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Property and Environment Evaluation of Cement Replaced with Treated Reclaimed Concrete Slurry Waste

Jun Ren[1], Yunqiu Xue[1], Birunxuan Liu[1], Ji Zhang[1] and Min Liu[2]

[1]School of Architecture and Planning, Yunnan University, Kunming, 650500, PR China,
renjun@ynu.edu.cn (J. Ren), yn1415560930@163.com (Y. Xue), brxliu@outlook.com (B. Liu),
JiZhangxm@163.com (J. Zhang)

[2]Bureau of Public Work of Baoan District. Shenzhen, Shenzhen, 518103,
liuminwhut@hotmail.com (M. Liu)

Abstract. *The development of the cement industry consumes piles of natural resources and generating huge amount of waste and causing serious pollution, which can be partially solved by replacing with other cementitious materials, in particularly, solid waste. Reclaimed concrete slurry waste (RCSW), a corrosive and hazardous the residues from the reclaimed system for retrieving the aggregates from the returned concrete or cleaning the concrete mixer and trucks in the ready-mixed concrete plant, could that cannot be used to manufacture reclaimed concrete. However, the pre-hydration limits the hydraulic property of RCSW, which requires the proper treatment. This paper investigated the effect of three different treatment methods in improving the performance of RCSW and its feasibility of replacing cement under different substitution ratio in manufacturing reclaimed concrete. The treatment included sieving, shearing and ball-milling, and the substitution ratio was set as 15%, 30% and 45%, respectively. In addition to compressive strength and hydration properties, the environment impact of the cement paste replaced with RCSW were investigated as well. The results showed that compared within three methods, the shearing and ball-milling generated the treated RCSW with smaller particle size and high roundness. For the RCSW substituted cement paste, the substitution with 15% of treated RCSW provided the highest strength, meanwhile, while at a higher substitution ratio significantly reduced the compressive strength. The 15% of ball milling treated RCSW produced more products during the hydration process, resulting in a denser structure. According to the economic and environmental calculations, RCSW substitution reduced CO_2 emissions, in which, the ball-milling method showed a lower carbon footprint.*

Keywords: *Reclaimed concrete slurry waste, Treatment approach, Substitution content, Compressive strength, Microstructure, Environmental impact.*

1 Introduction

Under the pressure of sustainability, the cement industry, which emits 5-8% of human-made CO_2 emissions and consumes 12-15% of the total energy (Dinga and Wen 2022), plays a pivotal role in reducing CO_2 emissions (Fennell et al. 2022). Therefore, replacing Portland cement (PC) with other cementing materials embedded with lower CO_2 footprint, is becoming urgent (Bogas et al. 2022). Approaches, such as 1) substitution the PC with supplementary cementitious materials (SCMs), such as fly ash (FA)(Yu et al. 2021), ground granulated blast furnace slag (GGBS) (Gu et al. 2022), or calcined clay (Zhu et al. 2022); or 2) application of low-carbon cementitious materials, i.e., alkali-activated cement (Ma et al. 2016), carbonatable pastes (Luo et al. 2022), or clay-based cement (Huang et al. 2020), have been widely studied and even, attempted to be used in engineering application.

Although construction and demolition waste has attracted the research interests for many civil engineers, reclaimed concrete slurry waste (RCSW), the residues from the reclaimed system for retrieving the aggregates from the returned concrete or cleaning the concrete mixer and trucks in the ready-mixed concrete plant, has been normally ignored. As a corrosive, harmful waste including lots of relatively inert particles, for example, the pre-hydrated cement, RCSW cannot be directly utilised in manufacturing reclaimed concrete, which requires the application of proper treatment.

Therefore, in this study, the effects of three treatment, including sieving, shearing and ball-milling, and of the different substitution ratios with the treated RCSM, on the compressive strength, hydration and microstructure of cementitious materials replaced with treated RCSW, was investigated. Moreover, the environmental impact of RCSW blended cement was estimated and compared.

2 Materials and Methods

2.1 Materials

The reclaimed concrete slurry waste (RCSW) was provided by Xiamen Xinhang Xiangsheng Concrete Co., Ltd, China. The standard cement (GB8076-2008) supplied by Fushun Aosaier Co., Ltd was used. To improve the potential hydraulic property of the RCSM, three approaches, in terms of sieving, shearing, and ball-milling, were applied to treat the raw RCSM. The air-dried RCSM blocks were first crushed by hand to prepare the raw powder. Then the hand-crushed powder was dried in an oven at 105 ºC for 24 h to remove the additional moisture before treatment. For different treatment, the 45 µm sieve was used for sieving; the herb dry crusher (Lingsum, China) was used for shearing and the Retsch OM400 Planetary Ball Mill (Fisher Scientific) was used in ball-milling. The property of the treated RCSM is presented in Table 1.

