shear modulus. Highest average values of the dynamic modulus of elasticity had a sample with the finest micronized old concrete (CEM + MOC B_2) of 9.5 ± 0.1 GPa. This is the same value as a reference sample with Portland cement (CEM) and 0.3 GPa more than a reference sample of a paste composed of cement and non-milled old concrete (CEM + OC). Also, a reference sample composed of cement (CEM) shows a faster increase in the dynamic modulus of elasticity between 7 and 28 days by 3.5 GPa. It is because in old

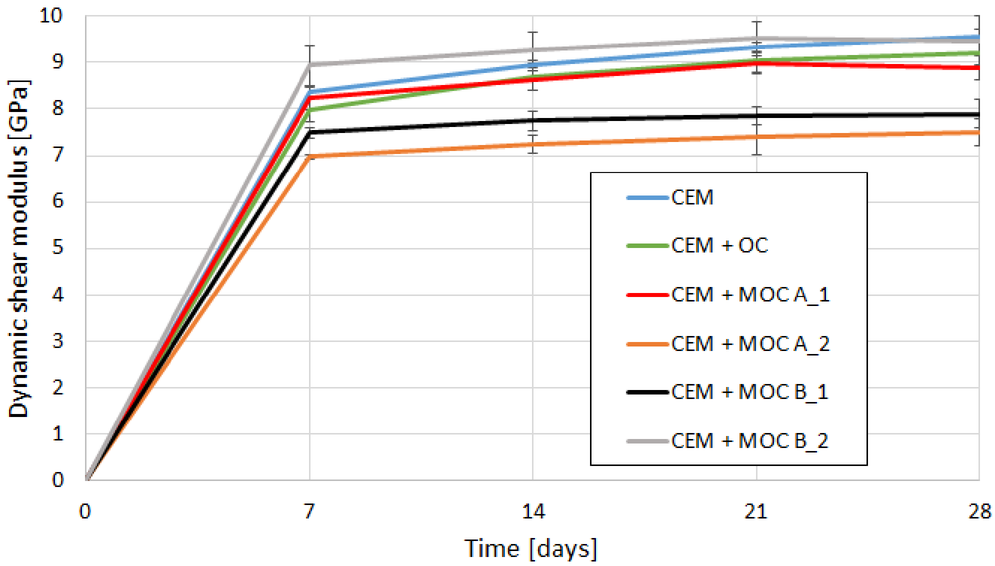

FIGURE 4. Development of dynamic shear modulus.

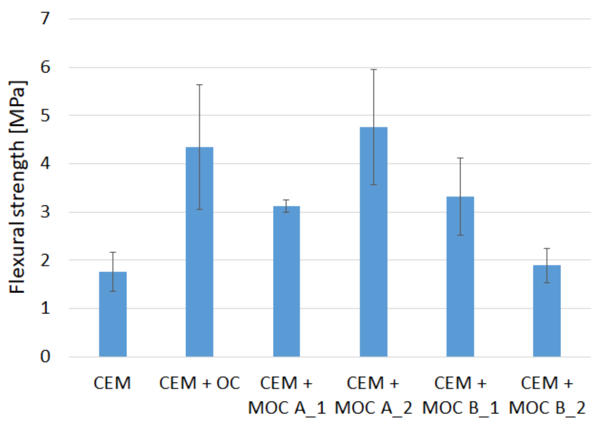

FIGURE 5. Flexural strength of tested samples.

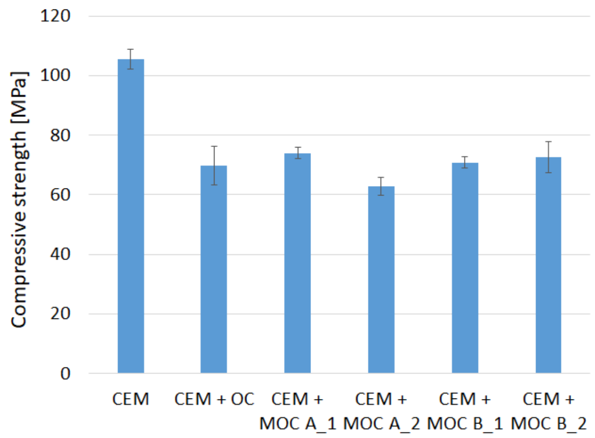

FIGURE 6. Compressive strength of tested samples.

concrete the majority of unhydrated clinkers are composed of belite that hydrates in a long time. Figure 5 shows the flexural strength of the tested materials.

