Experimental Study of Ductility of High Strength Concrete with the Addition of Randomly Oriented Steel Fibers

R Hanumantha Reddy[1], Dr. K. Rajasekhar[2], Dr. C. Sasidhar[3]

[1]*Lecturer in Civil Engineering, Govt. Polytechnic, Pillaripattu (Nagari), Chittoor Dt, Andhra Pradesh, India.*

[2]*Senior Professor of Civil Engineering, Department of Civil Engineering, Siddartha Educational Academy Group of Institutions, SEAT, Tirupati, (India).*

[3]*Senior Professor of Civil Engineering, Department of Civil Engineering, JNTU College of Engineering, JNTUA, Ananatapuramu, Andhra Pradesh , India.*

Abstract: **The present scenario of the world poses many challenges to the Civil Engineers due to the advancements in the Science & Technology creating complex situations where the structures are going to sustain. Further, the tremendous increase in land cost necessitates the use of high rise buildings, which are almost like mini cities, subjected heavier stresses at the lower storeys. Another challenge for the Civil Engineer would be the rehabilitation and retrofitting of old structures. The liquid retaining structures should be leak proof, and it may not be possible to avoid growth and propagation of micro cracks with normal concrete. Industrial structures, which are susceptible to high temperatures and various chemical exposures, is another area requiring special attention. Hence use of High Strength Concrete (HSC) is a necessity. But the HSC by its nature exhibits brittleness compared to the Normal Strength Concrete (NSC). The ductility can be imparted to the HSC by the addition of steel fibres. Industrial waste like fly ash, is essential to achieve high strength because of its high specific surface area and pozzolanic reactivity requiring less water binder ratio. This research work exhibits the improvement of ductility of HSC with the addition of randomly oriented steel fibers.**

Key Words: **Fibre index (Fi), Volume fraction of fiber (Vf), fly ash, Aspect Ratio (AR), Ductility Factor (Df).**

Materials: **Fly ash, Cement, Aggregates, Super Plasticisers, Steel fibers.**

I. INTRODUCTION

The main accepted properties of HSC are more linear response, less micro cracking, higher modulus of elasticity, higher tensile strength and less creep but its main disadvantage is the brittleness. The addition of steel fibers to HSC results in improved structural properties such as better resistance against cracking, impact, thermal shocks, wear, fatigue and spalling in addition to the improvement in mechanical properties such as compressive, flexural, tensile and shear strengths, ductility and toughness. The use of good quality fly ash reduces water demand and hence improves the strength of concrete. The addition of fly ash also improves the workability at green stage and density at hardened state. Many researchers in the past made studies to improve the compressive strength of concrete by the inclusion of the fibers. Hence an attempt is made to study the improvement of ductility of the HSC by the addition of the steel fibers.

II. NEED FOR THE STUDY

The preliminary observation shows that the ductility of fly ash concrete can be improved by adding the random oriented straight steel fibres, which has been suggested by few investigators.

The investigators do not include all the parameters, which are affected by the addition of random oriented straight steel fibres. Due to the limited felt data available, it has been necessary to investigate all the parameters, which represent the ductility, are hereby investigated.

In the present investigation, the effect of straight steel fibres with random orientation on the following parameters are studied: The steel fibres of volume fractions 0%, 0.3%,0.7% and 1.0% with aspect ratios 50 and 80 are added and 88 specimens, i.e., four cubes of 100x100, four prisms of 200x100x100mm and 400x100x100mm were cast and the effect due to the addition of Steel Fibers was studied on the parameters, i.e., i) Compressive strength, ii) Modulus of rupture, iii) Ultimate stress, iv) Strain at Ultimate stress, v) Strain at 85% of Ultimate stress in the ascending portion of stress strain curve and vi) Strain at 85% of Ultimate stress in the descending portion of stress strain curve.

III. PREPARATION OF SPECIMENS

Mix details for each batch of Concrete: Trial mixes were attempted to obtain M70 grade of concrete. The final mix proportions adopted in the present investigation is 1:0.495:1.1:0.055:0.27 (C:FA:CA:Flyash:Water). For this mix cement is replaced with 10% fly ash (which passes through 150μ sieve). Super plasticizer of 11.02 1/m3 of concrete is used.

