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Contribution of steel fiber as reinforcement to the properties of cement-based concrete: A review

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Abstract. During the past decades, development of reinforcing materials caused a revolution in the structure of high strength and high performance cement-based concrete. Among the most important and exciting reinforcing materials, Steel Fiber (SF) becomes a widely used in the recent years. The main reason for addition of SF is to enhance the toughness and tensile strength and limit development and propagation of cracks and deformation characteristics of the SF blended concrete. Basically this technique of strengthening the concrete structures considerably modifies the physical and mechanical properties of plain cement-based concrete which is brittle in nature with low flexural and tensile strength compared to its intrinsic compressive strength. This paper presents an overview of the work carried out on the use of SF as reinforcement in cement-based concrete matrix. Reported properties in this study are fresh properties, mechanical and durability of the blended concretes.

Keywords: concrete; steel fiber; physical properties; mechanical properties

1. Introduction

Concrete as the most widely utilized material in construction and buildings perhaps comes second only to water on earth. Its history begins more than a century since cement was known. Concrete's structure is a complex system of many interacting components which is produced by mixing cementing materials, water, aggregates and some appropriate admixtures in required proportions. A mixture of aforementioned components when positioned in different forms and allowed to cure and hardened into rock-like mass is known as concrete (Beall and Jaffe 2003). It is well known that plain, unreinforced concrete is a brittle material having high compressive strength but low tensile, flexural and residual strength as well as low strain capacity requires reinforcements for structural usage (Bentur and Mindess 2006).

Traditionally, continuous reinforcing steel has been used in concrete structures to resist tensile and shear stresses. On the other hand, fiber reinforcement in concrete is comparatively short discontinuous and randomly distributed throughout the concrete matrix (Cunha *et al.* 2011). Therefore fibers can be most effectively utilized to resist crack propagation, since they are more homogeneously distributed throughout the concrete matrix and more closely spaced than traditional continuous steel reinforcements (Altun *et al.* 2007). Furthermore, the addition of fibers into a concrete matrix enhances fractural toughness by exhibiting much greater post-cracking resistance than plain concrete (Kim *et al*. 2011, Cagatay and Dincer 2011). It should be noted that design codes do not allow the total substitution of steel reinforcement with fibers alone as they do not supply sufficient resistance to tensile stresses of structural magnitude (ACI 544.1R-96).

It is worth mentioning that different type of fibers can be used to reinforce concrete. Among fibers, Steel Fiber (SF) is the most popular and widely used type of fibers in concrete structures (Khaloo and Sharifian 2005, Molaei 2003). Due to the focus of this review on SF, the remaining sections will elaborate on definition of fiber reinforced concrete with more emphasis on the role of SF on fresh and hardened properties of blended concrete.

1.1 Definition of fiber reinforced concrete

The term Fiber Reinforced Concrete (FRC) can be defined as a composite material made with hydraulic cement, water, fine and coarse aggregates and incorporating discrete discontinuous fibers (ACI 211.5R-01). On the other words, FRC can be considered as a composite material with two phases in which concrete corresponds to the matrix phase and the fiber represents the inclusion phase (Konsta-Gdoutos 2006). The function of randomly distributes discontinuous fibers is to bridge across the cracks that develop supplies post-cracking ductility (Bentur and Mindess 2006, Van Chanh 2004). That is, the fibers tend to increase the strain at peak load, and provide a great deal of energy absorption in post-peak portion of the load vs. deflection curve (Van Chanh 2004). If the fibers are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage (Ramli 2008, Ramadoss and Nagamani 2013).

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1.2 Types of fibers

Different kinds of fibers were used to reinforce brittle materials earlier than cement detection since Egyptian and Babylonian civilizations (Padmarajaiah and Ramaswamy 2001). Up to now, there are several types of fibers which made with deferent kind of materials such as steel, textiles, graphite, glass, kevlar, polypropylene have been known and widely used to improve performance of concrete for more than 90 years (Zheng and Feldman 1995). Previously, horsehair was utilized in concrete mix and straw in mud bricks (Rajeshkumar *et al.* 2010). In the early 1900s, asbestos fibers were utilized in cement based concrete, and in the 1950s the idea of composite materials came into being and fiber-reinforced concrete was one of the areas of interest (Jain and Kothari 2012). By the 1960s, steel, glass, and synthetic fibers such as polypropylene fibers were utilized in cement based concrete, and research into new fiber-reinforced concretes continues today (Vijai *et al.* 2012).

