Int. J. of GEOMATE, Sept., 2015, Vol. 9, No. 1 (Sl. No. 17), pp. 1441-1446
Geotech., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

STRENGTH, MODULUS OF ELASTICITY AND SHRINKAGE BEHAVIOUR OF CONCRETE CONTAINING WASTE CARPET FIBER

A.S.M. Abdul Awal[1], Hossein Mohammadhosseini[2], M. Zakaria Hossain[3]

[1,2] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[3] Graduate School of Bioresources, Mie University, Tsu-City, Japan

ABSTRACT: This paper presents test results on some physical and mechanical properties of concrete containing fiber from recycled carpet waste. Five concrete mixes namely plain concrete (PC) i.e. concrete without carpet fiber, as control and carpet fiber reinforced concrete (CFRC) mixes containing 0.5%, 1.0%, 1.5% and 2.0% polypropylene (PP) waste carpet fibers were made and tested for compressive, tensile and flexural strengths, modulus of elasticity and shrinkage at curing periods of 1, 7 and 28 days. It has been found that the addition of carpet fiber reduced the workability and density of concrete. Concrete containing carpet fiber exhibited lower compressive strength and modulus of elasticity than plain concrete. The carpet fibers, however, effectively improved the splitting tensile and flexural strengths of concrete. The obtained values of shrinkage revealed that the shrinkage strain of carpet fiber reinforced concrete was higher than that of plain concrete. On the basis of short-term investigation, the one-year shrinkage values of both plain concrete and concrete containing carpet fiber were also predicted by extrapolating the data obtained during this period. The results obtained in this study indicate that waste carpet fiber can suitably be used as fiber reinforcement in concrete with satisfactory performance.

Keywords: Fiber reinforced concrete, Waste carpet fiber, Strength, Modulus of elasticity, Shrinkage

1. INTRODUCTION

The production and landfilling of waste materials are big problems throughout the world. Recycling of the waste materials and their use in construction industries are increasing in both the developed and developing countries. This has led to green and sustainable construction by reducing the cost of the production of construction materials and waste management. However, with the increasing demand of waste materials in engineering applications, it is necessary to clearly understand their physical and mechanical properties. Concrete is the most widely used construction material. However, it has low tensile strength and low energy absorption [1]. An effective method to enhance the mechanical properties of concrete is by adding small fraction of short fibers to the concrete [2-4]. Among others, the most common fibers used in construction are, steel fibers, synthetic fibers such as nylon and polypropylene, glass fibers, natural fibers and fibers from pre and post-consumer wastes. Since the advent of fiber reinforcing of concrete, a great deal of testing has been led on different fibrous materials to determine the real characteristics and benefits for each product. Over the decades different types of synthetic fibers have been successfully used to reinforce concrete.

Synthetic fibers are developed mostly to supply the high demand for carpet and textile products. Nylon and Polypropylene are the most synthetic fibers used in these industries [5-7]. Huge amount of carpet waste is produced and part of these wastes are in the form of fibrous materials. Generally, industrial carpet wastes are from face and back yarns. The face yarn is usually polypropylene or nylon fibers and the back yarn is mainly in the form of woven sheets (Fig.1). These fibers are mainly 50%-70% nylon and 15%-25% polypropylene. The advantages of using such recycled fibers include generally lower cost to process than virgin fibers, light in weight, good acid and alkali resistance and non-absorbent of water [2,5,8].

Fig. 1 Waste products from industrial carpet: a) face yarn b) back yarn

In the last decades researchers have investigated the effects of utilization of different types of fibers in plain concrete on various engineering properties. Wang [9, 10], Vilkner et al. [11], and Zhou and Xiang [12] have studied the effects of addition of waste carpet fibers on physical and mechanical properties of concrete. They concluded that carpet fiber decreased the workability and compressive strength of concrete with reference to concrete without using carpet fibers. However, carpet fibers have been shown to exhibit a positive response in terms of flexural strength, impact strength and toughness of concrete [1, 12, 13].

