DIFFERENT PROPERTIES OF STEEL FIBRES REINFORCED CONCRETE-REVIEW ARTICLE


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Properties of fibre reinforced concrete (FRC) are mainly influenced by type and amount of fibres. Practically, fibre properties are defined by the fibre producers. The mechanical behaviour of fibre reinforced concrete depends largely on the interactions between the fibres and the brittle concrete matrix: physical and chemical adhesion; friction; and mechanical anchorage induced by complex fibre geometry or by deformations or other treatments on the fibre surface. The mechanical performance of steel fibre reinforced concrete (SFRC) is also highly influenced by the fibre dispersion, since the effectiveness of fibre reinforcement depends on the orientation and arrangement of the fibres within the cement matrix, in which, short and randomly distributed steel fibres are often used for concrete reinforcement since they offer resistance to crack initiation and, mainly, to crack propagation.

In present paper we intended to give an overview of different parameters and their influence on the behaviour of SFRC.

Keywords: FRC, steel fibres, SFRC, mixing time

1. INTRODUCTION

Fibre reinforced concrete (FRC) is concrete reinforced with more or less randomly distributed fibres. In FRC, thousands of small fibres are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties in all directions (*Amit Rana, 2013).*

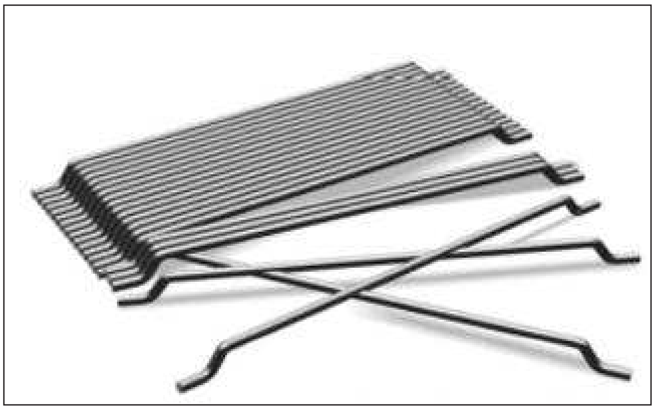
Favourable experiences with fibre reinforced concrete (FRC) resulted in its increasing application. Fibres are used to improve properties of fresh or hardened concrete, respectively. Toughness and residual strength after cracking of concrete can be significantly increased by application of fibres. Nowadays residual tensile strength of FRC is one of the most important parameter both for design and for practice *(Erdélyi, I993)*. The mechanical properties of FRC depend on the material properties of fibres (e.g. strength, stiffness), fibre geometry and surface, amount of fibres matrix properties (e.g. strength, stiffness, Poisson's ratio), interface properties (adhesion, frictional and mechanical bond) and loading condition *(Naaman, Najm, 1991; Kim, Naaman El-Tawil, 2008; Aydm, 2013; Felekoglu, 2014)*. Testing and modelling of bond behaviour of fibres are important to realize the characteristic of FRC *(Kovács, Balázs, 2003, 2004; Zhao, Verstrynge, di Prisco, Vandevalle, 2012; Balázs, 2012; Halvax, Lubloy 2013-1; Halvax, Lublóy, 2013; Zile, Zile, 2013: Breitenbucher, Meschke, Song. Zhan, 2014)*.

2. STEEL FIBRES

Steel fibres are defined as short, discrete lengths of steel that having an aspect ratio (ratio of length to diameter) from about 20 to 100. The classification according to American Society for Testing and Materials (ASTM) A 820 divided this materials into four general types of steel fibres which known as cold-drawn wire, cut sheet, melt extracted and other fibres based on the product used in their manufacture. The steel fibres have many types based on surface roughness and shape such as copped, hooked ends, crimpled and wavy *(ACI Committee 1996).* Typical equivalent diameter of steel fibres ranges from 0.15 mm to 2 mm and length from 6 mm to 76 mm. The tensile strength of steel fibre goes up to 2 Giga Pascal (GPa) and modulus of elasticity to 200 GPa *(ACI Committee, 1996; Hannant,, 1978)*. The performance of steel fibres is influenced by many factors such as shape, fibre content and aspect ratio. The fibre with deformed shape or hooked end see *(fig. 1)* usually behaves better than straight ones due to better bond with concrete *(Syed, 2012).*

