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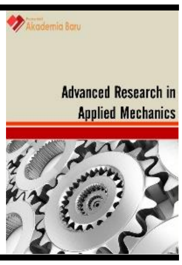

Long Term Behaviour of Fibrous Concrete Composite (FCC): A Conspectus

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ABSTRACT

Fibrous concrete composite (FCC) have been applied in numerous civil engineering structures, such as pavements, dams, runway, hydraulic structures, aircraft parking, and runway. The desire for their usage as being due to their unique properties compared with other materials. The stability of fibres in cement concrete appears to be good enough, but further long term tests are necessary to evaluate their durability and performance under mechanical sustained load. This is owing to the dearth in knowledge on the fibrous concrete particularly bio fibrous concrete composites (BFCC) behaviour and response to compressive, flexural and uniaxial tensile sustained loads. Therefore, an in-depth study into the creep performance of BFCC is necessitated to understand the long term behaviour of this biodegradable and environmental friendly construction product. This will avail the structural engineers and builders' adequate understanding and data for design construction purpose of this green concrete product.

Keywords:
Bio fibrous concrete composite, creep, fibrous concrete composite, kenaf fibre, long term

1. Introduction

Contrasting to other construction materials such as steel, concrete is known to significantly experience deformation under the application of sustained load and service conditions [1]. Although a number of research have been done as regards the time-dependent deformation in concrete mechanical properties, Alizadeh *et al*. [2] explained in their work that the understanding of creep of cement-based systems is limited up till now. Since creep is the increase in the strain of a material or structure under a constant load over a period of time, Majority of authors have approved that creep primarily take place in the hydrated cement paste, owing to the rise in the change in dimension of structure or material under sustain load over time . Meanwhile, it has been seen that when concrete is exposed to loading, aggregate of normal weight does not really creep, the mechanism of creep rests with the paste [3]. In this light, Bernard [4] theorised that concrete under constant load, will lead to the movement of moisture within the calcium silicate hydrated (C-S-H) phase of cement paste. The study of MacKay [5] also supported this statement.

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Research on the effect of factors such as stress intensity, age at loading on creep of plain concrete, steel fibrous concrete and synthetic fibrous concrete have been very commonly carried out on steel, glass and synthetic fibrous concrete. Research efforts in the past three decades had revealed that much remains to be done for a good understanding of time-dependent deformation of BFCC utilization in the concrete construction. The effect of fibre length, fibre volume, various admixtures and additives in the concrete mix, the influence of static sustained loading, ambient conditions and the development of creep prediction model with evaluation on structural members are the insufficient available data for design during design stage of concrete structure [6–9]. Most of the existing creep studies have been carried out using steel fibre and synthetic fibre.

2. Long Term Deformations of Concrete

2.1 Origin

A prominent role is being performed by the hydrated cement paste in concrete composite long term deformations. It is the origin of concrete composite creep deformations and drying shrinkage. There exist a number of forms in which water in hydrated cement paste are housed. The firmness with which these water are held determines the basis of their classification [3], as illustrated in Figure 1.

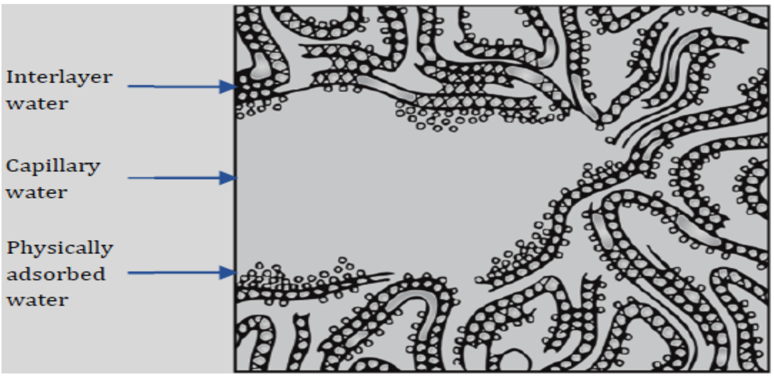

Fig. 1. Hydrated cement paste and water type in it [10]

The voids of the hydrated cement paste houses the capillary water which is one of the types of water in the hydrated cement paste, the solid surface imposed attractive forces have no affect it. The water adsorbed to the solid surface is accountable to by these forces. The second form which is the interlayer water is explained by Mehta and Monteiro [10] has been connected to the C-S-H structure and strong drying processes is the only means this water can be lost in the hydrated cement paste. Moreover, cement hydrated phases thus bound part of the water chemically.

