Abstract—This review article gives a brief overview of publications related to the effects of different types of fibres on the properties of Self-Compacting concrete (SCC). Self-compacting concrete containing fibres is a high performance building material which has the combined properties of SCC having improved characteristics with the addition of fibres.

Keywords—Fibre reinforced self-compacting concrete, Steel fibres, Polypropylene fibres, Hybrid fibres.

I. INTRODUCTION

Concrete is presently no more a material comprising of cement, aggregate, water and admixtures. It is in fact an engineered material with a few additional constituents. The concrete today can deal with any particular necessities under the most critical conditions. New age concrete needs to fulfill different execution criteria i.e., it ought to have high fluidity, self-compatibility, high strength, high durability, better serviceability and long service life. In order to satisfy these criteria self-compacting concrete (SCC) was developed. SCC is a mix that can be compacted into every corner of formwork by means of its own weight and without the need for either external or internal vibration for compaction, and also without affecting its engineering properties. The use of such concrete saves time, labor and energy. The requirement of SCC is not only the need of modern fast growing urban cities but also special applications in special engineered structures like bridges and under water construction where concrete without vibration is in demand.

SCC has to be a stable mixture to prevent segregation of solids during the flow and should have high slump which can be ensured by the use of super-plasticizers and viscosity modifying agents. The amount of cement and cement replacement materials are to be selected carefully for a proper balance between the solids and liquids in the mix and to create good paste content. The concept of SCC was first proposed by Okamura in 1986 at the University of Tokyo and the prototype was first developed by Ozawa et al. in 1988. This led many contractors to develop large in-house R&D facilities to use their own SCC technologies.

SCC is considered to be an advanced construction material, as this concrete does not require to be vibrated to accomplish full compaction. It offers numerous benefits and advantages over ordinary concrete. These days the use of mineral admixtures in SCC also helps to make it more eco-friendly and economical. The inclusion of fibres in the SCC mix enhances the mechanical properties and ductility of the concrete. Fibres arrest the growth of micro-cracks and improves its flexural and tensile strength. The shape and large surface area of the fibres however influence the workability of SCC. Hence the amount of fibres to be added in the SCC mix is restricted, depending on the fibres type utilized and the composition of the SCC mix. To make the best utilization of the fibres, they should be homogeneously dispersed in the mix without clustering/balling.

In the production and application of SCC, mixture design is very important. So far there is no unique, widely applicable mixture design method to obtain high quality SCC. There are many mixture design methods proposed by various researchers in their publications. Based on the principles of mix design those methods can be classified as (1) Empirical design method, (2) Compressive strength method, (3) Close aggregate packing method, (4) Statistical factorial model, (5) Rheology of paste model. According to the requirements, different methods were considered and detailed in their publications.

Many researchers have worked in developing fibre-reinforced self-compacting-concrete (FRSCC) in recent decades. In this paper some of the major studies carried out on FRSCC are documented and briefly reviewed for further research and development.

II. ROLE OF STEEL FIBRES

Kishor S. Sable, et al. [1] in their research explored the utilization of different steel fibres with various aspect ratios in structural concrete to upgrade the mechanical properties of self-compacting concrete. The study focuses on investigation of the properties of SCC with and without fibres, and also assesses the effect of fly ash replacement on the rheological properties of FRSCC.
Two different aspect ratios of steel fibres, i.e., 50 and 80 with volume fraction 2.5% are studied in making the SCC mixes. A 30% replacement of cement with fly ash is studied with constant water powder ratio of 0.408. The targeted strength is M30. This examination was done by carrying out a few tests like the workability tests of SCC, compressive strength test, tensile and flexural tests. The examination demonstrates that it is conceivable to use SCC with fly ash and fibres as the fresh properties of mixes satisfy EFNARC conditions. The hooked end and crimped fibres have good bond in the matrix resulting in better strength. Additionally the use of fly ash in SCC enhances microstructure of solid that is likely to improve all the mechanical properties of the mix.

B. Krishna Rao, et al. [2] performed an examination on steel fibres reinforced self-compacting concrete with steel fibres of different aspect ratios and different volume fractions. Fresh and hardened properties of the concrete were studied, and the change in ultimate strength was found. Results acquired from the majority of the mixes fulfill the lower and maximum cutoff points proposed by EFNARC. The results of this investigation show that optimum volume fraction and aspect ratio of fibres for good performance regarding strength was found to be 1% and 25 respectively. They also concluded that using high-volumes of fly ash increases the workability characteristics of SCC mixes.

