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A Review Paper Presenting an Overview of Various Tests Conducted in the Field of Steel Fibre Reinforced Concrete

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Abstract- Concrete has a high compressive strength but a low tensile strength, which is well known in the civil engineering community. This is the main cause of sudden/brittle failure in concrete. The material is unable to slowly stretch out and give sufficient warning and time for evacuation before failing. This is the main reason why steel is widely used in the tensile zone of reinforced concrete sections to make up for its lack of tensile strength. In recent years, the concept of composite materials came into being, and fibre-reinforced concrete (FRC) was one of the topics of interest1. It showed fascinating advantages when compared to plain and reinforced concrete, thus leading to increased research regarding it. The purpose of this paper is to review and summarise open-source papers published since 2011 presenting various tests conducted on steel fibre reinforced concrete, conduct a gap analysis on the results if possible, and identify the future scope of further research in the field.

Keywords- Fibre Reinforced Concrete (FRC), Steel Fibre Reinforced Concrete (SFRC), mechanical properties, properties, crack, ductility, fibres, steel fibres, concrete, reinforced concrete, thermal properties, impact energy, failure, compressive strength, workability, strengths, fatigue behaviour, critical shear displacement, shear strength, split tensile strength, flexural strength, magnetic field.

I. INTRODUCTION

Fibre-reinforced concrete (FRC) is concrete containing fibrous material that increases its structural durability. It contains short freefibres that are uniformly distributed and randomly oriented1 as shown in the figure below:

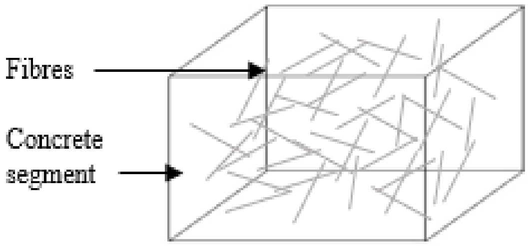

Fig 1.

Variedresearch done in this field led to the conclusion that the characteristics of fibre-reinforced concrete change with varying concretes, fibre materials, geometries, distribution, orientation, and densities1.

The fibres will be our main concern. Their primary function in concrete reinforcement is to prevent crack spread by applying pinching stress at the fracture tip, which raises the composite mix's ultimate cracking strain relative to the unreinforced mix.6To achieve this, FRCs use different types of fibres, some of the most common ones being:

1. Polypropylene fibres:
One of the cheapest and most readily accessible fibres, are employed in small volume fractions (0.5 to 15 in concrete)in the industry because they are hydrophobic, resistant to most solvents, and have a melting point of about 165 °C.

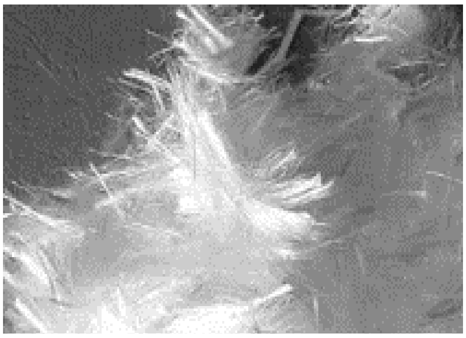

Fig 2.

2. Glass fibres–These are made of separate filaments of glass, each of which is delicately threaded to form a strand. The strand is then cut into pieces of varying lengths or joined together to create fabric rugs, mats, tapes or ribbons.

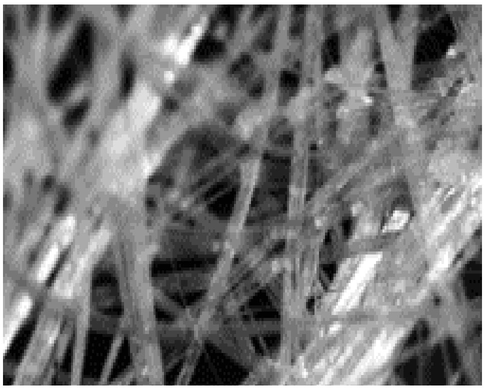

Fig 3.

3. Carbon fibres:

It has a very high elasticity and flexural strength modulus. Although they have strength and rigidity that is significantly greater than that of steel, they are nonetheless extremely vulnerable to surface damage.