The exposure of cement paste to a situation where the saturated humidity is higher than the humidity of the ambient conditions gives birth to drying shrinkage. A forfeiture of physically adsorbed water from C-S-H ensues in such circumstances. Nevertheless, it should be noted that if the loss of adsorbed water is as a result of sustained stress exertion on hydrated cement paste, the consequential deformations is credited to the phenomenon of creep. Although, creep in concrete could be as a result of other effects, the furthermost appears to be forfeiture of adsorbed water [10, 11].

Creep develops with respect to time and the degree of hydration influenced it considerably. At early stages other volume variations may perhaps take place, for instance, owing to the reduction in the thermal shrinkage (temperature after the hydration heat) dissipation, to plastic shrinkage (vaporization on the surface) and to the inner exclusion of capillary water in moisture-sealed conditions as a result of chemical combination for the duration of hydration (autogenous shrinkage). Neville [3] and Mehta and Monteiro [10] gave more information on volume variations of concrete composite in their book.

2.2. Long Term Deformations Classification

A Concrete total strain is simply referred to the result of elastic strain, shrinkage and creep as illustrated in Figure 2a. The initial strain at the application of the load is primarily elastic, albeit it may comprise a non-elastic component [12]. There are different types of shrinkage, though out of them all, carbonation shrinkage only improves in equivalent time scale as drying shrinkage [13,14].

Creep is succinctly put as the bringing together of two constituents that hinge on the ambient humidity. Basic creep, drying creep, transitional thermal creep and wetting creep are all different types of creep [13].

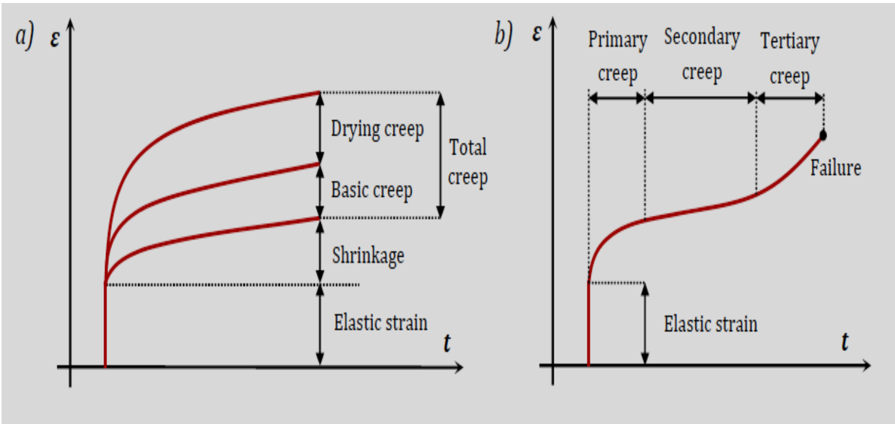

Fig. 2. (a) Total strain of concrete with time (b) general form of ε-t curve for materials subjected to creep [12]

Figure 2b presents the common practice of the strain-time (ε-t) curve relationship for a material exposed to creep. The primary, secondary and the tertiary creep are three phases of creep occurrence after the initial elastic strain. All through the primary creep, the creep rate decreases with time, whereas the secondary creep tallies to a stable state creep rate. For normal intensities of stress up to 40% of the compressive strength, the primary creep might not be differentiated from the secondary creep. Tertiary creep happens when concrete is exposed to high levels of stress (above 40% of the compressive strength) [15].

The outcomes of creep may be conveyed by the creep coefficient which is the ratio between creep strain and elastic strain. When the stress is aloof from concrete, the material displays an instantaneous recovery followed by a time-dependent recovery known as creep recovery. Thus, the subjected concrete under sustained load presents a residual strain or irretrievable once the specimen is unloading [12].

When a sample is exposed to an unsealed or drying condition, the time-dependent deformation is referred to as drying creep. There exist a similarity between drying shrinkage and creep due to their dependence on specimen size and environment, whereas basic creep depends on the material property only. The phenomena accountable for drying shrinkage are known to be stress-induced shrinkage and surface micro-cracking [16].

The amalgamation of the drying and basic creep phenomena gives birth to total creep in reality, one being the leading factor, occasionally. The Pickett effect which is as well termed drying creep is the surplus of creep at drying over the entirety of shrinkage and basic creep. Creep experiences is more in the course of loading condition if the evaporable water is more. The creep is said to be further pronounced than the first two cases as soon as the concrete drying out during loading. The inconsistency previously mentioned is reported to be caused by a mechanism referred as drying creep and was said to be first reported by Pickett [17].

