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FATIGUE PARAMETERS OF SELECTED FIBER CONCRETES ON THREE-POINT BEND SPECIMENS

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Summary: *The paper presents the influence of the various concrete mixtures on fatigue parameters measured on three-point bending specimens. These specimens are the most frequently used for fracture laboratory testing, especially of quasi-brittle cement-based composites. From the test results, the effects of the fibre type and the fibre content on concrete fatigue behaviour are studied. According to the regression technique, Wöhler curve for predicting the fatigue life of each concrete mixture are suggested. Keywords of the paper are fatigue/fracture parameters and fibre reinforced cement-based composites.*

1. Introduction

The fatigue behavior of concrete has received considerable attention from investigators in the field of concrete structures. There are several reasons for interest in cyclic loading for concrete. The uses of higher strength concrete and lightweight concrete, as well as, reductions in safety margins, have resulted in more slender structures in which the dead load forms a smaller part of the total load. It is recognized that the material properties may be significantly affected by repeated loading. Despite all this the importance of fatigue of the concrete in reinforced concrete structures is sometimes doubted. This is mainly because no clear concrete fatigue failures are known from the literature.

During the past three decades, a number of works pertaining to experimental and analytical methods for evaluating the strength characteristics of fiber reinforced concrete have been published under varied specimen types, fiber types, fiber contents, curing time and testing methods (e.g. Chang et al., 1993; Lee & Barr, 2004; Choi & Yuan, 2005; Nieto et al., 2006; Singh et al., 2006).

Fatigue loading is usually divided into three categories i.e. low-cycle, high-cycle loading and super-high-cycle fatigue (Lee & Barr, 2004). It is supposed here that the studied materials are intended for using in high-cycle fatigue region. The paper continues and develops the previous study of co-authors (Seitl et al., 2009a; Seitl et al., 2009b).

The aim of the paper is to present and compare selected fatigue and fracture mechanics parameters of advanced building materials marked here as BS 080405, HD 080326 and SK

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080404. The experimental measurements were made at two levels. The first one was a static measurement and its results are represented by values of effective fracture toughness of the material. The second level is connected with high-cycle fatigue – Wöhler curves of three study materials were determined. The obtained experimental results are compared with literature data.

2. Materials, equipment and test procedure

The experimental test program has been carried out at the Laboratory of Civil Engineering Faculty of Brno University of Technology in Czech Republic. Both static and fatigue tests were carried out in laboratories where temperature and relative humidity values did not undergo significant fluctuations. The controlled values for temperature and relative humidity were 22 ± 2 °C and 50%, respectively.

The tested specimens were prepared from mixtures of which the compositions are presented in Table 1. Two types of fibres were used: (i) "BS" Special combination of polypropylene and polyethylene, properties of fibres were as follows – tensile strength 610 MPa, modulus of elasticity 5.2 GPa, diameter 0.48 mm, length 55 mm, (ii) "HD", "SK" Alkali-resistant glass fibres (glass with high content of zirconium oxide), tensile strength 3500 MPa, modulus of elasticity 73 GPa, diameter 14 μm, length 12 mm.

Table 1 Composition of mixtures

Component [Unit]	*BS 080405*	*HD 080326*	*SK 080404*
CEM I 42.5 R Mokra [kg/m^3]	820	1000	800
Sand, 0/4 mm [kg/m^3]	1300	940	1200
Water [kg/m^3]	197	280	280
Stachement 2060 superplasticizer [kg/m^3]	12	15	15
Polymer fibers BS 55 mm [kg/m^3]	2.5	–	–
Glass fibers HD/SK 12 mm [kg/m^3]	–	6	5

The experimental data are carried out from the three-point bending (3PB) tests. Fig. 1 shows the geometry of the 3PB specimens; nominal dimensions were L = 400, S = 300, W = 100 and thickness = 100 mm. The initial notch was made by a diamond saw that fabricated the 2-2.5 mm wide notches with controlled notch profiles and orientation. The numerical study of the influence of the shape of a saw-cut notch on experimental results is shown in (Seitl et al., 2008). In this study 3PB specimens with notch to width a_n/W ratios of about (i) 0.33 were produced for subsequent static tests, and (ii) 0.10 were produced for subsequent fatigue crack growth testing.

The static tests were carried out in a testing machine made by the Zwick/Roell Company. The deflection control was used; the loading rate was 0.05 mm/min. During tests load–deflection diagrams were recorded. Effective fracture toughness was evaluated using the Effective Crack Model (Karihaloo, 1995; Shah, 2002). This model combines linear elastic fracture mechanics and the crack length approach.