Fibers can be divided into two groups; those with elastic moduli lower than the cement matrix, such as cellulose, nylon, and polypropylene and those with higher elastic moduli such as asbestos, glass, steel, and carbon (Behbahani 2010). More addition, a different classification can be made according to the source of the fiber material such as metallic, polymeric, or natural. Table 1 shows the different types of common fibers as well as their properties.

1.3 Advantageous of using fibers in concrete

The use of fibers in concrete has been associated with the following essential assets:

Table 1 Typical properties of fibers (ACI 544.1R-96)

TypeofFiber	Tensile Strength (MPa)	Young's Modulus (GPa)	Ultimate Elongation (%)	Specific Gravity
Acrylic	210-420	2.1	25-45	1.1
Asbestos	560-980	84-140	0.6	3.2
Carbon	1800-2600	230-380	0.5	1.9
Glass	1050-3850	70	1.5-3.5	2.5
Nylon	770-840	4.2	16-20	1.1
Polyester	735-875	8.4	11-13	1.4
Polyethylene	700	0.14-0.42	10	0.9
Polypropylene	560-770	3.5	25	0.9
Rayon	420-630	7	10-25	1.5
Rock Wool	490-770	70-119	0.6	2.7
Steel	280-2800	203	0.5-3.5	7.8

- Improved mix cohesion, improving pumpability over long distances (Rajeshkumar *et al.* 2010)
- Improved freeze-thaw resistance (Savas *et al.* 1997)
- Improvedfire resistance as well as resistance to explosive spalling in case of a severe fire (Aydın *et al.* 2008, Kodur *et al.* 2003)
- Improved impact strength (Nili and Afroughsabet 2010, Sivakumar and Santhanam 2007)
- Increased resistance to plastic shrinkage (Forgeron and Trottier 2011)
- Improved compressive strength (Martínez-Barrera *et al.* 2011, Cagatay and Dincer 2011)
- Improved tensile strength (Shah 1992)
- Improved flexural strength (Çağlar *et al.* 2002)

As stated earlier in the preceding sections, the focus of this review is on the steel fibers as they are widely used in concrete structures. Therefore, the remaining sections will be discussed on the types of steel fibers and their influence on the concrete properties.

2. Steel fibers

Steel fiber reinforced concrete is a composite material made of hydraulic cement, fine and coarse aggregate, and a dispersion of discontinuous, small steel fibers (ACI 544-3R). It may also contain pozzolans and admixtures commonly used with conventional concrete. Use of steel fibers has been well known as complementary reinforcement to develop certain properties of concrete structures (Nawy 2008). Due to its smart properties, the use of steel fiber reinforced concrete has continually increased during the last decades (Wang and Lee 2007, Nili and Afroughsabet 2010, Dinh 2009, Behbahani 2010, Kim *et al.* 2011, Zarrin and Khoshnoud 2016). It is presently utilized not just in common civil and industrial constructions and buildings, but also in a lot of other fields such as bridges, earthquake and impact resistant structures, hydraulic structures, airport and highway pavements, tunnels etc. (Abbas 2011). Steel fibers can be utilized to develop several properties of blended concrete such as tensile strength, first-crack flexural strength, compressive strength, ductility, fatigue life, and impact strength as well to explosive charges and to cavitation during high-velocity water flow. It is worth mentioning that steel fiber reinforced concretes also have shown excellent resistance to corrosion from deicers or seawater as well as twenty seven percent less wear than control concrete specimens in a laboratory study (ACI 544.1R-96). To this end, fiber reinforced high-strength concrete is applied not just in new buildings, but it is also used for retrofitting of existing structures (Hamad and AbouHaidar 2011).

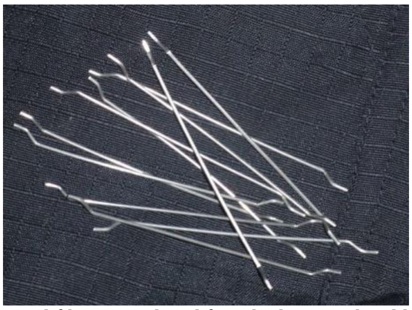
It is worth mentioning that the fibers may take many shapes as can be seen in Fig. 1. Their cross sections include circular, rectangular, half-round, and irregular or varying cross sections. They may be straight or bent, and come in various lengths (Shah and Ribakov 2011).

