CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

9.1 General:

The motivation for the present investigation has been presented in chapter 1. The need for conducting a feasibility study for producing SIFCON with locally available low tensile strength steel wire fibres is identified. The need to understand the behavior of thus produced SIFCON in compression, tension, flexure, shear and torsion is identified. The necessity to access the shrinkage behaviour of SIFCON produced with mineral admixtures was felt. Also, the behaviour of SIFCON at elevated temperatures has to be studied for application as a refractory material. The aims and specific objectives are decided accordingly for the present investigation.

Once the aim and objectives are decided, the state of the art of the technology related to the present work is reviewed. From this review the aim and objectives of the present investigation has been validated.

The implementation strategy is then decided. Accordingly experimentation in the laboratory is planned. A total number of 36 SIFCON mixes are prepared and tested for assessing its behavior in compression, tension and flexure. A total number of 37 shear specimens mixes have been cast and tested. Also 27 number of torsion beams are cast and tested to understand the behavior of SIFCON in torsion. Shrinkage test has been conducted strictly as per IS 1199 - 1959 code on 36 number of shrinkage specimens. A total number of 30 cube specimens and 60 number of cylinder specimens are also tested at elevated temperatures.
The effect of volume percentages of fibres, aspect ratio and mineral admixtures on the behaviour of SIFCON has been established through these experimental results. Simple regression models are also developed for predicting compressive, tensile and flexural strengths of SIFCON. A torsion model is also developed. The study established the feasibility of producing SIFCON with locally available low tensile strength steel wire fibres for greater applications in India and other developing countries.

9.2 Conclusions:

Based on the results of the experimentation and the analysis of the results, the following conclusions seem to be valid.

1) The literature survey carried out led to the identification of the need for conducting the feasibility study of producing SIFCON with locally available low tensile strength steel wire fibres.

2) With the increase in volume percentage of steel fibres, the compressive strength of SIFCON also increases.

3) Addition of low tensile strength steel wire fibres has significantly increased the compressive strength of SIFCON. A maximum increase of about 88% is observed when compared to reference M20 concrete mix.

4) With the increase in fibre aspect ratio the compressive strength of SIFCON increases marginally. When compared to fibres of 40 aspect ratio, an increase of about 11% in compressive strength is observed for SIFCON containing fibres of 60 Aspect ratio.

5) The effect of fibre aspect ratio is not as pronounced as that of percentage volume of fibres on compressive strength.
6) Mineral admixtures like silica fume and metakaolin can be used with advantage in producing SIFCON.

7) Use of silica fume and metakaolin resulted in an increase of 11% and 14% in compressive strength respectively. When compared to silica fume, metakaolin contributed to higher compressive strength.

8) As the percentage volume of fibres increases, the tensile strength of SIFCON also increases.

9) Addition of low tensile strength steel fibres contributed to a significant increase in tensile strength of SIFCON. A maximum increase of 306% in tensile strength is observed.

10) The increase of Aspect ratio of fibres has only a marginal influence on the tensile strength of SIFCON in the ranges tested.

11) From viewpoint of tensile strength also mineral admixtures like silica fume and metakaolin are quite beneficial in producing SIFCON.

12) The modulus elasticity of SIFCON produced with low tensile strength fibres is in the range of 22,700 MPa to 26,800 MPa in the ranges tested.

13) The load deflection response of SIFCON in flexure is recorded. SIFCON beams show greater stiffness when compared to reference M20 concrete beams.

14) The energy absorbed by SIFCON mixes is considerably higher then that of reference plain concrete mix. A maximum increase of 975% is observed which confirms the extreme ductile behaviour of SIFCON produced in this investigation.

15) The flexural strength of SIFCON increases with increase in volume percentages of fibres. A significant increase of about 375% in flexural strength is observed due to the
addition of steel wire fibres. Thus it can be concluded that the addition of steel wire fibres significantly contributes to the increase of flexural strength.

16) The fibre aspect ratio has reasonable influence on the flexural strength of SIFCON. An increase up to 29% has been observed for aspect ratio of 60 when compared to corresponding mix with 40 aspect ratio.

17) Use of silica fume and metakaolin increased the flexural strength to the extent of 17% and 27% respectively.

18) With the increase in percentage volume of fibres, the torsional strength of SIFCON increases in the ranges tested.

19) The torsional strength of SIFCON is significantly greater than M20 concrete and fibre reinforced concrete. A maximum increase of 487% in torsional strength is observed over reference M20 concrete mix. When compared to fibre reinforced concrete mix the SIFCON possess 170% greater torsional strength.

