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Steel Fiber Reinforced Concrete under Cyclic Loading: An Overview

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Abstract*: In recent years, it has been recognized that addition of small closely spaced and uniform dispersed discrete steel fibers in concrete substantially improve its static and dynamic properties. The addition of steel fibers from 0.5 to 2.0 per cent by volume in concrete is found to impart superior strength characteristics i.e. compressive strength, flexural strength, shear strength, fatigue strength and impact resistance. Recently, the use of steel fibers has increased in flexural members and columns of concrete structures subjected to cyclic loadings such as bridge decks, highway roads, runways of airports, offshore platforms and buildings. It is necessary to obtain more information on the mechanical behavior of steel fiber reinforced concrete under cyclic loading in attempting applications of SFRC in structural members. The present investigation was planned to study the plain and steel fiber reinforced concrete under cyclic loading. The basic parameters of the study were fiber contents expressed as volume fraction and stress levels expressed as a percentage of the maximum flexural strength. The fiber contents used were 0.5 and 1.0% by volume of concrete. The beams were tested at three stress levels i.e. 85%, 90%, and 95%. Straight mild steel fibers were used in the study with an aspect ratio of 70. The physical properties of the basic constituent material viz, cement, sand, coarse aggregate, steel fiber were obtained as per relevant Indian standard specification. The compressive strength of concrete was obtained at 28 days. The mix proportion used was 1: 1.52:1.88 by weight with a water-cement ratio of 0.47. In fresh state properties of SFRC, workability tests present were carried out with indicators of workability i.e, slump, compaction factor and inverted cone test. From the study, it was found that the addition of fibers to the concrete affects the cyclic loading life significantly under flexural cyclic loading. The variability in the cyclic loading life of specimen is quite large as expected in any cyclic loading test programme. The ultimate failure followed almost immediately after the first crack.

***Keywords*: Steel fibers, cyclic loading, concrete.**

1. Introduction

Small closely spaced and uniformly dispersed discrete fibers in concrete would substantially improve its static and dynamic properties. The addition of steel fibers in concrete considerably improves the static flexural strength, impact strength, shear and torsional strength, direct tensile strength, fatigue strength, shock resistance, ductility, and failure toughness. In many applications, particularly in pavements and bridge deck overlays, the flexural fatigue strength and endurance limit are important design parameters because these structures are designed on the basis of fatigue load cycles. The greatest advantage of adding fibres to concrete is the improvement in fatigue resistance. Plain concrete has a fatigue endurance limit of 50 to 55 per cent of its static flexural strength. A properly designed FRC can achieve a 90 to 95 per cent endurance limit. Theoretically, with a higher endurance limit, the concrete cross section could be reduced. Alternatively, using the same cross section could result in a longer life span or higher load carrying capacity or both [24]. This study was aimed at experimentally obtaining fatigue properties (fatigue life, the increase in deflections) of plain and SFRC beams subjected to repeated loading. Experiment were conducted for three loading levels (i.e. 85%, 90% and 95% of static ultimate load) and two fibre contents (i.e. 0.5 and 1.0%).

A. *Constituent materials*

In addition to conventional concrete, fibres of a great variety in various sizes and shapes are included in the fibrous concrete. sisal etc. in various shapes and sizes. A convenient numerical parameter- describing a fibre is its `aspect ratio', which is the ratio between the fibre length and its diameter (or equivalent diameter in case of non-round fibres). The aspect ratios normally range from about 30 to 150 for lengths of - 6 mm to-76 mm [37]. Steel fibres are extensively used in engineering works. Most of the steel fibres available for use in concrete are obtained by cutting and drawing. The effective and efficient use of fibres in the fibrous concrete depends largely on the uniform dispersion of fibres in the concrete, aspect ratio, volume percentage, size, gradation and quantity of coarse aggregate and the water-cement ratio.

B. *Problems with SFRC*

A significant problem with fibrous concrete mixes is to ensure adequate workability (flowability and compactibility) that will facilitate the concrete to be placed, compacted and finished with ease and also ensuring an adequate distribution of fibres. Balling of the fibres in the mixer prevents uniform distribution and also causes problems when concrete is placed. Due to the balling of fibres, fibrous concrete would not achieve the required improvement in the various properties which are needed.The use of superplasticizers eliminates the problem of reduced workability. Superplasticizers are mainly sulphonated melamine formaldehyde condensates (SMF) or sulphonated napthalene formaladehyde condensates (SNF) or modified lignosulfonates. They increase the workability of fibrous concrete without affecting its strength properties. Balling of fibres can be eliminated by use of special vibrating sieves or by manual sprinkling of fibres during mixing while mixer is kept rotating.

