Controlling Shrinkage Cracks Propagation in Rigid Pavements Using Banana Fibre Reinforced Concrete

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Abstract

Cracking in Rigid Pavements is a common issue. Out of different types of cracking, drying shrinkage causes visible cracking in Plain Cement Concrete (PCC) as it shrinks and the developed stresses exceeds its tensile strength capacity. Movement of heavy traffic cause propagation and widening of cracks. This ultimately reduce the serviceability and durability of Pavements. The overall aim of the research program is to improve the performance and durability of rigid pavements exposed to heavy traffic loading. The specific goal is to use Banana Fibre in Reinforced Concrete to improve the post cracking behaviour of concrete in rigid pavements and limit the propagation and widening of shrinkage cracks. Cylinders of diameter 100 mm and height 200 mm are prepared using mix design ratio of 1:2:4 having water cement ratio 0.6 and fibre content 0.5% by mass of concrete. Specimens are kept in water for 28 days and then tested using ASTM standard C496/C496M-17. The splitting tensile strength of BFRC specimen turned out to be 44% less than that of PCC. The fibres caused a strong bridging effect that shows fibres have a good tensile and bond strength to improve the post cracking behaviour of concrete, also the percentage of fibre content has a direct relation with the splitting tensile strength. The advantage of Bridging effect can be utilized to increase the splitting tensile strength of BFRC over PCC by optimizing the percentage of fibre content.

Keywords: Banana Fibre Reinforced Concrete, Rigid Pavements, Shrinkage Cracking, Bridging Effect, Tensile Strength.

1. INTRODUCTION:

Rigid pavements are constructed in areas which are exposed to movements of heavy traffic. The sole purpose of a rigid pavement is to provide efficient, smooth and comfortable ride and long-term durability against dynamic loading. Rigid pavements are expensive in terms of initial cost as compared to flexible pavements but have minimal cost of maintenance. Due to high flexural strength of concrete, vehicular load is homogenously transferred to underlying layers, reducing stress concentration at subgrade level (Chang and Chai 1995). Elastic modulus and shear modulus of rigid pavement is much greater than flexible pavement. Degradation of concrete starts with the early age micro cracking (Guo and Weng 2019). The durability of rigid pavement is controlled by various mechanical properties. These mechanical properties are compromised with the development of cracks. Various types of cracking that a pavement encounter during its life are early age micro cracking, longitudinal cracking, thermal cracking, shrinkage cracking, etc. Concrete made of Portland cement has a brittle behaviour and is weak in tension. Due to this brittle behaviour, concrete has low resistance to temperature and volumetric stresses with low strain capacity in tension and low toughness thus resulting in development of cracks.

When concrete expands or shrinks, stresses are developed which produce cracks on the surface of rigid pavement. Surface of the pavement is exposed to atmosphere and the layer of concrete underlying is not, concrete on surface dries and shrinks at a different rate as compared to underlying layer. The underlying layer of concrete acts as a restraint to shrinkage, resulting in cracking of the surface layer. The governing property of concrete that is responsible for shrinkage cracking is its split tensile strength. During drying shrinkage, stresses are developed in concrete and when these stresses exceed the tensile strength capacity of concrete, shrinkage cracks appear on the surface. After cracking starts, the deterioration rate of concrete pavement increases as the traffic loading boosts crack propagation and expansion. Once Shrinkage cracks appear, the pavement is highly exposed to adverse climatic effects including water rolling effect during raining seasons. Water gets absorbed in these cracks and damages the underlying layers by causing partial settlement as well as thermal cracking due to temperature variation. In such scenarios post construction cost of maintenance increases for remedial measures. Concrete is weak in encountering tensile stresses so it is fortunate that the issue of shrinkage cracks propagation can only be resolved by improving the post cracking behaviour using other additives like reinforcement, fibres, etc.

