# Fatigue Damage of Concrete under Uniaxial Compression

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**Abstract.** This paper presents the results of a study on the fatigue damage of concrete under uniaxial compression. Based on the experiment results, the change law of fatigue modulus is put forward. Then the paper presents a fatigue damage model. By reference to the concept about the damage variable defined by some scholars, the formula of the damage variable is proposed and the damage variable curves along with recycle ratio (n%) are mapped. At last, the fitted equation of the damage variable along with recycle ratio is proposed. The fitting effect is very good and the correlation coefficients are above 0.95.

## Introduction

The bridge bears the repeated vehicle load continuously and the fatigue failure is the main consequence, so exploring the effect of vehicle load on the bridge has evolved into a fatigue issue[1]. Concrete is the major component of the concrete bridge, on account of which the fatigue properties of materials are essential to the study of fatigue damage of structure,so a good many scholars have carried out the study on the fatigue properties of concrete material, making some achievements.

This paper discusses the fatigue damage of high-strength concrete under axial compression by means of uniaxial compression experiment. In this paper, analysis of variation in fatigue strain and fatigue modules is carried out. Based on the experimental data and the definition of fatigue damage variable, the fitted equation of the damage variable is proposed.

## The fatigue experiment of concrete

In this experiment, the concrete cubic sample is used, of which the size is 15 cm and the characteristic strength is C60. After 28 days standard curing and another 90 days positioned naturally, the concrete samples will be tested by the fatigue testing equipment called MTS-2500. In this paper, the average compressive strength of concrete samples calculated by experimental data is 58.9Mpa. The fatigue load is imposed by the sine wave mode of which the amplitude is constant until the failure of the concrete sample or the designated number of cyclic loading. According to the maximum stress level, there are five working conditions and each condition includes three concrete samples. The working conditions of fatigue experiment are displayed in Table.1. In Table.1,S is the maximum stress level, which equals the maximum loading force divided by the failing load for the concrete samples. R is the stress ratio,which equals the minimum number divided by maximum loading force.

Table.1 The working-conditions of fatigue experiment

| S | R | Frequency [Hz] | The number of samples |
|---|---|---|---|
| 0.86 | 0.10 | 5 | 3 |
| 0.76 | 0.10 | 5 | 3 |
| 0.71 | 0.10 | 5 | 3 |
| 0.66 | 0.10 | 5 | 3 |
| 0.60 | 0.10 | 5 | 3 |

## The experimental results and analysis

**Fatigue life.**According to the experiment result, the fatigue life of concrete samples under the different stress levels is measured, displayed in table.2.

**Cyclic stress-strain curves.** Based on experimental result, the cyclic stress-strain curves in fatigue direction for the concrete samples are mapped in Fig.1 and the cyclic stress-strain curves adhere to the following change rule: the curve is convex to the principal stress axes with the characteristics of sparse-dense–sparse and the obvious hysteretic phenomenon, which indicates there are plastic deformations in the concrete samples.

Table.2 The fatigue life

| S | $N_f$ (the fatigue life) |
|---|---|
| 0.86 | 380 590 270 |
| 0.76 | 2800 8212 6713 |
| 0.71 | 10292 33512 29531 |
| 0.66 | 62138 12120 193256 |
| 0.60 | $2\times10^6$ (not broken) |

