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Effect of Textile Sludge on Strength, Shrinkage, and Microstructure of Polypropylene Fiber Concrete

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Abstract: Textile sludge has complex components and certain toxicity, which is in urgent need of resource treatment. The effect of textile sludge replacing cement and aggregates on the properties of polypropylene fiber concrete has been investigated by testing the compressive strength, drying shrinkage, heavy metal leaching concentration, micro morphology, and nanomechanical properties. The results show that the utilization of 10% textile sludge replacing cement increases the later strengths of concrete and decreases the drying shrinkage due to its denser microstructure. With the further content increase of textile sludge replacing cement, the strengths of concrete are reduced and the drying shrinkage is increased. The utilization of textile sludge replacing aggregates increases the compressive strengths of concrete and the drying shrinkage at every age, and among them, the concrete with 15% textile sludge replacing aggregates shows the highest compressive strengths, and the drying shrinkage of concrete increases with the content increase of textile sludge replacing aggregates. The concrete with textile sludge is a good solidification with heavy metal ions. The utilization of 10% textile sludge replacing cement improves the microstructure of concrete and helps to produce more high-density calcium silicate hydrate and reduces the thickness of the interfacial transition zone.

Keywords: textile sludge; strength; polypropylene fiber concrete; shrinkage; microstructure

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1. Introduction

Textile sludge is generated during the liquid effluents treatment processes of the textile industry, and is mainly composed of various bacteria, colloids, organic and inorganic particles, and some heavy metals [1]. Textile sludge is a dangerous waste sludge and is difficult to dispose of. The undisposed textile sludge not only occupies a large amount of farmland but also causes greater environmental pollution, which seriously hinders the sustainable development of textile industry. The disorderly disposal of textile sludge costs a lot of money, which urgently needs improvement. The current research shows that calcination has gradually developed into one of the main disposal technologies for textile sludge [2].

With the proposal of low-carbon global, the green and low-carbon sustainable development of building materials, especially concrete, has gradually become the consensus all over the world. The resource utilization of solid waste in concrete has also become one of the important measures for the construction industry to achieve low-carbon development. Zhan et al. [1] investigated the physiochemical interactions between textile sludge and cement. The results indicated that the textile sludge dramatically retarded the cement hydration at different ages, and textile sludge can be stabilized by the hydration of cement, which posed no environmental risk. Zhan and Poon [3] reported that it was practicable to reuse the textile sludge for the production of non-load bearing concrete blocks which had the desirable properties of strength and shrinkage. Goyal et al. [4] found that textile sludge did not reduce the strength of the mortar and paste when its substitution of cement is within 5%; however, there was a remarkable loss in strength for the higher substitution level. Kasaw et al. [5] also reported that textile sludge was used to prepare regular and quality concretes with a substitution rate of 20% for cement. Rahman et al. [6] investigated the effect of textile sludge as the substitutions of sand or Portland cement on strength, water absorption, and porosity of mortar and concrete. The results demonstrated that textile sludge was suitable as a raw material for the manufacture of non-structural building components where the lower strength was acceptable.

On the other hand, concrete is a typical porous material consisting of a solid skeleton, micropores, and microcracks. The utilization of fibers in concrete can reduce the number and control the propagation of microcracks due to the bridge effect [7]. Due to the excellent corrosion resistance and low cost, polypropylene fiber is widely applied to enhance concrete properties [8–10]. Akhmetov et al. [11] reported that polypropylene fiber increased the flexural strength and drying shrinkage of self-compacting concrete. Ahmed et al. [12] investigated properties of high strength polypropylene fiber concrete with recycled aggregate. The results proved that polypropylene fibers played an important role in improving mechanical properties of concrete. Bentegri et al. [13] found that the shape, length, and dosage of polypropylene fibers had a great effect on the fresh concrete properties. However, polypropylene fiber concrete also shows some technical defects such as poor workability [14], so different mineral admixtures such as metakaolin and slag are often utilized to improve the workability of polypropylene fiber concrete [9,15,16].

Though textile sludge can be regarded as mineral admixture to prepare concrete, there is little work on the effect of textile sludge on the properties of fibers concrete. In this paper, the effect of textile sludge replacing cement and aggregates on compressive strength and drying shrinkage of polypropylene fiber concrete is investigated; the heavy metal leaching concentration is also tested, and the mechanism is analyzed with the combination of micro morphology and nanomechanical properties, which can provide the technical support for the promotion and application of textile sludge in concrete and contribute to the low-carbon development of the construction industry.

2. Experimental Details

2.1. Raw Materials

The used cement was strength grade of P·II42.5. Table 1 presents the main physical properties of cement. Textile sludge was from Zhejiang Province in China. Textile sludge was firstly dried at 100 °C and calcinated at 1000 °C for 3 h. The image of the calcinated textile sludge before grinding is shown in Figure 1. After that, the calcinated textile sludge was ground to a specific surface area of 434 m^2/kg. Figure 2 presents the grading curves of textile sludge and cement, which shows that the size of calcinated textile sludge is smaller than that of cement. Hence, calcinated textile sludge can act as microaggregate when used as a partial replacement for cement or aggregates in preparation of concrete. The activity index of textile sludge was 81.7% at 28 days according to the Chinese standard of GB/T 51003-2014 named technical code for application of mineral admixture. Meanwhile, Table 2 shows the main chemical compositions of textile sludge and cement.