3(a) Preparation of fibre

The fibres are obtained by cutting the G.I. binding wire into required length, to (T et the desired aspect ratio. Binding wire of diameters 0.41 mm and 0.70 are chosen such that the fiber can be oriented freely in the mix. And the details are given below. Small bundles of 15-20 wires are prepared and cut into pieces of required length with the help of shear cutting machine. The fibre is weighed and kept for mixing according to the requirement for each set of specimens.

Sl. No.	Aspect ratio(l/d)	Diameter, d (mm)
1	50	0.70
2	80	0.41

3(b) Measurement of Strains

Testing is conducted as per IS:516-1959, according to which the gauge length should not be less than 100 mm and not more than half the length of the specimen. In this test, gauge length of 100 mm is selected to the conditions laid down by IS:516-1959. Two steel frames are fixed at a centre-to-centre distance of 100 mm apart symmetrically along the length of the specimen, by means of four screws at central point on the four faces of specimen. Four dial gauges with least count of 0.002mm are fixed at four corners of frame to account for incidental eccentricities that are likely to occur during placing of specimens. The swivelling head was arranged carefully to avoid the eccentric loading. The specimen which is ready for testing (with four dial gauge arrangement) is shown in

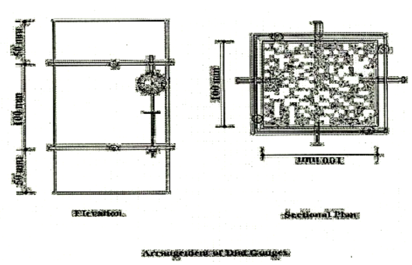

Figure.1.

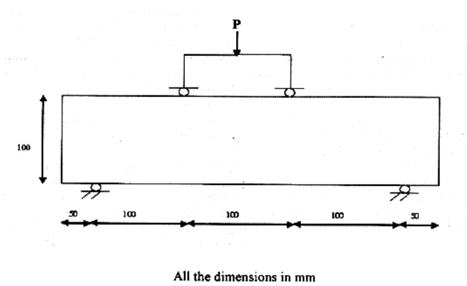

Figure.2

3(c) Testing of Prisms under Uni-axial Compression:

The specimen is oriented centrally on the cross head of universal testing machine. The bottom cross-head is raised such that both the heads are in touch with the specimen. Proper range of loading is selected and needle indicator is set to zero. A load of 5000Lb is initially applied to check the sound working of gauges and to give chance of initial adjustments at the contact of the heads and specimen is unloaded after which the dial gauges are set to initial reading. Loading is done under strain rate control at a. rate of 0.1mm/30 sec and at each 30 see, load and dial gauge readings are recorded. The above strain rate control loading is adopted to get drooping portion of stress strain curve.

During testing the load first crack was noted down. Observations after ultimate strength are taken up to 80 to 85% of the ultimate. strength to get the dropping portion of stress strain curve to study the post ultimate behaviour of specimens.

The average of four dial gauge readings were taken to arrive at the deformation under compressive loading the average change in the length was divided by gauge length to get the compressive strain. Four stress-strain curves were drawn for the same set of parameters, the average of which is taken to get stress-strain curve of specimen.

3(d)Testing of Cubes under Uni-axial Compression:

The specimen is oriented centrally on the cross head of universal testing machine. The specimen is kept in the testing machine such that, the casting face and loading face are normal to each other. The bottom cross-head is raised such that both the heads are in touch with the specimen. Proper range of loading is selected and needle indicator is set to zero. A load of 5000 Lb is initially applied and released, to check the contact of loading head and loading face of the cube. The cube is tested for its ultimate load.

3(e)Testing of prisms under bending (Modulus of Rupture):

The prism is kept as a simply supported beam and tested in flexure under two-point loading. The loading arrangement is as shown in the Figure2. The specimen is tested until the fracture.