2. Review of literature

Historically the inclusion of natural or synthetic fibrous substance to a brittle matrix, to improve its properties has been effectively carried out for many hundred of years. The use of straw to strengthen semi-baked bricks and stabilise the dimensional stability and the addition of horse hair to reinforce mud plaster have been in use since ages. Jute and other natural fibres for reinforced cement and plasters have met with a great deal of success. The idea of closely spaced reinforcement for cement components with the help of metal mats or fabric was first formulated by MONIER about a hundred years ago. But the recent interest in reinforcing portland cement-based materials with randomly distributed fibres was spurred by pioneering research on steel fibre reinforced concrete conducted in Unite States in the 1960s. Since then there has been substantial research and developmental activities throughout the world. From the research results of the worldwide laboratory studies on SRFC, it has been established that the addition of steel fibres of suitable size, shape and aspect ratio to properly designed concrete mixes of concrete, it is possible to improve its resistance to tensile stresses and modify the brittle behaviour considerably. Fibre addition improves the impact and fatigue resistance and thermal cracking is eliminated. In this chapter, the work done previously has been briefly reviewed.

The idea of reinforcing cement with fibres was first put forward by Porter in 1910 [1]. A dramatic increase in the physical properties of the concrete by mixing cutnails and spikes was claimed. An unlikely increase of nearly eight times the ordinary strength was quoted. Porter thus concluded, "Indeed it is not at all improbable that the reinforcement of this nature, i.e. supplying resistance to particles throughout the mass, by introducing here and there short pieces of steel, on the tensile side, specially will come in use, thus making concrete a truly homogeneous material. In 1963, Romualdi and Batson [2 studied the mechanics of crack arrest in concrete and behaviour of reinforced concrete beams with closely spaced reinforcement. They concluded the mixing closely spaced steel fibres in concrete improves the first crack strength. These fibres act as a crack arresters, preventing the advancing microcracks by applying pinching the forces at the crack tips and thus delying the propagation of cracks. The existence of crack arrest mechanism in closely spaced wire reinforced concrete also suggests that such a material could be expected to offer high fatigue and impact resistance. They established that the increase in strength of concrete was inversely proportional to the square root of the wire spacing. In 1964, Romualdi and Mandel [3] demonstratedρ that continuous reinforcing steel wires could be replaced by randomly oriented small pieces of steel wires uniformly dispersed in the concrete matrix. They showed that the spacing concept was also applicable to the randomly distributed steel fibres, but in this case a correction factor was needed to account for the portion of the fibres which were not properly oriented for effective crack control. They also suggested that the closely spaced fibres should drastically increase the performance of the reinforced composite by isolating and thus limiting the size of the 'half crack length. They also gave the equation for determining the spacing of randomly distributed fibres, S, as follows:

$$S = 13.8\, d\sqrt{1/\rho}$$

Where, d - diameter of fibre, ρ- volume fraction of fibres Shah and Rangan [4] in 1970, worked on ductility and fracture toughness of concrete with and without steel fibres. They showed that ductility and fracture toughness of concrete is highly improved with the addition of steel fibres. It was' also observed that the increase in the volume of fibre increased, the first cracking stress. For spacing less than critical which was reported 25 mm for concrete made with 10 mm maximum size aggregate, spacing had less influence on the crack propagation than for spacing larger than 25 mm. Chen and Carson [5] in 1971 studied the effect of steel fibres on the compressive and tensile strength of the mortar and concrete. It was reported that optimum tensile and compressive strength of mortar could be achieved at 0.75% of 12.5mm sized fibres and further that concrete gave the best results of tensile and compressive strength at 2% of 12.5 mm sized steel fibres. Synder and Lankard [6] reported in December 1972, that significant increase in first crack flexural strength and ultimate flexural strength of mortar and concrete can be achieved, through the use of short length (0.625 cm to 7.5 cm) and small diameter (0.15 mm to 0.79 mm) steel fibres. They also observed that there exists a linear relationship between the first crack flexural strength and ultimate flexural strength as a function of fibre content for 0.25 mm x 25.4 mm fibres in a mortar containing four per cent volume of fibres. Batson, Lankard, and Hooks in November 1972 [7] studied the fatigue strength of steel fibre reinforced concrete. They reported that an increase of 74 - 80% of static flexural strength at two million stress reversal cycles.

