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Effect of Activation Recycled Concrete using Different Admixtures on the Strength and Modulus of Elasticity of the Resulting Cement Composite

HRBEK Vladimír[1,a], ZOBAL Ondřej[1,2,b], PROŠEK Zdeněk[1,2,c], ĎUREJE Jakub[1,d] and TESÁREK Pavel[1,e]

[1]CTU in Prague, Faculty of Civil Engineering, Department of Mechanics, Thákurova 7, 166 29 Prague 6, Czech Republic

[2]University Centre for Energy Efficient buildings, Czech Technical University in Prague, Třinecká 1024, 273 43 Buštěhrad, Czech Republic

[a]vladimir.hrbek@fsv.cvut.cz, [b]ondrej.zobal@fsv.cvut.cz, [c]zdenek.prosek@fsv.cvut.cz, [d]jakub.dureje@fsv.cvut.cz, [e]pavel.tesarek@fsv.cvut.cz

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Abstract. The demanding process of recycling building waste, including concrete, is a very topical topic. One of the possibilities of processing of waste concrete and subsequent use is its milling, i.e. mechanical activation. Concrete powder can be thermally activated, but it is an energy-intensive process and is produced CO_2. This paper deals with the improvement of mechanical activation with help of various admixtures and their influence on the material and strength characteristics.

Introduction

The mechanical activation of recycled concrete involves a very fine fraction of the waste concrete (< 1 mm). Coarse fractions are commonly used as aggregate or filler in concrete, wider use of very fine fraction (powder) has not yet been found. The cement paste forms a larger part of the fine fraction when recycling concrete and causes greater water absorption. However, other crushing and milling of powder can eliminate this problem [1]. The old cement paste contains unhydrated grains. The milling to a finer fraction can help activate these grains, so we talk about mechanical activation. The this way treated material can then be used as a substitute for cement in concete, but maximal 15%, with higher substitution there is a significant decrease in compressive strength and an increase in water absorption [2,3]. A fine fraction of recycled concrete can be successfully used to reinforce the underlying layers of railway constructions [4].

Concrete powder can be thermally activated, but it is an energy-intensive process and is produced CO_2. It has been proven that a new "clinkering" at temperatures of 500 to 800 ° C has a positive effect on the fine fraction of recycled concrete, because it is possible to replace the cement with this dehydrated powder while maintaining the strength of the concrete. As other results show, when combined dehydrated concrete with fly ash or slag can be strength of concrete further increased [5-9].

This document shows a combination of mechanical activation of the powder from recycled concrete and various additives with goal to improve material and strength characteristics of cement composite.

Materials and test specimens for the experiments

The basic reference mixture is made of cement paste from cement with designation CEM I 42.5 R The second reference mixture is composed of 50 % cement and 50 % recycled concrete from the railway sleepers. Lime hydrate, slag and fly ash were used as additives for further cement substitution. The chemical name of lime hydrate is calcium hydroxide and is prepared by firing pure gypsum, subsequently it is grinded and hydrated. Calcium hydrate has strong alkaline properties and is used in the building industry for the production of dry plasters and mortar mixtures [10]. The slag forms a waste material in the process melting of iron ore in blast furnaces, but due to its hydraulic properties it is widely used in the building industry for the production of mixed cements [11]. Fly ash is a waste material from coal combustion in thermal power plants, but just as the slag is used for its hydraulic properties and the ability to reduce the hydration temperatures in the building industry in cement and concrete. For the experiment, standard fly ash was used according to ČSN EN 450-1 from locality Mělník [12,13].

Altogether, 11 different mixtures were prepared - 2 references mixtures with designation CEM and CEMREC-5050 and 9 mixtures with other additions. The designation of the other mixtures depends on the type and quantity of the additive used - the lime hydrate Ca, the fly ash FA and the slag S. The substitution was 5, 10 and 15 % weight of cement. Water and binder ratio was same for all mixtures and his value was 0.35. Table 1 summarizes the designation and composition of the mixtures. All specimens have the shape of beams with dimensions of 40 × 40 × 160 mm and 6 pieces of each mixture have been made. Individual beams were taken from molds after 24 hours and stored in a water bath at 20 °C for 28 days.

Tab.1 Designation and composition of the mixtures.