The addition of waste carpet fibers in the concrete mix is a new area of research which needs considerable attention. Although a number of research works were conducted on the utilization of this fiber in concrete to enhance general properties of concrete, it necessary to conduct in-depth study on the behavior of concrete with the wide range of mix proportions. Since a small amount of short fibers has been recommended for the improvement of the properties of concrete such as impact resistance and tensile strength [14-17], it paves the way to use carpet fibers to obtain more detail on strength and deformation behavior of concrete containing this fiber. The objective of this study is to investigate in detail the effect of the addition of waste carpet fibers on workability and density, strength, modulus of elasticity and shrinkage of concrete at different volume fractions of 0.5%, 1.0%, 1.5% and 2.0% fiber. In addition, the properties of carpet fiber itself such as tensile strength, density and melting point are also studied and presented.

2. EXPERIMENTAL PROGRAM

2.1 Materials and Mix Proportioning

Ordinary Portland cement (OPC) with a specific gravity of 3.13 was used in this study.

A saturated surface dry river sand passing through 4.75 mm sieve having water absorption of 0.70% was used as fine aggregate. The fineness modulus and specific gravity of river sands were found to be 2.4 and 2.6 respectively. Crushed granite of 10 mm size with specific gravity of 2.7 having 0.5% water absorption in a saturated surface dry (SSD) condition was used as coarse aggregate.

The waste carpet fibers used were obtained from ENTEX Carpet Industries Sdn. Bhd, Malaysia. The multi-filament polypropylene carpet fibers were 0.45 mm in diameter and 30 mm in length. The properties of the carpet fiber used are shown in Table 1. The mix proportions of carpet fiber reinforced concrete (CFRC) are given in Table 2. A control mix of plain concrete (PC) without any carpet fibers was also made for comparison and four fiber volume fractions, V_f of 0.5%, 1.0%, 1.5% and 2.0% were employed in this investigation. It is to note that no mineral or chemical admixtures were added in the concrete mixes.

2.2 Casting and Testing of Concrete Specimens

The workability of concrete mixes was measured by the slump test in accordance with BS EN 12350-2:2009. Compressive strength test was conducted with 100 mm cube specimens (BS EN 12390-3:2009 and BS EN 12390-2:2009). Cylinders measuring 100 mm x 200 mm were prepared for splitting tensile strength test (ASTM C496 / C496M – 11) and 100 mm x 100 mm x 500 mm prism specimens were made for testing the flexural strength at 28 days (BS EN 12390-5:2009). The splitting tensile strength and compressive strength tests were measured at the age of 1, 7 and 28 days. A short investigation for a period of 28 days was carried out for the shrinkage test following (ASTM C 157 and ASTM C 490). All tests were performed at an average room temperature of 27^{o}C with the relative humidity, RH of 80 ± 5 %.

Table 1 Properties of polypropylene waste carpet

Fiber	Fiber type	Length (mm)	Diameter (μm)	Density (kg/m^3)	Tensile strength (MPa)	Melting point (^{o}C)	Reaction with water
PP waste carpet fiber 	Multi-filament	30	450	940	32.4	170	Hydrophobic

Table 2 Mix proportions of concrete mixes (kg/m^3)

Mix	Water	Cement	Fine aggregate	Coarse aggregate	Carpet fiber
PC	215	430	840	910	0.0
0.5% CFRC	215	430	840	910	4.7
1.0% CFRC	215	430	840	910	9.4
1.5% CFRC	215	430	840	910	14.1
2.0% CFRC	215	430	840	910	18.8

3. RESULTS AND DISCUSION

3.1 Properties of Fresh Concrete

The fresh concrete properties in terms of workability and density are presented in Table 3. The slump test was conducted to measure the workability of PC and CFRC. As expected, the workability of concrete containing PP waste carpet fibers having same water/cement ratio of 0.50 in all mixes was reduced with the slump values ranging from 10 to 40 mm. The sturdy fiber-matrix bond and the absence of superplasticizer would have caused this reduction in the slump value of concrete. It can be seen that the workability of CFRC was also influenced by the fiber volume fraction. At V_f = 0.5%, the slump value was 40 mm compared to the 55 mm slump value obtained for the PC. At higher volume fraction, for example, concrete with 2.0% fiber content, the slump values dropped to 10 mm. This indicates that the addition of PP waste carpet fibers significantly reduced the workability of concrete mix. A comparable observation has been made by Wang et al. [2], who reported that the inclusion of higher amount of carpet fiber in concrete reduced the slump value even to near zero.