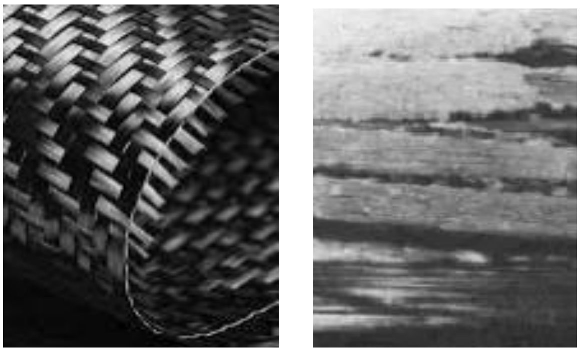

Fig 4. (a), (b) microscopic view.

4. Natural fibres:

These fibres come from the bodies of plants or animals or from geological processes4. Although less expensive than steel or glass fibres, they are more inert.3

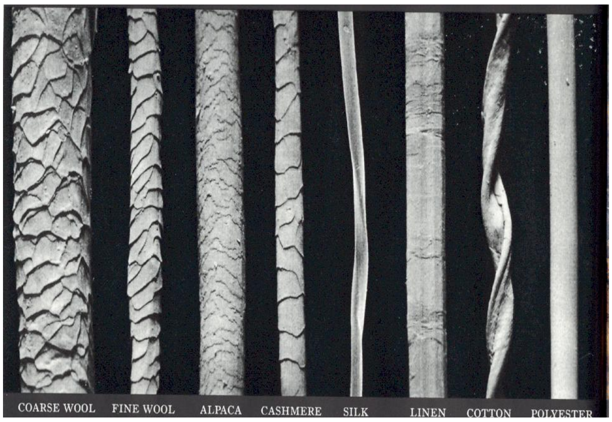

Fig 5.

5. Steel fibres:

These are short-length steel wires or thin steel sheets and are most commonly manufactured using the cut wire/cold-drawn process.

Fig 6.

The focus of this paper will be to review papers related to Steel Fibre Reinforced Concrete (SFRC).

Steel fibres are added as supplementary materials and spread uniformly at random in low amounts, i.e. between 0.3% and 2.5% by volume in ordinary concrete, to create steel fibre-reinforced concrete7. There are many different shapes of steel wires available for this purpose, including:

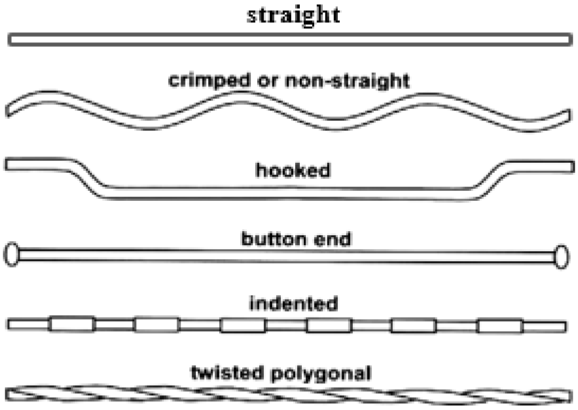

Fig 7. Types of steel fibres.

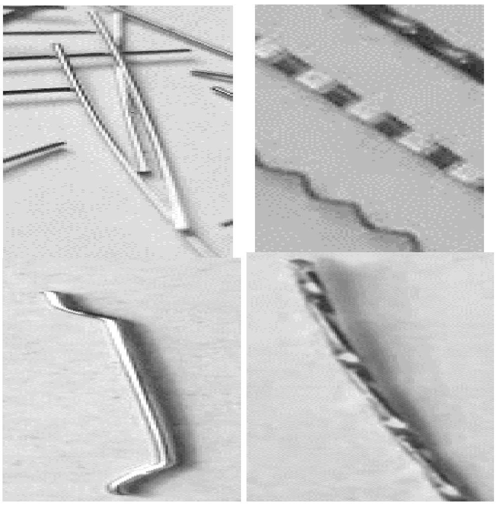

Fig 8. From left: (a) straight fibre, (b) crimped fibre, (c) hooked fibre, (d) twisted polygonal fibre.

It has been noted that the reinforced concrete section's mechanical characteristics and durability were enhanced most by the addition of steel hooked fibres. Concrete that has steel fibre reinforcement has better resistance to cracking and crack propagation. It demonstrated an improvement in tensile strength, flexural strength, shock resistance, fatigue resistance, ductility, and crack arrest.

II. LITERATURE REVIEW

Owing to the segregation or balling of steel fibres while mixing and compacting SFRC, the energy needed for mixing, transporting, putting, and finishing SFRC is a little larger. This should be prevented to ensure that fibres are distributed evenly, which is often accomplished with a pan mixer and fibre dispenser. The amount of enhancement in the mechanical properties of SFRC is determined by variables such as shape, size, volume, percentage, and dispersion of fibres.

