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RESEARCH

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Experimental Study on Modification of Grouting Material for Joints of Prefabricated Buildings

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Abstract

In order to apply grouting material to the joints of fabricated buildings and make it meet the performance demands of low shrinkage, strong bond, and high toughness of joint materials for prefabricated buildings, the expansion agent (EA), neoprene latex (NL), and rubber particles (RP) were used to modify the grouting material, and the effects of different dosages of the three components on the working performance, mechanical properties, and expansion or shrinkage properties of the grouting material were investigated. The results show that the EA decreases the flexural strength-to-compressive strength ratio (FCR) of the grouting material and enhances the vertical expansion rate and bond strength. The dosage of EA and the curing conditions have a significant effect on the expansion rate of the hardened grouting material. The grouting material can still maintain its 0.0022% free expansion rate with a 7% EA dosage at 120 d. The NL significantly inhibits the vertical expansion of the fresh mortar but inhibits the drying shrinkage of the grouting material after hardening, improves the FCR and bond strength; the 7 d bond strength under a 5% NL dosage can reach 4.27 MPa. The RP inhibits the vertical expansion of the fresh mortar and the drying shrinkage after mortar hardening; with the increase of its dosage, the bond strength of the grouting material increases first and then decreases, the 28 d FCS of the grouting material peaked at 0.173 at 10% dosage.

Keywords Prefabricated building, Grouting material modification, Vertical expansion rate, Flexural strength-to-compressive strength ratio, Bond strength, Free expansion rate, Optimal dosage

1 Introduction

Prefabricated concrete constructions contain a lot of moist joints. With the advancement of research on seismic performance and connection forms of joints, there are generally a large number of connection or structural steel bars at the joints at present, and the area available for construction operations is limited, making vibration difficult. Traditional joint materials, however, lack fluidity and cannot ensure that filling joints will be compact. As time goes on, the joint becomes more prone to issues like hollow drums, cracking, and water seepage, which damage the structure's durability. Grouting material can be a good solution to this problem. Grouting material generally uses ordinary Portland cement as a cementitious material and is mixed with a high-efficiency water-reducing agent to improve the flow performance. As it has good fluidity, high early strength, good compactness, and other excellent engineering properties, it has been widely used in the fields of concrete road and bridge surface, bridge reinforcement, channel seepage prevention, crack repair, sleeve connection for prefabricated construction, etc. (Chen, 2020; Gao, 2020; He & Feng, 2023; Hu, 2021; Liu, 2022; Sun, 2007; Xie, 2021; Yin, 2014). However, cement-based grouting material still has shortcomings such as large shrinkage and easy cracking (Chang et al.,

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2022; Lu et al., 2016; Zhou et al., 2020), and the performance requirements of joint materials in actual projects are diverse, such as low shrinkage, strong bond, high toughness, etc. Therefore, the corresponding modification research on grouting material can lay a good foundation for its application in the joints of prefabricated concrete structures.

According to the Technical Specification for Application of Cementitious Grouting Materials (GB/T 50448, 2015), the volume deformation requirements of mortar plasticity (0–3 h) and hardening stage (3–24 h) have been proposed in order to ensure the compactness of grouting material filling, but the volume change of grouting material in the later hardening stage has not been taken into account. If the grouting material experiences significant shrinkage in the later hardening period, the joint is vulnerable to shrinkage cracks, and the major method to reduce the dry shrinkage of the grouting material after hardening is to add the expansion agent (EA). Currently, EA can be divided into three categories according to their effective components: sulfoaluminate, calcium oxide, and magnesium oxide. Zhang and Liu et al. found that the early expansion efficiency of sulfoaluminate and calcium oxide EA was more obvious, while the late expansion efficiency of magnesium oxide EA was better (Liu et al., 2022; Zhang, 2012a, 2012b). Ye investigated the effects of magnesium oxide EA and calcium sulfoaluminate-calcium oxide EA on the volume stability of high-strength grouting material under various curing conditions. The findings revealed that magnesium oxide EA was less dependent on water than calcium sulfoaluminate-calcium oxide EA (Ye et al., 2018). Liu et al. studied the influence of the free expansion rate of grouting material under curing conditions and determined the optimal dosage of EA in order to avoid excessive expansion of grouting material resulting in beam cracks (Liu et al., 2008a, 2008b).

Additionally, the bond strength of mortar is crucial for resolving issues with cracking and leaking at the joints of prefabricated components (Jiang, 2020), and the improvement of bond strength is mainly focused on polymer modification technology. Cationic neoprene latex waterproofing mortar was used in the building waterproofing project of the 1990 Asian Games in Beijing, and good results were achieved (Chen, 1995). Wu tested the bond strength of polymer-modified mortar using the "8" matrix method, and the results revealed that the bond strength and the crack resistance were significantly higher than those of regular mortar (Wu, 2006). Wang et al. modified the mortar with SRB latex, and found that although the bond strength of the mortar were significantly improved, the chemical stability and temperature adaptability of SRB latex in the cement-based system still needed to be further explored (Wang et al., 2007). Xie studied the improvement effect of various polymers on the performance of mortar, and proposed the preparation process and curing system of bonded mortar suitable for polymer modification. However, it is still necessary to further study whether the modified mortar can meet the requirements of low shrinkage and strong bonding at the same time (Xie, 2001).

Adding ductile components to mortar is one way to improve its toughness. Some scholars have found that the addition of RP to cement-based materials can improve the shrinkage, toughness, and impact resistance of the materials (Liu et al., 2011; Zhang, 2012a, 2012b). However, the interface contact between RP and cement is fragile, and in the current research, RP is usually added together with emulsified asphalt (EP) for modification (Oikonomou et al., 2009, Huang et al., 2001). Li et al. believe that EP can not only bond with cement hydration products, but also bond well with RP, so they designed the EP–RP cement mortar system. The research results show that EP can aggregate into a film at the interface of cement and RP, and the tensile strength and breaking elongation of mortar can be improved (Li et al., 2020). Bing et al. added EP to rubber concrete and found that after film formation, EP could cover the surface of RP, effectively transfer internal stress, and delay crack expansion during brittle failure of concrete. EP can effectively improve the bond between RP and the cement interface (Bing et al., 2014). Lin et al. studied the effects of different RP dosages and corresponding EP dosages on the mechanical properties of RP–EP concrete, and obtained the optimal EP coating layer number to determine the EP dosage (Lin et al., 2023).

