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Mechanical Properties and Time-Dependent Deformations of Polypropylene Fiber Concrete

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Abstract. An investigation was conducted to study the effects of polypropylene fiber used for reinforcing concrete mixes and to obtain basic strength and time-dependent deformation data for applying fiber to the construction and civil engineering work. The compressive, splitting tensile and flexural strength tests were performed by changing fiber weight content from 0.1% to 3% of the cement weight content. In addition, the effects of fiber on time-dependent deformations such as drying shrinkage and creep were also investigated. As a result, it was found that the use of polypropylene fiber considerably increases the tensile strength as the fiber content is increased. The compressive and flexural strengths, on the other hand, were consistently the same for various fiber contents as compared to the corresponding plain concrete strength values. One potential advantage of a high fiber weight content was its contribution to the enhancement of the time-dependent deformation properties of concrete. Compared to corresponding plain concrete, there was a favorable decrease in drying shrinkage and creep of specimens containing various fiber contents. In particular, the 3% weight content exhibited a significant reduction in time-dependent deformations.

Introduction

The effect of reinforcing concrete with polypropylene fibers has been the subject of several publications for the past 25 years. However, some discrepancies still exist between the data published by different workers, which makes it necessary to perform more experiments to measure the mechanical and time-dependent properties. For example, some of the published results show an increase in the tensile, compressive and flexural strengths [1,pp. 227-235; 2, pp. 247-256; 3] as the fiber content is increased, while the other publication shows a reduction in the compressive and flexural strengths with increased fiber ratio [4]. On the other hand, other workers [5] have indicated a slight decrease in compressive strength and an increase in flexural strength when fibers are used. Recent research paper [6] has shown that fibers orientations to the stress direction can influence the tensile properties of polypropylene reinforced cement, therefore, more testing is needed to explore these differences. Generally speaking, it can be concluded from the results that the effect, positive or negative, of the polypropylene fibers on the flexural and compressive strengths from the commonly used low fiber ratio is small.

With respect to time-dependent deformation properties, there seems to be a scarcity of data on polypropylene concrete composites in the published literature [7]. The use of fiber reinforcement results in some reduction of volumetric changes leading to some important applications of fiber reinforced materials. One application may be in prestressed concrete members where prestress losses are mainly influenced by shrinkage and creep deformations. Therefore, there is a strong need for experimental studies to characterize the influence of polypropylene fibers on the shrinkage and creep properties of fiber concrete.

The present work was, therefore, carried out to determine the effect of high fiber weight content in concrete on mechanical properties and time-dependent deformations.

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Materials and Experimental Details

Concrete mixes containing ordinary Portland cement, washed marine sand, crushed limestone coarse aggregate, water, admixtures and different percentages of fiber content were studied.

The ordinary Portland cement used satisfied the requirement of BS 12 [8]. Locally washed marine sand was used, which had specific gravity of 2.66 and its grading fell within Zone F of the British standard BS 882 [9]. Crushed Ras-al Khaimah limestone used as coarse aggregate had maximum size of 10 mm and a specific gravity of 2.69. The sieve analysis of fine and coarse aggregates is carried out according to BS 812 [10], and is presented in Table 1.

Table 1. Sieve analysis of fine and coarse aggregates

Sieve size (mm)	Percentage passing	
	Coarse aggregate[1]	Fine aggregate[2]
14.0	100	
10.0	90	
5.0	15	100
2.36	0.3	98
1.18		96
0.600		84
0.300		62
0.150		15
0.075		0.5
Specific Gravity	2.69	2.66

[1] Results mainly satisfy the grading requirements for 10 mm nominal size coarse aggregate according to BS 882 : 1983.

[2] Results mainly satisfy the grading requirements for Zone F (limit F) for fine aggregate according to BS 882 : 1983.

