International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-2 Issue-4, September 2013

Flexural Fatigue Studies for SFRC under Compound Loading For Different Stress Ranges

Hanumantharayagouda, Amaresh.S. Patil

***Abstract** -This paper presents a study on fatigue behavior of non-fibrous concrete and SFRC subjected to repeated loading. It is aimed to study the behavior of Non fibrous concrete and SFRC under constant amplitude and compound amplitude loading. A total number of 140 prism specimens of size 75x100x500 mm were tested under flexural fatigue loading using havier sine wave loading in order to obtain the fatigue lives of Non fibrous concrete and SFRC at different stress levels. About 10 prism specimens are subjected to static flexural test to determine the static flexural strength of Non fibrous concrete and SFRC prior to fatigue testing. The specimens incorporated 1% volume fraction of crimped steel fibers of size 0.55mmϕ X30 mm. About 30 prism specimens were tested under constant amplitude fatigue loading. Fatigue life data obtained has been analyzed in attempt to determine the relationship among stress level and number of cycles of failure. About 110 prism specimen was tested under compound fatigue loading in order to check the validity of miner's hypothesis.*

***Keywords:** Fatigue; compound loading; steel fiber reinforced concrete (SFRC); flexural strength.*

I. INTRODUCTION:

Rational design of concrete structures requires an accurate knowledge of concrete properties under anticipated loading conditions. A large volume of information is available on behavior of concrete under static loading conditions. However relatively limited information is available on behavior of concrete subjected to dynamic loadings. Structures that are subjected to repeated loads are susceptible to failure due to fatigue. Fatigue is a progressive permanent internal changes in the materials that occur under the actions of cyclic loadings. These changes can cause progressive growth of cracks present in the concrete system and eventual failure of structures when high levels of cyclic loads applied for short times or low levels of loads are applied for long times. Fatigue strength data of concrete and other materials that are used in these structures for obtaining their safe, effective and economical design are needed [1].

The fatigue may be simple or compound and can occur in different forms. In rigid pavements, fatigue failure begins with initiation of micro-cracks within the concrete layers under the application of wheel load due to moving traffic. These cracks usually start from bottom of the concrete layer and propagate upto surface, resulting in deterioration of pavement due to decrease in flexural strength and subsequent loss of pavement materials through the developed cracks.

Revised Manuscript Received on 30 September 2013.

* Correspondence Author
Hanumantharayagouda, Student, Department of Civil Engineering (M.Tech Structures), P.D.A. College of Engineering, Gulbarga, Karnataka State, India.
Amaresh.S. Patil, Associate Professor, Department of Civil Engineering, P.D.A. College of Engineering, Gulbarga, Karnataka State, India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

Therefore fatigue is an important factor to be considered for designing of cement concrete pavements.

Systematic study carried by many researches has shown that the incorporation of steel fibers into the concrete matrix significantly improves flexural strength. Most of the studies on steel fiber reinforced concrete were mainly confined to the determination of its flexural fatigue endurance limit for different type/volume fraction/aspect ratio of fibers (Batson et al.1972, Ramakrishnan et al. 1987, Tartro 1987, Ramakrishnan 1989, Jhonston and Zemp 1991). Some investigations focused on studying other aspects of fibre reinforced concrete in respect of fatigue. Yin et al.(1995) studied the fatigue behaviour of steel fibre reinforced concrete under uni-axial and bi-axial compression and observed that the S-N curves can be approximated by two straight lines connected by a curved knee instead of a single line. Wei et al.(1996) studied the effect of fiber volume fraction, amount of silica fume and their composite action on fatigue performance of SFRC. Ong et al.(1997) investigated the behavior of steel fiber mortar overlayed concrete beams under cyclic loading whereas the behavior of composite concrete sections reinforced with conventional steel bars and steel fibers, and subjected to flexural cyclic loading was analyzed by Spadea and Bencardino (1997). Jun and Stang (1998) reported that the accumulated damage level in fiber reinforced concrete in fatigue loading was 1-2 order of magnitude higher than the level recorded in static testing of the same material. Effect of fly ash on fatigue properties of hardened cement mortar was studied by Taylor and Tait(1999) whereas, Daniel and Loukili (2002) investigated the behavior of high strength reinforced concrete under cyclic loading. SFRC with two types of hooked end steel fibers was tested by Cachim et al.(2002) in an experimental study to evaluate the performance of plain and fiber reinforced concrete under compressive fatigue loading. In review paper, Lee and Barr (2004) provided a general overview of recent developments in the study of the fatigue behavior of plain and fiber reinforced concrete.

