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Studies on Steel Fibre Reinforced Concrete – A Sustainable Approach

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Abstract— There is a growing awareness of the advantages of fibre reinforcement techniques of construction all over the world. Even though concrete possesses several desirable properties, its relative low tensile strength and deformation properties prompted many researchers to work on to improve these properties. One such development of improving or modifying the brittle characteristics of concrete is by supplementing the concrete matrix with fibre reinforcement. Steel Fibre Reinforced Concrete has become very popular due to its exceptional mechanical performance compared to the conventional concrete.

The concrete is considered to be the second in consumption by mankind, first being the water. The manufacture of cement and steel causes several adverse impacts to the environment. It is inevitable to think about sustainable development by reducing the wastes generated or reusing it. This paper aims to have a comparative study between ordinary reinforced concrete and steel fibre reinforced concrete. The fibres which were used in the study were the turn fibres. They were the scraps from the lathe shops. Experimental investigations and analysis of results were conducted to study the compressive & tensile behaviour of composite concrete with varying percentage of such fibres added to it. The concrete mix adopted were M20 and M30 with varying percentage of fibres ranging from 0, 0.25, 0.5, 0.75 & 1%. On the analysis of test results the concrete with turn steel fibres had improved performance as compared to the concrete with conventional steel fibres which were readily available in market. These sustainable improvements or modifications could be easily adopted by the common man in their regular constructions.

Index Terms— Steel Fibre, Turn fibres, Compressive strength, Tensile strength, Sustainable.

1 Introduction

FIBRE reinforced concrete is relatively a new construction material developed through extensive research and development work during the last two decades. It has already found a wide range of practical applications and proved to be a reliable construction material having superior performance characteristics compared to conventional concrete. Incorporation of fibre in concrete has found to improve several properties like tensile strength, cracking resistance, impact and wear resistance, ductility and fatigue resistance. Many fibres like asbestos, steel, nylon, coir, etc have been used in the past. Out of these asbestos fibres concrete is successful, although its exposure is detrimental to the health of human beings. Steel fibres improve ductility, flexural strength and toughness. Corrosion damage and increased density are the drawbacks of the steel fibres.

Further development in the field of fibre reinforced concrete was due to introduction of high strength fibres like glass and carbon fibres. The initial studies showed deterioration of glass fibres due to corrosive alkali environment of the cement paste. The alkali resistant glass fibre, which is developed, recently has overcome this defect and can be effectively used in concrete. Steel Fibre Reinforced Concrete (SFRC) has an untapped potential application in building frames due to its high seismic energy absorption capability and relatively simple construction technique. To tap such potential, the existing body of knowledge on SFRC must be expanded to provide a proper basis for officials to add this method of construction to the provisions of the building code. The purpose of this research is to expand the body of knowledge on the application of SFRC. By adding fibres made of steel to reinforced concrete the joint is toughened which enables the structure to be more durable. The concrete is considered to be the second in consumption by mankind, first being the water. The manufacture of one tonne of cement releases approximately one tonne of carbon dioxide to the atmosphere. The steel industry also produces such impacts to the environment. Thus it is high time to think about sustainable development and reduce the wastes generated or reuse it. This paper aims to have a comparative study between ordinary reinforced concrete and steel fibre reinforced concrete thereby adding to that body of knowledge through experimental investigation and analysis by performing tests on steel fibre incorporated cubes & cylinders and motivating sustainable development.