In general, although there are some studies on the expansion or shrinkage properties of modified grouting materials as well as the bonding properties and toughness of mortar or concrete, the modification of grouting materials for low shrinkage, strong bond, and high toughness at the same time has received less attention in research. And many studies are often focused on the effect of modified materials on the performance of grouting materials after hardening, while ignoring the effect of modified materials on the working performance. In this study, in order to meet the requirements of low shrinkage, strong bond, and high toughness of joint materials for prefabricated buildings, EA, NL, and RP were used to modify the traditional grouting materials. The effects of these three different components on the working properties (fluidity, setting time, and vertical expansion rate), mechanical properties (flexural strength, compressive strength, FCR, and bond strength), and expansion or shrinkage properties (free expansion rate, restricted expansion rate, etc.) of the grouting material were studied, and the optimal

Table 1 Chemical compositions of cementitious materials

Material	Mass fraction (%)						
	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	SiO_2	Loss
PC	8.87	4.27	54.11	3.08	2.21	24.35	1.94
LP	2.90	1.20	45.19	1.78	–	17.23	37.85
EA	2.54	0.96	53.42	2.00	23.57	5.46	12.12

Table 2 Physical and mechanical properties of PC

Specific surface area (m^2/kg)	Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)	
	Initial setting	Final setting	3d	28d	3d	28d
350	198	254	6.3	9.5	34.5	55.8

Table 3 Physical and mechanical properties of EA

Specific surface area (m^2/kg)	Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)		Restricted expansion rate (%)	
	Initial setting	Final setting	7d	28d	7d	28d	In water 7d	In air 21d
290	145	220	6.5	8.6	36.1	51.8	0.045	0.005

Table 4 Quartz sand particle gradation

Sieve hole size (mm)		1.18	0.6	0.3	0.15	Bulk density (g cm^{-3})	Fineness modulus
Sieve residuals/%	S1	59.38	40.02	0.60	–	1.342	3.59
	S2	–	21.28	77.11	1.61	1.353	2.20

dosage of the three components was obtained, providing a technical reference for the application of modified grouting material in prefabricated building joints.

2 Experiment

2.1 Raw Materials

1) Cementitious materials

The cementitious material consists of P·II52.5 Portland cement (PC), limestone powder (LP), and EA, of which the EA belongs to the calcium oxide-calcium sulphoaluminate EA. The chemical composition of each component is shown in Table 1, and the physical and mechanical properties of PC and EA are shown in Tables 2 and 3.

Table 5 Performance indexes of RP

Average particle size (μm)	Apparent density (g cm^{-3})	Specific surface area (m^2/g)	Fineness modulus	Bulk density (g/L)
713.22	0.93	0.0184	2.34	398.1

2) Aggregate

The aggregates used in this test include quartz sand and RP. The quartz sand contains two different particle sizes, ranging from 16 to 30 mesh (S1) and 30 to 50 mesh (S2), respectively, and their respective particle gradations are shown in Table 4. The RP is produced by a company from waste tires, and its mesh number is 20. Other technical details of RP are listed in Table 5.

Table 6 Performance indexes of PCE

Bulk density (g/L)	Fineness	Residual moisture	Water reduction rate
500–700	≥ 90%	≤ 3%	≥ 25%

Table 7 Performance indexes of F

Gas generation capacity (ML g^{-1})	Average particle size (μm)	Ash content (%)
500–700	10–12	≤ 0.05

Table 8 Performance indexes of D

Bulk density (g/L)	Moisture content (%)	PH
300 ± 100	≤ 5	7 ± 1.0

Table 9 Performance indexes of NL

PH	Solid content (%)	Viscosity (MPa S)	Breaking elongation (%)	Density (g cm^{-3})
7.0	60	10–55	470	≥ 1.08

Table 10 Performance indexes of EP

Type	Average particle size (μm)	Density (g cm^{-3})	Solid content (%)
Slow cracking	2.63	0.96	58

3) Admixture

The admixtures used in the test include polycarboxylic acid high-efficiency water-reducing agent (PCE), foamer (F), defoamer (D), NL, and EP, in which NL is an anionic neoprene latex and EP is an anionic emulsified asphalt. They are all commercially available products, and their performance indexes are described in Tables 6, 7, 8, 9, 10.

2.2 Experiment Plan

In order to clarify the effect of each component on the properties of the grouting material, this test was designed with a basic group and nine modified groups. In the modified group, EA is mixed internally at 5%, 7%, and 9% of the mass of the cementitious material; NL is mixed externally at 2.5%, 5%, and 7.5% of the PC mass; and RP is mixed internally by replacing 5%, 7%, 10%, and 15% of the S1 with equal volume. The dosage of EP was calculated according to the asphalt particle accumulation film model proposed by Lin et al. (2023), and the dosage used in this test was equal to the mass of six layers of asphalt overlay. The total dosage of F and D is 0.188% of PC mass, and the dosage of PCE and water is adjusted according to the initial fluidity so that the fluidity is controlled at 350 ± 15 mm. If NL is added, the water content of NL should be deducted from the water content of the group. The design of the mix proposition is shown in Table 11.

2.3 Experiment Method

2.3.1 Mixing Method

The grouting material is mixed as shown in Fig. 1. The solid materials, such as cementitious materials, aggregates, and admixtures, are first put into the mixer and mixed for 30 s to ensure that the materials are well mixed.

Table 11 Mix proportion of modified grouting material (g/L)

Group	PC	LP	EA	W	S1	S2	PCE	F + D	NL	RP	EP
BG	660	360	76.8	264	400	500	2.3	1.24	/	/	/
E2C0R5	660	360	76.8	264	380	500	2.3	1.24	/	5.94	0.90
E2C2R5	660	360	76.8	257.4	380	500	2.8	1.24	16.5	5.94	0.90
E2C5R5	660	360	76.8	250.8	380	500	4.0	1.24	33	5.94	0.90
E2C7R5	660	360	76.8	244.2	380	500	4.8	1.24	49.5	5.94	0.90
E1C2R5	660	360	53.4	257.4	380	500	2.8	1.24	16.5	5.94	0.90
E3C2R5	660	360	100.9	257.4	380	500	2.8	1.24	16.5	5.94	0.90
E2C2R7	660	360	76.8	257.4	372	500	2.8	1.24	16.5	8.34	1.26
E2C2R10	660	360	76.8	257.4	360	500	2.8	1.24	16.5	11.91	1.80
E2C2R15	660	360	76.8	257.4	340	500	2.8	1.24	16.5	17.87	2.70

BG indicates the basic group; E1–E3 represents 5%, 7%, and 9% dosage of EA, respectively; C0–C7 represents 0%, 2.5%, 5%, and 7.5% dosage of NL, respectively; R5–R15 represents 5%, 7%, 10%, and 15% dosage of RP, respectively

Fig. 1 Mortar mixing

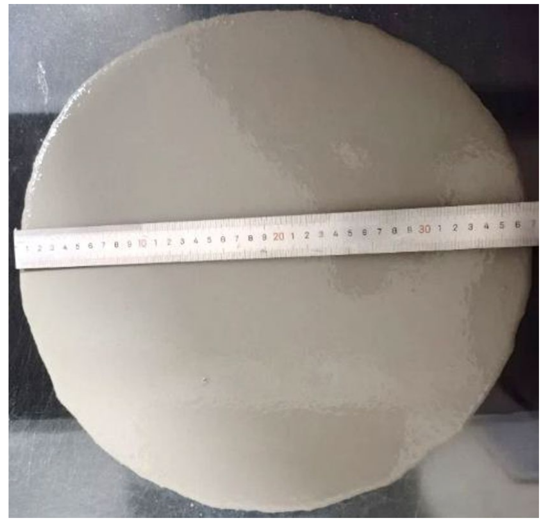


Fig. 2 Determination of mortar fluidity

The water–NL–EP mixture is then added and mixed at low speed for 90 s, stopped for 30 s, and then continued to mix at high speed for 120 s to obtain a well-dispersed grouting material.

