CHAPTER – V

DISCUSSION OF RESULTS
CHAPTER - V

5.0 DISCUSSION OF THE TEST RESULTS

5.1 BEHAVIOUR OF CEMENT MORTAR AND CONCRETE WITH SILICA FUME

5.1.1 Physical Properties of Silica Fume

As seen from Table-4.1.3 the fineness of silica fume (indigenous) is above 18500 cm²/gm. This shows that silica fume has super fine and its reactivity will be more though it is basically pozzolanic in nature. Because of its greater fineness quite obvious that in mixes blended with silica fume the water demand will be more. Hence workability studies also necessary in dealing with silica fume blended cements. This also indicates that when higher percentages of silica fume are used in mortar or in concrete mixes the use of plasticising admixtures becomes necessary. The results of chemical analysis indicate that the silica fume possesses high percentage of reactive silica. As a result of this, silica fume blended cements would yield better strength properties compared to other pozzolanas.

5.1.2 Basic Studies on Cement Mortars with Silica Fume (indigenous) (Ref. Table 4.2.1)

The results of tests conducted on standard mortar cubes with various percentages of silica fume show that the highest strength gain is obtained with 15 % silica fume used as replacement to cement. As the percentages of silica fume in mixes increases there is a gradual drop in the compressive strength. Hence it is clear that the optimum percentage of silica fume with cement is around 15% to give optimum strength. As already stated because of its greater fineness the water demand increases with increase in percentage of silica fume. Hence for a fixed water by cement ratio the available water is not sufficient to make all the fine particles of silica fume reacting particularly when silica fume percentage is high. As a result of this some of the silica fume in the mix might be left as non reactive. Hence there is a drop in strength. When higher
percentages of silica fume are proposed to be used with cement it may become necessary to employ plasticising admixtures to maintain workability towards strength gain.

5.1.3 Properties of Concrete with Silica Fume (indigenous) (Ref. Table 4.2.4 and Fig. 5 & 6)

Considering nominal concrete mix with silica fume admixture it is observed that as the percentage of silica fume is increased in the mix there is strength increase up to a maximum of 15% replacement of cement by silica fume. This phenomenon is true at all ages. As the percentage of silica fume is increased beyond 15% the strength falls gradually. This has been true at all ages. Hence in general, it can be concluded that silica fume helps in strength gaining of concrete mix up to a maximum 15%. Thus, there is no use of higher percentages (beyond 15%) of silica fume in the concrete mix as far as strength is concerned. The same phenomenon has occurred with cement mortars also.

With 15% silica fume in the mix, the 7 days strength is increased by 6% to 7%. With a maximum of 50%, the 7 days strength is decreased by 12 to 15%. At the age of 28 days, concrete with any percent of silica fume has shown increased strength. With 15% silica fume the increase in the 28 days strength is 25% to 30%, with 50% silica fume this increase is negligible. Hence it is true that longer ages contribute towards better strength in the case of silica fume concretes also. Further this validates the theory that optimum dosages of silica fume in concrete contribute towards better strength.
5.2 EFFECT OF SILICA FUME ON SPLIT TENSILE STRENGTH AND FLEXURAL STRENGTH

5.2.1 Effect of Silica Fume on Split Tensile Strength of Concrete
(Ref. Table-4.3.3)

The increase in strength after 28 days curing for Silica fume concrete over conventional concrete with silica fume replacement of 5% is 8.69%, for 10% it is 13.38%, for 15% it is 19.73% and for 20% it is 9.03%. Highest tensile strength has again resulted with 15% of silica fume in concrete. More than this may not help in generating higher strength concrete and it may be due to non-availability of free lime content in cement and non-availability of water to react with silica present in silica fume.

5.2.2 Effect of Silica Fume on Flexural Strength of Concrete
(Ref. Table-4.3.4)

The increase in the flexural strengths for silica fume concrete over conventional concrete with silica fume replacement of 10%, 15% and 20% are 8.2%, 16% and 4.8% respectively. All these strengths are more than 1/10 of the corresponding compressive strength. The maximum increases in flexural strength is also caused with 15% silica fume in concrete. More than this may not help in generating higher strength concrete and it may be due to non-availability of free lime content in cement and non-availability of water to react with silica present in silica fume.

Hence, it can be seen that the optimum percentage of silica fume to be used in the mix is same for all the strength proportions.
5.3 BEHAVIOUR OF CONCRETE WITH SILICA FUME AND FLY ASH BLENDS

5.3.1 Behaviour of Concrete with Fly Ash
(Ref. Table-4.2.3 and Fig. 1 & 2)

Studies have been conducted on fly-ash concretes it can be seen that there is a gradual fall in 28 days compressive strength when the fly-ash percentage is higher in the mix. The studies have indicated that 28 days compressive has fallen by nearly 25% with 50% fly-ash replacement. The same behaviour can be observed at other ages also.

Fly ash is basically an inert pozzolanic material the silica presented in fly ash combines with the free calcium hydroxide available during hydration to give useful cementitious product. Compare to silica fume the fineness of fly ash is lesser. Concrete with fly ash content particular with higher percentages required higher ages to gain in strength. Hence it is advisable to use lower dosage (upto 25%) of fly ash in nominal concrete.

