Cracks Restriction Pertinent to Fiber Reinforced Composites Usage: A Review

Mahmoud Abo El-Wafa

King Abdulaziz University, Faculty of Engineering at Rabigh, Dept. of Civil Engineering, 21911 Rabigh, Kingdom of Saudi Arabia

Abstract: ***This paper presents an elaborative discussion on the issue of cracks restriction pertinent using fiber-reinforced composites, FRCs. It is proposed as an outline of the kinds of commercially accessible FRCs and how they perform on cracks restriction. It discusses frequently practical terminology of mechanical behavior that procedure a fundamentals for recognizing materials performance. Historical assessment is projected to help building a experience for what is currently understood about FRCs rather than historical statement for cracks restriction. References from both early and contemporary authors are included as a means of tying the issue together along a time line. However, the construction path is one of the major desirable paths for FRCs globally. FRCs are utilized in a extensive range of applications in building ranging from recovery of existing structures to the full-scale usage for new projects because of the benefits they deliver over conventional construction materials. Such benefits include but not limited to lightness, high mechanical performance and possibility of manufacturing in any form, ease of setting up and lesser necessity for supporting structure, controlled anisotropy, high specific strength and specific stiffness. All these multifarious features of FRCs are knocking the doors for new paths of myriad requests in the construction industry. This paper accordingly attempts to review on the specific areas of the current utilization trend of FRCs on cracks restriction of the construction industry.***

Keywords: fiber-reinforced composites, cracks restriction, polypropylene and steel fibers, serviceability

1. Introduction

The term fiber-reinforced composites (FRCs) is defined by ACI 116R, Cement and Concrete Terminology, as concrete containing dispersed randomly oriented fibers [1]. The FRCs are increasingly being used in engineering applications, particularly for civil engineering structures, with entering a new era when the construction industry faces an additional challenge: how to control concrete cracking to build concrete structures that are environmentally more sustainable and have a good serviceability. It needs to understand not only the reasons for the serviceability failures that involving by excessive cracking and/or excessive deflection, but also how to develop the FRCs that produce sustainable and serviceable structure. A wide variety of the FRCs are available today for applications as advanced composite materials, which have been emerged as the most exciting and promising composite materials in strengthening and serviceability of concrete structures. Cracking behavior of concrete structures is of interest for evaluation of serviceability performance. In designing reinforced concrete, it is not enough just to ensure that the steel and concrete are not over stressed. The structure must remain serviceable under environmental conditions. Volumetric change generates internal micro cracking, which may develop into full cracking, as well as, the growth of cyclic cracking in concrete is attributed to the inherent weakness of concrete in tension, which lead to losing the serviceability of concrete structures. Thus, the cracking of concrete under restrained conditions and cyclic loading is considered a major serviceability problem of concrete structures. The FRCs are believed to be one of the most effective ways of controlling such cracking, due to sufficient bridging forces to suppress crack opening and redistribute the stress to the nearby matrix [2-3]. Moreover, the FRCs when uniformly distributed within concrete play an active role in improving the serviceability problem of concrete structures [4]. Therefore, this new generation technology utilizes short fiber-reinforced composite materials, which have a great impact on all concrete structures under different loading manners for strengthening and serviceability development. The synthetic polypropylene fibers and steel fibers are introducing revolutionary changes in the structural application of concrete structures. These concrete fiber composites are excellent candidates for strengthening and serviceability of highways, bridges, airfields, tunnels, explosion resistant structures, and earthquake resistance construction. The new generation of fibers is being developed, which can be used at higher addition rates to bring about major improvements in the characteristics of composites. In current construction practice, discontinuous metallic and non-metallic fibers are added to matrices at relatively low volume fractions (usually ≤ 1.0 %), mostly in order to improve the toughness and the post cracking ductility of the composite and hence improve the serviceability of concrete structures under all modes of loading.

Therefore, the intending to be as brief as is consistent with the goals of the discussion is divided into three parts: Technology of FRCs, Performance of cracks restriction, and Development of FRCs applications.