It was observed that plain, straight, and round fibres form a very weak bond, which results in low flexural strength. Although the workability was reduced when the aspect ratio* was increased, the flexural strength increased. This problem is solved using Superplasticizers. Most of the steel fibres used on fields have an aspect ratio between 48 and 60. Flexural strength was 2.5 times higher with the inclusion of steel fibres up to 5% by volume. The production of numerous precast concrete goods, including manhole covers, concrete pipes, etc., uses the SFRC frequently.

Behbahani, Hamid & Nematollahi, Behzad, [2011], is a review paper on SFRC that gives a summary of the material's mechanical characteristics, benefits, and applicationsAn improvement in compressive strength, spalling resistance**, toughness and ductility is observed. The shear strength increases noticeably. The mechanical qualities improved more when steel fibres with different aspect ratios were used, to the point where the traditional tensile reinforcement could be totally and successfully substituted(Noghabai, 2000; Williamson, 1978). However, since the improvement in tensile strength is significantly smaller for fibres that are scattered more or less randomly, adding fibres just to improve the direct tensile strength is likely, not practical. Compared to plain concrete, impact resistance was observed to be 8 to ten times greater, implying a significant boost in toughness.

Interestingly, it was discovered that in a chlorine-rich setting, corrosion of the SFRC fibres near the surface caused by cracks was less severe and that no concrete bursting or disintegration was observed as a result.It was discovered that electrical resistance decreased as the percentage of steel fibres increased.(Tsai et al., 2009).It is observed that steel fibres have a far higher impact on concrete's flexural strength than it does on direct tension or compression(Hartman, 1987).

A.A. Adeyanju and K. Manohar, (2011, December 20), is a document that details an experimental analysis of the thermal characteristics of steel fibre-reinforced concrete and iron filings for solar/thermal energy storage purposes. Six concrete cube samples (10 cm x 10 cm x 10 cm) were tested (A, B, C, D, E and F).

The following tests were run:
1. Slump test:
Presenting the effects on the work ability of SFRC.

2. Compressive Strength Test:
Demonstrated through tests that were done after 28 days of curing. The compressive strength of the concrete is found to be higher than that of plain concrete and concrete with iron infill. In comparison to plain concrete, the addition of steel fibres with a length of 5 cm increased strength the most, while adding fibres with lengths of 2.5 cm and 1 cm did not affect the outcome. Compressive strength has been shown to rise as density rose, as was expected.

3. The thermal conductivity, diffusivity and resistivity test:
Results showing that the presence of steel fibres increases heat conductivity and that the greater the thermal conductivity, the lengthier the steel fibres are exhibited. Similar outcomes were shown for thermal diffusivity*, density and thermal storage capacity. Thermal resistivity shown by the samples was the inverse of thermal conductivity.

4. Additional observations were made showing:

- The orientation significantly affects the samples' tensile strength.
- Even though the compressive strength improvement was not noticeable, a major increase in post-crack ductility was seen.
- Fibres with better bond characteristics (i.e., deformed fibres, or fibres with greater aspect ratio) generate greater toughness values than smooth, straight fibres (volume densities were kept consistent).

G. Murali, A.S. Santhi, G. Mohan Ganesh, (2014), the article presents the effects of crimped and hooked end fibres (aspect ratio = 50) on the impact resistance of fibre-reinforced concrete (FRC) by varying the dosage of steel fibres. All throughout the experiment, Ordinary Portland cement of grade 53 (ASTM type I) was employed. A superplasticizer based on Polycarboxylic-ether helped to increase workability. Six cubes were subjected to an impact test (100mm x 100mm x 100mm). According to the compressive tests, concrete with hooked end fibres fared better than concrete with crimped fibres. The Impact test results showed that plane concrete was the poorest, collapsing after just fifteen strikes, followed by concrete with crimped fibres, which was able to withstand 2.6 times as many strikes on average, lastly followed by concrete with hooked fibres, which could withstand 2.9 times as many blows on average. The post-crack ductility significantly increased, despite the fact that the rise in compressive strength was not considerable.Additionally, the impact energy upon failure for FRC with hooked end fibres grew as a result. An Ultrasonic Pulse Velocity test was performed as well, and it was repeated three times until the sample collapsed.

