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EFFECT OF SLAG CONTENT ON SELF-HEALING PROPERTIES OF CEMENT MORTAR

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ABSTRACT

The effects of different content (10,20,30%) of slag on the hydration characteristics of cement and the self-healing properties of cement mortar were studied. The hydration heat, hydration products, mechanical properties and micro-structure of cement mortar were characterized by Digital cement hydration heat meter, X-ray diffraction (XRD), Ultrasonic nondestructive testing instrument and Scanning electron microscope (SEM) etc. The self-healing capacities of cracked cement mortar were characterized by strength restoration ratio and changes of ultrasonic wave. The results show that the accelerating period of cement hydration is prolonged with the increase of slag content; and the early hydration exothermic temperature decreased . The strength restoration ratio of mortar and the change of ultrasonic wave have similar laws, both of which decreased first and then increased with the increase of the content of slag, and the effect is best when the slag content is 30%. The strength restoration ratio increases with increasing water in the curing conditions.

1. INTRODUCTION

Concrete as a quasi-brittle material, it is difficult to avoid cracking in the service environment. The survey shows that about one-fourth of these recently completed projects have quality problems, and 50% of them have concrete cracks[1].In the early stage of micro-crack formation, if the crack can not be repaired in time, it will not only adversely affect the strength and durability of the concrete, but also cause the crack to deteriorate rapidly and even cause the brittle fracture of the concrete[2-4]. Proper use of self-healing properties of concrete can not only make the concrete with quality defects repaired, and even make the scrap concrete project come back to life [5-6], therefore, in recent years, self-healing concrete has become a hot spot.Then, the current slag is often used in high-strength concrete and high performance concrete, with slag to replace part of cement, not only can save cement, reduce pollution and reduce costs, but also Improve the properties of concrete , especially in terms of improving durability [7].When the cement mixed with a certain amount of slag, the hydration of cement and self-healing properties become more complex [8-9], Therefore, it is necessary to further study the cement hydration law, concrete strength and self-healing performance.In this paper, the influence of different contents of slag on the hydration and self-healing properties of cement mortar was studied.And improve the performance of concrete, so as to better serve the actual project.

2. Experimental

2.1 Raw materials

Commercial cement for the test of ordinary portland cement P.O42.5Rwith a specific surface area of 325m^2/kg, a standard consistency of 27.4%, initial setting time of 158min, final setting time of 258min, chemical composition shown in Table 1; The chemical composition of the slag used in Table 1; sand with standard sand and ordinary river sand, fineness modulus of 2.9. Mixing water is tap water.

Tab 1 Chemical composition of commercial cement and slag/wt%

Compositions	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	SO_3
P.O42.5	18.52	3.84	5.58	54.00	4.52	0.74	0.19	3.57
slag	31.8	0.36	15.4	40.6	7.92	0.22	0.31	2.44

2.2Preparation of test blocks and cracks of cement mortar

CementK10, cement K20 and cement K30 were prepared by adding 10%, 20% and 30% slag respectively in commercial cement,A mortar block of 40 mm × 40 mm × 160 mm was prepared with cement K10, cement K20 and cement K30 in a proportion (cement: standard sand: water = 1: 3: 0.5).After standard curing for 28d, 56d and 118d,The compressive strength and ultrasonic wave velocity of the test piece were measured. The 28-day mortar block was pre-cracked and marked, and then the compressive strength and ultrasonic wave velocity were measured after 28 days and 90 days .The prefabricated cracks were prepared by mortar test pieces. After curing for 28 days, the specimens were placed on the pressure table and pressed on the sides. The test pieces were repeatedly pressed three times with 90% the ultimate pressure of the test pieces.

2.2 Testing and characterization

2.3.1 Determination of hydration heat

The PTS-12S digital cement hydration heat tester produced by Wuhan Botai New Technology Co, Ltd is used to analyze the difference of exothermic heat of cement in early stage.

2.3.2Determination of hydration product

The type of hydrated product was measured using an Ultima IV X-ray diffractometer produced by Nippon Polytechnic Co, The instrument used copper target, wavelength λ = 0.154nm, working voltage 40Kv, operating current 40mA, scanning range 5-80 degrees, scanning speed 10 degrees / min, step 0.02 degrees / step.