2.3. Creep Behaviour of Concrete under Sustained Load

Figure 3 illustrates the performance of concrete under the action of constant loading. Concrete is known to creep over log time or even indefinitely under load [18]. Once concrete is subjected to a sustained load, it experiences an instantaneous (elastic) deformation initially, afterwards it moves into a primary region. The rate of this deformation rate drops shortly at this region with respect to time. At the removal of the imposed sustained load on the tested concrete sample, an elastic strain full recovery is thereafter experienced by the unloaded specimen.

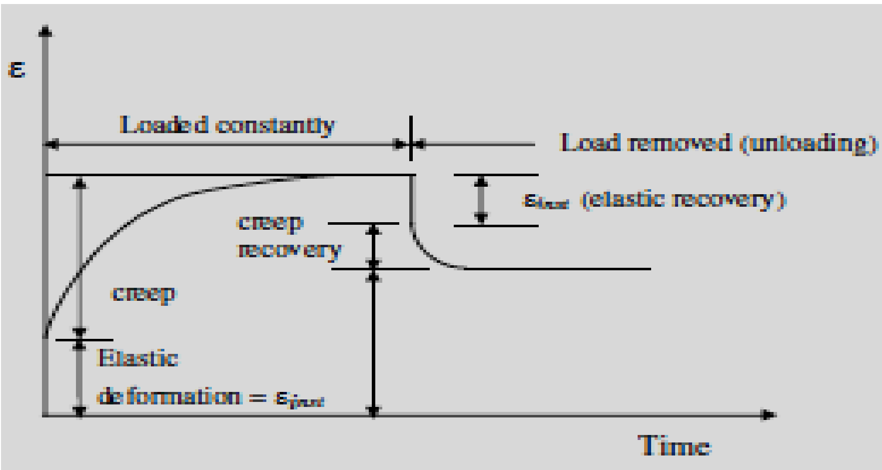

Fig. 3. Strain-time relationship of concrete under sustained loading

Previous research on concrete creep as shown that concrete recovery strain is lesser when compared to initial elastic strain, given that elastic modulus of the material thus increase with respect to time. After this stage, the specimen experience creep delayed recovery [1]. Concrete creep deformation occurs in three stages [19]. The reason of the distinction was to show the difference between recoverable and residual deformation. At the instance of loading a concrete, the initial increase in deformation is called primary creep and the secondary creep is relatively a stable deformation region which is principal in the medium to long term.

3. The Theory of Fibrous Concrete Composite (FCC)

Owing to concrete brittle nature, the durability and strength of concrete are usually affected by the ensuing cracks that occurs when it is subjected to stress or loads [20,21]. FCC is simply defined as concrete comprising of fine and coarse aggregates, binder, water, short disconnected fibre which in most scenarios it's randomly dispersed in the concrete, in consequence, enhanced properties of concrete is obtained in all ramifications. It should also be mentioned that a number of cement extenders could be added and superplasticisers to modify the rheology of the mix. The inclusion of fibres in concrete is meant to advance its tensile strength, energy absorption capacity, deformation and cracking behavioural characteristics of concrete thereby controlling the fracture process by bridging the cracked plane [20,22–24]. Furthermore, members subjected to flexure also experience a reduced deflection and crack width owing to the fibre presence. These fibres thus become effectively active and engaged when there is a formation of crack in the concrete member. The fibre consequently hinders the post crack formation of normal concrete by the help of the residual strength generated by the fibres. The post cracking performance or conduct of the fibrous concrete is usually categories as either strain-hardening or strain-softening, subject to fibre type, length, aspect ratio and volume fraction of the fibre [25,26] as illustrated in Figure 4.

When the concrete composite post crack strength thus increased further than its first crack strength (бt), then the post cracking comportment is said to be strain hardening. Strain hardening behaviour is peculiar to materials described as high performance materials, also multiple cracking is usually associated with their post cracking region in the concrete composites. Usually at stress бw, crack localisation normally begins and the crack width (w) increases with decreasing stress. For instances, concrete composites such as ultra-high performance fibrous concrete composites (UHPFCC), high performance fibrous concrete composites (HPFCC) and strain hardening cementitious composites (SHCC) exhibits this pattern of behaviour [25,27–31]. Conversely, when a concrete composite displays a post cracking strength lower than the first cracking strength (бt), the crack is usually localised and the behaviour is general referred to as strain softening. Usually, low modulus fibrous concrete composites (FCC) falls into this classification. This post cracking behaviour, referred to as strain softening is associated and displays by bio fibrous concrete composite (BFCC) which was actually the fibre type utilized in this research work.