All recycled material mixtures have a higher flexural strength than the reference cement. This is because old concrete is mostly inert and therefore does not release large amounts of hydration heat and thus smaller volumetric changes. These aspects have resulted in a decrease in the amount of microcracks and thus an increase in flexural strength. Figure 6 shows the results of the compressive strength of tested materials. The highest average compressive strength was achieved at the sample with the coarsest micronized old concrete (CEM + MOC A_1) at 74.0 ± 1.9 GPa and it is 30 MPa less than the reference cement sample (CEM). Results of the compressive strengths of the sample with recycled materials were approximately 30 % less than reference sample. Because it was used 30 wt. % of recycled material, it can be stated that during milling there was minimal activation of unhydrated clinkers in old concrete.

5. CONCLUSIONS

This work focuses on the effect of micronized old concrete as a partial substitute for Portland cement. The resulting cement pastes contained 70 wt. % Portland cement and 30 wt. % different kinds of micronized old concrete. Based on the results, it can be concluded that:

- The results show a gradual increase in the dynamic modulus of elasticity between 7 and 28 days in all samples with micronized old concrete.
- The highest average values of the dynamic modulus of elasticity were achieved for the sample with the finest micronized old concrete (CEM + MOC B_2) of 9.5 ± 0.1 GPa.
- All recycled material mixtures have a higher bending strength than the reference cement.

- The results of the compressive strengths of the sample with the recycled materials are approximately 30 % less than reference sample.

In the future, the research will focus on direct detection of the amount of unhydrated clinker and confirmation of the effect of micronization on their uncover.

Acknowledgements

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References

[1] S. Ahmari, X. Ren, V. Toufigh, L. Zhang. Production of geopolymeric binder from blended waste concrete powder and fly ash. *Construction and Building Materials* **35**:718–729, 2012.

[2] J. Schoon, K. De Buysser, I. Van Driessche, N. De Belie. Fines extracted from recycled concrete as alternative raw material for portland cement clinker production. *Cement and Concrete Composites* **58**:70–80, 2015.

[3] A. Pasandin, I. Pérez. Overview of bituminous mixtures made with recycled concrete aggregates. *Construction and Building Materials* **74**:151–161, 2015.

[4] F. Rodrigues, M. T. Carvalho, L. Evangelista, J. de Brito. Physical–chemical and mineralogical characterization of fine aggregates from construction and demolition waste recycling plants. *Journal of Cleaner Production* **52**:438–445, 2013.

[5] Z. Shui, D. Xuan, W. Chen, et al. Cementitious characteristics of hydrated cement paste subjected to various dehydration temperatures. *Construction and building materials* **23**(1):531–537, 2009.

[6] Z. Shui, D. Xuan, H. Wan, B. Cao. Rehydration reactivity of recycled mortar from concrete waste experienced to thermal treatment. *Construction and Building materials* **22**(8):1723–1729, 2008.

[7] J. Schoon, L. Van der Heyden, P. Eloy, et al. Waste fibrecement: An interesting alternative raw material for a sustainable portland clinker production. *Construction and Building Materials* **36**:391–403, 2012.

[8] V. Corinaldesi, G. Moriconi. Behaviour of cementitious mortars containing different kinds of recycled aggregate. *Construction and building materials* **23**(1):289–294, 2009.

[9] Z. Prošek, J. Trejbal, J. Topič, et al. Utilization of the waste from the marble industry for application in transport infrastructure: mechanical properties of cement pastes. In *IOP Conference Series: Materials Science and Engineering*, vol. 236, p. 012092. IOP Publishing, 2017.

[10] Information on `http://www.lavaris.cz`.