Use of Banana Fibres in Concrete to Mitigate Shrinkage-Crack Propagation in Concrete Roads

Abaid ur Rehman[1] and Mehran Sudheer[2]

1. Corresponding Author. Site Engineer, Al-Kamal International Construction Engineers, Islamabad, Pakistan.
   Email: abaidurrehman.61994@gmail.com
2. Corresponding Author. Lab Engineer, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan.
   Email: mehransudheer8@gmail.com

Abstract

Sustainable development of nation's infrastructure in developing countries is a major challenge in this era. There is an emerging trend of using locally available natural fibres in structural applications to support sustainable development in these countries. Banana fibre is abundantly available and can be utilized in concrete roads. These roads are prone to hair line micro cracking i.e., shrinkage cracking, instigated by drying shrinkage due to volumetric changes in concrete during the curing. The overall aim of this study is sustainable development of concrete roads by using Banana Fibre Reinforced Concrete (BFRC). And the specific aim is to investigate the tensile behaviour of BFRC in comparison with conventional plain concrete (PC). Mix design of 1:2:4 is adopted and 0.5% banana fibre by mass of concrete is used in BFRC specimen. Standard cylinder specimens (100mmx200mm) of PC and BFRC each are casted and cured for 28 days. Split tensile test is performed on these specimens. BFRC depicted decreased tensile strength and energy absorption as compare with PC. On the other hand, BFRC showed an immense increase in toughness value. This improved behaviour of BFRC toughness can help in reducing the resulting shrinkage cracking propagation. It is recommended that, mechanical properties of BFRC in addition with so other strengthening admixtures and its usage as a commercial product should be explored in depth.

Keywords: Shrinkage cracking, Crack propagation, Banana Fibre Reinforced Concrete, split tensile strength, Tensile energy absorption, Bridging effect.

1. INTRODUCTION:

Concrete pavements are durable structures and preferred more over flexible pavements. Concrete pavements provide more strength. These pavements need less maintenance. But these are also prone to number of pre mature failures. Shrinkage cracking is one of these premature failures, which later on results in various distresses of pavements and ultimately lessens the design life of the structure (Kumar et al. 2012). These cracks are also responsible for creation of chain and transverse cracking in concrete pavements (Niken et al. 2016). Figure 1(a), (b) and (c) shows shrinkage crack propagation after six months, one year and two year of construction, respectively. The thickness of the lines indicate the width of cracks. These issues are resolved by many researchers by use of fibres to lessen the impact of damage caused due to poor construction practices.

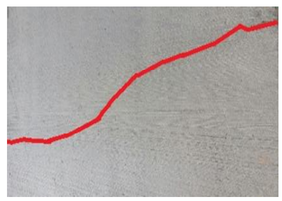
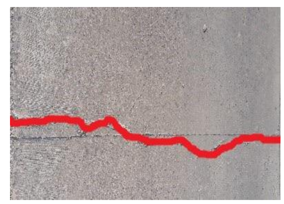
a.  b.  c. 

Figure 1: Shrinkage-crack propagation, a. after six months of construction, b. after one year of construction and c. after two years of construction

Rai and Joshi (2014) conducted a research to study the effect of fibre reinforced concrete on the shrinkage cracking in comparison with conventional concrete. They concluded that fibre reinforced concrete showed resistance against shrinkage cracking as compared to plain concrete. Fibres like polypropylene in restrained concrete can lessen the drying shrinkage percentage (Yousefieh et al. 2017). Use of mineral fibres and nano silica showed improved behaviour in mechanical properties of concrete (Larisa et al. 2017). Debate on natural fibres all over the world is increasing. Utilization of natural fibres as a source of raw materials for the different industries due to their eco-friendly nature and for accomplishing the idea of global sustainability has been increased. Experts are looking for the new economical, environment friendly and sustainable techniques in construction. Researchers are focusing on agricultural waste as one potential of source energy. Today throughout the global, increase in awareness about issues of environment is acting as the strong motivation for the utilization of natural fibres in various kinds of industries. However, there is a changing trend in use of natural fibres in structural applications.

