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RESEARCH ARTICLE

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EXPERIMENTAL STUDY ON STEEL FIBRE REINFORCED CONCRETE

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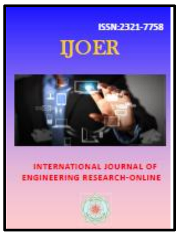

ABSTRACT
Concrete plays a major role in the construction industry. However, concrete is weak in tension, in order to overcome this, normally reinforcements are used in construction. But these reinforcements won't be able to stop initiating tensile cracks and other defects in concrete. Aim of this study is to find the optimum volumetric percentage of steel fibre required to increase the tensile strength of concrete with laboratory experiments. For that, seven groups of grade 30 concrete were produced with the addition of steel fibres at different volumetric percentages: 0% (as a control specimen), 0.77%, 0.86%, 0.93%, 1.00%, 1.07% and 1.47% by absolute weight of concrete. Steel fibres with aspect ratio, l/d = 50 with 0.50 mm diameter and hooked at both ends, were used in this study. The effects of adding Steel fibres in concrete were measured for the cube compressive strength (fcu) and splitting tensile strength (f ct). Result data clearly shows higher percentage increase in 7 and 28 days compressive strength and tensile strength for 0.86% steel fibres added concrete.
Keywords—Steel fibre; mechanical properties; normal weight concrete;

I. INTRODUCTION

Concrete is the most commonly used material for civil engineering works because it promises a lot of advantages. Concrete itself can be cast in any shape, has excellent resistant to water and high temperature, requires less maintenance are some of the obvious advantages. Also it is one of the most economical materials in the industry. Yet brittle failure and associated creep and drying shrinkage, which lead to cracking problems limits the application of the material. This can be overcome by the inclusion of a small amount of short randomly distributed fibres (steel, glass, synthetic and natural). Fibre reinforced concrete (FRC) is cement based composite material that has been developed in recent years. According to [1], "Among the fibres being used for concrete reinforcement steel fibre is the most commonly used fibre (50% of the total tonnage used) followed by polypropylene (20%), glass (5%), and other fibres (25%)".

The concept of using fibres to concrete is very rare although the modern development of Fibre Reinforced Concrete (FRC) started in early sixties. Fibre reinforced concrete (FRC) may be defined as a composite material made with OPC, aggregates and incorporating discrete discontinuous fibres. Fibres are produced from different materials in various shapes and sizes from typical fibre materials. Fibre reinforced concrete has been successfully used in ground bearing floor slabs, architectural panels, structures in seismic regions, thin and thick repairs, heavy duty pavements for airports, docks and harbours, tunnel linings and many other applications because of its excellent flexural – tensile strength, resistance to splitting, impact resistance and excellent permeability [2]. For FRC to be a viable construction material, it must be able to compete economically with existing reinforcing system.

Main reason for selecting steel fibre is; it has higher modulus of elasticity than concrete. Generally, if the modulus of elasticity of the fibre is higher than the matrix, they help to carry the load by increasing the tensile strength of the material. Advantages of steel fibre reinforced concrete (SFRC) [3] are:

1. High performance and crack resistance
2. Fast and perfect mixable fibres
3. It improves the toughness characteristics of the hardened concrete.
4. Ensure protection of concrete due to ill effects of moisture by reducing the permeability and water Migration in concrete.

Disadvantage of steel fibre reinforced concrete (SFRC):

1. Very high cost for steel fibres.
2. Uniform distribution of steel fibres can't be obtained because steel fibres have higher tendency to ball or clump together.
3. Adverse effect on the workability of the fresh mix.

Theoretically, there are three (3) parameters which Influence the mechanical properties of steel fibre reinforced concrete [4];

1. Steel fibres itself by considering type, geometry, aspect ratio, volume fraction, orientation and distribution of Steel fibres in concrete.
2. Matrix by considering strength and maximum aggregate size used, water/cement ratio, type of cement and supplementary cementitious material.
3. Specimen by considering the size, geometry, and method of preparation of the specimen.

