論 文 の 内 容 の 要 旨

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Evaluation of degradation and evolution of crack-bridging performance of fibers under flexural fatigue in SFRC structural beams

(SFRC梁の曲げ疲労載荷下における繊維架橋効果の減少と発現の評価)

Among several modes of failure in reinforced concrete (RC) structural members such as bridge girders and slabs, the fatigue failure is associated with progressive, permanent, and localized internal changes in the material caused by repeated stresses. Consequently, the fatigue design and safety of RC structures give many concerns to sustain millions of repeated cyclic loads over a specified design lifetime, avoiding any kind of structural failure and undesired degradation on the material strength particularly the rupture failure of ordinary reinforcing steel bars. Incorporating steel fibers in concrete, steel fiber reinforced concrete (SFRC) exhibit an improved flexural fatigue performance in a manner of higher strength and longer fatigue life, through the additive toughness strength and fracture energy comparing to normal concrete (NC). Accordingly, the bridging mechanism induced by fibers, that involves the transfer of tensile stress from the matrix to the fibers by interfacial bonding or/and by interlock between the fibers and matrix for the deformed shape fibers, is necessary to be evaluated.

This research focuses on the evaluation of the crack-bridging strength induced by steel fibers from the structural experimental response of SFRC beams subjected to cyclic loading using the sectional analysis calculations inversely. A review of the literature reveals that fatigue is a limiting design consideration for structures. This research work aims to understand the degradation and evolution mechanism of the crack-bridging strength under a wide range of fatigue stress levels with constant and various amplitude cyclic loading through increasing or decreasing the maximum fatigue load levels over the whole fatigue life of SFRC structural beams with different material and steel fibers properties.

Firstly, the degradation in crack-bridging strength of SFRC structural beams with 1.5% by volume of single hooked-end steel fibers under constant amplitude cyclic loading for different flexural fatigue stress levels is evaluated over the fatigue life using an inverse analysis method. The experimental flexural response is monitored during static and fatigue tests, and compared with the calculated one from the section analysis calculations through the execution of the inverse analysis method. Based on the results, the crack-bridging strength is shown to degrade gradually at different flexural fatigue stress levels over the fatigue life. As well, the crack-bridging strength degradation regarding the evolution of the maximum rebar strain relationship is provided, having a constant linear degradation mechanism regardless of the fatigue stress levels. Further, the residual flexural capacity at the end of fatigue life is shown to be little different from the original capacity obtained in static loading when the flexural fatigue stress level is low.

As structures are subjected to variable amplitude cyclic loading during their service life, in reality, wherein crack-bridging strength induced by steel fibers influences by the preceding loading history and remains unexplored. Secondly, research work is carried out to present an experimental investigation of SFRC structural beams with 1.5% by volume of hooked-end steel fibers under variable amplitude flexural fatigue loading. By utilizing the inverse analysis method with section analysis calculations, a crack-bridging degradation and evolution diagram were captured while increasing and decreasing the fatigue load level over the fatigue life. The result showed that the crack-bridging strength is increasing while increasing the maximum fatigue load level during fatigue life, which indicates the contribution of a new part of fibers in resisting the tensile stress as the crack opening. On the other hand, decreasing the maximum fatigue load level leads to a decrease followed by stabilizing the crack-bridging strength because of lower pullout stresses on the resisting fibers. Further, a crack-bridging degradation and evolution diagram regarding the evolution of maximum rebar strain is proposed, which would be a valuable tool in the flexural fatigue design and assessment of SFRC structural beams.

Finally, a parametric study was carried out to study the effect of changing material properties such as concrete compressive strength, beam's reinforcement ratio, and fiber's geometry and volume fraction on the proposed crack-bridging degradation and evolution diagram. The increased concrete compressive strength resulted in a lower degradation rate of the evaluated crack-bridging strength regarding the evolution of maximum rebar strain. The decreased reinforcement ratio resulted in a lower degradation rate of the evaluated crack-bridging strength regarding the evolution of maximum rebar strain. The lowered volume fraction of double hooked-end steel fibers resulted in a higher degradation rate of the evaluated crack-bridging strength regarding the evolution of maximum rebar strain, with the insignificant effect of the fiber's hooks level. A little change in the degradation rate of crack-bridging was observed due to the enhancement in the material properties.