In 1974 Johnston [8] reviewed the mechanical properties of steel fibre reinforced mortar and concrete. For this, a comparison was made between the plain and fibrous concrete. For this study, a fibre concentration (1, 1.75,2.5) percentage by volume of concrete, aspect ratio (20, 40, 60, 80, 100, 120) and fibre type (circular, rectangular and Duoform) were adopted as variables. It was concluded that the improvement in the properties imparted by fibres is mainly dependent on fibre concentration and aspect ratio. The magnitude of improvement is directly proportional to fibre concentration by weight and also proportional to the fibre aspect ratio raised to a power of the order of 1.5. It was also shown that deformed Duoform fibres are somewhat superior to the uniform types. Available data for mortar indicates that 6% by weight of fibres at aspect ratio 100 increase the flexural toughness by 8-12 times, impact strength by 100-150%, tensile strength by 30-35 % and compressive strength by 10- 20%. In 1975 Neville [9] published in two volumes the proceedings of Symposium of International Union of Testing and Research Labroatories for Material and Structures (RILEM) on fibre reinforced cement concrete. These proceedings contain collection of very useful papers covering the various aspect ratios of fibre reinforced materials.

In october 1978, Kothari and Bonel [10] reported the influence of fibre aspect ratio, volume fraction and chemical treatment of fibres with epoxy resin on the compressive and tensile properties of steel fibre reinforced concrete in the hardened state. They concluded that the chemical treatment of fibres with epoxy resin increases both compressive (maximum increase being 22.17%) and tensile strength (maximum increase 57.4%) of the compressive. Also the chemical treatment of the fibres with epoxy resin resulted in the increased ultimate tensile strength of the composite. The epoxy coated fibres offered a greater pullout strength and greater resistance to the progressive debonding that occurs to the progressive debonding that occurs in tensile failures. In 1979 Halvorsen and Kesler [11] reported that the failure of steel fibre reinforced beam is typically characterised by cracking of the matrix followed by pullout of the individual fibres. To compare the behaviour of concrete reinforced with plain and deformed steel fibres, moment curvature relationship were determined experimentally. The fibre contents with each of six fibre geometries were used. The result indicates that the post cracking resistance may vary considerably depending on the fibre ductility and failure mode of individual fibres, as well as fibre content. In October 1979, Walkus, Januszkiewiez and Jeruzal [12] studied the cracking behaviour, strength properties and deformation properties of tensile specimens of concrete reinforced with short steel fibres. It was noticed that the addition of steel fibres to the concrete up to a critical amount of 1.2% to 1.8% by volume increased in strength. A volume of about 1.2% of steel fibres appears to be the best. The influence of micro reinforcement arrangement on cracking behavior was analyzed on the basis of X-ray photographs. It was observed that the Location of crack depends on orientation and number of fibres in the cross-section. In May-June 1980, Ramakrishnan et al [13] made a comparative study of the properties of concrete reinforced with straight fibres and fibres with deformed ends glued together into bundles. One of their major finding was that about 60% of the bundled fibres with hooked end gave essentially the same concrete properties on 100% of the straight fibres. The properties studied were (a) flexural fatigue (b) static flexural strength including load-deflection curves, modulus of rupture, determination of first cracking load and determination of post-cracking strength for two sizes of beam (c) impact strength to first crack and ultimate-failure (d) compressive strength (e) workability including Vee-Bee, slump and inverted cone time immediately after mixing and after one hour. In 1981, Kukreja [14] studied the structural characteristics of steel fibre reinforced concrete. The basic design parameters investigated were compressive strength, tensile strength (direct and indirect) modulus of rupture, modulus of elasticity and extent of increase in ultimate moment of resistance, ductility, shear strength, stiffness etc. of a fibre reinforced concrete section. For this study he took fibre concentration and aspect ratio as a variable. From the study it was concluded that the maximum increase in compressive strength is 17% at fibre content of 1.5% by volume and having an aspect ratio of 100 % maximum increase in modulus of elasticity reported was 16%. The addition of fibre increases the strain at maximum stress and at ultimate stage by about four times each over that of plain concrete. The tensile strength increased by a maximum of 46% at 1 % fibre concentration and an aspect raio of 80.