It is also worth mentioning that a convenient numerical parameter called the aspect ratio is used to describe the geometry. This ratio is the fiber length divided by the diameter. If the cross section is not round, then the diameter of a circular section with the same area is used (ACI 544.4R-88).

2.1 Typical properties of steel fibers

Steel fibers are obtainable in various lengths involving 6 to 80 mm along with a cross section area between 0.1 and 1.5 mm 2 (Shah and Ribakov 2011). It corresponds to a diameter between 100 and 1000 µm (Shah and Ribakov 2011, ACI 544.4R-88). The normal tensile strength of steel fibers is in the range of 500 up to 2600 MPa or 4 to 40 ksi (Shah and Ribakov 2011, Merkblatt des VDS 2005).

1. Cold Drawn Carbon Wire Steel Fiber

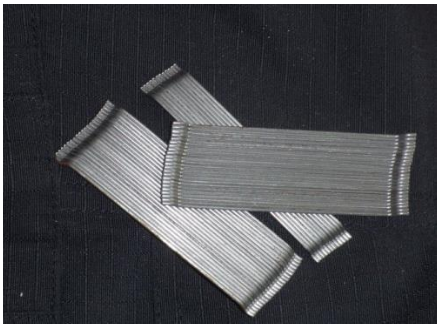


Carbon steel fiber is produced from high-strength cold-drawn steel wire; conform to ASTM 820, widely used for concrete reinforcement

2. Slit Sheet Carbon Steel Fiber

Slit sheet carbon steel fiber is used as a replacement for traditional reinforcement in various concrete applications

3. Glued Steel Fiber

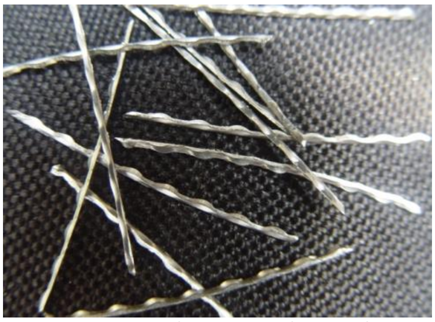


Glued steel fibers are filaments of wire, deformed and cut to lengths, for reinforcement of concrete, with hooked ends. It is easy to separate in the mixer and can avoid balling in concrete matrix

4. Melt Extract Stainless Steel Fiber

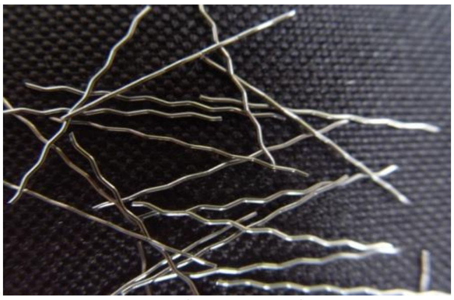
Melt extract stainless steel fiber is produced by melting elements in a crucible. A flywheel is then introduced to the crucible and droplets of molten metal are spun into the open air and hardened

5. Slit Sheet Stainless Steel Fiber



Slit sheet stainless steel fiber is manufactured from coil by chopping the width of the stainless coil, it is used for precast shapes and castable project

6. Cold Drawn Stainless Wire Steel Fiber



Cold drawn stainless steel fiber is manufactured by high quality stainless steel wire, mainly used for castable requirements in refractory field

Fig. 1 Various types of steel fibers (Adopted from China National Building Materials (Group) Corporation (CNBM))

Also they have a relative density of appropriately 7800 kg/m3 (Shah and Ribakov 2011, Bakaert product data base). They are of circular or rectangular cross sectional shape and are produced by cutting or chopping steel wires or by shearing sheets of flattened metal sheets and steel bars (Shah and Ribakov 2011, ACI 544.4R-88, Šalna and Marčiukaitis 2010). It is worth to mention that the fibers are generally crimped or bent with either a hook at the end of each fiber or a tiny head in order to get better the connection between fiber and concrete matrix (Maidl 1995). The typical properties of steel fiber are also summarized in the Table 2.

Table 2 Typical properties of steel fibers (Shah and Ribakov 2011, ACI 544.4R-88, Šalna and Marčiukaitis 2010)

Relative Density (kg/m^3)	Diameter (μm)	Tensile Strength (MPa)	Modulus of elasticity (ksi)	Strain at Failure (%)
7800	100-1000	500-2600	70-380	0.5-3.5

2.2 Amount of usage

The amount of steel fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed volume fraction (Vf). Vf typically ranges from 0.1 to 3% (ACI 544-3R, Wang *et al*. 2000).