Five identical concrete mixes having different percentages of fiber content of 0.0%, 0.1%, 0.5%, 1.0% and 3.0% were used in this investigation. All mixes have cement content of 390 kg/m^3, marine sand content of 640 kg/m^3, limestone coarse aggregate of 1000 kg/m^3, water content of 190 kg/m^3 (200 kg/m^3 for 3.0% fiber weight content), air entraining agent (Cormix 4) of 0.5 lit/m^3 and superplasticizer agent (Fosroc 430) of 1.5 lit/m^3, (used only for 1.0% and 3.0% fiber concrete mixes). The 20 mm polypropylene fibrillated chopped fibers produced by Shell Chemicals have a linear density of 750 m/kg, average breaking strength of 57.2 kg and average twist of 46 turns/m. The fibers were dispersed evenly throughout the mix and added half a minute before the end of the mixing period in order to allow a sufficient time for their even distribution in the mixture. The slump of the concrete mixes was ranged from 100-150 mm. It is important to note that the use of air entraining agent in association with the superplasticizing admixture (for 1.0% and 3.0% fiber concrete mixes) has resulted in a good workable and pumbable concrete.

The test specimens used were 100 × 200 mm cylinders (100 mm in diameter and 200 mm high) for compressive strength, shrinkage and creep, 100 mm cubes for splitting tensile strength and 100 × 100 × 500 mm prisms for flexural strength. The concrete specimens were prepared and tested in laboratory condition at 23°C and 68%

relative humidity. The concrete specimens were kept in water tanks under laboratory condition for 28 days until testing. Compressive, splitting tensile and flexural strength testing were done at 28 days and were determined according to BS 1881 : 1983 : part 116 [11], part 117 [12], part 118 [13], respectively. All the strength results are the average of three specimens for each concrete mix. The creep tests are performed at the age of 28 days for a period of 28 days. The test results of shrinkage and creep were based on the average of two cylinders for each mix and test. It is generally accepted that creep under constant stress approximately is proportional to the stress-strength ratio, up to stress-strength ratio of 0.3 to 0.4. Therfore, the tests in this study were conducted at 0.33 stress ratio. The Tyler creep rigs were used to load the creep cylinders and a mechanical extensometer was used to measure the creep and shrinkage deformations. Shrinkage was treated as additive, *i.e.* creep was defined as the change in deformation since loading, corrected for the shrinkage of companion specimens not subjected to load.

Results and Discussion

The densities of the various mixes are shown in Table 2. A slight reduction in density can be noticed in polypropylene concrete mixes which can be attributed to lower fiber densities compared to concrete.

Results of the compressive, splitting tensile and flexural strengths after 28 days of water curing for mixes with 0.0% to 3.0% fiber content are shown in Table 2 and

Table 2. Strengths of polypropylene concrete at 28 day curing

Fiber content wt%	Density[1] kg/m³	Compressive strength[2] MPa	Tensile strength[3] MPa	Flexural strength (MOR)[4] MPa
0.0	2155	17.2	1.08	4.5
0.1	2144	14.0	1.21	4.1
0.5	2103	16.3	1.34	2.8
1.0	2109	14.1	1.72	2.5
3.0	2120	12.6	2.48	3.0

[1] Test in accordance with BS 1881 : Part 114 : 1983.

[2] Test in accordance with BS 1881 : Part 116 : 1983.

[3] Test in accordance with BS 1881 : Part 117 : 1983.

[4] Test in accordance with BS 1881 : Part 118 : 1983.

Note: The values obtained for each property in this table are based on an average of three specimens for each concrete mix.