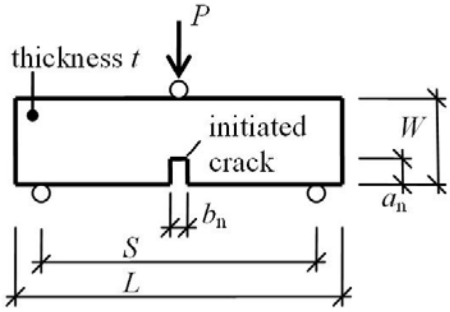

Figure 1 Schematic of three-point bend (3PB) specimen geometry

The experiments results of fatigue test (Wöhler curves) were carried out in a computer-controlled servo hydraulic testing machine (INOVA–U2). Fatigue testing was conducted under load control. The stress ratio R=0.1 was selected to avoid shifting of the beams with cycling while generating stresses that could be considered representative of dead loads in beams. The load frequency used for all repeated-load tests was 10 Hz. Along with data points, the analytical expressions for the curves in the following form were obtained through linear regression $S=a\times\log N+b$, where S is stress amplitude, N is number of cycles and a, b are the material parameters.

3. Results from static and fatigue tests

Experimental static load–deflection curves (*l–d* diagrams) were used; every curve was assessed separately, and the variability of the effective fracture toughness is described by the estimation of the first two statistical moments (mean value and standard deviation) – see Table 2.

Table 2 Results of static fracture tests

Specimen	*Value* $[MPa.m^{1/2}]$	*Mean Value* $[MPa.m^{1/2}]$	*Standard Dev.* $[MPa.m^{1/2}]$ *(COV [%])*
BS080405_U01	1.190	1.161	0.086 (7.4)
BS080405_U02	1.229		
BS080405_U03	1.064		
HD080326_U04	1.194	–	–
SK080404_U05	1.122	1.052	0,089 (8.4)
SK080404_U06	0.952		
SK080404_U07	1.082		

From the test which was conducted in order to observe the fatigue life and the strength with changes of the materials parameters are presented in Figs. 2 and 3. The tested materials are loaded in the range of high-cycle fatigue; therefore an upper limit on the number of cycles to be applied was selected as 2 million cycles. The test was terminated when the failure of the specimen occurred or the upper limit of loading cycles was reached, whichever occurred first.

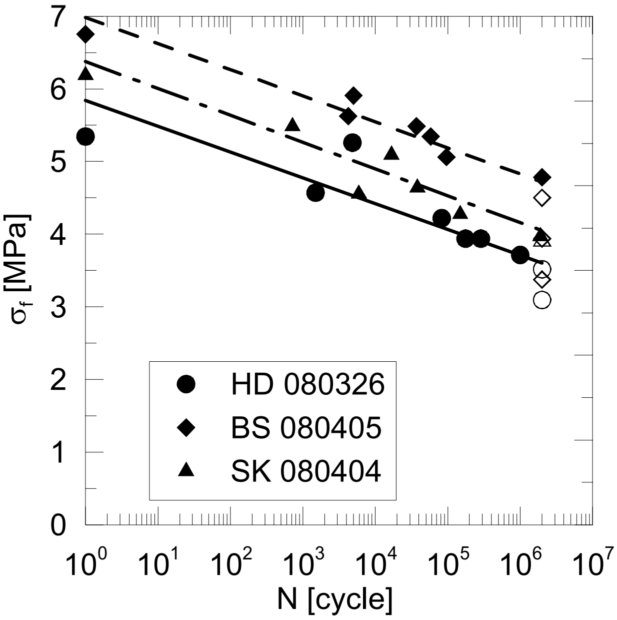

Figure 2 *S–N* diagrams for HD 080326, BS 080405 and SK 080404 materials. The empty symbols are for non ruptured specimens

The results of the fatigue tests under varying maximum bending stress level are summarized in Fig. 2 where maximum bending stress in the fatigue experiment is plotted against the logarithm of number of cycles to failure. Along with data points, by regression analysis, for the curves (in the form $\sigma_f = a \times \log N + b$) were obtained the following equations. The regression equations and the regression coefficients (R^2 is index of dispersion) for the present tested materials are:

BS 080405 $\log N = 5.84 \times \sigma_f^{-0.0333}$ and $R^2 = 0.74$,

HD 080326 $\log N = 6.98 \times \sigma_f^{-0.027}$ and $R^2 = 0.92$,

SK 080404 $\log N = 6.37 \times \sigma_f^{-0.0313}$ and $R^2 = 0.88$.

