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Research Article

Effect of Polypropylene Fiber on the Strength and Dry Cracking of Mortar with Coal Gangue Aggregate

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Fine coal gangue aggregate (CGA) has a high water absorption, which increases the cracking risk of mortar caused by dry shrinkage. The effects of polypropylene (PP) fiber on the fluidity, strength, dry shrinkage, and cracking of CGA mortar were studied in this paper. The results show that PP fiber reduces the fluidity of CGA mortar, but PP fiber improves compressive and flexural strengths, especially at the early stages. PP fiber also effectively decreases dry shrinkage and the risk of cracking. Overall, PP fiber can effectively improve the properties of CGA mortar.

1. Introduction

Coal gangue is a kind of solid waste discharged during coal mining. Explosion caused by spontaneous combustion during the stacking of coal gangue often happens. It also seriously pollutes the soil and groundwater [1]. Many relative studies and applications have been carried out in China. Coal gangue is mainly used to make sintered brick instead of clay [2], but the application has been limited after 2017 due to high energy consumption in production and high sulfur content in the gas. Coal gangue with a high content of kaolinite also can be used as an active mineral admixture by calcination at 600–700°C [3], but a great amount of fly ash and blast-furnace slag can be used.

River sand has been a kind of shortage resource in China, but the demand for fine aggregaterises in recent years. CGA becomes a new try at present. It often decreases the workability and strength of concrete [4], and high replacement will aggravate the effects [5]. For a replacement of 100%, compressive strength, tensile splitting strength, and elastic modulus are reduced by 19.4%, 36.1%, and 32.2%, respectively [6]. The axial compression failure mode also will transform from shear failure to longitudinal splitting failure [7]. The above effects of CGA are related to its low strength and high water absorption [8]. If CGA is activated, the strength of concrete may be improved [9].

The high water absorption of CGA also seriously affects dry shrinkage, and the cracking also frequently happens, especially for plastering mortar. However, relevant studies are very rare. Wang [4] found that CGA increases drying shrinkage by 62%–92% in 360 d. Shrinkage-reducing admixture can reduce this effect but also decrease the strength [10]. Therefore, how to effectively reduce dry shrinkage caused by CGA needs a lot of research.

Fiber reinforcement is an effective method to improve the cracking resistance of concrete. PP fiber is a kind of common fiber due to its low price and excellent performance. PP fiber can obviously reduce dry shrinkage [11–13], and higher PP fiber content will enhance the effectiveness [14]. The physical properties of PP fiber, such as elasticity module [15] and length [16], also have some effects. In addition, PP fiber results in a reduction of chloride diffusivity [17].

Coal gangue due to low strength is usually made to fine aggregate. Fine CGA plastering mortar often has a high w/b, so the cracking frequently occurs. The effect of PP fiber on the drying shrinkage of fine CGA mortar or concrete is also rarely paid attention. Therefore, in this paper, PP fiber was introduced to a mortar in which fine CGA was used to replace all river sand. The effects of PP fiber on dry shrinkage and the cracking were studied here. The changes in mortar's fluidity and strength caused by PP fiber were also considered.

2. Raw Materials and Experimental Methods

2.1. Raw Materials. PO 42.5 cement adopted here met the requirements of GB175-2007. The chemical composition of coal gangue is shown in Table 1. Fine aggregate made by coal gangue met the requirements of II zone in GB/T 14684–2011, as shown in Table 2.

Table 1: Chemical composition of coal gangue (%).

SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	TiO_2	Na_2O	MgO
57.92	22.99	7.58	5.29	1.66	1.43	1.14	0.90

Table 2: The size distribution of CGA.

Screen size (mm)	Accumulated retained percentage	
	Experimental value	The requirement of II zone
4.75	3	10~0
2.36	17	25~0
1.18	45	50~10
0.60	68	70~41
0.30	90	92~70
0.15	99	100~90

The property indexes of PP fiber are shown in Table 3. A kind of polycarboxylic acid superplasticizer was used, and water reducing rate was 20%. Mixing water used was tap water.