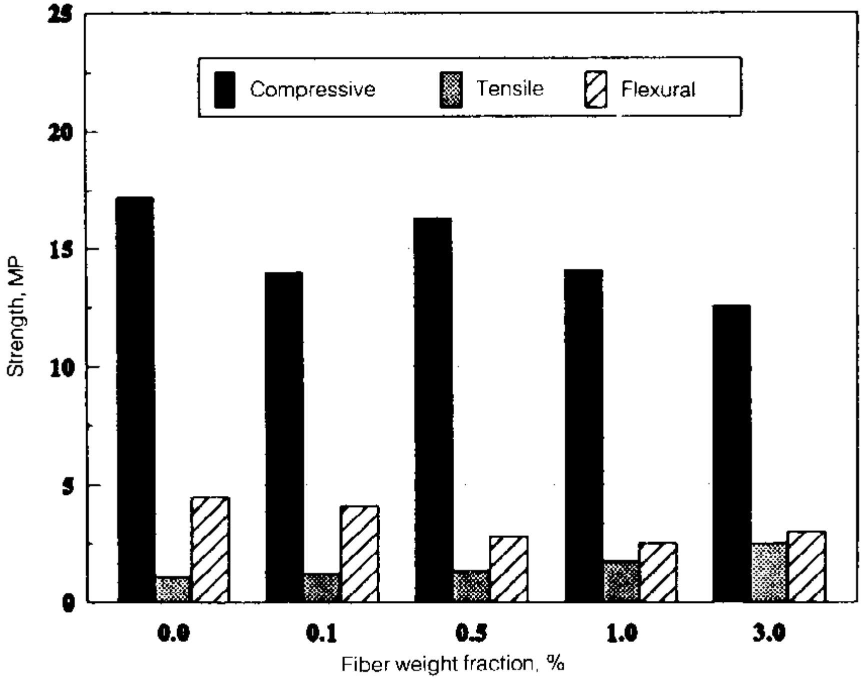

Fig. 1. Compressive, flexural and tensile strengths of polypropylene fibre concrete at 28 days of curing.

Fig. 1. The 28-day compressive strengths for fibrous concrete decrease from 17.2 MPa for 0.0% fiber weight content to 14.0 MPa, 16.3 MPa, 14.1 MPa and 12.6 MPa for 0.1%, 0.5%, 1.0% and 3.0% fiber weight contents, respectively. The decrease in the 28-day compressive strengths for fibrous concretes compared to non-fibrous concretes is 18.6%, 5.2%, 18.0% and 26.7% for 0.1, 0.5%, 1.0% and 5.0% fiber contents, respectively. The high reduction in compressive strength for the 3.0% fiber concrete is partially influenced by the higher water content used in the mix (200 kg/ m^3).

On the other hand, the 28-day splitting tensile strengths presented in Table 2, increase from 1.08 MPa for 0.0% fiber content to 1.21 MPa, 1.34 MPa, 1.72 MPa and 2.48 MPa for 0.1%, 0.5%, 1.0% and 3.0% fiber weight contents, respectively. These values represent increase in the 28-day splitting tensile strength of fibrous concretes over the non-fibrous concrete by 12.0%, 24.1%, 59.2% and 129.6% for 0.1%, 0.5%, 1.0%, and 3.0% fiber contents, respectively. These results indicate that the influence of the polypropylene fibers on the 28-day splitting tensile strength is more pronounced than that on the 28-day compressive strength. This is particularly apparent for 3.0% fiber content, which yields increase in tensile strength of 129.6% while the decrease in the compressive strength is only 26.7%. It seems that the role of the fibers in reducing the number and sizes of microcracks delays the occurrence of tensile failure since the nucleating points (*i.e.* microcracks) for major cracks are reduced.

Table 2 also shows that the 28-day flexural strength as measured by modulus of rupture (MOR) decreases from a value of 4.5 MPa for 0.0% fiber content to 4.1 MPa, 2.8 MPa, 2.5 MPa and 3.0 MPa for 0.1%, 0.5%, 1.0% and 3.0% fiber weight contents, respectively. These values represent percentage reductions of 8.9%, 37.8%, 44.4% and 33.3% for 0.1%, 0.5%, 1.0% and 3.0% fiber weight contents, respectively. The magnitudes of these reductions are somewhat higher than those in the compressive strength. It is not clear why flexural strength was reduced by the use of fibers which is in contrary with results obtained by other workers [3;5], however, it should be recognized that there is some odd results in testing fiber reinforced concrete because of the random orientation of the fibers and possible non-uniform distribution of fibers in concrete [3], especially with limited amount of specimens used in this investigation. Therefore, further testing is planned to explore the diferences in flexural strength.

These results show that the compressive strength and the flexural strength are reduced as the fiber content is increased. It can be concluded that the compressive and flexural strengths are consistent since the strength variations between various fibrous and non-fibrous concrete mixes are relatively small. The splitting tensile strength, on the other hand, is clearly increased as the fiber content is increased.

