Hindawi
Advances in Materials Science and Engineering
Volume 2021, Article ID 9956897, 10 pages
https://doi.org/10.1155/2021/9956897

Research Article

Experimental Study on the Mechanical Properties of the Fiber Cement Mortar Containing Polyurethane

Xijun Zhang,[1,2,3] **Hongyuan Fang**,[1,2,3] **Mingrui Du**,[1,2,3] **Mingsheng Shi**,[1,2,3] **and Chao Zhang**[1,2,3]

[1]*School of Water Conservancy Engineering, Zhengzhou University, Zhengzhou 450001, China*
[2]*National Local Joint Engineering Laboratory of Major Infrastructure Testing and Rehabilitation Technology, Zhengzhou 450001, China*
[3]*Collaborative Innovation Center of Water Conservancy and Transportation Infrastructure Safety, Henan Province, Zhengzhou 450001, China*

Correspondence should be addressed to Mingrui Du; mingruidu331@163.com

Received 23 August 2021; Accepted 29 October 2021; Published 11 November 2021

Academic Editor: Zbyšek Pavlík

Polymer is a kind of high molecular elastic material. The polymer cement mortar composite material formed by mixing it with cement mortar has the advantages of light weight, high strength, and good durability compared with traditional mortar materials. The effect of polyurethane polymer content on mechanical properties and microstructure of polyvinyl alcohol (PVA) fiber cement mortar was studied by compressive test, flexural test, and SEM analysis. The test results show that as the content of polyurethane increases, the compressive strength gradually decreases, and the flexural strength gradually increases. The addition of polyurethane helps to optimize the microstructure of PVA mortar, improve the compactness of the material, and enhance the bending resistance of the mortar. The mechanical properties of materials obtained from the experiment can provide references for engineering applications.

1. Introduction

Fiber cement mortar has the advantages of high strength, good ductility, and superior fracture performance [1, 2]. Polyvinyl alcohol (PVA) fiber is a high-strength and high-modulus synthetic fiber with low density, good dispersion, and high bonding strength with cement mortar [3, 4]. It not only improves the toughness of cement mortar but also inhibits the generation and development of early cracks in cement mortar. At present, many scholars study the effect of PVA fiber on the performance of cement mortar [5, 6]. Yuan et al. [7] studied the effect of PVA fiber dispersion on the properties of cement-stabilized macadam. The results show that when the mass ratio of PVA fiber to fly ash is greater than 1 : 50, the dispersion coefficient is greater than 0.95. PVA fiber can be evenly dispersed in cement-stabilized macadam, and the compressive strength and splitting strength of PVA cement-stabilized macadam are significantly higher than ordinary stabilized macadam. The mechanical properties of fiber-reinforced cement-based materials may vary greatly due to specific loading conditions. Ranjberian and Mechtcherine [8] studied the influence of loading parameters on crack bridging of PVA fiber-reinforced cement-based materials under cyclic tension compression condition. It was concluded that the bridging capacity decreased with the increase of cycle times under reverse tension compression loading. A damage quantification method was proposed.

However, the further increase in the strength performance of the cement-based materials by adding fibers is hard to achieve. This is because the excessive fibers may gather into clumps.

Polymer enhanced cement-based materials have the advantages of high tensile strength, good wear resistance, impermeability, and corrosion resistance and have good bonding performance with the old concrete [9–11]. Wang

et al. [12] systematically studied the polymer concrete materials used for rapid pavement repair, obtained the best mix ratio, and put it into practical application. The results show that it not only has good adhesion with waste cement blocks but also can be quickly repaired within two hours, which is superior to the related Chinese standard. Ukowski and Dbska [13] evaluated the performance of polymer cement mortar under sulfate attack. Through the changes in quality, compressive strength, and microscopic observations, the polymer cement composite material still has better sulfate resistance than Portland cement with enhanced sulfate resistance. Gadea et al. [14] studied the cement with different quality of rigid polymer foam waste, aggregate, and water to get different grades of mortar and compared with lightweight mortar produced by cement-based mixture. The results show that the increase of polymer dosage will affect the density and mechanical properties of mortar and improve the workability and impermeability of mortar. The feasibility of this type of polymer mortar material is confirmed [15, 16].

Therefore, it holds a great potential to add the polymer into the fiber enhanced cement-based materials to furtherly increase the strength performance. In this study, the self-developed nonaqueous reactive polyurethane material was prepared, which is formed by the reaction of polyether polyol and isocyanate [6] and polyurethane with PVA fiber cement mortar as a new repair material was carried out. The research compares the performance of polyurethane-modified PVA cement mortar and ordinary PVA cement mortar through compressive test, tensile test, and microstructure analysis.

2. Experimental Processes

2.1. Raw Materials. In this study, ordinary Portland cement (OPC, Type P.O. 52.5), wollastonite, and silica fume were used as the binder materials, and the commercially available quartz sand with particle size of about 0.18–0.40 mm was used as fine aggregate [17]. Wollastonite and silica fume are commonly used additives in concrete [18] and their incorporation in cement-based composites not only can reduce the carbon footprint [19] but also can improve the shrinkage resistance and water retention [20]. The main chemical compositions of OPC, wollastonite, and silica fume are listed in Table 1.