From other hand, the behaviour of SFRC can be classified into three groups according to its application, fibre volume percentage and fibre effectiveness. For instance SFRC is classified based on its fibre volume percentage as follows: 1-Very low volume fraction of SFs (less than 1% per volume of con-

Fig. 1: Hooked-end Steel Fibres (Marcelo, 2017)



crete), which has been used for many years to control plastic shrinkage and as pavement reinforcement. 2- Moderate volume fraction of SFs (l% to 2% per volume of concrete) which can improve modulus of rupture (MOR), flexural toughness, impact resistance and other desirable mechanical properties of concrete. 3-High volume fraction of SFs (more than 2% per volume of concrete) used for special applications such as impact and blast resistance structure; these include SIFCON (Slurry Infiltrated Fibre Concrete), SIMCON (Slurry Infiltrated Mat Concrete; *Hamid, 2011).*

3. PHYSICAL PROPERTIES IN FRESH CONCRETE

The use of fibres is known to affect the workability and the flow characteristics of plain concrete essentially. Many researchers investigated the effect of the aspect ratio and volume content on the flow ability of concrete *(Noor et al., 2006).* Strictly speaking, the higher the aspect ratio is, the fewer fibres could be included to surpass the critical fibre content. For the same fibre content, better workability is achieved at lower aspect ratios *(Kareem and Naranyanan, 1983).*

4. MECHANICAL PROPERTIES

4.1 The effect of steel fibre on compressive, splitting tensile and flexural strength of concrete

The compressive strength test is considered the most suitable method of evaluating the behaviour of SFRC for underground construction at an early age, because in many cases (such as in tunnels) SFRC is mainly subjected to compression *(Ding, Wolfgang, 2000).* However, many researchers believed that steel fibres do not have the significant influence on the compressive behaviour of concrete due to the small volume of fibres in concrete mix *(Armelin, Helene, 1995).* In general, the effect of addition of steel fibres on compressive strength ranges from negligible to marginal and sometimes up to 25% as reported by *(Balaguru, Shah, 1992*).

Nagarkar et al. (1987) indicated that the compressive strength, splitting tensile and flexural strengths increase with increasing fibres content. The compressive, splitting tensile and flexural strength increased by 13-40% for fibrous concrete containing steel fibres with aspect ratio of 105 at 0.5% volume fraction. Dawood and Ramli (2010) had investigated the effect of steel fibre content with different percentages of steel fibre from (0-2%) on the flowable mortar. The results indicated that the compressive strength has increased by 21% as the steel fibre fractions was 1.25%. On the other hand, the flexural strength results recorded a significant increase of about 200% by the inclusion of steel fibre up to 1.75%. These results according to the authors are related to the improvement of mechanical bond between the cement paste and the steel fibres when the flow of mortar is adequately applied.

4.2 The effect of steel fibre on toughness and impact capacity of concrete

Nataraja et al. (1999), Banthia, Sapp (2007) and Dawood, Ramli (2009) studied the affect of steel fibres on toughness. It can be observed that the toughness improves with the increasing content of fibres, the reason being the ability of fibres in arresting cracks at both micro-and macro-levels. At micro-level, fibres inhibit the initiation of cracks, while at macro-cracks; fibres provide effective bridging and imp art sources of toughness and ductility.

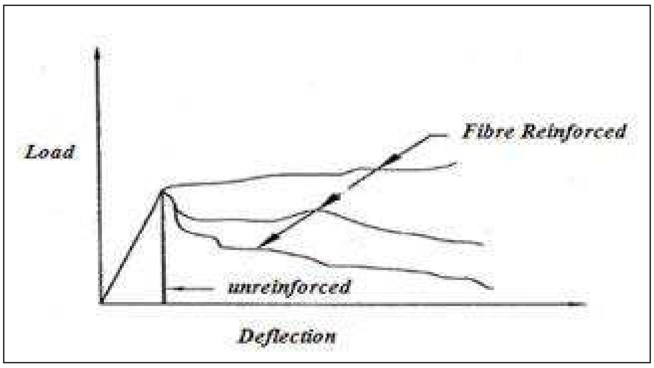


Fig. 2: Load-Deflection Curves for Plain and Fibrous Concrete (ACI 544.IR, 1996)

