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Engineering Performance of High Strength Concrete Containing Steel Fibre Reinforcement

The development and utilization of the high strength concrete in the construction industry have been increasing rapidly. Fiber reinforced concrete is introduced to overcome the weakness of the conventional concrete because concrete normally can crack under a low tensile force and it is known to be brittle. Steel fibre is proved to be the popular and best combination in the high strength concrete to result the best in the mechanical and durability properties of high strength concrete with consideration of curing time, steel fibre geometry, concrete grade and else more. The incorporation of steel fibre in the mortar mixture is known as steel fibre reinforced concrete have the potential to produce improvement in the workability, strength, ductility and the deformation of high strength concrete. Besides that, steel fibre also increases the tensile strength of concrete and improves the mechanical properties of the steel fibre reinforced concrete. The range for any high strength concrete is between 60MPa-100MPa. Steel fibre reinforced concrete which contains straight fibres has poorer physical properties than that containing hooked end stainless steel fibre due to the length and the hooked steel fibre provide a better effective aspects ratio. Normally, steel fibre tensile strength is in the range of 1100MPa-1700MPa. Addition of less steel fibre volumes in the range of 0.5% to 1.0% can produce better increase in the flexural fatigue strength. The strength can be increased with addition of steel fibre up to certain percentage. This paper will review and present some basic properties of steel fibre reinforced concrete such as mechanical, workability and durability properties.

Keywords: *high strength concrete, steel fibre, mechanical properties, compressive strength, durability, tensile*

1. Introduction

As everyone knows, concrete is most broadly used construction material in the world due to its ability to be fabricated in any form and any shape. Concrete has replaces old construction materials such as brick and stone masonry. The strength and durability of concrete could be changed by making proper and controlled changes in its ingredients such as cemetitious material, aggregate and water and by adding some particular ingredients. For this reason concrete is very well suitable for a wide range of applications. Nevertheless concrete has some deficiencies such as low tensile strength, low post cracking capacity, brittleness and low ductility, limited fatigue life, incapable of accommodating large deformations and low impact strength. The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete.

It should be pointed out that currently there is high demand of high strength concrete in the construction of long span bridges which is to improve the durability, high rise buildings and walkaways. The high compressive strength provide by the concrete is the main reason why it is been used widely [1]. Besides that, the improvement of the reinforced concrete on the elements like durability, flexural strength and the modulus of elasticity is also the reason and the characteristic of usage of the high strength concrete [2]. The durability, compressive strength and the fracture of toughness of the reinforced concrete can be improved or modified by the addition of steel fibers [3]

The disadvantage encountered of the high strength concrete is the explosive failure and its brittleness and not much experimental studies have been carried out in the durability properties of steel fiber high strength concrete [4]. As compared to normal reinforced concrete, steel fiber reinforced concrete produces very good dynamic performances such as high resistance to projectile penetration and this have become a practice in the part of composite concrete. Steel fiber also enhance the mechanical strength and the durability properties of steel fiber reinforced concrete [5]

Steel fibers can be classified into different sizes and shapes, Scientific research of fiber reinforced concrete was done in 1963 in the USA [6]. The influence of fiber in concrete benefits by many factors such as the matrix strength, fiber content, and mixing of the concrete. To enhance the workability and stability of the steel fiber reinforced concrete, addition of chemical admixtures such as super plasticizer should be added.

The main purpose of constructing steel fiber reinforced concrete mix is to provide an adequate workability and efficient concrete. The addition of steel fiber should be followed by the addition of cement paste in order to maintain the level of workability and maintain the adequate load of the concrete. The amount of the cement paste is depending on volume of fibre; shape, size and characteristic of the fibre and cement paste flow characteristic [6].

2. Mechanical Properties

The volume fraction of 1.5% steel fiber used the compressive strength increases which means that it stated the highest compressive strength result at the volume of 1.5% [7]. As the volume of steel fibers increases to 2% the compressive strength decreases slightly. Besides that, the splitting tensile strength of the High strength fiber reinforced concrete increases when there is an increase in the steel fiber volume [7]. The types of steel fiber used have a major influence in the mechanical properties of mortar reinforced concrete. Several investigation and experiments on the influence of the material and the mix proportion to the mechanical properties of steel fiber reinforced concrete have been carried out [8]. Normally, the incorporation of steel fiber changes the brittle failure mode of high strength concrete to more ductile [9].