High-strength polyvinyl alcohol (PVA) fiber with elastic modulus of over 35 GPa, polyether polyol (Type WANEFO AM®9100-2A), and isocyanate (Type WANEFOAM® 9100-2B) were also incorporated. Polyether polyol and isocyanate were bought from Wanhua Chemical Group Co., Ltd., in Shandong Province, China, and when they are mixed at a mass ratio of 1 : 1, the nonfoaming polyurethane matrix with high flexibility and high yield strength can be obtained [21]. PVA fiber and polyurethane components mainly worked as the reinforcing materials in the cement-based composites [22, 23]. Besides, the high performance polycarboxylate water-reducer (Type PCA®-I) and industrial defoamer (Type J-198) were also incorporated as extra additives to regulate the workability of fresh cement-based composites.

2.2. Sample Preparation. In order to make the polyurethane-PVA fiber enhanced cement-based composite materials (PFCBCM), first, OPC, wollastonite, silica fume, and fine aggregates were uniformly mixed using a JJ-1 Type electrical mixer and then pouring the water solutions containing water-reducer and defoamer into the powdered mixtures and stirring the fresh composites for another 1 minute. Afterwards, PVA fibers were added into the mixtures as they were stirred in the next 3 minutes of mixing. Next, the mixture of polyether polyol and isocyanate (at a mass ratio of 1 : 1) was poured into the fresh cement-based composites containing PVA fibers, and the obtained mixtures were stirred for another 1 minute. The mixing design of the polyurethane-PVA fiber enhanced cement-based composites is as shown in Table 2.

The prepared PFCBCM were poured into the molds and then vibrated for about 2 minutes to release the residual air bubbles. The inner walls of the molds had been coated with demolding agent. After vibration, the excess composites were removed from the top of molds. The composites were cured in an environment with temperature of 23°C and relative humidity of 56% for 24 hours before demolding. After demolding, the hardened samples were cured in the same environment before conducting the mechanical properties tests. Cubic samples and prismatic samples were prepared for testing the uniaxial compressive strength and flexural strength of the composites, respectively. The geometric dimensions and tests of these two types of samples are shown in Figure 1.

2.3. Mechanical Properties Testing and Characterization. Both the uniaxial compression test and three-point bending test were carried out on the PFCBCM for characterizing their compressive strength and flexural strength, respectively [24, 25]. The testing procedure was conducted according to the requirements of Chinese standard GB/T17671-1999 [26], and the electro-hydraulic servo testing machines with type of WHY-2000 and WHY-300/10 were adopted for the uniaxial compression test and three-point bending test, respectively. The loading rates for the compressive strength and flexural strength characterizations were 2400 N/s and 50 N/s, respectively. Figure 2 shows the force diagram of the samples during the three-point bending test. Some petroleum jelly was used to reduce the friction action where the samples and testing machines contact. The compressive strength and flexural strength of the PFCBCM at the age of 7 days, 14 days, and 28 days were experimentally measured, and three samples were used for the mechanical properties' characterization.

Scanning electron microscope (SEM) experiment was carried out to characterize the microstructure properties of PFCBCM at age of 28 days. The micromorphology of the samples was observed at an accelerating voltage of 20 kV and amplification factor of 200X-2000X at a KYKY-EM6200 SEM system. Before observation, a gold layer was sprayed on the surface to increase the conductivity.

X-ray diffraction technique (XRD) was adopted to find out the influences of polyurethane on the phase compositions of the hardened composites.

Table 1: Chemical components of OPC, wollastonite, and silica fume.

Chemical components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Particle size (μm)	Loss on ignition (%)	Whiteness (%)
OPC	20~24	4~7	2.5~6.0	62~67	3.5	3~32	—	-
Wollastonite	48~52	—	≤0.5	45~48	—	2~4	≤2.5	≥90
Silica fume	92.75	0.28	0.59	0.28	0.89	0.5~1.5	3.26	—

Table 2: Mix ratio of polyurethane-PVA fiber cement mortar (kg/m^3).

Material	Cement	Wollastonite	Silica fume	Quartz sand	Polyurethane	PVA	PCA	Defoamer	Water
P-0	750	37.9	99	1100	0	14.3	8.25	0.55	297
P-5	736	37.2	97	1079	37.4	14.3	8.25	0.55	297
P-10	722	36.5	95	1059	74.3	14.3	8.25	0.55	297
P-15	708	35.8	93	1039	111.7	14.3	8.25	0.55	297
P-20	694	35.1	92	1018	148.5	14.3	8.25	0.55	297