2.2. Experimental Method. The mixing ratio of cement, fine CGA, and water is 1: 3: 0.5. The amount of PP fiber was 0.6 kg/m^3, 0.9 kg/m^3, 1.2 kg/m^3, and 1.5 kg/m^3 (mortar volume), respectively. The amount of water-reducing agent is 0.8% of cement.

Fine CGA and PP fiber was firstly mixed to increase the dispersion of PP fiber at 62 r/min for 30 s. In another 30 s, cement and the mixture of water-reducing agent and water were added. After standing for 60 s, the mortar was mixed at 125 r/min for 1 min.

The fluidity of mortar was obtained by measuring the spread diameters of fresh mortar without vibration according to JC/T 985–2017.

Flexural and compressive strengths of mortar were measured according to GB/T 17671–1999. The sizes of samples were 40 mm × 40 mm × 160 mm. According to the deviations of Tables 4 and 5, the adverse effect of fiber distribution on the strengths is little in our experiments.

Dry shrinkage was measured according to JC/T 603–2004. The sizes of samples were 25 mm × 25 mm × 280 mm. After unmoulding at 24 h, the samples were continued to be cured at 20°C ± 1°C and more than 95% RH for 2 days. The lengths (L_0) were measured. And then, the samples were placed at 20°C ± 1°C and 50% RH. The lengths of samples (L_n) were measured at 7 d, 14 d, 21 d, and 28 d. Dry shrinkage rate was calculated according to

$$S_n = \frac{(L_0 - L_n) \times 100}{250}, \quad (1)$$

where S_n is the dry shrinkage rate at n day (%); L_0 is the length at 3 d, mm; L_n is the length at n d, mm; and 250 is an effective testing length, mm.

Plastic shrinkage is also thought to be the early-aged stage of dry shrinkage, but mortar is very easy to crack in this stage when it is exposed to powerful sunlight or wind. The cracking of CGA mortar in the stage was measured according to the plate cracking test provided by CCES 01–2018. The sizes of samples were 600 mm × 600 mm × 50 mm. The surface was immediately covered with plastic film after moulding. The ambient temperature was maintained at 20°C, and the relative humidity was 60%. After 2 hours, the plastic film was removed, and the surface was blown by an electric fan at a wind speed of 8 m/s. The total number of cracks and the length and highest width of every crack at 24 h were recorded. The crack's length and the shortest distance of two endpoints of every crack were measured by a ruler. The highest width of every crack was automatically measured using a good crack width-measuring instrument. The distance between the lens and measuring surface was maintained at about 6 mm. The magnification (optical) was 40 times every measure. When the crack is longer, it will get divided into several segments, and the maximum value was selected. The length and highest width of each crack were measured 3 times, and the average value was taken. The average area per crack and the number of cracks and cracking area per unit area were calculated at 24 hours according to

$$a = \frac{1}{2N} \sum_{i=1}^{N} (W_i \times L_i), \quad (2)$$

$$b = \frac{N}{A}, \quad (3)$$

$$c = a \times b, \quad (4)$$

where a is the average area of per crack, mm^2; b is the number of cracks in unit area, 1/m^2; c is the total cracking area in unit area, mm^2/m^2; N is the total number of cracks; W_i is the highesr width of the i^{th} crack, mm; L_i is the length of the i^{th} crack, mm; and A is the upper surface area of the plate, mm^2. The amount of plate samples was two.

3. Results and Discussion

3.1. Fluidity. The fluidity of CGA cement mortars with PP fiber is shown in Figure 1. PP fiber decreases the fluidity of CGA mortar, and a higher amount of PP fiber will enhance the effect. For example, when the amount of PP fiber increases from 0.6 kg/m^3 to 1.5 kg/m^3, the fluidity decreases by 15%. These results are also similar to other studies [11, 12]. It

Table 3: Properties indexes of PP fiber.

Type	Length (mm)	Diameter (μm)	Density (g/cm^3)	Tensile strength (MPa)	Elastic modulus (MPa)	Softening point (°C)	Tensile limit (%)
Monofilament	3	0.91	>400	>3500	160	165	15

Table 4: Testing results of flexural strengths and their deviations.