2.3.2 Performance Test Methods

1) Working performance test

The fluidity and vertical expansion rate of the grouting material were tested according to “Technical Specification for the Application of Cementitious Grouting Materials” (GB/T 50448, 2015), and the setting time was tested according to “Standard for Test Methods for the Performance of Ordinary Concrete Mixes” (GB/T 50080, 2016), as shown in Figs. 2, 3, and 4, respectively.

2) Mechanical properties test

The flexural and compressive strengths of the specimens were tested according to the "Cementitious Sand Strength Test Method (ISO) Method" (GB/T 17671, 2021). Figs. 5 and 6 display the test device. After 24 h, the molds were released, and specimens were placed in a standard curing room for 14 days, where the cured temperature was 20 ± 2 °C and the relative humidity was 95%, after which they were transferred to a dry room, where the cured temperature was 20 ± 2 °C and the relative humidity was 50 ± 5%, and then taken out at the corresponding age for mechanical properties testing. The molding and curing of the specimens can be seen in Figs. 7 and 8. In addition, the tensile bond strength was tested with reference to the "Standard for Basic Performance Test Methods for Construction Mortars" (JGJ/T70, 2009). Fig. 9 shows the test device.

3) Expansion or shrinkage properties

The free expansion rate was determined in accordance with "Standard for Basic Performance Test Methods for Construction Mortars" (JGJ/T70, 2009), and the restricted expansion rate was determined in accordance

Fig. 3 Determination of the vertical expansion rate

Fig. 4 Determination of setting time

Fig. 5 Flexural strength test

with Appendix A in "Concrete Expanders" (GB/T 23439, 2017), and the test method is shown in Fig. 10. After being cast into the mold, the specimens are immediately covered with plastic film for curing, and the molds are removed after 24 h. The curing condition is consistent with the specimens tested for mechanical properties.

3 Results and Discussion

3.1 Working Performance

The specific test results for the working performance of modified grouting material are shown in Table 12. The three elements of the working performance—fluidity,

Fig. 6 Compressive strength test

Fig. 7 Specimen molding

Fig. 8 Specimen curing

Fig. 9 Bond strength test

Fig. 10 Determination of restricted and free expansion rate

setting time, and vertical expansion rate—are explained below.

3.1.1 Fluidity

As can be seen from Table 12, the effect of the three components on grouting material fluidity differs. RP and EA have a lesser effect on grouting material fluidity, while with an increase in NL, the initial fluidity of the grouting material tends to decrease and the amount of PCE required increases, indicating that NL has a negative effect on the fluidity of the grouting material. In contrast, Li and Shi showed that polymer emulsions could improve the fluidity of fresh mortar (Li, 2011; Shi, 2011). It is presumed that the cause of this situation is the insufficient initial mixing time of the grouting material. The NL has a certain viscosity, and with the increase in its dosage, part of the NL agglomerates in the slurry, making it difficult to fully disperse. Therefore, grouting materials mixed with NL need to be mixed for a longer time to ensure that they are fully dispersed.

3.1.2 Setting Time

Fig. 11 shows how the amount of each component affects the mortar's setting time. As can be observed, each component has a different influence pattern. With an increase in NL content, the grouting material takes longer to set, whereas an increase in EA and RP content shortens the time it takes. Compared to the 0% group, the initial and final setting times of the grouting material at 7.5% NL increased by 120.3% and 97.6%, respectively. This is due to the fact that the NL wraps the cement hydration products, preventing further cement hydration, and that the NL's carboxyl groups can establish ionic connections with the calcium ions generated during cement hydration, affecting the cement's hydration rate (Cherkinski, 1987). The initial and final setting time of the grouting material was reduced by 23.3% and 22.3%, respectively, when the EA was mixed at 9% compared to 5%. The initial and final setting time of the grouting material with 15% RP is only 8.3% and 5.6% shorter than with 5%. Overall, RP has the least effect on the setting time.

3.1.3 Vertical Expansion Rate

The effect of the amount of each component on the vertical expansion rate of the grouting material is shown in Fig. 12. It is clear that the three components' overall impacts differ significantly from one another. NL has a significant negative effect on the vertical expansion rate of the grouting material. The 3-h vertical expansion of the grouting material is reduced by 42.7%, 89.3%, and 92.0%, and the 24 h vertical expansion is reduced by 39.3%, 90.9%, and 93.3% when the NL dosage is increased sequentially from 0% to 7.5%. According to GB/T 50448, grouting material with NL of 5% and 7.5% does not meet the requirements. This is because the grouting material's ability to expand during the plastic stage primarily depends on the F-generated bubbles, and as the amount of NL increases, the slurry's viscosity rises and the bubbles' resistance to emergence increases. As a result, the expansion performance gradually becomes worse; additionally, during the slurry hardening stage, the increased NL dosage causes the hardened mortar's porosity to increase, which increases drying shrinkage. Therefore, the vertical expansion rate of the grouting material gradually worsens during the hardening stage. In order to make the vertical

Table 12 Working performance of modified grouting material

Group	PCE (g)	Fluidity (mm)		Setting time (min)		Vertical expansion rate (%)		
		Initial	After 30 min	Initial setting	Final setting	3 h	24 h	Δ_{24h-3h}
BG	2.3	353	322	348	476	0.514	0.454	−0.06
E2C0R5	2.3	363	336	369	499	0.560	0.670	0.110
E2C2R5	2.8	346	355	554	702	0.321	0.407	0.086
E2C5R5	4.0	348	354	724	974	0.060	0.061	0.001
E2C7R5	4.8	342	336	813	986	0.045	0.045	0.000
E1C2R5	2.8	350	357	675	873	0.312	0.359	0.047
E3C2R5	2.8	344	352	518	678	0.331	0.412	0.081
E2C2R7	2.8	345	354	549	691	0.138	0.328	0.190
E2C2R10	2.8	346	357	526	675	0.166	0.268	0.102
E2C2R15	2.8	345	353	508	663	0.116	0.259	0.143