Designation of the mixture	Composition of the mixture [%]					w/b [-]
	Cement	Rec. concrete	Lime	Fly ash	Slag	
CEM	100	0	0	0	0	0.35
CEMREC-5050	50	50	0	0	0	0.35
CEMREC-5050-Ca05	45	50	5	0	0	0.35
CEMREC-5050-Ca10	40	50	10	0	0	0.35
CEMREC-5050-Ca15	35	50	15	0	0	0.35
CEMREC-5050-FA05	45	50	0	5	0	0.35
CEMREC-5050-FA10	40	50	0	10	0	0.35
CEMREC-5050-FA15	35	50	0	15	0	0.35
CEMREC-5050-S05	45	50	0	0	5	0.35
CEMREC-5050-S10	40	50	0	0	10	0.35
CEMREC-5050-S15	35	50	0	0	15	0.35

Methodology and evaluation of experiments

For all fresh mixtures, the consistency and workability was determined using a flow test on Hägermann’s table [14]. On all test samples, the dynamic and shear modulus of elasticity was evaluated using a non-destructive resonance method [15]. On half of specimens, the compressive and tensile strength after 28 days was tested using destructive experiments according ČSN EN 196-1 and verified procedures [16,17].

Consistency. The flow test on the Hägermann's table verified the consistency and workability of the individual fresh mixture. The Table 2 shows average volume density and evaluation of consistency and workability.

Tab.2 Average values of the volume density and consistency and workability

Designation of the mixture	ρ_{avg} [kg/m^3]	Spillage - avg [mm]
CEM	2088.4 ± 11.2	218.5
CEMREC-5050	1977.7 ± 7.0	191.5
CEMREC-5050-Ca05	1958.0 ± 4.0	176.5
CEMREC-5050-Ca10	1906.0 ± 17.1	168.5
CEMREC-5050-Ca15	1876.8 ± 4.5	138.5
CEMREC-5050-FA05	1926.7 ± 4.4	209.5
CEMREC-5050-FA10	1907.6 ± 3.0	199.5
CEMREC-5050-FA15	1866.8 ± 6.6	212.5
CEMREC-5050-S05	1965.2 ± 5.2	218.5
CEMREC-5050-S10	1959.6 ± 5.6	239.0
CEMREC-5050-S15	1956.0 ± 2.0	236.0

Average spillage of reference mixture CEM was 218.5 cm. The substitution of 50 % weight cement with recycled concrete reduced spillage of 12.4 %. The individual additives had different effects on consistency and workability. As expected, lime hydrate degraded the workability significantly, when using 5 % by 19.2 % and using 15 % even by 36.6 %. The mixture with fly ash varied to 10 % less, and when slag added, the spillage increased by almost 10 %.

Dynamic and shear modulus of elasticity. All 66 test specimens were dried, measured and weighed after taking out from the water bath, so that the required parameters were obtained - dimensions and volume density - for later evaluation of the modules. The influence of additives at substitution max 15 % to the volume density is minimal, as well as the 50% substitution of cement by the recycled concrete itself (difference maximal 11 %).

The transverse frequency for each test body was measured. The measurement itself was non-destructive and was made after 7, 14, 21 and 28 days to observe the impact of the additives. Tables 3 and 4 show the average values of the dynamic modulus of elasticity E_{dyn} and the shear modulus of elasticity G and their standard deviations (for most mixtures it is 1 to 2 %, for some mixtures with lime hydrate and fly ash it is up to 5 %). Graphs on Fig. 1 and 2 depict changes on modules values within 28 days.

