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Optimization of cement composites composition with milled recycled concrete and admixture of slag and lime hydrate

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Abstract. Sustainable development and construction is a very topical topic. This is related to waste management, where construction waste is a significant part and waste concrete is one of the most voluminous components. It turns out that after the necessary modifications (such as milling) waste concrete can be returned back into the building process, not only in the form of aggregates, but also as part of the binder. This paper deals with optimization of the composition of cement composites using recycled ground concrete, lime hydrate and other waste material – slag. Selected parameters such as workability, modulus of elasticity and strength are monitored.

Introduction

This paper builds on previous research and composition of the mixtures has been optimized and designed on the basis of several phases of experiments [1-3]. Milled recycled concrete is only composed of a combination of structural concretes, because concretes as used in other applications (e.g. drain channel) as a potential component of the binder not worked. However, it was confirmed that treatment of recycled concrete by milling works as a mechanical activation. The selected admixtures slag and lime hydrate and their amounts should help to alkaline activate the unhydrated grains of clinkers of milling recycled concrete, i.e. chemical activation. The paper presents the effect of composition optimization on wet mixture workability and on the mechanical properties of the hardened mixture.

Used materials and composition of the mixtures

It has been proposed and solved a total of 7 mixtures with designation CR-LS I-VII. The mixture CR-LS I was reference and consisted only of Portland cement CEM I 42.5 R from Radotín and milled recycled concrete in ratio 50:50. The mixtures CR-LS II-VII consisted of 50 % by weight milled recycled concrete and a various ratio of cement (35.0; 37.5 and 40.0 %), slag (10 %) and lime hydrate (2.5 and 5.0 %). Milled recycled concrete was obtained from structural concrete. Slag was used in two variants, slag I is blast furnace slag and slag II is steel slag. The slag is used same as a fly ash for its hydraulic properties and the ability to reduce the hydration temperatures in the building industry in mixed cement and concrete [4]. All mixtures had the same water coefficient of 0.35 and workability was tested. Table 1 summarizes the designation and composition of the mixtures and their workability.

Table 1: Composition of the mixtures and their workability.

Designation of the mixture	Composition of the mixture [%]					w/b [-]	Spillage – avg. [mm]
	Cement	Rec. concrete	Lime	Slag I	Slag II		
CR-LS I	50.0	50.0	0.0	0.0	0.0	0.35	201.0
CR-LS II	40.0	50.0	0.0	10.0	0.0	0.35	200.0
CR-LS III	37.5	50.0	2.5	10.0	0.0	0.35	201.5
CR-LS IV	35.0	50.0	5.0	10.0	0.0	0.35	201.5
CR-LS V	40.0	50.0	0.0	0.0	10.0	0.35	204.0
CR-LS VI	37.5	50.0	2.5	0.0	10.0	0.35	203.5
CR-LS VII	35.0	50.0	5.0	0.0	10.0	0.35	197.0

Test specimens and methodology and evaluation of experiments

Test specimens had the standard shape of beam with dimensions 40 × 40 × 160 mm. For all fresh mixtures, workability resp. the fluidity of the mixture was verified by a standard cone spill test on fresh mixture. On all test samples, the dynamic and shear modulus of elasticity was evaluated using a non-destructive resonance method after 7 and 28 days [5]. Thereafter, 28 days compressive strength and tensile strength in bend were measured with help destructive tests according ČSN EN 196-1 [6].

Workability. The workability was verified with help spillage of cone. This methodology is described in the standard ČSN EN 12350-5 [7]. The flow table test is displayed on the Fig. 1. Each cone-shaped test specimen was tapped 15 times after mixing and the diameter and height were measured in two perpendicular directions.

The Table 1 shows evaluation of workability. Average spillage of reference mixture CR-LS I was 201 cm. This value is only about 8 % lower than spillage of mixture composited from only cement with same water ratio [3]. This fact means good workability of mixtures with milled recycled concrete. The used admixtures of slag and lime hydrate and the proposed substitution size had no big effects on consistency and workability. This is another positive fact.

Fig. 1 The flow table test – mixture CR-LS VI.

Dynamic and shear modulus of elasticity. All test specimens were stored in the water bath at temperature 21 °C throughout the hardening period. Test beams were dried, measured and weighed after taking out from the water bath. Required parameters (dimensions and volume density) for evaluation of the modules of elasticity were obtained. Average volume density of reference mixture CR-LS I was 1956.6 kg/m^3. This value is only about 7 % lower than average value of volume density of mixture composited from only cement with same water ratio [3].

The influence of admixtures slag and lime hydrate to the volume density is minimal (maximal 2.2 %), as well as the 50% substitution of cement by the recycled concrete (difference maximal 11 %, [3]). The transverse frequency for each test body was measured. The measurement itself was non-destructive and was made after 7 and 28 days to observe the impact of the additives. Tables 2 and 3 show the average values of the volume density ρ_{avg}, the dynamic modulus of elasticity E_{dyn} and the shear modulus of elasticity G and their standard deviations (by volume density for all mixtures maximal 1 %, by modulus for all mixtures maximal 3 %).