2.3.3 Strength restoration ratio

Test equipment for the Wuxi Instrument and Equipment Co.,Ltd., produced by TYE-2000B-type pressure testing machine. The formula for calculating the 28-day strength restoration ratioψis given in Equation 1,

$$\psi = [(\overline{f}_{90d} - f_{28d})/(f_{118d} - f_{28d})] \times 100\% \quad (1)$$

(ψ represents the pre-crack test piece strength restoration ratio, f_{28d} represents the test piece28d compressive strength, f_{118d} represents test piece 118d compressive strength, $\overline{f}_{90d}$ represents the pre-crack test piece 90d after repair of compressive strength)

2.3.4 Determination of ultrasonic wave velocity

The ultrasonic wave velocity of mortar block was measured by TICO concrete ultrasonic tester. After the pre-crack maintenance n days, the formula for calculating the changes of ultrasonic wave is shown as formula 2,

$$\varphi_n = [(\bar{v}_n - v_{28})/(v_{n+28} - v_{28})] \times 100\% \quad (2)$$

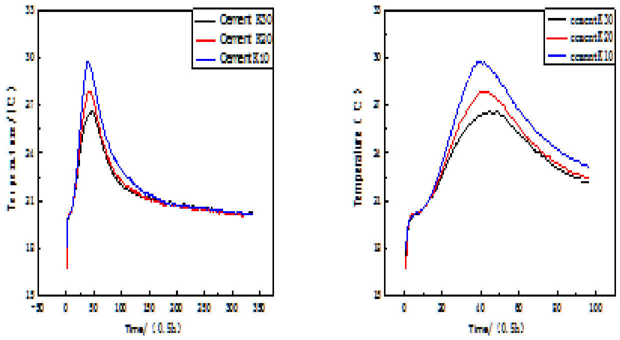
(v_{28} represents the 28-day ultrasonic wave velocity of the test piece without cracks, $\bar{v}_n$ represents the ultrasonic wave velocity of the test piece after n days after the prefabricated cracks are maintained, v_{n+28} represents the ultrasonic wave velocity of the test piece (n + 28) days without cracking)

2.3.5 SEM analysis of hydration product morphology

The morphology of the hydration products at the fracture section was measured with a JSM-7800F field emission SEM manufactured by JEOL Ltd. The fracture surface morphology was observed at a pressure of 5 kV and a magnification of 2000.

3 Experimental results and discussion

3.1 hydration heat



(a) Cement hydration for 7 day

(b) 48 hours of cement hydration

Fig.1 Hydration of cement with different content of slag

From the 7-day hydration curve in Fig. 1 (a), it can be seen that the induction period of the cement hydration process is short and not obvious. The hydration process mainly includes acceleration, deceleration and stabilization. The acceleration period lasted for 20-23h and the deceleration period lasted for 18-25h. The steady-state process curve almost coincided. Within a certain range, the higher the slag content, the lower the peak value of early exothermic hydration temperature, and the difference is large. Cement hydration heat within 3 days after mixing the fastest heat, the amount of different three cement can reach the exothermic peak, and into the stable period.

From Figure 1 (b) cement and water mixing within 48h of hydration heat can be seen in the early hydration process of cement differences in the process of hydration. The induction period of cement hydration is not obvious, and the accelerating period lasts longer. The accelerating period of cement K10, K20 and K30 was 20h, 21h and 22.5h, the peak value of exothermic temperature was 29.71 ℃, 27.88 ℃ and 26.59 ℃respectively. Within a certain range, with the increase of the slag content, the cement hydration accelerating period increased, and the exothermic temperature peak value decreased. The difference of the exothermic temperature of hydration is different when the dosage is different, and it can be seen that the effect of the slag content on the hydration heat of early cement is great.

