Construction and Building Materials 93 (2015) 180–188

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Use of macro plastic fibres in concrete: A review

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HIGHLIGHTS

- This paper reviews latest research on using macro plastic fibres to reinforce concrete.
- Effects of macro plastic fibres on fresh and hardened concrete properties are summarised.
- Macro plastic fibre reinforced concretes show excellent post-cracking performance.
- Degradation and pull-out behaviour of macro plastic fibre in concrete are reviewed.
- Cost and environmental benefits and applications of fibre reinforced concrete are discussed.

ARTICLE INFO

Article history:
Received 18 March 2015
Received in revised form 11 May 2015
Accepted 14 May 2015

Keywords:
Macro plastic fibre
Concrete
Fibre production
Reinforcement
Application

ABSTRACT

Use of macro plastic fibres to reinforce concrete has attracted widespread attention from both scientists and construction industry due to the multiple sustainability benefits they offer, compared to steel fibres and steel reinforcing mesh. This paper critically reviews the current state of knowledge and technology of using macro plastic fibres to reinforce concrete. Detailed review on the various preparation techniques and the resulting properties of macro plastic fibres are presented and the effects of macro plastic fibres on the fresh and hardened concrete properties are discussed in this paper. The effect of macro plastic fibres on workability, plastic shrinkage, compressive strength, splitting tensile strength, flexural strength, post-crack performance and dry shrinkage is discussed in this paper. Pull-out behaviour and degradation behaviour of the fibre in the concrete are also reviewed. Finally, cost and environmental analysis and some applications of the plastic fibre reinforced concrete are discussed.

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http://dx.doi.org/10.1016/j.conbuildmat.2015.05.105
0950-0618/

1. Introduction

Concrete is essentially a mixture of cement, aggregate and water. It is widely used in construction industry because all the raw materials required are widely available and are of low cost. Concrete is very strong in compression; however, it has a very low tensile strength. To improve its tensile strength, reinforcing steel is often used in the concrete. Apart from traditional steel reinforcement, various fibres are also used to improve the properties of concrete, mainly for enhancing the tensile strength. There are mainly four types of fibres which can be used to reinforce concrete: steel fibre, glass fibre, natural fibre and synthetic fibre [1].

Steel fibres can greatly improve the tensile strength and the flexural strength of concrete due to their ability to absorb energy [2] and control cracks [3]. Their electric [4], magnetic [5] and heat [6] conductivity properties make them suitable for some special applications. However, corrosion of steel fibres can be detrimental and lead to rapid deterioration of concrete structures [7]. Glass fibre has an excellent strengthening effect [8] but poor alkali resistance [9]. Natural fibres, such as wood [10], sisal [11], coconut [12], sugarcane bagasse [13], palm [14], and vegetable fibres [15], are cheap and easily available, but they have poor durability. Synthetic fibres can be made of polyolefin [16], acrylic [17], aramid [18], and carbon [19]. They can prevent plastic shrinkage cracks in fresh concrete [20] and improve post-cracking behaviour of concrete [21].

The schematic diagram in Fig. 1 shows the different failure modes associated with the fibre reinforced concrete [22]. Fibre rupture (1), pull-out (2) and debonding of fibre from matrix (4) can effectively absorb and dissipate energy to stabilise crack propagation within concrete. Fibre bridging the cracks (3) reduces stress intensity at the crack tip. In addition, the fibre bridging can decrease crack width, which prevents water and contaminants from entering the concrete matrix to corrode reinforcing steel and degrade concrete. Fibre in the matrix (5) prevents the propagation of a crack tip. Consequently, minor cracks will be distributed in other locations of the matrix (6). Although every individual fibre makes a small contribution, the overall effect of reinforcement is cumulative [22]. Therefore, the fibres can effectively control and arrest crack growth, hence preventing plastic and dry shrinkage cracks [23], retaining integrity of concrete [24], and altering the intrinsically brittle concrete matrix into a tougher material with enhanced crack resistance and ductility [25]. In order to achieve considerable reinforcement, the fibres should have high tensile strength and Young's modulus [26].