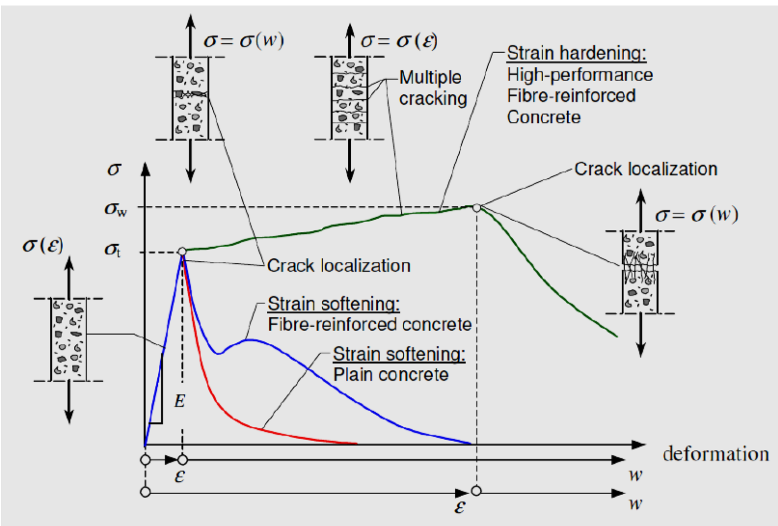

Fig. 4. Cementitious composites tensile reaction categorisation [32]

Referring to Figure 4, a classic reaction of FCC further than the first crack strength was illustrated there in. It could be seen that PC expresses no resistance whatsoever after the first crack while the FCC demonstrates a first drop in stress but soon reflects increased energy absorption due to fibres bridging the cracked planes. SHCC are still basically being used as protective coatings in structures such as large dams, tunnels or irrigation canals [33]. While the strain softening concrete composites are used in engineering cementitious composite (ECC) for RC beams strengthening, seismic structural elements, impact and blast resistant protective panels, RC beams durability enhancement against corrosion and unreinforced masonry (URM) walls strengthening [34,35]. The type of fibres adopted for the production of FCC, to a large extent have much influence on its post cracking responses. This is owing to the reason that some fibres possess somewhat high tensile capacity which invariably enhances the concretes toughness and tensile capacity. The fibre and matrix interaction when the concrete is subjected to loading is the most essential phase of the tensile capacity enhancement of the concrete. This is because, the applied stress on FCC element is normally being initially carried by the concrete matrix virtually absolutely until the initiation of crack and then stresses are being transferred to be borne by the fibres from the matrix. As opposed to SHCC, it ought to be well-known that for a typical FCC, the fibres crack bridging capability is lesser than the concrete cracking strength.

Also, debonding only begins to occur in FCC when the pull out stress surpasses the bond stress at the interface between the fibre and the matrix. At this stage, the process controlling stress transfer from the matrix to the fibre becomes more of a frictional slip [36]. It is remarkable to point out that until crack is formed in the matrix, the major role to be played by the fibres is not significant. However, the usual random distributed of fibre in concrete matrix makes the redistributed of stress to be across all sections of the concrete member in so doing improving the energy absorption capacity of the FCC. High deformation vigour of FCC is now of great advantage (significant ductility and crack control) in many applications such as pavements, offshore structures, shotcrete, seismic structures, repairs, precast structures, hydraulic structures, etc. [37].

Regardless of all the noteworthy research and advances in the field of FCC, their still exist a dearth in the usage of FCC in structural applications. The nonexistence of suitable standards and appropriate certification is one of the issues impeding its use [38]. Besides, available guiding principle for the use of FCC such as FIB Model Code 2010 [39], did not considered FCC creep deformation [40]. A research into the time-dependent deformation performance of BFCC subjected to sustained loading will be a major input to the future development of harmonised design guiding principle or standard code for short and long term use and behaviour of structural BFCC.