In March-April 1984 ACI Committee [15] published its guidelines for specifying, mixing, placing and finishing steel fibre reinforced concrete. Guidance is provided in mixing techniques to achieve uniform mixtures, placement techniques to assure adequate compaction and finishing techniques to assure surface textures. In 1985, Fanella and Nasmen [16] reported stress-strain properties of fibre reinforced mortar in compression. A comprehensive experimental programme was designed to show the effect of fibre addition on compressive stress-strain curves. It was concluded that presence of fibres in concrete matrix changes the basic characteristics of its stress-strain curves. A higher fibre content produces a less steep descending portion, which results in a higher ductility and toughness of the material. The strain at the peak stress of fibre reinforced concrete was found to vary linearly with volume fraction of fibres. In 1987, Kaushik, Gupta and Tarafdar [17] studied the ultimate strength of fibre reinforced concrete beam vis-a-vis shear failure. The scope of the study was limited to observations on the gain in strength compared to ordinary RCC beam without fibres, deflection, curvature, rotations and crack pattern. The variables for this study were taken as ratio (60, 80, 100) and fibre volume fraction (0.0, 0.5, 1.0, 1.5). It was reported that the inclusion of fibres of aspect ratio 100 increase the ultimate shear strength by 67.26%. The average maximum strain in fibre reinforced concrete beams were of the order of 0.007 as compared to 0.0035 reported for plain reinforced concrete beams. In 1987, Coeradini, Scoccia and Volpe [18] discussed the statistical evaluation of the effect of cement content, water/cement ratio and fibre content on 28 days compressive strengtrh, tensile strength, secant moudlus of elasticity,first crack moment and failure bending moment of SFRC. The study showed that fibre content negligibly influences the 28 days compressive strength and secant modulus of elasticity (about 5 to 10%), moderately increases the first crack moment, while strongly influences the tensile strength (106%), failure bending moment (190%). In 1987, Dwarkanath and Nagraj [19] studied the flexural behaviour of reinfored fibre concrete beams. For this study, they considered two types of fibre locations, (i) location of fibres over the entire depth, (ii) locatiion of fibres over the half depth of the beam in the tension side. They observed that partial inclusion of the fibres over half the depth, in the case of under reinforced beams, is equally beneficial as the full depth inclusion in controlling cracking and deflection and in increasing the stiffness of the beam right from the beginning of loading upto the failure. In case of over reinforced beams, fibres in small quantities (0.75 %, 1.5 %) as used in this investigation, are not found to be effective in bringing about any appreciable modification in the deformatiion behaviour of the beams.

In 1987, Ramakrishnan and Josifik [20] studied the characteristics and flexural fatigue strength of concrete steel fibre composite. The variables for study were volume fraction and types of fibre. It was concluded that satisfactory workability can be maintained in fresh concrete reinforced with corrugated melt-extracted steel fibres even with the addition of 1 % fibres by volume. Compared to plain concrete, the fibre reinforced concrete has less bleeding, more stable and had better finishability. It was reported that addition of fibres does not produce any significant change in compressive strength and pulse velocity values. A significant increase in the static flexural strength was noticed in fibrous concrete. Due to the inclusion of fibres, the mode of failure with a great increase in post crack energy absorption capacity, there was a significant increase in toughness index. In 1987, Wu, Shivraj and Ramakrishnan [21] presented a paper on SFRRC. In this paper, they presented the results of an investigation carried out to determine the flexural fatigue, endurance limit and impact strength of SFRRC at 0.5 %, 1 % and 1.5 % by volume of fibre. These properties are compared with the same refractory concrete mix without steel fibre. They concluded that the fatigue strength increased appreciably by the addition of stainless, steel fibres to the concrete. The fatigue strength was 1.61 MPa for plain concrete and 2.6 MPa, 4.19 MPa and 4.82 MPa for concretes reinforced with 0.5%, 1.0% and 1.5% by volume of steel fibre respectively. These values correspond to increase of 61%, 159%, and 199% respectively. In 1987, Rarnakrishnan, Oberling, and Tatnall [22] presented a paper on flexural fatigue strength of steel fibre reinforced concrete. In this paper, they presented the results of an experimental investigation to determine the flexural fatigue strength of concrete reinforced with collated hooked and steel fibres. They concluded (1) The addition of fibres did not produce any significant change in the compressive strength, static modulus, and pulse velocity values. A significant increase in the static flexural strength (modulus rupture) was noticed with fibre contents, (2) .Due to the addition of steel fibres the mode of failure was changed from a brittle failure to a fully ductile failure with a great increase in the post-crack energy absorption capacity. There was a significant increase in the toughness index, (3) .The addition of collated hooked- end steel fibres had considerably increased the flexural fatigue strength of the concrete. When compared to plain concrete, the flexural fatigue strength was increased by 200 to 250 per cent and the endurance limit (for 2 million cycles) was increased to 90 to 95 per cent.