Mounir M Kamal, et al. [3] performed tests on SCC to study their mechanical properties and determine the optimum dosage of both steel and polypropylene fibres content to be used in SCC to satisfy the workability conditions. The effective optimum percentage for steel and polypropylene fibres was found to be 0.75% and 1% of cement content respectively. It was also found that addition of these fibres increases the compressive strength, reduces the bleeding, increases the impact resistance and further leads to more ductile failure pattern with the appearance of cracks prior to failure.

A. Khaloo, et al. [4] studied the mechanical performance of SCC reinforced with steel fibres. They studied the effect of steel fibres on fresh properties of concrete, compressive strength, splitting tensile strength, flexural strength, and flexural toughness of SCC specimens. Different steel fibres volume fractions were studied, and reference mixes considered were of strength 40MPa and 60MPa. Results showed that with addition of 2% steel fibres workability reduces far below the minimum limits specified by EFNARC.

The presence of steel fibres increased the splitting tensile strength and flexural toughness of the SCC specimens in low fibres volume, and it also showed that beams made with medium strength SCC had more flexural toughness compared to beams made with high strength SCC.

Mustafa Sahmaran, et al. [5] carried out an experimental program to investigate the effect of fibres on SCC. In their work they considered two different types of steel fibres. The authors concluded that by using considerable fibres inclusion i.e., 60kg/m³ it is possible to accomplish self compaction. All mixes considered had good flow-ability characteristics. The use of a commercial super plasticizer named ‘Smart flow’ proved to be economical also. This work also states that to get high workability and to retain that workability with the inclusion of fibres, the amount of paste in the mix should be increased and this gives better dispersion of fibres also.

Mustafa Sahmaran, et al. [6] made a study on fresh and mechanical properties of fibre reinforced self-compacting concrete incorporating high volume fly ash. Suitable super plasticizer and VMA were used to get a stable mix. Compressive strength, splitting tensile strength and ultrasonic pulse velocity of the concrete were studied for the hardened properties. The results of this work show that in spite of reduction in strength of concrete it is possible to produce FRSCC incorporating high-volume fly ash with 50% replacement of cementitious material. There is also increase in workability characteristics due to more paste content in the mix. This work also concludes that fibres geometry affects the properties of SCC mixes both in fresh and hardened states.

R. Deeb, et al. [7] made a study on Self compacting high and ultra-high performance concretes and the steps taken to develop them are briefly enlisted in this work. Their main aim was to research and report how the mixture of solids and liquids and the type of chemical admixture to be selected for developing concrete with self-compatibility which ensures right flowing and passing capacity even with the involvement of different types of steel fibres. The plastic viscosity of thus produced mixtures were estimated by a simple micromechanical procedure explained briefly in their paper. Their work concludes that it is successfully possible to attain self-compaction for high and ultra-high performance concrete mixes with good flow-ability and no segregation. A good paste content ensures good mix and distribution of fibres. Steel fibres of 30mm length and 0.55mm diameter with crimped ends showed an all over good performance compared to other long fibres used in this experiment.
It was also found that additional improvements could be made to mixes with fibres by adjusting the type and amount of Super plasticizer.

Cristina Frazao, et al. [8] investigated the durability aspect of steel fibre reinforced SCC. The mechanical properties were also assessed. Steel fibres to the extent of 60kg/m³ were used and this did not affect the self-compaction characteristics of SCC i.e., it was a stable mix with good flowing and passing ability. Two mixes were studied with and without fibres. This work concludes that concrete mixes with steel fibres has good resistance to carbonation, diffusion coefficient remained unchanged for both the mixes, inclusion of steel fibres showed 63% less electrical resistivity compared to plain SCC. Air penetrability and water absorption were same for both the mixes. Post-cracking flexural resistance and the energy absorption increased with addition of fibres. Corrosion of steel fibres could induce cracking in concrete leading to decreased tensile strength, but this is only in case of extreme aggressive environment.

M. Pajak, et al. [9] made a detailed study on flexural behavior of SCC with straight and hooked end steel fibres. Different volume fractions of steel fibres were studied and compared to normal vibrated concrete. RILEM TC 162-TDF and EN 14651 were referred for all the laboratory tests conducted. They determined that flexural tensile strength could be described with same formulas for both steel fibres in SCC and steel fibres in normal concrete. Increase of fibres percentage increased the flexural strength and fracture energy, and also increased with fibres dosage. From this work it was concluded that the flexural behavior of SCC is comparable with normally vibrated concrete and the increase of fibres dosage increases the pre-peak and post-peak parameters of SCC.