Segregation problem related to the use of short discontinuous steel fibers have been encountered because the fibers have the ability to cling and nest together by interlocking which happens during mixing. This issue can be controlled manually using vibrating screens to disperse the discrete steel fibers in the concrete mix [8].

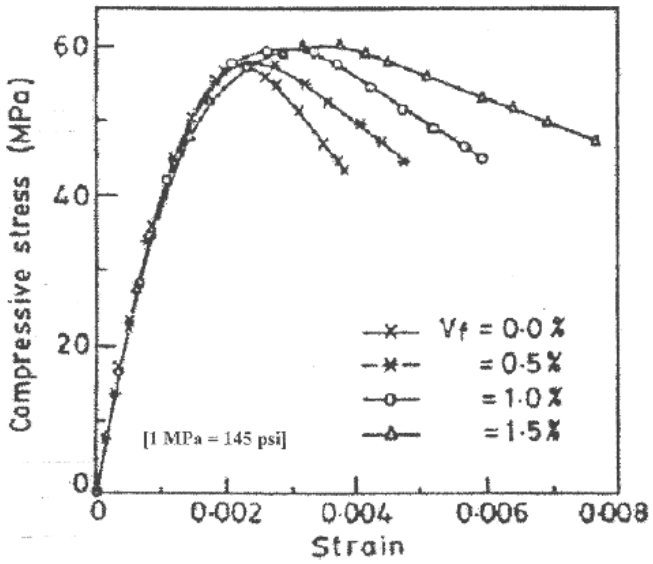

Figure 1. Effects of steel fiber on compressive stress-strain curve of fiber reinforced concrete [10]

The addition of steel fiber provides a little enhancement in the compressive strength of concrete when compared to normal reinforced concrete. The steel fibers have the tendency to increase the post cracking ductility [2]. Compressive strength is in the range of 40Mpa-85Mpa for steel fiber reinforced concrete [11]. The range of compressive strength for high strength steel fiber reinforced concrete

is between 60Mpa-90Mpa. Figure 1 shows the effects of steel fiber on compressive stress-strain curve of fiber reinforced concrete. The relationship between the duration of mixing, the mixing sequence, volume of steel fiber and the steel fiber geometry is found to have influence on the segregation of fiber during mixing.. The addition of steel fiber into the wet concrete matrix can avoid fiber agglomeration because if the mix is too dry or wet it can cause bundling of steel fibers [12]. In the range of 76 days, it have been indicated that the compressive strength of high strength steel fiber reinforced concrete gradually increases the maturity of the concrete in the range of 24%. [13].

Water reducing admixtures which is known as the super plasticizer can be added to improve the workability of a concrete during the mixing operation [14]. For the concrete which is containing steel fibers the amount or the volume of super plasticizer (SP) is used to maintain flow rate of fresh mortar mix at around 150mm-160mm to ensure good workability. The main purpose of super plasticizer is to control the water binder ratio and reduce the water content during mixing [14].

At the percentage range of 0.75% to 1% volume of steel fiber improves the ductility, confinement and the deformability of steel fiber reinforced concrete. Thus, there is no considerable effect on the modulus of elasticity of the concrete. The inclusion of steel fiber prevent sudden failure for reinforced concrete and composites columns [15]. The modulus of elasticity of concrete increases gradually with the increase in steel fiber volume due to higher modulus of elasticity of the steel fiber and will reduce the degree of shrinkage cracking. (Ming et al, 1997).

When cracking occurs as the concrete hardens, the steel fiber distributed evenly to block the crack. Thus, it contributes good strength to the concrete and with the inclusion of steel fibers [15]. Increase in the percentage of void ratio of fiber reinforced concrete is related to the or caused by the Inadequate compaction of the mixes. Incorporation of uniformly distributed short steel fibers increases the void content and the decreases the workability due to the cement based materials. The reason workability reduces is because of the surface area of the concrete resulting in the variation from the same mix [15].