In literature [7] variable amplitude fatigue studies have been carried out on plain concrete to verify the validity of Miner's hypothesis. Miner's hypothesis assumes that damage accumulates linearly with the number of cycles applied at a particular stress level. As per Miner's hypothesis the failure criterion is written as:

$$\sum_{i=1}^{k}\left(\frac{n_i}{N_i}\right)=1.0$$

Where,

n_i= Number of cycles applied at stress level i

N_i = Number of cycles to failure at stress level i

K = Number of stress levels use3

*Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)*
© Copyright: All rights reserved

II. RESEARCH SIGNIFICANCE AND SCOPE

In the present investigation an attempt has been made to study the fatigue behavior of Non fibrous and SFRC under constant amplitude and compound loading. Multistage constant amplitude loading has been used as compound fatigue loading in the present investigation. To investigate the fatigue behavior a series of prism specimens of size 75mm×100mm×500mm were tested under flexural fatigue loading. The proposed study was done in two stages.

In the first stage, the mix proportions for M40 grade concrete are established by conducting three trial mixes. To establish the mix proportion, 28 day cube compressive strength was determined. Also the value of 28 day static flexural strengths of Non fibrous concrete and fibrous concrete were established. In the second stage, study of behavior of fibrous and non fibrous concrete under constant amplitude fatigue loading is carried out. Also flexural fatigue studies on fibrous and non fibrous concrete is carried out under compound loading. A total number of 30 prism specimens were tested under constant amplitude fatigue loading. S-N relations were established from regression analysis of fatigue data. A total number of 110 specimens have been tested under compound fatigue loading to verify the validity of Miner's hypothesis and also to perform statistical analysis using two parameter Weibull distributions.

III. EXPERIMENTAL INVESTIGATION

The experimental investigation includes casting of 150 prisms and 20 cubes. To determine the compressive strength of concrete, 20 cubes of size 150×150×150mm are cast (10 for Non fibrous and 10 for fibrous). For determining the static flexural strength 10 prisms of size 75×100×500mm are cast (5 for Non fibrous and 5 for fibrous). A total number of 140 prisms were used for fatigue studies. A total number of 30 prisms are subjected to constant amplitude loading and 110 prisms were subjected to compound loading.

IV. LABORATORY TESTS

4.1 Materials

Ordinary Portland cement of 53 grade satisfying the requirements of IS 8112-1989, from single batch has been used in the present investigation. The coarse fraction consisted of equal fractions of crushed stones of maximum size of 12mm. Fine aggregate used was natural sand with grading conforming to Zone II. High range water-reducing admixture (HRWA) of type Conplast SP-430 is used in the present investigation to enhance workability. Steel fibers of round crimped type with diameter 0.55mm and length 30mm (aspect ratio = 54) has been used in the present investigation. The fiberous concrete is produced by using 1% by volume fraction of steel fibers.

4.2 Mix proportions

Trial mixes were optimized, experimentally to achieve M40 grade concrete with water to cementitious ratio of 0.41. High range water-reducing admixture (HRWA) of type Conplast SP-430 has been used in the present investigation in order to enhance workability. The dosage of superplasticizer used was 0.8% and 1.1% by weight of cementitious materials for Non fibrous and fibrous concrete respectively.

