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Influence of Modified Epoxy Resin, Methyl methacrylate and Sodium Methyl Silicate on the Properties of Ancient Masonry

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In this paper, the performance enhancement of ancient masonry cementing materials was studied by using organic polymer materials. By comparing and analyzing the test results in several aspects: Cube compression test process and failure mode pre and post reinforcement, cubic compressive strength, test process and failure mode pre and post reinforcement of uniaxial compression of prism, peak stress, peak strain, ultimate strain and elastic modulus et al. The results showed that the enhanced test pieces incorporated of epoxy resin modified, methyl methacrylate and sodium methyl silicate have higher performance than the substrate test pieces. The results show that it is feasible to use organic polymer materials to strengthen ancient masonry cementing materials, which can effectively improve the bearing capacity and deformation, meanwhile the epoxy resin modified with organic materials has the greatest improvement. Therefore, the epoxy resin modified with organic materials has a very good effect on the performance enhancement of ancient masonry cementing materials.

1. Introduction

Most of the existing buildings are brick masonry structures. With the passage of time, most ancient masonry blocks suffer from different degrees of damage, such as weathering of blocks and lack of cementing materials. The ancient masonry is made of sintered clay brick and cemented material. It mainly depends on the bonding action of cementing material to become a whole. If the cementing material weathers, it will lead to looseness or cracking, which will eventually lead to the integrity and the bearing capacity of the ancient masonry structure are reduced, which weaken the overall seismic performance of the structure. Yu et al. (2005) have found that the properties of cementing materials have a great impact on ancient masonry. Lu (1985) studies found that ancient Greeks used lime as a cementing material in the 8th century BC. Since then, in order to improve the deficiency of lime as a cementing material, Yang et al. (2009) added sticky rice mortar, and Ji et al. (2013) used tun g oil as additives in the mortar. Compared with ordinary mortar, it has greatly improved its cohesiveness and impermeability. Through the study of the existing historical relics at home and abroad, it is found that the traditional cementing materials play a great role in the preservation process, but with the passage of time, the properties of these materials are greatly declined. How to improve their properties is extremely important for the restoration of ancient masonry. At present, Jiang (2003) and Huang et al. (2000) have found that grouting organic materials are often used to improve the properties of cementing materials (Li and Ren, 2018). On the basis of the existing research, in order to find the performance enhancing materials suitable for ancient masonry and provide reference for the restoration and protection of ancient buildings, this paper chooses modified epoxy resin slurry, methyl methacrylate slurry (Editorial department of Guangzhou chemistry, 1991) and silicone slurry to carry out experimental study on the performance enhancing of different ancient masonry substrate material specimens.

2. Summarized of test

The original materials of ancient masonry traditional masonry materials are selected, including combined mortar, sticky rice mortar, hemp mortar. Chemical grouting materials were selected, including epoxy resin modified, methyl-methacrylate, sodium methyl-silicate.

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Due to the particularity of ancient masonry, there are no special codes to evaluate the mechanical properties of ancient masonry mortar. In this study, the mechanical properties of ancient masonry mortar were evaluated by referring to the current industry standard "Standard for Testing Methods of Basic Properties of Building Mortar" (JGJ/T70-2009).

2.1 Specimens design

The size of specimen of mortar cube compressive strength is 70.7mm×70.7mm×70.7mm and the size of specimen of prismatic uniaxial compressive strength is 70.7mm×70.7mm×216mm. The specimen was numbered and demoulded after 2 days of rest, and maintained under natural conditions until the prescribed age of 28 days. Three different kinds of traditional masonry mortar have been produced. They are epoxy resin modified, methyl-methacrylate, sodium methyl silicate. The volume ratio of loess and quicklime in the mixed mortar is 8:2. The sifted loess and lime are mixed in proportion. After that, the mixed water is added to the mixed mortar, and the electric mixer is used to mix evenly for reserve. As the volume ratio of ash to soil in hemp mortar is 5:5, the sticky rice mortar is slowly added into water under stirring. After being slurried, it is mixed with the loess and mixed with an electric stirring device for reserve. As the volume ratio of lime to soil is 9:1, the sifted loess and raw lime are mixed in proportion, and then the mixed lime is mixed with mixing water. The mixture is evenly made into mud by electric stirring device. The volume ratio of lime-soil to hemp silk is about 100:6. Mix well and reserve.