The fatigue strength with 2 million repeated loading cycles in SK 080404, HD 080326 and BS 080405 shows about 67%, 70% and 66% to the first static flexural strength, respectively.

Finally, let's compare the linear regression lines for the present and the literature results taken from (Lee & Barr, 2004), where authors provide an overview of recent developments in study of the fatigue behavior of plain and fiber reinforced concrete. They consider three types of concrete – plain and reinforced by steel fiber with 0.5% and 1% fiber content. For our studied materials, it is interesting to compare obtain results with the date for the plain concrete.

The results of the test are recorded in a normalized Wöhler diagram, see Fig. 3 where on one axis the normalized stresses ($S_n = \sigma_f/\sigma_s$; σ_f–the values of fatigue loading stress and σ_s–values of static maximal stress) is given and on the other axis the numbers of cycles until failure on log scale are presented. The Wöhler curves coefficients for analytical expression in the form $S_n = a \times \log N + b$ are presented in Table 3; the last column are values of indexes of dispersion R^2.

It can be seen that for small values of N, the σ_f–N curves tend to converge to σ_f values that are greater than the static value $N = 1$. This is mainly because the compressive strength used as a reference was obtained from the static tests in which the loading rate is much lower than that of the fatigue tests.

In Fig. 3, the results for each beam type are shown in the normalized form, obtained by dividing the value in Fig. 2 with the corresponding average value of static flexural strength for the same batch of specimens. Comparison between S_n–N curves for: plain concrete, from (Lee & Barr, 2004) and presented results for BS 080405, HD 080326 and SK 080404 is shown.

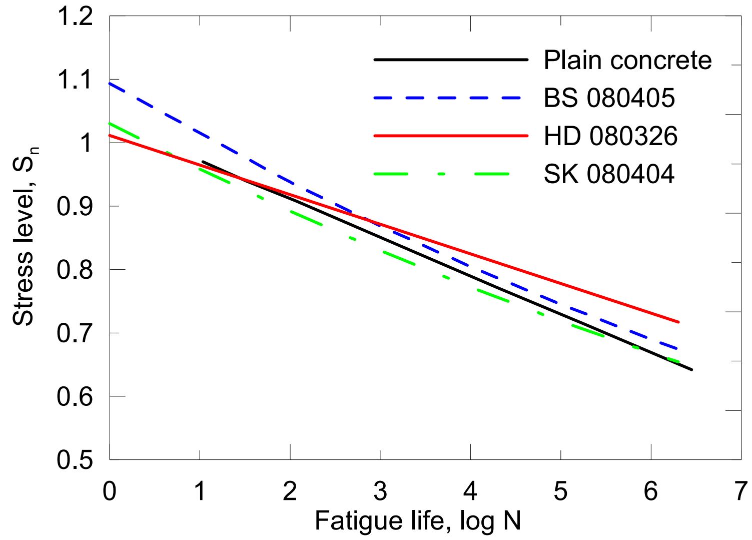

Figure 3 Comparison between S_n–N curves for plain concrete, from (Lee & Barr 2004) and presented results for BS 080405, HD 080326 and SK 080404

Table 3 Coefficients of S_n–N curves and indexes of dispersion

Material	*a and b in the fatigue equation*		R^2
	a	*b*	
Plain concrete	-0.0606	1.0327	0.72
BS 080405	-0.0617	1.0632	0.74
HD 080326	-0.0524	1.0343	0.92
SK 080404	-0.0597	1.017	0.88

4. Conclusion

According to the performed fracture/fatigue tests, the followings can be concluded:

- Selected fatigue and fracture mechanics parameters of advanced building materials SK 080404, BS 080405 and HD 080326 were studied and fracture toughness and S–N curves were experimentally determined.
- The obtained experimental results pointed out some of the most relevant characteristics of the behavior of fiber cement based composites under monotonic/static and fatigue loading necessary for application in civil engineering industry.

- The key to the success of improving the fatigue life of concrete with the addition of fibers seems to be related with the distribution of the fibers in concrete. In fact, if the fibers are not well dispersed in concrete, the addition of fibers may have a detrimental effect on the fatigue life of fiber cement based composites.

It can be concluded that for utilization of the material under dynamic loading HD 080326 composite is preferable.

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