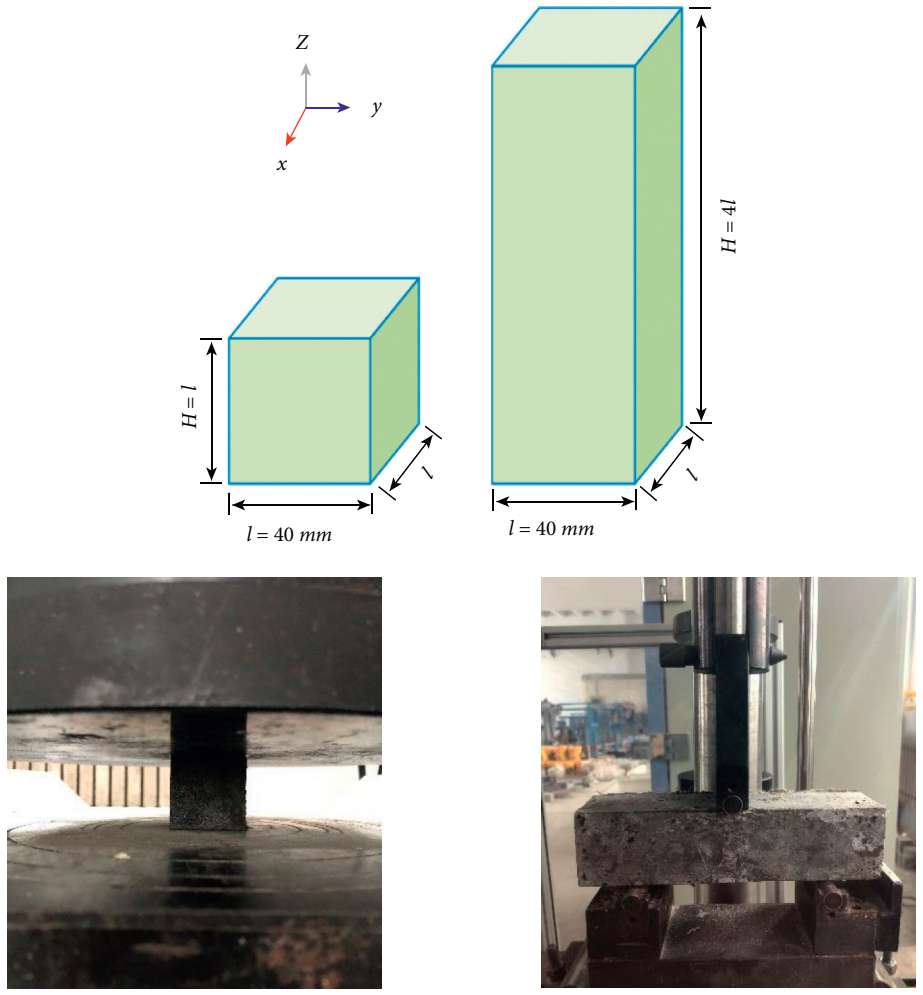


Figure 1: The geometric dimensions and tests of cubic samples and prismatic samples.

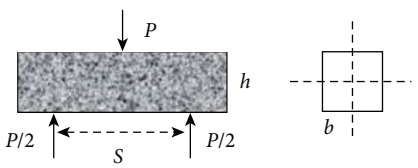


Figure 2: Schematic diagram and cross-section of three-point bending test.

3. Results and Discussion

3.1. Mechanical Properties of PFCBCM Samples under Uniaxial Compression. The damage pattern of the PFCBCM specimen with a curing age of 28 days is shown in Figure 3. As shown in Figure 3, the damage forms of unmodified PVA mortar and polyurethane-modified PVA mortar are different. The mortar matrix contains pores, moisture, microcracks, etc. The damage form is more complicated. The nature of compressive failure occurs on the plane of maximum principal stress. In the compressive stress-strain curve, when the stress level is low, the matrix will not produce cracks. When the stress level is higher, the microcracks will grow in the matrix. As the stress level increases, the size and number of microcracks will gradually increase. Finally, the shear failure surface is formed in the direction of 30°~60°with the load after several microcracks are penetrated. The polyurethane is added into the mortar matrix to prevent the propagation of the original defects in the matrix and improve the deformation ability of the matrix, toughness, and impact resistance. Therefore, penetrating cracks, elastic failure will not be formed. During the loading process, according to Griffith microcrack strength theory (formula (1)), the elastic modulus decreases with the increase of polyurethane content, so the fracture stress also decreases with the increase of polyurethane content [27].

$$\sigma_c = \sqrt{\left(\frac{E\gamma}{4c}\right)}, \tag{1}$$

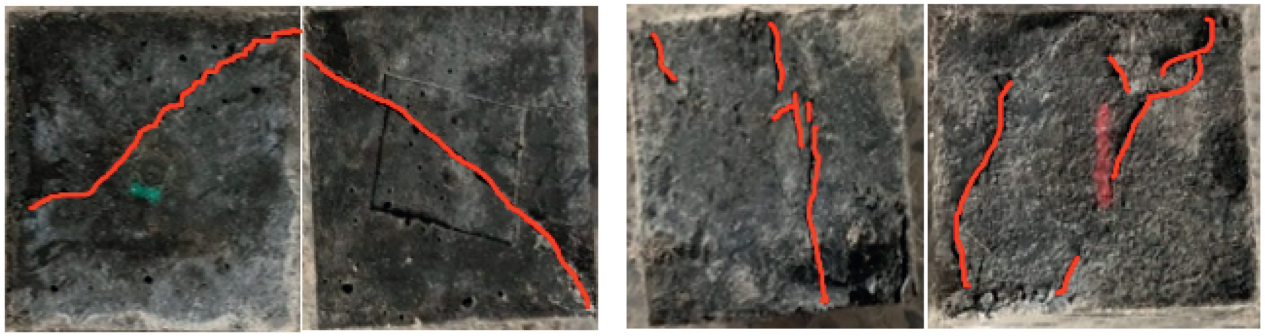
where σ_c is the fracture strength; E is the elastic modulus; γ is the surface energy density; and $4c$ is the (hole) crack length.