Table 1. Main physical properties of cement.

Specific Surface Area/(m^2/kg)	Initial Setting Time/min	Final Setting Time/min	Flexural Strength/MPa		Compressive Strength/MPa	
			3 Days	28 Days	3 Days	28 Days
373	172	238	3.8	7.0	20.7	49.6

Figure 1. Textile sludge before grinding.

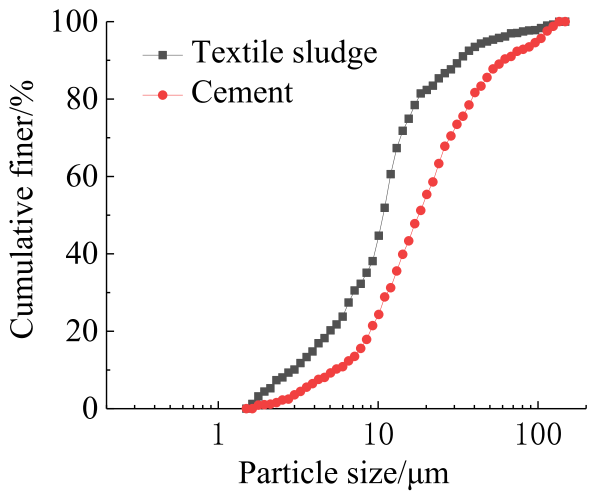


Figure 2. Grading curves of cement and textile sludge.

Table 2. Chemical compositions of textile sludge and cement/%.

Materials	SO_3	Al_2O_3	SiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	Loss on Ignition
Cement	2.39	4.25	21.78	3.26	61.01	1.24	0.32	0.03	0.23	3.78
Textile sludge	5.76	20.21	12.34	39.87	6.34	0.06	0.08	1.67	1.55	9.78

The polypropylene fiber with the diameter of 27 μm and the length of 19 mm was employed. Crushed limestone was employed as coarse aggregates with the size range from 4.75 mm to 19.0 mm. River sand was utilized as fine aggregates, whose fineness modulus was 2.6. Polycarboxylic superplasticizer admixture with the solid content of 27.8%, which had a water reduction of 24.3%. Tap water was used in this study.

2.2. Mix Proportions

For investigating the effect of textile sludge on properties of polypropylene fiber concrete, textile sludge replacing cement and aggregates was used to prepare concrete, and meanwhile the control concrete without textile sludge was also prepared. The proportion of fine aggregate to total aggregates was 43% and unit weight of concrete was kept constant. The amount of polycarboxylate superplasticizer was adjusted by controlling the concrete slump in the range of 180 mm to 200 mm. The contents of textile sludge replacing cement and aggregates were 10%, 15%, and 20%, respectively. The content of polypropylene fiber in all concrete was kept at 1 kg/m^3. Table 3 shows the details of mix proportions of polypropylene fiber concrete with textile sludge.

Table 3. Mix proportions of polypropylene fiber concrete with textile sludge (kg/m^3).

Number		Cement	Textile Sludge	River Sand	Crushed Limestone	Water	Polypropylene Fiber	Superplasticizer
Control	TS-0	400	0	783	1037	172	1	5.8
Replacing cement	RC-10	360	40	783	1037	172	1	6.5
	RC-15	340	60	783	1037	172	1	7.2
	RC-20	320	80	783	1037	172	1	8.2
Replacing aggregate	RA-10	400	40	765	1015	172	1	7.1
	RA-15	400	60	757	1003	172	1	8.5
	RA-20	400	80	748	992	172	1	9.5

2.3. Test Methods

2.3.1. Compressive Strength Test

Cubic concrete with the dimensions of 150 mm × 150 mm × 150 mm was manufactured for the compressive strength test according to the Chines standard of GB/T50081-2019. Concrete was manufactured at room temperature, and after one day, concrete was demolded to be cured in standard curing room with the relative humidity more than 95% and the temperature of 20 ± 2 °C up to the tested ages.

2.3.2. Drying Shrinkage Test

Drying shrinkage of concrete with the dimensions of 100 mm × 100 mm × 400 mm was tested by erecting the dial indicator based on the Chinese standard of GB/T50082-2009. The temperature and relative humidity of testing environment were controlled at 20 ± 2 °C and 60 ± 5%, respectively. The tested ages were 1, 7, 28, 60, 90, 150, 180, and 210 days.