PP (%)	3d testing (MPa)	Average (MPa)	Deviation (%)	3d testing (MPa)	Average (MPa)	Deviation (%)
0	5.67	5.78	1.90	9.53	9.78	2.56
	5.99		3.63	9.68		1.02
	5.68		1.73	10.13		3.58
	6.48		0.15	9.87		2.66
0.6	6.6	6.49	1.69	10.06	10.14	0.79
	6.39		1.54	10.49		3.45
	5.81		6.74	9.72		2.99
0.9	6.31	6.23	1.28	10.38	10.02	3.59
	6.57		5.46	9.96		0.60
	5.98		0.67	9.87		0.70
1.2	5.63	5.94	5.22	10.43	9.94	4.93
	6.21		4.55	9.52		4.23
	5.76		1.20	9.55		3.24
1.5	6.23	5.83	6.86	10.29	9.87	4.26
	5.50		5.66	9.77		1.01

Table 5: Testing results of compressive strengths and their deviations.

PP (%)	3d testing (MPa)	Average (MPa)	Deviation (%)	3d testing (MPa)	Average (MPa)	Deviation (%)
0	18.6	19.3	3.63	42.8	43.8	2.28
	19.4		0.52	44.7		2.05
	19.1		1.04	42.9		2.05
	20		3.63	43.8		0.00
	19.2		0.52	44.9		2.51
	19.5		1.04	43.7		0.23
0.6	21.9	22.7	3.52	49.7	48.5	2.44
	22.8		0.44	49.2		1.41
	22.3		1.76	47.6		1.89
	21.9		3.52	46.8		3.54
	23.8		4.85	48.3		0.45
	23.5		3.52	49.5		2.03
0.9	22.8	22.7	0.51	46.2	47.4	2.57
	22.1		2.57	47.2		0.46
	22.5		0.81	48.1		1.44
	21.9		3.45	49.2		3.76
	23.6		4.04	46.5		1.93
	23.2		2.28	47.3		0.25
1.2	21.2	22.2	4.65	43.6	45.8	4.77
	22.2		0.15	44.8		2.15
	21.3		4.20	47.2		3.09
	23.5		5.70	46.9		2.44
	22.1		0.60	46.5		1.57
	23.1		3.90	45.7		0.18
1.5	21.7	21.4	1.32	46.4	45.3	2.39
	20.5		4.28	45.1		0.48
	20.7		3.35	43.7		3.57
	22.1		3.19	44.6		1.58
	20.9		2.41	47.2		4.16
	22.6		5.53	44.9		0.92

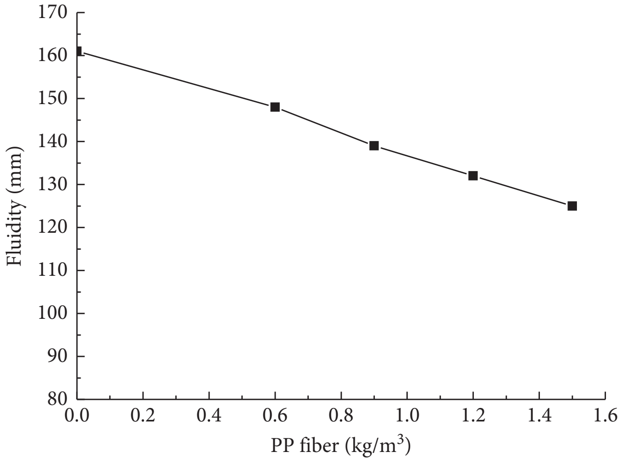

Figure 1: Effect of PP fiber on the fluidity of CGA mortar.

is generally thought that fine and long PP fibers are irregularly distributed in the mortar, and a similar mesh structure [11, 12] will be formed which impedes the relative movement of particles. The higher the fiber content is, the greater the impedance will be and the lower the fluidity of mortar will be. Therefore, too many fibers will reduce their dispersion in mortar. In addition, PP fiber with larger length-to-diameter ratio also reduces the fluidity of mortar because it clumps easily in mortar mixing [16].