To enhance the mechanical properties, especially to control the issues of cracks propagation, possible solutions can be admixtures, reinforcement, fibres, etc. Nowadays researchers are widely using fibres as additives to enhance the mechanical properties of concrete. Instead of synthetic fibres like glass fibre, carbon fibre and plastic fibres, plant fibres come under the category of renewable materials that possess a potential to create environmentally friendly products (Kumar et al. 2016). Mostafa and Uddin (2015) investigated the mechanical properties of banana fibre in compressed earth blocks. Fibres create a bridging effect during the development of cracks in concrete and improve its post cracking behaviour (Prasannan et al. 2018). Banana Fibres are lignocellulose material having up to 56% cellulose content that plays a key role in determining its mechanical properties. Banana fibres with a diameter of 80 – 250 mm have a tensile strength ranging from 54 MPa to 754 MPa and density 1350 Kg/m^3 (Ali 2012). Banana fibres are lightweight, less extensible with considerable heat and fire resistance (Sakthivel et al. 2019). Banana fibres, if used as a reinforcing material with different percentages in concrete can play a vital role in increasing the tensile strength of concrete that will reduce the cracks propagation caused after tensile failure.

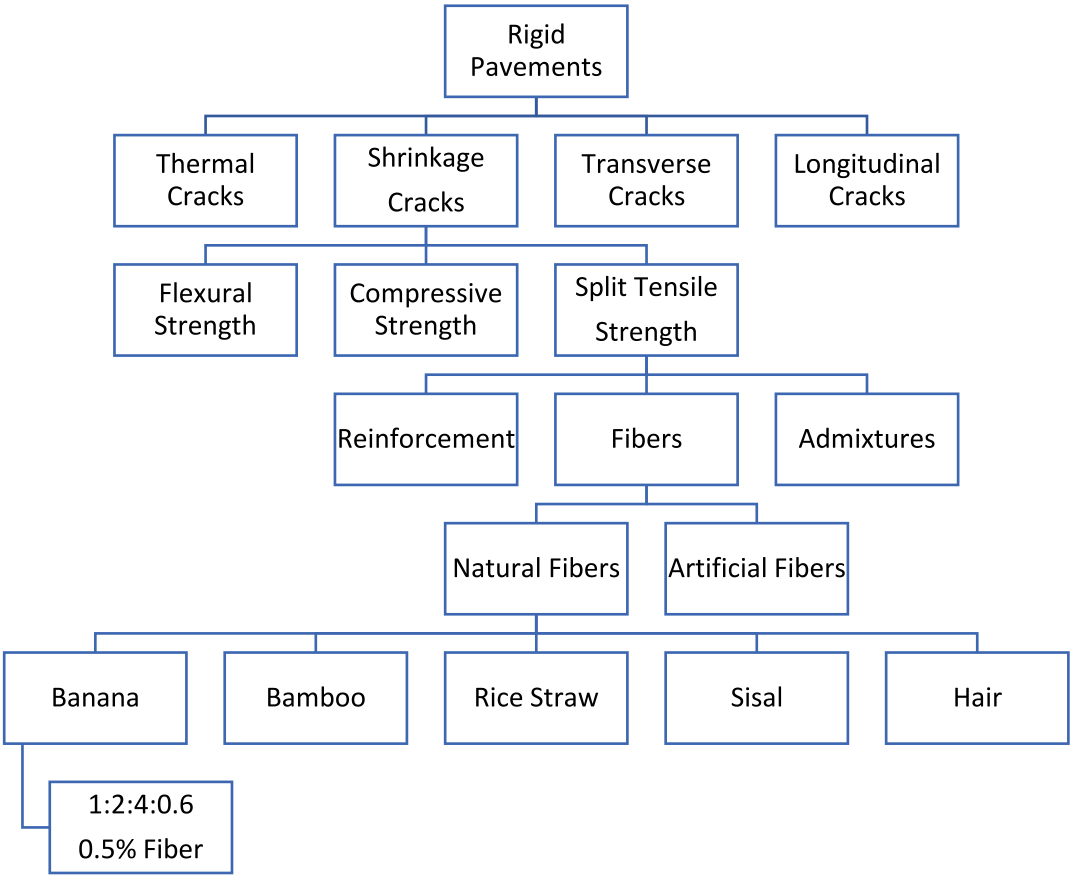

Figure 1: Flow chart representing pavement issues, governing properties and applied solution

Figure 2: Shrinkage cracking in rigid pavement

Prasannan et al. (2018) investigated the mechanical properties of concrete using 1% and 1.5% banana fibre. To the best of author's knowledge, no work has been done to control shrinkage cracks propagation in rigid pavements using banana fibre. Thus, current research is aimed to study the split tensile behaviour of BFRC using 0.5% banana fibre in concrete for its implementation in rigid pavements to achieve better post cracking properties.