Banana fibre is abundantly available and can be utilized in concrete roads. Mostafa et al. (2015) expressed that banana fibres can be utilized in compressed earth block creation, and they reported improved compressive and flexure strength of banana fibre reinforced specimens in comparison with unreinforced specimens. Binici et al. (2005) reported that in an immense amount of agricultural by-product created each midyear in Turkey. Agriculturists consume it, causing environmental harm. Rather than being scorched, agricultural fibres can be utilized as a part of mud block creation. In the same way, banana fibre is abundantly available as an agricultural by-product in Pakistan and being used as export product. Sakthivel et al. (2019) did research study on the mechanical properties of banana fibre reinforced concrete. Apart from enhanced mechanical properties, they reported banana fire was found good in fire resistance. Keeping in mind, enhanced properties of banana fibre reinforced concrete, they recommended to explore its future prospects for construction industry as an environment friendly material. To the best of author's knowledge, the research conducted to control shrinkage cracks by using BFRC in concrete roads is limited. Therefore an experimental study is planned to investigate the potential of BFRC in concrete roads. The overall aim of this research is sustainable development of concrete roads by using Banana Fibre Reinforced Concrete (BFRC). And the specific aim is to investigate the tensile behaviour of BFRC in comparison with conventional plain concrete (PC). Percentage of banana fibre used is 0.5% by mass of concrete is used in BFRC specimen.

2. EXPERIMENTAL PROCEDURES:

2.1 Raw materials:

Raw materials which are used to prepare specimens comprises of ordinary portland cement, sand having fineness modulus of 2.6 and specific gravity of 2.63, aggregates of maximum size 19 mm, and banana fibres of maximum length 50 mm.

2.2 Mix design and casting procedure:

In the mix design ratio of PC, the ratio of 1:2:4 is used for cement, sand, and aggregate respectively with a water-cement (W/C) ratio of 0.6. The mix design and (W/C) ratio for BFRC is equivalent as compared to PCC irrespective to that 50 mm long fibres having 0.5% proportion, by mass of concrete. All quantity of materials is mixed by mass. For preparation of concrete rotating drum concrete mixer is used. In making plain cement concrete, raw materials including water are transferred in the drum of the conventional concrete mixer following the sequence of aggregates first, sand second, cement third and water in the last, and it is rotated for three minutes. Slump test is performed before filling moulds and the result of slump is 2-cm.

For preparation of banana fibre reinforced concrete, an alternate approach is embraced to avoid the accumulation of banana fibres in blender bars of concreting drum. The materials are placed in drum in three layers. In first layer, 33% of total aggregates is spread in the drum followed by cement, fibres and sand. In this way, fibres are sandwiched between aggregates and sand. A similar strategy is embraced for the remaining material. The blender is halted at the point where addition of layer is to done and remaining water is included. Concrete mixing machine is rotated again for 1 minute.

2.3 Specimens:

The cylinders were casted for conduction of split-tensile strength test for PC and BFRC; having standard size (100mm x 200mm). Total 4 specimens were casted (2 PC + 2 BFRC). For BFRC, filling and compaction of the mix in the moulds requires special consideration. Therefore, another approach is adopted to remove air voids and to achieve self-compaction, in addition to standard compaction method. The mould lifted up to a height of 200mm approximately and afterward dropped to the floor. After 24 hours, the specimens are de-moulded and placed in the curing tank for 28 days. The density of PCC and BFRC is determined by using ASTM C138/C138M-16 procedure.

2.4 Split-tensile strength test:

The split-tensile strength is performed on the test specimens as indicated by the ASTM standard

C496/C496M11. The split-tensile strength, split-tensile behaviour, split-tensile energy absorbed before crack and split tensile toughness are determined.

3. RESULTS:

3.1 Split-tensile behaviour:

Load versus time curves under split tensile loading for PC and BFRC are shown in Figure 2(a). The crack development in specimens under split-tensile loading at initial, peak and ultimate loads is presented in Figure 2(b). The upper two images i.e., Figure 2(b) demonstrate the underlying crack in PC and BFRC. The underlying crack in the specimens of PC and BFRC is noted at 100% and 95% of their comparing maximum loads. The underlying crack length and width in BFRC is lesser when contrasted with PCC. The length of initial crack around 60 mm to 75 mm is observed in BFRC. At this point, the separated pieces of PC can be around the first crack observed with no time distinction, while pieces of BFRC are held together as a result of the interlocking impact of fibres. At the maximum load, when contrasted with PCC, the observed number of splits, their length and width at the maximum load are less in BFRC as shown in Figure 2(b). At this stage, the greatest length of crack in the specimen of BFRC is amplified up to around 75 mm. The test is proceeded even after the maximum load to see the sample behaviour. At the ultimate load, there are various cracks and the most extreme split lengths for the example of BFRC is developed up to around 90 mm as shown in Figure 2(b). For observation of fibre failure, specimens of BFRC are deliberately broken into two pieces after the ultimate load application.