3.2. Strength. The effects of PP fiber on the strengths are related to its amount as shown in Figure 2. When the amount of PP fiber is 0.6 kg/m^3, the mortar has higher strengths. Compressive strengths at 3 d and 28 d are increased by 17.6% and 10.7%, respectively. However, higher amount of PP fiber, such as 0.9 kg/m^3, will decrease the strength. Overall, PP fiber still increases the strengths of mortar, especially at the early stages. For example, compressive strengths of mortar with 1.5 kg/m^3 of PP fiber at 3 d and 28 d are increased by 10.9% and 3.4%, respectively, compared with those of mortar without PP fiber. Leong et al. [12] also found that PP fiber plays a more evident strengthening role at the early stage than at the later stage.

3.3. Cracking and Dry Shrinkage. The effects of PP fiber on the dry shrinkage of CGA mortar are shown in Figure 3. The CGA mortar without PP fiber has very large dry shrinkage, but when PP fiber is added, the rates of dry shrinkage at all ages are decreased. Especially for the sample with 0.9 kg/m^3 of PP fiber, the rates of dry shrinkage at 7 d, 14 d, 21 d, and 28 d is decreased by 18.1%, 16.9%, 17.0%, and 18.3%, respectively. This indicates that PP fiber has a similar effectiveness in CGA mortar and other mortars [11–14].

The improvement of PP fiber on the cracking of CGA mortar is shown in Figure 4 and Table 6.

CGA mortar without PP fiber has many long and wide cracks at 24 h. When PP fiber is added, the number of cracks is significantly reduced and the cracks also become fine and short (Figure 4(b)). For example, the mortar with 0.9 kg/m^3 of PP fiber has much lower *a*, *b*, and *c* values which are reduced by 79%, 67%, and 93%, respectively, compared with the corresponding values of the mortar without PP fiber. This indicates that PP fiber can improve the cracking resistance of CGA mortar. However, higher amount of PP fiber may reduce the effectiveness on dry shrinkage and cracking resistance of CGA mortar.

3.4. Discussion. The above results indicate that PP fiber can increase the strength of CGA mortar and reduce the risk of cracking. These effects are related to the role of PP fiber in the mortar. PP fiber has large elongation capacity, while cement mortar is a kind of brittle material. When the mortar suffers from tension stress, mortar matrix is affected more greatly. Even when mortar matrix is broken, PP fibers were only pulled out from mortar (Figure 5). Therefore, PP fibers can prevent cracks from extending before being pulled out [18].

This behavior of fibers is related to their bridging effect in the mortar which can be testified in Figure 6. Several fibers are pulled out, but a PP fiber of two ends rooted in the mortar matrix is also found. Leong et al. [12] thought that the bridging of fiber can prevent the development of cracks. PP fiber is also tightly wrapped by cement paste, but the bond of PP fiber with mortar matrix is generally considered to be a physical bond [18]. The binding force is related to the elastic modulus and surface state of fiber. Fiber with high surface roughness or elastic modulus has a high binding force with paste [19, 20]. Spiral or hooked fibers also have a greater adhesion with paste than linear fibers [21, 22].

The disorderly distributed network structure also produces a high binding force which prevents the relative movement of paste particles [18]. However, too much fiber will reduce the continuity of cement paste and the distributive uniformity of fiber in mortar [11, 12]. As a result, the positive effects of PP fiber on the strength and dry shrinkage will be reduced.