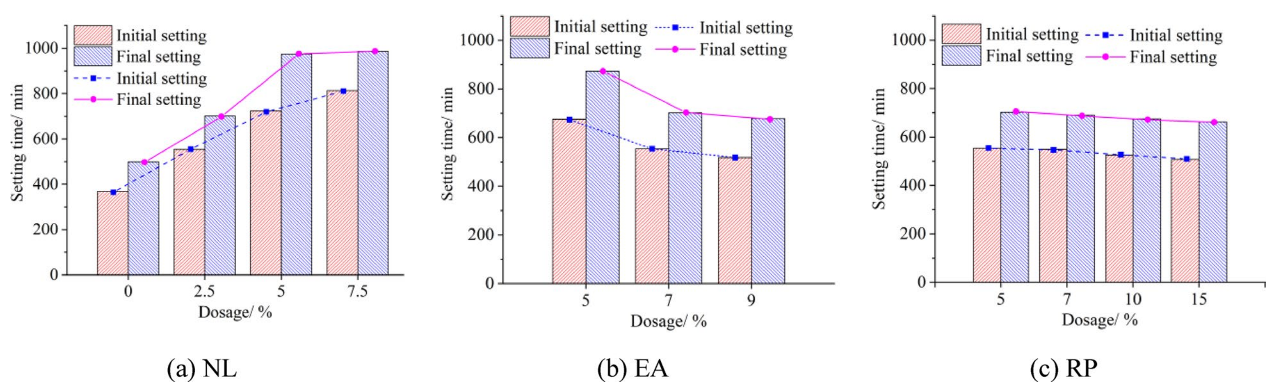


Fig. 11 Influence of different dosage of different components on setting time

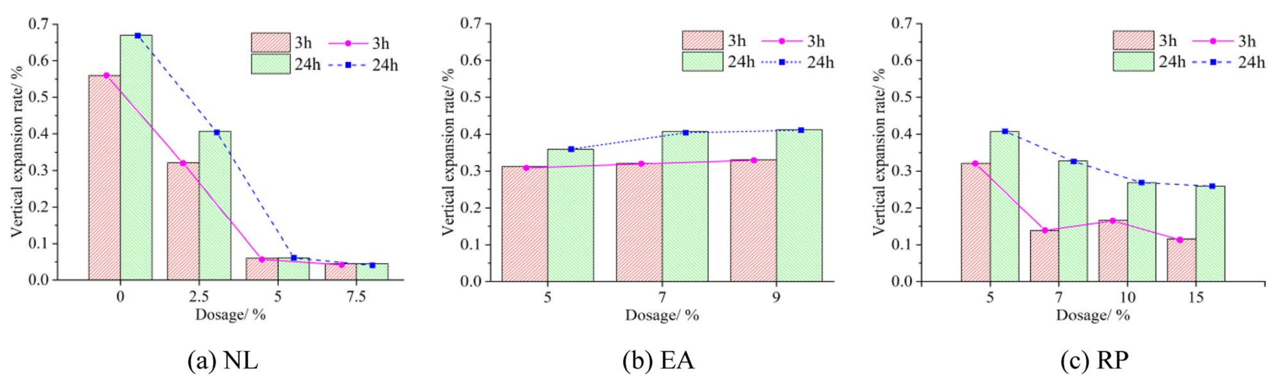


Fig. 12 Influence of different dosage of different components on vertical expansion rate

expansion rate of 5% and 7.5% NL grouting material meet the requirements, the dosage of F and D should be increased appropriately. In contrast to NL, EA promotes the vertical expansion, and the effectiveness of this promotion is primarily seen during the slurry's hardening stage. Comparing the 9% EA to the 5% EA group, the 3-h vertical expansion rate increased by 5.7%, while the 24-h vertical expansion rate increased by 16%. This is because the EA has no impact on the expansion effect of the F during the plastic stage and only causes volume expansion after the grouting material has hardened. Similarly, it can be seen that the RP partially inhibits the vertical expansion in Fig. 12c, the inhibition is noticeably less obvious during the hardening stage. This is probably because the RP has a certain level of toughness that prevents the drying shrinkage of the grouting material during this stage.

3.2 Mechanical Properties

3.2.1 Flexural Strength and Compressive Strength

Table 13 displays the specimens' flexural and compressive strengths at various ages. Figs. 13 and 14 show the effect of the dosage of each component on the flexural

Table 13 Flexural and compressive strength

Group	Flexural strength (MPa)					Compressive strength (MPa)				
	1d	3d	7d	14d	28d	1d	3d	7d	14d	28d
BG	8.4	11.6	11.8	11.8	12.7	46.7	69.6	41.5	80.3	100.3
E2C0R5	7.8	10.7	11.3	12.2	14.2	40.1	65.6	71.2	72.0	95.2
E2C2R5	6.4	10.3	11.0	11.5	14.1	34.1	58.2	61.9	69.5	86.6
E2C5R5	5.5	10.5	11.1	11.9	13.3	24.3	57.3	60.2	62.3	75.9
E2C7R5	4.3	8.4	10.9	11.6	11.9	17.7	43.3	48.8	57.5	65.9
E1C2R5	7.3	10.4	12.3	12.4	14.8	37.6	59.8	67.0	70.8	85.5
E3C2R5	5.4	9.8	10.6	10.8	13.9	31.6	58.3	62.1	67.0	86.8
E2C2R7	6.3	9.7	10.8	11.6	14.5	28.4	59.5	65.4	70.1	87.7
E2C2R10	6.2	10.3	11.1	12.1	14.6	28.2	60.0	62.3	67.3	84.5
E2C2R15	5.4	8.7	10.9	11.2	11.4	24.6	58.6	62.4	66.1	81.0

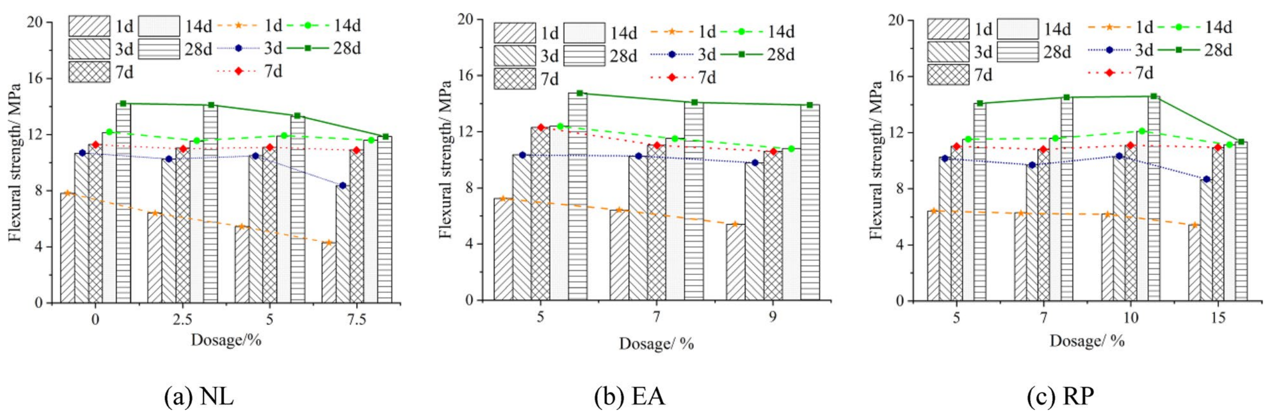


Fig. 13 Influence of different dosage of different components on flexural strength