Therefore, this study is conducted to achieve several objectives

1. To study the mechanical properties of SFRC with super plasticizer i.e. compressive strength and splitting tensile strength of grade 30 concrete with 7 different steel fibre volumetric percentages of 0%, 0.77%, 0.86%, 0.93%, 1.00%, 1.07%, and 1.43%.
2. To determine the mechanical properties and cost benefits of SFRC.

II. LITERATURE REVIEW

In the past decades, fibres have been used to reinforce brittle materials. Most recently asbestos fibres were used. But it was considered as a harmful substance. Reinforcing a brittle matrix with discrete fibres is an old concept. Modern era use of fibres was started in early 1960s [5]. In the early days only straight steel fibres were used. It was found out major improvement occurred in the areas of ductility and fracture toughness. Also flexural strength increases were also reported. The law of mixture was applied to analyze the fibre contributions. Later some of the researches identified fibre reinforced concrete can be designed to obtain a specific ductility or energy absorption [6]. Even the patents have been granted since the turn of the century for various methods of reinforcing concrete with steel, until late 1950s developing SFRC technology was not concerned. Still that time steel fibres have been optimized to some extent for incorporation into concrete.

Fibre reinforcement is in the form of short discrete fibres, so they act effectively as rigid inclusions in the concrete matrix. Physically they behave same as aggregate inclusions; therefore steel fibre reinforcement cannot be concluded as a direct replacement of longitudinal reinforcement in reinforced or prestressed structural members. However to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions using steel fibre reinforcement in concrete is a best solution.

If fibres are properly bonded in the hardened stage it will interact with the matrix at the level of micro-cracks and make effective bridge in concrete material to stress transfer, this will delay the unstable growth of crack up to a greater extent. If the fibre volume fraction is sufficiently high, increase in tensile strength is sufficiently high. Depending on fibre length and bonding characteristics it will restrain crack opening and crack growth even if they reach the tensile capacity of the composite by effectively bridging across macro-cracks [7].

The basic problem in SFRC is producing uniformly distributed steel fibres with sufficient workability in the fresh mix to permit proper mixing, placing and finishing. The performance of the hardened concrete is enhanced more by fibres with high aspect ratio; since this improves the fibre-matrix bond but high aspect ratio adversely affects the workability of the fresh mix. In general, the problems of both workability and uniform distribution increase with increasing fibre length and volume [8].

Obtaining uniform fibre distribution may be disturbed by tendency for steel fibres to ball or clump together. According to [8] clumping may be caused by the following factors:

1) The fibres may already be clumped together before they are added to the mix; normal mixing action will not break down these clumps.
2) Fibres may be added too quickly to allow them to disperse in the mixer.
3) Too high a volume of fibres may be added.
4) The mixer itself may be too worn or inefficient to disperse the fibres.
5) Introducing the fibres to the mixer before the other concrete ingredients will cause them to clump together.

As recommended by [9], "when used in structural applications, steel fibre reinforced concrete should only be used in a supplementary role to inhibit cracking, to improve resistance to impact or dynamic loading, and to resist material disintegration. In structural members where flexural or tensile loads will occur the reinforcing steel must be capable of supporting the total tensile load" and also [10] observed that the optimum volumetric percentages of SF dosages must be in the range between 0.75% and 2.0%. Obviously, SF dosages higher than 2% become ineffective because of the physical difficulties in providing a homogenous distribution of Steel fibres throughout the structural members.

By considering technical, economical and practical facts for this study selection of steel fibre dosage is based on the industrial practices. For being economically feasible, in the industry fibre volumetric percentage should be less than 2%. So during this study it was maintained up to 1.47%. Fibre dosage selection was based on its length in this study because this is the common practice in the industry. According to the manufacturers 2.9 km recommendation length of steel fibre is 10 kg. To overcome the clumping following steps were carried out during the mixing of concrete

1. Steel fibres were washed by water and separated.
2. Fibres added into the mixer in constant and nominal speed.
3. Volume of fibres is maintained in an acceptable range.
4. Introducing the fibres to the mixer after the other concrete ingredients were added and mixed.