Tab.3 Average values of the dynamic modulus of elasticity and standard deviation

Designation of the mixture	E_{dyn} [GPa]							
	$E_{dyn,7}$	$\sigma_{x,Edyn,7}$	$E_{dyn,14}$	$\sigma_{x,Edyn,14}$	$E_{dyn,21}$	$\sigma_{x,Edyn,21}$	$E_{dyn,28}$	$\sigma_{x,Edyn,28}$
CEM	22.719	0.188	24.765	0.186	25.714	0.188	26.335	0.219
CEMREC-5050	17.265	0.063	18.678	0.056	19.149	0.045	19.450	0.057
CEMREC-5050-Ca05	15.699	0.083	17.148	0.086	17.638	0.089	17.891	0.116
CEMREC-5050-Ca10	13.421	0.094	15.301	0.728	15.118	0.107	15.347	0.104
CEMREC-5050-Ca15	12.183	0.204	13.365	0.242	13.748	0.245	13.946	0.213
CEMREC-5050-FA05	15.105	0.058	15.980	0.842	17.092	0.049	17.415	0.029
CEMREC-5050-FA10	14.339	0.082	15.847	0.056	16.389	0.052	16.776	0.057
CEMREC-5050-FA15	13.055	0.087	14.510	0.090	15.087	0.098	15.570	0.089
CEMREC-5050-S05	14.855	0.013	16.915	0.019	17.528	0.003	17.884	0.023
CEMREC-5050-S10	13.338	0.059	15.283	0.072	15.918	0.055	16.323	0.076
CEMREC-5050-S15	12.377	0.029	14.164	0.049	14.780	0.037	15.181	0.038

Tab.4 Average values of the shear modulus of elasticity and standard deviation

Designation of the mixture	G [GPa]							
	G_7	$\sigma_{x,G,7}$	G_{14}	$\sigma_{x,G,14}$	G_{21}	$\sigma_{x,G,21}$	G_{28}	$\sigma_{x,G,28}$
CEM	8.997	0.087	9.824	0.053	10.021	0.115	10.646	0.381
CEMREC-5050	6.939	0.023	7.534	0.042	7.679	0.063	7.744	0.072
CEMREC-5050-Ca05	6.364	0.101	7.039	0.049	7.189	0.088	7.221	0.095
CEMREC-5050-Ca10	5.455	0.086	6.266	0.367	6.131	0.104	6.102	0.070
CEMREC-5050-Ca15	4.765	0.236	5.335	0.054	5.331	0.024	5.507	0.059
CEMREC-5050-FA05	6.077	0.021	6.571	0.310	6.820	0.071	6.952	0.058
CEMREC-5050-FA10	5.863	0.047	6.440	0.075	6.808	0.303	6.673	0.092
CEMREC-5050-FA15	5.331	0.033	5.964	0.096	6.054	0.103	6.256	0.049
CEMREC-5050-S05	5.820	0.094	6.656	0.037	6.808	0.049	7.037	0.071
CEMREC-5050-S10	5.249	0.119	5.945	0.078	6.133	0.039	6.385	0.030
CEMREC-5050-S15	4.746	0.049	5.587	0.075	5.691	0.060	5.888	0.119

