"PERFORMANCE OF STEEL FIBRE REINFORCED CONCRETE IN RIGID PAVEMENTS"

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Abstract:
The purpose of this dissertation is to investigate how simply supported steel fibre reinforced concrete slabs behave under flexural fatigue loading. Under low stress ratios, the strength characteristics of steel fibre reinforced concrete (SFRC) with 1% steel fibre volume fraction are investigated. Studying how steel fibre reinforced concrete (SFRC) responds to compressive, flexural, and fatigue loads is another goal. The link between stress level S and the number of cycles to failure N is developed using the fatigue life data that was collected.

Keywords:
Steel fibre, SFRC, Fatigue loading, Portland cement.

I- INTRODUCTION:

The rigid pavements are rigid i.e. they do not flex much under loading like flexible pavements. They are constructed using cement concrete. The concrete pavement, because of its rigidity and high modulus of elasticity, tends to distribute the applied load over a relatively wide area of soil. Thus the major portion of the structural capacity is supplied by the slab itself and which is in contrast to flexible pavement. The major factor considered in the design of concrete pavement is the strength of the concrete itself. In this case, the load carrying capacity is mainly due to the rigidity and high modulus of elasticity[13]. H.M. Westergaard is considered the pioneer in providing the rational treatment of the rigid pavement analysis.

Pavement structures are non-deterministic in nature. Large random variabilities and uncertainties of almost every parameter are associated with the pavement design, construction and performance. However, current design practices in India are deterministic, in that all design factors are assumed to be exact quantities. Stresses in concrete pavements stem from a variety of sources of which the applied wheel load, changes in temperature and moisture content of the concrete and the volumetric changes in the foundation soil are by far the most important.

The concrete pavements in India are subjected to repetitive axle loads of commercial vehicles ranging from 20kN to as high as 200kN. This continuous repetitive axle loads causes various flexural and fatigue damages. It should be noted that the rigid pavement will fail under a wheel load when the bending moment are so large that the flexural stresses exceed the modulus of rupture of concrete.

The performance of a pavement or overlay depends on the engineering properties of the materials used in construction. The use of fibre reinforcement is grabbing more attention in concrete pavements. The concept of fibre reinforcement is as old as the use of brittle materials such as clay bricks or concrete. Concrete fibre composites technology has grown over last three decades in to a mature industry. Since the pioneering research on steel fibre reinforced concrete conducted in United States in 1960's there has been substantial research and development throughout the world. Thereafter, various sorts of fibre materials have been investigated ever since and are utilized for different applications.

Steel fiber reinforced concrete is defined as concrete containing randomly oriented discontinuous discrete steel fibers.

The fibre reinforced concrete is a composite material made with Portland cement, aggregate and incorporating discrete discontinuous fibres. The plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributed discontinuous fibre is to bridge across the cracks that develop provides some post-cracking 'ductility'.

Steel Fibre Reinforced Concrete (SFRC) is concrete containing dispersed steel fibres. The most significant influence of the incorporation of steel fibres in concrete is to delay and control the tensile cracking of the composite material. Concrete is a brittle material that will not carry loads under pure bending when cracked. By incorporating steel fibres the mechanical properties of the concrete is changed resulting in significant load carrying capacity after the concrete has cracked (Chen, 2004). Laboratory studies on SFRC specimens suggest that dispersion of steel fibres in concrete improves the mechanical characteristics of the composite, notably resistance to dynamic load (Banthia et al., 1995), shear strength (Khaloo and Kim, 1997), fatigue resistance (Johnston and Zemp, 1991) and post-cracking strength (Elsaigh and Kearsley, 2002). As far as slabs on the ground are concerned, the major incentive for adding steel fibres is to improve the flexural behaviour of the slab.

Nowadays, the application of fiber in concrete increases gradually as an engineering material demand. The knowledge is not only necessary to provide safe, efficient and economic design for the present, but it also to serve as a rational basis for extended future applications. The steel fiber has wide range of usage in pavements, bridge deck, industry floor, precast products etc.

The application of SFRC in civil construction are the most popular due to its improved resistance to cracking, fatigue, abrasion, impact, durability, and conventional reinforced concrete.

1.1 Types of Fibres

There are various sorts of fibre materials which are utilized for different applications.
They are made out of glass, carbon, wood, akwara, coir, polypropylene, polyethylene, synthetic, galvanized iron, steel, organic and inorganic fibres etc.