5.3.2 Behaviour of Concrete with Silica Fume and Fly Ash
(Ref. Table-4.2.5 to 4.2.8 and Fig. No. 7 to 14)

In the preceding discussion, it has been established that as the percentage of fly ash is increased the compressive strength of concrete up to the age of 28 days is getting gradually decreased. When silica fume is used instead of fly ash in the matrix, the strength is increased up to 15% and then it is gradually dropping down with higher dosages. To study the influence of combined admixture (Fly-ash + silica fume) on concretes strengths are found at different ages. The strength variation is discussed as follows

With 20% fly ash in the mix it is found that as the proportion of silica fume is increased from 0% to 20% by simultaneously reducing the fly ash, compressive strength is getting increased. For this case, a maximum compressive strength of 33.5 N/mm² has been achieved with 15% silica fume and 5% fly ash in the mix. This serves as a guidance for the use of silica fume along with fly ash. Similarly in a total
admixture of 30% a maximum strength of 27 N/mm² has been achieved with 22.5% of silica fume and 7.5% of fly ash. For this combination it can be said that even with 22.5% of fly ash and 7.5% of silica fume an optimum strength of 21.5 N/mm² has been achieved for nominal 1:2:4 mix. Similarly in the case of 40% total admixture, with 30% fly ash and 10% silica fume an optimum strength of 20.5 N/mm² has been achieved. A combination of 25% fly ash + 25% silica fume has given a strength 22 N/mm² at the age of 28 days.

Hence it can be seem that silica fume is quite effective in giving the required strength even when it is combined with fly ash. Though silica fume alone contributes towards higher strengths, the mix becomes expensive. Hence by using silica fume in combination with fly ash, the cost of the mix also can be checked, at the same time required strength can also be achieved. A combination of 30% fly-ash and 10% silica fume in the mix gives a practical useful strength even for a nominal concrete mix.

5.4 EFFECT OF CURING ON COMPRESSIVE STRENGTH

It has been well established that when fly ash is used in the mix, strength gaining of concrete with age assumes greater importance. In fact when fly ash is used in the mix at higher dosages (40% to 60%), full required strength cannot be gained even at the age of 28 days. This effect is considerably reduced when fly ash + silica fume combination is used in the mix. In most of the cases discussed above required strength is being achieved at 28 days when silica fume is used in combination with fly ash. However it can be stated that still higher strengths can be achieved at the ages beyond 28 days because both fly ash and silica fume are pozzolanic in nature.

Hence it can be concluded that by using silica fume in contribution with fly ash sufficient strengths can be achieved at the age of 28 days even when the total percentage of the admixture (fly ash + silica fume) is around 50%.
5.5 OTHER ADVANTAGES OF POZZOLONIC ADMIXTURES

It has been established that by properly selecting a combination of fly ash and silica fume the cost of concrete can be made optimum. In addition to this cost there are several advantages of using the pozzolanic admixtures in the concrete mix. Fly ash and silica fume help in the preparation of a denser concrete with lesser permeability. This helps in controlling the deterioration of concrete. Alkali aggregate reaction is controlled and the durability of concrete is very much enhanced. The behavior of concrete in respect of shrinkage and creep will be better when the above admixtures are employed.

5.6 SILICA FUME CONCRETE WITH STEEL FIBRES

5.6.1 Effect of Silica Fume and Fibre on Workability
(Ref. Table 4.3.1 and Fig. 15 & 16)

The workability of silica fume concrete without fibres measured by compaction factor test is almost same as that of conventional concrete upto 20% silica fume replacement. The loss in workability is negligible. The workability of fibrous silica fume concrete decreases with increase in fibre content. This decrease is due to large surface area of fibres. For example referring to table 4.3.1. It can be seen that the workability of normal concrete with 15% silica fume and no fibres the compaction factor is 0.862. This has comedown to 0.821 with the addition of 1.5 fibres. The workability has been rendered from medium to low with the presence of fibres of larger volume. Hence to obtain optimum properties for silica fume concrete mixes with fibres, it becomes necessary to employ plasticising admixtures.

5.6.2 Effect of Fibre on Compressive Strength of Fibrous Silica Fume Concrete
(Ref. Table 4.3.2 and Fig. 17)

The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 5% and 0.5% volume of fibre is 17.4%, with 0.75% volume of fibres it is 19.92%, for 1.00% volume of fibres it is 20.6% and for 1.5% volume of fibres it is 23.26%.
The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete, with silica fume replacement of 10% and 0.5% volume of fibres it is 19.51% for 0.75% volume of fibres it is 22.4% for 1.00% volume of fibres it is 22.91% and for 1.5% volume of fibres it is 28.6%.

The increase the compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 15% and 0.5% volume of fibres is 24.10%, for 0.75% volume of fibres, it is 26.83% for 1.0% volume of fibres it is 27.72% and for 1.5% volume of fibres, it is 34.53%.

The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 20% and 0.5% volume of fibres is 18.05%, for 0.75% volume of fibres, it is 19.51% for 1.0% volume of fibres, it is 20.66% and for 1.5% volume of fibres, it is 21.28%.

For any percentage of silica fume in the mix of concrete, the compressive strength in the present case has increased with increase in percentage of fibres. For an optimum 15% of silica fume and 1.5% steel fibres have shown an increase of nearly 34.53% in 28 days compressive strength.