III. ROLE OF POLYPROPYLENE (PP) FIBRES

Syal Tarun, et al. [10] used hybrid fibres i.e., steel and polypropylene fibres in different combinations and studied their effects on the workability and compressive strength parameters of SCC. Their study consisted of three hybrid mixes with 0.5% volume fraction of fibres. The materials used were relevant to the Indian Standard Specifications. The test procedure for workability was fulfilled according to the requirements of EFNARC-2005. From their test results it was concluded that usage of steel fibres increases the overall strength and the polypropylene fibres, due to its light weight, is helpful in optimizing the self-weight of SCC.

Ding Y., et al. [11] in their experimental work proposed suitable fibre types and fibre dosages for high performance SCC. They made different series of experiments to evaluate the influences of fibres on the mixes and reported that combination of steel fibres and PP-fibres (i.e cocktail fibres or hybrid fibres) gives an optimal fibre reinforcement for self-compact-concrete.

Farhad Aslani, et al. [12] conducted both experimental and analytical studies on SCC using steel fibres, polypropylene fibres and hybrid fibres where they obtained information about the mechanical properties and also other relationship models which predict the strength of the mixes. The results of this study concluded that the compressive strength and modulus of elasticity of hybrid fibres based SCC are higher than those having steel fibres and polypropylene fibres alone. The tensile strength and modulus of rupture of SCC mixes with steel fibres only is higher compared to all other mixes.

H. Mazaheripour, et al. [13] studied lightweight self compacting concrete having polypropylene fibres. The fresh and hardened properties of the mixes were studied. It was found that the lighter the concrete more self-compaction takes place, in this case the concrete was lightened by 75% of normal weight which increased the fresh properties massively. Increasing the percentage of polypropylene fibres reduced the slump which can be maintained by the use of super plasticizer to a certain extent. With the optimum usage of these fibres it was found that there is no increase in compressive strength but increased tensile strength and flexural strengths.

T. Suresh Babu, et al. [14] developed a standard grade self-compacting concrete of mix M30 in order to produce fibres reinforced self-compacting concrete using different mineral admixtures of Fly Ash, GGBS and a combination of both in suitable proportions. Studies were conducted on the mechanical behavior like stress-strain properties and modulus of elasticity. An equation relating Compressive Strength (f㎝) and Modulus of Elasticity (E㎝) was proposed for plain SCC and GFRSCC mixtures as E㎝ = 4700 vfK and E㎝ = 5700 vfK respectively. An increase of 21.5% in the value of modulus of elasticity was observed with GFRSCC mix. Toughness or energy absorption capacity of GFRSCC mixture is improved by 40% compared to plain SCC mix, whose ductility has improved by over 21% due to the addition of 0.6kg/m³ of glass fibres to SCC mix. The investigations have been further extended for the study of application in flexure by casting and testing under reinforced SCC and GFRSCC beams, and it was found that load carrying capacity of GFRSCC increased from 7.5% to 20%.
Seshadri Sekhar T., et al. [15] carried out an experimental investigation on glass fibres reinforced self-compacting concrete and suggested an optimum percentage of fibres to be used to get the enhanced mechanical properties such as compressive strength, split tensile strength and flexural strength while satisfying the fluidity characteristics like flow-ability, filling-ability, passing-ability and resistance to segregation. The following conclusions were drawn from this report:

- As compared with conventional concrete the glass fibres reinforced SCC gives the higher strengths on long duration.
- The mechanical properties of glass fibres reinforced SCC are in accordance with the expected trends in conventional glass fibres reinforced concretes.

Seshadri Sekhar T., et al. [16] present an experimental investigation on the properties like workability and strength of glass fibres reinforced self-compacting concrete, using lowest possible water powder ratio in the development of SCC mixes. They concluded that the mechanical properties of glass fibres reinforced SCC of grades M50, M55, M60 and M65 are in accordance with the expected trends in conventional glass fibres reinforced concretes.