Table 1 Mix proportion of M40 grade concrete

Ingredients	Proportion
Water (kg/m^3 of concrete)	196
Cement (kg/m^3 of concrete)	466.098
Fine Aggregate (kg/m^3 of concrete)	465.243
Coarse Aggregate (kg/m^3 of concrete)	1182.16
Mix Proportion	W : CM:Fine Agg : Coarse Agg
	0.41: 1.0: 0.99: 2.54

4.3 Test procedure and test results

4.3.1 Static flexural strength

The static flexural test for each mix was carried out to establish the maximum stress levels for the fatigue tests. Five prisms for Non fibrous concrete and five prisms for fibrous concrete were tested using third points loading on a 400mm effective span. The average of these five tests was taken as static flexural strength "f_{sf}" of the mix.

4.3.2 Compressive strength

Cube specimens of size 150mm×150mm×150mm were used for determining compressive strength. The results of 7days and 28days compressive tests are given in table 2, where each value represents the average of five specimens

Table 2 Compressive and static flexural strength results

Type of concrete	Compressive strength in MPa		Static flexural strength in MPa
	7 days	28 days	28 days
Non fibrous concrete	33.921	51.971	4.918
SFRC	36.624	56.157	6.174

4.3.3 Fatigue Testing

4.3.3.1 Constant Amplitude Fatigue Testing:

Fatigue test specimens were tested under one-third point loading using frequency of loading as 4Hz. Since the present investigation was aimed at pavement application haiver sine wave form of cyclic loading was used. Typical fatigue test set up and loading pattern used are shown in figure 1 and 2 respectively. All the fatigue specimens were tested after 90 days from casting so as to give allowance for sufficient strength gain. Specimens were cured for 28 days by ponding method and then covered with polythene bags up to 90 days. Minimum stress in fatigue loading was maintained at 1% 0f maximum stress. Minimum stress was used mainly to prevent any possible movement of specimens at support during testing and to stimulate residual stresses in the pavement to a certain degree. The fatigue tests were conducted at various stress level "s", which relates the maximum fatigue stress "f_{max}" to corresponding static flexural strength "f_{sf}" (thus, $S = f_{max}/f_{sf}$). The stress level "S" ranged from 0.65 to 0.85. Constant amplitude fatigue test results for Non fibrous concrete and fibrous concrete are tabulated in table 3.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)
© Copyright: All rights reserved

Figure 1 Flexural fatigue test setup

Table 3 Fatigue life data under constant amplitude loading

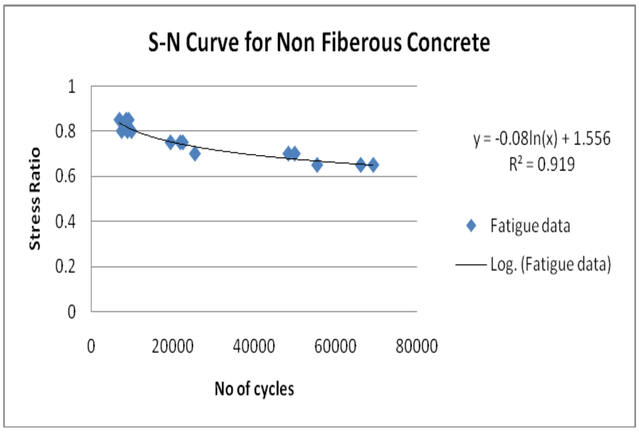
DESIGNATION	STRESS RATIO/ SLNO	0.85	0.80	0.75	0.70	0.65
Non Fibrous concrete	1	6784	7325	19340	25349	66120
	2	8450	8735	21758	48323	69214
	3	9042	9745	22378	49892	55397
Fibrous concrete	1	12879	20864	26790	33458	83893
	2	14322	21945	27658	49577	91949
	3	15768	22768	28903	68609	100000