Steel Fibres

Steel fibres normally used are cut from mild steel wire. The wire diameter adopted is in range of 0.15 mm to 1.0 mm. The length of steel fibre is generally 30 to 50 mm for extensive engineering projects are found to be suitable.

1.2 Types of Steel Fibres

1. Mild steel fibres
2. Stainless steel fibres

Shapes of steel fibres: The steel fibres are available in various shapes and sizes.

1. Hooked end steel fibres
2. Crimped round and flat steel fibres
3. Flat end steel fibre.

1.3 Shaktiman Steel fibres:

In this study, the steel fibres used are round crimped steel fibres. Shaktiman Round Steel Fibers used in this study are being produced by M/s. STEWOLS INDIA (P) LTD (Formerly Stewols& Co) was their most modern factory situated at Nagpur, Maharashtra State, India.
The fibres are factory-crimped to improve bonding characteristics with concrete and are available in diameters ranging from 0.45mm to 1.00mm and lengths from 25mm to 60mm.

1.3.1 Applications of Shaktiman Steel Fibres (As per company)

a) Flooring applications:

Industrial floors, jointless floors, floors on piles, lightly loaded floors, liquid tight floors and composite metal decking. Other applications include foundations, traditional cellar and basement walls and compression layers.

b) Hard standing and heavy-duty applications:

Parking lots, playgrounds, airport runways, taxiways, maintenance hangars, access roads and workshops. Shaktiman steel fibres are hugely used in Ports and Containers for port pavements, container terminals, bulk storage areas access roads and for army tank movement.

c) Special applications:

Shotcreting, slope stabilization, pre cast concrete production tunnel and mining shafts and under water concrete reinforcement. Steel fibre is also widely used in manufacturing pre cast walls, overlays, manhole covers, piles, pillars.

1.3.2 Advantages of Steel Fibre Reinforced Concrete (SFRC) (As per details of company pamphlet)

- **FLEXURAL STRENGTH:** 1 1/2 to 3 times increase in first crack and flexural bending strength can be achieved over plain concrete using Steel Fibre.
- **FATIGUE RESISTANCE:** The fatigue strength of steel fibre concrete is 1 1/2 times that of conventional concrete.
- **IMPACT RESISTANCE:** Steel fibres greatly increase concrete's resistance to damage from heavy impact. Highly recommended in use where heavy impacts are expected.
- **CORROSION:** In Rebar the corrosion travels. Steel Fibre being a discontinuous, corrosion will be arrested to the damaged portion and will not be transported like in Rebar.
- **SHRINKAGE:** Steel fibres themselves do not affect the shrinkage rate but they do minimize and help eliminate shrinkage cracks.
- **ABRASION RESISTANCE:** Steel Fibres offer a high degree of protection against abrasion and gouging along with any spalling being greatly reduced.
- **PERMEABILITY:** By effectively reducing the micro cracking SFRC will reduce the overall porosity of the matrix, making the concrete less permeable.
- **CRACKING:** Concrete has always been an unpredictable material and no methodology can entirely eliminate cracking. Using SFRC offers an effective means of controlling cracks.

1.3.3 Disadvantages of Steel Fibre Reinforced Concrete (SFRC).

- The non-uniform distribution of fibres results in poor workability. The workability and compaction standard of the mix is improved through increased water/cement ratio or by use of some kind of water reducing admixtures (Superplasticizer).
- The decreased workability affects the consolidation of the fresh mix. Even prolonged external vibration fails to compact the concrete.

II-LITERATURE REVIEW:

G. C. Martin et al. [1], Historically fibre have been used to reinforce brittle materials since ancient times; straws were used to reinforce sun baked bricks, horse hair was used to reinforce plaster and recently asbestos fibres are being used to reinforce Portland cement. The low tensile strength and brittle character of concrete have bypassed by the use of reinforcing rods in the tensile zone of the concrete since the middle third of the nineteenth century. The first patent for SFRC was filed in California by A. Bernard in 1874. A patent by H. Alfen in France, 1918 was followed by G. C. Martin in California, 1972 for SFRC pipes. H. Etheridge in 1931 examined the use of steel rings to address the anchorage of steel fibres. The World War II and later years saw G. Constatineso taking patents out in England, 1943 and U.S.A., 1954. This was followed by numerous patents, but the widespread use was hindered by high cost, poor testing facilities and parallel rapid development of concrete reinforced with steel bar and wire system. It was not until by James Romualdi in 1962 at the Carnegie Institute of Technology that a clearer understanding of the properties of SFRC emerged. Steel fibre reinforce shotcrete has been a later extension of this understanding, with the first application being to stabilize the rock slope of a tunnel portal, Idaho in 1972.