2.3.3. Heavy Metal Leaching Concentration Test

Heavy metal leaching concentration of polypropylene fiber concrete with textile sludge was tested based on the Chinese standard of GB5085.3-2007. Firstly, 5.7 mL glacial acetic acid was dissolved in deionized water, and the volume was fixed to 1 L to obtain the acetic acid extractant. Secondly, 10 g powder derived from concrete was dissolved in 200 mL, and then, it was shaken on the oscillator for 24 h, and after that, it was statically settled for 24 h. Finally, the upper layer solution was taken and filtered until it was clear, and the heavy metal leaching concentration was determined by the inductively coupled plasma emission spectrometer.

2.3.4. Microstructure Test

Micro morphology was also observed through JSM-6360LV scanning electron microscope. Concrete was broken into some fragments consisting of mainly mortar, and then soaked in ethanol solution, and dried before the micro morphology test.

The nanomechanical properties of polypropylene fiber concrete with textile sludge were tested with Hysitron Ti Premier nanoindentor, whose indenter was Berkovich. The main process of sample preparation and test is shown in Figure 3. The prepared sample was about 10 mm cube. The grids of 10 × 10 and 4 × 25 were adopted to investigate the nanomechanical properties of the matrix and interface transition zone (ITZ), respectively. The distance between adjacent indentations was kept constant 10 μm. The maximum load of 4000 μN with 2 s was used, and the loading and unloading speed of test was 800 μN/s.

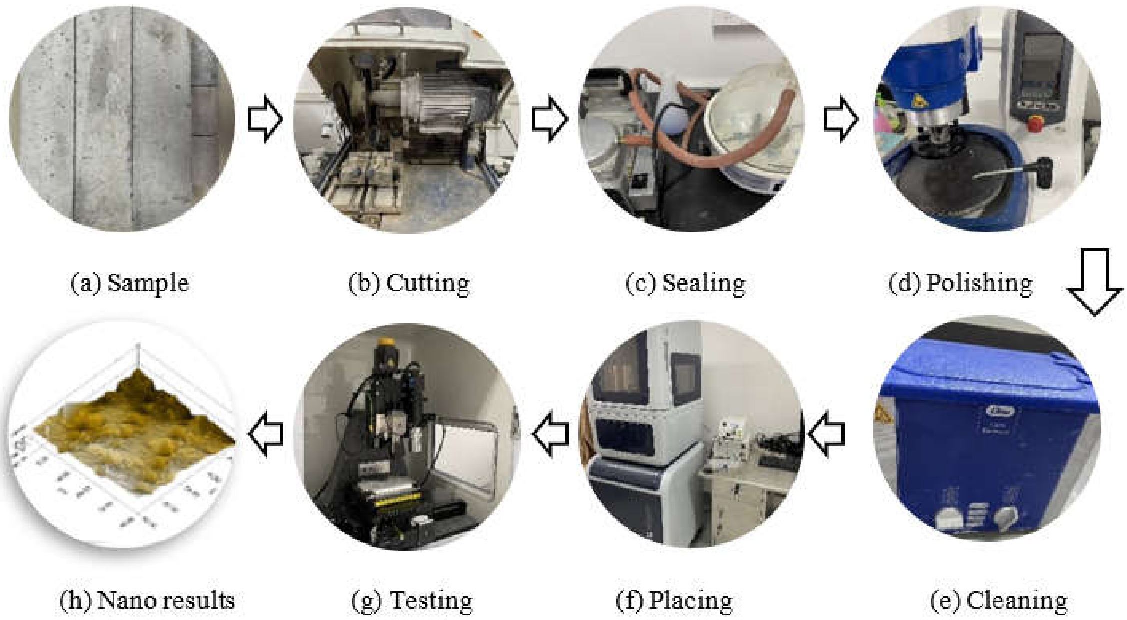
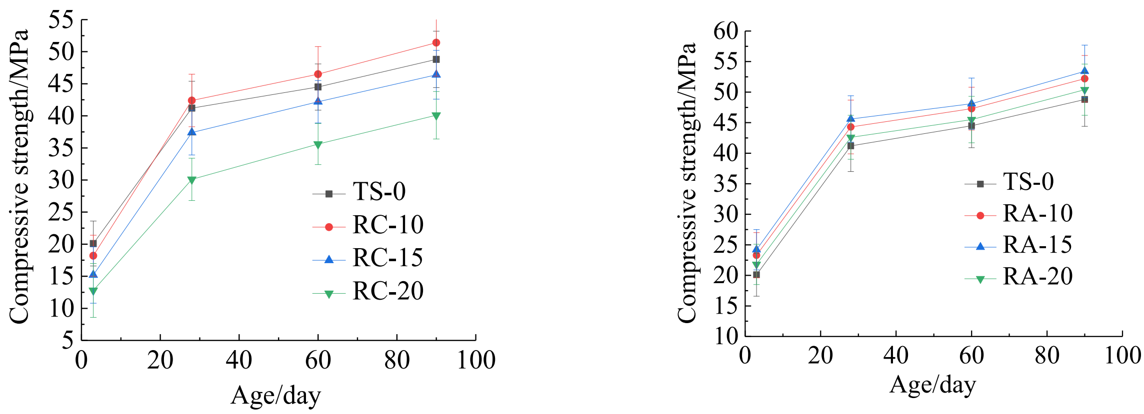


Figure 3. Main process of sample preparation and test of nanomechanical properties.