Table 3 Workability and density of fresh concrete

Mix	Slump (mm)	Fresh concrete density (kg/m^3)
PC	55	2385
0.5% CFRC	40	2328
1.0% CFRC	20	2290
1.5% CFRC	15	2210
2.0% CFRC	10	2150

Table 3 reveals that the carpet fiber had a negative influence on the density of concrete. Concrete containing PP carpet fibers showed a lower density than the plain concrete. On average, 0.5% CFRC and 1.0% CFRC mixes exhibited 2.4% and 3.9% lower density respectively as compared to concrete without any fiber. For further increase in fiber volume fraction say at V_f = 2.0%, the reduction in density was about 10%. This is because of the lower density of the polypropylene carpet fibers (940 kg/m^3) that ultimately affected the whole mass. This reduction in density of concrete is an advantage of using the waste carpet fibers in reducing the overall weight of structure.

3.2 Compressive Strength and Modulus of Elasticity

The experimental data obtained for compressive strength and modulus of elasticity of concrete are summarized in Table 4. It has been found that for the addition of fibers at 0.5% dosage, a decrease of 8.6% in compressive strength was observed. Further increase in fiber content reduced the compressive strength further as compared to that of plain concrete. Similar findings have been revealed by Wang et al. [2] and Vilkner et al. [11] where the addition of carpet fibers into the concrete was found to attain lower compressive strength. Although the compressive strength of fiber reinforced concrete was affected by the addition of carpet fiber, the failure mode, however, exhibited a considerable change from fragile to a ductile state. Due to bridging action of the fiber, the cube specimens were not crushed into pieces rather held their integrity up to the end of the test. A typical failure mode of the 100 mm cube specimen under compressive strength test is illustrated in Fig 2.

The values of modulus of elasticity presented in the Table 4 are obtained from the following expression (Eq. 1), given by Neville and Brooks [18]:

$$E_{c,\,28} = 20 + 0.2\, f_{cu,\,28} \qquad (1)$$

where E_c is the modulus of elasticity and f_{cu} is the cube compressive strength of concrete.

The results obtained in this study visibly shows that the modulus of elasticity of concrete containing carpet fibers in association with its lower compressive strength was lower than that of plain concrete.

Table 4 Mechanical properties of plain concrete and carpet fiber reinforced concrete

Mix	Mechanical properties							
	Compressive strength (MPa)			Splitting tensile strength (MPa)			Flexural strength (MPa)	Modulus of elasticity (GPa)
	1-day	7-day	28-day	1-day	7-day	28-day	28-day	28-day
PC	23.4	38.2	46.5	1.6	2.2	2.7	5.3	29.3
0.5% CFRC	19.9	34.1	42.7	1.8	2.8	3.1	6.2	28.5
1.0% CFRC	15.2	28.7	29.1	1.9	2.7	3.3	5.4	25.8
1.5% CFRC	18.0	29.3	30.7	2.1	2.9	3.5	5.1	26.1
2.0% CFRC	11.4	21.7	25.5	1.9	2.6	3.0	4.4	25.1

Fig. 2 Failure mode of concrete cube under compressive load.

For example, the 28-day modulus of elasticity of plain concrete with the corresponding compressive strength value of 46.50 MPa was found to be 29.30 GPa. A slightly lesser value of 28.5 GPa was obtained for concrete with 0.5% of carpet fibres having 28-day compressive strength of 42.70 MPa. This is to be expected, because modulus of elasticity generally increases with an increase in the compressive strength of concrete, although there is no precise form of relationship.

3.3 Splitting Tensile and Flexural Strengths

The splitting tensile strength of both normal and fiber reinforced concrete measured at different curing periods of 1, 7 and 28 days are also given in Table 4. Data presented in Table 4 suggest that along with curing time, the addition of carpet fiber in concrete mix had a positive response on tensile strength of concrete. The 28-day splitting tensile strength of concrete without any fiber, for instance, was 2.7 MPa. At the same age a higher value of 3.5 MPa was obtained for concrete with 1.5% carpet fiber.