Balasubramaiam.k., bharat kumar, s. Gopalkrishanan and v.s.parameswaran (1996) et al. [2], Was to evaluate the use of SFRC for road pavements and compare its performance to plain concrete under traffic loading. The influence of SFRC properties on performance and design aspects of concrete roads were discussed. Results from road trial sections, tested under in service traffic, were used to validate the use of the material in road. From their work they conclude that Fiber reinforced concrete has advantage over normal concrete particularly in case of cement concrete pavements. The most significant influence of the incorporation of steel fibers in concrete is to delay and control the tensile cracking of the composite material. This positively influences mechanical properties of concrete. These improved properties resulting SFRC being a feasible material for concrete road pavements.

Niranjana. G., mathew. S and jayabalan. P. (2000) et al. [3], To analyze the mechanical characteristics of the waste steel scrap material which is available from the lathe was used as a steel fiber for pavement construction to optimize the fiber content. The application of Steel Fiber Reinforced Concrete (SFRC) as composite matrix is potentially advantageous from the point of view of its capacity to bear much higher stresses. Under similar loading conditions pavement thickness can considerably be reduced in SFRC, hence reduction in material and cost. Sound SFRC pavement promises an appreciably higher life expectancy, reduced crack growth offers better serviceability and minimum corrosion. From the experimental studies and subsequent pavement analysis carried out as per IRC: 58-2002, it was concluded that the compressive strength of SSFRC increased when compared to plain cement concrete. Addition of steel scraps increased the flexural strength of SFRC to great extent.

W a elsaigh's (2005) et al. [4], Research was to evaluate the use of SFRC for road pavements and compare its performance to plain concrete under traffic loading. The influence of SFRC properties on performance and design aspects of concrete roads were discussed. Results from road trial sections, tested under in-service traffic, were used to validate the use of the material in roads. Performance and behaviour of a SFRC test section was compared to a plain concrete section. The performance of thinner SFRC ground slabs was found comparable to thicker plain concrete slabs.

Ravisankar. U., h. V. Venkata krishna and sures (2006) et al. [5], Has selected Indented and hooked steel fibers as two possibilities for use in roller-compacted concrete for pavements. Appropriate unit water content, sand percentage, and fiber content were determined while water was reduced by a suitable degree by incorporating a super plasticizer in appropriate proportion. The target consistency was given in terms of a vibration compaction value as measured by a Swedish-type Vee-Bee apparatus. Segregation was reduced by using steel fibers, and the fiber orientation in the concrete tended to approach the horizontal when compaction was with a surface vibrator.They concluded that the mix design procedure for SFRCC to be used as pavement material is the same as for conventional pavement concrete in that the choice of appropriate sand percentage and fiber content is very important. The properties of hardened SFRCC, such as flexural strength, are remarkably better than those of conventional RCC.

Ravindra v. Solanki (2011) et al. [6], Establishes the use of steel fiber in many effective ways improving the strength and an improvement in fatigue life of the pavement together with developing improved resistance to crack and et al., thus being considered as hfghjk,./cost-effective technology and design of road construction.

Objectives of the study were to find out effect of change of percentage of fibers in concrete mix proportion and find out thickness reduction of concrete slab with respect to loading. The studies emphasize that fiber reinforcement in a cement bound road base has the potential to improve performance by improving fatigue life of the base and improved resistance to reflective cracking of the asphalt. The studies also established that the properties of hardened SFRCC, such as flexural strength, are remarkably better than those of conventional RCC. Thus, the use of steel fiber for effective pavement construction can be suggested positively.

Paulo B.Cachim et al [7], Studied the fatigue behaviour of fiber-reinforced concrete in compression. An experimental program has been carried out to evaluate the performance of plain concrete and fiber-reinforced concrete under compressive fatigue loading. Two types of hooked-end steel fibers (30mm length and 60 mm length) have been tested and their performance compared. The displacements and the acting load were measured during the tests so that several material parameters could be identified and assessed. The correlation between the secondary creep rate and the fatigue life was investigated. The addition of fibers to concrete provides an increase in the deformation at failure. This additions ductility of fiber-reinforced concrete may be very important if stress redistribution between sections take place. The 60 mm fibers used in the experiments may be too long for the sectional characteristics of the specimens, creating conditions for a shorter fatigue life of fiber concrete.