Figure 4 shows the representative stress-strain curve of PFCBCM samples with different contents of polyurethane at the age of 28 days. From Figure 4, one can read that the entire stress-strain curves of the PFCBCM samples can be divided into five different sections. OA: initial compaction section, the addition of polyurethane makes the initial compaction stage relatively lagging, filling the pores and cracks of the mortar structure. In the initial loading stage, the stress-strain curve is concave, which is caused by the internal pores of the material being compacted and closed; AB: in the linear elastic stage, the stress increases almost linearly with the strain, but the slope of the curve of the unmodified material is significantly greater and the failure threshold is not reached; BC: strain softening stage, in which microcracks begin to form and spread, indicating that plastic deformation has occurred. The addition of polyurethane effectively inhibits and reduces the occurrence of cracks so that the specimens produce small cracks without forming through seams (as shown in Figure 3). When the polyurethane content changes, the yield stage of the specimen before reaching the peak strength is longer; CD: the stress drop stage is caused by the coalescence of microcracks in the sample, and the specimen enters the yield failure stage. In contrast, the postpeak stress-strain curve of the unmodified material decreases rapidly, indicating that there is brittle failure; DE: residual strength section, in which the axial strain of the samples increases while the stress keeps almost unchanged.

Figure 4 also shows that when the mass content of polyurethane in the composites increases, the axial strain at which the initial compaction section is over becomes larger and the strain softening stage becomes more obvious; meanwhile, the slope of the liner elastic stage and the peak stress declines. These observations indicate the reduced strength of polyurethane-PVA enhanced cement-based composites under compression.

As shown in Figure 5, the peak strain depends on polyurethane-cement ratio and curing time. When the mass content of polyurethane in the composites increases, the axial strain at which the initial compaction section is over becomes larger and the strain softening stage becomes more obvious; meanwhile, the slope of the liner elastic stage and the peak stress declines. These observations indicate the reduced strength of polyurethane-PVA enhanced cement-based composites under compression. Because the mortar material structure itself has different initial defects, but polyurethane will affect the uniformity and continuity of the material microstructure and then affect the mechanical properties of the material. Based on the stress-strain curves, the compressive strength and elastic modulus of the PFCBCM can be obtained, and their variations versus the mass content of polyurethane are as shown in Figure 6. It can be seen from Figures 6(a)–6(c) that the peak strength shows a decreasing trend with the increase of polymer content. The main reason is that the elastic modulus of polymer materials is lower than that of cement and fine aggregates, which can only withstand tensile stress and have poor ability to withstand compressive stress. When the polymer content is 0–20%, the maximum peak strain of the HPMPCM sample is 3.0%. That is to say, when it reaches 3.0%, these materials enter the crack propagation stage and begin to slowly fail, which is the CD stage in Figure 4.

Figure 6(d) depicts the relationship between the peak strength of the PFCBCM sample and the elastic modulus. Elastic modulus can be regarded as an index to measure the difficulty of elastic deformation of materials. The larger the value is, the greater the stress of certain elastic deformation will be, that is, the greater the material stiffness, the smaller the elastic deformation will be under the action of certain stress. As shown in Figures 6(a)–6(c), the elastic modulus of PFCBCM samples with the same curing age is greater than that of unmodified PVA mortar. For polyurethane-modified mortar materials, the peak strength initially decreases with the increase of polyurethane content and then increases (the critical point is 10%). However, the change pattern of elastic modulus is not uniform. It can also be seen from Figures 6(a) and 6(b) that the peak strength of the 7 days and 14 days samples decreases with the increase of the polyurethane content, and the maximum reduction is 40.6% and 45.4%, respectively. Although the peak strength of the 28 days sample also showed a decreasing trend (Figure 6(c)), the relative reduction degree was relatively weak, with the maximum value of 18.1%. When the polyurethane content was 5%, the peak strength of the sample was 60.2 MPa, which was only 1.6% lower than that of the sample without polyurethane. The peak strength and elastic modulus of mortar materials with different curing times were analyzed



(a) (b)

Figure 3: Damage mode of PFCBCM (a) without polyurethane and (b) with polyurethane.

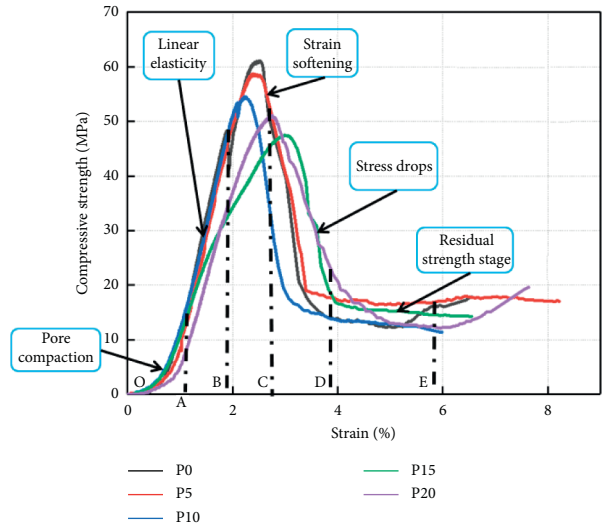


Figure 4: Representative stress-strain curves of 28 days PFCBCM samples with different contents of polyurethane.