Low tensile strength and low strain capacity which are the common issues of unreinforced concretes have been traditionally removed through the use of pre-stressing steel or reinforcing bars in concrete. Steel for reinforcement is adjusted in the structure to increase performance. Fibres, which are generally distributed randomly throughout the concrete matrix, are applied in structural applications as a conventional reinforcement material. Fibres have traditionally been applied for reinforcing the brittle materials. Straw and horsehair respectively applied for reinforcing sun baked bricks and masonry mortar are as the traditional reinforcing method. The pueblo house reinforced with straw built in 1540 is considered as the construction made up of sun baked bricks. Invention of the Hatschek process in 1898 as a way of investigating cement paste matrix has been stated as one of the latest usages of asbestos fibres. Asbestos cement construction is widely used in material construction. However, because of the health problems stemming from asbestos fibres, other alternative fibre materials were applied in 1960s and 1970s.

New methods of fibre reinforcement have made scholars to believe that both bio and synthetic fibres can be appropriate for concrete reinforcement [41,42]. As a result, there has been a great deal of R&D investments on applications of FCC. The latest progress in the area of fibre reinforcement are derived from three reports produced by ACI Committee [43], RILEM's committee [44] and Precast/Pre stressed Institute [45,46]. Based on these reports, a brief description of the latest progress on FCC is presented in [47–49]. As can be seen, the fibres that can be used for concrete reinforcement are classified into synthetic, glass, steel and natural fibres.

4. Research Findings and Recommendations

4.1. Findings on Bio Fibre Application in Concrete Composite

The structural performance of concrete composite can be significantly affected by time dependent deformation of structural elements. For these reason, an adequate consideration must be given to time dependent property of concrete at the design stage of the engineering structures. In most cases, this deformation occurs as a result of sustained load generally referred to creep, or moisture loss due to unrestrained shrinkage. Recently, a huge research effort has been tailored towards the usage of bio fibres in concrete composite reinforcement [50–52]. The increasing interest in it usage is due to the several favourable properties it proffers to concrete when compared to conventional plain concrete, steel and synthetic fibrous concrete [50,53]. Though bio fibres are low modulus fibre, with low tensile strength compared to high modulus fibre such as steel fibre. Steel fibres' large tensile strength does not actually account for the improved properties of fibrous concrete composites. Thus, the fibre-matrix bond strength and fibre aspect ratio are responsible for the improved properties exhibited by fibrous concrete composites [53].

Therefore, it is obvious that considering bio fibres for concrete composite reinforcement is worthwhile and of immense advantage to the environment, and contributing to a greener planet. The possibility of using low modulus fibres in concrete composite reinforcement is corroborated by the successful use of relatively soft fibre such as kenaf, sisal, jute, bamboo, coir and polypropylene in previous researches conducted [33,53–55].

Recently, Kenaf fibre is receiving increasing attention both in the research field and industrial application environs [56,57]. Its application in composite production among other natural fibres is due to the ease in accessibility of Kenaf fibre locally, and its economic benefits with regards to price. Other reasons includes; improvement of life cycle and durability in structure, resistance to corrosion, and other tremendous properties it possess when compared with other bio fibres.

Interest is also rising towards the inclusion of Kenaf fibre in concrete, this is meant to obtain a sustainable green material and save our environment from being dominated with concrete products that could pollute and contribute to global warming. Concrete composite made of short discontinuous Kenaf fibres which is simply referred to Kenaf bio fibrous concrete composite (KBFCC), has been under broad research in the past few years and has several interesting engineering properties when likened with the plain conventional concrete composite [51,52]. Application of this green material in civil engineering construction is geared towards building floor constructions, concrete beams, concrete pavement and bridge deck. By virtue of craving to apply Kenaf Fibre in construction, an understanding of the long term performance of KBFCC under sustained uniaxial compression load (creep) is evidently required. This is of utmost importance because; creep has the possibility to prompt excess deflection and or stress relaxation which may invariably lead to the deformation of the concrete and subsequently to collapse in respect to time. Limited study on the effect of bio fibre reinforcement on deformations of cementitious materials at varying load intensity, varying fibre content and different loading age are reported in literature.

Concrete degree of hydration is affected by its compressive strength [58]. Therefore, parameters such as fibre inclusion, load intensity, temperature, curing type, age of loading, humidity and age of testing, which influence hydration of cement will also affect the development of strength. Fibres effect on the performance of concrete material on the interfacial bond strength amid matrix and the fibres; factors which influence strength of concrete, consequently, certainly influence bond strength.