III-EXPERIMENTAL PROGRAMM:

The main objective of this experimental investigation is to study the performance of non-fibrous and steel fibre reinforced concrete slabs under flexural fatigue loading by adding 1% volume fraction of steel fibres.

In the first stage the basic tests were carried out to check the physical properties of materials used and the properties of concrete in fresh state like compaction factor test, density determination of concrete.

In the second stage, testing of hardened concrete is done. The cube compressive strength, flexural strength of prisms and slabs, and flexural fatigue strength test or repeated load test of slabs is carried out.

3.3 Materials

The materials used in this investigation are cement, fine aggregate, coarse aggregate, water, superplasticizer and Shaktiman steel fibres.

3.3.1 Cement

Ordinary Portland Cement (OPC 43 grade) of BIRLA SHAKTI group from a single batch was used throughout the course of the investigation. The properties of Cement and the test results carried out in the laboratory are shown in table 3.1

3.3.2 Fine Aggregate

Locally available river sand belonging to zone II is used for the project work. The sieve analysis data and physical properties of fine aggregates used are shown in table 3.2

3.3.3 Coarse Aggregate

In this investigation, crushed basalt stones of size 12mm down is used. The sieve analysis data and physical properties of coarse aggregate of 12 mm are shown in table 3.3

3.3.4 Water

Potable tap water is used in the present investigation for both casting and curing of specimens.

3.3.5 Superplasticizer

The High range water-reducing admixture (HRWA) from Fosroc Chemicals India Limited, Banglore of type Conplast SP-420 has been used in this work. The addition of superplasticizer to steel fibre reinforced concrete helps in improving workability for higher fibre volume mixes.Conplast - SP420, a concrete Superplasticizer based on Sulphonated Naphthalene Polymer is used as a water-reducing admixture and to improve the workability of steel fibre reinforced concrete.

Conplast SP-420 has been specially formulated to give high water reduction up to 25% without loss of workability or to produce high quality concrete of reduced permeability.

The physical properties of Conplast SP-420 as per Fosroc Chemicals Ltd. Are as under:

Specific gravity	:	1.220 to 1.225
Chloride appearance	:	Nil as per IS 456
Appearance	:	Brown liquid
Air entrainment	:	Approx 1%
Compatibility	:	Can be used with all types of cements except high alumina cement.

3.3.6 Steel Fibres:

The steel fibres used in this investigation are 'Shaktiman Crimped Round Steel Fibres' of diameter 0.55 mm and length 30 mm (Aspect ratio 54). A uniform volume fraction of steel fibres as 1.0% has been used in this investigation.

The fibres are randomly oriented throughout the concrete as random orientation of steel fibres gives better results compared to that of parallel and perpendicular to applied load orientation of steel fibres[10].

IV- Fatigue:

Fatigue may be defined as a process of progressive, permanent internal structural changes in a material subjected to repeated loading. Considerable interest has developed in the fatigue strength of concrete member in recent years. Fatigue problems may arise in concrete structures that are continuously subjected to repetitive loadings. The concrete civil engineering structures such as bridges, pavements and offshore structures are normally subjected to repetitive fatigue load; thus, adequate reliability against fatigue failure is required in these structures. The development of highway systems in the 1920s led to further interest in the fatigue of concrete. Concrete pavements for highways are subjected to millions of cycles of repeated axle loads from trucks and automobiles. Airport pavements are subjected to a smaller no of repeated loadings during their designed life ranging from about several thousand to several hundred thousand cycles of repeated loadings. With the regard to cyclic loading, a distinction is generally made between low-cycle and high-cycle fatigue. The farmer involves few load cycles (<10000) with high stresses (similar to those induced by an earthquake), while the latter is characterized by a much larger number of cycles with lower stresses (such as those induced by rotating machinery).

In a 1980 review of the fatigue of plain concrete dealing with both compression and flexure, Hsu categorized fatigue applications as follows.