The increase of pores volume in steel fiber reinforced concrete will raise the value of the corresponding ultrasonic-pulse velocity. In other words, when there is a decrease in the unit weight it will increase the ultra-pulse velocity of the concrete. Specimen that been tested for 28days, the average results that obtained for the ultra-pulse velocity is around 4543m/s for the control mixture or known as normal concrete. The relationship between the ultra-pulse velocity and the unit weight is existing in conventional concrete [16]

Increase of the water cement content ratio will improve and increase the workability of the steel fiber reinforced concrete. Increasing the sand content, decreasing the fiber diameter also the water cement ratio provide good workability on the concrete [15]. The advantage of using steel fibers increases the unit weight of the concrete with the volume of steel fibers used and the aspect ratio. The flexural strength increases with the addition of steel fiber and also

increases the tensile strength. The tensile strength is higher in the range of 11%-54% of the control mixture. Flexural strength of the steel fiber reinforced concrete is higher in the range of 3%-8% of the controlled mixture. The results for the flexural strength is always much more higher than the tensile strength [17].

S.Tokgoz (2012), concludes that the mechanical properties can be improved by the addition of steel fibers. The inclusions of steel fiber have prevented the crushing of concrete core, cover spalling and buckling of the reinforcement bar. It is been observed that this addition of steel fibers in the concrete reduces the buckling failure for both reinforced concrete and composite columns. Perhaps, the ultimate strength capacities and the load deflection curve provide a very good degree of accuracy on the theotherical results of both steel fibers and plain high strength reinforced concrete and also the composite columns. [17].

Three different types of fiber experiments have been conducted by Yao [14] which is the steel fiber, carbon fiber and the polypropylene fiber to provide the best in both mechanical and durability properties. Experiment was carried out and a result was obtained that Steel fiber gave the highest strength and polypropylene fiber gave the lowest compressive strength among all the three types of fiber. The amount of super plasticizer was used is until reach a amount of flow at 160mm. In this research, it is mentioned that the addition of steel fiber increases the modulus of rupture and the polypropylene gave the lowest modulus of rapture. The ductility characteristic improved in addition of steel fiber which resulted an increase in the flexural strength which was higher than the other type of fiber used. The usage of short fibers can provide good bridging to resist cracking propagation [14].

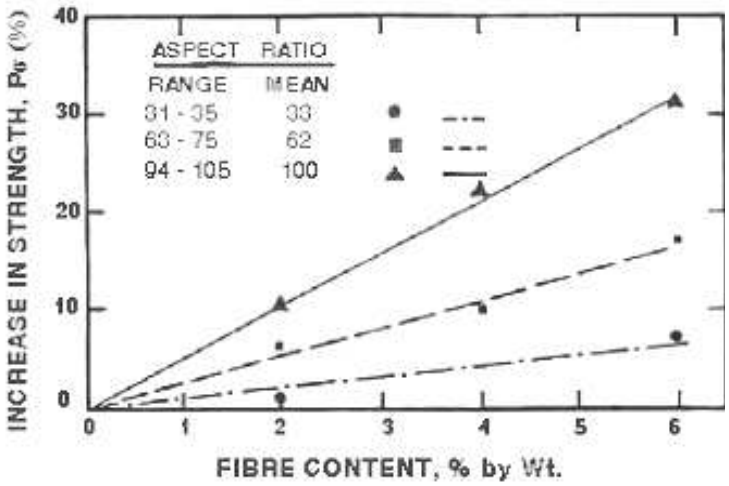

Figure 2. Influence of fibre content on tensile strength [17]

Steel fibre 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, as shown in Figure 2. Splitting-tension test show comparable result. Hence, adding fibres simply to increase the direct tensile strength is probably not worthwhile. Though, as in compression, steel fibres do lead to major increases in the post-cracking behaviour or toughness of the composites [12,14,17].