2. EXPERIMENTAL PROCEDURE:

2.1 Raw Materials:

Ordinary Portland Cement, locally available fine and coarse aggregates, water and banana fibres are used for the preparation of PCC and BFRC. The length of each banana fibre is 50 mm.

2.2 Mix Design and Casting Procedures:

For the preparation of BFRC, the mix design ratio used is 1:2:4 (Cement: Sand: Aggregate) with 0.6 water cement ratio. Banana fibres are added 0.5% by mass of concrete. Firstly, one third of the coarse aggregates and fibres are added in the drum mixer with three quarters of water and then mixer is rotated for two minutes. Then two third fine aggregates are added and mixer is rotated for another two minutes duration. Then rest of the materials are added and mixer is rotated for three minutes. Slump test is performed to investigate the workability of BFRC as per specifications of ASTM C143 / C143M-15a and then specimens are prepared.

For the preparation of PCC, the mix design ratio used is 1:2:4 (Cement: Sand: Aggregate) with 0.6 water cement ratio. All materials along with water are poured in the drum mixer and then rotated for a duration of four minutes. Same standard test is performed to check the workability of PCC.

2.3 Specimens:

Cylinders for both PCC and BFRC, having 100 mm diameter and 200 mm height are prepared using standard procedure of filling in three layers and temping each layer with 25 blows with temping rod of 16 mm diameter. The unit density of PCC and BFRC is determined as per ASTM standard C138 / C138M – 16. The density of PCC and BFRC specimens came out to be 2426 kg/m^3 and 2196 kg/m^3 respectively.

2.4 Splitting Tensile Strength Test:

To determine splitting-tensile strength of PCC and BFRC cylinders, test is performed according to ASTM standard C496 / C496M-17. Compression testing machine is used to test all cylinders for studying splitting tensile behaviour and determining splitting-tensile strength. The splitting-tensile load-time curves are also obtained for all specimens.

3. RESULTS AND ANALYSIS:

3.1 Splitting Tensile Strength Behaviour:

Splitting tensile test is performed for both PCC and BFRC specimens. Figure 3a shows the strength time curves for both PCC and BFRC. The cracking pattern from the initiation of first crack to the application of maximum load is observed visually. Figure 3b shows the specimens of PCC and BFRC at first crack, cracks at maximum load and cracks at ultimate load. In PCC and BFRC specimens, first crack is observed at 100% and 99.5% of the maximum load respectively. Splitting effect is visualized after maximum load in PCC specimen after which the specimen broke in two pieces. In case of BFRC, a strong bridging effect was observed and the concrete was held by the fibres before splitting due to strong bond between fibres and cement matrix. The cracks widened slowly even after the application of ultimate load. After testing, the specimens were intentionally broken to study the post testing fibre condition.