Observations revealed that in every case (in both plane concrete and FRC), the pulse's speed continued to decrease after impact. Although the behaviour of crimped and hooked-end fibre is identical, hooked-end steel fibre demonstrated a little larger strength as well as impact resistance. Failure patterns are scrutinised as well as the link between the UPV and the number of blows under impact loadis observed.

Abdul Ghaffar, Amit S. Chavan, and DrR.S.Tatwawadi, (2014, Mar), identify and contrast the differences between concrete with and without steel fibres in terms of its characteristics. Tests for compression and flexure were conducted. With increasing fibre dosage rates ranging from 0% to 5% with an interval of 0.5% by weight of cement. 11 concrete mix batches (M35) have been used. The major goal of the test programme was to investigate how hooked steel fibres, used in varied percentages, affected different concrete strengths under dry and wet circumstances. According to the experimental findings, the ideal volume percentage of fibres that provides the greatest strength at 28 days is 3.0%. Flexural strength rises with a rise in fibre content up to 4.0% before falling.Additionally, it can be seen that the outcomes of both experimental and predictive analysis are in general in agreement. It presents research on the ductility of SFRC as well as its wet and dry densities.

ZhangChong, Gao Danying & GuZhiqiang, (2017), this study examines how steel fibrereinforced high-strength concrete behaves when subjected to varying degrees of stress.Fatigue failure**/fatigue behaviour is discussed. A total of six beams with the size of 1200cm×120cm×200 cm are tested in flexural fatigue at different stress levels. The steel fibres in the specimens are of the "hooked" variety. The 500 kN MTSTM fatigue testing machine was used. Beams with a span of 1000 mm were tested in a four-point configuration. The beams were preloaded twice before the test to guarantee sufficient interaction between both the beams and the supports. The beams were subjected to stresses ranging from 0.1 to 0.8, with the minimum stress level being set at 0.5, 0.55, 0.6, and 0.7. There were two types of tests performed: static and flexural.As the most of faults continued toward the top of the beam, exhibiting good ductility in steel fibre reinforcement, the results of the static test revealed a sharp increase in tensile reinforcement strength to yield strength. After 2 million repetitions, the steel fibre reinforcement underwent brittle failure, as determined by the results of the flexural test.

Hajforoush, Mohammad, Kheyroddin, Ali, Rezaifar, Omid & Kioumarsi, Mahdi, (2021), in this work, the microstructural and mechanical characteristics of freshly cured concrete samples is studied. Splitting tensile strength is predicted as a function of compressive strength. Type-II Portland cement is used along with hooked-type steel fibres. Tests were conducted on day-28 of curing. An Electron microscope was used to scan the images of the microstructure of the SFRC. Steel fibres at volume ratios of 1 and 1.5% were examined. A Uniform Magnetic Field (UMF) with a flux density of 500mT was applied.

Using a mathematical model based on the Bingham model, **Viller et al., 2019** examined the dynamic behaviour of steel fibres in cement mortars exposed to magnetic fields. SFRC showed a substantial increase in mechanical strength when fibre content was increased to 1.5%. The cement hydration process was enhanced. Owing to the linear arrangement of steel fibre interaction with one another, it was found that magnetic fields can also improve the electrical conductivity of concrete. As a result, this approach is helpful for a variety of applications, including electromagnetic shielding and power system grounding. Due to water being a polar molecule, magnetising the water molecules while mixing concrete helps increase workability. Other physical characteristics of water such as surface tension, viscosity, temperature, electric conductivity, pH, solubility, specific weight, and permeability pressure are also greatly influenced.

Gholhaki et al., 2018 did similar research producing similar results. According to earlier research, a direct magnetic field application could improve the mechanical qualities of freshly made concrete. The compressive strength of cement pastes increased by up to 13% when exposed to modest magnetic fields according to a study by Soto-Bernal et al., 2015. Additionally, similar outcomes were noted in a different experimental study carried out by Abavisani et al., 2018 in which adding a magnetic field to concrete increased its mechanical strength by roughly 17%. The use of UMF boosted the compressive strengths of both fresh and cured concrete samples at the age of 28 days. The placement of steel fibres in the concrete mixture was then demonstrated to be perpendicular to the crack plane, where their fibre bridging function could easily control the fissures. Because the effect of the magnetic field on the concrete increased the C-H-S gel formation with a less granular and thicker morphology during the reaction with water, resulting in a decrease in the porosity value and subsequently an increase in the compressive strength of concrete, the results obtained were in allowable agreement with the findings by Abavisani for fine aggregate concrete exposed to a magnetic field.

