

# Fatigue Strength of High Strength Concrete under Cyclic Loading

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**Abstract**— The interest in the fatigue of concrete began more than a hundred years ago with the development of reinforced concrete. The technological development in high strength concrete (HSC), has led to construction of modern complicated structures of considerable height and span. However, HSC is more brittle than conventional concrete, so, an alternative method to enhance ductility is to add fibers into the concrete matrix thus fiber reinforced concrete is made. Nowadays, the fatigue behavior of fiber reinforced concrete is getting more and more attention due to frequent application of cyclic loads as shown in figure 1. The aim of the present study is to investigate the fatigue strength of conventional HSC. The M60 grade concrete has been designed as per ACI-211.4-R based on trial mixes. Four concrete beams were cast of reinforced conventional HSC. All the beams have been tested under three point loading using 500 kN servo controlled actuator. The stress ratio in the range of 0.7-0.9 with an interval of 0.1 was incorporated for cyclic loading of beams. From the experimental data obtained, a relationship between S-N has been developed. An equation has been proposed to predict the fatigue strength of conventional (without fibers).

**Key words:** Flexural fatigue, Fatigue equation, High strength concrete (HSC)

## I. INTRODUCTION

### A. Fatigue:

Fatigue failure can be defined as a failure that occurs below the stress limit of a material when it has been exposed to repeated loading. Some materials have a fatigue limit, which implies that below this load no fatigue failure will occur. Fatigue tests are often very expensive and time consuming to perform due to the many factors that influence the fatigue capacity. The many factors lead in turn often to great variation in the results.



Fig. 1: Aircraft Runway Subjected to Repetitive Cyclic Loads

From the Table 1 it can be noted that if a fatigue test only lasts a few load cycles it is named low-cycle fatigue (LCF). The limit that is used is approximate up to  $10^3$  ( $-10^4$ ) load cycles. If the test lasts longer than this limit it is called high-cycle fatigue (HCF). There is also a third limit for a fatigue test, approximately  $10^7$  load cycles, called

super-high cycle fatigue (SHCF) which is not so common.[8]

### B. Materials and Methodology:

Ordinary Portland cement of 53 grades and specific gravity of 2.95 conforming to IS 269-1976[10] was used. The fine aggregates passing through 4.75 mm sieve and having specific gravity of 2.69. The coarse aggregates passing through 4.75 mm and retained on 10 mm sieve were used in the present experimental program. A commercially available BASF master glemium B8233 was used for all concrete mix. Tap water was used.

### C. Mixing and Casting Of Concrete:

Aggregates and cement were first mixed and fibers were then added. Then mixed with water and super plasticizer of dosage of 2% by weight of cement was added until a homogeneous concrete was obtained. The uniformly mixed concrete was then poured in the formwork and compacted using needle vibrator.

### D. Methodology:

In the present study the mix design for high strength concrete for M60 was developed based on trial batches. Six numbers of cubes and four cylinders have been cast for assessing the compressive and split tensile strength of concrete. A total of four numbers of beams of 150 mm × 200 mm × 1200 mm with and without fibers have been cast.

Flexural strength of the beam is first evaluated under monotonic three point loading prior to fatigue testing as shown in figure 2. Fatigue strength was evaluated using 500 kN servo controlled actuator under different stress ratio varying from 0.7 - 0.9 and the number of cycles before failure is noted. The graph representing the stress ratio and number of cycles to failure was developed using regression analysis.

### E. Fatigue Analysis:



Fig. 2: Experimental Setup of Fatigue Testing

F. Results and Discussions:

Compressive Strength: The average of three samples was taken as the representative value of compressive strength of concrete for each batch and is tabulated in Table 1.

Specimen ID	Compressive Strength (MPa)	Average Compressive strength (MPa)
A	63.22	65.4
A1	65.40	
A2	67.58	

Table 1: Average Compressive Strength of Cubes

G. Split Tensile Strength:

The average of two samples was taken as the representative value of split tensile and is tabulated in Table 2.

Specimen ID	Split Tensile Strength (MPa)	Average Split Tensile strength (MPa)
A	5.62	5.315
A1	5.01	

Table 2: Average Split Tensile Strength of Cylinders

H. Fatigue Strength of Concrete:

It is defined as the intensity of cyclic stress that can be withstood by a specimen for a given number of cycles. Fatigue test results are tabulated in Table 3

I. S-N Curve/ Wohler Diagrams:

The stress level versus the number of cycles until failure is known as S-N diagrams or Wohler diagrams. It is an assessment of the influence of stress level on the fatigue life of concrete. The fatigue life of different specimens of conventional HSC is represented in Figure 3. The regression equation for conventional HSC beam (Eq.4.1) generated from the S-N curve can be used to estimate fatigue cycles at various stress amplitudes.

$$S = -0.11 \ln(N) + 2.156 \quad (R^2=0.985)$$

Equation 1: Fatigue Equation for Conventional HSC

N= Number of cycles to failure

R = Stress Ratios

Specimen	Stress Ratio (S)	Flexural strength ( $f_r$ ) in kN	Max. Load ( $f_{max}$ ) in kN	Min. Load ( $f_{min}$ ) in kN	No of Cycles to Failure
A1	0.9	55.0	49.5	5.5	80,259
A2	0.8		44		1,60,563
A3	0.7		38.5		4,65,952

Table 3: Fatigue Test Results

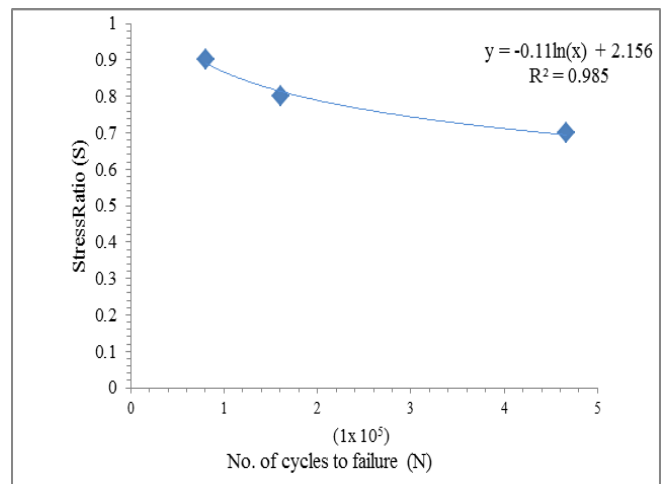


Fig. 3: S-N Curve for Conventional HSC Beams

II. CONCLUSIONS

The following conclusions are deduced from this present experimental investigation.

- (1) The variation of fatigue life at various stress levels can be well studied using S-N plot and fatigue equation was proposed for conventional HSC given below:

$$S = -0.11 \ln(N) + 2.156$$

- (2) Concrete fatigue strength is influenced by the range of cyclic loading. In general, a decrease of maximum stress level or stress range enhances fatigue life of concrete.
- (3) The fatigue strength of HSC is 71.25% of monotonic flexural strength.

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