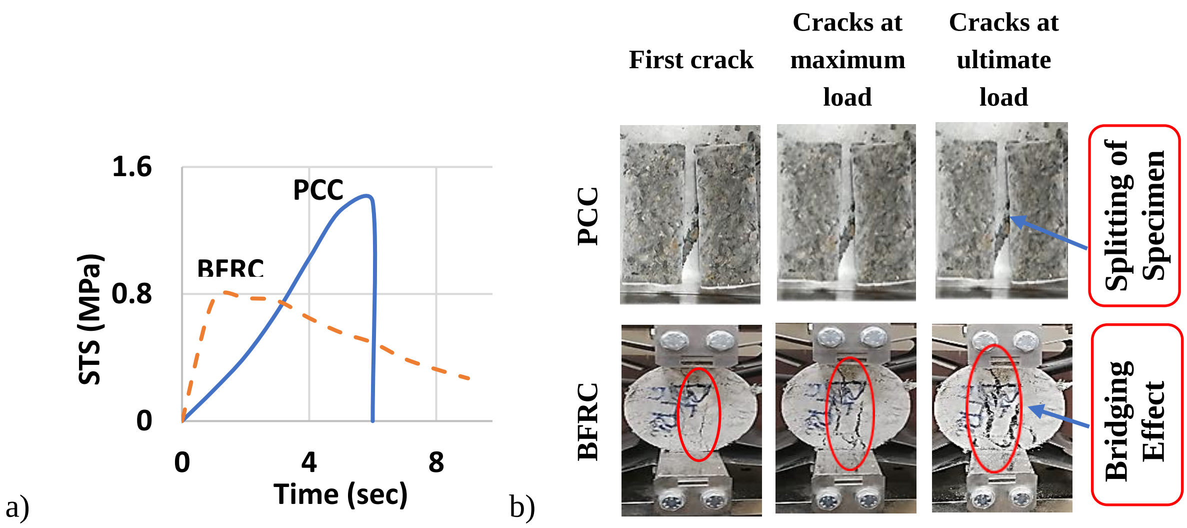

Figure 3: Splitting tensile behavior of PCC and BFRC specimens, a) Strength-time curve, b) Cracking pattern

3.2 Splitting Tensile Strength Parameters:

The maximum load and corresponding splitting tensile strength of PCC and BFRC specimens were obtained and shown in Table 1. The first crack in PCC specimen appeared after 8 seconds at the maximum load of 45 kN. While in case of BFRC, first crack occurred at very first second at the load of 24.30 kN. After first crack the specimen took considerable load due to the fibres holding the concrete. The splitting tensile strength of BFRC reduced up to 44% less than that of PCC. This is due to the balling effect, low percentage of banana fibres, inadequate mixing and improper compaction of concrete. The splitting tensile strength of fibre reinforced concrete increases with the increase in banana fibre percentage.

Table 1: Splitting tensile strength parameters

Specimens	Max. Load (kN)	STS (MPa)
(1)	(2)	(3)
PCC	45	1.38
BFRC (0.5%)	24.40	0.77

4. KEY ASPECTS FOR USING BFRC IN RIGID PAVEMENTS:

The specimens are broken intentionally to visualize the fibre behaviour. Broken specimen is shown in Figure 4. After analysing the broken specimen visually, both fibre breakage and pull out behaviour are noticeable but fibre breakage is observed to be more than fibre pull out. Fibres pull out occurs when tensile strength of fibres is greater than bond strength between fibres and cement matrix. The bridging behaviour is beneficial for controlling the propagation of shrinkage cracks in rigid pavements. Fibres are able to prevent widening of cracks which can reduce the deterioration of concrete in case of rigid pavements. This can increase the lifespan of pavement exposed to heavy traffic.

Figure 4: Fibres breakage and pull-out behavior

The failure of BFRC is observed to be ductile than the brittle behaviour of PCC. The bond between concrete and fibre prevented the spalling of concrete. As it is a pilot study, a drum mixer is used to prepare concrete. The improper mixing, strangling of fibres and poor compaction led to the balling effect in concrete. Also, less fibre percentage i.e. 0.5%, decreased the splitting tensile strength of concrete. Other way round, the strong bridging effect in concrete indicates the presence of strong bond between concrete matrix and fibre.

The observation from the testing shows that the performance of fibre in bearing the tensile stresses has enhanced the tensile property of overall concrete matrix. This property can delay the propagation and widening of cracks in rigid pavements exposed to heavy traffic and adverse climatic conditions which will minimize the deterioration of rigid pavement and increase its durability.

5. CONCLUSIONS AND RECOMMENDATIONS:

The study investigates the post cracking behaviour of BFRC in rigid pavements using mix design ratio 1:2:4 and banana fibre 0.5% by mass of concrete. The splitting tensile strength of BFRC decreased as compared to PCC due to less fibre percentage and balling effect.
Following are the conclusions drawn from the conducted research:

- Brittle failure of concrete changed into relatively ductile failure due to the presence of banana fibre.
- The banana fibre created bridging effect in the concrete improving the post cracking behavior of concrete.

By optimizing the fibre content, the splitting tensile strength of BFRC can be increased. Increased strength and improved post cracking behaviour of BFRC can limit the propagation and widening of cracks thus delaying the deterioration of rigid pavements.

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