III. RESEARCH METHODOLOGY

As with any other type of concrete, the mix proportions of SFRC depend upon the requirements for a particular job, in terms of strength, workability, and so on. In this study, workability of concrete mix was maintained in a specified range. For that purpose water and admixture content were added during the experiment and by measuring the slump of fresh mix it was ensured. Plain and SF added concrete are created with similar performance but with different proportion of ingredients.

Seven different concrete mixes were used in this study. Mix proportion for each mix is given in compressive strength (Figure 1) and cylindrical concrete samples of long for splitting tensile Strength (Figure 1). The type of Steel fibres used in the study has a diameter of 0.75 mm and 60 mm long hooked ends, giving an aspect ratio (l/d) of 80.

The method of concrete mix design for plain concrete with no steel fibre dosage was according to the BRE Design of normal concrete mixes. The controlled slump of fresh concrete was in the range of 60 – 180 mm and super plasticizer was added during the mixing process in order to increase the workability of fresh concrete. Water dosages were adjusted at the mixing time by checking slump of mix. Slump test was carried out according to the BS 1881-102:1983. Steel fibres were added last to the fresh concrete in the drum mixer during the mixing process.

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Table – 1. These mixes were designed to achieve same concrete grade -30 with different dosage of steel fibres and admixtures.

No	Cement (kg)	Water (kg)	W/C	Fine aggregates (kg)	Coarse aggregates(kg)	Fibre (kg)	Admixtures (l)
	370	145	0.39	780	1095	-	3.71
	370	165	0.44	780	1095	18.86	3.71
	350	130	0.37	800	1080	20.62	3.54
	350	140	0.4	800	1080	22.33	3.67
	350	140	0.4	800	1080	24.15	3.85
	350	150	0.43	800	1080	25.83	3.85
	350	140	0.4	800	1080	34.46	4.23

Six cubes and six cylinders were cast for each batch and compacted. All samples were cured in water until the test day i.e. 7 and 28 days. The method of testing in compressive strength (figure 2) and splitting tensile strength (figure 3) were in accordance with BS 1881-115:1983 and BS 1881-117:1983.

Fig. 1. Cube and Cylinder specimens

Fig. 2. Digital compression testing machine

Fig. 3. Splitting tensile testing machine

IV. RESULTS AND OBSERVATION

The results of compressive strength and split tensile strength study are given in Tables 2 and 3 for different concrete mixes at 7 days and 28 days respectively. Results are presented in graphical form in figures 4 and 5

TABLE 2 COMPRESSIVE STRENGTH OF CUBES

	Compressive strength	
Mix	7 days	28 days
	(MPa)	(MPa)
1	37.6	55.4
2	32.4	41.2
3	54.9	61.4
4	45.2	50.8
5	42.4	53
6	40.2	44.5
7	31.9	42.3

TABLE 3 SPLITTING TENSILE STRENGTH OF CYLINDERS

	Tensile strength	
Mix	7 days	28 days
	(MPa)	(MPa)
1	1.44	2.04
2	2.9	3.05
3	3.24	3.54
4	2.91	3.09
5	2.84	3.02
6	2.43	2.71
7	2.49	3.14

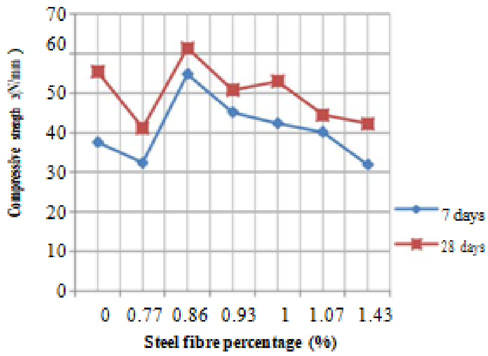

Fig. 4. Relationship between compressive strength (fcu) and steel fibre percentage (%)