Figure 1: Preparation of Partial Cube and Prism Test Pieces in the Test

Table 1: Cube Test Piece Grouping, Numbering

Reinforced Material	Substrate		
	Combined Mortar(C)	Sticky Rice Mortar(S)	Hemp Mortar(H)
Nothing	CC1~CC3	SC1~SC3	HC1~HC3
Epoxy Resin Modified(E)	CEC1~CEC3	SEC1~SEC3	HEC1~HEC3
Methyl methacrylate(M)	CMC1~CMC3	SMC1~SMC3	HMC1~HMC3
Sodium Methyl silicate(S)	CSC1~CSC3	SSC1~SSC3	HSC1~HSC3

Table 2: Prismatic Specimens Grouping, Numbering

Reinforced Material	Substrate		
	Combined Mortar(C)	Sticky Rice Mortar(S)	Hemp Mortar(H)
Nothing	CP1~CP6	SP1~SP6	HP1~HP6
Epoxy Resin Modified(E)	CEP1~CEP6	SEP1~SEP6	HEP1~HEP6
Methyl methacrylate(M))	CMP1~CMP6	SMP1~SMP6	HMP1~HMP6
Sodium Methyl silicate(S)	CSP1~CSP6	SSP1~SSP6	HSP1~HSP6

The selected performance-enhancing organic materials include epoxy resin modified, methyl methacrylate, sodium methyl silicate. Because of the particularity of modified epoxy resin, the grouting fluid of modified epoxy resin used should have low viscosity and high fluidity. The materials used are directly supplied from the manufacturer. The manufacturer has made some improvements according to the requirements we have put forward. The materials of components A and B are used. When used, the volume ratio of components A and B is 2:1. Methyl methacrylate is prepared from four main materials: methyl methacrylate main agent, initiator, accelerator and oxygen scavenger. Before methyl methacrylate is used, the oxygen scavenger is put into the main agent, stirred to dissolve and used as liquid A. Then the initiator and part of the oxygen scavenger are mixed evenly as liquid B. When used, liquid A and liquid B are mixed in proportion of 1:1 volume ratio, and the initiator is added. Sodium methyl silicate is prepared by diluting the original solution of sodium methyl silicate with water, and the volume ratio is about 1:12-15. It should be prepared in appropriate amount each time.

The test was based on three kinds of substrates and three kinds of reinforcing materials. The cubes and prismatic test blocks were made from the substrate and the substrate and the reinforcing material mixture, which are shown in Figure 1. The combinations of test block material are shown in Tables 1 and 2.

2.2 Cube compressive strength test

2.2.1 Test setup

The test equipment is a microcomputer-controlled electro-hydraulic servo universal testing machine with a maximum range of 100kN. The instrument manufacturer is Jinan Hengrui Gold Testing Machine Co., Ltd., as shown in Figure 2.


(a)


(b)

Figure 2: Universal Testing Machine for Testing

2.2.2 Evaluation method of cubic compressive strength test results

The cubic compressive test results are processed according to the requirements of the relevant chapters of the industry standard JGJ/T07-2009 "Standards for Testing Methods of Basic Performance of Building Mortar". The data processing method of the test is shown in: $f_{m,cu}=Nu/A$

Where the cube compressive strength (MPa) is expressed by $f_{m,cu}$, accurate to 0.1MPa, Nu indicates the failure load of specimens (*N*) and A represents the specimen bearing area(mm^2).

Note that the compressive strength of mortar cube specimen should be accurate. 0.1MPa.

In addition, the arithmetic average value of the three specimens is 1.3 times as the average value of the mortar cube compressive strength of the three specimens (accurate to 0.1 MPa).