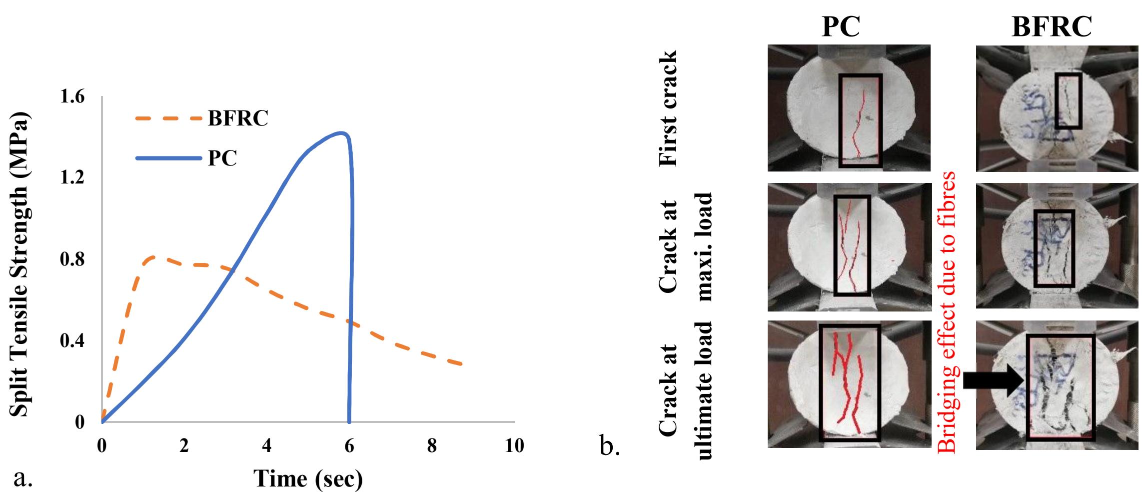


Figure 2: Split-tensile behaviour of PC and BFRC a. split tensile strength versus time, and b. crack development

3.2 Split-tensile strength (SS), split-tensile energy absorbed before crack (SE_1) and split-tensile toughness (SE_T):

For computing the split-tensile strength (SS), the peak load value from split-tensile load versus time curve is utilized according to ASTM standard. For split-tensile absorbed energy before crack (SE_1) calculation, the portioned part of area under split-tensile load versus time curve up to the first crack load is utilized. Similarly, the split-tensile energy absorbed after crack (SE_2) is computed by using the area under split-tensile load versus time curve from the first crack load to the peak load. Splitting-tensile absorbed energy up to the peak load (SE) is taken as the entire area under split-tensile load-time curve from zero to the peak stress. Splitting-tensile toughness (SE_T) is taken as the ratio of the splitting tensile absorbed energy up to peak load to the splitting-tensile energy absorbed before crack (SE/SE_1).

Table 1: SS, SE_1, SE_2, SE, SE_T of PC and BFRC

Parameter	**Concrete type**	
	PC	**BFRC**
SS (MPa)	1.43	0.83
SE_1 (kN.s)	176.67	18.8
SE_2 (kN.s)	0	118.3
SE (kN.s)	176.67	137.1
SE_T	1	7.29

The split-tensile strength SS of PC and BFRC are 1.43 MPa and 0.83 MPa respectively, which means the split tensile strength of the BFRC is decreased by 42% in comparison with PC. The comparison of SS, SE_1, SE and SE_T is shown in Figure 4. BFRC showed decreased results in results of SS, SE_1 and SE_T for BFRC in contrast with PC by 42%, 90% and 33% respectively. The split-tensile toughness of BFRC showed extreme increase in its value as compare with PC.

