INFLUENCE OF POLYMER ON MECHANICAL STRENGTH AND STRUCTURE OF MORTAR

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Abstract. The paper mainly studies the effects of polymer on the mechanical strength and microstructure of mortar, and analyzes the influence of 1%, 5%, 10% polymer content and curing methods on the strength growth and microstructure. The results show that the addition of polymer prolongs the initial and final setting time. When the polymer content is less than 10%, the compressive strength gradually decreases with the increasing polymer content, and the flexural strength of mortar after polymer addition decreases slightly. The mechanical strengths are the best under 7 days of water curing and 21 days of air curing. SEM analysis shows that high content of polymer will delay and inhibit the hydration of cement, and introduce a certain amount of bubbles, thus affecting the strength.

Keywords: polymer; mortar; microstructure; mechanical strength.

Introduction

Cement mortar is a kind of building material widely used in the world at present and is an important part of plastering works and masonry works. However, it has the disadvantages of low flexural strength, high brittleness and large shrinkage [1]. The researchers found that adding polymer additives into the cement matrix was an effective method to improve its performance. Research shows that the polymer can optimize the internal structure of cement mortar and improve its working performance [2].

Generally, the setting time of cement mortar is prolonged after polymer is added, the influence of the amount of polymer is more significant. Generally, the use of polymer will weaken the compressive strength of cement mortar and improve its flexural strength. The mix proportions of polymer mortar (polymer cement ratio, water cement ratio, lime sand ratio, etc.) are the main factors affecting the strength of mortar [3-5].

The polymer can be organic silicon, neoprene latex, acrylate lotion, etc., so that the mortar has good impermeability, crack resistance and waterproof performance. For example, after the silicone waterproof agent is mixed into the cement mortar, under the action of carbon dioxide in water and air, it can generate methyl siloxane, which can be further condensed to form a reticular methyl silicone resin waterproof membrane [6]. The penetration into the base course can block the pores inside the cement mortar to increase the compactness, improve the impermeability, and thus play a waterproof role. For another example, after latex resin polymer is mixed into the mortar, because it can be evenly distributed on the surface of the fine aggregate inside the mortar and coagulate at a certain temperature, the cement, aggregate and polymer form a complete network film with each other to seal the path of the mortar gap, thus preventing the immersion of the medium, greatly reducing the water absorption of the mortar, and correspondingly improving the impermeability [7].

The curing method has a certain influence on the flexural and compressive strength of the polymer modified mortar. Shi et al. [8] studied the effects of curing humidity on the late compressive strength of SBR modified mortar and SAE modified mortar, and found that the effect of humidity on the late compressive strength of these two kinds of emulsion modified mortar was not obvious. Çolak [9] also found that the mechanical strength was adversely affected by the curing conditions of adding superplasticizer and VAE into cement mortar and then putting them into lime water for curing. Ramli et al. [10] found that the permeability of three different polymer modified mortars changed with the change of curing humidity, and there was a linear relation between the compressive strength and permeability.

Materials and methods

PO 42.5 Portland cement is used as cement, the fine aggregate is quartz sand with particle size of 0.15-0.2mm, and polymer is redispersible polymer latex powder. The physical and chemical properties of cement are listed in Table 1 and 2, and the physical properties of polymer are shown in Table 3.

Table 1

Physical properties of cement

Fineness (80 µm, %)	Water content for standard consistency, %	Time of setting, h		Compressive strength, MPa		Flexural strength, MPa	
		Initial	Final	7d	28d	7d	28d
2.86	24.85	3.24	4.65	25.52	43.07	6.13	9.24

Table 2

Chemical composition of raw materials (wt.%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	SO_3	Loss
21.27	6.72	2.21	63.17	1.32	0.16	1.88	3.27

Table 3

Physical properties of polymer

Solid content, %	pH	Viscosity at 25 º, mPa s	Density, $g \cdot cm^{-3}$	Mean grain size, nm	Glass transition temperature, ºC
55	8	50-100	1.03	155	7

The mixture compositions of the test samples are summarized in Table 4. The strength and setting time of cement mortars were measured according to the Chinese standard GB17671-1999. Cement mortars with the size of 40 × 40 × 160 mm were prepared at the water to cement ratio of 0.5 and aggregate to cement ratio of 1.5, then the samples were placed for standard curing with relative humidity of 98% and temperature of 20 ± 2 ºC. Compressive and flexural strength were measured at 3, 7, 28 and 60d with average results from at least three samples. The microstructure of the cement mortars was investigated with a scanning electron microscope (SEM) on freshly broken surfaces.