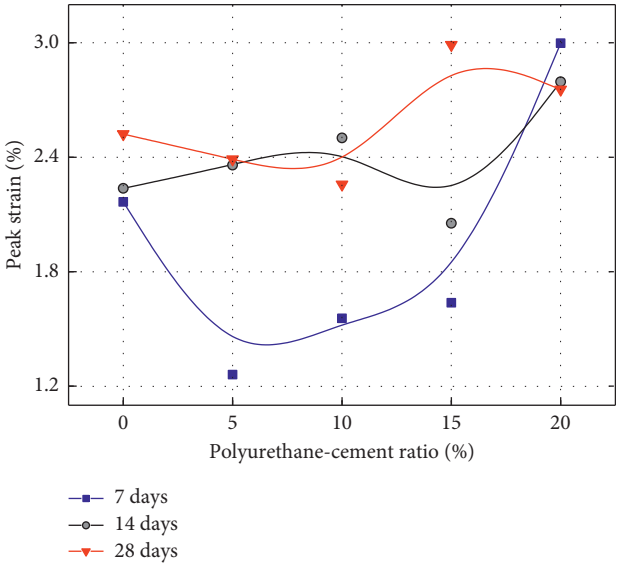


Figure 5: Variations of peak strain of PFCBCM versus mass content of polyurethane.

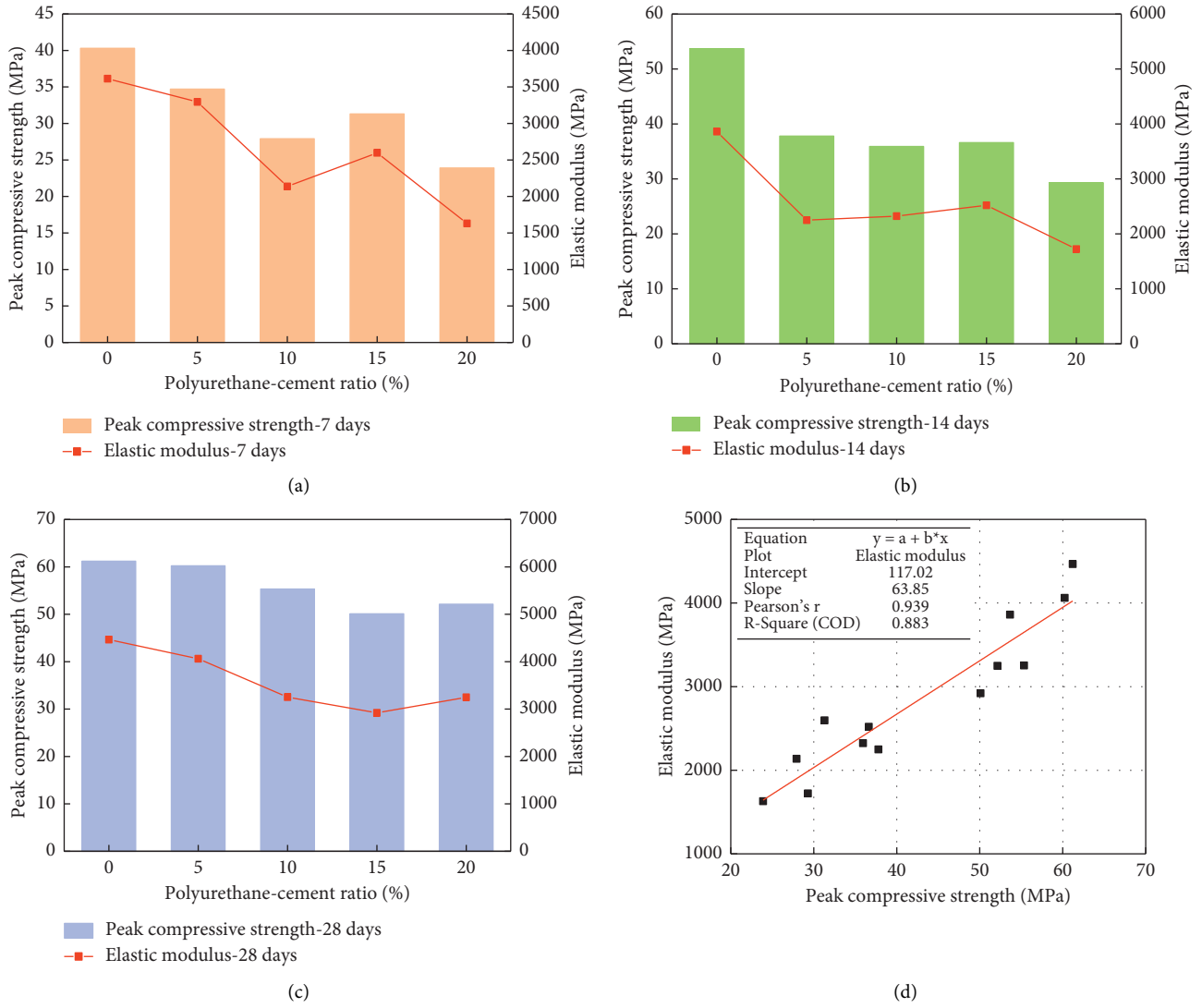


Figure 6: Variations of peak compressive and elastic modulus of PFCBCM composites versus mass content of polyurethane. (a) 7 days. (b) 14 days. (c) 28 days. (d) Fitting result.

by regression statistics analysis (Figure 6(d)). The elastic modulus and peak strength are consistent with the linear regression equation ($y = a + bx$). The correlation coefficient is 0.939, and the complex correlation coefficient is 0.883. The extension of the curing time increases the compressive strength of the PFCBCM sample, thereby increasing the elastic modulus.

It can be seen from Figure 7 that after blending the polyurethane slurry, with the increase of polyurethane content, the residual compressive strength of each group of mortar specimens increases first and then decreases. The change is greatest when the content is 10%, and compared with the unmodified mortar material, the early residual strength is almost higher than that of the unmodified mortar. The mortar specimens mixed with polyurethane showed ductile failure to varying degrees in the compression test, which improved the brittleness and toughness. The filling of the polyurethane in the mortar helped to inhibit and slow down the occurrence of internal defects in the mortar.