The flexural strength of concrete containing carpet fiber at 28 days for each mix is also presented in Table 4. As can be seen in the Table, the flexural strength of CFRC mixes were increased with respect to that of the plain concrete mix. On average, flexural strength increased by 17% and 1.8% for 0.5% and 1.0% fiber content respectively as compared to that of plain concrete. It is interesting to note that the flexural strength was increased for fiber content of up to 1.0%; further increase in fiber volume, however, reduced the strength value.

3.4 Drying Shrinkage

The measured values of shrinkage over a period of 28 days are plotted in Fig. 3. It can be seen that the shrinkage strain of concrete containing carpet fibre was higher than that of plain concrete. The magnitude of shrinkage of plain concrete at 28 days was 490.44 x 10^{-6}. At the same time about 9% higher value of shrinkage i.e. 534.60 x 10^{-6} was recorded for the concrete with 0.5% carpet fiber, and this value continued to increase with the function of the fiber volume fraction. At each age, however, the difference in values are less. This phenomenon may be attributed for the higher porosity in the concrete mixtures compared to that in plain concrete due to the addition of polypropylene carpet fibers and voids produced by segregation of aggregates. Somewhat similar trend has been observed by Wang et al. [2] who used carpet fiber along with other recycled fibers in the concrete mix.

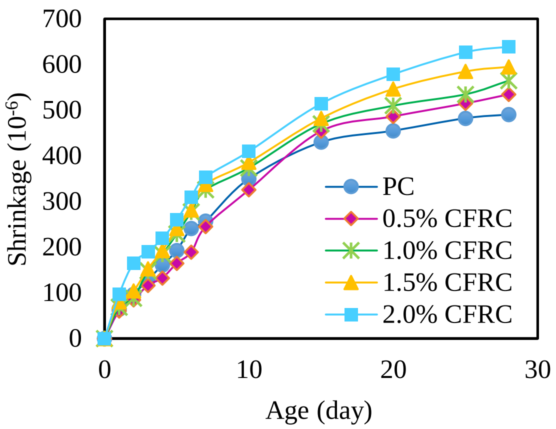

Fig.3 Shrinkage strain of PC and CFRC

Various expressions are available for the prediction of the development of shrinkage with time. Among which, the equation developed by ACI 209R-92-1994, is perhaps the most elaborate. Although the equation can be used to estimate ultimate shrinkage of a wide range of moist-cured concretes, prediction of shrinkage by this equation is subject to considerable variation. An improvement in the accuracy of prediction of shrinkage is made by Neville and Brooks [18], in which long-term shrinkage values can be obtained by extrapolating the short-term tests of 28-day duration. The following expression was, thus, applied to predict the one-year shrinkage of plain concrete and concrete containing carpet fiber.

$$S_h(t, \tau_0) = S_{h,28} + 100\,[3.61 \log_e(t- \tau_0) - 12.05]^{1/2} \quad (2)$$

Where $S_h(t, \tau_0)$ = long-term shrinkage (10^{-6}) at age t after drying from an earlier age τ_0, $S_{h,28}$ is shrinkage (10^{-6}) after 28 days, and $(t - \tau_0)$ is the time since start of drying (>28 days).

Following the above expression (Eq. 2), the one-year prediction shrinkage strains for concrete with different amount of fiber are shown in Table 5. Data displayed in this Table indicate that along with the time, the addition of carpet fibers visibly increase the shrinkage strain values of concrete.

Table 5 One year predicted shrinkage values

Mix	28-day Shrinkage (10^{-6})	1-year Predicted Shrinkage (10^{-6})
PC	490.4	789.8
0.5% CFRC	534.6	833.9
1.0% CFRC	565.0	864.3
1.5% CFRC	635.2	934.5
2.0% CFRC	667.3	966.7

4. CONCLUSION

In this study the effects of the addition of industrial waste carpet fiber on properties of fresh and hardened state properties of concrete have been evaluated. Based on the experimental findings it is concluded that the addition of carpet fibers, in general, resulted in decrease of workability and density of concrete. The modulus of elasticity in association with the lower compressive strength value was found to decrease with the increase in the amount of fiber content. Carpet fibers, however, significantly improved the splitting tensile strength of concrete. Meanwhile, concrete containing carpet fibers exhibited somewhat higher shrinkage strain. Although it is possible to predict long-term behavior from short-term data, long-term investigation including durability aspects have been put forward as recommendation for future study in order to understand fully the behavior of this material in concrete.