5. SFRC BENEFITS AND APPLICATIONS

The beneficial influence of SFs in concrete depends on many factors such as type, shape, length, cross section, strength, fibre content; SFs bond strength, matrix strength, mix design, and mixing of concrete. Typical load-deflection curves for plain concrete and FRC are shown in *Fig. 2 (ACI 544. IR, 1996).* The addition of SFs in the conventional reinforced concrete (RC) members has several advantages such as 1- SFs increase the tensile strength of the matrix, thereby improving the flexural strength of the concrete. 2- The crack bridging mechanism of SFs and their tendency to redistribute stresses evenly throughout the matrix contribute to the post-cracking strength and restraining of the cracks in the concrete. 3- Increase ductility of the concrete. 4- SFRC is more durable and serviceable than conventional RC *(Rapoport et al., 2001; Grzybowski and Shah, 1990; Grzybowski 1989).* 4- Steel fibres reduce the permeability and water migration in concrete, which ensures protection of concrete due to the ill effects of moisture *(Amit Rana, 2013).*

The disadvantages of fibre-reinforced concrete are the reduced workability and the possibility of corrosion stains if the fibres are exposed at the surface "in case of steel fibres (*ACI 546R-04; Fowler, 2009*).

Nowadays, SFRC is used at an increasing rate in various applications such as the followings. Highway and air-field pavements, Hydraulic Structures, Fibre Shotcrete, Refractory Concrete, Precast Application, Structural Applications.

6. FIBRE PULL-OUT TEST

Many studies have been conducted to investigate the bond behaviour of steel fibre embedded in concrete, it can be seen that several researchers have focused on using pull-out test (*Fig. 3)*. But only focusing on the bond behaviour of a single fibre *(Di Francia, 1996).*

The studies referred to in the next sentences reveal that there are several parameters that can influence the pull-out behaviour, namely: the adoption of hooks at the ends of the fi-