According to Knapton (2003) the recommended dosage rate of steel fibers is usually between 20 and 40 kg/m^3.

The greater the dosage rate the greater is the flexural strength of the concrete. It should be mentioned that, usually the steel fibers are incorporated last to the freshly mixed concrete, care being taken to ensure that no clumps are added and the fibers are rapidly moved from the entry point to the mixer. Alternatively they may be added onto the aggregate on the conveyor belt (Newman and Choo 2003). As long as the aspect ratio of the fiber is less than 50, the fibers may be dispensed directly without any risk of balling. With higher aspect ratios some manufacturers employ special packing techniques to reduce the risk (Technical report Lewis 1992). However, visual inspection during pouring is necessary to check fiber distribution is satisfactory (Knapton 2003).

3. Fresh and hardened properties of steel fiber reinforced concrete

3.1 Workability

Workability is defined as the "property of freshly mixed concrete that determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished without segregation" (ACI 211.4R-93). In common practice, an assumption is made that the concrete workability is usually quantified by the result of the slump cone test (Ferraris *et al*. 2001) although, the ACI Committee 544 recommended the use of inverted slump cone test for workability of fiber reinforced concrete (Shah and Ribakov 2011).

Workability is affected by several factors including the concrete components and the conditions under which concrete is constructed. Literature mentions a long list of factors influencing concrete workability. Among them are: cement volume and properties, particle shape, size and proportion of aggregates, types and percentage of mineral and chemical additives, water to binder ratio, methods of mixing as well as the percentage and size of admixtures. In the same vein, the time factor is important when mixing the components and the time since water and cement made contact (Mindess and Young 1981, Neville and Brooks 1987, Bartos 1993, Scanlon 1994, Bartos 2013). Concrete workability is influenced by changes in both individual and interactive effects of these factors.

Compared to control cement based concrete, steel fiber reinforced concrete blends usually have higher cement plus fine contents and smaller aggregates (Labib and Eden 2006). ACI Committee 544.1R and Newman and Choo (2003) define that the slump decreases as the steel fiber content increases.

It is worth mentioning that, nowadays, generally the mixture used in the steel fiber reinforced concrete is of a usual type, although the quantities could be different for obtaining suitable workability and catch all the profits of the steel fibers. This may need controlling the aggregate size, adjusting the gradation, raising the cement content, and possibly adding extra admixtures such as super plasticizers to improve workability. In light of this fact, Bekaert (1990) concluded that in order to gain steel fiber reinforced concrete with acceptable workability and lowest shrinkage, the steel fiber blended concrete manufacturers should specify the following items:

• Quantity of cement should be between 320 and 350 kg/m^3
• 750-850 kg/m^3 good quality 0-4mm well graded sharp sand should be used
• Use a continuous aggregate grading with a maximum size of 28 mm for rounded gravel and 32 for crushed stone. Limit the fraction larger than 14 mm to 15-20%
• Characteristic compressive strength of at least 25 N/mm^2 should be used
• W/B ratio should be about 0.50, and should not exceed 0.55
• Using super-plasticizer is allowed to attain the required workability
• Admixtures of chloride or chloride containing concrete additives are not permitted

It is also worth mentioning that achieving adequate workability is one of the most important problems generated when using steel fiber reinforced concrete (Labib and Eden 2006). The addition of steel fibers into the concrete mix design influences its workability. According to Hannat (1978) and Swamy (1974) increasing in the steel fiber quantity and aspect ratio leading to reduce workability. More addition, the ACI Committee 544.1R reported that in the 0.25 to 1.5 volume percent witch is the standard ranges of volume fractions used for steel fiber reinforced concrete, the increasing the amount of steel fibers may condensed the measured slump of the cement based concrete in comparison to control concrete which is in the range of 25 to 102 mm.

So, due to the above-mentioned problems, incorporation of super plasticizer seems to be necessary for obtaining acceptable workability (120-150 mm) (ACI Committee 544.1R). In addition to the above, consideration the balling effect of steel fibers in concrete blend must be prevented.

To sum, despite of the benefits of steel fibers reinforcement, they could adversely affect the workability of freshly mixed concrete. That mean, concrete containing steel fibers causes difficulty in mixing, transporting, placing in the mold and compacting that can lead to excessive voids in hardened concrete.