3. Results and Discussions

3.1. Compressive Strength

The compressive strengths of polypropylene fiber concrete with textile sludge replacing cement and aggregates were obtained at 3, 28, 60, and 90 days, presented in Figure 4.



(**a**) Replacing cement (**b**) Replacing aggregate

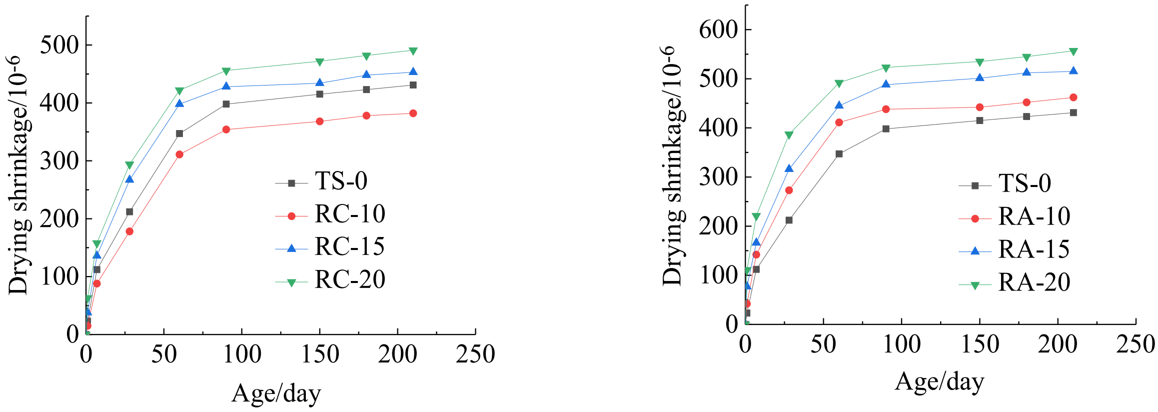
Figure 4. Effect of textile sludge on compressive strengths of polypropylene fiber concrete.

It can be observed from Figure 4 that the contents and replacing methods of textile sludge have the different effects on compressive strength of polypropylene fiber concrete. With regard to the textile sludge replacing cement, the compressive strengths of concrete gradually reduce with the increase of textile sludge contents. Compared to the control polypropylene fiber concrete, 10% textile sludge reduces the compressive strength of polypropylene fiber concrete at 3 days; however, it increases the compressive strengths at 28 days and later. In addition, 15% textile sludge reduces the compressive strength of polypropylene fiber concrete at all ages, and the reduction range is small. The 20% textile sludge remarkably reduces the compressive strengths of polypropylene fiber concrete. This may be related to the smaller particle size and lower activity of textile sludge. At the low replacing level, textile sludge can show the microaggregate effect, and its active effect exerts at the later hydration which produces more hydration products to densify the structure of concrete. However, with increasing substitution levels, and the quantity of calcium hydroxide (CH) is small due to the lower cement content which cannot stimulate the active effect of textile sludge to improve the development of compressive strengths of polypropylene fiber concrete.

With regard to the textile sludge replacing aggregates, compared with the control polypropylene fiber concrete, textile sludge increases the compressive strengths of polypropylene fiber concrete at all ages, and polypropylene fiber concrete with 15% textile sludge shows the highest compressive strength, and followed by polypropylene fiber concrete with 10% textile sludge. When textile sludge is used to replace aggregates, the actual water to binder ratio reduces. The greater the textile sludge content is, the smaller the actual water to binder ratio is, and hence the compressive strengths of polypropylene fiber concrete with textile sludge increase. However, the compressive strength of the polypropylene fiber concrete does not increase monotonically with the amount of textile sludge added. The increase in compressive strength of concrete mixed with 20% textile sludge is less than when the textile sludge content of the concrete is lower. This may be due to the lower aggregate content weakening the skeleton action of the aggregates.

3.2. Drying Shrinkage

The drying shrinkage of polypropylene fiber concrete with textile sludge replacing cement and aggregates is obtained at different ages shown in Figure 5.



(**a**) Replacing cement (**b**) Replacing aggregates

Figure 5. Effect of textile sludge on drying shrinkage of polypropylene fiber concrete.

It can be found from Figure 5 that the drying shrinkage of polypropylene fiber concrete with textile sludge develops rapidly within 90 days and becomes slow after 90 days. The replacing methods of textile sludge have the different effects on the drying shrinkage of polypropylene fiber concrete. With regard to the textile sludge replacing cement, compared with the control polypropylene fiber concrete, drying shrinkage of polypropylene fiber concrete with 10% textile sludge reduces by 11% at 210 days, and that of polypropylene fiber concrete with 15% and 20% textile sludge increases by 5% and 14% at 210 days, respectively. This may be related to the microstructure of polypropylene fiber concrete with textile sludge, especially pore structure. With regard to the textile sludge replacing aggregates, compared with the control polypropylene fiber concrete, the drying shrinkage of polypropylene fiber concrete increases with increasing textile sludge content, and drying shrinkage of polypropylene fiber concrete at 210 days increases by 7%, 19%, and 29% at 10%, 15%, and 20% of the addition of textile sludge, respectively, which indicates that the risk of cracking of polypropylene fiber concrete increases with the amount of textile sludge replacing aggregates.