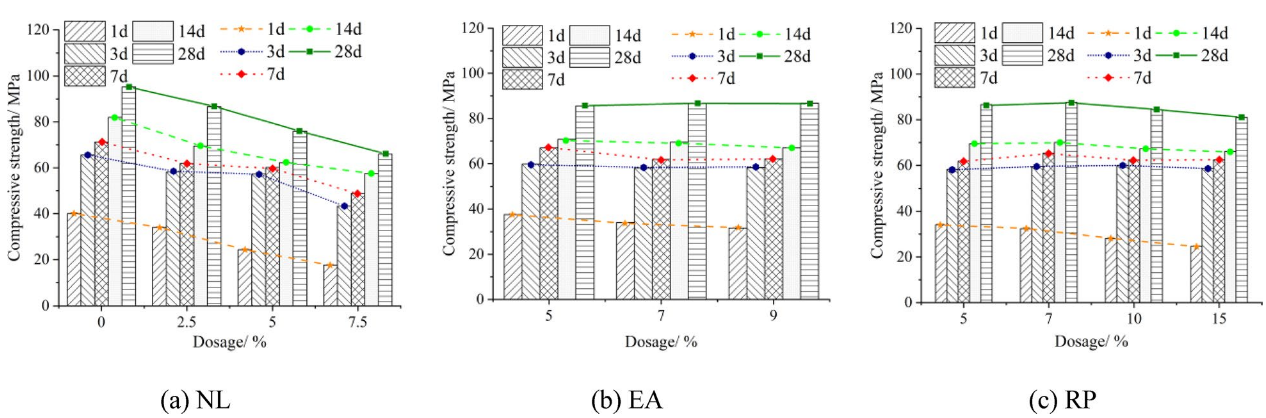


Fig. 14 Influence of different dosage of different components on compressive strength

and compressive strengths of the grouting material, respectively. The influence of the three components on the strength of the grouting material is basically the same, which declines as the dosage rises. In Figs. 13a and 14a, the flexural and compressive strengths of the grouting material at each age decrease with increasing dosage of NL, and the decline in compressive strength is even more significant. Compared to 0% dosage, the 28d flexural strength of 2.5%, 5%, and 7.5% NL grouting material decreased by 0.7%, 6.3%, and 16.2%, respectively, and the 28d compressive strength decreased by 9.0%, 20.2%, and 30.7%, respectively. However, for the 5% NL dosage group, the flexural strength at 3 d, 7 d, and 14 d was slightly higher than that of the 2.5% dosage group.

The flexural and compressive strengths of the grouting material at each age decrease with increasing dosage of EA, with an earlier strength loss being more obvious, as shown in Figs. 13b and 14b. Compared to the 5% dosage group, the 1d flexural strength of the 7% and 9% dosage groups decreased by 12.3% and 26.0%, respectively, and the 1d compressive strength decreased by 9.3% and 16%, respectively, the 28d flexural strength decreased by 4.7% and 6.1%, respectively, and the 28d compressive strength increased by 1.3% and 1.5%, respectively, this is due to the early volume expansion of the grouting material caused by the addition of the EA, which resulted in a looser internal structure and lower strength (Du, 2011). However, because the polymer can improve the denseness of the mortar at a later age (Li, 2011), the strength is compensated.

In Figs. 13c and 14c, the 1d flexural and compressive strengths of the grouting material decrease as the amount of RP increases; the 3d–28d flexural and compressive strengths tend to increase and then decrease; the flexural strength is greatest when the RP is mixed at 10%; the compressive strength is greatest when the RP is mixed at 7%. The analysis suggests that the EP may have wrapped some of the cement particles in the early stage, affecting the hydration process of the cement (Ye, 2012), so 1d strength of the grouting material decreases with increasing amounts of RP. In the mid- and late ages (3d–28d), RP fills the internal voids and boosts the mortar's strength; however, when the RP is mixed in larger quantities, some of it remains in the mortar in a free state because it is an inert organic material that is difficult to combine with the surface of cement hydration products (Li, 2005), which increases the likelihood of bond failure at the interface transition zone and lowers the mortar's strength. Additionally, the RP is very elastic and does not have the same capacity for deformation as the hydration products around it, which have a tendency to produce huge stress concentrations around them when subjected to external stresses (Liu et al., 2008a, 2008b), leading to the development of cracks. It suggests that 7% to 10% of RP is the proper dosage for the grouting material.

3.2.2 Flexural Strength-to-Compressive Strength Ratio (FCS)

The higher the FCS, the better the toughness of the mortar. The results of the grouting material FCS are shown in Table 14, and the effect of the dosage of each component on FCS is shown in Fig. 15. It is clear that the FCS of each modified group is higher than that of the basic group, and the three components' effects on the FCS follow three distinct patterns.

It can be seen in Fig. 15a that the FCS increases with the addition of NL in general, compared to the 0% dosage group, the 28d FCS increased by 9.4%, 17.4%, and 20.8% for the 2.5%, 5%, and 7.5% dosage groups, respectively. In contrast, the FCS of the grouting material decreases with the addition of EA, as shown in Fig. 15b, compared to the 5% dosage group, the 28d FCS decreased by 5.2% and 6.4% for the 7% and 9% dosage groups, respectively.