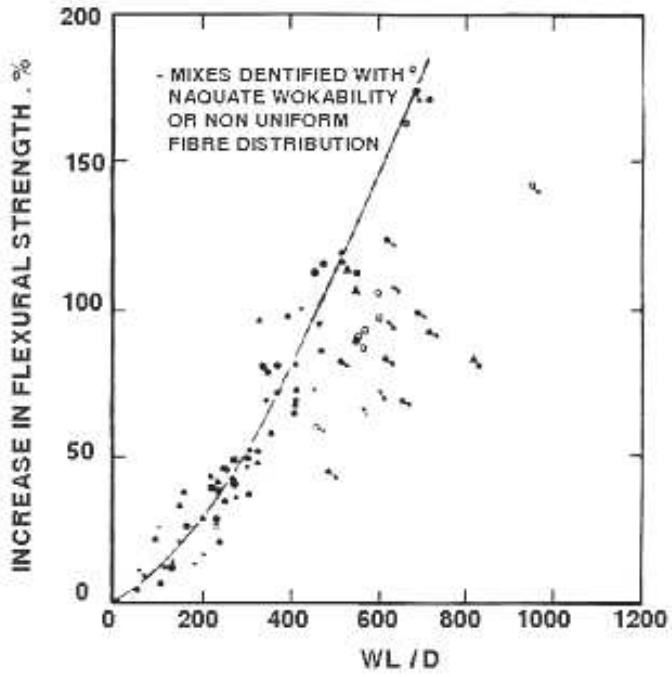

Figure 3. The effect of Wl/d on the flexural strength of mortar and concrete [18]

It should be pointed out that the steel fibre is commonly found to have aggregate much greater effect on the flexural strength of steel fibre reinforced concrete than on either the compressive or tensile strength, with increases of more than 100% having been reported. The increases in flexural strength are predominantly responsive, not only to the fibre volume, but also to the aspect ratio of the fibres, with higher aspect ratio leading to larger strength increases. Figure 3 visualizes the fibre effect in terms of the combined parameter Wl/d, where l/d is the aspect ratio and W is the weight percent of fibres. It should be noted that for Wl/d > 600, the mix characteristics tended to be quite inadequate. Deformed steel fibres show the same types of increases at lower volumes, because of their improved bond characteristics [17].

Several investigations on the influence of the materials and the mix proportion on the mechanical properties of the steel fiber reinforced concrete have been carried out. The potential strength capacities of steel fiber were much higher than other type of fiber and had increased the resistance of the reinforced composites. It is stated that there have been interfacial bonding between the fibers and the matrixes [18]. The relationship and the effects have been found between the sand content and the water-cement ratio on the ultimate flexural strength of fiber reinforced concrete. Which states that, at high water and cement ratio the increase in the sand content will definitely increase the flexural strength, where by at low water cement content ration there is no related significant change found on the flexural strength with change of sand content [18].

3. Workability properties

Major problem that is found in concrete is the segregation issue. Segregation is known as the separation between the water cement, aggregates and the fine sand which is unevenly distributed on the concrete throughout the mix. Segregation normally happened due to several factors such as over compaction during vibration of the mix or in other words excessive of vibration causes segregation where by causes the heavier composite settle at the bottom of the and the lighter composites settle on the top surface of the concrete. Besides that, improper vibration or less vibration also causes segregation to happen in the concrete [2,6].

Initially, due to this segregation problem the workability of the concrete will decrease and the surface structure of the concrete tends to be uneven as the concrete hardens. Segregation also occurs due to the effects or the volume of the water binder ration. Controlled or less water ration increases the workability of the concrete but the mixture must not be to dry and it will cause the mix to settle and hardened very fast and lead to segregation [7,11,16]. The flow of the concrete should be in the range of 150mm-160mm to avoid segregation and it is the best water content ratio to get high strength workability concrete. However segregation can be prevented by using the correct and suitable compaction technique [8, 16].

A particular fibre type, orientation and percentage of fibres, the workability of the mix decreased as the size and quantity of aggregate particles greater than 5 mm increased; the occurrence of aggregate particles less than 5 mm in size had little effect on the compacting characteristics of the mix. Figure 4 shows the effects of maximum aggregate size on workability [16]. The second factor which has a major effect on workability is the aspect ratio (l/d) of the fibres. The workability decreases with increasing aspect ratio, as shown in Figure 5, in practice it is very difficult to achieve a uniform mix if the aspect ratio is greater than about 100 [16].