In 1988, Shah, Daniel et al [23] published a paper on design consideration for steel fibre reinforced concrete. In this paper, they discussed mechanical properties used in design like compression, direct tension, flexural strength, flexural toughness, shrinkage and creep, freeze-thaw resistance, abrasion/cavitation/erosion resistance. Performance under dynamic loading. The dynamic strength of concrete reinforced with various types of fibre and subjected to explosive change dropped weights, and dynamic flexural, tensile and compressive load was 3 to 10 times greater than that for plain concrete. An impact test has been devised for fibrous concrete that uses a 4.5 kg hammer dropped on to a steel ball resting on the test specimen. For fibrous concrete, the number of blows to failure is typically several Hundred compared to 30 to 50 for plain concrete. In 1989, Rarnakrishnan, Wu and Hosalli [24] discussed the flexural fatigue strength, endurance limit, and impact strength of fibre reinforced concretes. They presented the results of an extensive experimental investigation to determine the behavior and performance characteristics of the most commonly used fibre reinforced concrete subjected to fatigue loading. A comparative evaluation of fatigue properties was presented for concretes with and without four types of fibres (hooked-end steel, straight steel, corrugated steel, and polypropylene) at two different quantities (0.5 and 1.0 percent by volume), using the same basic mix properties for all concretes. They concluded the fatigue strength increases with the fibre content for all fibre types. However, there is a larger increase in the fatigue strength with hooked-end fibres (47 per cent and 144 per cent, respectively, for 0.5 per cent and 1.0 per cent fibre contents) than with other fibres. The smallest increase in fatigue strength was found with polypropylene and straight steel fibres.

In 1989, Butler [25] presented a paper on the performance of concrete containing high proportions of steel fibres with reference to rapid flexural and fatigue. loading. For fibrous concrete he used Melt Exract type steel fibres of size 25 x 0.4 mm. He concluded that for plain concrete no failure occurred below 20 N/mm^2 maximum stress and trend seemed to be established for up to 1 million cycles. Thus the fatigue limit of plain concrete appeared to be about 50% of its ultimate strength obtained at conventional stressing rates. It was clear that no failure occurred at maximum stresses below 4, 6 and 8.5 MN/m2 for concrete with (1.2%), (2.3 %) and (3.3%) fibre contents. These trends were established up to 2-3 million cycles. The apparent fatigue limits increased from 60% to 80% the fibre enhancement. In 1990, Vasan [26] made an investigation on steel fibre reinforced concrete pavement. In this he evaluated the experimental behaviour of SFRC pavement laid directly over prepared subgrade. It is also planned to investigate the effectiveness and structural adequacy of SFRC overlay over SFRC/PCC pavement directly resting over prepared subgrade. For the study of fibre concentration (0.5 to 2%) by volume were used. It was observed that there is a considerable increase in flexural strength and compressive strength up to 1.25 % fibre concentration and beyond which increase is not appreciable due to the requirements of higher mortar content with increased fibre content, also the significant increase in load carrying capacity of SFRC pavement up to optimum volume of 1.25% beyond which rate of gain in strength is not considerable. It was also observed that deflection in PCC and SFRC pavement are quite small as compared to commonly adopted deflection value of 21.5 mm for concrete pavements and 13.0 mm for flexible pavements. In 1991, Johnston and Zemp [27] discussed the performance of steel fibre concrete under flexural fatigue loading. The performance of SFRC under flexural fatigue loading was examined in terms of fibre content (0.5 to 1.5 per cent by volume), fiber aspect ratio (47 to 100), and fibre type (straight, deformed, melt extract and slit sheet). They concluded that effect of fiber content, aspect ratio and to a lesser extent fiber type on the flexural fatigue performance of steel fibre reinforced concrete have isolated and identified for straight fibres mostly of uniform cross section. In terms of actual applied stress versus number of loading cycles,fibre content becomes the primary governing factor, with aspect ratio and type of fibre of secondary importance. The best performance was obtained with 1.5 per cent volume of 75 aspect ratio cold drawn wires type with a 100,000 cycle Limit of 6.9 MPa. In 1993, Soubra, Wight and Naaman [28] discussed on the cyclic response of fibrous cast-in-place connections in precast beam-column sub assemblages. They tested beam-column sub assemblages under cyclic loading to verify the possibility of obtaining a strong, ductile and energy dissipating connection between precast elements in seismic areas. They concluded that (i) The use of fiber reinforced concrete in the cast-inplace connection was very effective in improving the displacement ductility of the specimens. Displacement ductilities up to 6.0 were observed for the fiber reinforced concrete specimens as compared to a displacement ductility of 1.0 for control specimen (normal concrete in connection), (ii) Higher load levels were attained for the fiber reinforced concrete specimens that used fibers in the cast-in-place connection when compared to the control specimen. Maximum load levels for the fiber reinforced concrete specimens were up to 60 percent higher than the maximum load for the control specimen. In 1994, Santha Kumar [29] presneted a paper on ductility of FRC and its applications in the design of structures subjected to dynamic impact, blast and fatigue loads. In this paper he attempts to systematically describe the basic properties, behavior under dynamic fatigue and impact loads. The mode of fatigue failure change from brittle to ductile by the addition of fibers. A comprative evaluation of fatigue strength of commonly used fibres, show that. (i) Addition of hooked end steel, streight steel,corrugated and polypropylene fibres increase the flexural fatigue strength. (ii) Concrete mix reinforced with 1 % corrugated steel fibre casued a maximum increase in fatigue strength by 33%. (iii) The fatigue strength of fibre reinforced concrete increase with increase in fibre content.Plain concrete has a fatigue endurnace limit of 50% to 55 % of its static flexural strength. A properly designed FRC can achive 90% to 95% of its static flexural strength as its fatigue endurance limit. Thus using the same cross - section a longer life can be achieved for the FRC beam compared to RC beam of same dimension.