5.6.3 Effect of Fibre on Split Tensile Strength of Fibrous Silica Fume Concrete

(Ref. Table 4.3.3 and Fig. 18)

The increase in split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 5% and 0.5% volume of fibres is 12.37% for 0.75% volume of fibres, it is 18.72% for 1.0% volume of fibres, it is 25.08% and for 1.50% volume of fibres, it is 30.43%.

The increase in split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 10% and 0.5% volume of fibres, is 14.7% for 0.75% volume of fibres, it is 23.74%, for 1.00% volume of fibres, it is 27.42% and for 1.5% volume of fibres, it is 32.44%.
The increase in split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 15% and 0.5% volume of fibres is 24.08%, for 0.75% volume of fibres, it is 30.43% for 1.00% volume of fibres, it is 35.78% and for 1.5% volume of fibres, it is 56.52%.

Increase in split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 20% and 0.5% volume of fibres, is 14.71%, for 0.75% volume of fibres, it is 25.08% for 1.00% volume of fibres it is 29.4%, for 1.5% volume of fibres it is 51.1%.

For any percentage of silica fume in the mix of concrete, the split tensile strength has increased with increase in percentage of fibres. It is obvious that steel fibres contributes more towards tensile strength. With an optimum silica fume percentage of 15 and fibre percentage 1.5, the increase in split tensile strength is quite considerable and is around 56.5%.

5.6.4 Effect of Fibre on Flexural Strength of Fibrous Silica Fume Concrete
(Ref. Table-4.3.4 and Fig. 19)

The increase in flexural strength after 28 days during for fibrous silica fume concrete over plain concrete with silica fume replacement 5% and 0.5% volume of fibres, is 5.8%, for 0.75% volume of fibres, it is 17% for 1.00% volume of fibres, it is 22% and for 1.50% volume of fibres, it is 39.40%.

The increase in flexural strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement 10% and 0.5% volume of fibres, is 13.0%, for 0.75% volume of fibres, it is 22%, for 1.0% volume of fibres, it is 27.8% and for 1.50% volume of fibres, it is 44%.

The increase in flexural strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement 15% and 0.5% volume of fibres, is 17.8%, for 0.75% volume of fibres, it is 24.80%, for 1.0% volume of fibres, it is 37.8% and for 1.5% volume of fibres, it is 49.2%.
The increase in flexural strength after 28 days curing for fibrous silica fume concrete over plain concrete with silica fume replacement of 20% and 0.5% volume of fibres, is 14.80% for 0.75% volume of fibres, it is 20.40%, for 1.00% volume of fibres, it is 25.4% and for 1.50% volume of fibres, it is 34.20%.

For any percentage of silica fume in the mix of concrete, the flexural strength in present case has increased with increase in percentage of fibres. It is obvious that steel fibres contributes more towards flexural strength. With an optimum silica fume percentage of 15 and fibre percentage 1.5, the increase in flexural strength is quite considerable and is around 49.2%.

5.6.5 Effect of Silica Fume Dosage on Compressive Strength of Fibrous Silica Fume Concrete
(Ref. Table-4.3.2 & Fig.17)

The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with 0.5% volume of fibres and silica fume replacement of 5% is 17.4% for silica fume replacement of 10%, it is 19.51% for silica fume replacement of 15% it is 24.11% and for silica fume replacement of 20% it is 18.05%.

The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with 0.75% volume of fibres and silica fume replacement of 5% is 19.92% for silica fume replacement of 10%, it is 22.40% for silica fume replacement of 15% it is 26.83% and for silica fume replacement of 20% it is 19.51%.

The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with 1.00% volume of fibres and silica fume replacement of 5% is 20.6% for silica fume replacement of 10%, it is 22.91% for silica fume replacement of 15% it is 27.72% and for silica fume replacement of 20% it is 20.67%.

The increase in compressive strength after 28 days curing for fibrous silica fume concrete over plain concrete with 1.50% volume of fibres and silica fume replacement of 5% is 23.26% for silica fume replacement of 10%, it is 28.6% for silica fume
replacement of 15% it is 34.53% and for silica fume replacement of 20% it is 21.38%. Similar pattern can be observed with other percentages of fibres.

For any percentage of fibre in the mix of concrete, the compressive strength increases upto 15% and then decreases.

5.6.6 Effect of Silica Fume Dosage on Split Tensile Strength of Fibrous Silica Fume Concrete

(Ref. Table 4.3.3 & Fig.18)

The increase of split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with 0.5% volume of fibres and silica fume replacement of 5% is 12.37%, for silica fume replacement of 10% it is 14.71%, for silica fume replacement of 15% it is 24.08% and silica fume replacement of 20%, it is 14.71%.

The increase of split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with 0.75% volume of fibres and silica fume replacement of 5% is 18.73%, for silica fume replacement of 10% it is 23.74%, for silica fume replacement of 15% it is 30.43% and silica fume replacement of 20%, it is 25.08%.

The increase of split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with 1.00% volume of fibres and silica fume replacement of 5% is 25.08%, for silica fume replacement of 10% it is 27.42%, for silica fume replacement of 15% it is 35.78% and silica fume replacement of 20%, it is 29.43%.

The increase of split tensile strength after 28 days curing for fibrous silica fume concrete over plain concrete with 1.50% volume of fibres and silica fume replacement of 5% is 30.43%, for silica fume replacement of 10% it is 32.44%, for silica fume replacement of 15% it is 56.52% and silica fume replacement of 20%, it is 51.17%. Similar pattern can be observed with other percentages of fibres.