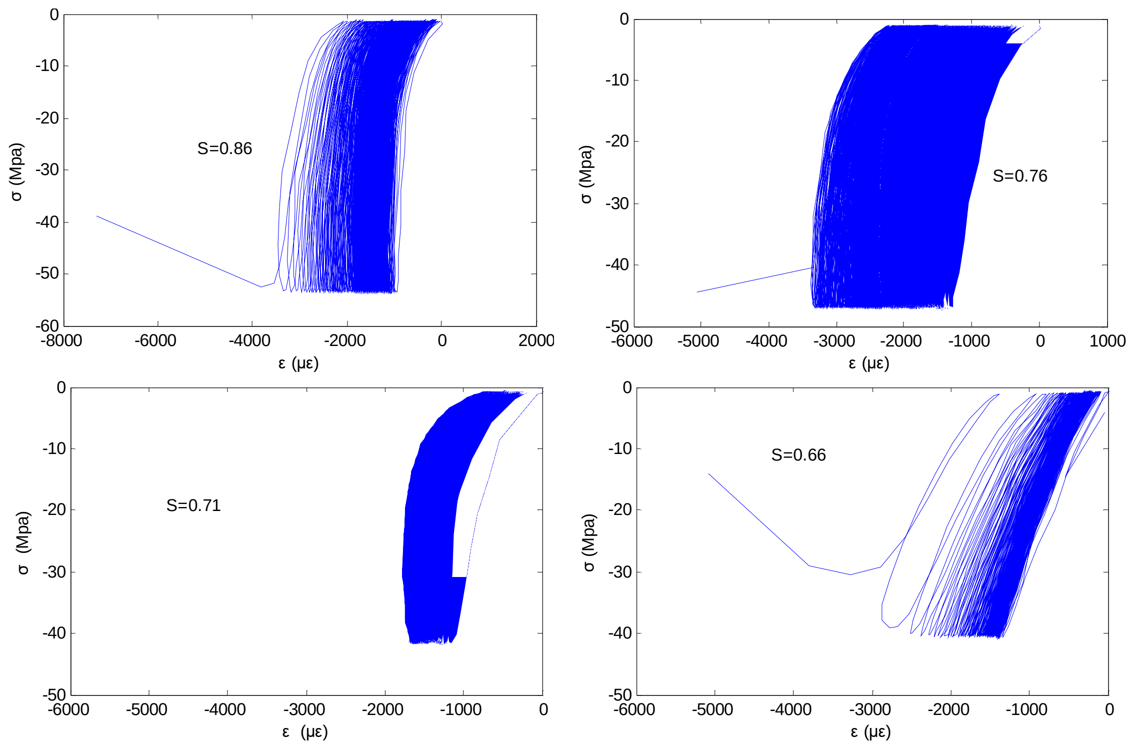


Fig.1 Cyclic stress-strain curves for concrete

**Fatigue modulus.** Fatigue strain can truly reflect the change rule of fatigue damage. Fatigue strain divides into two categories: $\varepsilon_{max}$ (the maximum fatigue strain) and $\varepsilon_{min}$ (the residual fatigue strain). The maximum fatigue strain is the one corresponding to the maximum stress under fatigue load and the residual fatigue strain is the plastic strain after unloading. According to the analysis on experimental results, similar to the research findings[1-4] of most scholars, fatigue strain appears marked change law which divides into three stages. That is to say, fatigue strain grows rapidly from zero and soon reaches the steady state in the first stage. In the second stage, fatigue strain grows slowly at a constant rate. In the third stage, fatigue strain grows sharply and the sample will be destroyed soon. The three stages respectively account for fatigue life of 5%, 85% and 10%. To reveal the decay characteristics of concrete performance under fatigue load, fatigue modulus is proposed by W. Hwang[5] and Kaida Zhang[6], which is calculated by the formula 1:

$$F_n = \sigma_{max}/\varepsilon_{max}\,. \tag{1}$$

Where, $F_n$ is fatigue modulus on the nth cycle; $\sigma_{max}$ is the maximum stress on the nth cycle; $\varepsilon_{max}$ is the maximum stress on the nth cycle.

The fatigue modulus curves which change with recycle ratio (n%) are mapped, displayed in Fig.2. Similar to fatigue strain, fatigue modulus also appears marked change law which divides into three stages. When concrete fatigue failure occurs, the ratio of fatigue modulus and the initial elastic modulus is about 0.34, of which the discreteness is small along with amplitude variation of fatigue load. It can be regarded as the one of the criteria for fatigue failure of concrete. That is, concrete will be destroyed when the fatigue modulus reaches this critical value.

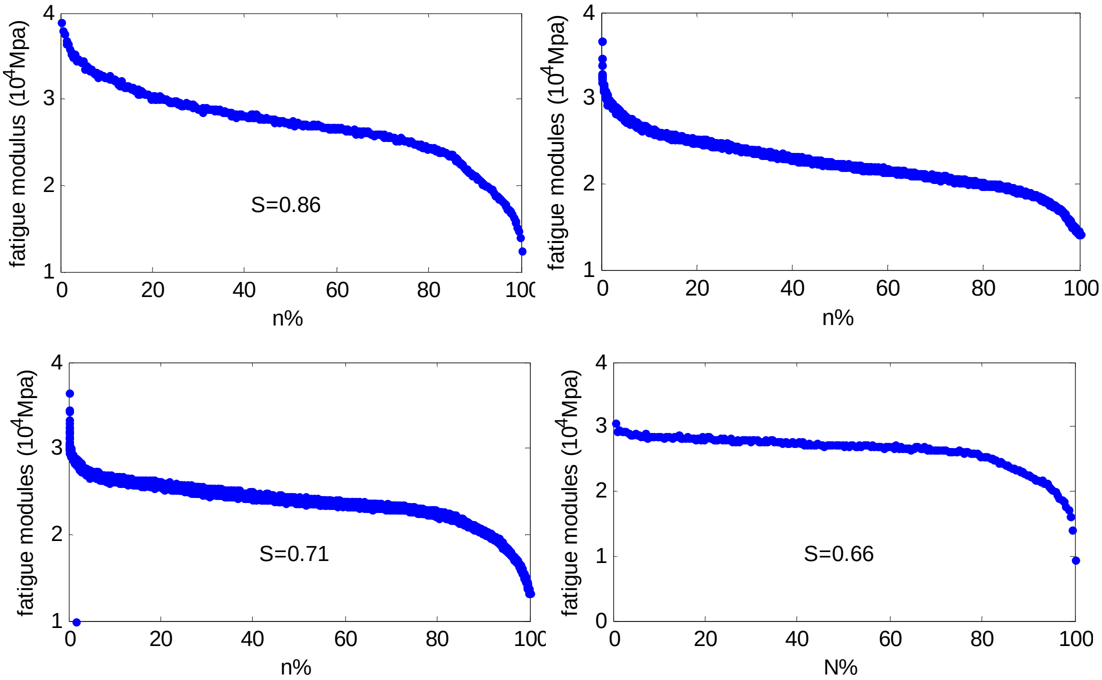


Fig.2 Experimental fatigue modules curves

**Fatigue damage model.**The cumulative internal damage is the underlying reason which leads to the deterioration of macro-mechanical properties of concrete structures. In order to describe the fatigue damage law quantitatively and qualitatively, it is necessary to choose the right damage variable which can measure internal injury of the material and explore its evolutional law during fatigue loading. From the point of view of engineering, we focus on the deterioration law of macro-mechanical properties, so fatigue modulus is usually chosen to define the damage variable which can be directly obtained from fatigue experiment.

