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Self-compacting concrete, protecting steel reinforcement under cyclic load: evaluation of fatigue crack behavior

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Abstract

The unique properties of self-compacting concrete of high workability without loss of stability and improved durability allow better protection of steel reinforcement in concrete structures. Recently, fatigue behavior has become more important for the design of constructions due to slimmer structures, which are more sensitive to fatigue loading. This article aims to evaluate the fatigue crack propagation rate in vibrated concrete and self-compacting concrete under different stress ratios using the Paris-Erdogan law, based on crack mouth opening displacement measurement from cyclic three-point bend tests on single edge notched beams.

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1. Introduction

Worldwide, the market share of self-compacting concrete (SCC) is rapidly growing because of the economic opportunities and improvements of the quality of the concrete and the working environment [3]. Its unique properties of high workability without loss of stability have allowed for complex construction and rigorous construction schedules. For example, SCC was used in the construction of the anchorage blocks of the Akashi Kaikyō Bridge in

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Japan, the suspension bridge with the largest main span in the world. The use of this new material shortened the anchorage construction period by 20%, from 2.5 to 2 years [13].

One of the original drivers in the development of SCC was increased durability of the finished product. The durability of concrete is governed by the permeability and uniformity of consolidation. SCC typically has a low water-cement ratio and high paste content. The high quality transition zone between the paste and aggregate also decreases permeability [17]. When it comes to the design of long lifetime structure, durability and especially permeability play an important role. A lower permeability decreases the chance of penetration of water and chemicals, which might otherwise lead to corrosion of the steel reinforcement. Low permeability thus increases the lifetime of the structure.

After two decades of research, the short term properties and behaviour of this new concrete type are thoroughly researched [10], while its long term fatigue behaviour is not yet fully understood. The availability of data from long term field performance is scarce because of limited use and relatively recent introduction [5]. However, a distinct fracture behaviour can be expected, since the strength of the cement paste and the location and size of the aggregates play an important role in the crack propagation phenomenon [8]. In order to reliably predict the behaviour of SCC in applications which involve millions of load cycles (e.g. bridges, beam cranes, offshore constructions), more research is required. Fatigue behaviour in concrete is a complex process, and even though a tremendous effort has been made by the international scientific community, no universally accepted strategy suitable to efficiently perform the fatigue assessment of concrete has been agreed yet [18].

This article aims to evaluate and compare the fatigue crack propagation rate in SCC and traditional vibrated concrete (VC) by the well-established Paris-Erdogan law [15]. Therefore, three types of concrete were assessed: a traditional VC, a SCC with comparable strength (SCC1) and a SCC with a comparable water/cement ratio (SCC2). Herein, VC is used for comparison, since its fracture properties are well known [2]. The comparison is based on data from three-point bend tests (3PBT) specimens, loaded under four different stress ratios, and was obtained from the research of Korte et al [18,19]. In this research, the data was obtained from static tests (strength of material, fracture toughness, Young's modulus and Poisson ratio) and by performing cyclic tests on notched specimens, while measuring the crack mouth opening displacement (CMOD) for each load cycle. For this study, finite element analysis software ANSYS [1] was then used to correlate the measured CMOD data with the Paris-Erdogan law for crack propagation. Herein, the crack propagation rate da/dN is plotted against the corresponding stress intensity range ΔK in a log-log graph. In a final step, the Paris-Erdogan law parameters C and m were obtained through linear curve fitting on the data points from the obtained graphs. The parameters C and m are then used to compare and evaluate the fatigue crack behaviour in SCC and VC.

2. Theoretical background

Fatigue may be defined as a process of progressive, permanent internal structural changes in a material subjected to repeated loading. In concrete, these changes are mainly associated with the progressive growth of internal microcracks, which results in a significant increase of irrecoverable damage. At the macro level, this will result in changes in the material's mechanical properties [14].

Three-point bend tests (3PBT) are often used to determine the fatigue fracture properties of structural materials such as cement based composites [16]. In the reference tests used in this research, the specimens were subjected to a sinusoidal load function (0.33 Hz) until failure, while measuring the CMOD at the crack mouth for each cycle, using a clip gauge. The 3PBT on single edge notched beams is a useful configuration for fracture toughness testing since it can be easily shaped and tested. For the test specimens, a value of $S/W=3$ was used in which S is the span between the supports, and W the depth of the specimen. Its geometry (Fig. 1) is included in all international standards for fracture toughness testing [6].

In order to evaluate fatigue behaviour of VC, the 3PBT results were correlated with the Paris-Erdogan law (eq. 1), which describes the relationship between the crack propagation rate da/dN and the stress intensity ratio ΔK [15]:

$$\frac{da}{dN} = C * (\Delta K)^m. \tag{1}$$