3.2 hydration products

The results of XRD analysis of cement hydrated products with slag are shown in Fig. 2,

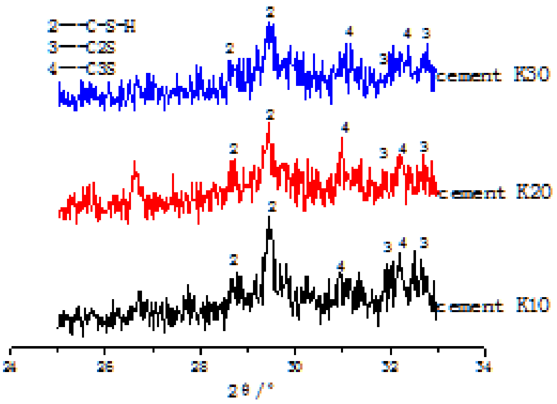


Fig. 2 XRD of the 25-33° section of the 28-day cement paste block

The content of C-S-H gel in the hydration product of cement decreased with the increase of the slag content, and the degree of early hydration decreased. The contents of C_3S and C_2S in the test pieces decrease with the increase of the slagcontent. When the slag is added into the cement, it has a certain physical filling effect, and also affects the crystallization rate and crystallization degree of $Ca(OH)_2$.

3.3 Strength restoration ratio

The change of compressive strength and strength restoration ratioof cement under different curing conditions is shown in Figure 3.

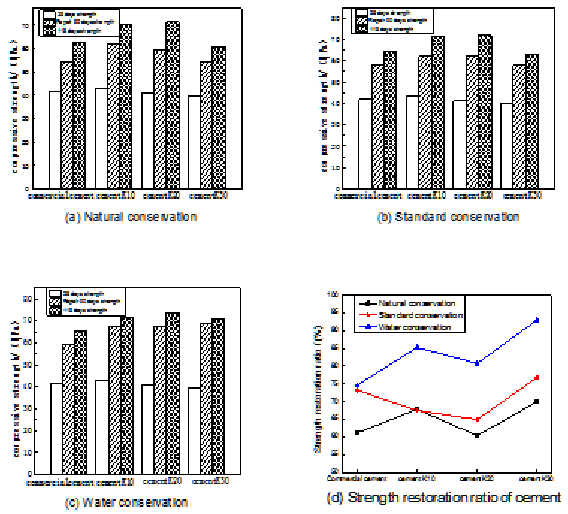


Fig.3 The compressive strength and strength restoration ratio of cement under different curing conditions

It can be seen from Fig.3 that the strength restoration ratio of test pieces made by cement K10, K20 and K30 are 67.9%, 60.4%, 70% respectively under natural curing condition,The recoveries were 67.5%, 65%, 76.8% under standard curing conditions, The recoveries of strength were 85.3%, 80.8% and 93% under water curing conditions. the content of 10% when the test piece 28 days the highest intensity. With the same curing condition, the strength of the cement mortar block after the pre-crack has been restored. With the increase of the slag content, the strength restoration ratio of the test piece decreases first and then increases. When the content of slag is 30%, the repairing effect is the best. The strength restoration ratio increases with the increase of the moisture supply in the curing condition. Adequate water supply, more conducive to the secondary hydration reaction, the formation of hydration products filled cracks, so that a more complete structure.

3.4 Changes of ultrasonic wave

The changes of ultrasonic wave of different cement mortar test pieces under different curing conditions show in Figure 4.

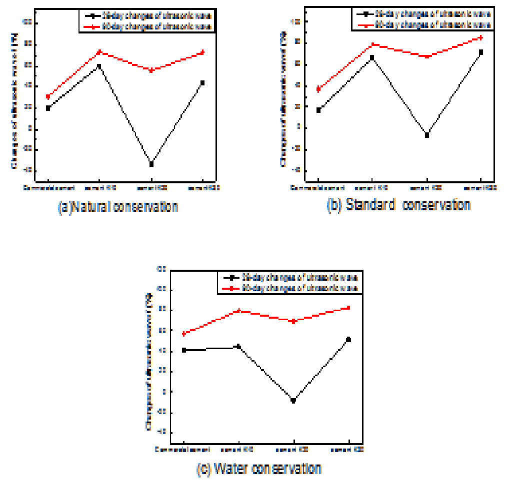


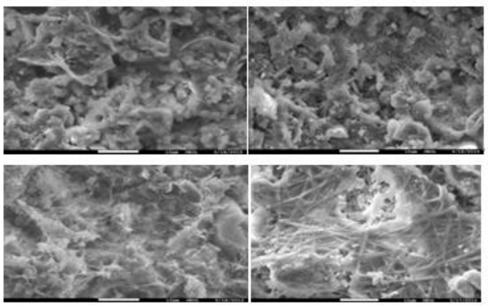
Fig.4 Changes of ultrasonic waveof cement mortar block with different amount of slag