In 1995, Yin and Hsu [30] made a investigation on the fatigue strength and behaviour of plain and fibre concrete. Seventy two steel reinforced concrete specimens, with 1 volume percent of 25 mm long fibres were tested under compression fatigue loading. They found that addition of fibres do not increase the endurance limit but is beneficial above the endurance limit in the low cycle region, furthermore, adding fibres to concrete increase its ductility, and change failure modes from splitting type to faulting types. They concluded that the fafigue strength of fibre concrete in baxial compression greater than that in uniaxial for any given number of load cycles.

A. *Formulation of problem*

With the growing interest in this new type of construction material due to its improved properties over conventional plain cement concrete and reinforced cement concrete, there is a need to make a comprehensive experimental study on economy aspect of this material. The present investigation was planned to study the steel fibre reinforced concrete under the cyclic loading and compare to plain concrete. The basic parameters of this study were the fibre content and stress levels. The experimental test programme consists of static and cyclic flexural loading of concrete beams reinforced with randomly spaced straight steel fibres. Fifty four beams (100 x 100 x 500 mm) and twenty seven cubes (150 x 150 x 150 mm) were tested. in the study. Fibre contents used were 0.0, 0.5, 1.0% by volume of concrete. The straight type fibres and 12.5 mm maximum aggregate size were used in the present study.

3. Conclusion

The present programme shows that the addition of straight steel fibres in the concrete improves its static and dynamic properties. On the basis of the limited experimental investigation, under taken the following conclusions may be drawn.

- Workability reduces with an increase in the fiber volume fraction.
- With an addition of straight fibers the cube compressive strength is increased considerably. The increase was 6.93% and 15.5% the fiber concentrations of 0.5 and 1.0% respectively.
- The ultimate flexural load under static loading also increased with an increase in the fiber content. The increase was 12.72% and 32.49% at a fiber concentration of 0.5% and 1.0% respectively.
- The addition of fibers to the concrete affects the cyclic loading life significantly under flexural cyclic loading. At a stress level of 0.85 the number of cycles to failure increased by 5 and 40 times respectively for 0.5 and 1.0% fibre content.

- The variability in the cyclic loading life of specimens is quite large as expected in any cyclic loading test programme.
- In terms of ultimate strength 1000 cycle endurance limit ranges from 87 to 90 per cent.
- In cyclic loading test, it was found that the failure of the specimens is usually due to pullout of fibers rather than breaking of fibers. The ultimate complete failure followed almost immediately after the first crack.

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