ROLE ALKALI ACTIVATED BINDERS IN CEMENT PASTES CONTAINING RECYCLED CONCRETE FINES

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Abstract - Production of cementitious materials utilizing demolition waste is usually limited to the use of coarse aggregates. On the other hand, utilization of fine fractions containing stripped mortar remains an issue to be solved. In the presented study, we studied pastes containing 50% finely ground recycled concrete, blended with Portland cement, fly ash, or blast furnace slag. The microstructure of these pastes was studied using SEM-BSE microscopy and EDX analysis, stages of hydration were monitored using calorimetry, and mechanical strength was determined from destructive tests. The results show that recycled even fine fractions of concrete waste can be efficiently incorporated into cementitious materials and even improve their properties.

I. INTRODUCTION

Concrete constitutes the biggest portion of demolition waste worldwide [1]. Newly established environmental laws motivate both research and industry to recycle this material with emphasis on replacing expensive Portland cement, whose production is associated with huge emissions of CO2 [2]. While the use of recycled concrete became a common practice in construction industry, fines constituted of subsieve fractions and stripped mortar have been deposited to landfills. However, these fines were reported to contain a portion of unhydrated clinker that can be potentially recovered [3]. Even though a few researcher teams focused on the activation of these liberated concrete fines, the procedure involved energetically demanding high temperature dehydration [4, 5], which is energetically demanding and expensive.

An alternative way exploiting grinding and blending with alkali activated binders (ABBs) is presented here. In particular, fly ash and blast furnace slag were blended with recycled concrete fines and Portland cement (PC) in an attempt to increase hydraulicity of the pastes. The impact of individual additive on microstructure and mechanical properties of PC-based pastes containing recycled concrete thoroughly studied.

II. MATERIALS AND METHODS

1.1 Investigated materials and samples

Ordinary PC, CEM I/42.5R (EN 197-1:2001), was used in this study. Besides a pure reference paste, all tested samples contained 50 w/t % finely ground recycled waste concrete (RC). The waste concrete powder was produced by crushing 20-years old railway sleeper to a 0–32 mm fraction, removal of steel rebars, separation of 0–16 mm fraction, and its grinding to 0–1 mm fraction using a high-speed 2×30 kW mill SKD 600, produced by Lavaris company (Czech Republic). The hydraulic reactions were supported by fly ash, produced by a Mělník coal-fired power plant, Czech Republic. Fine fractions of blast furnace slag were selected as an alternative alkali activated additive.

The chemical composition of all constituents was determined by X-ray fluorescence spectroscopy (XRF) using a SPECTRO XEPOS spectrometer equipped with 50 W/60 kV X-ray tube. A list of measurable oxides is presented in Table 1. The results indicate that PC was rich in CaO and SiO_2 in the ratio 3:2 and therefore the clinker contained mostly C_3S, lower amount of C_2S and less than 5 w/t % aluminosilicates. The high content of amorphous SiO_2 in fly ash was provided by the soluble glassy components that are chemically activated in alkaline environment [6]. The same applies to slag, which is also rich in Al_2O_3.

Component	PC	RC	Lime	Fly ash	Slag
	w/t % (±0.5 %)				
CaO	66.1	21.1	73.4	1.71	38.0
SiO_2	20.4	40.5	0.50	55.7	24.1
Al_2O_3	3.90	11.8	0.28	30.0	11.3
Fe_2O_3	2.86	4.10	0.23	1.12	4.33
SO_3	2.87	1.22	0.10	1.10	4.46
MgO	1.92	2.30	0.56	0.81	5.09
Na_2O	0.00	1.51	0.03	0.00	2.01
K_2O	0.00	1.83	0.07	0.00	0.95
other	0.10	1.16	0.24	1.09	2.52
LOI	1.85	14.5	24.6	8.53	7.33

Table 1. Chemical composition of PC, RC, and additives; most important oxides and loss on ignition (LOI) identified by the XRF.