For any percentage of fibre in the mix of concrete, the split tensile strength increases upto 15% silica fume replacement and then decreases.
5.6.7 Effect of Silica Fume Dosage on Flexural Strength of Fibrous Silica Fume Concrete
(Ref. Table-4.3.4 and Fig.19)

The increase in flexural strength after 28 days curing for fibrous silica fume concrete over plain concrete with 0.5% volume of fibres and silica fume replacement of 5% is 5.80%, for silica fume replacement of 10%, it is 13.00%. for silica fume replacement of 15%, it is 17.80% and for silica fume replacement of 20% it is 14.80%.

The increase in flexural strength after 28 days curing for fibrous silica fume concrete over plain concrete with 0.75% volume of fibres and silica fume replacement of 5% is 17%, for silica fume replacement of 10%, it is 22%, for silica fume replacement of 15%, it is 24.80% and for silica fume replacement of 20% it is 20.40%.

The increase in flexural strength after 28 days curing for fibrous silica fume concrete over plain concrete with 1.00% volume of fibres and silica fume replacement of 5% is 22.00%, for silica fume replacement of 10%, it is 27.80%. for silica fume replacement of 15%, it is 37.80% and for silica fume replacement of 20% it is 25.40%. Similar pattern can be observed with other percentages of fibres.

For any percentage of fibre in the mix of concrete, the flexural strength increases upto 15% silica fume replacement and then decreases.

5.6.8 Balling Effect due to High Percentage of Fibres

In the present investigation to study the strength properties of fibrous silica fume concrete, the percentage of steel fibres has been gradually increased from 0.5 % to a maximum of 1.5 %. A constant aspect ratio of 50, for fibres has been adopted. The fibres have been randomly mixed in concrete. If the study has been continued beyond 1.5% fibres it is doubtful that these strength results would be consistent, because with increase in fibre content balling effect may take place effecting the strength adversely.
5.7 RESULTS OF FLEXURE TESTS ON STANDARD BEAMS OF SILICA FUME FIBROUS CONCRETE

In addition to a flexural strength the properties like load deflection characteristics, cracking behaviour and ductility characteristics are also discussed here in for silica fume fibrous concrete beams of standard sizes tested in the laboratory.

5.7.1 Load Deflection Characteristics of Fibrous Silica Fume Concrete

Plain concrete is brittle in nature and the specimen fails suddenly under the ultimate load when tested for flexure. The value of modulus of rupture is low for plain concrete. Addition of fibres improves the load-deflection characteristics of silica fume concrete. It is seen from fig. 20 to 23 that a smooth non-linear relation is obtained between the load and deflection for fibrous silica fume concrete specimens. The increase in deflection with the increase of load is smooth and gradual.

The failure of fibrous silica fume concrete specimen under the ultimate load has not been sudden as in the case of plain concrete. Not only the failure is gradual their has been considerable increase in the ultimate load carrying capacity as well as flexural strength with the presence of fibres in silica fume concrete matrix.

5.7.2 Cracking Characteristics

(Ref. Table-4.3.5 to 4.3.8 and Fig 20 to 23)

The load at first flexural crack has been determined by visual inspection and all the beams with steel fibrous silica fume concrete showed consistently higher first cracking load over plain concrete specimens. The first crack and ultimate failure occurred almost at the same time in plain concrete specimens. In fibrous concrete, the first visible crack appeared after the specimen in loaded to 95% of its ultimate failure load. This may be taken as a warning before the failure unlike in the plain concrete specimens. It has also been observed from these investigations that the first crack and the ultimate failure loads are approaching higher values with the addition of more and more fraction if steel fibres in silica fume concrete.
It has been noticed that steel fibres are having significant effect in resisting the
growth of cracks as well as the propagation of cracks. This can be due to dissipation of
part of work done by external loads in destroying bond and it is causing frictional
slippage of the matrix with the fibres. Thus the energy available for developing the
crack surface is considerably reduced. The propagation of cracks is gradual. Hence it is
further validated that the fibres contribute towards arresting tension cracks even in
silica fume concrete.

The plain concrete beams have catastrophically failed into two pieces without
any warning. The crack propagation in fibrous silica fume concrete specimens has been
gradual because the tensile cracks have been arrested by the fibres present in the matrix.

5.7.3 Ductility Characteristics of Fibrous Silica Fume Concrete Beams

Unlike plain concrete beams the fibrous silica fume concrete beams have
exhibited better ductility characteristics. The beams of fibrous silica fume concrete on
only have taken more ultimate load but also exhibited better failure characteristics. The
deflection capacity is very much increased and the crack propagation has been gradual.
Even the final ultimate failure is not catastrophic, rather the failure is gradual.