2. Technology of FRCs

The most distinguishing feature of FRCs, in dissimilarity to traditional concrete, is its capability to reinforce locally the cracked matrix by transferring stresses across the ruptured surface. Whereas traditional concrete achieves a very partial stress transfer across cracks by aggregate interlock, the existence of fibers allows significant transfer of tensile loads across cracks till the fiber either pulls out or breaks. The basic standard in both historic and modern cases is to improve the properties of an inherently weak and brittle matrix by adding fibers to increase tensile strength and ameliorate brittleness giving enhanced ductility and toughness. This standard remains mostly unchanged nowadays, but the variety in fiber kinds, shapes, and sizes available to improve matrix characteristics that it has expanded significantly in modern years. Fiber composite materials in a matrix (paste, mortar, or concrete) can in general have two important effects. First, they tend to reinforce the composite under all modes of loading which induce tensile stress, e.g. direct tension, bending, and shear, and secondly, they improve the ductility and toughness of an otherwise inherently brittle matrix. The enhancements in these properties imparted by any particular fiber depend on various fiber parameters, notably the kind of fibers and its content that is usually specified as percent by volume of composite concrete and on the mode of loading. Thus, the addition of fibers to concrete, a quasi-brittle material, develops the post-cracking performance by rising ductility. The fibers convey tensile forces through cracks, decreasing the width of cracks compared to unreinforced concrete and developing the post-cracking performance of the concrete. The fibers can be gathered into two groups: those with low modulus of elasticity and high elongation properties and those with high modulus of elasticity. Synthetic, organic fibers, such as nylon, polypropylene and polyethylene, fit to the first group, while steel, glass, asbestos and carbon fibers fit in to the second one.

The advantages of synthetic fibers are controlled the cracking and improved the elasticity and load-carrying capacity.

Polypropylene fibers are probably the most common synthetics fibers because they are lightweight and identical cost-competitive. As with other synthetics, the design volume of polypropylene fibers is essential. Therefore, the polypropylene fibers are considered as attractive fibers between the synthetic fibers because of its outstanding resistance to moisture, acids or alkalis, and the cheapness of the raw material on a volume basis compared to steel or glass fibers. The polypropylene fibers are being used comprehensively in all kinds of concrete construction, and they have confirmed to be effective materials for controlling unsightly and troublesome cracking in concrete structures. Figure 1 shows of some geometrical shapes of polypropylene fibers.

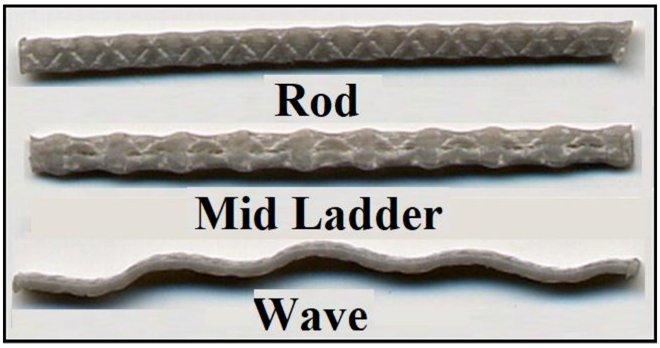

Figure 1: Geometrical shapes of polypropylene fibers

Steel fibers are the greatest kind of fibers used in the concrete composites. The generally utilize steel fibers are well-defined as short, discrete lengths of steel having an aspect ratio (ratio of length-to-diameter) from about 20 to 100, with numerous cross sections, using lengths among 25 and 60 mm and diameters among 0.4 and 1.3 mm. They are minor sufficient to be randomly dispersed in the matrix via usual mixing processes. Performances of steel fibers depend on several features, including the fiber material properties (fiber strength, stiffness and Poisson's ratio), fiber geometry (end-hooked, crimped and twisted fibers), fiber volume content, matrix properties (matrix strength, stiffness, Poisson's ratio), and interface properties (adhesion, frictional and mechanical bond). Figure 2 shows of some geometrical shapes of steel fibers.

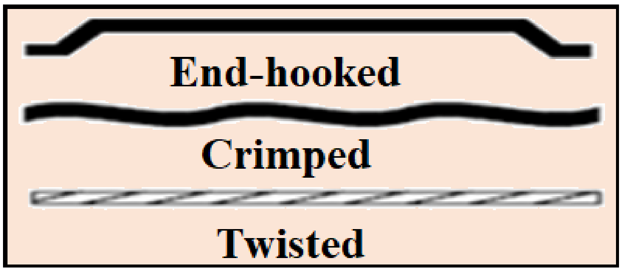

Figure 2: Geometrical shapes of steel fibers

Clearly, for each matrix, kind and quantity of fibers are essential parameters that influence the performance of steel fibers and its cost. However, the presentation of steel fibers can be enhanced to the opinion wherever it displays a deflection toughening comeback in flexure. Steel fiber reinforced concrete shows greater ductility compared to unreinforced composites, which fail in tension and flexure directly after the creation of a single crack. The steel fibers are utilized to stop/controller the plastic and drying shrinkage cracking in concrete. Additional investigation and improvement exposed that adding of steel fibers in concrete considerably growths its flexural toughness; the energy absorption capability, ductile performance prior to the ultimate failure, reduced cracking, and enhanced durability. The structural utilization of steel fibers include slabs of supported pile, ground slab, raft foundations, tunnel linings, various precast elements, and others. For some structural utilization of steel fibers are used in a complementary role to either constrain cracking, develop resistance to material deterioration as an outcome of shrinkage, impact load, fatigue load, thermal stresses or as an alternate to traditional reinforcement.