Table 2: Average values of the volume density and dynamic modulus of elasticity after 7 and 28 days.

Designation of the mixture	ρ_{avg} [kg/m^3]	$E_{p,7}$ [GPa]	$E_{p,28}$ [GPa]
CR-LS I	1956.6 ± 6.0	17.040 ± 0.043	19.038 ± 0.093
CR-LS II	1967.1 ± 20.1	16.029 ± 0.332	18.316 ± 0.454
CR-LS III	1924.1 ± 7.5	14.966 ± 0.412	17.016 ± 0.410
CR-LS IV	1914.1 ± 6.5	14.727 ± 0.214	16.912 ± 0.296
CR-LS V	1922.4 ± 6.4	15.229 ± 0.119	17.498 ± 0.138
CR-LS VI	1918.1 ± 3.2	14.773 ± 0.082	16.929 ± 0.196
CR-LS VII	1923.5 ± 9.4	14.459 ± 0.081	16.553 ± 0.057

Table 3: Average values of the volume density and shear modulus of elasticity after 7 and 28 days.

Designation of the mixture	ρ_{avg} [kg/m^3]	$G_{p,7}$ [GPa]	$G_{p,28}$ [GPa]
CR-LS I	1956.6 ± 6.0	6.839 ± 0.037	7.635 ± 0.039
CR-LS II	1967.1 ± 20.1	6.327 ± 0.038	7.391 ± 0.189
CR-LS III	1924.1 ± 7.5	6.021 ± 0.090	6.916 ± 0.151
CR-LS IV	1914.1 ± 6.5	5.829 ± 0.105	6.961 ± 0.113
CR-LS V	1922.4 ± 6.4	6.114 ± 0.059	7.119 ± 0.065
CR-LS VI	1918.1 ± 3.2	5.783 ± 0.039	6.928 ± 0.100
CR-LS VII	1923.5 ± 9.4	5.675 ± 0.028	6.786 ± 0.016

The average value of the dynamic modulus of elasticity of reference mixture CR-LS I was 17.0 GPa after 7 days and 19.0 GPa after 28 days (increase by about 12 %). This value is about 25 % lower after 7 days and about 28 % lower after 28 days (at an increase of about 16 %) than the dynamic modulus of elasticity of mixture composited from only cement with same water ratio [3]. The used admixtures of slag and lime hydrate and the proposed size of substitution caused a further reduction of the dynamic modulus of elasticity by up to 15 % (increase between 7 and 28 days by about 15 %).

The average value of the shear modulus of elasticity of reference mixture CR-LS I was 6.8 GPa after 7 days and 7.6 GPa after 28 days (increase by about 11.6 %). This value is about 24 % lower after 7 days and even about 28 % lower after 28 days (at an increase of about 18 %) than the dynamic modulus of elasticity of mixture composited from only cement with same water ratio [3]. The trend in the development of the values of the both monitored modulus of elasticity for the reference mixtures is thus identical. The used admixtures of slag and lime hydrate and the proposed size of substitution caused a further reduction of the shear modulus of elasticity by up to 7 % after 7 days and only up to 2 % after 28 days (increase between 7 and 28 days between 16 to 19 %).

Compressive and tensile strength. All test beams with dimensions 40 × 40 × 160 mm (ie 3 pieces for each mixture) were used for destructive measurement of tensile strength after 28 days (after non-destructive test). On the broken test samples after the tensile test, the compressive strength was tested (ie 6 pieces for each mixture). The measurement of tensile strength was carried out as a classic 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 mm2 and has been demarcated by the loading device. Table 4 summarizes the average values of compressive and tensile strengths and their standard deviation after 28 days. Fig. 2 and 3 show graphically the development of the strengths of the individual mixtures in %.

The value of tensile strength of the reference mixture CR-LS I was 6.3 MPa. This value is about 10.4 % lower than the tensile strength of mixture composited from only cement with same water ratio [3]. The used admixtures of slag and lime hydrate and the proposed size of substitution caused reduced the tensile strength between 5.5 to 31.8 %. Standard deviations fluctuated between 9.6 to 48.2 %. This large variance is probably due to shrinkage and follow-up microcracks. However this isn't so a big problem, because the test specimens aren't reinforced in any way.

The value of compressive strength of the reference mixture CR-LS I was 46.1 MPa. This value is about 60.0 % lower than the compressive strength of mixture composited from only cement with same water ratio [3]. The used admixtures of slag and lime hydrate and the proposed size of substitution caused reduced the compressive strength between 4.6 to 33.7 %. The increase in compressive strength over time is assumed for mixtures with slag. [8; 9]. Standard deviations fluctuated between 2.5 and 14.5 % (so high only for mixture CR-LS VI).