20) The fibre aspect ratio has significant influence on torsional strength of SIFCON. As the aspect ratio increases from 40 to 60, an increase of about 41% in torsional strength is observed.

21) Mineral admixtures contributed to a increase of 9 to 21% in torsional strength of SIFCON.

22) The T - θ curves for SIFCON are recorded. These curves reveal the superior torsional energy absorption capacity of SIFCON.

23) The shear strength of SIFCON is significantly greater than that of reference M20 concrete mix and it increases with increase in percentage volume of fibre. A gain of 356% in shear capacity is observed over reference mix.
24) The fibre aspect ratio has only a marginal impact on shear strength of SIFCON.

25) The use of mineral admixtures contributed to an increase of 4% to 9% in shear strength of SIFCON.

26) The drying shrinkage of SIFCON is in the range of $260 \times 10^{-6} - 564 \times 10^{-6}$.

27) The drying shrinkage of SIFCON is an order of magnitude less than that of reference M15 mix and steel fibre reinforced concrete mix.

28) As the percentage volume of fibre increases the drying shrinkage decreases.

29) The fibre aspect ratio has only a marginal influence on the drying shrinkage of SIFCON.

30) The use of mineral admixtures slightly increases the drying shrinkage of SIFCON. However, the benefits obtained in compression, tension, flexure, shear and torsion can over rule this aspect.

31) The compressive and tensile strengths of SIFCON increased when the specimens are exposed to $100^\circ$ C for 4 hours. The increase in the compressive strength is 17 to 38% and that in tensile strength being 147% to 329%.

32) At elevated temperatures of $200^\circ$ C and above the compressive and tensile strengths of SIFCON decreases. However, the percentage decrease is considerably less for SIFCON specimens as compared to reference M20 concrete mix. This establishes the superior performance of SIFCON at elevated temperature.

33) In the ranges tested the increase in percentage volume of fibre significantly improves the performance of SIFCON at elevated temperature.
34) The stiffness of SIFCON specimens is considerably higher than that of reference M20 concrete mix even at 300°C. The percentage loss of stiffness is considerably less for SIFCON as compared to reference M20 concrete mix.

35) With the increase in exposure duration the compressive strength, tensile strength and Young’s modulus of SIFCON decreases.

36) With the increase in percentage volume of fibre the percentage reduction in youngs modulus due to elevated temperature decreases. The percentage reduction in youngs modulus is considerably less as compared to that of reference M20 concrete mix.

37) Considering all the aspects of the present investigation it can be concluded that SIFCON can successfully be produced with locally available low tensile strength fibres.

38) The various regression models developed in the present investigation are given below.

1) Compressive strength 
\[ \sigma_c = 31.431 + 0.251 r + 0.767 v_f \]
(SIFCON with Matrix 1)
\[ \sigma_c = 10.358 + 0.703 r + 1.753 v_f \]
(SIFCON with Matrix 2)
\[ \sigma_c = 13.166 + 0.633 r + 2.029 v_f \]
(SIFCON with Matrix 3)

2) Tensile strength 
\[ F_{ct} = (K) \sqrt{f_{ck}} \]

3) Modulus of Elasticity 
\[ E = 3186 \sqrt{f_{ck}} \]

4) Flexural strength 
\[ F_r = k1 \sqrt{\sigma_c} + K2 \]

5) Shear Strength 
\[ \tau_s = (F) \times F_R \]

6) Torsional Strength 
\[ T_u = [105.55 - 3.82 v_f + 0.386 r] F_r \]
9.3 SUGGESTIONS FOR FUTURE WORK:

1) In the present investigation locally available low tensile strength steel wire fibres have been used in producing SIFCON. Investigation may be carried out to conduct feasibility of using different types of fibres in producing SIFCON.

2) In the present investigation, mineral admixtures have been used to the extent of 10% by weight of cement. Experimentation may be carried out to investigate the possibility of using higher dosage of mineral admixtures.

3) In the present investigation, the influence of aspect ratio has been studied in the range of 40 to 60. Future investigations may be planned with higher aspect ratios.

4) Investigations may be planned to produce different structural elements like beams and slabs with SIFCON and study their behaviour.

5) The results of the present investigations may be synthesized for developing macro mechanical models for SIFCON using Neural Networks/Genetic Algorithms/Fuzzy logic.