Therefore, the wide variety of fibers are offered nowadays for applications as advanced composite materials, which have been emerged as the most exciting and promising materials in strengthening and serviceability of concrete structures under different loading manners. In fiber composite concrete, cracks do not spread as much and it is supposed to be the most effective methods for controlling the cracking, thus increasing the serviceability of concrete structures is accomplished. Therefore, one of the main challenges nowadays is for strengthening and serviceability of concrete utilizing fiber composite materials.

Geometrical details and typical properties of the most popular kind of fibers used for cracks restriction as rod type of polypropylene fibers and end-hooked type of steel fibers

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are given in Table l.

Table 1: Geometrical details and typical properties of fibers

Geometry of fibers	*Density (g/cm^3)*	*Tensile strength (MPa)*	*Young's modulus (GPa)*
 Steel fibers (End-hooked type)	7.8	2000	200
 Polypropylene fibers (Rod type)	0.91	750	10

Consequently, the discrete synthetic polypropylene and steel fibers usage are considered as a new generation technology for accomplishments the sustainability and serviceability of concrete structures.

3. Performance of Cracks Restriction

3.1 Cracks classification

Concrete fabricators, engineers, designers and building specialists in the worldwide will approve on one matter that the concrete cracking can be everything from a nuisance to a nightmare. Regardless wherever cracks happen, they are a problem. The reparation of the cracking is generally just as severe and expensive. Traditionally, the trend for concrete to crack has been confirmed as predictable. The cracks happen as a result of stresses exist which surpass the strength of the concrete at a specific period, see Figure 3.

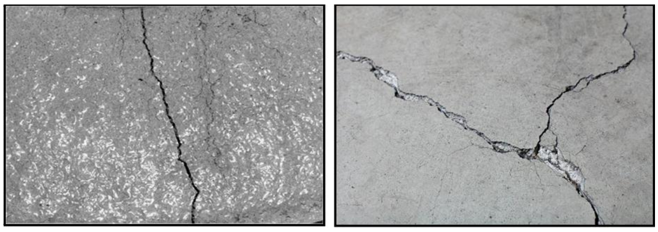

Figure 3: Shape of concrete cracking

Therefore, cracking control has become vital in order to that maintain the integrity and aesthetics of concrete structures. Describing the role played by fiber composite materials in control of concrete cracking requires distinguishing between conditions under which cracking is principally governed either by macroscopic tensile or compressive stresses. It should understand with some definitions:

- A micro crack is a crack whose length can be considered very small in relative to the dimensions of a specimen or a structure.
- A macro crack is a crack whose length cannot be considered very small in relative to the dimensions of a specimen or a structure.
- An active crack is a crack whose edges undergo normal or tangential displacements.
- A critical active crack is a crack that leads to a concentration of stresses and a localization of strains in concrete.

Logically, it follows from these definitions that an active macro crack is an active micro crack that has become critical. Therefore, information of the cracking performance of concrete becomes important. Thus, it should be understood clearly the concrete cracks timely in its loading. Most of the concrete cracks are a result of the following actions:

- Volumetric change produced by plastic shrinkage, drying shrinkage and creep under sustained load.
- Direct stress due to applied loads or internal stress because of continuity, reversible cyclic load and long-term deflection or environmental effects including differential movement in structural systems.
- Flexural stress due to bending moments produced by transverse loads.

While the result of these three actions is the development of cracks and the mechanisms of their development cannot be considered identical. Volumetric change produces internal micro cracking which may grow into complete cracking, while direct internal or external stress or applied loads could either produce internal micro cracking, such as in the case of cyclic due to reversible load, or flexural macro cracking leading to completely developed cracking. Consequently, all these tendencies need earlier control in cracking performance to achieve the serviceability requirements of concrete structures.