5.8 STUDIES ON MICRO SILICA COMPOSITES

5.8.1 Characteristics of Micro Silica

(Ref. Table-4.1.4 & 4.1.5)

Micro silica is a fine amorphous powder which can readily mix with cement to
form use-full compounds. Micro silica possess high percentage of (85%) reactive
silicon dioxide. Its pozzolanic action is very active. This may be due to greater
fineness and high reactivity. Based on properties micro silica can be adopted as a
useful pozzolanic replacement to the cement to produce Mortars or Concrctes with
enhanced properties.
5.8.2 Results of Cement Mortar Cubes With Micro Silica
(Ref. Table-4.4.1 and Fig. 24, 25 & 26)

In the preparation of standard cement mortar cubes to assess the cement strength a fixed w/c ratio is followed as per the codal procedure. However when cement is replaced with micro-silica by certain percentage this procedure may yield adverse results. Because the water content in the mix may not be sufficient to combine with all particles of micro-silica which are very fine. Hence to know the influence of micro-silica replacement on cement strength various w/c ratios have been adopted and strengths at various ages have been found. This procedure has been repeated for various percentages of micro-silica replacements. As seen from table-4.4.1-- and as shown in figure 24, 25 & 26 the optimum micro-silica percentage is 12%. Optimum strength results are obtained at w/c ratio in the range of 0.4 to 0.5. Beyond 12% micro-silica replacement there is no beneficial effect on strength. Strength of the sample increases with age upto a maximum of 90 days. These observations have been made use in assessing the behavior of micro-silica concretes.

5.8.3 Workability of Cement Concrete with Micro Silica
(Ref. Table-4.4.6)

Micro silica has very much superior fineness compared to cement. Where micro silica is used as partial replacement of cement more water is required to wet all the particles of micro silica and as such, the workability gets reduced for the same water/cement ratios. The workability tests have been conducted using compaction factor apparatus and the results are shown in table 4.4.6 for various concrete mixes. It can be seen from the table-4.4.6. that the water cement ratio is slightly increased to give almost medium workability. Along with water/cement ratio, a little adjustment is made in the quantity of sand also. In the case of high strength concrete mix, like M50 the design mix with or without micro silica possess slightly low workability. Hence it can be stated that, slight adjustments of water content and sand content are required for concrete mix with micro silica to maintain the required workability.
5.8.4 Mix Design with Micro Silica  
(Ref. Table-4.4.3 & 4.4.4)

In the present experimental investigation concrete mixes from M20 to M50 have been designed using IS code procedure (I.S Code 10.262). As per the codal procedure the target mean strength is arrived at based on statistical considerations. The required water cement ratio, water content, cement content are worked out. Checks are carried out for workability and maximum cement content. The quantities of coarse and fine aggregates are computed. The final mix proportions are arrived at after making trials. Following this procedure the mix proportions for various grades of concretes are worked out and they are shown in table-4.4.3. The quantities of material required for 1 Cu.m of concrete are shown in table-4.4.4. The cement content required for various grades of cement concrete has been directly replaced by 12%. Micro silica contents arrived at corresponding micro silica concrete mixes. In working out the mix proportions it is ensured that the cement content is not exceeded 450 Kg per cubic meter for any mix design. As per the stipulations of I.S 456-2000.

No special design procedure has been adopted for micro silica concrete. The mix proportions are evolved with direct replacement of cement by Micro silica at 12%, which is considered to be optimum. Only slight adjustment in water content is required to maintain workability. Hence it can be stated that for practical concrete mixes with micro silica direct replacement may be adopted.

5.8.5 Savings in Cement Content

In the present experimental investigation, cement has been replaced directly by micro silica to the extent of 12%. Hence saving in cement is only 12% and to that extent micro silica has been added. By doing so the strength and the other properties of concrete enhanced. In fact micro silica is more expensive than cement, hence replacement of cement by micro silica should not be viewed from economical point of view.

Hence it may be stated that in micro silica concretes replacement of cement does not lead to economy as Micro silica is relatively more expensive.
5.8.6 Strength of Micro Silica Concretes
(Ref. Table-4.4.2)

It can be seen that in all the design mixes from $M_{20}$ to $M_{50}$, replacement of cement by 12% micro silica has yielded better strengths. For example in the case of $M_{20}$ concrete the 28th day compressive strength has increased by 10% with the addition of 12% micro silica. Similarly there is increase in the other mixes also. Hence it may be stated that addition of micro silica results in better 28 days strength. Micro silica can be considered as a useful replacement to cement for the design of high strength concrete mixes.

5.8.7 Strength of Micro Silica Concrete with Age
(Ref. Table-4.4.2)

There are substantial increases obtained in strengths with the age of various mixes with micro silica. In the case of cement concrete without micro silica the increase in strength with age beyond 28 days is not significant. As already stated Micro silica is basically pozzolanic in nature. As such extended periods of curing has generated better strengths. Hence it may be finally stated that development of strength takes place in Micro silica concretes even after 28 days of curing.

5.8.8 Acid Resistance of Micro Silica Cement Concrete
(Ref. Table-4.4.7)

In addition to strength, durability property is also important for concrete. When concrete is exposed to aggressive environment consisting of chlorides and sulphates it should not be subjected to deterioration. Pozzolanic admixtures as replacements for cement in concrete are known to enhance the durability property of concrete. To study the effect of micro silica replacement on durability, acid resistance tests have been conducted in the laboratory. Specimens of concrete cured for 28days are exposed to (a) 2% HCl (b) 2% $H_2SO_4$. The period of exposure is kept as 7days, 14 days and 90 days. Both types of specimens with and without micro silica have been tested for comparison. Two grades of concrete i.e $M_{20}$ and $M_{50}$ have been tried in the test. The results of acid Resistance tests conducted on the above specimen are given in table-4.4.7. The photographs are shown 8.1.1, 8.1.2, 8.1.3, 8.1.4.
1. **Specimens Exposed to 2% HCl:**

From the table 4.4.7, it can be seen that there is not much difference between normal specimens and micro silica specimens when they are exposed to 2% HCl. After exposure to 7 days, 14 days and 90 days the loss of weight measured is almost same in specimen with or without micro silica. Hence the micro silica material used in the present investigation is not contributing much towards chloride resistance. This is true for any grade of concrete.