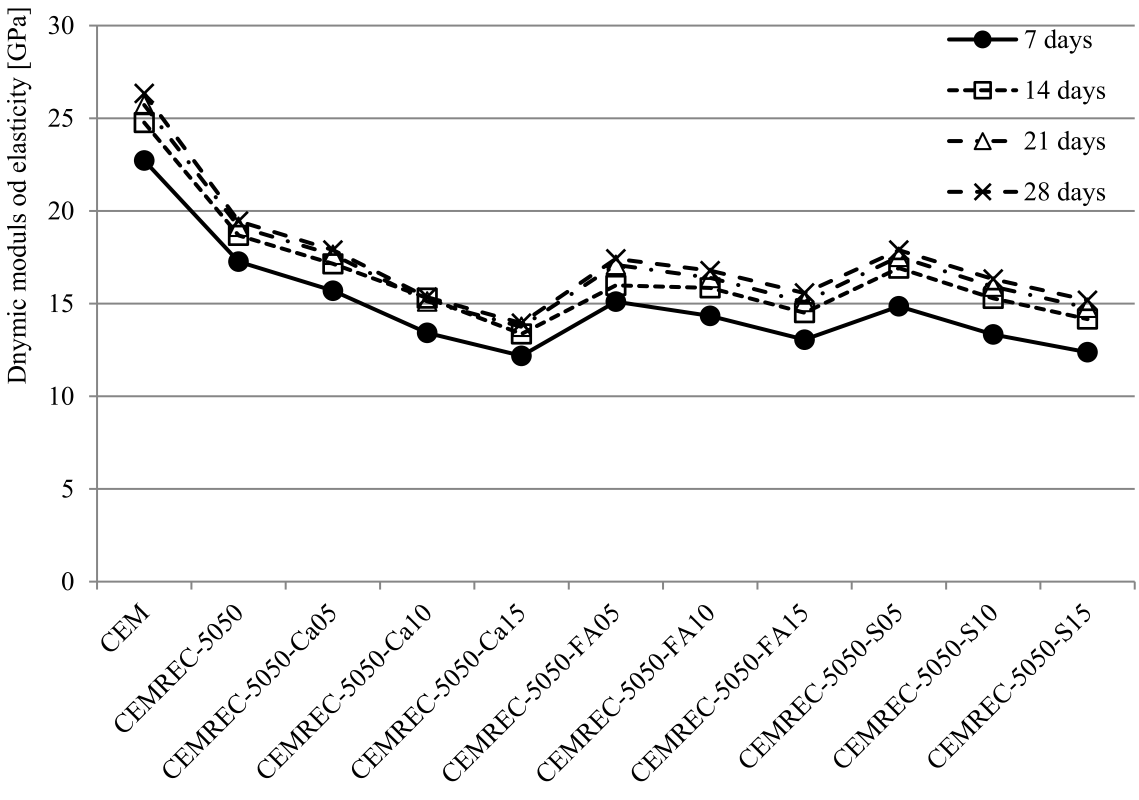

Fig. 1 Development of dynamic modulus of elasticity of individual mixtures during 28 days

Both the evaluation of the dynamic module and the shear modulus showed a great influence of 50% substitution of cement with recycled concrete. The decrease in the dynamic modulus was 22.8 %, in the shear modulus was almost the same, 23.3 %. The largest decrease in module values occurred in mixtures with 15 % lime hydrate and slag, ie mixture CEMREC-5050-Ca15 and CEMREC-5050-S15. All values increase over time. The dynamic module increased for reference mixture CEM by 15.9 % and by 12.7 % for CEMREC-5050 after 28 days. The shear module increased for reference mixture CEM by 11.8 % and by 11.6 % for CEMREC-5050 after 28 days.