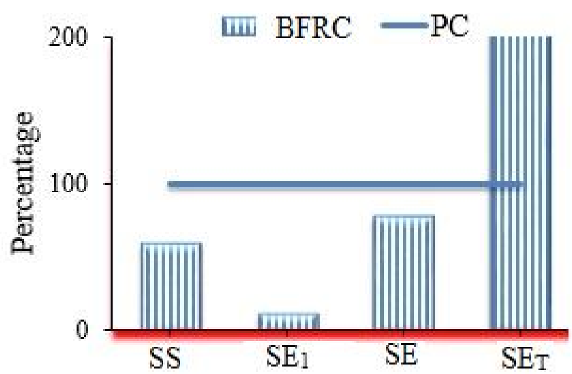


Figure 3: Comparison of SS, SE_1, SE and SE_T of PC and BFRC

4. KEY ASPECTS FOR USING BFRC IN CONCRETE ROADS:

Shrinkage-crack propagation in concrete pavements can be bonded with different factors which include shrinkage, penetration of water, and tensile strength etc. Due to volumetric changes, shrinkage cracking results, which can be eliminated, if the split- tensile strength of concrete is greater than the tensile stresses induced by volumetric changes due to shrinkage. It depicts that shrinkage cracking can be controlled by tensile strength of concrete. Bending stresses in concrete structures are introduced by differential settlement in these structures. Similarly, cracks due to bending stresses would be controlled if bending strength of the concrete is greater than these stresses. Therefore, bending strength of the concrete is also needed to highlight in controlling cracks. In order to avoid formation of severe distresses in concrete pavements, it is necessary to increase the absorption, toughness and energy absorbed after ultimate loads of concrete. For reducing the rate of cracking in concrete pavements, it is essential to investigate materials by means of less shrinkage in addition with better mechanical properties (tensile strength, flexural strengths and toughness).

Experimental behavior of PC and BFRC to reduce the rate of shrinkage cracking is inspected, in the current study. When contrasted with that of PC, the BFRC demonstrates ineffective results in split-tensile strength SS, split-tensile energy absorbed before crack SE_1, total split-tensile energy absorbed SE. An extreme enhancement in SE_T is seen when contrasted with that of PC. Though, the split-tensile strength of BFRC is not found sufficiently effective but the increased toughness of BFRC can help in reducing propagation of shrinkage cracking which ultimately will stop different distresses in concrete pavements.

Figure 4: Fibre behavior in broken test specimen

BFRC gives a bridging effect while failing, hence changing the failure mode and pattern. Figure 4 shows fibre pull out and fibre de-bonding. It is observed that, nearly 70% of fibres are pulled out and that of 30% are broken on the broken surface of specimen. The pulled out observed in broken specimen is due to lesser bond strength between banana fibres and concrete matrix. The reason can be that fibres were not properly dispersed while mixing

5. CONCLUSIONS:

This study highlights the usage of banana fibre reinforced concrete to avoid shrinkage-crack propagation in rigid pavements. Mix design of 1:2:4 with water cement ratio 0.6 was adopted to prepare PC and BFRC specimens. BFRC specimens included banana fibres of 5 cm length. Split-tensile behaviour of samples was judged. Following conclusions can be drawn from the conducted study:

- The increased toughness value of BFRC can help in controlling the propagation of early age shrinkage cracking in concrete pavements.
- The bridging effect of BFRC prevented the shrinkage cracks from getting deep under increased loading during testing. BFRC specimen did not break into two pieces like PC specimen.

The results show a potential in BFRC to be used for mitigation of shrinkage cracks in concrete roads. It is recommended that, mechanical properties of BFRC in addition with so other strengthening admixtures and its usage as a commercial product should be explored in depth.

ACKNOWLEDGEMENTS:

The authors are thankful to Mr. Nasir Shabbir for his technical guidance during the lab work. The authors are also thankful to Engr. Dr. Majid Ali for his valuable guidance during this research work. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

REFERENCES:

Suresh Kumar, K. S., Kamalakara, G. K., & Kamble, S. (2012). Fatigue analysis of high-performance cement concrete for pavements using the probabilistic approach.

International Journal of Emerging Technology and Advanced Engineering, 2(11), 640-644.

Niken, C., Siswanto, Y., & Tjahjono, E. (2017). Cracking of open traffic rigid pavement. In MATEC Web of Conferences (Vol. 101, p. 05009). EDP Sciences.

Rai, A., & Joshi, Y. P. (2014). Applications and properties of fibre reinforced concrete. Int. Journal of Engineering Research and Applications, 4(5), 123-131.

Yousefieh, N., Joshaghani, A., Hajibandeh, E., & Shekarchi, M. (2017). Influence of fibers on drying shrinkage in restrained concrete. Construction and Building Materials, 148, 833-845.

Larisa, U., Solbon, L., & Sergei, B. (2017). Fiber-reinforced concrete with mineral fibers and nanosilica. Procedia Engineering, 195, 147-154.

Mostafa, M., & Uddin, N. (2015). Effect of Banana Fibers on the Compressive and Flexural Strength of Compressed Earth Blocks. Buildings, 2015, 5(1), 282-296.

Binici, H., Aksogan, O., & Shah, T. (2005). Investigation of fibre reinforced mud brick as a building material. Construction and Building Materials, 19(4), 313-318.

Sakthivel S., Parameswari, R., Gomathi, M., Sangeetha S. (2019). Experimental Investigation on Concrete with Banana Fiber and Partial Replacement of Cement by Banana Leaf Ash. International Research Journal of Engineering and Technology, Vol 6, Issue 3.