"Low-cycle "is the term applied to structures exposed to earthquakes and loads less than 1000 cycles of load. The "high-cycle "category starts with airport pavements and bridges expected to withstand up to 100000 load cycles, and extends to highway bridges and pavements, railway bridges and ties subjected to up to 10 million cycles. Rapid transit structures and structures exposed to wave action are in a "super-high-cycle "category that may be expected to sustain 10 million or more load cycles during service life.

V- RESULTS & DISCUSSION

Table 5.1: Density in (KN/m^3) and Compaction Factor of Concrete

Specimen type	Density (kN/m^3)*	Compaction Factor
N.F	25.05	0.93
V_f– 1.0%	26.72	0.94

*Average of three specimens is taken

Table 5.2Compressive strength of cubes in N/mm^2

Specimen type	Compressive* strength after 7 days curing	Compressive* strength after 28 days curing
N.F	40.45	44.55
V_f– 1.0%	45.77	47.82

*Average of five specimens is taken

Table 5.3Flexural strength of prisms in N/mm^2

Specimen type	Flexural * strength after 28 days curing
N.F	3.44

V_f– 1.0%	5.52

*Average of five specimens is taken

Table 5.4Static Load Carrying Capacity Of Slabs in KN

Specimen type	Static Load Carrying Capacity Of Slabs after 28 days curing
N.F	30.15
V_f– 1.0%	33.48

*Average of five specimens is taken

Table 5.5 Flexural Fatigue Test: Non-Fibrous slabs

SI.No	Stress Ratio	Load Applied	Average No. of Cycles for Failure
1	0.45	1300	13
2	0.40	1200	18
3	0.35	1100	78

*Average of five specimens is taken

Table 5.6 Flexural Fatigue Test: Fibrous slabs

SI.No	Stress Ratio	Load Applied	Average No. of Cycles for Failure
1	0.45	1300	100020*

*Slabs did not failed upto an endurance limit.
*Average of five specimens is taken.

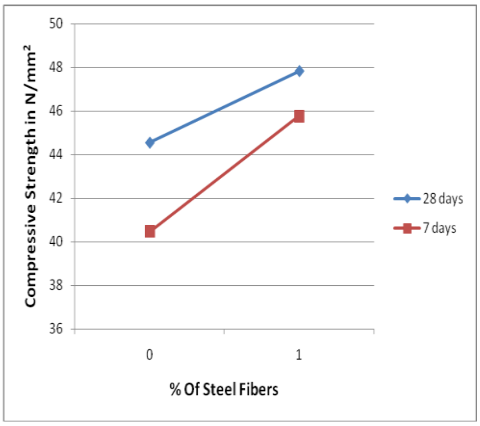

Fig.5.1: Compressive Strength V/s volume fraction of fibres

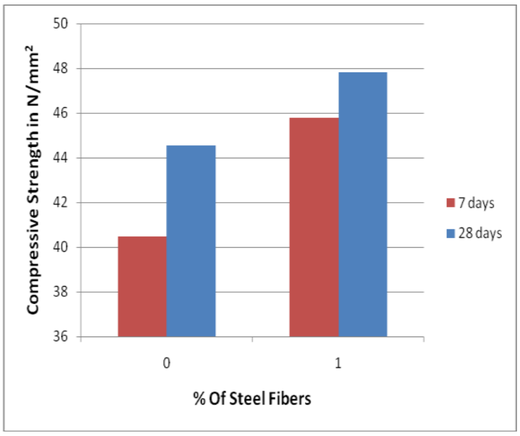

Fig. 5.2: Relative increase in compressive Strength V/s volume fraction of fibres

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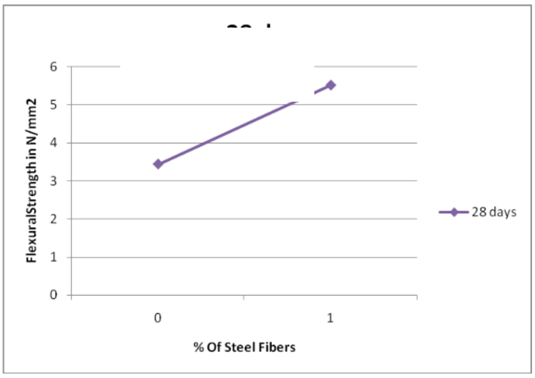