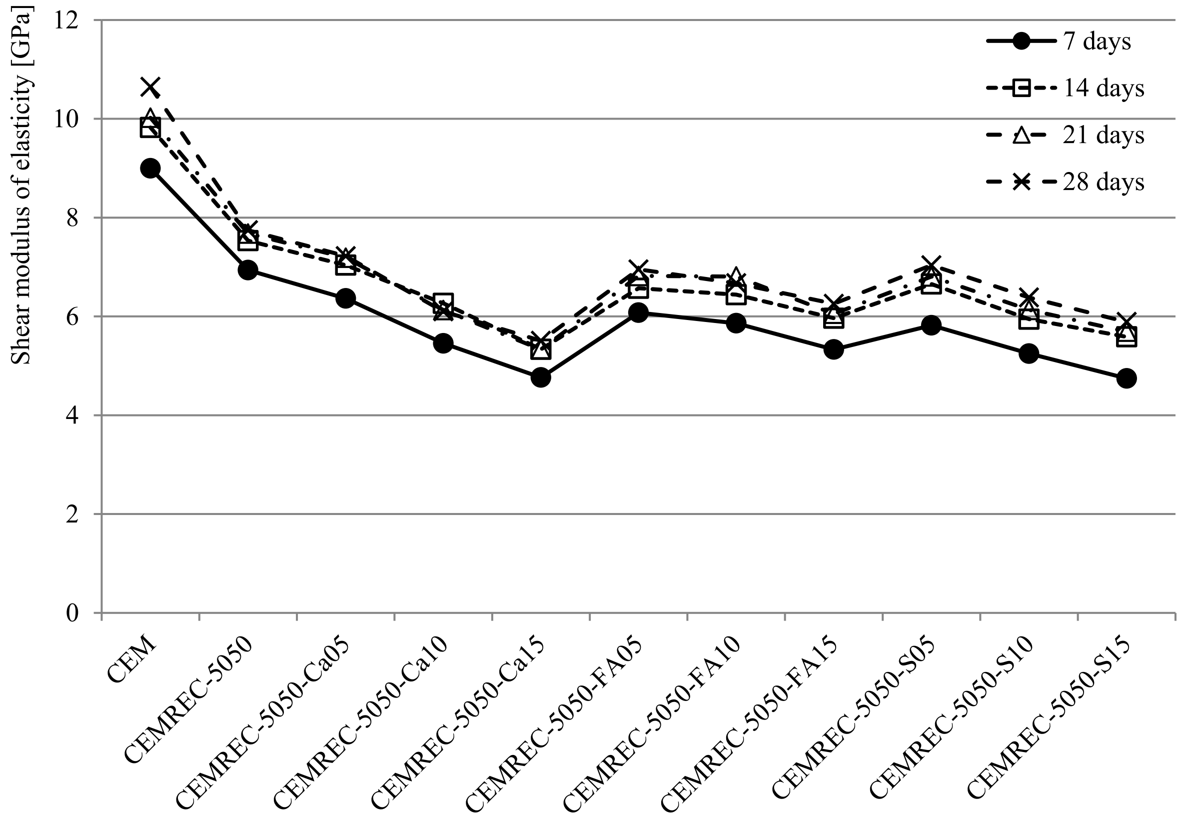

Fig. 2 Development of shear modulus of elasticity of individual mixtures during 28 days

Compressive and tensile strength. Half of test beams with dimensions 40 × 40 × 160 mm, ie 33 pieces, were used for destructive measurement of tensile strength after 28 days. The other half will be tested after 90 days. On the broken test samples after the tensile test, the compressive strength was tested (ie 6 bodies for each mixture). The measurement of tensile strength was proveded as a three point test. Distance of supports was 100 mm and test was calculated by help of the maximum force. The area under compressive load had size 160 mm^2 and has been demarcated by the loading device.

Tab.5 Average values of the compressive and tensile strength and their standard deviation after 28 days

Designation of the mixture	Compressive and tensile strength [MPa]			
	$\sigma_{c,28}$	$\sigma_{x,\sigma c,28}$	$\sigma_{t,28}$	$\sigma_{x,\sigma t,28}$
CEM	115.228	6.659	7.131	0.905
CEMREC-5050	50.256	1.455	6.169	0.470
CEMREC-5050-Ca05	44.065	2.527	5.926	0.308
CEMREC-5050-Ca10	36.298	1.041	5.671	0.409
CEMREC-5050-Ca15	30.755	1.361	4.161	1.620
CEMREC-5050-FA05	44.150	2.425	6.287	0.717
CEMREC-5050-FA10	38.712	3.140	6.188	0.344
CEMREC-5050-FA15	34.201	1.645	5.615	0.484
CEMREC-5050-S05	44.907	1.484	7.474	0.269
CEMREC-5050-S10	36.785	1.371	6.272	0.460
CEMREC-5050-S15	32.532	1.497	6.329	0.369