Table 4: Average values of the tensile and compressive strength after 28 days.

Designation of the mixture	$f_{t,28,p}$ [MPa]	$f_{c,28,p}$ [MPa]
CR-LS I	6.391 ± 2.125	46.1 ± 2.0
CR-LS II	6.043 ± 0.969	44.0 ± 3.7
CR-LS III	4.528 ± 2.184	42.9 ± 1.1
CR-LS IV	5.985 ± 1.172	35.2 ± 2.5
CR-LS V	5.741 ± 0.553	40.3 ± 3.4
CR-LS VI	4.361 ± 0.561	42.0 ± 6.1
CR-LS VII	4.704 ± 1.489	40.1 ± 3.2

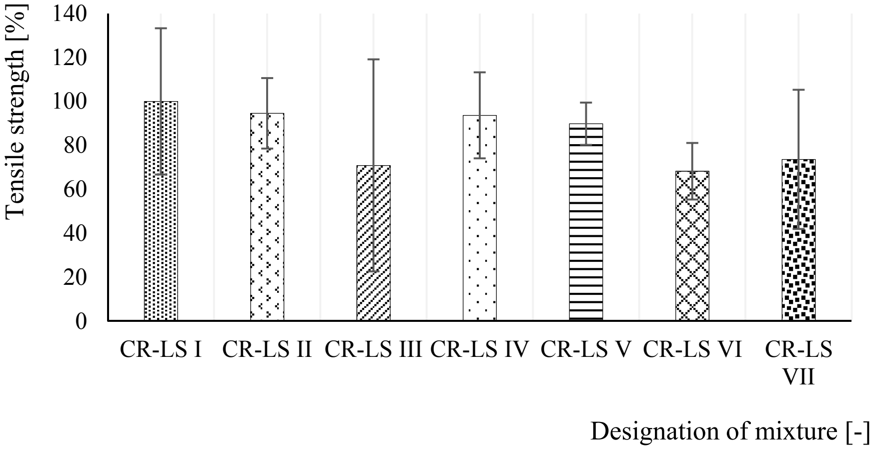

Fig. 2 Average values of tensile strength after 28 days.

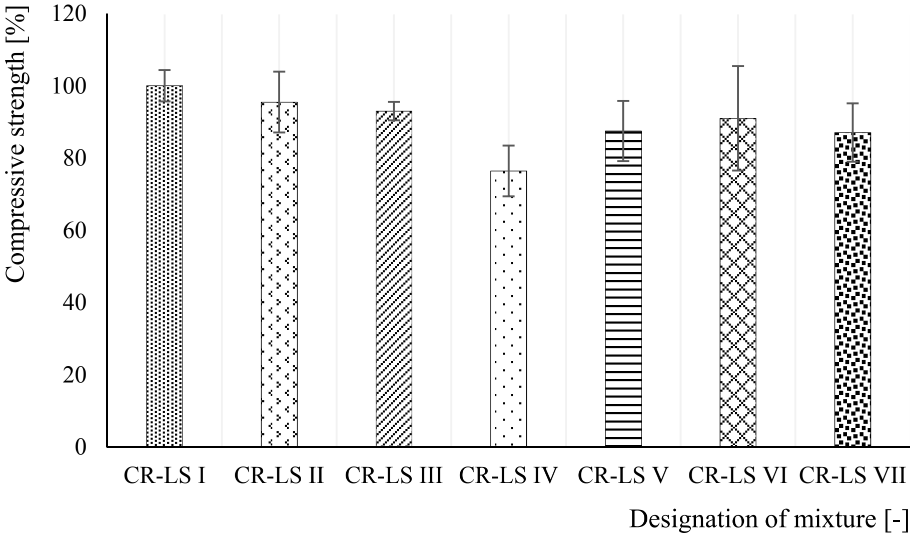

Fig. 3 Average values of compressive strength after 28 days.

Conclusions

The proposed cement substitution by milled recycled concrete in the matrix was 50 % by weight for all mixtures. Furthermore, admixtures of slag and lime hydrate were used. Selected properties were compared with the reference mixture. The influence on volume density was almost zero. The substitution also had minimal effect on the workability of the mixture. The change of dynamic modulus of elasticity resp. the shear modulus between proposed mixtures was maximal up to 15 % resp. only up to 7 % after 28 days.

The change of tensile strength resp. the compressive between proposed mixtures was maximal up to 31.8 % resp. only up to 33.7 % after 28 days. The difference of one of the most important parameters of compressive strength compared to a compound composed of only cement is high 60 %, but with a strength about 40 MPa after 28 days, some special applications can be easily considered (e.g. foundation constructions). Thus, optimized designed blends with recycled concrete and admixture of slag and lime hydrate and the values of the monitored parameters show the correct direction of research with the possibility of use in building practice.

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