Table 1. Size distribution and roundness of the raw materials

Cement	Treatment	Particle size (D50)/µm	Roundness
PC	None	14.42	0.612
RCSW	Sieving	37.20	0.544
	Shearing	20.88	0.612
	Ball-milling	19.45	0.634

2.2 Sample Preparation

The weight replacement ratios of all treated RCSW were fixed as 15 %, 30 %, and 45 %. Therefore, a total of 10 mixes were prepared from the treated RCSW and PC, and the mixing proportion of the cementitious materials are listed in Table 2, and the procedure was followed by Chinese standard (GB8077-2012).

Table 2. Mix proportions of different pastes.

Sample	**Cement (%)**	**RCSW (%)**			**W/B**
		Sieving	Shearing	Ball-milling	
PC	100				0.37
PCS-A15	85	15			0.37
PCS-A30	70	30			0.37
PCS-A45	55	45			0.37
PCS-B15	85		15		0.37
PCS-B30	70		30		0.37
PCS-B45	55		45		0.37
PCS-C15	85			15	0.37
PCS-C30	70			30	0.37
PCS-C45	55			45	0.37

Note: PC stands for Portland cement, **PCS** for Portland cement substituted by RCSW, **"PCS-A", "PCS-B", and "PCS-C"** represents for the RCSW treated by **sieving, shearing and ball-milling** approach, respectively**.** Moreover, the number of 15, 30 and 45 represents the weight replacement ratio of RCSW**.**

2.3 Test Methods

The workability of cement paste was conducted by a minislump test according to Chinese standard (GB/T 8077-2012). The cube specimens of cement pastes with a size of 40 × 40 ×40 mm and under standard curing for 1, 7, 28, and 56 d were used for the compressive strength test. The hydrated products were characterized by XRD with CuKα radiation (D8 type XRD machine by Bruker, Germany), the comprehensive thermal analyzer STA 409PC (Nachi Shanghai Co., Ltd), while the morphology was investigated by a Quanta TM 250 FEG field emission scanning electron microscope (SEM).

3 Results and Discussion

3.1 Workability

The initial workability of the cement paste replaced with treated RCSW are presented in Figure 1. As shown in the figure, under all the three treatment and substitution ratios, the replacement of RCSW significantly reduced the minislump of the cement paste. Moreover, comparing with the three treatment, the highest reduction in initial workability was observed in the sample by sieving, which could be possibly due to the fact that the sieving provided the largest particle size of RCSW as shown in Table 1. Moreover, both the shearing and ball-milling treatment offered the cement particles a better roundness (Table 1), which may benefit the dispersing the cement particle. Finally, it should be noted that, lower minislump spread was also observed for all treatments, with the poorest dispersion at 45% at a higher replacement ratio. These results indicate that the RCSW negatively contributed to the workability of the cement paste.

3.2 Compressive Strength

The compressive strengths of cement paste cured at 1, 7, 28, and 56 d are shown in Figure 2. As shown in the figure, compared to the PC, the substitution of RCSW reduced the compressive strength of cement paste at all curing ages, excepting for PCS-C15 where a slightly higher compressive strength than PC was observed at 28 d and 56 d. This reduction was more evident, when the substitution ratio was higher and the curing age was short (i.e., 1 and 7 d). Comparing with the treatment, both shearing and ball milling improved the reduction in compressive strength, which probably due to the improved hydraulic properties of RCSW to generate more hydration products. It should be noted that, although shear and ball-milling treatments improved the compressive strength of RCSW cement paste, those improvement was more efficient at a lower substitution ratio of 15%. Because when it reached 30% or higher, the reduction in compressive strength was only confined within 10% at PCS-C30 at 56 d.