5. ACKNOWLEGEMENTS

The authors wish to acknowledge the co-operation and technical support received from the staff of Structure and Materials laboratory of the Universiti Teknologi Malaysia (UTM) in conducting the experimental work. Special thanks to ENTEX Carpet Industries SND. BHD, Malaysia for making this research possible by providing the waste carpet fibers.

6. REFERENCES

[1] Hsie M, Tu C and Song P, "Mechanical properties of polypropylene hybrid fiber-reinforced concrete," Materials Science and Engineering A, vol. 494, 2008, p. 153–157.

[2] Wang Y, Wu H and Li C, "Concrete Reinforcement with Recycled Fibers," Materials in Civil Engineering, vol. 12, 2000, pp. 314-319.

[3] Suna Z and Xu Q, "Microscopic, physical and mechanical analysis of polypropylene fiber reinforced concrete," Materials Science and Engineering A, vol. 527, 2009, p. 198–204.

[4] Altun F, Tanrıöven F and Dirikgil T, "Experimental investigation of mechanical properties of hybrid fiber reinforced concrete samples and prediction of energy absorption capacity of beams by fuzzy-genetic model," Construction and Building Materials, vol. 44, 2013, p. 565–574.

[5] Wang Y, "Fiber and Textile Waste Utilization," Waste Biomass, vol. 1, 2010, pp. 135-143.

[6] Reis J. M, "Effect of Textile on the Mechanical Properties of Polymer Concrete," Materials Research, vol. 12, no. 1, 2009, pp. 63-67.

[7] Wang Y, "Fiber Recycling in the United States," School of Materials Science & Engineering, Georgia Institute of Technology, Atlanta, Georgia, 2013.

[8] Ucar M and Wang Y, "Utilization of recycled post consumer carpet waste fibers as reinforcement in lightweight cementitious composites," International Journal of Clothing Science and Technology, vol. 23, no. 4, 2011, pp. 242-248.

[9] Wang Y, "Concrete reinforcement with recycled fibers from carpet industrial waste," Materials in Civil Engineering, 1997, pp. 103-104.

[10] Wang Y, "Utilization of recycled carpet waste fibers for reinforcement of concrete and soil," Polymer-Plastics Technology and Engineering, vol. 38, no. 3, 1999, pp. 533-546.

[11] Vilkner G, Meyer C and Shimanovich S, "Proprties of glass concrete containing recycled carpet fibers," in 6th International RILEM Symposium on Fibre-Reinforced concretes, Varenna, Italy, 2004.

[12] Zhou J and Xiang H, "Research on Mechanical Properties of Recycled Fibers Concrete," Applied Mechanics and Materials, Vols. 94-96, 2011, pp. 1184-1187.

[13] Miraftab M, "Novel application of pre-and post consumer carpet wastes in concrete," 1999.

[14] Schmidt H and Cieslak M, "Concrete with carpet recyclates: Suitability assessment by surface energy evaluation," Waste Management, vol. 28, 2008, pp. 1182-1187.

[15] Song P, Hwang S and Sheu B, "Strength properties of nylon- and polypropylene-fiber-reinforced concretes," Cement and Concrete Research , vol. 35, 2005, pp. 1546– 1550.

[16] Qian C and Stroeven P, "Development of hybrid polypropylene-steel fibre-reinforced concrete," Cement and Concrete Research , vol. 30, 2000, pp. 63–69.

[17] Mazaheripour M, Ghanbarpour S, Mirmoradi S and Hosseinpour I, "The effect of polypropylene fibers on the properties of fresh and hardened lightweight self-compacting concrete," Construction and Building Materials, vol. 25, 2011, pp. 351–358.

[18] Neville A and Brooks J, Concrete Technology, 2nd ed., Pearson, 2010.

Int. J. of GEOMATE, Sept., 2015, Vol. 9, No. 1 (Sl. No. 17), pp. 1441-1446.
MS No. 4345 received on Sept. 16, 2014 and reviewed under GEOMATE publication policies.

Corresponding Author: A.S.M. Abdul Awal