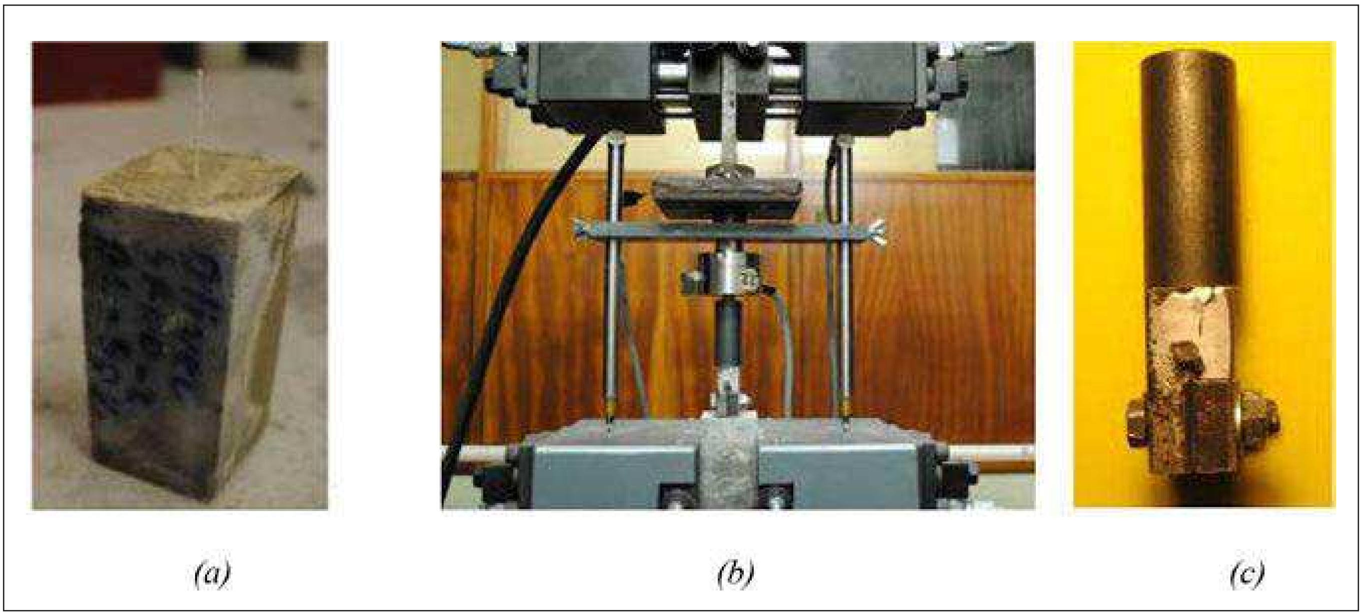


Fig. 3: Single fibre pull-out tests, a) test sample, b) test setup and c) the clamping mechanism (Lerch, 2018)

bre, the geometry of the hooks, the orientation and embedded length of the fibre, fibres and the mechanical properties of the matrix, the amount of fibres and the loading rate *(Balázs, Polgár, 1999; Kovács, Balázs, 2003)*. Consequently, almost all properties of SFRC changes with the changing of the surface and the shape of fibres. Currently, the most widely used fibres in structural concrete industry, in terms of configuration, are either smooth or with hooks at the ends. The choice between these two types of fibres depends on the desired behaviour of the FRC *(Bentur, 2007)*.

The appropriate fibre length is very important for effective usages of fibres. If the fibre lengths are too short the fibres will pull out from the mixture and the whole load bearing capacity of the fibres cannot be utilized *(Fig. 4)*.