In order that hardened properties of concrete are not adversely affected, investigation of freshly mixed properties of fiber reinforced concrete is very important. Review of literature shows that there are other factors that can affect the fiber reinforced concrete's rheology. These are: total surface area, modulus of elasticity of fiber, rheological behavior of concrete without fiber, and processing techniques (Laskar and Talukdar 2008).

On the other hand, the other factor which has a major effect on workability is the aspect ratio (l/d) of the fibers. The workability decreases with increasing aspect ratio. In common practice it is very hard to achieve a uniform mix if the aspect ratio is larger than about 100 (Van Chanh 2004).

3.2 Compressive strength

Compressive strength of concrete refers to its capacity to withstand the axial pressures that it receives. It is commonly identified by the limit to which a material can endure the pressure and being crushed. Hence, compressive strength is considered as an index of hardened concrete and is important to be determined for the specific purposes of its use to make sure that the given compressive strength will meet the requirement of its application. There are several factors that determine the compressive strength of the concrete including the type and percentage of cement, water content, size and amount of additives and aggregates, mixing procedures, and compaction as well as curing process (Neville 2002, Najigivi 2011, Nazerigivi *et al.* 2017).

Typical compression tests of steel fiber reinforced concrete are conducted on concrete cylinders or cubs made with cement-based concrete having different amount of steel fibers to examine compression behavior of steel fiber concrete blends. Literature shows the effects of volumetric ratio of steel fibers on compressive strength, corresponding peak of strain and also the compressive stress-strain curve. The test results of Dbakal *et al*. (2005) show that the more the amount of fibers the higher the compressive strain the cylinder can sustain. They also detected that both compressive strength and the strain corresponding to the peak stress growth with the addition of steel fibers. Their experimental results also show that if the compressive stress and strain are normalized with respect to the compressive strength and the peak strain respectively, the resulting normalized stress-strain curves lie close to each other and are not influenced by the fiber content. They also proposed an equation to represent this unique relationship among the normalized compressive stress and strain.

To this end, they examined a series of compression tests on cubes with 150 mm edge and also cylindrical specimens with 150 mm x 300 mm edge, using a modified test method which gave the complete compressive strength, static, dynamic modulus of elasticity, ultrasonic pulse velocity and stress-strain behavior utilizing 8% silica fume with and without steel fiber of volume fractions of 0, 0.5, 1.0, and 1.5%, Portland Pozzolona cement. They concluded that the incorporation of steel fibers, silica fume and cement has produced a strong composite with superior crack resistance, improved ductility and strength behavior prior to failure. They also found that the addition of fibers provided better performance for the cement-based composites, while silica fume in the composites may adjust the fiber dispersion, and improve strength and the bond between fiber and matrix with dense calcium-silicate-hydrate gel.

Moreover, Pawade *et al*. (2011) and Vairagade *et al*. (2012a) investigated a series of compression tests on steel fiber reinforced concrete. They have designed and used cube and cylindrical specimens with SFRC containing fibers of 0% and 0.5% volume fraction of hook end and crimped round steel fibers of 50, 53.85, 62.50 (copper coated) aspect ratio without admixtures. They found that comparing the result of SFRC with plain M25 grade concrete, the positive effect of steel fiber with 0.5 percentage increases in compression and splitting improvement of specimen at 7 and 28 days, determined the positive effects of steel fiber to concrete with different amounts.

Also Barros and Figueiras (1999) investigated the specimens and structural elements made of steel fiber reinforced concrete. In their study, the fiber content ranged from 0 to 60 kg/m3 of concrete. Using the results of the uniaxial compression tests performed under displacement control condition and a stress-strain relationship for fiber concrete in compression was derived. They carried out three-point bending tests on notched beams in order to simulate the post-cracking behavior and to evaluate the fracture energy. They developed a layered model for the analysis of steel fiber reinforced concrete cross sections based on the constitutive relationships derived from the experiments. Their model performance and the benefits of fiber reinforcement on thin slabs reinforced with steel bars were assessed by carrying out tests on slab strips and showed the performance of using steel fiber in concrete structures.

More addition, regarding to the literature reviewed by Balaguru and Shah (1992) and Shahidan (2009), by adding the steel fiber in concrete matrix, the strength increase and exceeds to 25%. Commonly the strength is increase when using the deformed fiber and usually the quantity of steel fiber used in concrete is limit to 100 lb/yd3 (60 kg/m3) or less than 0.75%.