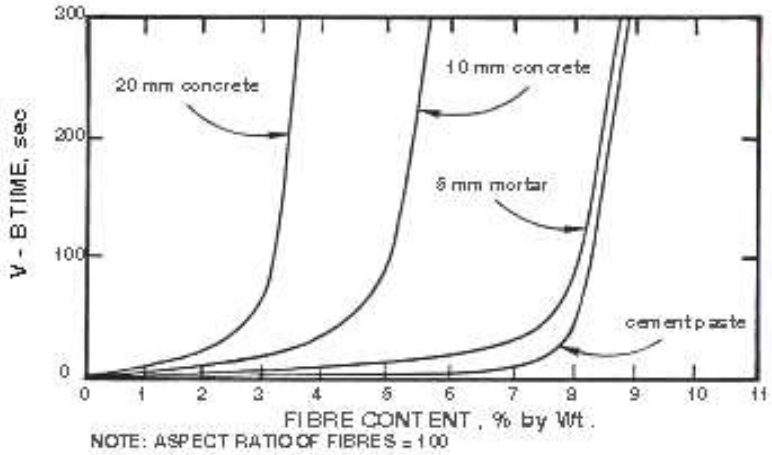

Figure 4. Workability-fibre content relationship for matrices with different maximum aggregate sizes [16]

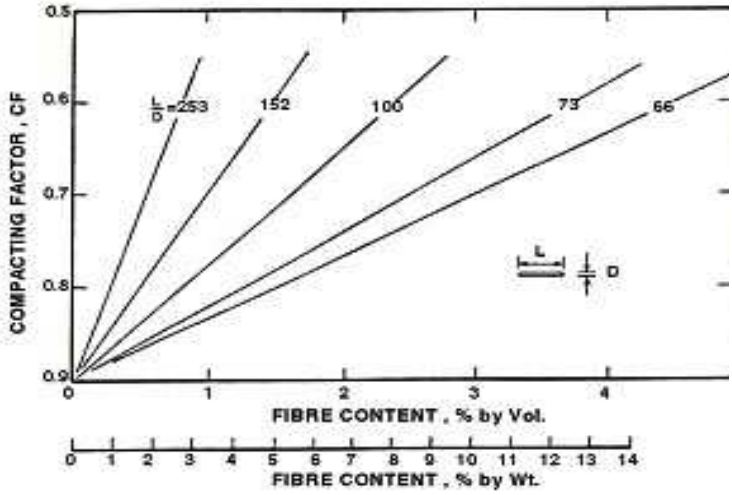

Figure 5. Effect of fibre aspect ratio on the workability of concrete, as measured by the compacting factor [16]

4. Durability properties

The ability of the concrete to resist chemical attack, weathering condition and abrasion to maintain its engineering properties is known as durability. Different types of concrete results different degree of durability. Besides that, to provide a better ultimate durability life for the concrete is affected by the ingredients of the concrete, the proportioning of the mixtures and also the interaction and the curing

method done. Steel fiber effect the durability of the concrete in the long term and is used to enhance the flexural strength, toughness and the shrinkage cracking of the concrete [2,8]

Permeability of the concrete refers to the ability of the substance or water to penetrate into the concrete. In other words, permeability can be defined as the ability that governs the rate of the flow of fluid to penetrate in to a porous solid. Permeability effect the durability of the concrete in the long term [19].

The curing duration has a significant is effect on the porosity value. This says that, as the day of curing increases the porosity value drops which mean that the porosity value for the 7th day curing testing result will be greater than the curing in the 28th day. This factor is related due to the hydration process of pores and voids which occurs to fill the capillary pores and reduces the permeability of the concrete. Steel fibers have the special characteristic and the ability to reduce the porosity of a concrete and this caused by the duration of the vibration which is taken place. In other word, the duration of the vibration to compact the concrete takes much longer for the steel fiber reinforced concrete compared to the normal controlled concrete. The volume of fiber been used and the length of fiber clearly influences in the porosity and the permeability. The results in this research states that high porosity does not mean it will result in high permeability [20].