It is needed to note that PP fibers only prevent the development of cracks but do not inhibit their generation

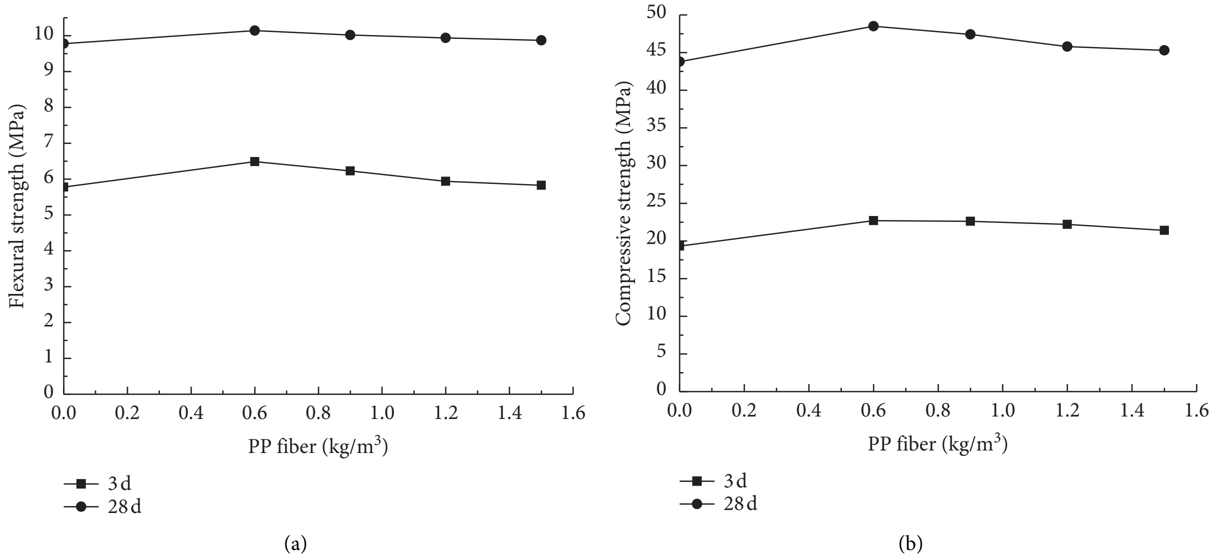

Figure 2: Effect of PP fiber on the strength of CGA mortar. (a) Flexural strength. (b) Compressive strength.

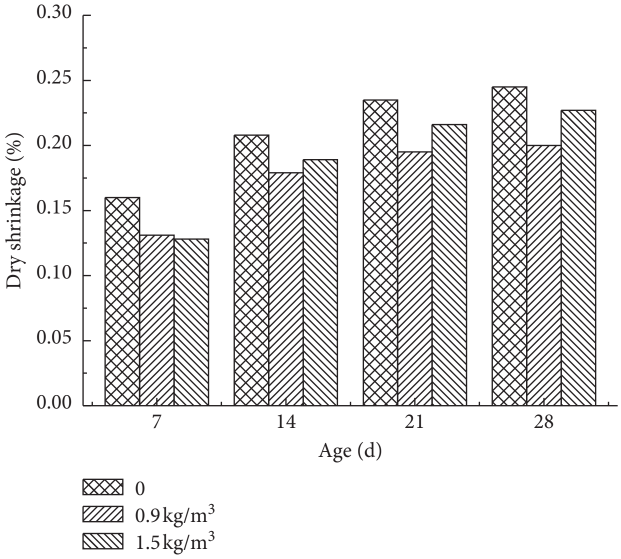

Figure 3: Effect of PP fiber on the dry shrinkage of CGA mortar.

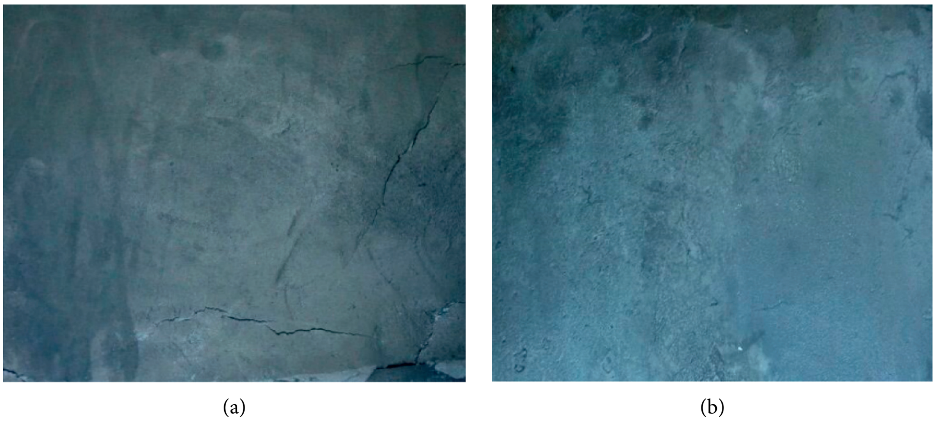
(a) (b)