2. **Specimens Exposed to 2% H₂SO₄:**

The results of specimens exposed to 2% H₂SO₄ indicate that micro silica helps concretes considerably in resisting sulphates. There is a reduction of weight loss of nearly 50% in the case of micro silica compared to normal specimens for specimens exposed for 7 days. Similarly in the case of specimens exposed for 14 days and 90 days there is a substantial saving in weight, in the case of micro silica specimens compared to those without micro silica. Hence it can be concluded that micro silica helps concrete in having better sulphate resistance. Micro silica can be recommended as a useful admixture to enhance durability of concrete in aggressive environments consisting of sulphate.

5.8.9 **Drying Shrinkage**

(Ref. Table-4.4.9)

From table 4.4.9 it can be seen that with 12% replacement of cement by micro silica the drying shrinkage decreases. While it is 0.10MM at replacement, it has gone upto a Maximum of 0.12 mm at no replacement. i.e., a decrease of 14% the allowable maximum drying shrinkage for fly ash concretes is 15% for grade I fly ash. The maximum percentage of drying shrinkage observed in experiments are found to be below this value.
5.8.10 Creep of Micro Silica Concrete  
(Ref. Table-4.4.10)

From the results of the creep studies tabulated in table 4.4.10 for a stress strength ratio of 0.4 it can be seen that the elasticity shrinkage immediately after loading observed for no replacement concrete is 1.52mm whereas it is 1.54mm for 12% replacement of cement by micro silica. The increase in creep is 1.3% more for 12% replacement.

5.8.11 Permeability of Micro Silica Concrete  
(Ref. Table-4.4.8)

The results tabulated in table 4.4.8 it can be seen that for all mixes i.e., M15, M20 and M25 the permeability is observed to be reduced in Micro silica cement concrete in all grades. In M15 Mix, the coefficients of permeability observed are 25.11x 10^{-8} M/sec. And 10.29 x 10^{-8} M/Sec. For 0% and 12% replacement i.e., 59% reduction of permeability at 12% replacement. Similarly for M20 and M25 concretes, the reductions observed are 55% and 54% respectively at 12% replacement. Hence even 12% micro-silica has contributed towards a more impermeable concrete.

5.8.12 Micro Structure of Micro Silica Concrete  
(Ref. Photographs 8.1.5, 8.1.6, 8.1.15, & 8.1.16)

To know the internal microstructure of concrete with and without micro silica photographs have been taken of crushed concrete after conducting compression test at the age of 28 days on both the types of specimens. These are shown in figure 8.1.6 without micro silica and 8.1.5 with micro silica.

It is quite clear from the magnified photographs (8.1.15 & 8.1.16) that the micro structure of concrete has been rendered more glassy and crystalline compared to the one’s with out micro silica. Because of this phenomena micro silica concrete is more strong in compression compared to ordinary concrete. In addition micro silica concretes more impermeable in nature.
5.9. STUDIES ON FIBROUS MICRO SILICA COMPOSITES

5.9.1 Effect of Micro Silica and Fibre on Workability
(Ref. Table-4.5.1)

The workability of fibrous micro silica concrete decreases with increase in Fibre content. This decrease is due to the large surface area of fibres. Addition of plasticiser becomes necessary to maintain the required workability, particularly when the fibre percentage is more. Hence the presence of fibres reduces the workability of micro-silica concrete also.

5.9.2 Effect of Fibre on Compressive Strength of Fibrous Micro Silica Concrete
(Ref. Table-4.5.2 and Fig. 27)

The increase in compressive strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.5 is 14.8%, for 0.75% by volume of fibres is 16.7%, for 1.0% by volume of fibres is 24.5%, and for 1.5% by volume of fibre is 28.3%.

The increase in compressive strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.45 is 14.3%, for 0.75% by volume of fibres is 17.8%, for 1.0% by volume of fibres is 22.9%, and for 1.5% by volume of fibre is 26.1%.

The increase in compressive strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.4 is 12.2% for 0.75% by volume of fibres is 15.2%, for 1.0% by volume of fibres is 19.7%, and for 1.5% by volume of fibre is 24.5%.

The increase in compressive strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.35 is 15.3% for 0.75% by volume of fibres is 17.3%, for 1.0% by volume of fibres is 21.3%, and for 1.5% by volume of fibre is 24.2%.
Hence, from the above it can be seen that the fibre content is contributed towards the increase in compressive strength of micro-silica concrete. As the fibre content is increased the compressive strength also gets increase. The maximum % fibres tried in the presence investigation is 1.5%. The increase in compressive strength with increase in fibre content is true for all the w/c ratios. But on close examination it can be seen that 0.5 water cement ratio looks to be optimum to give the highest compressive strength at the highest fibre content of 1.5%. For w/c ratio less than 0.5 like. 0.45, 0.4, etc. a maximum fibre content of 1.5% is giving slightly lesser strength compared to that of 0.5 w/c ratio. This may be due to insufficient dispersion of fibres in the matrix at lower w/c ratio.