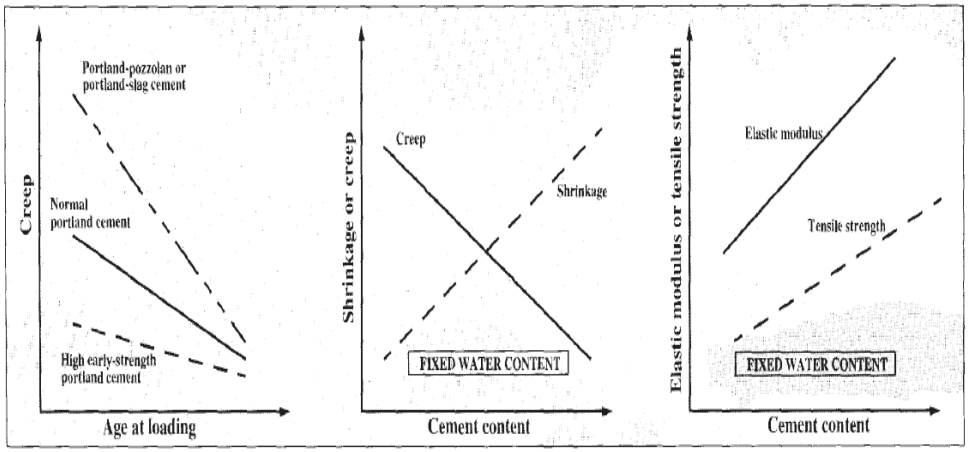

Figure 6. Relationship between the concrete strength and other properties of concrete [21]

High strength concrete contains more cement content and tends to shrink more. The usage of the Portland cement and the reduction in the water content (*w/c*) increase the strength of the concrete. Once it increases the strength, the elastic modulus of the concrete also increases where by reduces the creep coefficient. This is why the tendency of the high strength concrete is more prone than the low strength concrete. Figure 6 shows the relationship between the

concrete strength and other properties, combination of the thermal and drying shrinkage which causes cracks in concrete, not the vibration of the mix and the hardening process of the concrete. Therefore, proper balance of the cement content which should be not too low and not too high should be maintained to produce concrete which is not prone to cracking and provide good durability for the long term and mechanical properties. Besides that, Portland cement contain cement content of 400kg/m3 or more to provide a very durable long term high strength concrete [21].

The cracking mechanism of steel fiber reinforced concrete resulted in the improvement of strength, stiffness, ductility and also the thermal loading [21]. Figure 7 shows the effect of short and long steel fibers on the macro and micro cracking. There are three major factors on crack controlling property on the behavior of steel fiber reinforced concrete which produces a:

- Well defined post cracking behavior of the fibers to the composites.
- The cracks increase greater toughness and the ductility to the composite prior to failure.
- Onsets of the flexural cracking delayed by steel fiber during the first crack and increase the tensile strain.

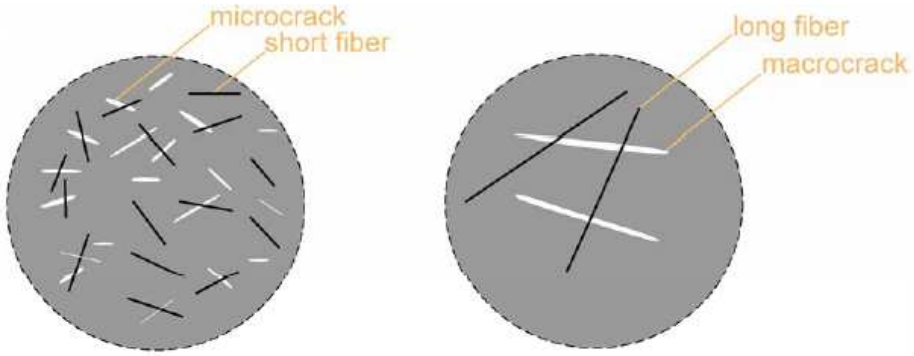

Figure 7. Effects of short and long steel fiber on the micro cracking and macro cracking [21]

3. Conclusion

This paper summarizes three main properties of of steel fibre reinforced high strength concrete which are mechanical, workability and durability properties. As been discussed, the investigation on the introduction of effect of steel fibres could be still promising as steel fibre reinforced concrete is used for sustainable and long-lasting concrete structures. Steel fibres are extensively used as a fibre reinforced concrete all over the world. Lot of research work had been done on steel fibre reinforced concrete and lot of researchers work prominently over it. This review study tried to focus on the most significant effects of addition of steel fibers

to the concrete mixes on the three properties mentioned previously. The steel fibres are frequently utilized fibre for fibre reinforced concrete out of available fibres in the current market. According to many researchers, the addition of steel fiber into concrete creates low workable or inadequate workability to the concrete, therefore to solve this problem of superplasticizer without affecting other properties of concrete may introduce.

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