3.2. Bending Mechanical Properties of PFCBCM. It can be seen from Figure 8 that the flexural strength of the mortar first increases and then decreases with the increase of the polyurethane content. The improvement of flexural strength is mainly due to the polyurethane emulsion fills the pores of cement mortar materials, increases the compactness, reduces the formation of cracks, and improves the bonding between aggregate and cement matrix. When cracks are generated during the loading process, the polyurethane plays a role in inhibiting the propagation of the cracks, thereby improving the flexural strength of the mortar. It can be seen from Table 3 that the bending/compression ratio of the mortar increases due to the incorporation of high polyurethane, which indicates that the high polyurethane improves the plasticity and toughness of the mortar.

3.3. Microstructure Properties of PFCBCM Composites. In order to observe more accurately, the SEM test was carried

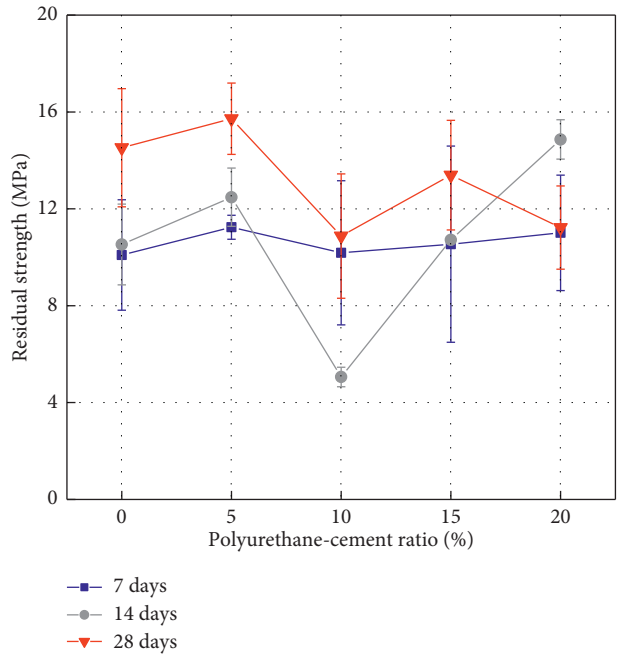


Figure 7: Variations of residual strength of PFCBCM versus mass content of polyurethane.

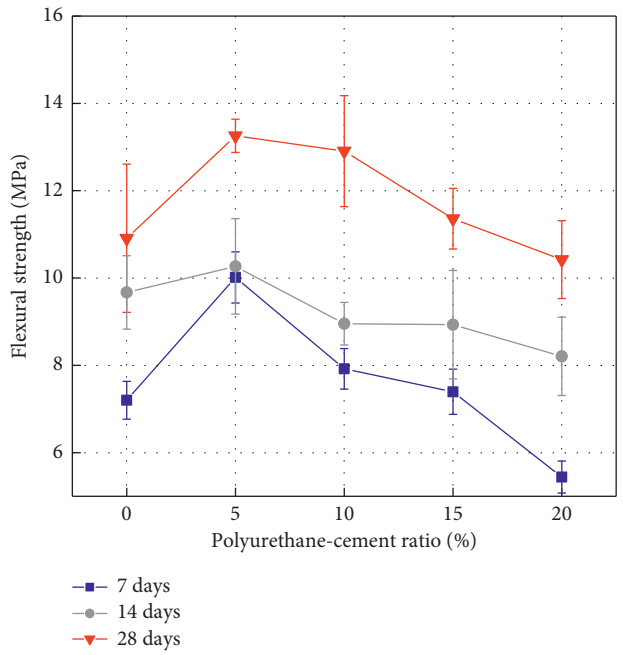
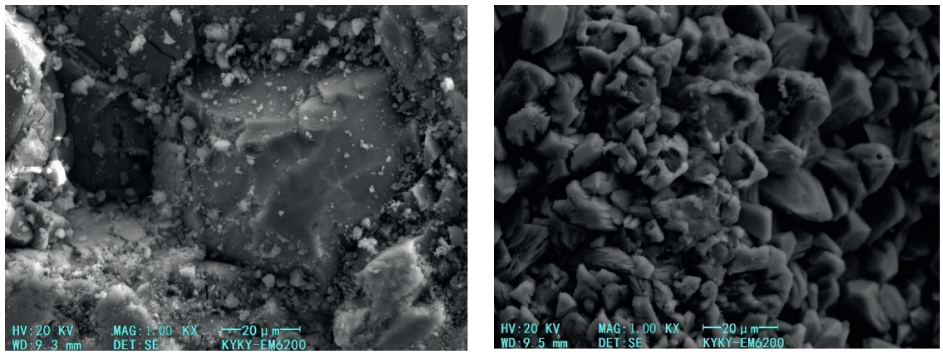


Figure 8: Variations of flexural strength of PFCBCM versus mass content of polyurethane.

out. As shown in Figure 9, there are microcracks and holes in the cement mortar material without high polyurethane, unevenness, and fast hydration reaction speed will lead to cracks and defects. It can be seen from Figure 9(b) polyurethane content that a layer of polyurethane film is formed on the surface of the particles. The formation of the polyurethane film inhibits cement hydration, reduces the internal pores of the material, and improves the bond between aggregate and cement matrix. Thus, a more compact microstructure is formed and therefore has a higher flexural strength. In order to verify that the polyurethane inhibits the cement hydration, the research carried out XRD tests. It can be seen from Figure 10 that regardless of whether polyurethane is added or not, the hydration products of $Ca(OH)_2$ and C-S-H gel are present, as well as C_3S. Since high polyurethane can inhibit cement hydration, the diffraction peak intensity of $Ca(OH)_2$ and CSH gel in cement mortar material without polyurethane is higher than PFCBCM (P5),

Table 3: Flexural/compression strength ratio of mortar.