When preparing the tested pastes, PC was blended with RC and additives to form binders specified in Table 2 using an electric blender. The water to binder ratio was kept constant, w/b = 0.35. The pastes were cast into 40×40×160 mm prismatic molds and removed after 24 hours.

After the first day of hardening, the specimens were submerged in water and stored at 22±1 ◦C. Six prismatic specimens represented each batch. These were subjected to both non-destructive and destructive testing of mechanical properties, along

with two specimens prepared only for microscopic examination.

Mixture	PC	RC	Additives			w/b	Flow test [mm]
			Lime	Fly ash	Slag		
C	100%	0%	0%	0%	0%	0.35	218×219
CR	50%	50%	0%	0%	0%	0.35	191×192
CRA_5	45%	50%	0%	5%	0%	0.35	210×209
CRA_10	40%	50%	0%	10%	0%	0.35	210×210
CRA_15	35%	50%	0%	15%	0%	0.35	212×213
CRS_5	45%	50%	0%	0%	5%	0.35	232×230
CRS_10	40%	50%	0%	0%	10%	0.35	238×240
CRS_15	35%	50%	0%	0%	15%	0.35	238×239

Table 2. Summary of tested pastes; percentages represent weight ratio of individual constituents

1.2 Microscopy and chemical analyses

A scanning electron microscope (SEM) FEG-SEM Merlin ZEISS was used for studying the microstructure of pastes. The SEM analysis in backscattered electron microscopy (BSE) mode enabled highlighting individual phases because the grayscale intensity in the image depends on the atomic mass. The chemical analysis was carried out using an energy dispersive spectrometer (EDS) produced by Oxford Instruments.

The mapping of microstructure was carried out at 300× and 500× magnifications, in order to detect small phases, such as unhydrated clinker, up to larger ones, such as RC grains. PyPAIS software [7] was used for automated identification of phases.

III. RESULTS

1.3 Morphology and chemical composition

The atomic weight and percentage for each phase were established from five BSE-EDS measurements on distinct samples under 300× and 500× magnifications. The individual phases were identified using stoichiometry, see Table 3.

Phase	Paste			
	C	CR	CRA_15	CRS_15
Clinker	8.7±1.4	2.5±0.6	1.7±0.9	1.5±0.4
$Ca(OH)_2/CaCO_3$	13.0±2.8	6.3±1.3	4.8±1.5	11.2±1.2
C-S-H/C-A-S-H	76.8±3.1	77.1±4.2	80.1±2.3	65.3±3.5
Crystalline SiO_2	0.8±0.7	13.0±3.4	10.8±1.3	21.6±3.0
Microscopic pores	0.7±0.4	0.7±0.3	1.7±0.3	1.8±0.1

Table 3. Volumetric fractions of phases in the studied pastes.

PC contained a high amount of clinker (about 95 vol %), and because C3S reacts in the early of hydration, pure Portland cement pastes contained about 8.7 vol % unhydrated clinker rich in C2S. SiO2 was introduced into the mixture in the form of impurities during the cement production. The presence of RC containing a mineral aggregate resulted in the contamination of pastes by SiO2. Larger amount of kneading water and its access to clinker grains in PC through RC embedded in the matrix supported the hydration and resulted in a 70 vol% reduction of unhydrated clinker in the studied specimens.

Hydration of glassy components in fly ash in CRA_15 pastes consumed a portion of $Ca(OH)_2$. The CRA_15 pastes had a higher concentration of microcracks, attributed to early-stage shrinkage during hardening. Unlike in other pastes, there was a high concentration of more chemically stable C-S-H gel detected in the vicinity of RC grains, rendering the matrix stronger and potentially more resistant to chemical agents.

CRS_15 pastes also contained a higher amount of microcracks and high content of inert SiO_2 and $CaCO_3$ minerals. Similarly to the pastes with fly ash, the precipitation of $Ca(OH)_2$ around grains of RC was also detected in CRS_15 pastes.

1.4 Hydration heat

Specific heat flow and cumulative hydration heat were measured to identify hydration stages and evaluate the total heat released during the first 5 days of the measurement. The outputs were normalized to 1 g of PC in the mixture to reveal the contribution of individual additives.