3.3. Heavy Metal Leaching Concentration

Chemical compositions of textile sludge are relatively complex, generally containing some heavy metal ions such as arsenic, chromium, copper, and zinc, which have the great adverse effect on environment. Therefore, the solidity of these heavy metal ions in concrete was investigated by leaching experiments. The heavy metal leaching concentration of polypropylene fiber concrete with textile sludge is tested at 28 days which is compared with the limiting value of the Chinese standard of GB5085.3-2007, shown in Table 4.

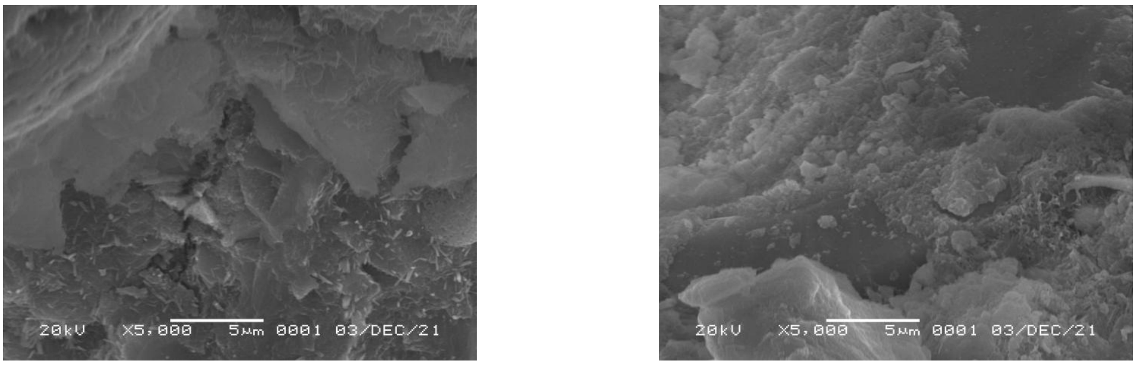
Table 4. Heavy metal leaching concentration of polypropylene fiber concrete with textile sludge/(mg/L).

Element	TS-0	RC-10	RC-15	RC-20	RA-10	RA-15	RA-20	Limiting Value
Cr	0.25	0.23	0.27	0.30	0.21	0.18	0.23	15
Ni	0.02	0.02	0.03	0.04	0.02	0.01	0.02	5
Cu	0.13	0.12	0.15	0.17	0.10	0.09	0.12	100
As	0.01	0.01	0.02	0.03	0.01	0.01	0.01	5
Ba	0.05	0.04	0.07	0.08	0.03	0.02	0.04	100
Pb	0.02	0.02	0.03	0.05	0.01	0.01	0.02	5
Zn	2.16	2.01	2.21	2.25	1.99	1.88	2.02	100

It can be found from Table 4 that the heavy metal leaching concentration of polypropylene fiber concrete with textile sludge is similar with that of the control polypropylene fiber concrete, which is much lower than the limiting value of Chinese standard. It was also found that the higher compressive strength of concrete corresponds to the lower heavy metals leaching concentration, which indicates that the dense structure and hydration products of concrete show a good solidification effect on heavy metal ions of textile sludge.

3.4. Morphology

In order to further master the microstructure of concrete, the scanning electron microscope (SEM) images of polypropylene fiber concrete with 10% textile sludge replacing cement which has the higher later compressive strength and minimum drying shrinkage and control polypropylene fiber concrete at 28 days were obtained, presented in Figure 6.



(**a**) TS-0 (**b**) RC-10

Figure 6. SEM images of polypropylene fiber concrete with textile sludge.

It can be found according to SEM images at the magnifications of 5000× that the control polypropylene fiber concrete mainly consists of aggregates with various sizes, unhydrated particles, and kinds of hydration products which overlap each other; however, there still are some pores with small size and especially connected microcracks, which degrade the internal structure of concrete. Meanwhile, compared with the control polypropylene fiber concrete, polypropylene fiber concrete with 10% textile sludge replacing cement shows the denser internal structure, and aggregates are covered by kinds of hydration products with different shapes and sizes, which forms the overall structure without obvious pores and connected microcracks, and the results correspond to the higher compressive strengths.

3.5. Nanomechanical Properties

In general, properties of concrete are mainly related to its microstructure, especially pore structure [17,18]. Nanomechanical properties play an essential role in determining macroscopic properties of concrete [19,20]. Based on the different nanomechanical properties, cement matrix mainly consists of pore, low-density C-S-H (LD C-S-H), high-density C-S-H (HD C-S-H), CH, and unhydrated particle, which have stable elastic modulus ranges of less than 15 GPa, 15–25 Gpa, 25–35 Gpa, 35–50 Gpa, and more than 50 GPa, respectively [21]. Hence, the cement matrix of polypropylene fiber concrete with 10% textile sludge replacing cement and control polypropylene fiber concrete at 28 days are selected, and their nanomechanical properties are obtained, shown in Figures 7 and 8, respectively.