Table 14 FCS and bond strength

Group	FCS					Bond strength (MPa)	
	1d	3d	7d	14d	28d	3d	7d
BG	0.180	0.167	0.158	0.147	0.127	3.13	3.51
E2C0R5	0.195	0.162	0.159	0.169	0.149	3.66	3.87
E2C2R5	0.189	0.176	0.178	0.166	0.163	3.12	3.43
E2C5R5	0.225	0.183	0.185	0.191	0.175	3.71	4.27
E2C7R5	0.244	0.193	0.223	0.202	0.180	3.65	4.16
E1C2R5	0.193	0.173	0.184	0.175	0.172	2.4	2.56
E3C2R5	0.171	0.167	0.171	0.161	0.161	3.37	3.86
E2C2R7	0.194	0.163	0.165	0.166	0.166	4.13	5.18
E2C2R10	0.220	0.172	0.178	0.180	0.173	4.89	5.24
E2C2R15	0.221	0.148	0.175	0.169	0.140	3.74	4.83

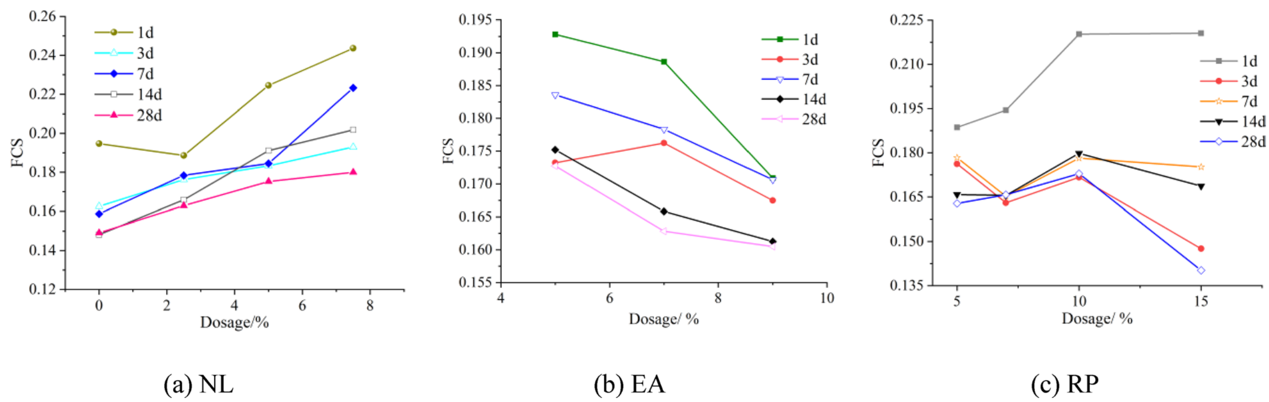


Fig. 15 Influence of different dosage of different components on FCS

Fig. 15c shows that the grouting material's early (1d) FCS increases with the addition of RP, medium-term (3d, 7d) fluctuates with the addition of RP, and the late (14d, 28d) increases and then decreases with the addition of RP. When the RP mixed at 15%, the FCS decreases significantly with the increase of age, so in order to improve the FCS in the late stage, the optimal dosage of RP is 10%.

3.2.3 Bond Strength

The results of the bond strength test are listed in Table 14. The effect of the dosage of each component on the bond strength is shown in Fig. 16. In general, bond strength increases with age. NL, EA, and RP all improve the bond strength of the grouting material, but they have different influence patterns on the bond strength. The bond strength fluctuates with increasing NL dosage and peaks at 5% dosage; the influence pattern is similar to the results of the experiment in the literature (Ge, 2008). The analysis indicates that at 2.5% NL dosage, the improvement in bond strength by the polymer is not significant due to the low dosage; in addition, NL introduces a small amount of air bubbles, making the interfacial bonding area smaller and the interfacial bonding strength slightly lower than the 0% dosage group; as the NL dosage increases, the apparent viscosity of the fresh slurry increases; the van der Waals force between the interface also increases, thus the bond strength gradually rises (Yang, 2016). Furthermore, the bond strength continuously increases with the increasing EA dosage. Compared to the 5% EA dosage group, the 7d bond strength increased by 34.0% and 50.8% in the 7% and 9% dosage groups, respectively. The analysis suggests that the EA makes the mortar expand more and the bonding interface shrink less, enhancing the interface bond strength. At the same time, the bond strength of the grouting material rises and then falls as the RP content rises, peaking at 10%.

3.3 Expansion or Shrinkage Properties

3.3.1 Free Expansion Rate

The test results for the free expansion rate are shown in Table 15 and Fig. 17.

It can be seen that the free expansion or shrinkage performance of the grouting material in each group behaves in a similar pattern in Fig. 17. All specimens expand in

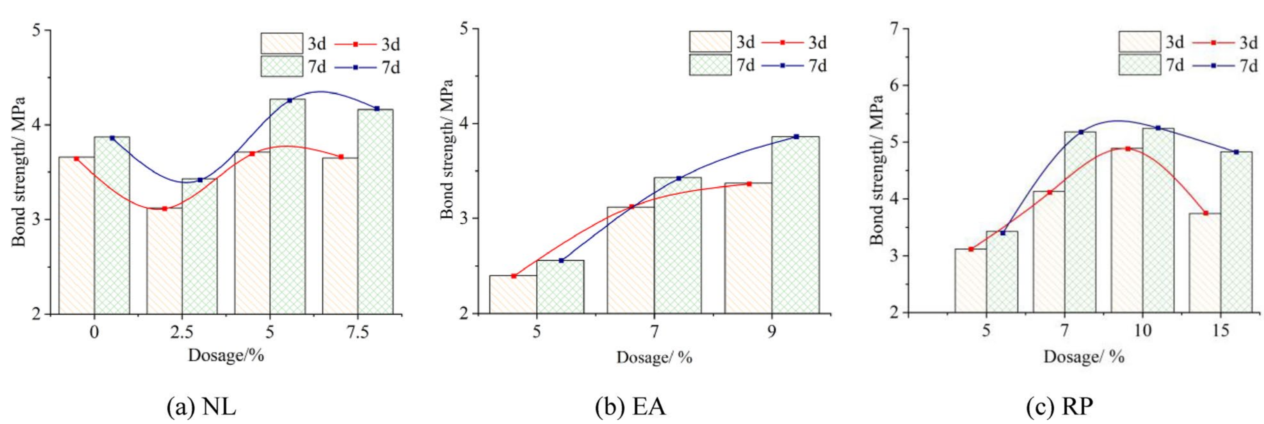
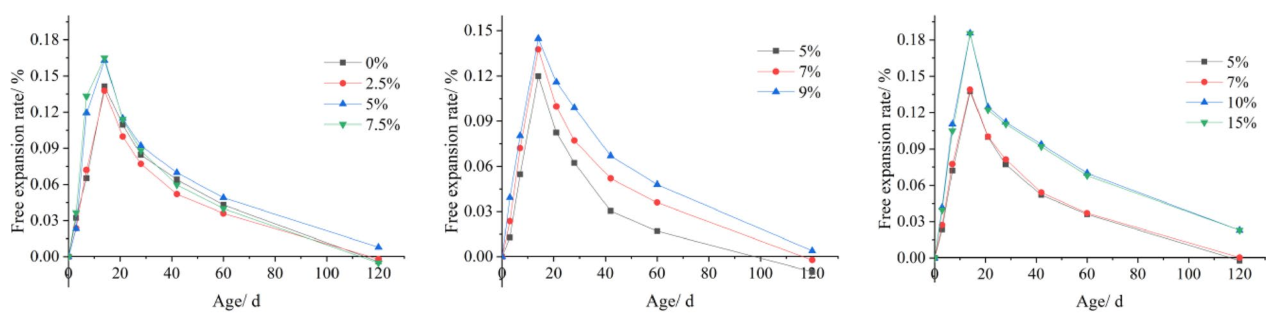