IV. DISCUSSION ON TEST RESULTS

From the experimental study conducted to study the ductility of steel fibre reinforced High strength fly ash concrete, the experimental observations are presented as follows.

a.Behaviour of specimens under loading during the test:

The High strength fly ash concrete specimens i.e., without steel fibres have spalled appreciably and split, thus confirming brittle failure. Where as, the specimens with straight steel fibres have shown little spalling and splitting. The specimens with steel fibres continued to deform even after the ultimate strength without sudden decrease in the strength and they developed a drooping portion considerably. Thus, warning of failure could be observed, which is an indication of ductile failure. This tendency of ductile failure improved with the volume content of fibre up to 0.7%.

The specimens with 1.0% volume content of fibre have shown decreased workability, ultimate strength and lower ductility, probably due to the balling effect of fibres. The problem of decreased workability due to balling of fibres leads to difficulty in compaction because of harshness of mix.

All the specimens failed by de-bonding of fibres i.e., pulling out fibres from concrete.

b. Failure Mode:

During the application of load, it is observed that several random fibers were pulled out from the surface of concrete. The irregular failure surface can be seen in this failed concrete, which is in contrast to the plain high strength concrete. During the compression test, the popping sound of the fiber failing by pulling out is one of the special phenomena for high strength fiber concrete tests.

Two distinct type of failure modes were observed during the tests.

a) High strength concrete without fibers: The crack propagates parallel to loading direction.
b) High strength concrete with fibers: The type of failure is marked by bulging of the specimen in lateral direction, with cracking along the surface near the middle zone, which demonstrates how the addition of fibers increases the ductility in a high strength concrete.

c. Effect of steel fibers on the Characteristic Compressive Strength of Concrete:

The results of the tests conducted on the cubes are shown in the figure.3. From the figure, it can be observed that characteristic compressive strength has increased with the addition of fibres i.e., up to 0.7 % volume content of fibres. It can also be observed that the specimens with Aspect Ratio 50 have shown slightly higher strength than specimens with Aspect Ratio 80. It indicates that with increase in aspect ratio, characteristic compressive strength may decrease.

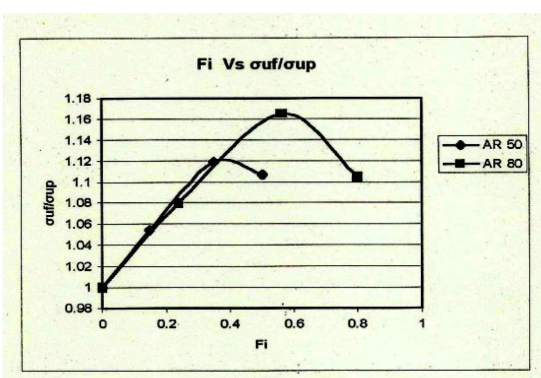

Figure.3

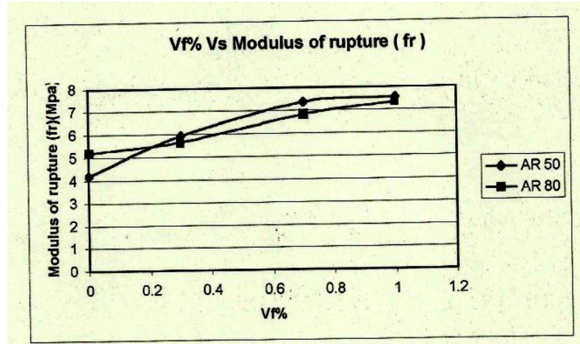

Figure.4

d. Effect of steel fibres on the Modulus of Rupture of Concrete:

From the experimental values of flexure load, i.e., tests conducted on the prisms as simply supported beams, the modulus of rupture (bending tensile strength) is calculated. The variation of Modulus of Rupture with respect to the percentage volume content of fibre is shown in Figure.4. From this figure, it is clear that the fibres will contribute to the increase in Tensile Strength of Concrete in both of the specimens with aspect ratio 50 and 80. But compared to specimens with aspect ratio 80, specimens with aspect ratio 50 have shown higher modulus of rupture. But for specimens with volume fiber content more than 0.7%, the modulus of rupture ceases to increase. It may be due to the non-homogenous mix caused by less workability. It can be observed that the presence of fibres will arrest the propagation of existing micro crack and at the same time it allows the formation of new crack. That means micro crack spacing and width of crack also decrease. This would enable to increase the tensile strength of concrete.

e. Effect of steel fibres on the Peak Stress of Stress-Strain curve:

From the Figure.5 & 6, it can be observed that the Peak Stress of High strength fly ash concrete is increased with the addition of fibres i.e., up to 0.7% volume content of fibres both in Aspect ratio 50 and 80.

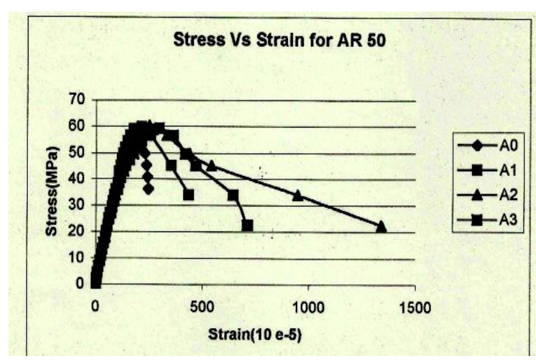

Figure.5

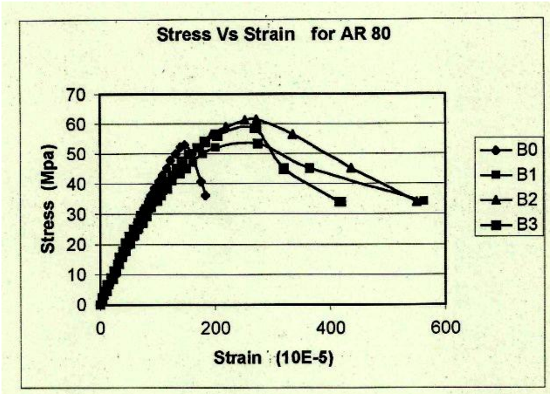

Figure.6

f. Effect of steel fibres on the Strain at Peak stress of Stress-strain curve:

The figure 5 & 6 shows stress-strain curves for aspect ratio 50 and 80 respectively. These stress-strain curves show that the peak stress and strain corresponding to the peak stress are function of fiber volume content. The addition of steel fibers increases the strain corresponding to peak stress, but does not produce much effect on the peak stress. This may be attributed to the reduced workability caused by adding fibers to a lower water-cement ratio matrix. In the concrete matrix, the aggregate may affect the orientation of fiber, and the fibers parallel to the loading direction may even produce lower strength due buckling of fibers. The fibers perpendicular to the loading direction, however, can increase the compressive strength, because the fibers tend to confine the lateral expansion of the specimen, there by reducing crack propagation. It is also observed from the figure.7 that Strain at Peak stress is increased with the addition of fibres. The strain at peak stress keeps on increasing with fibre content up to 0.7% volume fiber content and beyond that increases with decreasing rate.