They also defined that in special case, where the fiber volume content is more than 3% the strength is increase and not significant in high strength concrete. According to them, the strength is increase by 13% - 40% for steel fibrous concrete as mentioned before.

Furthermore, they noted that the incorporation of steel fiber could increase the strain at peak load and more reproducible descending branch. Besides that, the steel fiber reinforced concrete also can absorb much more energy before start to failure compare to plain concrete.

Finally, the test results from Nagakar *et al.* (1987) again confirmed that the compressive strength increased by addition of steel fiber in to the control concrete and Vairagade *et al.* (2012b) also have found with same volume fraction, change in length of fiber result nearly minor effect on compressive strength of steel fiber reinforced concrete.

3.3 Tensile strength

It is well known that the tensile strength of concrete, is much lower than the compressive strength (about 10% of the compressive strength of the concrete), because of the ease with which cracks can propagate under tensile loads, and is usually not considered in design (it is often assumed to be zero) (Neville 2002, Najigivi 2011). However, it is an important property, since cracking in concrete is most generally due to the tensile stresses that occur under load, or due to environmental changes. The failure of concrete in tension is governed by micro cracking, associated particularly with the interfacial region between the aggregate particles and the cement. The load applied (compressive force) on the concrete specimen induces tensile and shear stresses on the aggregate particles inside the specimen, generating the bond failure between the aggregate particles and the cement paste (Najigivi 2011).

The most important effect of fibre addition to cement based concrete is the delay and control of tensile cracking in the concrete structures (Ramakrishnan 1988). Through interrupt micro-cracks, several of the physical and mechanical properties of the concrete are improved (Labib and Eden 2006). The level of improvement achieved, compared to control concrete, depends on the dosage rate and type of fibre (ACIFC 1999).

According to ACI Committee 544.1R and Mirsayah and Banthia (2002) by addition of steel fiber into the concrete mixture the tensile strength significantly improved.

Also Adeyanju and Manohar (2011) concluded that fibres aligned in the direction of the tensile stress may bring about very large increases in direct tensile strength, as high as 133% for 5% of smooth, straight steel fibres. However, for more or less randomly distributed fibres, the increase in strength is much smaller, ranging from as little as no increase in some instances to perhaps 60%, with many investigations indicating intermediate values. Moreover Akinkurolere (2010) obtains similar results for splitting-tension test of steel fiber reinforced concrete and Vairagade *et al.* (2012b) was also observed that, the split tensile strength of fiber reinforced concrete was dependent on length of fiber used. That mean, by addition of longer length fiber, the split tensile strength increases.

It is worth mentioning that when the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fiber reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and prestressed structural members. However, because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions (Van Chanh 2004).

To sum, it should be noted that for design purposes a very detailed knowledge about the tensile carrying behavior of steel fibered reinforced concrete is needed. Because it is affected by different parameters like steel fibers' geometry and content, bond strength between fiber and binder matrix, strength of the matrix, shrinkage of the concrete orientation of fibers, etc. (Vairagade 2012a)

3.4 Flexural strength

Flexural strength is one measure of the tensile strength of concrete and defined as its ability to withstand failure from bending. The flexural strength found is expressed as the "Modulus of Rupture" (MR) in MPa or psi. The flexural MR can vary from about 12% to 20% of the compressive strength of the concrete. Designers of concrete structures, where bending is an integral function of the structure, must take into consideration (Najigivi 2011).

It is now well established that one of the significant properties of steel fiber reinforced concrete is its excellent resistance to cracking and crack propagation. As a result of this ability to prevent cracking, steel fibre reinforced concrete possess improved extensibility and tensile strength, together at first crack and also at ultimate, specifically under flexural loading; and the steel fibres are able to hold the concrete matrix together even after extensive cracking.

The increase in flexural strength is particularly sensitive, not only to the fibre volume, but also to the aspect ratio of the fibres, with higher aspect ratio leading to larger strength increases (Ali 2012). As was indicated previously, fibres are added to concrete not only to improve the strength, but primarily to improve the toughness, or energy absorption capacity. Commonly, the flexural toughness is defined as the area under the complete load-deflection curve in flexure; this is sometimes referred to as the total energy to fracture (Perumal 2014, Kim *et al*. 2009). Alternatively, the toughness may be defined as the area under the load-deflection curve out to some particular deflection, or out to the point at which the load has fallen back to some fixed percentage of the peak load (Van Chanh 2004).