Fig. 16 Influence of different dosage of different components on bond strength

Table 15 Free expansion rate of modified grouting material

Group	Free expansion rate (%)							
	3d	7d	14d	21d	28d	42d	60d	120d
BG	0.0229	0.0569	0.1391	0.1029	0.076	0.0531	0.0317	−0.0117
E2C0R5	0.0324	0.0651	0.1413	0.1096	0.0847	0.0642	0.043	−0.0041
E2C2R5	0.0237	0.0721	0.1377	0.0998	0.0771	0.052	0.036	−0.0022
E2C5R5	0.0233	0.1193	0.1629	0.1148	0.0921	0.0698	0.049	0.0079
E2C7R5	0.0367	0.1333	0.165	0.1141	0.0881	0.0598	0.0404	−0.0052
E1C2R5	0.0129	0.0547	0.1199	0.0825	0.0624	0.0304	0.017	−0.0112
E3C2R5	0.0393	0.0804	0.1449	0.1159	0.099	0.067	0.048	0.0040
E2C2R7	0.0271	0.0775	0.1388	0.1001	0.0814	0.054	0.037	0.0003
E2C2R10	0.0419	0.1105	0.1855	0.1245	0.1121	0.0938	0.07	0.0229
E2C2R15	0.0395	0.105	0.1852	0.1221	0.1105	0.0919	0.068	0.0229

Positive values in the table indicate expansion deformation, negative values indicate shrinkage deformation



(a) NL (b) EA (c) RP

Fig. 17 Influence of different dosage of different components on free expansion rate

the first 14 d and begin to shrink when moved to a dry room, with shrinkage leveling off as age increases, and the partially modified group still has some expansion at 120 d. As can be seen from Fig. 17a, the free expansion rate of the grouting material before 14d increases as NL dosage increases; the 14 d free expansion rate reached a maximum at the 7.5% NL dosage group. After 14 d, the specimens were cured under dry conditions, and the 5% NL group remained expanded at 120 d, while the 7.5% NL group developed shrinkage deformation. During the 14 d to 120 d drying shrinkage stage, the 7.5% NL group showed the fastest decrease in curve, which is similar to the results of Jiang et al and He. (He, 2011; Jiang et al., 2002). This is because as the NL dosage increases, the support of the polymer film gradually increases, reducing the drying shrinkage. When too much NL is mixed (≥7.5%), too many air bubbles are introduced, which leads to an increase in the porosity of the grouting material, causing it to shrink more. Fig. 17b shows that the free expansion rate at all ages increases significantly with increasing dosage of EA, the 9% EA group retains its expansion deformation at 120 d. The analysis suggests that because CaO in the EA hydrates to become $Ca(OH)_2$, which boosts the mortar's volume with a maximum expansion rate of 0.0393%, and due to the 14 d standard curing, the hydration reaction within the grouting material is sufficient, causing the grouting material to have a low porosity, so it's drying shrinkage develops slowly, and it's 120 d free expansion rate is still positive. Fig. 17c shows that the expansion performance of the grouting material is enhanced with the increase in the amount of RP, the expansion performance at 10% and 15% is significantly improved, and the free expansion rate remains positive at 120 d. This is because RP is easily deformable and ductile, filling the mortar pores and inhibiting the drying shrinkage of the mortar (Oikonomou et al., 2009).

3.3.2 Restricted Expansion Rate

Table 16 displays the test results for the restricted expansion rate. It can be seen in Fig. 18 that the overall restricted expansion performance behaves in a similar

Table 16 Restricted expansion rate of modified grouting mortar

Group	Restricted expansion rate (%)							
	3d	7d	14d	21d	28d	42d	60d	120d
BG	0.0057	0.0397	0.0692	0.0496	0.0303	0.0136	−0.0013	−0.0274
E2C0R5	0.0216	0.0473	0.0732	0.0516	0.0323	0.0160	0.0013	−0.0238
E2C2R5	0.0182	0.0471	0.0749	0.0527	0.0338	0.0167	0.0035	−0.0205
E2C5R5	0.0206	0.0470	0.0763	0.0582	0.0403	0.0208	0.0072	−0.0162
E2C7R5	0.0222	0.0497	0.0782	0.0610	0.0419	0.0216	0.0096	−0.0154
E1C2R5	0.0123	0.0367	0.0609	0.0399	0.0223	0.0050	−0.0104	−0.0316
E3C2R5	0.0405	0.0625	0.0862	0.0678	0.0493	0.0278	0.0170	−0.0116
E2C2R7	0.0182	0.0471	0.0749	0.0527	0.0338	0.0167	0.0050	−0.0205
E2C2R10	0.0183	0.0507	0.0797	0.0537	0.0353	0.0185	0.0058	−0.0204
E2C2R15	0.0239	0.0541	0.0828	0.0580	0.0416	0.0218	0.0063	−0.0179

Positive values in the table indicate expansion deformation, negative values indicate shrinkage deformation

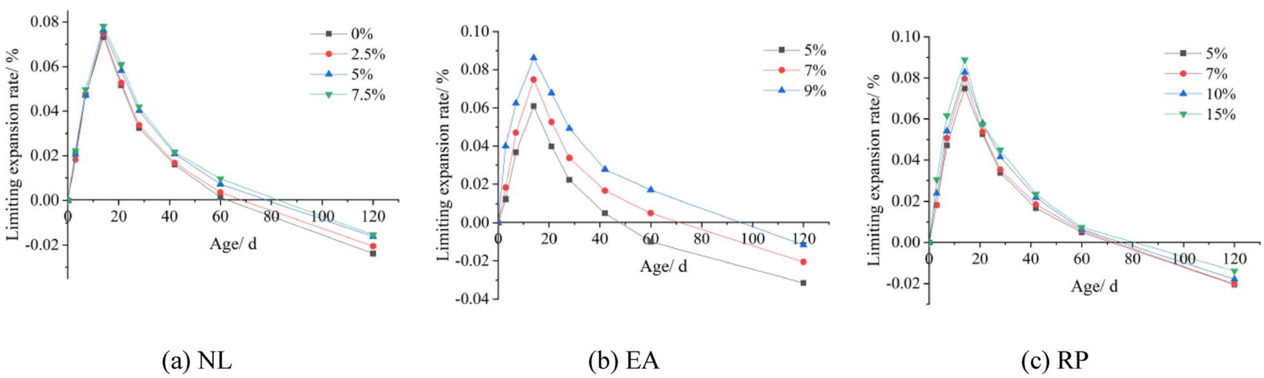


Fig. 18 Influence of different dosage of different components on restricted expansion rate

pattern to that of free expansion. However, unlike free expansion, each modified group exhibits negative shrinkage at 120 d. This is because the longitudinal restrictor reduces each group's expansion rate, making it below the free expansion rate. Comparing Fig. 18a to c, it is clear that among the three components, the amount of EA has the most apparent impact on the restricted expansion rate. Compared to the 5% dosage group, the 120d restricted shrinkage is decreased by 35.1% and 63.3% in the 7% and 9% dosage groups, respectively.