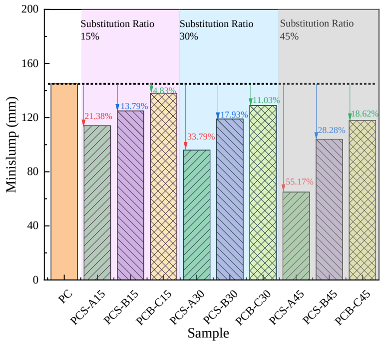
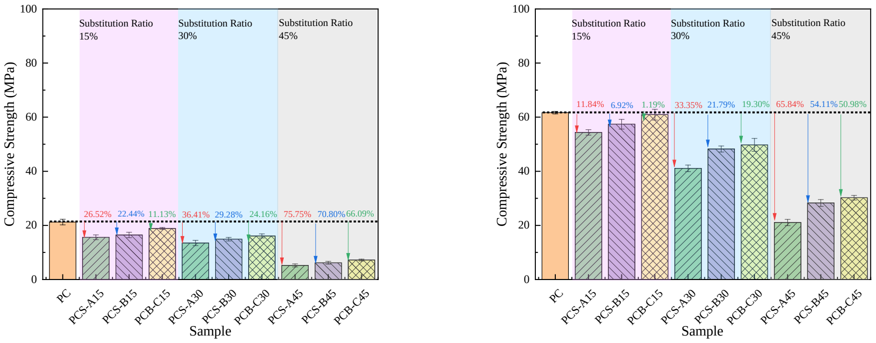
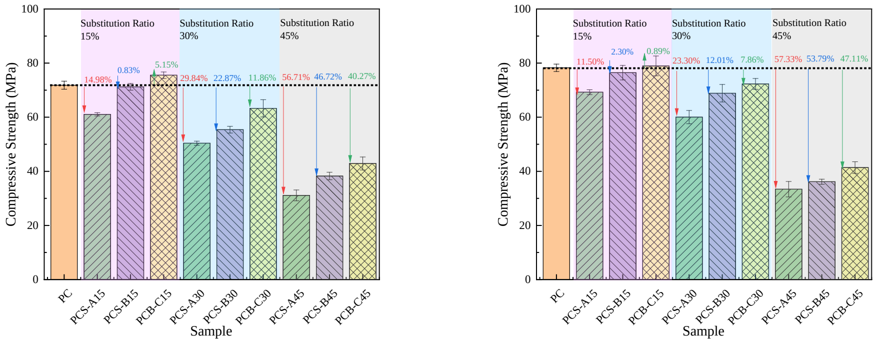


Figure 1. Effect of substitution content of RCSW under different treatment on workability of cement paste



(a) (b)

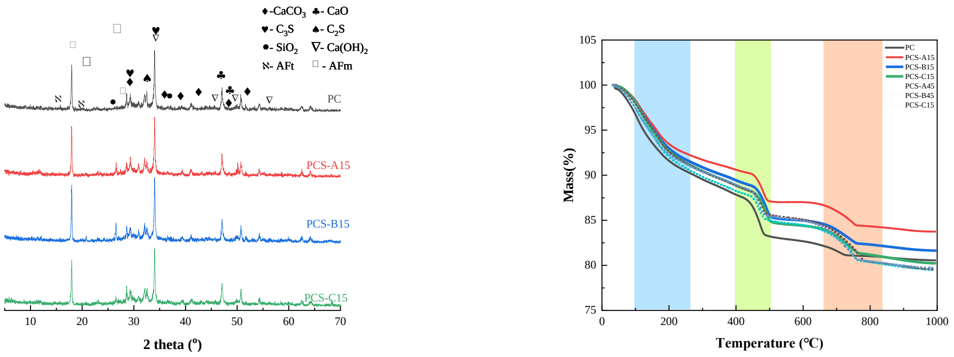


(c) (d)

Figure 2. Effect of substitution content of RCSW under different treatment on compressive strength of cement paste: (a) 1 d, (b) 7 d, (c) 28 d and (d) 56 d

3.3 Hydration Product

The hydration product of the cement paste with 15% of treated RCSW cured at 28 d were characterised by XRS and TGA, which are presented in Figure 3. As shown in Figure 3(a), it can be seen the XRD pattern, compared to PC, after cured at 28 d, the addition of RCSW under all three treatment did not significantly change the pattern of the specimen, indicating that the RCSW had not change the type of hydration product. Moreover, it can be seen from Figure 3(b) that the incorporation of RCSW significantly reduced the amount of hydration products in three different temperature ranges, i.e., the first loss between 60 °Cand 250 °Cdue to the dehydration reactions of several hydrates as C-S-H, and ettringite; the second loss between 375 °C and 600 °C due to the de-hydroxylation of portlandite; and the third loss between 625 °C and 875 °C due to the decarbonation of Portlandite. Therefore, based on the characterisation results, it can be deducted that although the RCSW did not change the type of hydration product, the quantity of the hydration product was changed.

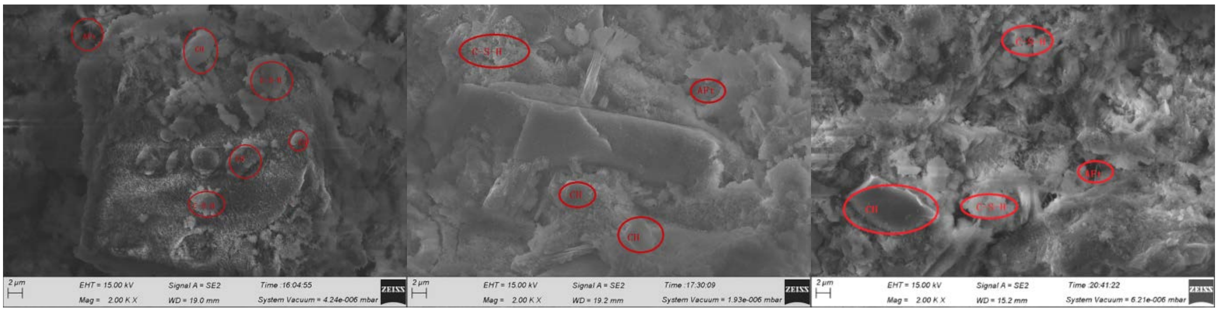


(a) (b)