Arabi N.S Al Qaudzi et al., [17] investigated the effect of different specimen shape on mechanical properties of Polypropylene fibres reinforced SCC exposed to elevated temperature (200°C–600°C). They studied different shapes of specimen i.e. cylindrical and cubical specimens which were subjected to 200°C–600°C temperature for a duration of 24 hours. The thermal shock induced by cylindrical specimens caused severe damage to the concrete and lead to reduction of compressive strength. This lead to a conclusion that shape of the specimen affects the mechanical properties under elevated temperatures. The addition of polypropylene fibres enhances the residual strength and fracture energy of concrete specimens when subjected to thermal shock. The experimental procedure was carried out with a constant water to powder ratio of 0.32 and the fibres were varied with volume fraction 0%, 0.05%, 0.10% and 0.15%. Short PP fibres of 19mm length were used in this experiment. The specimens were cast and cured for 89 days in water at 20°C and then tested at different elevated temperatures and heating period. The samples later were cooled down to room temperature and tested for compressive strength. Their study concluded that the use of polypropylene fibres does not affect the compressive strength upto 200°C – 400°C but when the temperature is increased to 600°C the compressive strength of the specimens is affected.

The optimum percentage of polypropylene fibres to be used for cylindrical specimen should be 0.05% and for cubical specimens it is 0.10% so that the compressive strength increases and provides fire resistance. The cubical specimens showed a better compressive strength than cylindrical specimens at elevated temperatures.

Sabry A Ahmed [18] made an extensive investigation on the properties and meso-structural characteristics of linen fibre reinforced self-compacting concrete in slender columns. Their experimental work consisted of 2 – 4 kg/m³ of linen fibres (30mm long), and used dolomite as coarse aggregate. The w/p ratio and the percentage of high range water reducers were constant for all mixes. Three mixes tested were plain SCC, and SCC with moderate and maximum content of fibres. Fresh concrete tests were carried out according to EFNARC standards. To assess the hardened properties the method used by Torrijos et al., was implemented without change. The following conclusions can be drawn from this article: The use of fibres reduces the workability but it is still in range recommended for SCC. The compressive strength was improved by 8.3% and split tensile strength was improved by 17.6% at 2kg/m³ addition of fibres. The meso-structural analysis showed that the hardened properties did not vary significantly along the height of columns. The aggregate distribution was slightly more homogeneous in case of LFRSCC, and the variation of fibres density along the height of columns was relatively high.

Mounir M. Kamal et al., [19] Extended their studies to study the possibility of producing fibres recycled self-compacting concrete (FRSCC) using crushed red brick and crushed ceramic as coarse aggregate. Polypropylene fibres were used in recycled self-compacting concrete to improve fresh and hardened properties of this type of concrete. Polypropylene fibres volume fraction varied from 0 to 1.5% of the volume of concrete with aspect ratio 12.5 and the fresh properties of FRSCC were evaluated using slump flow, J-ring and V-funnel tests. Compressive strength, Tensile strength, Flexural strength tests were performed in order to investigate the mechanical properties. Results showed that the optimum volume fraction of polypropylene fibres was 0.19% and 0.75% for the mixes with crushed red brick and ceramic as coarse aggregate respectively. At optimum volume fraction of polypropylene fibres; the mixes with crushed ceramic yields to improve in the compressive strength compared to the mixes with crushed red brick as recycled aggregate.
At optimum dosage of polypropylene fibres, FRSCC mixes with crushed ceramic and crushed red bricks yields to improve the compressive strength compared to the mixes with crushed ceramic and crushed red bricks without fibres. This leads to improvement in the tensile and flexural strength at optimum dosage of fibres. The use of recycled aggregates reduces the overall compressive strength compared to dolomite mix of 36MPa at 28days.

IV. CONCLUSION

The following conclusions are drawn from the literature review done on fibres inclusion in self compacting concrete:

- Steel fibres improve the quality of hardened state concrete by showing increase in strength up to certain volume fraction.
- Usage of more fibres fraction in SCC improves the hardened state but reduces the fresh state properties, hence optimum percentage of fibres are to be used while creating SCC.
- Fibres form a bridge between micro cracks and hence they resist in enlargement of the crack width.
- Hooked or Crimped steel fibres are proved more effective than straight steel fibres as better bonding is seen in the matrix.
- Steel fibres reinforced self-compacting concrete shows excellent tensile strength, flexural strength, shock resistance, fatigue resistance, ductility and crack arrest.
- Flexural strength improvement of medium strength SCC is greater than high strength SCC.
- Optimum replacement of cement by flyash improves the fresh properties of SCC as it acts as a filler and improves the paste content.
- Polypropylene fibres added in small quantity improves the tensile and flexural strengths.
- Fibres overcome the limitations of normal concrete of brittle failure, high shrinkage cracking and low durability.
- Steel fibres have been applied in various professional fields of construction, irrigation and architecture.

REFERENCES