Limited by length, only the test process of compressive test block of sticky rice mortar substrate cube is shown in Figure 3.


(a) Field Test

(b) Destructive Form

Figure 3: Sticky Rice Mortar (S) Substrate Test

The test results of three kinds of substrate mortar cubes are shown in Table 3 and the compressive test of the reinforced material cube test blocks are shown in Table 4 to 6.

Table 3: Results of Cube Compression Test for Substrate Mortar

Type of Mortar	Specimens Number	Failure Load /kN	Bearing Area /mm^2	Compressiv Strength /MPa	Average of Compressive Strength /MPa
Combined Mortar	CC1	5.52	4998.49	1.1	
	CC2	6.55	4998.49	1.3	1.6
	CC3	6.37	4998.49	1.3	
Sticky Rice Mortar	SC1	6.75	4998.49	1.4	
	SC2	6.44	4998.49	1.3	1.8
	SC3	7.29	4998.49	1.5	
Hemp Mortar	HC1	9.62	4998.49	1.9	
	HC2	9.45	4998.49	1.9	2.5
	HC3	10.33	4998.49	2.1	

Table 4: Test Results of Compression Test on the Cube Block of Reinforced Material with Combined Mortar

Reinforced Material	Group Number	Failure Load /kN	Bearing Area /mm^2	Compressive Strength/MPa	Average of Compressive Strength /MPa	Rate of Compressive Strength /%
Epoxy Resin Modified (E)	CEC1	8.06	4998.49	1.6	2.3	43.8%
	CEC2	9.96	4998.49	2.0		
	CEC3	8.95	4998.9	1.8		
Methyl Methacrylate (M)	CMC1	6.79	4998.49	1.4	1.9	18.8%
	CMC2	7.79	4998.49	1.6		
	CMC3	7.87	4998.49	1.6		
Sodium Methyl-Silicate (S)	CSC1	6.46	4998.49	1.3	2.0	25.0%
	CSC2	8.25	4998.49	1.7		
	CSC3	8.35	4998.49	1.7		

Table 5: Test Results of Compression Test on the Cube Block of Reinforced Material with Sticky Rice Mortar

Reinforced Material	Group Number	Failure Load /kN	Bearing Area /mm^2	Compressive Strength/MPa	Average of Compressive Strength /MPa	Rate of Compressive Strength /%
Epoxy Resin Modified(E)	SEC1	10.53	4998.49	2.1	2.8	55.6%
	SEC2	9.60	4998.49	1.9		
	SEC3	11.74	4998.49	2.3		
Methyl Methacrylate(M)	SMC1	10.33	4998.49	2.1	2.5	38.9%
	SMC2	9.21	4998.49	1.8		
	SMC3	9.40	4998.49	1.9		
Sodium Methyl-Silicate(S)	SSC1	8.64	4998.49	1.7	2.1	17.8%
	SSC2	7.15	4998.49	1.4		
	SSC3	8.68	4998.49	1.7		

Table 6: Test Results of Compression Test on the Cube Block of Reinforced Material with Hemp Mortar

Reinforced Material	Group Number	Failure Load /kN	Bearing Area /mm^2	Compressive Strength/MPa	Average of Compressive Strength /MPa	Rate of Compressive Strength /%
Epoxy Resin Modified(E)	HEC1	16.26	4998.49	3.3	4.0	60.0%
	HEC2	14.36	4998.49	2.9		
	HEC3	15.60	4998.9	3.1		
Methyl Methacrylate(M)	HMC1	12.31	4998.49	2.5	3.3	32.0%
	HMC2	12.57	4998.49	2.5		
	HMC3	13.53	4998.49	2.7		
Sodium Methyl-Silicate(S)	HSC1	11.26	4998.49	2.3	2.9	16.0%
	HSC2	10.49	4998.49	2.1		
	HSC3	11.67	4998.49	2.3		

It can be seen from the test results in Table 3 to 6 that the compressive strength of the cubes of combined mortar, sticky rice mortar and hemp mortar added with modified epoxy resin increased by 43.8 %, 55.6 % and 60.0 % respectively, and that of combined mortar, sticky rice mortar and hemp mortar with methyl methacrylate increased by 18.8%, 38.9% and 32.0% respectively, and that of combined mortar, sticky rice mortar and hemp mortar with sodium methyl silicate increased by 25%, 17.8% and 16% respectively. Therefore, the modified epoxy resin in the three kinds of reinforcing materials has the best effect on improving the strength of the substrate mortar.