Fig .5.3: Flexural strength V/s Volume fraction of fibres

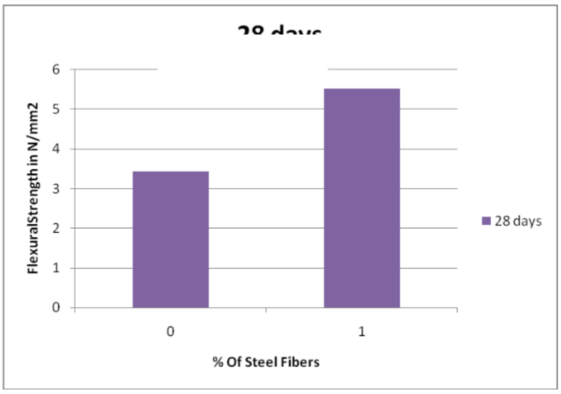

Fig .5.4: Relative increase in Flexural strength V/s Volume fraction of fibres

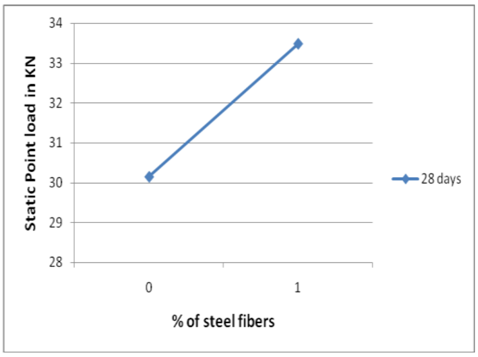

Fig.5.5: Static Point Load V/s volume fraction of fibres

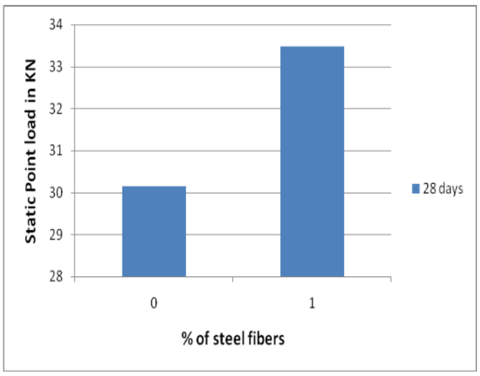

Fig .5.6: Relative increase in Static Point Load V/s Volume fraction of fibres

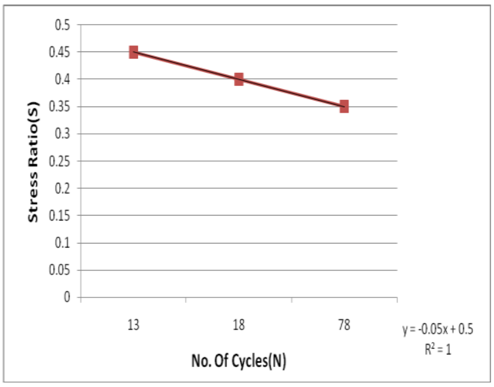

Fig.5.7: S-N Curve for Non-Fibrous Slabs

VI- CONCLUSION:

1. The addition of steel fibres has increased the density of concrete from 25.05kN/m^3 for plain concrete to 26.72 kN/m^3 for steel fibre reinforced concrete.
2. The average compressive strength for 28 days attained is 47.82MPa for 1.0% steel fibres.
3. The increase in compressive strength of 13.14% was observed for fibrous concrete when compared with non-fibrous concrete at age of 7 days, which again increased to 14.12% for age of 28 days.
4. The average flexural strength for 28 days attained was 5.52MPa for fibrous prism
5. The increase in flexural strength of 60.46% is observed when compared to that of non-fibrous concrete.
6. The average point load carried by fibrous slab was 33.48KN and that carried by non-fibrous slab was 30.15KN. An increment of 11.05% was observed in fibrous slabs when compared to non-fibrous slabs.
7. The nature of failure in static flexural load was identical for both non-fibrous and fibrous specimens.
8. Mode of failure of non-fibrous specimens under static conditions was sudden.
9. It is observed that the cracks in fibrous specimen did not propagate through the cross section of slabs. Cracks were arrested due to steel fibres leading to more number of cracks.
10. For non-fibrous slabs, under flexural test, the average no. of cycles for failure are 13,18 and 78 for respective stress ratios of 0.45,0.40 and 0.35.
11. No failure of fibrous slabs was observed in flexural fatigue test upto an endurance limit of 1,00,000 load cycles.

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