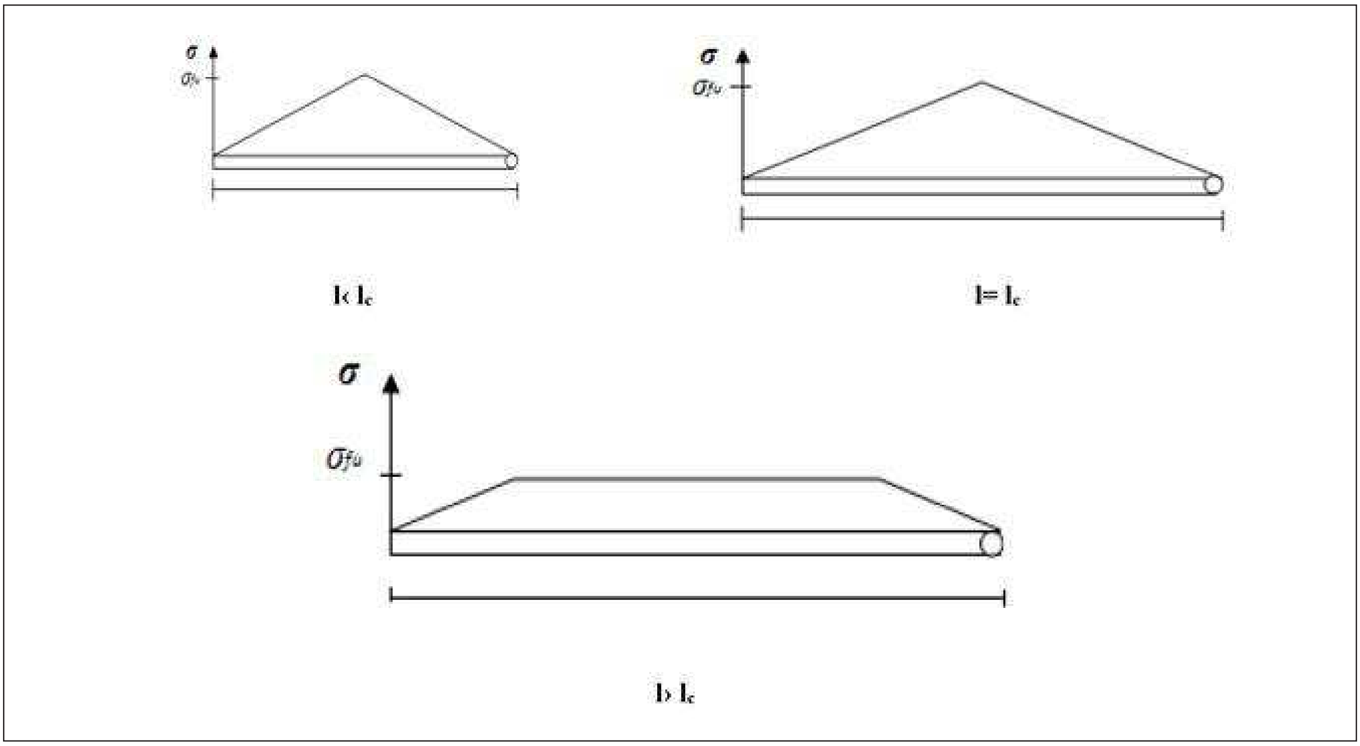
7. PARAMETERS INFLUENCING SFRC

7.1 Effect of mixing time

Manufacturers of the fibres have not determined the maximum allowed mixing time after addition of fibres to concrete so far. A lot of tests indicated different changes of fibre properties due to mixing. Different ways of mechanical deterioration was observed depending on the material, production technology, coating, size and surface of fibres. It is an important question whether the properties of fibres are significantly influenced by the longer mixing time than the minimum or not. *(Czoboly and Balázs, 2016)*

Czoboly and Balázs (2016) state that no significant change of properties of fibres in case of non-coated steel fibre caused by mixing in concrete. Shape deformation was observed for

Fig. 4: Tensile stress of the fibres with different lengths (lc - critical length=fibre length at which the fibre first breaks instead of being pulled out) (Kelly, 1973)



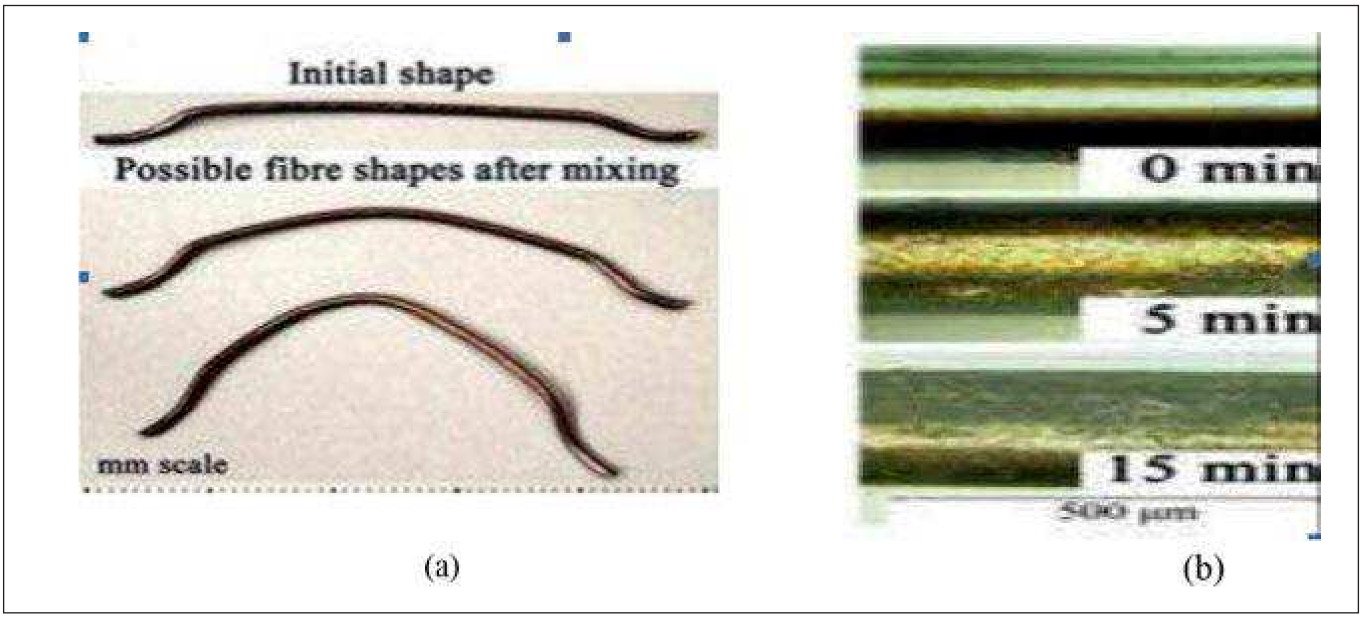


Fig. 5: Deterioration Modes of steel fibres, a) shape deformation, b) abrasion of coating of steel fibre (Czoboly and Balázs, 2016)

some fibres during mixing. The shape deformation probably does not significantly influence the properties of FRC. Abrasion of coating and also shape deformation were observed in case of coated fibres during mixing.