2.3 Uniaxial compression test of prism

2.3.1 Test process

The uniaxial compression test of combined mortar substrate prisms is given as shown in Figure 4.

The process of uniaxial compression test of three kinds of substrate prisms is known. There are many longitudinal cracks in the upper part of the combined mortar after being pressed, which break down suddenly after reaching the peak load and break into many blocks along the crack. There are no obvious cracks on the surface of sticky rice mortar at the initial stage of loading. With the increase of load, there are many discontinuous longitudinal cracks on the surface of specimens, which extend from the middle to two ends, and finally show splitting failure. Several micro-cracks appeared on the surface of the mortar of hemp knife, which developed from top to bottom, and appeared splitting failure in the back oblique direction.

The test process of combined mortar substrate with reinforced materials (CEP, CMP, CSP) is given here, as shown in Figure 5.

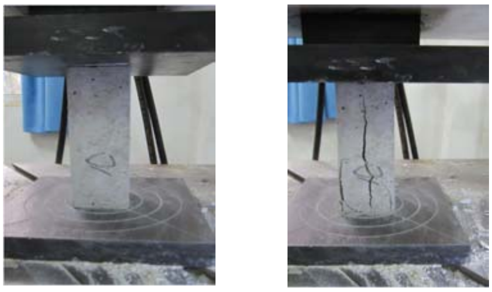

Figure 4: Testing Process of Combined Mortar(C)

Figure 5: Test Process of CEP Test Block

The process of uniaxial compression test of combined mortar substrate with reinforced materials prisms is known. After the CEP specimens are loaded, several fine cracks appear at the top of the specimen. With the increase of the load, an oblique main crack is formed. After the CMP specimens are loaded, several longitudinal cracks appear at the top of the specimen. After the CSP specimens are loaded, cracking occurred in the upper and lower parts. The process of uniaxial compression test of sticky rice mortar substrate with reinforced materials prisms is known. After the SEP specimens are loaded, the irregular cracking appeared at the top of the prism, then the vertical crack extended downward, and the lower crack also appeared and extended upward. After SMP specimens are loaded, the surface cracks appear fine and develop from the middle to the upper part. After reaching the peak value, the cracks continue to extend, expand and connect, forming the macroscopic crack part to fall off and destroy. The cracks first appear in the middle of the SSP specimen after loading. With the increase of load, the vertical cracks in the middle extend to both ends. The process of uniaxial compression test of hemp mortar substrate with reinforced materials prisms is known. After loading, cracks first appear at the two ends of HEP specimen, and then an oblique main crack is formed at the top. With the increase of load, the width and length of the crack continue to increase, and there are signs of dislocation. When HMP specimens are loaded, cracks first appear in the upper part. When HSP specimens are loaded, fine cracks appear on the upper surface, and flake-like outward cracks occur.

2.3.2 Test results and analysis

The main results of uniaxial compression tests of several test block prisms are shown in Table 7.