3.3.3 Effect of Curing Conditions on Free Expansion or Shrinkage

The expansion or shrinkage properties of the grouting material are significantly impacted by the curing conditions. Five groups of free expansion samples of the same mixture ratio (E2C2R5) were cured under the following five different curing conditions: A. after demoulding, the specimens are cured in a standard curing room for 7 d and then transferred to a dry curing room at 21 °C and 50% relative humidity; B. the specimens are sealed and covered in plastic film once they have been demolded so they can hydrate under humidity isolation. They are then cured in a dry curing room to keep the temperature constant; C. the specimens are cured in water for 7 d after demoulding and then transferred to a dry room for curing; D. the specimens are cured in water for 3 d after demoulding and then transferred to a dry room for curing; E. the specimens are not sealed after demoulding and are cured directly under natural conditions. The specimens were tested for free expansion rate at 3 d, 7 d, 28 d, and 80 d, and the results are shown in Table 17.

Fig. 19 shows that there is a large difference in the expansion or shrinkage properties of the grouting material under the five different curing conditions. The specimens exhibited a large expansion deformation after 7 d of water curing under C conditions and maintained an expansion rate of 0.007% after 73 d of dry curing. The expansion rate at 7 d for specimens cured under condition A is much less than the 7 d expansion rate under condition C, although it maintains a fast increase in expansion during the initial 7 d. And at 28 d, shrinkage

Table 17 Free expansion rate of the grouting material under different curing conditions

Curing condition	Free expansion rate (%)						
	3d	7d	14d	21d	28d	50d	80d
A	0.0495	0.1050	0.0317	0.0034	−0.0081	−0.0293	−0.0501
B	0.0160	0.0112	0.0017	−0.0044	−0.0098	−0.0416	−0.0619
C	0.0879	0.1841	0.1157	0.0800	0.0638	0.0295	0.0071
D	0.0874	0.0514	0.0275	0.0047	−0.0088	−0.0377	−0.0586
E	−0.0207	−0.0243	−0.0414	−0.0430	−0.0501	−0.0684	−0.0874

Positive values in the table indicate expansion deformation, negative values indicate shrinkage deformation

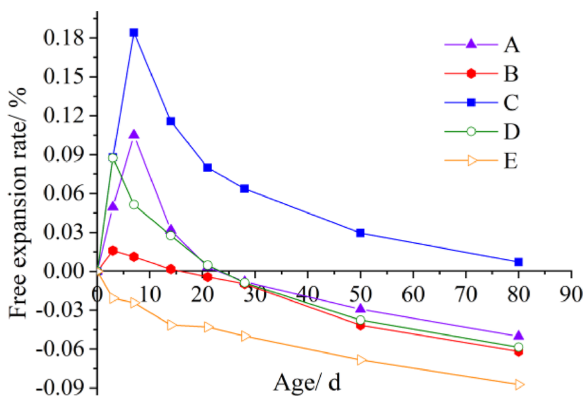


Fig. 19 Free expansion rate with age under different curing conditions

deformation has already begun to appear, and it can be seen that the expansion performance of the water-cured 7 d specimens is significantly better than the standard 7 d specimens, indicating that the EA needs to draw a large amount of water from the environment in order to support its continuous hydration and produce expansion properties. The specimens in the D condition displayed the same expansion properties as Group C up to 3 d, but shrinkage deformation occurred between 21 and 28 d, indicating that the 3 d water curing time was not sufficient to produce sufficient expansion. In addition, under B curing conditions, the specimens reached their maximum expansion after 3 d and began to shrink after 14 d. The shrinkage continued to develop at a later stage, indicating that the sealed, moisture-insulated environment was not favorable to the development of the expansion properties of the grouting material. The specimens achieved a shrinkage deformation of 0.05% at 28 d and even 0.09% at 80 d under E curing conditions. This is because in the early stages of hydration, the EA and the cement compete for water, which increases the drying shrinkage of the grouting material. Therefore, the grouting material mixed with EA should be strengthened with early curing to prevent the mortar from shrinking at an early stage and producing greater shrinkage deformation at a later stage.

In summary, the early curing humidity and the time to maintain humidity have a great influence on the expansion rate of the grouting material. Good humidity conditions can make the grouting material constantly absorb water from the outside to promote the hydration of the EA. The curing conditions are therefore preferable to Method C. However, as the grouting material is fitted to the precast elements on both sides and is difficult to maintain with sufficient moisture in practice, the actual change in expansion or shrinkage of the grouting material is closer to the volume change under curing B or E.

4 Conclusions

(1) The addition of NL increases the viscosity of the fresh slurry, and the mixing time should be extended in order not to affect the fluidity of the grouting material. With an increase in NL dosage, the grouting material's initial and final setting times are significantly prolonged, and its vertical expansion is significantly inhibited. In addition, the flexural and compressive strengths of the grouting material decreased significantly after the NL modification, but the FCS and bond strengths increased. The expansion before 14 d was enhanced with the increase in NL, and the drying shrinkage after 14 d was inhibited. When the dosage of F and D is reasonable, the NL dosage should be about 5%.

(2) With the increase in the amount of EA, the fluidity and setting time of the grouting material decrease. EA promotes the vertical expansion of the grouting material, and the effectiveness of this promotion is primarily seen during the slurry's hardening stage. The flexural strength, FCS, and early compressive strength of the grouting material decrease with increasing EA dosage, but the bond strength and the expansion rate then increase. Considering the influence of EA on the working performance, mechanical properties, and expansion or shrinkage properties of the grouting material, 7% EA is enough.

(3) The influence of RP on the fluidity and setting time of the grouting material is relatively small, and it mainly promotes vertical expansion during the hardening stage of the slurry. As RP increased, the flexural strength, compressive strength, 28 d FCS, and bond strength of the grouting material increased first and then decreased; the flexural strength, 28 d FCS, and bond strength of the grouting material peaked at 10% dosage. With the increase in RP, the expansion performance of the grouting material after hardening is significantly improved, and the shrinkage during dry conditions is also suppressed. RP mainly affects the mechanical properties and expansion or shrinkage properties of the grouting material, and its optimal dosage is 10%.

Author contributions
XL provides guidance on research direction, and paper and experimental work. QL conducts experiments, analyses and processes data and writes papers. BZ helps with experiments and checks papers. All authors read and approved the final manuscript.

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Data availability
All data are displayed in the article.

Declarations

Competing interests
The authors declare that they have no competing interests.

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