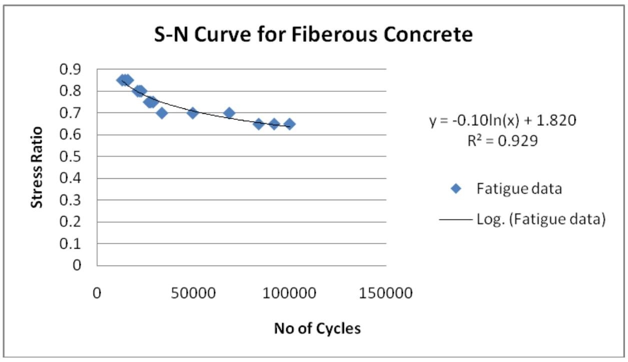
V. DETERMINATION OF S-N RELATION

S-N relations were developed by carrying out regression analysis on fatigue test data of constant amplitude loading. The S-N curves determined for the two types of concrete are shown in figure below. S-N relations for Non fibrous and fibrous concrete are shown in equations (1) and equations (2) respectively along with R^2 values where R is the coefficient of correlation.

$S = -0.08\ln(N) + 1.556$ $(R^2 = 0.919)$ (1)

$S = -0.10\ln(N) + 1.820$ $(R^2 = 0.929$ (2)





VI. COMPOUND FATIGUE TESTING

In present investigation behavior of SFRC under compound fatigue loading, which is a common type of loading in case of road pavements was studied. Compound fatigue testing was carried out on Non fibrous and fibrous concrete specimens. Two stage, three stage and four stage constant amplitude fatigue loading have been used as compound fatigue loading. In two stage loading test specimen was subjected to a fixed number of load cycles at a particular stress level in the first stage and after the first stage amplitude was changed corresponding to second stress level and maintained constant up to failure. In three stage fatigue loading three stress levels have been applied to the test specimen. Fixed number of load cycles was applied for two stress levels and testing was continued up to failure at the third stress level. In four stage loading fixed number of load cycles were applied for three stress levels and at fourth stress level specimen was tested up to failure. Minimum stress was maintained at 1% of the corresponding maximum stress for all the specimens. Test results of compound fatigue loading were used to check the validity of Miners hypothesis for Non fibrous and fibrous concrete.

6.1 Analysis of test results of compound fatigue loading

Test results of compound fatigue testing along with calculation of cumulative damage factor for Non fibrous concrete and fibrous concrete are shown in tables 4 to 9. Stress levels shown in tables 4 to 9 are given in the order in which they have been applied to the specimens during testing. Fatigue lives at different stress levels in table 4 to 9 have been calculated from equations (1) and equations (2). Cumulative damage factor i.e., Miner's sum varied between 0.123 to 1.960 for Non fibrous concrete and 0.086 to 1.562 for fibrous concrete. Miner's sum showed dependency on type of compound fatigue loading and also on the sequence of loading.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

Table 4. Cumulative Damage Factors for Non fibrous Concrete for Two Stage Compound Fatigue Loading

Specimen identity	No of load cycles applied at stress level		Fatigue life at stress level		Cumulative damage factor M=[n_1/ N_1]+[n_2/ N_2]
	n_1	n_2	N_1	N_2	
	S = 0.65	S = 0.70	S = 0.65	S = 0.70	
NF FFT 62	10,000	2398	82868	44356	0.175
NF FFT 96	10,000	144	82868	44356	0.124
NF FFT 91	10,000	9014	82868	44356	0.324
NF FFT 97	10,000	3365	82868	44356	0.196
NF FFT 82	10,000	8246	82868	44356	0.306
NF FFT 102	10,000	101	82868	44356	0.123

Table 5 .Cumulative Damage Factors for Non fibrous Concrete for Three Stage Compound Fatigue Loading