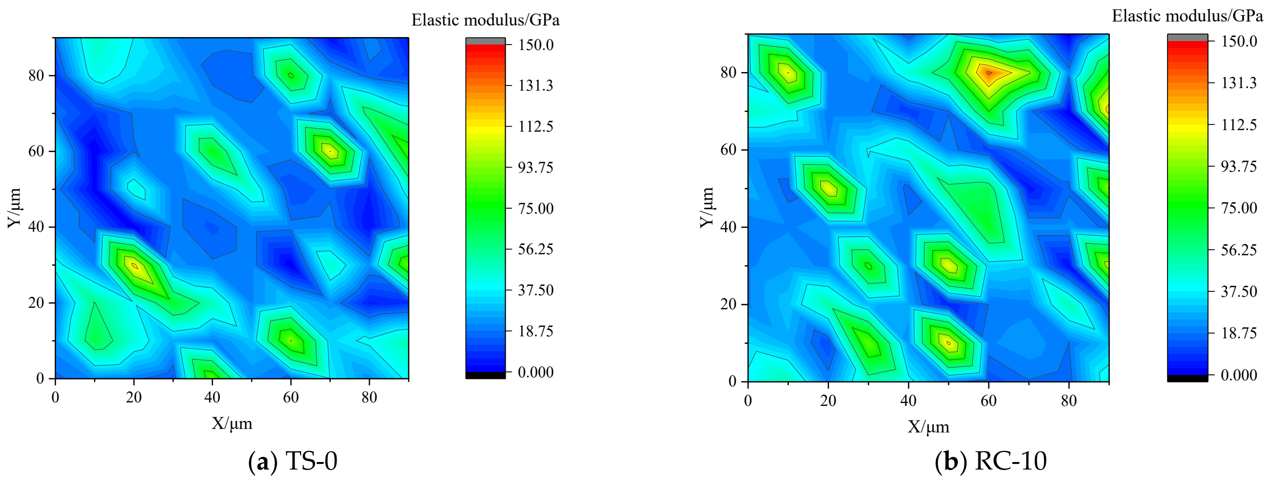


Figure 7. Distributions of elastic modulus of cement matrix.

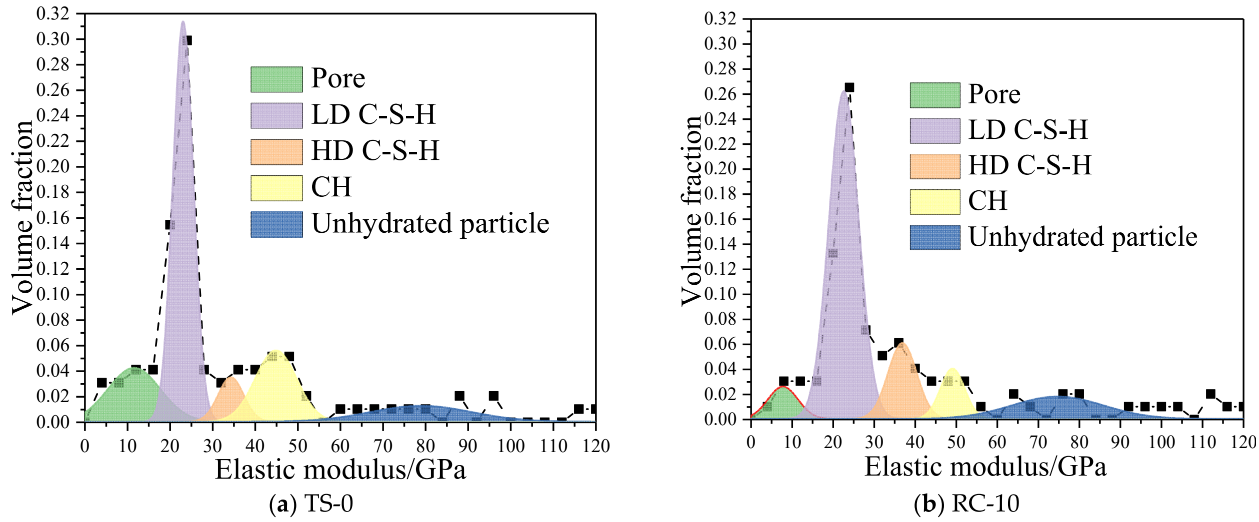


Figure 8. Frequency distributions of elastic modulus of cement matrix.