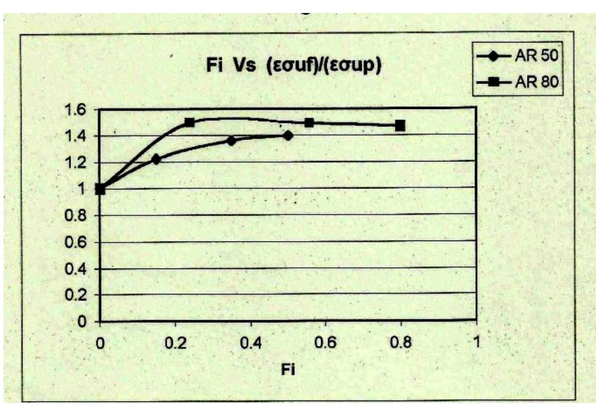

Figure.7

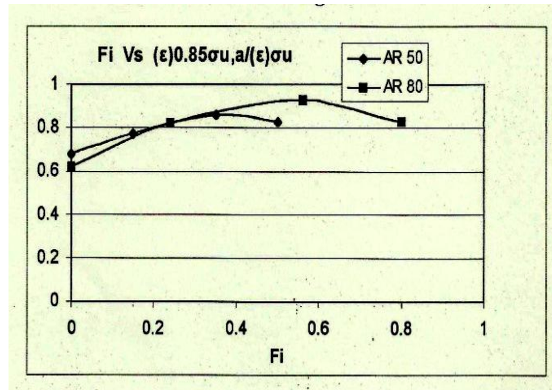

Figure.8

g. Effect of steel fibres on the Strain at 85% of Peak stress: Strain curve (Ascending Branch)

From the figure.8, it can be observed that strain at 85% of peak stress (ascending) of High strength fly ash concrete is increased with the addition of fibres. The strain at 85% of peak stress keeps on increasing with fibre content but beyond 0.7% volume fiber content the strain starts decreasing. The variation of the above results is shown in following Figure.

h. Effect of steel fibres on the Strain at 85% of Peak stress of Stress-strain curve (Descending Branch):

From the figure.9, it can be Observed that strain at 85% of peak stress in the descending portion of the stress-strain curve of fly ash High Strength concrete is increased with the addition of fibres. The strain at 85% of peak stress keeps on increasing with volume percentage of fibre.

The prominence of fibres is felt at the ultimate and more in the drooping portion of the stress- strain diagram. The stress in concrete after reaching the ultimate, shows that the fibres are arresting the widening of existing cracks. At the same time fibres are causing to originate new set of cracks. Because of this, the strain at 85% of peak stress in the drooping portion is increased.

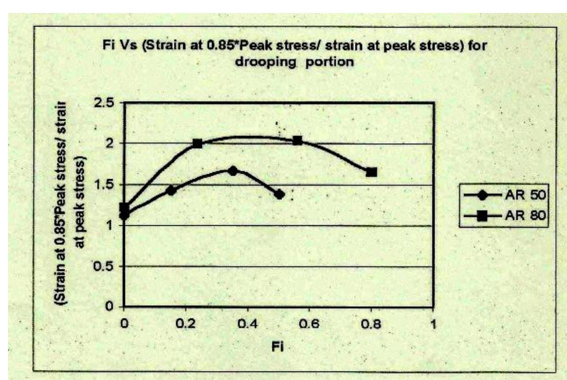

Figure.9

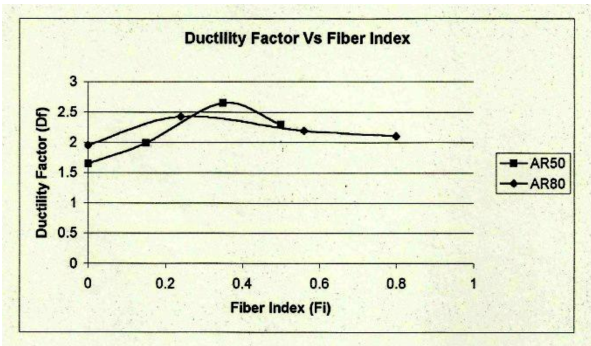

Figure.10.

i. Effect of steel fibre on Ductility Factor:

Ductility of a material is represented by the stress-strain curve parameters. To quantify the ductility, the ratio of strains in the descending and ascending portions of stress-strain curve at the same level of stress may be adopted. In the present work, Ductility Factor (Df) is defined as the ratio of Strain at 85% of Peak Stress in the drooping portion and to the strain at 85% of Peak Stress in the ascending portion of the stress-strain curve.

Ductility Factor (Df) = $\varepsilon 0.85\sigma u,d \,/\, \varepsilon 0.85\sigma u,a$

From the experimental data the ductility factor based on the above definition, is calculated for each percentage volume content of fibre and are shown in the figure.10. From this figure, it can be observed that Ductility Factor increases up to around 0.7% in both the specimens with aspect ratios 50 and 80. But specimens with Aspect Ratio 80 have shown more ductility than specimens with aspect ratio 50.Beyond 0.7% of volume content of fiber, the ductility factor has decreased due to the balling effect of fibers. At higher volume contents of fiber, the fibers are not uniformly distributed due to the balling of fibers.

V. CONCLUSIONS

From the discussion of test results, the following conclusions are arrived.

- The presence of steel fibers in the fly ash high strength concrete reduced the spalling of concrete
- The mode of failure is changed from brittle to ductile due to the inclusion of fibres in the fly ash High strength concrete.
- All the specimens failed by de-bonding of fibers i.e., pulling out fibers from concrete.
- At higher percentage volume content of fibre (1.0%), the mix became harsh and the workability decreased.
- The characteristic Compressive Strength and Modulus of Rupture of fly ash High strength concrete increased up to 0.7% volume content of fibre. The increase in compressive strength of concrete with aspect ratio 80 (around 16% for Vf% of 0.7%) is more than with aspect ratio 50 (around 12% for Vf% of 0.7%).
- The important parameters of stress- strain curve i.e., Ultimate Stress and Strain at Ultimate Stress are increased with volume content of fibre up to 0.7% and beyond 0.7% the corresponding values decreased. It is observed that the specimens with aspect ratio 80 have sustained more strain than the specimens with aspect ratio 50.
- The ductility parameters i.e Strains at 85% of peak stress in the ascending and descending portions of Stress-Strain curve for fly ash High strength concrete, are increased with the increase in volume content of fibre up to 0.7%. When the volume content of fibre is more than 0.7%, the ductility parameters decreased due to the balling effect of fibers.
- It is observed that the Ductility of fly ash high strength concrete is increased with the increase in volume percentage content of steel fibers i.e., up to 0.7% of volume fiber content and beyond that the ductility decreased.
- The prominence of fibres is felt at the ultimate stage and particularly, in the drooping portion of the stress-strain diagram.

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REFERENCES

[1]. Lin Showmay Hsu and Cheng-Tzu Thomas Hsu, "Stress-Strain Behavior of Steel-Fiber High Strength Concrete under Compression," ACI Structural Journal, Title no. 91-S44, July-August 1994, pp. 448-457.

[2]. Surendra P. Shah and B.Vijaya Rangan, "Fiber Reinforced Concrete Properties," ACI Journal, Title no. 68-14, February 1971, pp. 126-134.

[3]. Dr.Yuwaraj Maratrao Ghugal, "Effects of Steel Fibers on Various Strengths of Concrete," ICI Journal, October-December 2003, pp. 23-29.

[4]. K.Balasubramanian, B.H.Bharatkumar, S.Gopalakrishnan and V.S.Parameswaran, "Flexural behaviour of steel fibre reinforced concrete beams under static load," Journal of Structural Engineering, Vol. 25, No. 3, October 1998, pp. 167-172.

[5]. T.Y.Lim, P.Paramasivam, and S.L.Lee, "Bending Behavior of Steel-Fiber Concrete Beams," ACI Structural Journal, Title no. 84-S54, November-December 1987, pp. 44-56.

[6]. Tat-Seng Lok and Jin-Song Pei, "Flexural Behavior of Steel Fiber Reinforced Concrete," Journal of Materials in Civil Engineering, May 1998, pp. 86-97

[7]. H.V.Dwarakanath and T.S.Nagaraj, "Comparative Study of Predictions of Flexural Strength of Steel Fiber Concrete," ACI Structural Journal, Title no. 88-S73, November-December 1991, pp.

[8]. Yogendran V., B. W. Langan, M. N. Hague, and M. A. Ward, "Silica Fume in High-Strength Concrete," ACI Materials Journal, Title no. 84-M15, March-April 1987, pp. 124-129.

[9]. Tamil R. Nail(and Bruce W. Ramme, "High-Strength Concrete Containing Large Quantities of Fly Ash," ACI Materials Journal, Title no. 86-M9, March-April 1989, pp. 111-116.