Specimen identity	No of load cycles applied at stress level			Fatigue life at stress level			Cumulative damage factor M=[n1/N1]+[n2/N2]+[n3/N3]
	n_1	n_2	n_3	N_1	N_2	N_3	
	S = 0.65	S = 0.70	S = 0,75	S = 0.65	S = 0.70	S = 0.75	
NF FFT 90	10,000	10,000	627	82868	44356	23742	0.372
NF FFT 95	10,000	10,000	2105	82868	44356	23742	0.435
NF FFT 39	10,000	10,000	8109	82868	44356	23742	0.688
NF FFT 79	10,000	10,000	915	82868	44356	23742	0.385
NF FFT 82	10,000	10,000	892	82868	44356	23742	0.384

Table 6.Cumulative Damage Factors for Non fibrous Concrete for Four Stage Compound Fatigue Loading

Specimen identity	No of load cycles applied at stress level				Fatigue life at stress level				Cumulative damage factor M
	N_1	n_2	n_3	n_4	N_1	N_2	N_3	N_4	
	S = 0.65	S =0.70	S =0.75	S =0.80	S=0.65	S =0.70	S =0.75	S =0.80	
NF FFT 98	10,000	10,000	10000	14214	82868	44356	23742	12708	1.886
NF FFT 92	10,000	10,000	10000	837	82868	44356	23742	12708	0.833
NF FFT 104	10,000	10,000	10000	15154	82868	44356	23742	12708	1.960
NF FFT 57	10,000	10,000	10000	1739	82868	44356	23742	12708	0.904
NF FFT 99	10,000	10,000	10000	4018	82868	44356	23742	12708	1.083
NF FFT 75	10,000	10,000	10,000	3396	82868	44356	23742	12708	1.034

Table 7.Cumulative Damage Factors for fibrous Concrete for Two Stage Compound Fatigue Loading

Specimen identity	No of load cycles applied at stress level		Fatigue life at stress level		Cumulative damage factor M=[n_1/ N_1]+[n_2/ N_2]
	n_1	n_2	N_1	N_2	
	S = 0.65	S = 0.70	S = 0.65	S = 0.70	
F FFT 62	10,000	6644	120572	73130	0.174
F FFT 59	10,000	211	120572	73130	0.086
F FFT 89	10,000	1940	120572	73130	0.109
F FFT 136	10,000	1556	120572	73130	0.104
F FFT 130	10,000	7990	120572	73130	0.192

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

Table 8.Cumulative Damage Factors for fibrous Concrete for Three Stage Compound Fatigue Loading

Specimen identity	No of load cycles applied at stress level			Fatigue life at stress level			Cumulative damage factor M
	n_1	n_2	n_3	N_1	N_2	N_3	
	S = 0.65	S = 0.70	S = 0.75	S = 0.65	S = 0.70	S = 0.75	
F FFT 92	10,000	10,000	8269	120572	73130	44356	0.406
F FFT 90	10,000	10,000	6595	120572	73130	44356	0.368
F FFT 91	10,000	10,000	8109	120572	73130	44356	0.402
F FFT 98	10,000	10,000	1499	120572	73130	44356	0.253
F FFT 97	10,000	10,000	997	120572	73130	44356	0.242
F FFT 111	10,000	10,000	3656	120572	73130	44356	0.302

Table 9.Cumulative Damage Factors for fibrous Concrete for Four Stage Compound Fatigue Loading

Specimen identity	No of load cycles applied at stress level				Fatigue life at stress level				Cumulative damage factor M
	n_1	n_2	n_3	n_4	N_1	N_2	N_3	N_4	
	S = 0.65	S = 0.70	S =0.75	S=0.8	S=0.6555	S = 0.70	S = 0.75	S = 0.80	
F FFT 93	10,000	10,000	10000	30054	120572	73130	44356	26903	1.562
F FFT 97	10,000	10,000	10000	3170	120572	73130	44356	26903	0.817
F FFT 135	10,000	10,000	10000	11578	120572	73130	44356	26903	0.875
F FFT 100	10,000	10,000	10000	3135	120572	73130	44356	26903	0.562
F FFT 102	10,000	10,000	10000	144428	120572	73130	44356	26903	0.981
F FFT 73	10,000	10,000	10,000	6197	120572	73130	44356	26903	0.675