Table 4

Mixture compositions (weight ratio)

Sample	Water to cement ratio	Aggregate to cement ratio	Polymer dosage (%, percentage of cement quality)
A1	0.5	1:1.5	0
A2	0.5	1:1.5	1
A3	0.5	1:1.5	5
A4	0.5	1:1.5	10

Results and discussion

Effect of polymer on the setting time of cement

It can be seen from Fig. 1 that with the increase of polymer content, the final setting time increases with the increasing polymer content, and the initial setting time changes little.

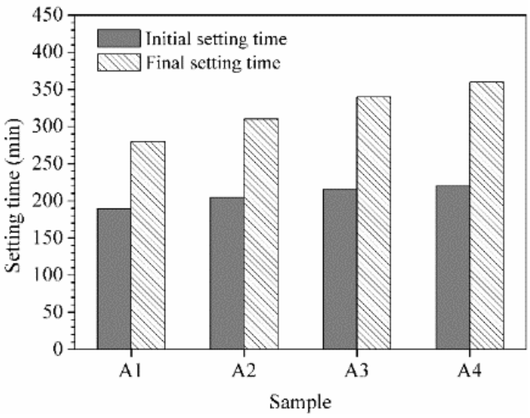

Fig. 1. **Setting time of mortars with different polymer contents**

The initial setting time of sample A4 increases by 15.7% compared with sample A1, while the final setting time increases by 28.6%. It can be seen that polymer has a certain retarding effect. Due to the water resistance of the polymer, the contact between water and cement is hindered to some extent [11]. At the same time, part of the cement is wrapped by the polymer particles, which slows the cement hydration and setting.

Effect of polymer on the mechanical strength of mortar

It can be seen from Fig. 2 that, compared with the reference sample A1, the flexural strength at each age before 28 days shows a significant downward trend, and the downward trend is more obvious with the increase of the amount of polymer. However, after 28 days of age, the flexural strength of mortar with 5% polymer content (No. A3) is higher than that of mortar with 1% polymer content (No. A2). The strength of mortar with 10% polymer content has a large increase after 28 days, and the difference of the flexural strength under various polymer content is reduced at 60 days.

It can be seen from Fig. 3 that, compared with the reference sample A1, the compressive strength at each age decreases significantly after adding polymer, and with the increasing polymer content, the compressive strength decreases more. At 60d age, compared with the reference sample without polymer, the compressive strength of mortar decreases by 8.1 MPa (15.6%) for 5% polymer content. In addition, the compressive strength decreases by 16.8 MPa (32.4%) for 10% polymer content.

This shows that when the polymer content in cement mortar is 1% or more, the increase of the strength is restrained to a certain extent. With the increasing polymer content from 1% to 10%, the inhibition effect is more and more obvious. Compared with the flexural strength, the increase of the compressive strength is more significantly affected by polymer.

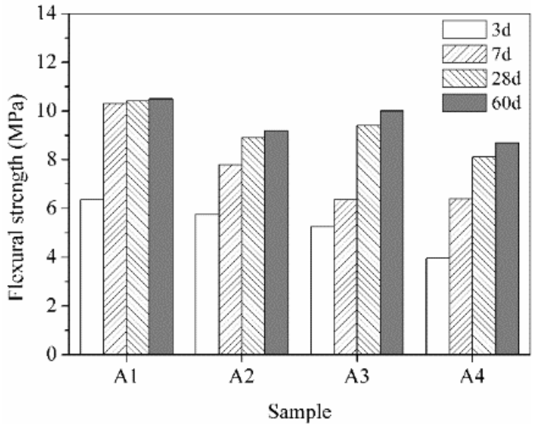

Fig. 2. **Flexural strength growth curve of polymer mortar**

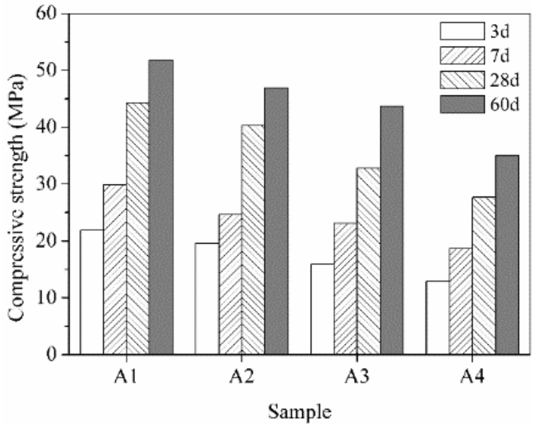

Fig. 3. **Compressive strength growth curve of polymer mortar**

Effect of curing methods on mechanical properties of polymer mortar

The three curing systems are summarized below.