Number	Flexural/compression strength (MPa)		
	7 days	14 days	28 days
P0	0.18	0.18	0.18
P5	0.29	0.27	0.22
P10	0.28	0.25	0.23
P15	0.24	0.28	0.23
P20	0.23	0.28	0.20



(a) (b)

Figure 9: SEM pattern (a) without polyurethane and (b) with polyurethane.

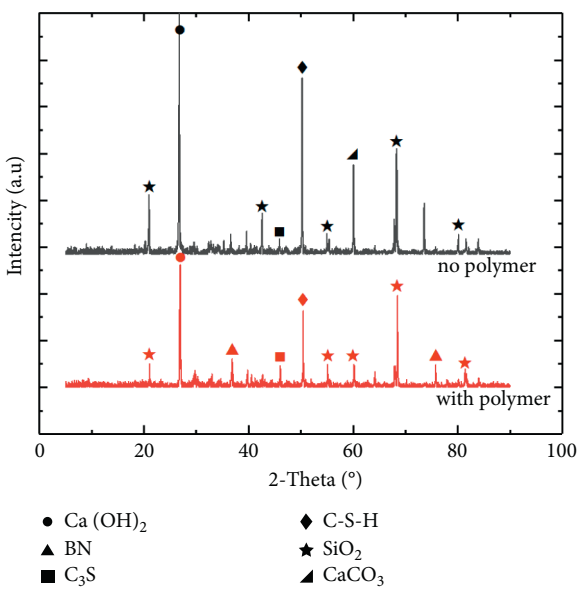


Figure 10: X-ray diffraction pattern without polyurethane and with polyurethane (P5).

which indicates that adding high polyurethane will inhibit the production of $Ca(OH)_2$ and C-S-H gel. In other words, calcium ions and hydroxide ions may accumulate in the solution, but $Ca(OH)_2$ precipitation will not be generated.

4. Conclusions

Compared with traditional mortar materials, polyurethane cement mortar composite materials have the characteristics of light weight, high strength, and good durability. The research on it through mechanical and microscopic tests summarizes as follows:

(1) The compressive strength of PFCBCM decreases with the increase of the polyurethane content. Because the polyurethane occupies a certain volume in the cement mortar material, its elastic modulus is less than that of cement and fine aggregates, and its ability to withstand compressive stress is poor.

(2) After the cement mortar material is mixed with high polyurethane, it prevents the expansion of microcracks in the matrix and improves the deformability of the matrix, toughness, and impact resistance.

(3) The addition of high polyurethane improves the flexural strength of PVA cement mortar, increases the compactness of the structure, and inhibits cement hydration. In the microcracks generated during the loading process, the polyurethane plays a role in inhibiting the crack propagation.

(4) The increase of polyurethane determines the improvement of mechanical properties and durability of modified cement mortar.

(5) According to XRD analysis, the formation of a small amount of C-S-H gel in polyurethane-modified PVA cement mortar is the main reason for improving the mechanical properties of cement mortar.

Data Availability

The data used to support the findings of this study are available from the first author upon request.

Conflicts of Interest

The authors declare that the work described has not been published before; that it is not under consideration for publication anywhere else; that its publication has been approved by all co-authors; and that there are no conflicts of interest regarding the publication of this article.

Authors' Contributions

Xijun Zhang wrote the original draft and curated the data; Mingrui Du conceptualized the study; Hongyuan Fang was responsible for funding acquisition; Xijun Zhang developed the methodology; Mingsheng Shi did project administration; Mingrui Du supervised the study; Chao Zhang edited and reviewed the manucript.

Acknowledgments

The authors would like to acknowledge the support by the National Key Research and Development Program of China (Grant no. 2017YFC1501204) and the National Natural Science Foundation of China (Grant nos. 51679219 and 51909242).

References

[1] P. Rossi, "High performance multimodal fiber reinforced cement composites (HPMFRCC)," *ACI Materials Journal*, vol. 94, pp. 478–483, 1997.

[2] E. T. Dawood and M. Ramli, "High strength characteristics of cement mortar reinforced with hybrid fibres," *Construction and Building Materials*, vol. 25, no. 5, pp. 2240–2247, 2011.

[3] A. I. Petrov, A. A. Antipov, and G. B. Sukhorukov, "Base–Acid equilibria in polyelectrolyte systems: from weak polyelectrolytes to interpolyelectrolyte complexes and multilayered polyelectrolyte shells," *Macromolecules*, vol. 36, no. 26, pp. 10079–10086, 2003.

[4] Y. Qi, "Effect of feedstocks on structure and properties of high-strength high-modulus polyvinyl alcohol fiber," *China Synthetic Fiber Industry*, vol. 30, pp. 14–16, 2007.

[5] M. R. Karim and M. F. M. Zain, "Influence of slag and slag cement on the strength of sustainable concrete," *Advanced Materials Research*, vol. 383-390, pp. 3410–3415, 2012.