The presence of additives resulted in lowering the main peak of the specific heat flow, related mostly to the hydration of C_3S and formation of low-density C-S-H gel [8]. The addition of fine-grained slag resulted in the highest amount of heat, normalized to a weight of PC in the pastes.

The total heat normalized to the amount of PC and released during the first 5 days of hydration, was higher in the case of all binders containing RC. This indicates that the presence of RC promotes hydration and some portion of old clinker or other active components in RC could be reactivated.

1.5 Mechanical properties

It was expected that the introduction of mostly inert fine-grained RC would result in a less compact and more porous structure of pastes. On the other hand, RC promoted hydration of PC by allowing better access of water to clinker grains and acted as microfiller that reinforced the brittle matrix [9-11].

A series of compressive and bending tests were carried out to test this hypothesis and reveal the impact of RC and alkali additives on the strength of pastes. Even though the pastes with RC were relatively rich in C-S-H, their compressive strength

hardly reached 50% of the pure cement paste strength, independent of the duration of hardening, see Figure 1.

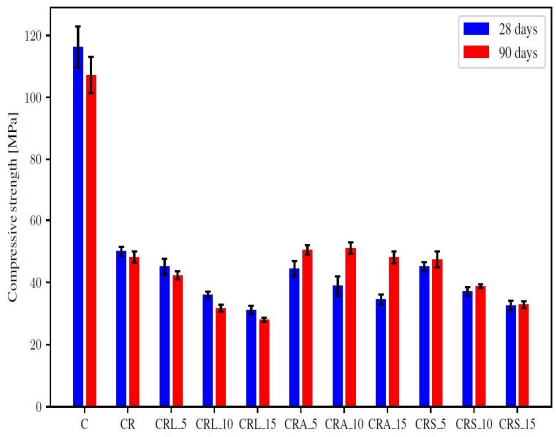

Fig. 1. Compressive strength of pastes after 28 and 90 days of hardening.

The addition of fly ash in all tested concentrations increased the compressive strength after 90 days of hardening, attributed to the formation of C-S-H gel that was detected in the vicinity of RC grains. The 5 w/t % replacement of PC by slag in CRS 5 paste did not cause any strength reduction, but larger replacements resulted in strength deterioration. The compressive strength of pastes blended with fly ash and slag increased from 28th to 90th day of hardening as a consequence of the ongoing formation of hydration products.

Even though the reference paste exhibited higher compressive strength than those containing RC, the tensile strength was enhanced by the presence of RC see Figure 2.

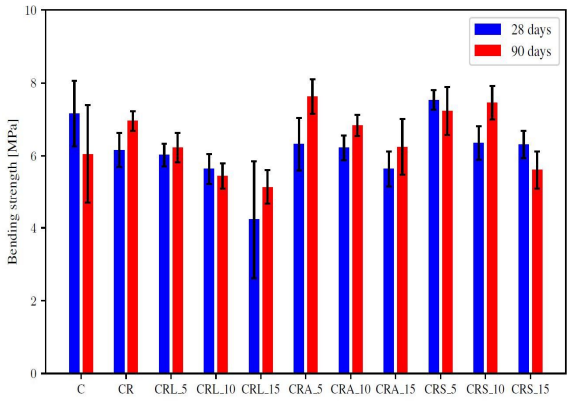

Fig. 2. Tensile strength in bending of pastes after 28 and 90 days of hardening.

IV. CONCLUSION

The presented study suggests that recycled concrete fines can be used for production of concrete without thermal treatment. The 50 w/t % substitution of Portland cement by mostly inert particles of finely ground recycled concrete led to a reduction of compressive strength, as a result of a less compact microstructure. However, the presence of recycled concrete promoted hydration of Portland cement by allowing better access of water to clinker. Recycled concrete acted as microfiller reinforcing a brittle cementitious matrix. Therefore, the tensile strength was higher in pastes containing recycled concrete fines. The addition of fly ash and slag led to an increased formation of C-S-H/C-A-S-H gels in the vicinity of recycled concrete grains.

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