From Fig.4, it can be seen that the changes of ultrasonic wave of the cement block K10, K20 and K30 under the natural curing conditions are 60%, -33.3%, 44.5 and 73.33%, 55.56% and 72.41% respectively at 28d and 90d, The changes of ultrasonic wave at the 28th and 90th days were 66.67, -6.45, 71.43 and 79.17%, 67.5% and 85.71% respectively In standard curing conditions.The changes of ultrasonic wave at the 28th and 90th day were 44.6%, - 7.69%, 51.72% and 80%, 69.57% and 86.33% respectively under the condition of water conservation.

The results are as follows: 1) Under the same curing conditions, the changes of ultrasonic wave decreases first and then increases with the increase of the slag content, and the changes of ultrasonic wave is the best when the content of the slag is 30%. The changes of ultrasonic wave is much lower than that of commercial cement and K10 block and K30 test piece at 28 days, and after 90 days is more than that of commercial cement. , Indicating that the slag participate in the latter part of the reaction, to improve the structure of compactness. 2) Comparing the changes of ultrasonic wave of different conservation conditions, it can be seen that before 28 days, the recovery rate of the test pieces with different dosage under the standard curing condition is the best. At 90 days, with the increase of the water supply in the curing environment , the changes of ultrasonic wave is increased and the changes of ultrasonic wave is the best under water conservation. Water sufficient environment, more conducive to the secondary hydration reaction, the formation of hydration products fill the pores, so that the structure is more compact.

3.5 Microstructure

SEM analysis can be more intuitive to see the fracture section of the healing situation. The results of SEMof the cement mortar with different content of slag in 90 days were shown in Fig. 5 (2000 ×).



(a)SEM images of test piece made of commercial cement
(b) SEM image of test piece made of cement K10
(c) SEM image of test piece made of cement K20
(d) SEM image of test piece made of cement K30

Fig.5 SEM images of cracks in 90 days of mortar test pieces with different amount of slag in water

From the SEM images, it can be seen that under the condition of water curing, the cross section of the fracture is different when the content of the slag is not same. When the content of the slag is 10%, the fracture section produces a lot of fibrous gel; , A large amount of gel and fibrous gel were formed in the fracture section. When the content of the slag was increased to 30%, a lot of fibrous gel and flaky gel were formed in the fracture section, and the structure was compact. Within a certain range, The higher the content, the better the gel formation.

3. Conclusion

The results of the study on the hydration characteristics of cement and the self-healing property of cement mortar are as follows:

(1) The induction period of cement with slag is very short during the hydration process.The accelerating time of cement with 10%, 20% and 30% slag was 20 h, 21 h and 22.5 h, respectively. The exothermic peak temperature was 29.71 ℃, 27.88 ℃, 26.59 ℃.Within a certain range, the accelerating period of cement hydration is prolonged with the increase of slag content, early hydration exothermic peak temperature is lower.

(2) The content of C-S-H gel decreased with the increase of slag content, and the degree of early hydration decreased. The contents of C_3S and C_2S in the test pieces decrease with the increase of the slag content.

(3) The strength of the test piece was the highest at 28 days.Under the same curing condition, with the increase of the slag content, the strength restoration ratioof the test piece decreases first and then increases, and the repairing effect is the best when the content of the slag is 30%. The strength restoration ratio increases with increasing moisture in the curing conditions.

(4) Under the same curing conditions, the changes of ultrasonic wave decreases first and then increases with the increase of the slag content, and the changes of ultrasonic wave is the best when the content of the slag is 30%.

(5) Under the same curing condition, the cross section of the fracture is different when the content of the slag is different, and the higher the content of the slag is, the better the gel formation is.

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