Czoboly et al (2016) have studied pull out behaviour of steel fibre with initial shape and after shape deformation. The tests indicated that the deformation of steel fibres could be observed after 5 minutes long mixing in concrete and the number of deformed fibres and the degree of deformation slightly increased as mixing time increased (*Fig. 5)*. Probably the shape deformation could slightly improve the anchorage capacity of steel fibres. The maximum pull out force was higher in case of fibres with shape deformation than in case of fibres with initial shape *(Lerch, 2018).*

7.2 Effect of mixer type

The mixer type has significant effect on the shape of the fibre and the deformation depends on the type of the fibre, length, geometry, and surface of the fibre.

For the tilting drum mixer, however, the mixing time is shown not to have a statistically significant influence on the performance of SFRC. It is clear that the drum mixer does not damage the fibres beyond a point where the performance is negatively influenced. It is believed that a tilting drum mixer represents a typical ready-mix truck, which should therefore not be a problem for macro synthetic fibre reinforced concrete. However, when pan mixers are used, e.g. in a precast factory, the mixing time should be no longer than what is needed to distribute the fibres evenly in the concrete. This is also only valid for this one type of fibre and it is recommended that every fibre type is checked that the performance is not negatively influenced before it is used *(Lerch, 2018).* The optimal mixing time depends on the mixer type (*Fig. 6)* as well as the type of fibre.

7.3 Effect of aggregate type

The influences of aggregate parameters on the properties of the SFRC, however, are generally not as well appreciated *(Adkgenç, 2015), (Mehta P K, 2006), (Meddah, 2010).* Since approximately 75% of the concrete volume is occupied by aggregates, it is known that the aggregate properties greatly affect the performance of the concrete.

The Surface deterioration was observed for coated steel fibres after mixing in concrete (*Fig. 5-b)*. The amount of abraded fibres increased as the mixing time increased. According to the test results the ratio of deteriorated macro polymer fibres was higher after mixing in crushed recycled aggregate concrete compared to mixing in concrete with natural sand and gravel aggregates. It could be explained by the sharper surface of crushed recycled aggregate compared to the sur-

Fig. 6: a) Pan mixer and b) tilting-drum mixer (Lerch, 2018)

face of gravel aggregate, otherwise it's good for SFs in case of deformation *(Czoboly and Balázs, 2016)*. So the type of aggregates have should be taken into account when we use some sensitive kind of fibres.

8. CONCLUSIONS

The inclusion of steel fibres in the concrete matrix leads to important changes in its behaviour, especially after cracking.

Main purpose of our study was to give an overview on the behaviour of steel fibre reinforced concrete especially the effect of key factors on the steel fibre and the anchorage between steel fibre/matrix interfaces. Thus different conclusions were drawn as follow:

- The homogeneous dispersion of the fibres is very important to achieve the best performance of FRC.
- The use of steel fibres according to many researchers may face drawback of inadequate workability or flow ability.
- Adding fibres into reinforced concrete in order to enhance the mechanical properties such as tensile and shear capacities of the structures has been thoroughly studied by several researchers.
- The manufacturers of the fibres should be specifying the duration of mixing after addition of fibres in concrete, taking into account the type of mixer.
- The compressive strength of the FRC specimens with steel fibres increases a mixing time increases. On the other hand the porosity of the SFRC decreases with the increase of the mixing time.
- Longer mixing times resulted in a slight increase of the post-cracking residual flexural strength of FRC beams containing steel fibres. The main reason for this was the increased compressive strength and increased number of the deformed steel fibres as the mixing time increased.
- Type of aggregate influences the surface of the fibre especially for the coated fibre. for instance mixing using crushed recycled aggregate concrete has more impact compared to mixing in concrete with natural sand and gravel aggregates

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