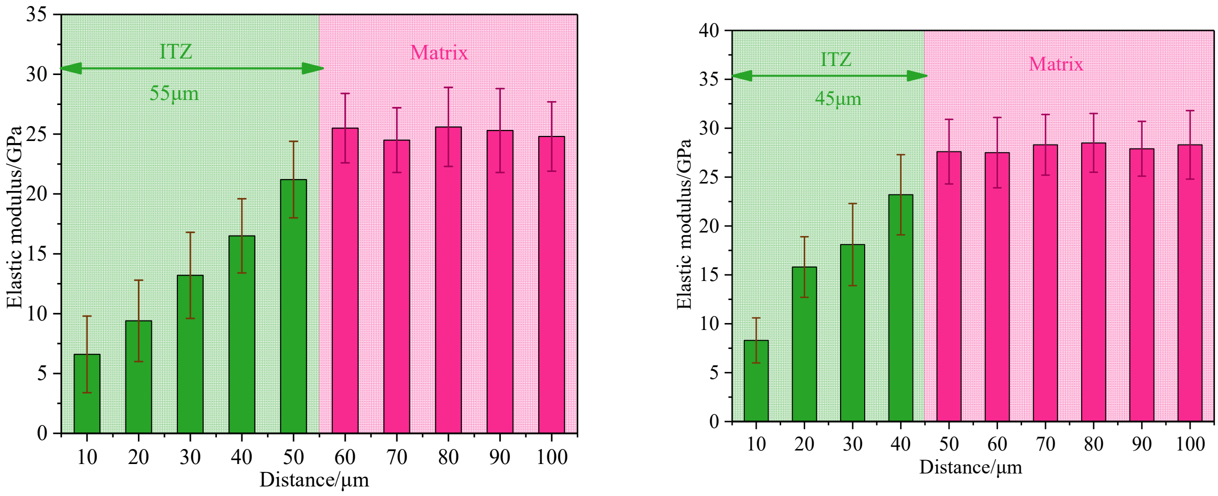
According to the results in Figures 7 and 8, the contents of phases of cement matrix of polypropylene fiber concrete with textile sludge can be calculated, shown in Table 5.

Table 5. Contents of phases of cement matrix of polypropylene fiber concrete/%.

Number	Pore	LD C-S-H	HD C-S-H	CH	Unhydrated Particle
TS-0	14.4	47.4	8.2	16.5	13.5
RC-10	10.2	43.9	14.3	11.2	20.4

It can be found from Table 5 that the content of C-S-H in cement matrix is highest. Compared with the control polypropylene fiber concrete, 10% textile sludge replacing cement reduces the contents of pore, LD C-S-H, and CH of polypropylene fiber concrete, but increases the contents of HD C-S-H and unhydrated particles, which indicates that more C-S-H, mainly HD C-S-H, is produced due to the active effect of textile sludge to densify the internal structure.

ITZ is the weakest region in concrete which is characterized by high porosity and has an essential effect on the property evolution of concrete such as mechanical properties, volume stability, and durability [22,23]. Hence, Figure 9 shows the elastic modulus of ITZs of polypropylene fiber concrete with textile sludge.



(**a**) TS-0 (**b**) RC-10

Figure 9. Elastic modulus of ITZs.

Generally speaking, the width of ITZ is the distance from the aggregate surface to the region with the steady elastic modulus. It is found from Figure 9 that with the increase of the distance from the aggregate surface, the elastic modulus increases continuously. The width of ITZ of control polypropylene fiber concrete is about 55μm, and 10% textile sludge replacing cement reduces the width of polypropylene fiber concrete, which is about 45 μm; meanwhile, it increases the stable elastic modulus of cement matrix to improve the microstructure of polypropylene fiber concrete.

3.6. Analysis and Discussion

Based on the above results, note that the calcinated textile sludge can be used as the material to replace cement or aggregates for preparing polypropylene fiber concrete, which certainly has the effect on the property evolution of polypropylene fiber concrete. Extensive studies [2,6] have confirmed that the calcinated textile sludge is a promising mineral admixture due to its active effect and microaggregate effect which is also verified by the results in Figure 2. When the calcinated textile sludge is used to replace cement, the microstructure and property evolution of polypropylene fiber concrete depend mainly on the content of calcinated textile sludge due to the fact that the activity of calcinated textile sludge is lower than that of cement; however, its average particle size is smaller than that of cement. According to the result of Figure 4a, the utilization of appropriate content (10%) of calcinated textile sludge degrades the early compressive strength but enhances the later compressive strength mainly due to the exerting active effect with the increase of curing ages. At the same time, SEM images of Figure 6 also indicate that the addition of 10% calcinated textile sludge improves the microstructure of polypropylene fiber concrete at 28 days qualitatively. In addition, the results obtained by the nanoindentor provide the quantitative information on the microstructure of polypropylene fiber concrete. According to the results of Table 5, the utilization of 10% calcinated textile sludge reduces the CH content due to the calcinated textile sludge replacing part cement and consuming some CH. The unhydrated particle contents are increased because of the lower activity of calcinated textile sludge. More importantly, the utilization of 10% calcinated textile sludge changes the ratios of LD C-S-H to HD C-S-H in polypropylene fiber concrete. It reduces the LD C-S-H content; however, it increases the HD C-S-H content. Some scholars [21] have verified that compared to LD C-S-H, HD C-S-H has the better mechanical properties and durability. Through increasing the proportions of HD C-S-H contents, most properties of concrete can be improved from the perspective of nano scale. Meanwhile, the pore content is also reduced due to the utilization of 10% calcinated textile sludge, which basically agrees well with the SEM images. In general, ITZ acts as a limiting phase for the development of properties of concrete [23–27]. Based on the results of Figure 9, the addition of 10% calcinated textile sludge reduces the width of ITZ of polypropylene fiber concrete and increases the elastic modulus of cement matrix. The improved microstructure of polypropylene fiber concrete containing 10% calcinated textile sludge leads to the reduced drying shrinkage. However, more calcinated textile sludge (15% and 20%) is used to replace cement, the microstructure of polypropylene fiber concrete is degraded due to the less cement contents. Compared to the favorable effect of more calcinated textile sludge, its bad effect is more obvious, which reduces the compressive strengths and increases the drying shrinkage, and the greater the calcinated textile sludge contents are, the more obvious the changed effect is.