[6] S. Wen, S. Wang, and D. D. L. Chung, "Piezoresistivity in continuous carbon fiber polymer-matrix and cement-matrix composites," *Journal of Materials Science*, vol. 35, no. 14, pp. 3669–3675, 2000.

[7] L. Yuan, N. Liang, C. Zhao, and C. Mazzotti, "Analysis on influence of the dispersion degree of PVA fibers on pavement performance of cement-stabilized macadam," *Advances in Civil Engineering*, vol. 2019, pp. 1–11, Article ID 5127015, 2019.

[8] M. Ranjbarian and V. Mechtcherine, "Influence of loading parameters in cyclic tension-compression regime on crack-bridging behaviour of PVA microfibres embedded in cement-based matrix," *Construction and Building Materials*, vol. 228, pp. 116760-116761, 2019.

[9] A. Danish, M. A. Mosaberpanah, and M. U. Salim, "Robust evaluation of superabsorbent polymers as an internal curing agent in cementitious composites," *Journal of Materials Ence*, vol. 56, no. 1, pp. 136–172, 2020.

[10] L. K. Aggarwal, P. C. Thapliyal, and S. R. Karade, "Properties of polymer-modified mortars using epoxy and acrylic emulsions," *Construction and Building Materials*, vol. 21, no. 2, pp. 379–383, 2007.

[11] Y. K. Wang, Y. S. Wan, and Q. Liu, "The study on interfacial shear properties of non-water reacted polymer and geomaterials," *Journal of Building Materials*, vol. 24, pp. 1–13, 2020.

[12] H. Wang, H. X. Liu, and C. H. Zhuang, "Study on the polyurethane concrete for the rapid repairment of highway pavement," *Applied Mechanics and Materials*, vol. 193-194, pp. 762–769, 2012.

[13] P. Ukowski and D. Dbska, "Effect of polymer addition on performance of portland cement mortar exposed to sulphate attack," *Materials*, vol. 13, no. 1, p. 71, 2020.

[14] J. Gadea, A. Rodríguez, P. L. Campos, J. Garabito, and V. Calderón, "Lightweight mortar made with recycled polyurethane foam," *Cement and Concrete Composites*, vol. 32, no. 9, pp. 672–677, 2010.

[15] L. X. Z. WANGLing-ling, "Modification of high performances of polymer cement concrete," *Journal of Wuhan University of Technology*, vol. 18, pp. 61–64, 2003.

[16] X. I. Xiao-Lin, M. M. Fang, Z. Y. Wen, Q. Yin, D. Lin, and H. C. Wang, "Analysis of action mechanism of PVA polymers on high performance cement-based composites," *Journal of Materials Science and Engineering*, vol. 2, 2008.

[17] N. M. P. Low and J. J. Beaudoin, "The flexural toughness and ductility of portland cement-based binders reinforced with wollastonite micro-fibres," *Cement and Concrete Research*, vol. 24, no. 2, pp. 250–258, 1994.

[18] X. Fu and D. D. L. Chung, "Combined use of silica fume and methylcellulose as admixtures in concrete for increasing the bond strength between concrete and steel rebar 11Communicated by D.M. Roy," *Cement and Concrete Research*, vol. 28, no. 4, pp. 487–492, 1998.

[19] A. B. Srinivasreddy, T. J. Mccarthy, and E. Lume, Effect of rice husk ash on workability and strength of concrete, 2013.

[20] T. A. Hammer, "Effect of silica fume on the plastic shrinkage and pore water pressure of high-strength concretes," *Materials and Structures*, vol. 34, no. 239, pp. 273–278, 2001.

[21] F. M. Wang, M. S. Shi, H. J. Li, and Y. H. Zhong, "Experimental study on the anti-permeability properties of polymer grouting materials," *Advanced Materials Research*, vol. 284-286, pp. 1952–1955, 2011.

[22] A. Ogawa, T. Horikoshi, and H. Hoshiro, "Polyvinylalcohol fiber reinforced cement-based composites/mit polyvinylalkohol (PVA) fasern verstrkte zement gebundene zusammengesetzte werkstoffe," *Restoration of Buildings & Monuments*, vol. 12, no. 2, pp. 101–108, 2006.

[23] A. Pearson and H. E. Naguib, "Novel polyurethane elastomeric composites reinforced with alumina, aramid, and poly(p-phenylene-2,6-benzobisoxazole) short fibers, development and characterization of the thermal and dynamic mechanical properties," *Composites Part B: Engineering*, vol. 122, pp. 192–201, 2017.

[24] D. Hoxha, V. N. Ungureanu, N. Belayachi, D. P. Do, and J. B. Thevard, "Hydromechanical properties of some mortars used in some ecologic construction techniques," *Advanced Materials Research*, vol. 587, pp. 6–10, 2012.

[25] A. P. Fantilli, B. Chiaia, and A. Gorino, "Ecological and mechanical assessment of lightweight fiber-reinforced concrete made with rubber or expanded clay aggregates," *Construction and Building Materials*, vol. 127, pp. 692–701, 2016.

[26] N. C. S. T. Committee, *Method of Testing Cements-Determination of Strength: GB/T 17671-1999*, Chinese Standard.net, China, 1999.

[27] J. M. L. d. Reis and J. O. M. L. Dos, "Effect of temperature on the mechanical properties of polymer mortars," *Materials Research*, vol. 15, no. 4, pp. 645–649, 2012.