4.2. Findings on Creep Deformation Behaviour of Bio Fibrous Concrete Composite

This time dependent behaviour property can then be included in the bio fibrous concrete design guidelines. Long term performance of concrete determined through the time-dependent properties has been researched since the early decades of the last century. According to Neville *et al*. [12], this time dependent deformation was first discovered at Purdue University, USA by Hatt in 1907 and he thereby published the first data on creep of reinforced concrete. Ever since, much research has being devoted to this complex problem in both the material and structural performance. This area of research continues to be active for a number of reasons, including the adoption of sustainable, renewable and green construction materials and significant structural effects caused by shrinkage and creep in fibrous concrete structures and in particular, the rapid development of BFCC such as KBFCC in recent years. However, despite major successes in the use of BFCC, the phenomenon on creep is still far from being fully understood.

From the available literature, it is presently evident that no specific research on the long term behaviour (creep) of biofibrous concrete composite exists. This has shown the necessity for investigation on long term performance (creep) of BFCC, as the study is yet to be established. Improved and novel application of bio fibres in concrete has been on the increase as a result of the stern campaign on sustainability and bio based economy for both developing and developed countries. Publications related to the mechanical properties of bio fibrous concrete composites (BFCC) are on the increase due to the continuous awareness of the importance and contributions of bio based products to the environment and our economy. However, study on long term performance of BFCC is still limited and these calls for more research efforts into this aspect of BFCC. In addition, the structural application of BFCC has being a concern due to the peculiarity of bio fibres low modulus characteristics [53]. Also, no design code allows for the creep of BFCC yet, compared to the conventionally PC. Concrete structures deformation under sustained loading is known to be several times larger than instantaneous deformation upon loading [11].

Hence, the creep deformation is seen as a necessary factor requiring attention as regards to long term performance of soft fibrous concrete composites. Studies considering creep deformation as an important factor in long term performance of fibrous concrete composites are commonly related to steel and polypropylene fibres. Most of this investigation examined flexural creep and literature records few tensile creep study. Arango [59] and Blanco [15] studied the flexural creep of steel fibrous concrete. Also studies done by several researchers [20,40,60,61] are also on flexural creep of fibrous concrete. The works of Kurtz and Balaguru [62] was on fibrillated polymeric micro-fibre, they tested the fibrous concrete post-crack strength under flexural sustained load of 24.9% at a low fibre volume of 0.1%. The limited available works on uni-axial tensile creep of cracked fibrous concrete composite are on synthetic and steel fibre.

Publications by Vrijdaghs *et al*.[63] and Babafemi and Boshoff [64] are on uni-axial tensile creep of cracked polymeric fibrous concrete composite. Conversely, Mouton and Boshoff [65] and Zhao *et al*. [66] reported the performance of uni-axial tensile creep of cracked steel fibrous concrete composite. However, Published works on the uni-axial tensile creep of cracked BFCC are yet to be reported to the author’s knowledge.

4.3. Recommendations for Further Research

Through this overview, a research gap has been found. Hence, the exploration of bio fibre as a reinforcing element in concrete to enhance its tensile strength, ductility and crack mouth opening will be of great technological improvement to the construction industry, and of immense contribution to our environment. To this extent, the fibrous concrete composite has been identified as being under studied in the aspect of its behaviour under sustained load over long time. Either under one dimensional compressive load, uniaxial tensile (direct tensile) load or flexural (bending) load. In order to adopt this recyclable, renewable, green materials and sustainable high performance concrete as innovative engineering construction product, its optimum performance under long term loading must be understood.

5. Conclusion

It is evident that there still exists a lacuna in understanding the time-dependent behaviour of fibrous concrete composite, particularly on the compressive creep BFCC, uni-axial tensile creep of cracked BFCC and flexural creep BFCC. Therefore, an in-depth study into the creep performance of BFCC is necessitated to understand the long term behaviour of this biodegradable and environmental friendly construction product. The effect of fibres inclusion in concrete remains passive until the activation of fibre which is manifested after cracking. This is because, forces and stresses in the concrete composite are transferred to the fibres bridging the cracks formed. Moreover, these fibres bridging the cracks are exposed to environmental conditions which affect the long-term performance and properties of the fibrous concrete composite. Additionally, the percentage of the post-crack strength of the creep load of BFCC is not known yet. Crack width under sustained loading is also serviceability issues that need to be considered in understanding the time-dependent deformation performance of BFCC. Understanding the theory of BFCC uni-axial tensile creep will facilitate the explanation of possible structure failures and extreme deformation of BFCC.

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