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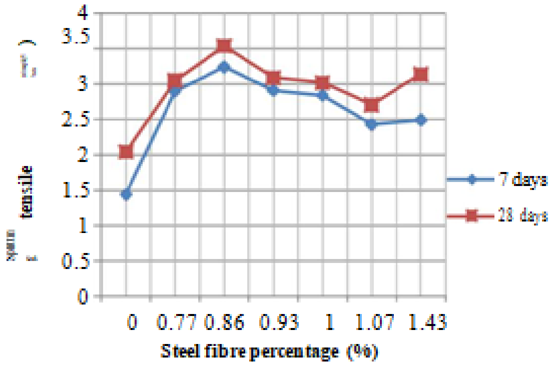

Fig. 5. Relationship between splitting tensile strength (fct) and steel fibre percentage (%)

For the cost calculations cement, sand and coarse aggregate prices were taken from the BSR 2015 Western province and fibre and admixture prices were given by the supplier (Table 4). Cost/tensile strength of each mix are tabulated in Table 5 and graphically represented in Figure 6.

It has been seen, that adding steel fibres to plain concrete can increase the splitting tensile strength, post cracking resistance and ductility. The steel fibres when uniformly dispersed throughout the specimens, acting as a reinforcement and help for better distribution of stresses. This uniform distribution was checked in each and every cylinder specimens by breaking them into two pieces. All along the specimens Steel fibres is uniformly distributed all most all the time (Figure 7). Therefore, the cracks occurred in SFRC specimens are smaller in size when compared with plain concrete.

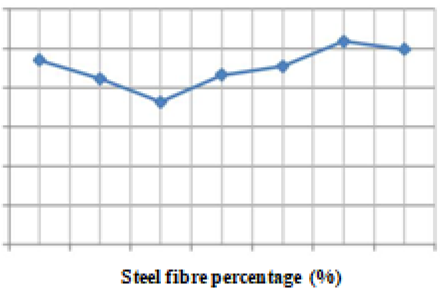

Fig. 6 Relationship between Cost/tensile strength and steel fibre percentage (%)

Smaller cracks occurred in SFRC cubes compared to plain concrete cubes. Also plain concrete cube samples failed as illustrated in the code of practice as shown in figure 8 and the samples with SRFC were although had cracks they were intact as shown in figure 9.

During the splitting tensile strength test two types of failures were observed in cylindrical specimens. For plain concrete, cylindrical specimens were completely split into two parts as shown in figure 10, but for SFRC there was only a single crack line occurred on the cross section starting from top to bottom of loading plate and this crack line continued along the length of the cylindrical specimen as shown in figure 11.

Fig. 7 Steel fibres distribution of cylinder specimen

Fig. 8 Failure of plain concrete

Fig. 9 Failure of SFRC Cube

Fig. 10 Failure of plain concrete Cylinder

Fig. 11 Failure of SFRC Cylinder

CONCLUSIONS AND RECOMMENDATIONS

1) It is observed that compressive strength and splitting tensile strength are higher side for 0.86% fibres as compared to that produced from 0.77%, 0.93%, 1.00%, 1.07% and 1.47%.
2) Change in splitting tensile strength with addition of steel fibres is highly significant compared to plain concrete strength.
3) Change in compressive strength with addition of steel fibres is insignificant compared to plain concrete strength.
4) When considering the mix proportions results data clearly shows that which mix (mix with SFRC 0.86%) has minimum water/cement ratio (0.37) have higher increase in splitting tensile strength and compressive strength.
5) Considering cost factors in range of 0.77% to 1.47% doesn't deviate much from plain concrete price. But it for 1N/mm2 0.87% has a lesser cost than other mixes.

It is recommended to study for other grades of concrete with different types of fibres, different water/cement ratio, with different aggregates and different dosages of super plasticizers. Factors affecting splitting tensile strength were fibre geometry, fibre volume, type of fibre and water/cement ratio so these should be checked with different mixes. Along with compressive strength and splitting tensile strength it is better to take account for flexural strength and modulus of elasticity of different mixes.

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