Filian, Belkis & Lantsoght, Eva & Yang, Yuguang, (2019), they used Critical Shear Displacement Theory to calculate the shear capacity of the SFRC beam. There are no stirrups on the beams. After cracks have formed, shear resistance occurs, and in those circumstances, fibres orthogonal to the fractures are shown to be the most efficient in bearing tension. This study determines the influence of fibres with the help of CSDT*Four models are developed for this report's use in determining the impact of fibres, the first of which is based on changes by Singh and Jain (2014) of the formula suggested by Dinh et al. (2011), the second comes from Mansoor (1972), and the third and fourth come from Lee et al. (2017), using suggested and greater values for critical shear displacement (Δcr) = 0.025 and 0.05respectively.Using experimental data from the literatureReza & Chao 2017; Rajan & Sharma, 2014; Shoaib et al., 2014; Singh & Jain, 2014; Dinh, et al. 2011; Kwak, et al. 2002; Mansur, et al. 1972; Ashour, et al. 1992; Chunxiang & Patnaikuni, 1999; Lim, et al., 1987; Casanova &Rossi 1999; Noghabai 2000; Pansuketal., 2017; Randletal., 2017; Tan, et al., 1993;the outcomes of the four models are contrasted.A MATLAB script is used to forecast shear capacity. These scripts can be found in Filian Abad, 2017.Expressions from these literaturesare used to predict the shear-carrying capacity of the steel fibres and those values are compared with the experimental results.

Kanagaraj, D & Ganesh, Siddes & Santhoshkumar, R & Thirumoorthi, D, (2019), This paper presents an experimental investigation on SFRC with the variation in steel fibre proportions from 0% to 1% of the concrete.It examines the samples' flexural strength, split tensile strength, and compressive strength. Hooked-type steel fibre, OPC M53, is employed. 15 cubes (150mm x 150mm x 150mm), 15 cylinders (d = 150mm, h = 300mm), and 15 beams (500mm x 100mm, 100mm) make up the total number of samples, and the experiment is carried out using a compression testing machine (CTM). The findings showed that SFRC's strength increased when 0.75% steel was added proportionally, but it decreased when the steel fibre proportion was increased to 1%.

Nguyen Van CHANH, discusses the mechanical characteristics, techniques, and uses of SFRC. The topics of compressive, tensile, and flexural strength are covered under mechanical characteristics. The technologies cover techniques for applying and combining SFRC as well as its limitations. Finally, it discusses the implementations of SFRC and the suggestions of ACI committee 544.

III. RESULT AND DISCUSSION

By now, it has been well established that SFRC is superior in Crack mitigation & providing resistance to crack propagation.

Incorporating fibres of different kinds to enhance concrete’s properties has been a fascinating concept for a long time and extensive research on the type of fibres and the effect it has on the mechanical properties of concrete has been done. In numerous tests, hooked end fibres outperformed every other type of fibre, exhibiting greater bond properties.

Along with that, the compressive strength of SFRC has been the subject of extensive study. It has been discovered that as density rises, compressive strength rises as well. It has been repeatedly demonstrated that raising the fibre content raises SFRC density all the while decreasing workability, which is dealt with with the help of superplasticizers. Additionally, more steel fibres result in better thermal conductivity, thermal diffusibility, and thermal storage capabilities. Similar research has been done on tensile strength, and it's been discovered that the alignment of the steel fibres has a significant impact on the tensile strength of SFRC. The most resistance to tension is provided by fibres that are perpendicular to the cracks, which also aids in SFRC exhibiting enhanced ductile behaviour at failure. Flexural strength increases as tensile strength does. The highest impact resistance is seen in SFRCs with hooked fibres.Applying magnetic field showed interesting results with regard to increased electrical conductivity, mechanical strength; especially compressive strength, hydration process, etc.

Some attention has also been given to studies regarding corrosion, electrical conductivity& resistivity, fatigue behaviour, shear strength, Ultrasonic Pulse Velocity Test, behaviour under magnetic flux, etc.

IV. CONCLUSION AND FUTURE SCOPE

This review paper presents an overview of various tests conducted by various researchers on SFRC including a brief description of their findings. Unlike conventional concrete and RCC, SFRC has proven itself to be superior on many occasions (or rather, tests).

SFRC is a thrilling subject and a lot of research has been done on its mechanical properties giving rise to many new findings and even more inquisitive questions. These tests only prove that SFRC has the potential to find use in many more fields than it currently does.

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