Figure 3. Characterisation on the hardened cement paste with RCSW cured at 28 d: (a) XRD patten, (b) TGA curve

3.4 Morphology

The SEM images of the cement paste with15% of treated RCSW cured at 28 d are presented in Figure 4. The hydration products of CH, C-S-H and AFt were identified in all samples after it cured at 28 d. Moreover, the ball-milling treated RCSW provided a denser microstructure.



(a) (b) (c)

Figure 4. SEM image for the hardened cement paste with RCSW cured at 28 d: (a) PCS-A15, (b) PCS-B15, (C) PCS-C15

3.5 Evaluation of the Environmental Impact

The total CO_2 emissions from cement production can be calculated as follows.

$$TotalCO_{2\,emission} = CO_{2\,calcination} + CO_{2\,fuel} + CO_{2\,electricity} \tag{1}$$

The raw material carbon emission was calculated by Eq. (2)

$$CO_{2\,calcination} = M_{CaO} \times \frac{44}{56} \times R_{CaCO_3} + M_{MgO} \times \frac{44}{40} \times R_{MgCO_3} \tag{2}$$

Where M_{CaO} and M_{MgO} are the proportions of calcium oxide and magnesium oxide in the clinker; R_{CaCO_3} and R_{MgCO_3} are calcium and magnesium in calcium carbonate and magnesium.
Calculation of CO_2 emissions from the combustion of fossil fuel ($CO_{2\,fuel}$):

$$CO_{2\,fuel} = F_f \times C_f \tag{3}$$

Where F_f represents the consumption of fossil fuels per ton of clinker(kg/t), C_f represents the emission factor of CO_2 produced from the combustion of per unit of fossil fuel combustion(kgCO_2/kg).
Calculation of CO_2 emissions from electricity ($CO_{2\,electricity}$):

$$CO_{2\,electricity} = E_e \times C_e \tag{4}$$

Where, E_e represents electricity consumption per ton of clinker production(kW h/t), and C_e represents electricity emission factors (kgCO_2/kWh).

Environmental assessment of RCSW substituted cement paste under 15% and 30% are summarised in Table 3. The environmental assessment includes carbon emission reduction per ton of cement with different replacement contents and carbon emission reduction per unit strength for 28 d compressive strength. The results showed that both the ball-milling and shearing treatment reduced the carbon emissions per unit strength when the substitution ratio was not over 15%. It should be noted that, the drying process could generate large amount of carbon, which can be reduced in actual production and therefore, could in turn provide a higher environmental benefits.

Table 3. Environmental assessment of RCSW substituted cement paste

Type	PC	PCS-A15	PCS-B15	PCS-C15	PCS-A30	PCS-B30	PCS-C30
Cement(g)	750	637.5	637.5	637.5	525	525	525
Sieving(g)		112.5			225		
Shearing(g)			112.5			225	
Ball-milling(g)				112.5			225
28 d compressive strength(MPa)	71.83	61.07	71.23	75.53	50.4	55.4	63.3
CO_2 emission(g)	622.5	556.05	584.06	578.48	489.59	541.63	534.45
CO_2 emission reduction(g)	0	66.45	38.44	44.02	132.91	80.87	88.05
CO_2 emission per MPa (g/MPa)	8.67	9.11	8.12	7.65	9.71	9.77	8.44
△R(%)	0	5	-6.3	-11.8	11.9	12.7	-2.7

4 Conclusions

In this paper, the effects of different treatment methods, including sieving, shearing, ball-milling, and of substitution ratio, on the property and environmental impact of RCSW replacement cement paste were investigated. Based on the investigation, the conclusions can be drawn as follows:

- The replacement of RCSW reduced the minislump of the cement paste, with lower minislump obtained at higher substitution ratio. Comparing with three treatment, ball-milling treatment provided higher minislump.
- Compared to PC, the replacement of 15% of ball-milling or shearing treated RCSW provided higher compressive strength. However, when increasing the substitution ratio to over 30% of RCSW, for all treatments, the strength was reduced.
- Compared to sieving treatment, though more energy was required from the treatment of ball-milling and shearing, they provided better environmental benefits.
- Although the effects of different treatment methods and substitution contents on the performance of RCSW replacement cement paste have been studied, there is a lack of comprehensive consideration of both material performance and environmental impact, and the optimal treatment method should be further explored.

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