1. dry curing: curing in 20 ± 3 ºC curing room, with relative humidity greater than (50 ± 10)%;

2. water curing: 20 ± 2 ºC water immersion curing;
3. mixed curing: curing in water at 20 ± 2 ºC to the age of 7 days, then curing in at 20 ± 3 ºC with relative humidity of (50 ± 10)% to 28 days.

The 28d flexural and compressive strength of mortar under different curing systems are illustrated in Fig. 4 and Fig. 5.

It is shown in Fig. 4 that the flexural strength of mortars under mixed curing is the highest, while the flexural strength of mortar under dry curing is the lowest. In addition, under mixed curing, the flexural strengths of A2 and A3 both exceed the flexural strength of the reference sample A1, while the flexural strength of A3 sample is the highest, and the 28d flexural strength is 11 MPa, this value is increased by 69.2% compared to A1 sample, this may be associated with the hydration process [12]. Fig. 5 shows that the compressive strength of mortars with different numbers is the lowest under dry curing. The difference between wet curing and mixed curing is not obvious for A1 sample, while the compressive strengths of mortars with polymer addition under mixed curing are 33.1%-56.3% higher than those under wet curing. It is also demonstrated in Fig. 5 that the compressive strength of mortars with different numbers decreases gradually when the polymer content increases from 1% to 10% under different curing systems. Therefore, under the wet curing condition, the flexural strength is only slightly higher than that of dry curing, but the compressive strength is high. Under the condition of mixed curing, the flexural strength of mortar is the highest, while the compressive strength is equivalent to that under wet curing.

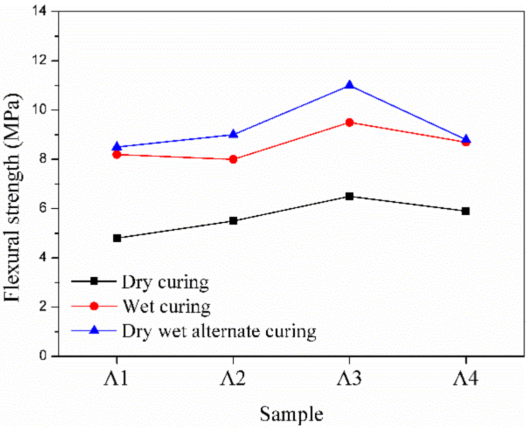

Fig. 4. **Flexural strength of mortar under different curing systems**

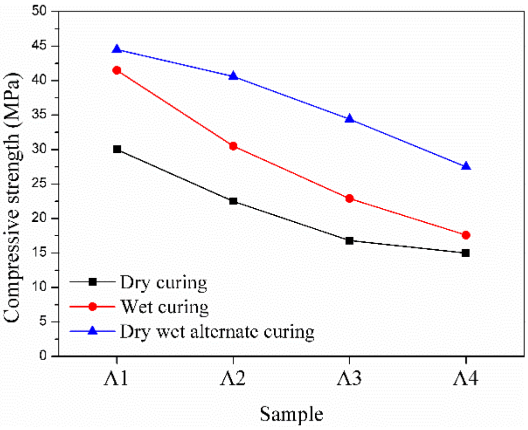

Fig. 5. **Compressive strength of mortar under different curing systems**

Effect of polymer on the microstructure of mortar

It is displayed in Fig. 6 that there are a large number of needles like calcium vanadate crystals and flocculent C-S-H gel in the SEM diagram of the benchmark sample A1 mortar. The combination between the hydration products is loose. After the polymer is added, the microcracks in A2 sample can be significantly reduced, and the compactness of the microstructure can be improved. The polymer film is filled or connected between the gaps or holes of cement hydration products.