Figure 4: Surface of CGA mortars with and without PP fiber. (a) Without PP fiber. (b) 0.9% PP fiber.

Table 6: Effect of PP fiber on the cracking of CGA mortar.

PP fiber (%)	A (mm^2)	B (1/mm^2)	C (mm^2/m^2)
0	122.6	25.0	3065.0
0.9	26.7	8.3	221.6
1.5	32.3	11.1	358.5

Figure 5: Flexural fracture of CGA mortar.

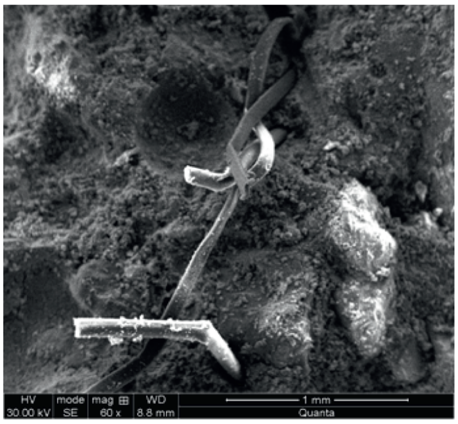

Figure 6: PP fibers inCGA mortar.

[18] as shown in Figure 4 and Table 6. Therefore, shrinkage-reducing agent or expansion agent should be introduced to eradicate dry cracking of CGA mortar.

4. Conclusion

The fluidity, strength, dry shrinkage, and cracking of CGA mortar with PP fiber were studied, and the conclusions are as follows:

(1) PP fiber decreases the fluidity of CGA mortar. With increase in the content of fiber, the fluidity is further decreased.

(2) PP fiber can improve the strength of CGA mortar, especially at the early stage, but there is an appropriate amount for PP fiber.

(3) PP fiber can decrease the dry shrinkage and cracking. However, when the amount of PP fiber exceeds a certain value, the effectiveness will be reduced.

PP fiber can effectively reduce the negative effects of coal gangue on cement mortar, but some reducing shrinkage measures still need to be considered.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] S. S Yan and W. Q. Zhang, "Dissolution properties of lead, chromium and cadmium in coal gangue," *Environmental Protection of Chemical Industry*, 2020.

[2] H. Xu, W. Song, W. Cao et al., "Utilization of coal gangue for the production of brick," *Journal of Material Cycles and Waste Management*, vol. 19, no. 3, pp. 1270–1278, 2017.

[3] J. Geng, M. Zhou, Y. Li et al., "Comparison of red mud and coal gangue blended geopolymers synthesized through thermal activation and mechanical grinding preactivation," *Construction and Building Materials*, vol. 153, pp. 185–192, 2017.

[4] Q. Wang, Z. Li, Y. Zhang, H. Zhang, M. Zhou, and Y. Fang, "Influence of coarse coal gangue aggregates on elastic modulus and drying shrinkage behaviour of concrete," *Journal of Building Engineering*, vol. 32, p. 101748, 2020.

[5] M. Xiao, F. Ju, and Z.-q. He, "Research on shotcrete in mine using non-activated waste coal gangue aggregate," *Journal of Cleaner Production*, vol. 259, Article ID 120810, 2020.

[6] Y. Zhang, Q. Wang, M. Zhou, Y. Fang, and Z. Zhang, "Mechanical properties of concrete with coarse spontaneous combustion gangue aggregate (SCGA): experimental investigation and prediction methodology," *Construction and Building Materials*, vol. 255, Article ID 119337, 2020.