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2 Literature Review

Concrete is one of the most versatile building materials. It can be cast to fit any structural shape from ordinary rectangular beam or column to a cylindrical water storage tank in a high-rise building. It is readily available in urban areas at relatively low cost. Concrete is strong under compression but weak under tension. As such, a form of reinforcement is needed. The most common type of concrete reinforcement is by steel bars. The advantages in using concrete include high compressive strength, good fire resistance, high water resistance, low maintenance, and long service life. The disadvantages in using concrete include poor tensile strength, and formwork requirement. Other disadvantages include relatively low strength per unit weight. Tensile strength of concrete is typically 8% to 15% of its compressive strength[6]. This weakness has been dealt with over many decades by using a system of reinforcing bars (rebars) to create reinforced concrete; so that concrete primarily resists compressive

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stresses and rebars resist tensile and shear stresses. The longitudinal rebar in a beam resists flexure (tensile stress) whereas the stirrups, which are wrapped around the longitudinal bar not only holds the longitudinal bars in position but also resist shear stresses. In a column, vertical bars resist compression and buckling stresses while ties resist shear and provide confinement to vertical bars. Cracks in reinforced concrete members extend freely until encountering a rebar and this is where the need for multidirectional and closely spaced reinforcement for concrete arises[9].

Reinforced bars (rebars), reinforcement grids, plates or fibres both organic and inorganic as well as composites have been incorporated to strengthen the concrete in tension. Steel fibre reinforced concrete (SFRC) comprises cement, aggregates and steel fibres. Steel fibre reinforcement cannot be regarded as a direct replacement of longitudinal reinforcement in reinforced and prestressed structural members. In tension, SFRC fails only after the steel fibre breaks or is pulled out of the cement matrix[1]. Properties of SFRC in both the freshly mixed and hardened state, including durability, are a consequence of its composite nature. The mechanics of fibre reinforcement which strengthens concrete or mortar is a continuing research topic. One approach to the mechanics of SFRC is to consider it as a composite material whose properties can be related to the fibre properties (volume percentage, strength, elastic modulus, and a fibre bonding parameter of the fibres), the concrete properties (strength and elastic modulus), and the properties of the interface between the fibre and the matrix.

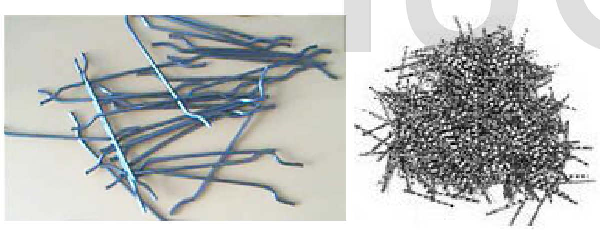

Fig 2.1 Steel Fibres
(Source: www.stewols.com)

Fibres are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibres produce greater impact, abrasion and shatter resistance in concrete. Generally fibres do not increase the flexural strength of concrete, and so cannot replace structural steel reinforcement. If the modulus of elasticity of the fiber is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. However, fibres which are too long tend to "ball" in the mix and create workability problems[4].

2.1 Fiber Properties

The fibre strength, stiffness, and the ability of the fibres to bond with the concrete are important fibre reinforcement properties. Bond is dependent on the aspect ratio of the fibre[6]. Steel fibres have a relatively high strength and modulus of elasticity. They are protected from corrosion by the alkaline environment of the cementitious matrix, and their bond to the matrix can be enhanced by mechanical anchorage or surface roughness[2]. Long term loading does not adversely influence the mechanical properties of steel fibres. In particular environments such as high temperature refractory applications, the use of stainless steel fibres may be required. Various grades of stainless steel, available in fibre form, respond somewhat differently to exposure to elevated temperature and potentially corrosive environments.

2.2 Manufactured Steel Fibres & Turn Steel Fibres

Round, straight steel fibres are produced by cutting or chopping wire, typically wire having a diameter between 0.25 to 1.00 mm. Flat, straight steel fibres having typical cross sections ranging from 0.15 to 0.64 mm thickness by 0.25 to 2.03 mm width are produced by shearing sheet or flattening wire. Crimped and deformed steel fibres have been produced with both full-length crimping, or bent or enlarged at the ends only. Some fibres have been deformed by bending or flattening to increase mechanical bonding. Some fibres have been collated into bundles to facilitate handling and mixing. During mixing, the bundles separate into individual fibres.