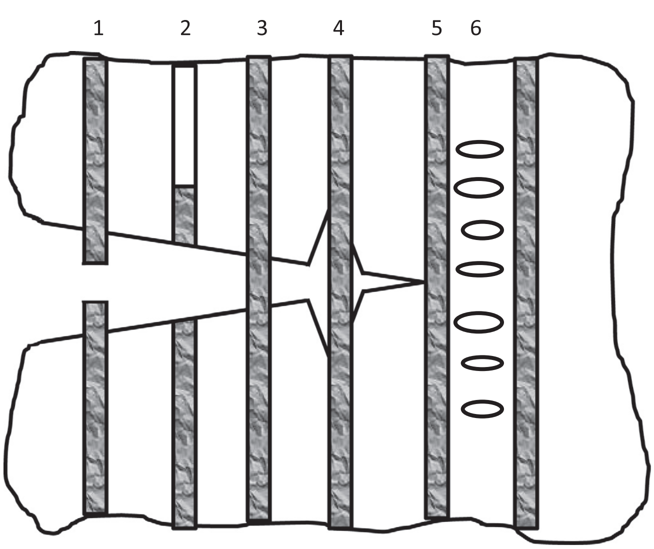

Fig. 1. Failure mechanisms in fibre reinforced concrete. (1) Fibre rupture; (2) fibre pull-out; (3) fibre bridging; (4) fibre/matrix debonding; (5) fibre preventing crack propagation; (6) matrix cracking [22].

Plastic fibres are synthetic fibres, which can be in the form of micro plastic fibres or macro plastic fibres. The micro plastic fibres refer to the plastic fibres whose diameter ranges from 5 to 100 μm and length is 5–30 mm [27]. These micro fibres can effectively control plastic shrinkage cracking [28], which is caused by shrinkage of fresh concrete during the first 24 h after placement due to excessive evaporation of bleed water [29]. However, they normally do not have obvious effects on the properties of hardened concrete, as reported by Pelisser et al. [30] and Habib et al. [31]. It is noteworthy that some micro plastic fibres, such as nylon fibres, can provide good thermal energy storage to concrete [32], effectively control shrinkage of concrete [33], and also significantly improve tensile strength and toughness of concrete [34].

The macro plastic fibres normally have a length of 30–60 mm and cross section of 0.6–1 mm^2 [35]. The macro plastic fibres are not only used to control plastic shrinkage [36], but also mostly used for controlling drying shrinkage [37]. Drying shrinkage occurs due to the loss of water molecules from the hardened concrete [38]. This type of drying shrinkage can occur in large flat areas like slabs in hot and dry environments like in North Queensland, Australia. A steel reinforcing mesh is normally used to prevent the drying shrinkage cracks; but now it is gradually being replaced by the macro plastic fibres because of ease of construction, reduced labour and lower cost. Another significant benefit is the post-cracking performance provided by the macro plastic fibres [39]. Brittle plain concrete has no effective post-cracking ductility, but the macro plastic fibres can considerably improve the post-cracking response of concrete, because the plastic fibres act as a crack arrester, and alter the intrinsically brittle concrete matrix into a tough material with better crack resistance and ductility. Therefore, when concrete breaks, the common large single cracks can be substituted by dense micro-cracks due to the presence of fibre reinforcement [40]. The macro plastic fibres now have become increasingly popular in the construction of concrete footpaths [41], precast elements [42] and shotcrete mine tunnels [43].

The aim of this paper is to critically review the present state of knowledge and technology of macro plastic fibre reinforced concrete. After a detailed review of various preparation techniques and resulting properties of macro plastic fibres, attention is paid to effect of the fibres on performance of the fresh and hardened concrete. The effects of macro plastic fibres on workability, plastic shrinkage, compressive strength, splitting tensile strength, flexural strength, post-crack performance and dry shrinkage are discussed in this paper. The pull-out behaviour and degradation behaviour of the fibre in the concrete are then studied. Finally, cost and environmental analysis and some applications of the plastic fibre reinforced concrete are presented.