Probably the most commonly used measure of toughness is the toughness index proposed by Johnston and incorporated into ASTM C1018. For all of the empirical measures of toughness, fibres with better bond characteristics (i.e., deformed fibres, or fibres with greater aspect ratio) give higher toughness values than do smooth, straight fibres at the same volume concentrations. Also the post-crack flexural performance is a most important part of the commercial uses of steel fibre concrete enabling reductions of thickness to be made in sections subject to flexure or point load (Newman and Choo 2003).

Finally, although by addition of steel fiber into the concrete mixture the tensile strength significantly improved (ACI 544.1R-96, Mirsayah and Banthia 2002) but much greater effect on flexural strength than on either compressive or tensile strengths, with increase of more than 100% has been reported by Johnston (1974) and Khaloo and Afshari (2005).

3.5 Impact strength

Impact strength is defines as the ability of a material to absorb mechanical energy in the process of deformation and fracture under impact loading. The term "impact strength," as well as the term "impact energy," is also applied to the amount of energy absorbed before fracture (Van Hauwaert *et al.* 1999).

The increase in ductility provided the steel fiber depends on the several factors, such as volume friction, fiber geometry, and composition of concrete. The increasing of volume friction of steel fiber in concrete can improve and increase the energy absorption capacity of cement based concrete. The investigation by Balendran *et al*. (2002) indicated that, the high volume of steel fiber in range 5%-20% could improve the strength and the ductility of concrete. However regarding to Khaloo and Raissi (2002), in slab application, it is recommend using the steel fiber volumetric percentage in range 1-2% because it can provide the higher energy absorption. With respect to fiber geometry, the length, diameter and aspect ratio are important for the performance of steel fiber reinforced concrete. For example by increasing the aspect ratio, the ductility increases as long as fiber can be properly mix with the concrete. Moreover, steel fiber ratios and curing age considerably affect the fracture properties of steel fiber reinforced concrete. A reasonable addition of steel fiber enhance the fracture toughness of concrete, while the fracture energy of concrete develop with curing time (Fu *et al.* 2014).

Based on the Kim *et al.* (2009) research, the strength and toughness of the composite were found to increase the higher loading based on the higher aspect ratio. Alongside that, the shape of steel fiber such as deformed and hooked-end steel fiber will provide the suitable energy absorption.

Also it was shown that the stress-strain behavior of hooked end steel fiber in comparison to control concrete was highly enhanced. Also again Impact strength and toughness, which defined as energy absorbed to failure are greatly increased (Van Hauwaert 1999), the increased in toughness results from the increased of the area under the load deflection curve in tension and flexure (Newman and Choo 2003).

The net result of all these is to impart to the fibre composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading (Van Chanh 2004).

Furthermore, the impact resistance of steel fiber reinforced lightweight aggregate concrete was evaluated by Song and Wang (2011). In their tests, 5 groups of disc specimens with different steel fiber volumes including 0.0%, 0.5%, 1.0%, 1.5% and 2.0% were tested. Their experimental results also confirmed that the impact resistance of lightweight aggregate concrete is improved with the increase in fiber volume.

To sum, nowadays it is well known that the main role of fibers is to bridge the cracks that develop in concrete and increase the ductility of concrete elements. Steel fibers increase the strain at peak load, and provide additional energy absorption ability of RC elements and structures. It was recently reported that they also considerably improve static flexural strength of concrete as well as its impact strength, tensile strength, ductility and flexural toughness (Gencoglu and Mobasher 2007).

3.6 Water absorption

Concrete resembles a "hard sponge" that absorbs liquids like water and other aggressive substances. The strength of concrete is reduced by the influence of such substances. Therefore it is essential to produce concrete with maximum impermeability to damaging liquids. Hence, the more impermeable the concrete, the greater will be its resistance to deterioration (Najigivi 2011).

Here the underlying theory is evidently that a piece of concrete is made up of water-impervious masses, interspersed with pores or capillaries, and that the more pores or capillaries the concrete has the greater will be its water absorption and the less its water-tightness; or, in other words, that the chief reason for the permeability of concrete is its porosity and that the water absorption of the dried specimen is a correct measure of this porosity (Castro *et al.* 2011).

Steel fibers have gained popularity in recent decades due to low fiber volume fraction, which enhances toughness, flexure strength and resistance to shrinkage-induced cracking (Hwang *et al*. 2015, Tamrakar 2012, Miloud 2005). However, there is little information available regarding the effect of steel fiber on the durability performance of concrete (Miloud 2005, Brandt 2009, Saricimen *et al.* 1995).