5.9.3 Effect of Fibre on Split Tensile Strength of Fibrous Micro Silica Concrete

(Ref. Table-4.5.3 and Fig. 28)

The increase in split tensile strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.5 is 12.5%, for 0.75% by volume of fibres is 13.1%, for 1.0% by volume of fibres is 20.6%, and for 1.5% by volume of fibre is 24.3%.

The increase in split tensile strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.45 is 7.5%, for 0.75% by volume of fibres is 10.8%, for 1.0% by volume of fibres is 16.2%, and for 1.5% by volume of fibre is 18.6%.

The increase in split tensile strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.4 is 6.9%, for 0.75% by volume of fibres is 9.7%, for 1.0% by volume of fibres is 14%, and for 1.5% by volume of fibre is 18.5%.

The increase in split tensile strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of
fibres and w/c ratio of 0.35 is 5.9%, for 0.75% by volume of fibres is 7.7%, for 1.0% by volume of fibres is 11.4%, and for 1.5% by volume of fibre is 14.0%.

As discussed under 5.9.2 even in the case of split tensile test a w/c ratio 0.5 looks to be optimum. For lower w/c ratios there may be dispersion problems at high fibre contents leading into reduction in strengths. The tested specimens are shown in photograph 8.1.14

5.9.4 Effect of Fibre on Flexural Strength of Fibrous Micro Silica Concrete (Ref. Table-4.5.4. and Fig. 29)

The increase in flexural strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.5% is 14.2%, for 0.75% by volume of fibres is 28.5%, for 1.0% by volume of fibres is 42.8%, and for 1.5% by volume of fibre is 47.6%.

The increase in flexural strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.45 is 18.2%, for 0.75% by volume of fibres is 31.3%, for 1.0% by volume of fibres is 44.3%, and for 1.5% by volume of fibre is 50.8%.

The increase in flexural strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.4 is 20%, for 0.75% by volume of fibres is 32.7%, for 1.0% by volume of fibres is 44%, and for 1.5% by volume of fibre is 56%.

The increase in flexural strength after 28 days curing for fibrous micro silica concrete over plain concrete with micro silica replacement of 12%, 0.5% by volume of fibres and w/c ratio of 0.35 is 13.5%, for 0.75% by volume of fibres is 18.6%, for 1.0% by volume of fibres is 25.4%, and for 1.5% by volume of fibre is 32.2%. 
5.9.5 Load Deflection and Ductility Characteristics of Fibrous Micro Silica Concrete
(Ref. Table-4.5.6 to 4.5.9, Fig. 30 to 33 & Photographs 8.1.7 to 8.1.9)

Plain concrete is brittle in nature and the specimen fails suddenly under the ultimate load. The value of modulus of rupture is low for plain concrete. Addition of fibres improves the load-deflection characteristics of micro silica concrete. It is seen from figures 30 to 33 that a smooth non-linear relation is obtained between the load and deflection for fibrous micro silica concrete specimens. The increase in deflection with the increase of load is smooth and gradual.

There is gradual increase in the value of modulus of structure with increase in fibre content over that of plain silica-fume concretes without fibres. This is true for all w/c ratios with 12% micro-silica and 1.5 % fibres the maximum increase in the value of modulus of rupture is nearly 50% over that of no fibre concrete.

Addition of fibres increases the ductility characteristics of Micro silica concrete. The failure of fibrous micro silica concrete specimen under the ultimate load has not been sudden as in the case of plain concrete. The ductility characteristics are similar to those already discussed under 5.7.1. The photographs are shown 8.1.7, 8.1.8 & 8.1.9.

5.9.6 Cracking Characteristics

The load at first flexural crack has been determined by visual inspection and all the beams with steel fibrous micro silica concrete showed consistently higher first cracking load over plain concrete specimens. The first crack and ultimate failure occurred almost at the same time in plain concrete specimens. In fibrous concrete, the first visible crack appeared after the specimen in loaded to 95% of its ultimate failure load. This may be taken as a warning before the failure unlike in the plain concrete specimens. It has also been observed from these investigations that the first crack and the ultimate failure loads are approaching higher values with the addition of more and more fraction of steel fibres in micro silica concrete.
It has been noticed that steel fibres are having significant effect in resisting the growth of cracks as well as the propagation of cracks. This can be due to dissipation of part of work done by external loads in destroying bond and its causing frictional slippage of the matrix with the fibres. Thus the energy available for developing the crack surface is considerably reduced.

The plain concrete beams have catastrophically failed into two pieces without any warning. The crack propagation in fibrous Micro silica concrete specimens has been gradual because the tensile cracks have been arrested by the fibres present in the matrix. Ductility characteristics are very much better with fibres.

Hence the concrete produced using Micro silica with certain percentage of fibres possesses optimum properties.

5.9.7 Permeability of Fibrous Micro Silica Concrete 
(Ref. Table 4.5.5 and Photograph 8.1.13)

As seen from table 4.5.5 the presence of 1% steel fibres has not much altered the permeability characteristics of micro-silica concrete. Hence, it can be concluded in the case of micro-silica concrete (with 12% micro-silica) the presence of steel fibres with an aspect ratio of 50 and the volume content of 1% only marginally effects the permeability characteristics. The test setup shown in photograph 8.1.13.