The 28-day shrinkage, creep and total time-dependent deformations of various polypropylene concrete mixes along with non-fibrous concrete mix are presented in Table 3 and Fig. 2. It is evident that the shrinkage of polypropylene fiber concrete mixes has shown a general tendency to decrease with the increase in fiber content, while the elastic deformation for all mixes seem to be unaffected by the use of fibers which shows a strain variation not more than 10 microstrains. The 28-day shrinkage deformation of fibrous concrete specimens of fiber weight content of 0.1%, 0.5%, 1.0% and 3.0% were 443, 421, 405 and 389 microstrain, respectively, as compared to 464 microstrain of plain concrete, leading to decrease in shrinkage of 4.5%, 9.3%, 12.7% and 16.2%, respectively. The reduction in shrinkage due to the presence of fibers is expected from a number of viewpoints. First, the fibers themselves do not exhibit any shrinkage, thus reducing the overall shrinkage of the mix. In addition, the fibers have a role in retaining the water in the concrete mix up to a certain limit which helps to delay the shrinkage. Therefore, addition of fibers to the concrete mixes is always advantageous in reducing shrinkage deformation.

Table 3. The 28-day time-dependent deformations of polypropylene concrete

Fiber weight content in percent	Deformations in microstrain (10^{-6})		
	Shrinkage	Creep	Total deformation (including elastic strain)
0.0	464	240	761
0.1	443	226	730
0.5	421	197	675
1.0	405	178	638
3.0	389	133	587

Note: All shrinkage, creep and total deformation values obtained in this table are based on an average of two specimens for each mix.

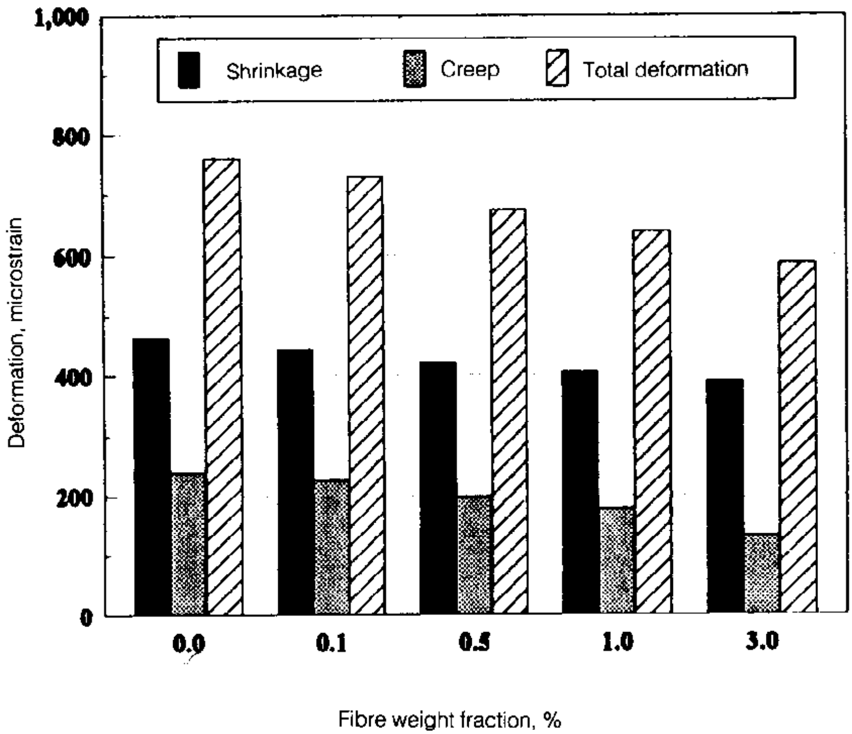

Fig. 2. The 28-day time-dependent deformation of polypropylene concrete.

With regard to the observed reduction in creep of fibrous concrete mixes when compared with non-fibrous concrete mix, the 28-day creep deformation for 0.0%, 0.1%, 0.5%, 1.0% and 3.0% fiber weight content concrete decreases from 240 microstrain to 226, 197, 178 and 133 microstrain, respectively, leading to decrease in creep of 5.8%, 17.9%, 25.8% and 44.6%, respectively. It is clear that the effect of fiber on creep deformation is more significant than on shrinkage deformation, in particular for fibrous concrete mix with 3.0% fiber weight content which showed a considerable reduction in creep. It is thought that the reduction in creep deformation due to the addition of fibers is due to the role of fibers in controlling or minimizing concrete microcracking. The relation between creep and microcracking has been discussed by other worker [14].