After 5% polymer is added, the micro cracks and defects in A2 sample tend to increase. This may be because, on the one hand, the polymer introduces a certain amount of bubbles to increase the porosity, in addition, it may be because the polymer inhibits the cement hydration, causing incomplete hydration of some cement [13; 14]. The polymer added into the mortar will increase the content of mortar macropores, especially when the polymer content is high (more than 5%), which is obvious.

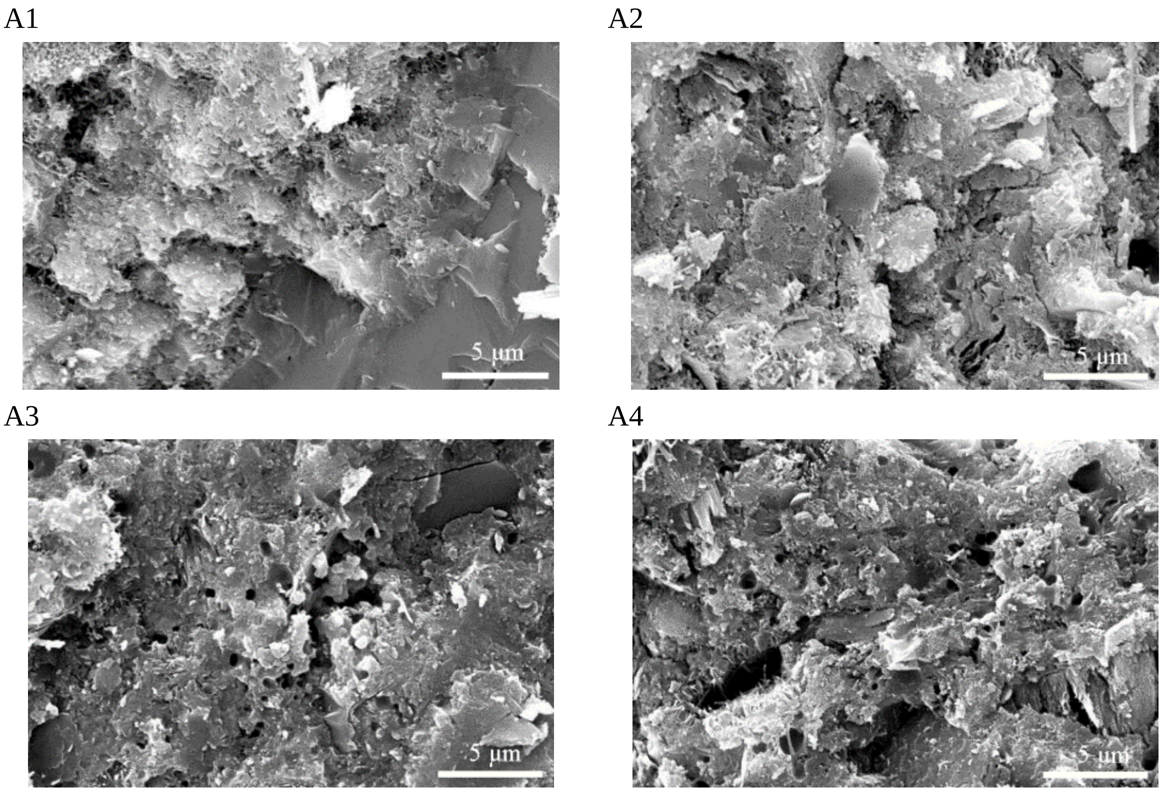

Fig. 6. **SEM of polymer mortar section**

Conclusions

The addition of polymer will delay the hardening and setting of cement, and the amount of polymer will increase from 1% to 10%, and the final setting time will be gradually extended. When the amount of polymer is increased from 1% to 10%, the compressive strength at each age decreases significantly after adding polymer, but there was no significant decrease in the flexural strength. The curing method has a significant impact on the mechanical strength of mortar. The compressive strength of mortars is the lowest under dry curing, and mixed curing is the most advantageous for compressive strength. The flexural strength of mortars with polymer addition exceeds the reference sample. Similarly, mixed curling is more conducive to the flexural strength than wet curling. Microstructural analysis shows that appropriate polymer addition can help improve the compactness of mortar.

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Author contributions

Conceptualization and writing, Chaocheng Yu; funding acquisition, Zhiguang Zhao; writing – review and editing, Xiaoling Qu; data curation, Sanyin Zhao. All authors have read and agreed to the published version of the manuscript.

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