According to the definition proposed by Xiaohui Zhang[7] , the damage variable is defined by formula 2:

$$D = a(1-F_n/F_0) . \quad (2)$$

Where, D is the damage variable, $D \in [0, 1]$; $F_n$ is fatigue modulus on the nth cycle; $F_0$ is the initial elastic modulus; a is a test constant.

For the moment, the whole process of fatigue strain has been fitted by individual scholars[8]. But the relation equation of the damage variable is rare reported. In this paper, the fitted equation of the damage variable is defined by formula 3:

$$D = b+cx+dx^{1.5}+ex^2 . \quad (3)$$

Where, D is the damage variable; x is recycle ratio(n%); b, c,d and e are test constants.

By formula 2 and 3, the calculated values and the fitting curves of the damage variable varying with recycle ratio (n%) are mapped, displayed in Fig.3. The fitting effect is very good and the correlation coefficients are above 0.95.

Table.3 Test constants

| S | b | c | d | e |
|---|---|---|---|---|
| 0.86 | 0.0223 | 0.0491 | -0.0099 | 0.00059 |
| 0.76 | 0.2515 | 0.0319 | -0.0059 | 0.00033 |
| 0.71 | 0.2790 | 0.0307 | -0.0066 | 0.00041 |
| 0.66 | -0.0334 | 0.0373 | -0.009 | 0.0006 |

## Conclusions

Based on the above analysis, the conclusions are as follows:

(1)Under the fatigue load of which the amplitude is constant,fatigue modulus of concrete appears marked change law which divides into three stages. The three stages respectively account for fatigue life of 5%, 85% and 10%.When concrete fatigue failure occurs, the ratio of fatigue modulus and the initial elastic modulus is about 0.34.

(2)According to the definition and experimental data, the fitted equation of the damage variable is proposed and the fitting effect is very good.

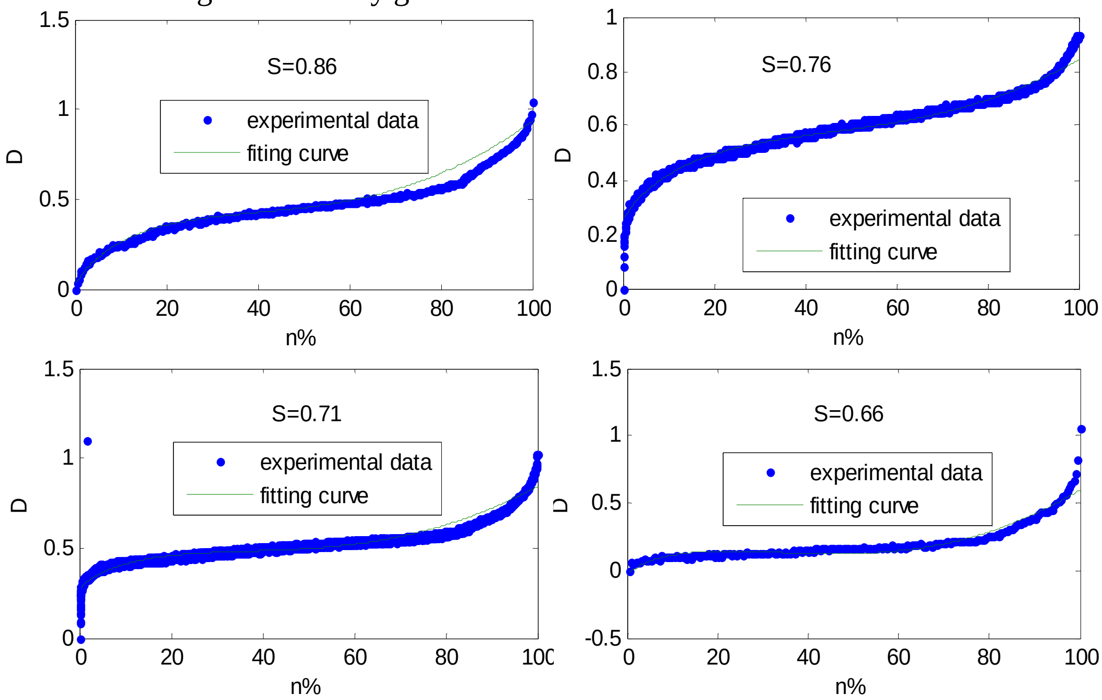


Fig.3 Experimental damage variable curves vs. fitting curves

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