Fibres are also produced from cold drawn wire that has been shaved down in order to make steel wool. The remaining wires have a circular segment cross-section and may be crimped to produce deformed fibres. Also available are steel fibres made by a machining process that produces elongated chips. These fibres have a rough, irregular surface and a crescent-shaped cross section.

Steel fibres are also produced by the melt-extraction process. This method uses a rotating wheel that contacts a molten metal surface, lifts off liquid metal, and rapidly solidifies it into fibres. These fibres have an irregular surface, and crescent shaped cross-section.

In this study the scraps from the lathe shops are used as the steel fibres. These fibres are of various types having various properties. The fibres need to be segregated as it contained all categories in which some were even brittle. Majority of the fibres were spiral which resembled springs while some were straight. The distribution of fibres was random.

3 Casting and Testing

Casting and testing of concrete cubes, cylinders, beams were done as per IS code recommendations. The proportioning of concrete mixes consists of determination of the quantities of respective ingredients necessary to produce concrete having adequate, but not excessive, workability and strength for the particular loading and durability for the exposure to which it will be subjected. Emphasis is laid on making the most economical use of available materials so as to produce concrete of the required attributes at the minimum cost. The basic assumption made in mix design is that the compressive strength of workable concrete is governed by the water cement ratio. The concrete mix adopted was M20 and M30 concrete with varying percentage of fibres ranging from 0, 0.25, 0.5, 0.75 & 1%. Even though the mix design need not be done for the basic mixes of M20 it was verified by designing it as per the quality of the material and other conditions. The M30 concrete mix design was carried out by incorporating the fly ash (along with cement) as the cementitious material which was generally adopted by many RMC plants widely.

Table 3.1 Mix proportion of M20

Free Water	Cement	FA	CA
191.5	383kg	572.1kg	1161.6kg

Table 3.2 Mix proportion of M30

Free Water	Cement & FA	FA	CA
163	300kg+100kg	622 kg	1227 kg

Nominal concrete cubes (15 cm x 15 cm x 15 cm), concrete cylinders (15 cm diameter and 30 cm long). A mixture of irregular and crimped shaped fibres (3cm - 4cm length) were mixed with the aggregate while casting the specimens, it was made sure that fibres were uniformly distributed throughout the mix.

3.1 Overview of Tests

Tests were conducted on concrete cubes using varying percentage of fibres to check for variations in compressive strength. Tests were conducted on concrete cylinders using varying percentage of fibres to check for variations in splitting tensile strength. For conducting the tests of compressive strength, two sets of ten cubes each of M20 & M30 mix were cast without fibres. Later, different sets of cubes were cast with fibre content ratio as 0.25%, 0.5% and 0.75%. The cubes were then transferred to curing tank for the required period of curing and tested. The results of compressive strength of M20 & M30 grade concrete cubes on 7th and 28th day are as tabulated in table 3.3 and table 3.4 below.

Table 3.3 Compressive strength of M20 grade concrete cubes

Fibre content (%)	7th Day		28th Day	
	Mean Load (kN)	Compressive strength (N/mm^2)	Mean Load (kN)	Compressive strength (N/mm^2)
0%	510.6	22.69	581.48	25.84
0.25%	458.8	20.39	463.14	20.58
0.5%	490.5	21.80	558.98	24.84
0.75%	482.6	21.45	556.16	24.71

Table 3.4 Compressive strength of M30 grade concrete cubes

Fibre content (%)	7th Day		28th Day	
	Mean Load (kN)	Compressive strength (N/mm^2)	Mean Load (kN)	Compressive strength (N/mm^2)
0%	694.58	30.87	885.68	39.36
0.25%	641.92	28.5	794.2	35.29
0.5%	669.68	29.76	845.3	37.57
0.75%	655.18	29.12	824.98	36.67