According to Miloud (2005) the addition of steel fibers, with a length of 30mm, did not affect the porosity when the amount ranged from 0.5 to 1% but beyond the 1% there was a slight decrease in porosity. He defined that the slight decrease reported in the porosity of specimens reinforced with steel fibers compared to the control concrete could be due to the fact that steel fiber reinforced concrete specimens needed a long duration of vibration, which could affect the pores sizes and distribution. It is worth mentioning that many studies have reported that steel fibers addition did not significantly increase the amount of pores above those calculated for plain concrete (Tamrakar 2012, Castro *et al*. 2011).

Also, a durability test of high-performance steel fiber reinforced concrete done by Ramodoss and Nagamani (2008) showed that water absorption and porosity do not change significantly compared to the control mixture without steel fibers. Regarding their research, Water absorption and porosity ranged from 1.86 – 1.91% (with W/B ratio 0.4) and 4.43 – 4.50% (with W/B ratio 0.5), respectively.

It should be noted that concrete is regarded as good quality if saturated water absorption is around 3%, according to The Concrete Society, United Kingdom (Sabir *et al.* 1998). Moreover, the study done by Ramadoss and Nagamani (2008) also show that water absorption and porosity decrease when water to cementitious ratio decreases.

It is worth mentioning that sorptivity is a material's ability to absorb and transmit water through capillary suction. Sorptivity is also related to absorption and is sometimes used as an indicator of the volum of capillary pore space or open porosity (Ramadoss and Nagamani 2008). According to Nawy (2008), a sorptivity value of less than 0.77 mm/ min is considered good quality in terms of durability performance. Finally, a study done by El-Dieb (2009) showed that in ultra-high strength concrete incorporating steel fibers, the sorptivity value did not change significantly for a fiber volume fraction range from 0.08 – 0.52%; its values ranged from 0.0353 – 0.0385 mm/ min, respectively. The study also found that sorptivity value decreases with age. It is also worth mentioning that due to the low permeability produced by controlling the cracking, fiber reinforced concrete is also widely used in silo buildings and basement floors and walls.

4. Conclusions

The employment of Steel Fiber (SF) in cement-based concrete has gained considerable importance because of the requirements of structural strength, safety and more durable construction in the future. Although extensive studies had been done on the fresh and hardened properties of Steel Fiber Reinforced Concrete (SFRC), but the study on the effect of SF with different sizes, shapes, amounts and types can still be a promising work as there is always a need to overcome the problem of brittleness of concrete. This literature review clearly demonstrates that SF is an effective additive that can contribute to physical and mechanical properties of concrete.

From previous research, it can concluded that although incorporation of SF beyond a specific volume may cause the limitations of the workability of freshly mixed SFRC due to higher difficulty in the spreading, but it can also easily compensate by use of super plasticizers. The use of short steel fibers improved the workability of the concrete mixture compared to the use of longer ones, as indicated by results from the slump tests. This supports the fact that the longer steel fibers with a hooked end have more detrimental interference with aggregate and can hinder flow more than the short steel fibers.

Additionally, from the previous studies it was concluded that the incorporation of SF into the concrete mixture could highly improve bond strength between the steel reinforcing bar and cement based concrete matrix, and enlarged the compressive, tensile and flexural strength up to 40%, 133% and 100%, respectively. Also impact strength of the blended concrete highly increased in the presence of steel fiber. A maximum of 127% increase in the impact strength value compared to the control concrete has been observed in the concrete mixtures steel fibers. Increases in the compressive strength for all SF blended concrete mixtures have been detected as a percentage of steel fiber volume increase.

Finally, this literature search showed that the water absorption of SFRC was investigated as one of the major problems of plain concrete, which highly can affect the durability of concrete. It was also reported that steel fiber blended concrete can decrease the total porosity of concrete and modifies the pore structure of the concrete, and reduce the permeability which allows the influence of harmful ions leading to the deterioration of the concrete matrix. Moreover steel fibre reinforced concrete is more durable than plain concrete due to reduce the number and controlling the width of cracks. It is also worth mentioning that the reinforcement bars cannot stop the development of micro cracks, but the randomly distributed fibers can prevent the micro cracks from propagating or widening and help to control the cracks. Overall, steel fibers in concrete mixtures performed well on both mechanical and durability aspects.

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