VII. CONCLUSIONS

The following conclusions are deduced from the study

- The inclusion of steel fibers in the concrete matrix resulted in improvement in compressive and flexural strength. The increase in compressive strength is found to be 8.05% and enhancement of flexural strength is found to be 25.539%
- The static flexural strength of fibrous concrete for 1% of fiber content is 6.174 MPa, which satisfies the requirement of IRC SP46-1997. Hence it is concluded that 1% fiber content by volume fraction is optimum for design.
- S-N relation for Non fibrous M40 grade concrete is $S = -0.08\ln(N) + 1.556$
- S-N relation for Fibrous concrete with 1% volume fraction of steel fiber is $S = -0.10\ln(N) + 1.820$
- Cumulative damage factor for Non fibrous concrete and Fibrous concrete under compound loading varied from 0.123 to 1.960 and 0.086 to 1.562 respectively. Hence it indicates that Miner's hypothesis gives unsafe as well as over safe predictions in case of compound fatigue loading.
- Comparison of compound loading with constant amplitude loading shows that compound loading is more critical than constant amplitude loading since the number of cycles observed were more in constant amplitude loading.
- Fibrous concrete is an economical and sustainable option for construction of rigid pavements.

REFERENCES

1. Tarun R. Naik, Shiw.S.Singh, Congli Ye, "Fatigue Behaviour of Plain Concrete made with or without Flyash" Electric Power Research Institute, 3412 Hillview Avenue Palo Alto, California 94304
2. Batson, G., Ball, C., Bailey, L., Lenders, E. and Hooks, j., Flexural Fatigue Strength of Steel Fiber Reinforced Concrete Beams. ACI Journal. Procedings, V ol. 69, N0. 11 November 1972, pp 673 – 677.
3. Cachim, P.B., Figueiras, J. A., Pereira, P. a. a., Fatigue Behaviour of Fibre Reinforced Concrete in Compression, Cement & Concrete Composites, Elsevier Science, 2002, 24, no. 2, pp. 211 – 217
4. Daniel, L. and Loukili, A., Behavior of High Strength Reinforced Concrete Beams under Cyclic loading, ACI Structural Journal, May – June 2002, pp. 248 – 256.
5. Jun, Z. and Stang, H., Fatigue Performance in Flexure of Fibre Reinforced Concrete, ACI Materials Journal, January – February 1998,
6. pp 58 – 67.
7. Ballinger, C.A. Cumulative Damage characteristics of Plain Concrete. Highway Research Record, NO. 370, 1972, pp. 48 -60.
8. A.J.M. Siemes. Miner's Rule with Respect to Plain Concrete Variable Amplitude Tests. ACI Special Publications, No. SP – 75, 1987, pp. 71 – 109
9. Aravindkumar. B. Harwalkar and Dr. S.S. Awanti "Fatigue Behivour of High Volume Fly Ash Concrete under Constant Amplitude and Compound Loading" IJCIET Vol 3 Dec (2012), pp. 404 – 414
10. Girish M.G, A. Chandrashekar and A.U. Ravishankar"Flexural Fatigue Analysis of Steel Fibre Reinforced Concrete" International Journal of Earth Sciences and Engineering.Vol 05, Oct (2012) pp 1352 – 1357

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

11. S.P. Singh & B.R. Ambedkar, Y. Mohammadi, S.K Kaushik "Flexural Fatigue Strength Predication of Steel Fiber Reinforced Concrete Beams" Electronic Journal of Structural Engineering 2008.
12. IRC 58 2011, Guidelines for the design of plain jointed rigid pavements for highways.
13. IRC SP: 46 – 1997, Guidelines for Steel Fiber Reinforced Concrete for Pavements, Indian Road Congress" New Delhi.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved