STRENGTH AND MICRO-STRUCTURAL CHARACTERISTICS OF CARBIDE SLAG INSPIRED SLAG-FLY ASH CURED DREDGED SLUDGE

by

Shun-Mei GONG [a], ***Song-Bao FENG*** [a*], ***Xiang-Yi YANG*** [b], ***Hai-Bin WANG*** [c], ***Ru HU*** [a], ***Shi-Quan WANG*** [a], ***Zhi-Yong NIU*** [a], ***Qi-Gui ZHANG*** [d], **and** ***Yu-Cheng WANG*** [a]

[a] National Engineering Research Center of Coal Mine Water Hazard Controlling, School of Resources and Civil Engineering, Suzhou University, Suzhou, China
[b] Shenzhen General Integrated Transportation and Municipal Engineering Design and Research Institute Co., Ltd., Shenzhen, Guangdong, China
[c] China Resources Wufeng Investment Co., Ltd., Shenzhen, Guangdong, China
[d] School of Architecture and Transportation Engineering, Guilin University of Electronic Science and Technology, Guilin, Guangxi, China

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The curing agent used to enhance and harden dredged sludge from urban rivers was formulated from industrial waste materials, including carbide slag, blast furnace slag, fly ash, and cement. Laboratory tests were conducted to examine the compressive strengths of the sludge samples after 7, 14, and 28 days of curing. Additionally, X-ray diffraction and thermogravimetric analysis were employed to examine the formation and micro-structure distribution characteristics of the solidified sludge products. These methods also provided insights into the synergistic curing mechanism of the cement-carbide slag-slag-fly ash composite system. The findings demonstrated that the following ratio of curing agent to cement: carbide slag: slag: fly ash = 10 : 5 : 7 : 3 is the ideal one.

Key words: *dredged sludge, carbide slag, blast furnace slag, fly ash, micro-structure*

Introduction

The treatment of sewage sludge has presented major obstacles to the building of municipal roads and subsea tunnels in recent years. High void ratio, low permeability, high water content, and low strength are typical characteristics of these waste sludges [1, 2]. Due to these properties, direct reuse in engineering projects is often unfeasible, and issues related to the stacking, storing, and transportation of them will result in significant land waste and environmental pollution [3]. As a result, a crucial area of interest for this endeavor is the investigation of environmentally friendly, low carbon, and green materials.

Portland cement can be replaced with alkali-activated gel materials, an innovative class of green construction materials [4], to promote sustainable industrial development. In summary, the current research primarily focuses on altering the curing agent formulation enhance the strength of sludge, with less emphasis on the integration of physical modification and

[*] Corresponding author, e-mail: fengsongbao123@163.com

chemical curing methods. The structural stabilization of these materials is crucial for ensuring construction safety.

Carbide slag, a strongly alkaline waste residue generated during the hydrolysis of calcium carbide, consists primarily of $Ca(OH)_2$ [5]. The mechanical properties, hydration mechanism and micro-structure of these materials were investigated. The aim is to propose an environmentally friendly and energy-saving scheme for recycling sludge as roadbed filler, promoting the resource utilization of both sludge and industrial waste.

Materials and experimental design

Materials

The raw materials used in the test include sludge, carbide slag, slag, fly ash, cement and water. The basic physical properties of the sludge samples, determined using the drying method, loss on ignition method and ring knife method, are presented in tab. 1.

Table 1. Indicators of basic physical properties of sludge

Parameters	Water content [%]	Liquid limit [%]	Plastic limit [%]	Liquidity index	Plasticity index	PH value	Organic content [%]	Density [gcm^{-3}]
Values	70	42.3	25.2	1.92	21.9	7.05	4.85	1.77

The chemical composition of the raw materials, along with the XRD test results, are shown in tab. 2 and fig. 1.

Table 2. Chemical composition of experimental materials

Raw materials	Percentage content of the sample (%)								
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	SO_3	K_2O	Others
Carbide slag	23.35	1.19	73.25	0.24	1.15	0.11	0.43	0.01	0.27
Slag	33.35	12.9	40.11	0.79	8.41	0.31	1.06	0.51	2.56
Fly ash	55.78	29.98	1.75	4.98	0.92	0.07	0.53	1.56	4.43
Cement	22.25	4.12	65.09	3.14	1.56	0.05	2.73	0.71	0.35

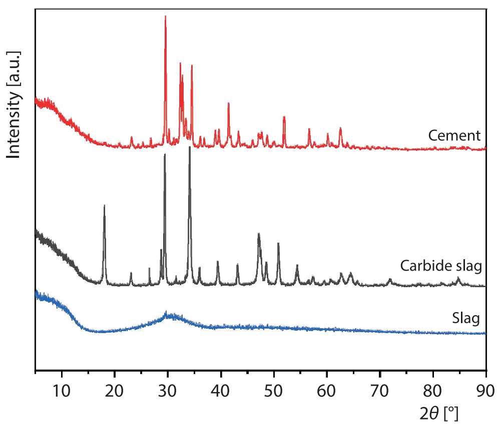

Figure 1. The XRD pattern of raw materials

Experimental design

Based on previous research [6-10], the test ratio design is shown in tab. 3.

Table 3. Ratio design

Group	Cement [%]	Slag/fly Ash	Carbide slag [%]	CW [%]	CD [days]	Sample number
1	10			70	7, 14, 28	C10
2	15					C15
3	20					C20
4	25					C25
5	10	1/9	5	70	7, 14, 28	G1F9
6		2/8				G2F8
7		3/7				G3F7
8		4/6				G4F6
9		5/5				G5F5
10		6/4				G6F4
11		7/3				G7F3
12		8/2				G8F2
13		9/1				G9F1

Results and analysis

Cement curing effect

The strength of samples cured for 28 days significantly improved from 820-1450 kPa, an increase of 1.77 times. These findings demonstrate that cement effectively enhances the strength of high water content sludge.

Curing effect of composite system

As shown in fig. 2, the strength of the samples cured for 28 days increased significantly from 1010-2480 kPa, which is 1.71 times higher than that of cement-cured sludge using the same proportion of curing agent. The results show that the optimum curing agent mix for this test is cement: carbide slag: slag: fly ash = 10 : 5 : 7 : 3.

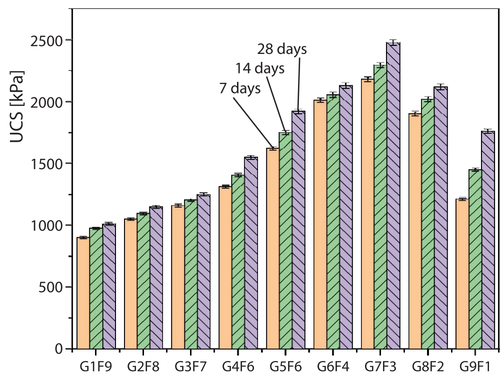

Figure 2. Effect of composite excitation of cement- carbide slag-slag-fly ash on the strength of sludge

The XRD analysis

Figure 3 presents the phase analysis results of the hydration products of G5F5, G6F4, G7F3, G8F2, and G9F1 samples after 28 days of curing.

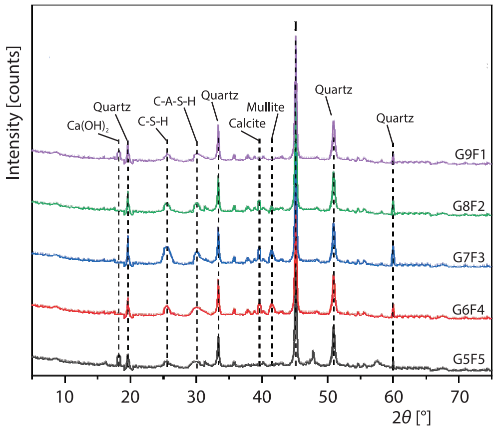

Figure 3. The XRD patterns of G5F5, G6F4, G7F3, G8F2, and G9F1 samples cured for 28 days

The thermogravimetric analysis

Thermogravimetric tests were carried out on G5F5, G6F4, G7F3, G8F2, and G9F1 samples after 28 days of carbonization. Figure 4 shows the TG-DTG curves of the measured samples. The weight loss rates of G5F5, G6F4, G7F3, G8F2, and G9F1 were 16.02%, 26.31%, 35.98%, 21.25%, and 18.82%, respectively. It is further illustrated that the sample G7F3 produces more cement hydration products. When the amount of slag increased from 5% to 7%, the weight loss rate of the sample increased by 19.96%, which may be due to the fact that the G7F3 sample produced more hydration products, which further verified that the G7F3 sample had higher strength. This further confirmed that the optimal curing agent content is cement: carbide slag: slag: fly ash = 10: 5: 7: 3.

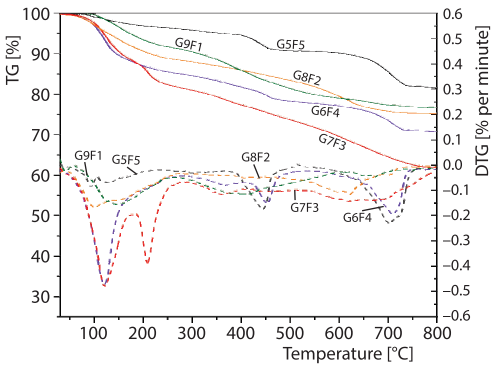

Figure 4. The TG-DTG curves of G5F5, G6F4, G7F3, G8F2 and G9F1 samples carbonized for 28 days

Conclusion

Based on indoor tests involving a cement, carbide slag, slag, fly ash and sludge curing system, the optimal raw material ratio was determined as cement: carbide slag: slag: fly ash = 10 : 5 : 7 : 3. Microscopic analyses utilizing XRD and TG-DTG revealed the presence of gel-like substances such as C-S-H and C-A-S-H, confirming that both hydration and pozzolanic reaction occurred within the carbide slag alkali-ex-cited slag-fly ash system. The new materials studied in this paper can be used as the filling of soft soil foundation materials, which is of great significance in solving the recycling of waste sludge and waste solid waste. In addition lowering air pollution and eventually achieving the goal of treating waste with waste, the novel construction materials under study can also satisfy the legislative requirements of low carbon environmental protection.

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