[7] M. Zhou, Y. Dou, Y. Zhang, Y. Zhang, and B. Zhang, "Effects of the variety and content of coal gangue coarse aggregate on the mechanical properties of concrete," *Construction and Building Materials*, vol. 220, pp. 386–395, 2019.

[8] S. W. Li, M. Zhou, and L. M. Zhang, "Characteristics of spontaneous combustion gangue coarse aggregate and its influence on concrete performance," *Journal of Building Materials*, vol. 23, no. 02, pp. 334–340, 2020.

[9] Z. Dong, J. Xia, C. Fan, and J. Cao, "Activity of calcined coal gangue fine aggregate and its effect on the mechanical behavior of cement mortar," *Construction and Building Materials*, vol. 100, pp. 63–69, 2015.

[10] H. Ma, H. Zhu, C. Wu et al., "Effect of shrinkage reducing admixture on drying shrinkage and durability of alkali-

activated coal gangue-slag material," *Construction and Building Materials*, vol. 270, Article ID 121372, 2020.

[11] X. Guan, J. Chen, J. Qiu, Y. Gao, and J. Gao, "Damage evaluation method based on ultrasound technique for gangue concrete under freezing-thawing cycles," *Construction and Building Materials*, vol. 246, Article ID 118437, 2020.

[12] G. W. Leong, K. H. Mo, Z. P. Loh et al., "Mechanical properties and drying shrinkage of lightweight cementitious composite incorporating perlite microspheres and polypropylene fibers," *Construction and Building Materials*, vol. 246, Article ID 118410, 2020.

[13] F. Alrshoudi, H. Mohammadhosseini, M. M. Tahir et al., "Drying shrinkage and creep properties of prepacked aggregate concrete reinforced with waste polypropylene fibers," *Journal of Building Engineering*, vol. 32, p. 101522, 2020.

[14] J. Gong, W. Zeng, and W. Zhang, "Influence of shrinkage-reducing agent and polypropylene fiber on shrinkage of ceramsite concrete," *Construction and Building Materials*, vol. 159, pp. 155–163, 2018.

[15] N. Yousefieh, A. Joshaghani, E. Hajibandeh, and M. Shekarchi, "Influence of fibers on drying shrinkage in restrained concrete," *Construction and Building Materials*, vol. 148, pp. 833–845, 2017.

[16] D. Shen, X. Liu, X. Zeng, X. Zhao, and G. Jiang, "Effect of polypropylene plastic fibers length on cracking resistance of high performance concrete at early age," *Construction and Building Materials*, vol. 244, p. 117874, 2020.

[17] V. Afroughsabet, L. Biolzi, P. J. M. Monteiro, and M. Monteiro, "The effect of steel and polypropylene fibers on the chloride diffusivity and drying shrinkage of high-strength concrete," *Composites Part B: Engineering*, vol. 139, pp. 84–96, 2018.

[18] H. R. Pakravan and T. Ozbakkaloglu, "Synthetic fibers for cementitious composites: a critical and in-depth review of recent advances," *Construction and Building Materials*, vol. 207, pp. 491–518, 2019.

[19] A. M. López-Buendía, M. D. Romero-Sánchez, V. Climent, and C. Guillem, "Surface treated polypropylene (PP) fibres for reinforced concrete," *Cement and Concrete Research*, vol. 54, pp. 29–35, 2013.

[20] L. Akand, M. Yang, and X. Wang, "Effectiveness of chemical treatment on polypropylene fibers as reinforcement in pervious concrete," *Construction and Building Materials*, vol. 163, pp. 32–39, 2018.

[21] J. Qi, Z. J. Z. Wu, and J. Wang, "Pullout behavior of straight and hooked-end steel fibers in UHPC matrix with various embedded angles," *Construction and Building Materials*, vol. 191, pp. 764–774, 2018.

[22] Y. Hao and H. Hao, "Pull-out behaviour of spiral-shaped steel fibres from normal-strength concrete matrix," *Construction and Building Materials*, vol. 139, pp. 34–44, 2017.