Table 7: Test Results of Uniaxial Compression of Prism

Sample Group	Peak Stress/MPa	Peak Strain	Ultimate Strain	Elastic Modulus E/MPa
C	0.7816	0.0145	0.0159	45.8
CEP	1.1001	0.0169	0.0179	62.3
CMP	0.9599	0.0156	0.0170	60.6
CSP	0.9235	0.0152	0.0171	59.2
S	0.4434	0.0112	0.0142	26.1
SEP	0.5909	0.0159	0.0196	83.3
SMP	0.5747	0.0158	0.0193	82.2
SSP	0.5425	0.0142	0.0187	76.3
H	0.9166	0.0231	0.0345	37.9
HEP	1.1553	0.0444	0.0577	53.7
HMP	1.0795	0.0420	0.0553	32.8
HSP	1.0935	0.0267	0.0367	36.5

It can be seen from Table 7 that the modified epoxy resin has the best peak stress effect on prisms. The peak stress of combined mortar specimens adding modified epoxy resin, methyl methacrylate and sodium methylene silicate is increased by 17.5 %, 29.6 % and 22.4 % respectively. The peak stress of sticky rice mortar specimens adding modified epoxy resin, methyl methacrylate and sodium methylene silicate is increased by 40.7 %, 22.8 % and 18.2 % respectively. The peak stress of hemp mortar specimens adding modified epoxy resin, methyl methacrylate and sodium methylene silicate is increased by 26.0 %, 17.8 % and 19.8 % respectively

(1) Peak strain and ultimate strain

The corresponding to the peak strain at the peak stress point can be obtained by experimental data, which reflects the deformation capacity of mortar under the maximum failure load. The ultimate strain is taken to correspond to the strain at the 85% peak stress of descending stage of the stress-strain curve. It can be seen from Table 7. Compared with the substrate specimens, the peak strain and ultimate strain of the prism specimens of combined mortar, sticky rice and mortar hemp mortar adding modified epoxy resin are increased by 41.1% and 35.9%, 37.6% and 36.9%, 81.8% and 10.3% respectively. Compared with the substrate specimens, the peak strain and ultimate strain of the prism specimens of combined mortar, sticky rice and mortar hemp mortar adding methyl methacrylate are increased by 16.6% and 12.6%, 31.3% and 31.0%, 5.6% and 9.3% respectively. Compared with the substrate specimens, the peak strain and ultimate strain of the prism specimens of combined mortar, sticky rice and mortar hemp mortar adding modified epoxy resin are increased by 4.8% and 9.3%, 26.8% and 31.7%, 15.6% and 6.4% respectively. In summary, the three kinds of substrate specimens with modified epoxy resin have better effect on the peak strain and ultimate strain of the specimen.

(2) Elastic modulus

The elastic modulus of mortar determined by this experimental method refers to the secant modulus when the stress is 40% axial compressive strength. Therefore, the secant modulus corresponding to the origin of the rising section of the stress-strain curve to the peak stress point of 40% is taken as the required elastic modulus.

It can be seen from Table 7. The elastic modulus of combined mortar specimens adding modified epoxy resin, methyl methacrylate and sodium methylene silicate is increased by216.9 %, 214.9 % and 192.3 % respectively. The elastic modulus of sticky rice mortar specimens adding modified epoxy resin, methyl methacrylate and sodium methylene silicate is increased by 35.1 %, 32.3 % and 29.3 % respectively. For the hemp mortar specimens, the elastic modulus increases by 41.7% with the addition of modified epoxy resin, and decreases by 13.5% and 3.7% with the addition of methyl methacrylate and sodium methyl silicate respectively. The reason why the elastic modulus of the combined mortar increases greatly after adding performance-enhancing materials is that the elastic modulus of the combined mortar is small. With the addition of performance-enhancing materials, the internal voids of the combined mortar are fully filled, so the elastic modulus of the material is greatly improved.

3. Conclusion

The related experimental research on the performance enhancement of organic chemistry materials: modified epoxy resin, methyl methacrylate and sodium methyl silicate were carried out by adding the traditional ancient masonry cementing materials of three different substrates. The results show that the modified epoxy resin not only improves the cubic compressive strength of three kinds of ancient masonry cementing materials with different substrates, but also markedly improves the peak stress, peak strain, limit strain and elastic modulus of prism specimens with three kinds of ancient masonry cementing materials with different substrates. It shows that the modified epoxy resin is a kind of performance enhancing material that can be used for ancient masonry. Therefore, it can provide reference for the restoration and protection of ancient buildings.

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