On the other hand, when the calcinated textile sludge is used to replace aggregates, the compressive strength and drying shrinkage of polypropylene fiber concrete show the different development laws. Generally speaking, aggregates such as fine aggregates and coarse aggregates act as a skeleton effect in concrete. The calcinated textile sludge is used to replace aggregates, the actual water to binder ratio is reduced due to the fact that calcinated textile sludge can be used as a promising mineral admixture, and of course, the skeleton effect of aggregates is also degraded. According to the results of Figure 4b, the improved effect of calcinated textile sludge replacing aggregates is greater than the degraded skeleton effect of reduced aggregate contents, which increases the compressive strengths of polypropylene fiber concrete. However, the polypropylene fiber concrete containing 15% calcinated textile sludge replacing aggregates shows the highest compressive strengths, which indicates that the optimal content of calcinated textile sludge replacing aggregates is 15%. When the content of calcinated textile sludge is more than 15%, the compressive strength of polypropylene fiber concrete containing 20% calcinated textile sludge is reduced, still higher than that of the control polypropylene fiber concrete. It shows that the degraded skeleton effect of reduced aggregate contents is gradually evident. In addition, as for the drying shrinkage of polypropylene fiber concrete, with the increase of calcinated textile sludge contents, the drying shrinkage of polypropylene fiber concrete is gradually increased due to the increased hardened paste contents and reduced aggregate contents.

According to the results in Figures 4 and 5, there are no direct relationships between drying shrinkage and compressive strengths of polypropylene fiber concrete containing calcinated textile sludge. The polypropylene fiber concrete containing calcinated textile sludge with the higher compressive strengths has a stronger ability to resist shrinkage, but its fine pore structure may generate greater shrinkage stress, which leads to the very complicated relationships between drying shrinkage and compressive strengths.

At last, textile sludge is also regarded as the hazardous solid waste for it contains some heavy metals, toxic organic matters, and chemical coagulants [1,2,28]. However, based on the results in Table 4, textile sludge is calcinated to produce concrete, and the toxic heavy metals are stabilized well, which indicates no environmental risks during the service. This may be attributed to the dense structure and solidification effect of polypropylene fiber concrete which needs to investigate furtherly.

4. Conclusions

In this paper, the effect of textile sludge replacing cement and aggregates on properties of polypropylene fiber concrete has been investigated by compressive strength, drying shrinkage, heavy metal leaching concentration, SEM, and nanomechanical properties. At the same time, the mechanism has been analyzed. Hence, the main conclusions can be presented as follows:

(1) Textile sludge replacing cement reduces the compressive strength of polypropylene fiber concrete at 3 days, but 10% textile sludge replacing cement increases compressive strength of polypropylene fiber concrete at 28 days and later, and the further increase of contents of textile sludge replacing cement reduces the later compressive strength. Textile sludge replacing aggregates increases the compressive strength of polypropylene fiber concrete at all ages, and polypropylene fiber concrete with 15% textile sludge replacing aggregates has the highest compressive strengths.
(2) 10% textile sludge replacing cement reduces drying shrinkage of polypropylene fiber concrete; however, the further increase of textile sludge contents increases drying shrinkage. On the other hand, with the increase of textile sludges replacing aggregates, the drying shrinkage of polypropylene fiber concrete increases gradually.
(3) Polypropylene fiber concrete with textile sludges has a good solidification effect on heavy metal ions, and the heavy metal leaching concentration is even lower than the limiting value of standard.
(4) 10% textile sludge replacing cement improves the microstructure of polypropylene fiber concrete, is in favor of the production of HD C-S-H, increases the elastic modulus of cement matrix, and reduces the width of ITZ.
(5) The replacing methods and contents of textile sludge in polypropylene fiber concrete should be considered in practical engineering, which can reduce costs and show good environmental benefits.

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Conflicts of Interest: The authors declare no conflict of interest.

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