There was no significant improvement in the results of the compressive strength as in the case of other conventional fibres. But as a part of the study, for conducting the tests of splitting tensile strength, the cylinders were cast in the cylindrical mould of size 15 cm diameter and 30cm height. Two sets of ten cylinders of M20 and M30 mix were cast as control specimens. Later, different sets of cylinders were cast, with fibre content ratio as 0.25%, 0.5%, 0.75% & 1%. Fibres were evenly distributed throughout the concrete mass. The cylinders were then, on the second day of casting, transferred to curing tank for a period of 7 days and 28 days and tested. The results of splitting tensile strength of M20 & M30 grade concrete cubes on 7th and 28th day are as tabulated in table 3.5 and table 3.6 below.

Table 3.5 Splitting Tensile Strength of M20 grade concrete cylinders

Fibre content (%)	7th Day		28th Day	
	Mean Load (kN)	Split Tensile strength (N/mm^2)	Mean Load (kN)	Split Tensile strength (N/mm^2)
0%	70.3	0.99	167.8	2.373
0.25%	118.8	1.68	175	2.476
0.5%	153.2	2.167	201	2.844
0.75%	110.8	1.528	186.4	2.637
1%	104.6	1.48	171	2.419

These results were very significant as it was at par with the results of the conventional fibres readily available in the market.

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Table 3.6 Splitting Tensile Strength of M30 grade concrete cylinders

Fibre content (%)	7th Day		28th Day	
	Mean Load (kN)	Split Tensile strength (N/mm²)	Mean Load (kN)	Split Tensile strength (N/mm²)
0%	89.2	1.262	183.8	2.6
0.25%	125.2	1.77	203	2.87
0.5%	140	1.98	224.4	3.17
0.75%	107.2	1.52	198.2	2.8
1%	98.8	1.39	189.6	2.68

Based on the experimental results the following observations were made:-

i. Significant increase in compressive strength was not obtained by the addition of turn steel fibres in concrete.
ii. The splitting tensile strength of plain concrete is improved by 20% for M20 concrete and 22% for M30 concrete by the addition of turn steel fibres.
iii. The M30 grade concrete mix design the cement content was partially replaced by Flyash.

4 Discussions

As the exploitation of the nature and natural materials had increased exponentially, new thoughts of recycling the wastes is the only way to preserve the nature. The above results are at par with the studies of conventional materials readily available in market. Several steel fibres that are commercially available in market were confined to the experimental or research needs. It is not commonly used by the human kind as the knowledge of adopting the same is still vague, even though much research on this subject had occurred in past two to three decades. The experimental procedures that were done and described in this paper could be adopted by the man kind as it proves to be better than ordinary grade of concrete that they adopt for their regular construction. The results of splitting tensile strength were to be encouraged as those could help the common man to sustain themselves even in adverse conditions of earthquakes. It was observed that the addition of steel fibres to the concrete increases the properties of concrete up to a certain limit. The fiber can work at both a micro and macro level. At a micro level fibres arrest the development of micro cracks, leading to higher flexural and tensile strengths, whereas at a macro level fibres control crack opening, increasing the energy absorption capacity of the composite. From the investigation, it was clear that 0.5% fibre content has a pronounced effect on the properties of concrete. Further increase in fiber content tends to be ineffective. Fibres added in higher volume fraction reduces workability of mixes as they clump together and tend to "ball". It results in higher presence of voids. Hence an optimum percentage of fibre content is always preferable.

5 Conclusions

The variation of direct compressive strength for concrete cubes was found to be inconsistent with the increase in percentage of fibres. The splitting tensile strength was increased by 20-22% for concrete cylinder samples with 0.5% fibre content in M20 and M30 Grade concrete mixes. Much research on readily available fibres was conducted with an additional input of cost for the purchase of fibres. But these tests were thus a true example of sustainable development as the recycling of scraps from lathe shops is done to improve the behavior of concrete and also the cement content was partially replaced by fly ash in higher grade concrete.

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