Table 3 presents the 28-day total deformation (elastic strain, shrinkage and creep) of the various fiber concrete mixes. It is clear that a significant drop in total deformation occurs with increasing the fiber weight content in concrete mixes. The 28-day total deformation for 0.0%, 0.1%, 0.5%, 1.0% and 3.0% fiber weight content concretes are 761, 730, 675, 638 and 587 microstrain, respectively, which indicates that the percentage decreases in total deformations are 4.1%, 11.3%, 16.2% and 22.9%, respectively. This reduction in total deformation is influenced by the same factors which influence the shrinkage and creep deformations. Therefore, it is concluded that the use of polypropylene fibers in concrete mixes can play a significant role in reducing shrinkage and creep, hence, leading to a reduction in total deformations.

Conclusion

In the light of the preceding results and discussion, the following can be concluded:

1. Workable high fiber content concrete mixes were achieved by using air entraining agent in association with superplasticizing admixtures.
2. The use of high polypropylene fiber weight content of 3.0% in concrete exhibited a tensile strength 2.3 times (129.6%) that of the non-fibrous concrete. Other fiber content mixes should reasonably increase in the tensile strength with increase of fiber content.
3. The concrete of various fiber contents showed some reduction in compressive and flexural strengths, as compared to non-fibrous concrete.
4. The 28-day shrinkage deformation of polypropylene fiber concrete has decreased by 4.5%, 9.3%, 12.7% and 16.2% corresponding to fiber weight content in concrete of 0.1/, 0.5%. 1.0% and 3.0%.

5. The effect of using polypropylene fiber in concrete to reduce deformations is more pronounced on creep than on shrinkage. The percentage decrease in creep was found to be 5.8%, 17.9%, 25.8% and 44.6% for 0.1%, 0.5%, 1.0% and 3.0% fiber weight content, respectively, when compared with non-fibrous concrete creep values.
6. Similarly, the 28-day total deformation were reduced by 4.1%, 11.3%, 16.2% and 22.9% for 0.1%, 0.5%, 1.0% and 3.0% fiber weight content concrete when compared with the non-fibrous concrete total deformation values.

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الخواص الميكانيكية والتشوّه المزمن للخرسانة المقوّاة بألياف البوليبروبلين

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ملخص البحث. تم في هذا البحث عمل دراسة على تأثير استعمال ألياف البوليبروبلين لدعم الخلطات الخرسانيّة وإيجاد المعلومات الأوليّة لقوى الخرسانة والتشوّه المزمن وذلك لاستعمال الألياف في أعمال الإنشاء والهندسة المدنيّة حيث تم عمل الفحوصات الخاصة بقوى الضغط والشد ومقاومة الثني وذلك باستعمال أوزان مختلفة من الألياف في الخرسانة وبنسب تتفاوت من ٠,١٪ إلى ٣٪ من محتوى وزن الأسمنت. بالإضافة إلى ذلك فقد تمت دراسة تأثير استعمال الألياف على التشوه المزمن للخرسانة مثل تقلص التجفيف والزحف. لقد دلّت النتائج على أن استعمال ألياف البوليبروبلين يؤدي إلى زيادة مقاومة الشد وذلك كلما زاد محتوى الألياف في الخرسانة في حين ظلّت نتائج مقاومة الضغط ومقاومة الثني متقاربة لمختلف نسب محتوى الألياف عند مقارنتها مع نتائج مقاومة الخرسانة الخالية من الألياف. من ناحية أخرى، كانت هناك بعض المميّزات الفعّالة في استعمال نسب عالية من محتوى وزن الألياف في الخرسانة لتحسين خصائص التشوه المزمن وذلك عند مقارنتها مع الخرسانة الخالية من الألياف حيث كان هناك نقص واضح في تقلص التجفيف والزحف لمختلف عيّنات الخلطات الخرسانيّة ذات الألياف.