3.2 Intrinsic cracking

In the concrete industry, internal stresses are considered as a major problem. These intrinsic stresses are generated due to the shrinkage of concrete and it is difficult to control these stresses because of their unpredictable variety and occurrence. the shrinkage of concrete causes the intrinsic cracking due to the internal settlement with the rapid water evaporation from the specimens. The formed of these cracks will occur within the first 24 hours after casting concrete. They can or cannot be immediately observable. Shrinkage cracks cannot be detected until some later time. These cracks are not structural in nature, but neither do they disappear once the concrete hardens. In fact, they extend as further drying takes place. Cracks growth the water diffusion into the concrete, permitting salts and other harmful compounds to penetrate which leads to reduce the durability and service life of concrete.

With the fiber composite materials, the construction industry nowadays has a controlling implement to constrain the creation of soft cracking. By presenting numerous fibers into the matrix, fibers provide concrete a secondary reinforcement. By using fiber composite materials in concrete, it can considerably decrease the creation of the plastic shrinkage cracks by increasing the tensile strain capacity of concrete. This reduction of plastic shrinkage cracks enables the concrete to develop its optimum long-term integrity.

3.3 Structural cracking

It is well recognized that the concrete is strong in compression but weak in tension. Thus, cracks occur in the tension zone of concrete structural members when the stress of the concrete outpaces the tensile strength or the strains exceeding the tensile capacity of concrete structural member. Immediately after the tensile stress in the structural members surpasses its tensile strength at a particular location, internal micro cracks form. These cracks create into macro cracks propagating to the external fiber regions of the structural members. Conversely, the constant and fatigue loads of heavyweight traffic on a main highways and bridges and heavy machinery used in industrial services can all lead to cracking. To combat the structural cracking, engineers conduct a serviceability examination of the concrete structures assuming a cracked section and design the structural members to withstand the various stresses from the external loads.

Potentially useful improvements in the cracking behavior of concrete structures can be affected by the incorporation of fiber composite materials. Fiber composite materials are an independent material technology that, when utilized with an engineer's recommendations, serve as a superior crack control mechanism in all stages of concrete development. In addition, the composite can become tougher and stronger due to the toughening result of the FRCs in front of the crack tip. Figure 4 shows influence of FRCs on cracks development.

Figure 4: Influence of FRCs on cracks development

Thus, the FRCs have a capability to adjust the cracking mechanism. By adjusting the cracking mechanism, the macro cracking develops to micro cracking. The cracks are slighter in thickness, thus reducing the penetrability of concrete and the ultimate cracking strain of the structures are improved. Furthermore, the FRCs have played a significant role in extending fatigue life, increasing the capability of fatigue load, decreasing fatigue damage gradation, and postponing the damage development of structures.

A great benefit of using FRCs besides reducing penetrability and reducing fatigue damage gradation is that fiber addition increases the toughness or residual load carrying capability after the first crack. Consequently, the FRCs have capability for satisfying the strengthening and serviceability requirements in cracking performance of structures.

4. Development of FRCs Applications

The development of FRCs applications is considered as necessary for many outstanding structures or for construction in special conditions. The greatest effective applications of the FRCs are those, which outcome from recognition the mechanical performance of the FRCs. There are numerous applications in which the fibers are proposed mainly to growing the integrity of the matrix. By this way, the favorably affect the integrity of the structural system and structural serviceability features of the design. Applications in the low fiber volume include the slabs on grade, composites bridge deck and so on. Furthermore, the FRCs have numerous potential areas of applications, such as concrete mass, pavements, airport runways, tunnel linings, precast products and so on. In these applications, the continued capability to transfer tensile stress, either through the matrix or through fibers, which bridge cracks, develops the serviceability features of design such as durability and toughness. Therefore, there are two groups of applications, one low fiber volume and the other concerning high fiber volume, each of which highlight the significance of fracture mechanics over the strength of materials approach to the FRCs investigation. Numerous applications of FRCs utilizing either polypropylene or steel fibers have been revealed. Consequently, the structural performance products built with FRCs have been laudable.

5. Conclusions

The wide variety of fibers are available today for applications as advanced composite materials, which have been emerged as the one of the most exciting and promising technologies in strengthening and serviceability of concrete structures under different loading manners. In fiber composite concrete, cracks do not spread as much and it is believed to be one of the most effective ways of controlling such cracking, thereby increasing the serviceability of concrete structures is achieved. Therefore, one of the main challenges today is for strengthening and serviceability of concrete utilizing fiber composite materials.

Consequently, the discrete synthetic polypropylene and steel fibers usage are considered as a new generation technology for achievements the sustainability and serviceability of concrete structures.

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