5.10 STUDIES ON MICRO SILICA CONCRETES WITH PLASTICISING ADMIXTURES

5.10.1 Workability of Micro Silica Concrete with Admixtures 
(Ref. Table 4.6.1 and Fig. 34 & 35)

Micro silica has very much superior fineness compared to ordinary Portland cement. Where micro silica is used as partial replacement of cement more water is required to wet all the particles of micro-silica and as such the workability gets reduced for the same water /Cement ratio. In the present investigation of a nominal mix $M_{15}$ (1:2:4) with and without Micro-Silica (12%) with different W/C ratio of 0.35, 0.40.
0.45, 0.50 (treating fine aggregate, course aggregate and cement are constant quantities and water quantity is the only variable w.r.t W/C) has been carried out. The workability tests have been conducted using compaction factor apparatus and the results are shown in table 4.6.1 for various W/C ratios. The effect of micro silica on the workability of micro-silica concrete can be seen from table-4.6.1. It is observed that the workability is reduced compared to the nominal mix.

To increase the workability of micro-silica concrete particularly at low W/C ratios water reducing admixtures such as superplasticiser (SP337) and plasticiser (P211) have been used separately at different dosages with and without micro-silica. The test results are shown in table 4.6.1. The effects of Super plasticiser and plasticiser on workability of micro silica concrete are shown separately in the same table. It can be observed from the results that the workability is increased in both the cases. Hence it can be stated that increase in water content or using of Super plasticiser are required for concrete with micro-silica to maintain the required workability. Further it can be stated that 12% of micro-silica in concrete gives optimum workability with 1.5% plasticiser at a w/c ratio of 0.5.

5.10.2 Effect of Superplasticiser on the Strength of Concrete (Ref. Table-4.6.3 and Fig. 36 & 37)

The concrete mix M15 (1:2:4) with different dosages of Superplasticiser (0.5, 1.0, 1.5%) and different W/C ratios has been used to prepare concrete cubes the test results are shown in table-4.6.3. It can be observed from table 4.6.3 that the 28 days strength has increases up to 10 % at 1.5% superplasticiser by weight of binder. Hence it can be stated that in nominal concrete mixes superplasticiser is useful in giving higher strengths at low water cement ratios and optimum 1.5% of superplasticiser has been achieved in the present case.
5.10.3 The Effect of Micro Silica and Superplasticiser on the Strength of Concrete

(Ref. Table-4.6.4 and Fig.38)

The concrete mix M_15 (1:2:4) with 12% micro silica and different dosages of Superplasticiser and different water/cement ratio has been used to prepare concrete specimens. The strength micro-silica concrete increased in the percentage of superplasticiser. Referring table 4.6.4 it can be observed that these strength has increased up to 10% at 1.5% superplasticiser by weight of binder. In general there is strength increases of micro silica concrete with increase in the percentage of superplasticiser out of the percentage tried 1.5% of superplasticiser to be given optimum strength for all w/c ratios in the case of micro-silica concrete.

5.10.4 Optimum Mixes with Micro Silica and Superplasticiser

Based on the discussion all ready made, it is generally observed Superplasticiser contributing towards strength increases in the case of micro silica concrete. This is true even upto a W/C ratio 0.5. In the case of nominal W/C ratios both plasticiser and superplasticiser give the required workability.

5.11 STUDIES ON MICRO SILICA REINFORCED CONCRETE BEAMS

5.11.1 Load Deflection Characteristics

(Ref. Table-4.7.1, Fig. 39 & Photographs 8.1.10, 8.1.11 & 8.1.12)

The results of experimental investigation for studying the load deflection behavior and failure characteristics of 100x150x1400 MM reinforced concrete beams with shear reinforcement under one third point loading tabulated on 4.7.1 and shown in fig. 39. Indicate the following.

From the data and curves it can be seen that the deflections are on slightly higher side for reinforced beams cast with ordinary concrete without micro silica when compared to 12% Micro silica reinforced concrete beams. This is true almost upto the failure even though at certain loads identical deflections are observed. However the differences are very minor. The first crack load for no replacement beam is 16 KN
with 0.05 MM deflection where as the load is 18 KN with 0.01 MM deflection for 12% replacement concretes. The second crack is observed to be formed at 20 KN in both cases. Third crack appeared at 30 KN for no replacement concrete beams where as for the 12% replacement concrete beams it is 31KN.

Hence it is cleared the presence of micro silica in the conventional R.C.C. beams has not caused any appreciably change in the flexural behaviour. The load deflection characteristics are affected only very marginal.

Photographs 8.1.10, 8.1.11, 8.1.12 shows the cracking pattern of the beams with and without replacement of cement by Micro silica. From this, it can be observed that the cracking behavior of both the beams are almost similar.

5.11.2 Effect of Fibres on Load Deflection Characteristics
(Ref. Table-4.7.1 and Fig. 39)

It can be seen that the presence of 1% fibres in reinforced micro silica concrete beams is advantages in respect of ductility. Though there is no reference in the ultimate load carrying capacity the beams are able to take more deflections. Even the formation of first crack and subsequent cracks has been delayed from considerably due to presence of fibres. Hence it may be concluded that in the present case the presence of fibres has helped in imparting more ductility and better cracking behaviour to reinforced cement concrete beams. This is true with and without micro silica.