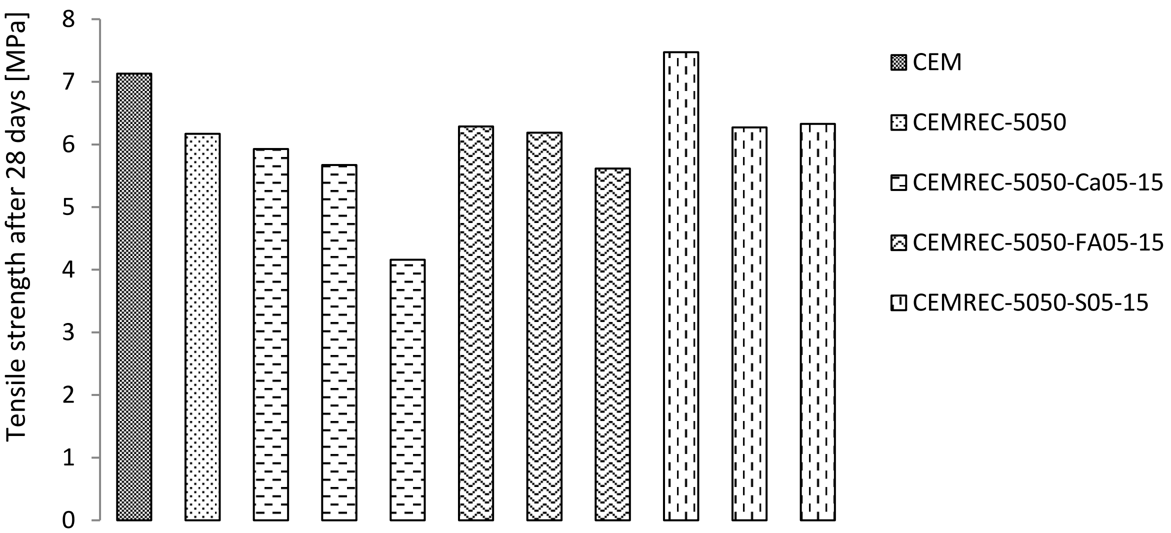

Fig. 3 Average values of tensile strength after 28 days

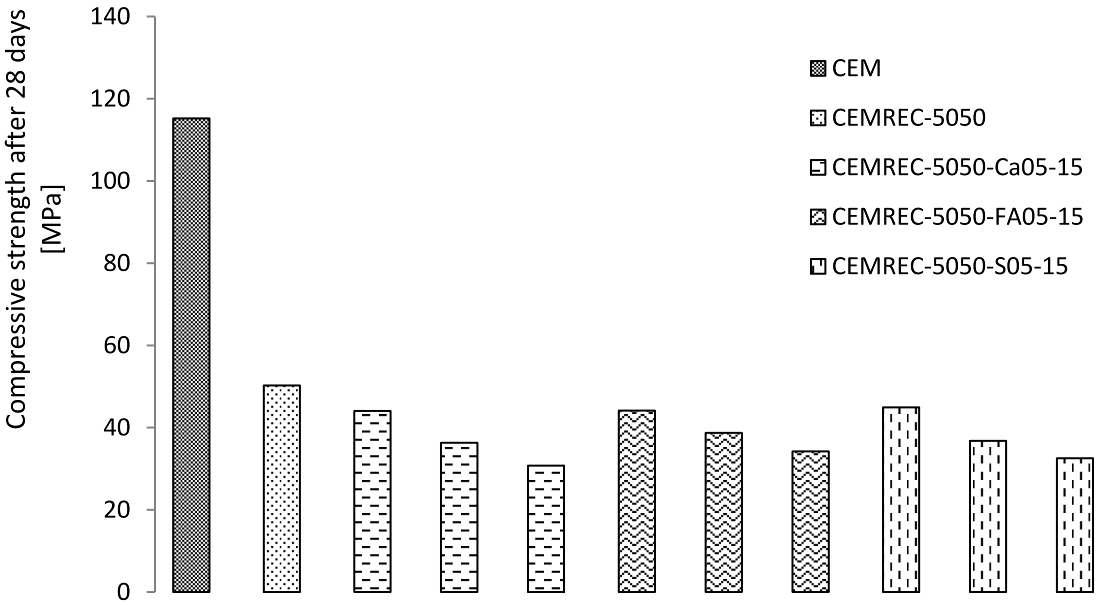

Fig. 4 Average values of compressive strength after 28 days

Table 5 summarizes the average values of compressive and tensile strengths after 28 days and their standard deviation. Fig. 3 and 4 show graphically the development of the strengths of the individual mixtures. The compressive strength of the reference mixture CEM is 115.2 MPa, by the mixture CEMREC is 50.3 MPa. The compressive strength values for mixtures with additives are between 30.8 and 44.9 MPa. A similar trend of development of strength can be observed for all mixtures with additives.

The tensile strength of the reference mixture CEM is 7.1 MPa, by the CEMREC mixture has value 6.2 MPa. The development of tensile strength values for mixtures with additives has a different trend over compressive strength. The mixture CEMREC-5050-S05 has a value of tensile strength even higher than the reference mixture (7.5 MPa).

Conclusions

Achieved results indicate that milled recycled concrete powder can be used for special applications in cement and concrete. The problem can occur with the consistency. The various grain curves of the individual components of the composite have certainly influence on consistency. The influence of particle size on the properties of the fresh and hardened mixture is also solved [18]. It is necessary to find the optimum between good workability and sufficient strength and material characteristics. When 50 % of cement was replaced with recycled concrete, the compressive strength decreased by more than 50 % but still reached values of about 40 to 50 MPa after 28 days. The tensile strength had not a dramatic decrease and the some additives had the other way around a positive effect. The increase in compressive strength over time is assumed for mixtures with fly ash and slag. [19,20].

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