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An analytical Approach for the Fracture Characterization in Concrete under cyclic loading condition

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Abstract
Fracture phenomenon in concrete is very complex due to its heterogeneity and size dependent properties, which are quasi nature. Moreover, it also susceptible to the type of loading and its rate. It has been proved by the scientific community that two stage crack propagation profile under cyclic loading depends on the geometric properties and loading frequency rate. In this study, an attempt has been made to develop an analytical model based on the stiffness degradation approach to better characterize the fracture behavior of concrete, especially under fatigue loading.

1. Introduction

Many civil engineering infrastructures frequently encounter repetitive loading during their service life. Due to the inherent complexity observed in concrete, like quasi-brittle materials, understanding the fatigue behavior in concrete still poses a challenge. Moreover, the fracture process zone characteristics ahead of the crack tip have been observed to be different in fatigue loading than in the monotonic cases. Therefore, it is crucial to comprehend the energy dissipation associated with the fracture process zone (FPZ) due to repetitive loading. It is well known that stiffness degradation due to cyclic loading provides a better understanding of the fracture behavior of concrete. Under repetitive load cycles, concrete members exhibit a two-stage stiffness degradation process. Experimentally it has been observed that the stiffness decreases initially with an increase in crack length and subsequently increases. In this work, an attempt has been made to propose an analytical expression to predict energy dissipation and later the stiffness degradation as a function of crack length.

Three-point bend specimens have been considered in the present work to derive the formulations. In this approach, the expression for the resultant stress distribution below the neutral axis has been derived by correlating the bending stress with the cohesive stresses developed ahead of the crack tip due to the existence of the fracture process zone. This resultant stress expression is utilized to estimate the dissipated energy due to crack propagation as a function of crack length. Further, the formulation for the stiffness degradation has been developed by relating the dissipated energy with the work done. It can be used to predict the critical crack length and fatigue life. An attempt has been made to understand the influence of stress amplitude on the damage pattern by using the information on the rate of stiffness degradation. It has been demonstrated that with the increase in the stress amplitude, the damage/FPZ proceeds more in the direction of crack propagation compared to the damage in the direction parallel to the span of the beam, which causes a lesser rate of stiffness degradation for the incremental crack length.

2. Results

The following results have been extracted using developed analytical model of energy dissipation under cyclic loading :

a. The dissipated energy under cyclic loading increases with an increase in crack length, but after reaching the maximum FPZ length, it attains a constant critical dissipated energy.
b. The stiffness degradation follows a similar crack propagation profile under cyclic loading. The rate of loss in stiffness decreases with the loading cycles up to the maximum FPZ length, but after that, it decreases at a faster rate when traction free crack propagation starts.

c. Maximum FPZ length and critical dissipated energy in the case of cyclic loading is not the only function of material property, but it also depends on the specimen geometry and both increase with the increase in specimen size.

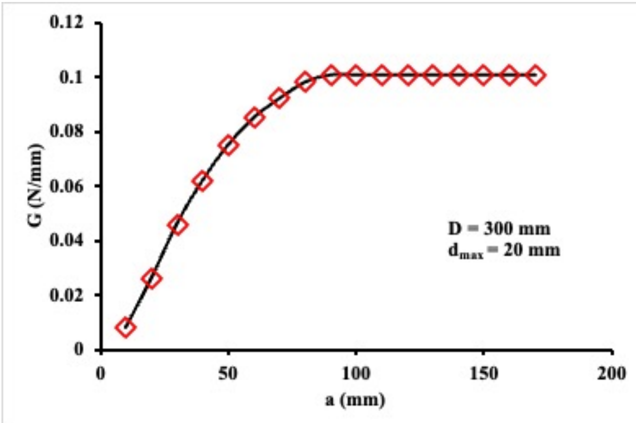

Fig.1 Energy release rate with crack length.

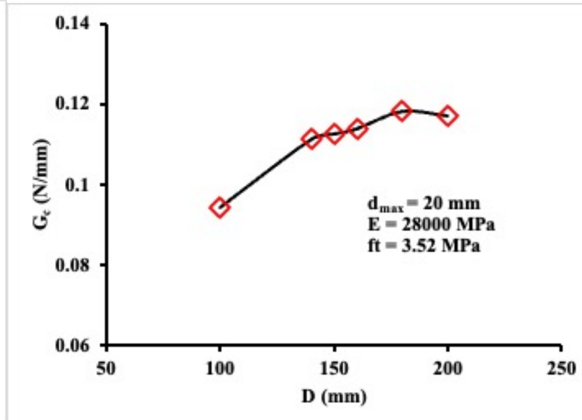

Fig.2 Critical energy release rate with specimen size

The above figure, Fig.1 shows the energy dissipation rate, (G) with crack length, (a) under the cyclic loading condition. Here, it can be seen the rate of energy dissipation increases with crack length initially, but after reaching a certain crack length, it becomes constant. Initially, the rate of increase in energy dissipation with crack length is decreasing, i.e. this is the stage of fracture process zone development, and it is offering resistance to the crack propagation. When it reaches the maximum FPZ length, the energy dissipation achieves the critical dissipation stage, and it turns to unstable crack propagation, where traction free crack propagation takes place. Figure, Fig. 2 shows the critical energy dissipation (G_c) with specimen size (D), where critical energy dissipation increases with specimen size. Critical energy can only increase if critical crack length (maximum FPZ length) increases if we keep the material property the same. Therefore, if we increase the specimen size, the maximum FPZ length will increase. In a similar way, the fatigue life of a structure also increases if we increase the specimen size, and it has been very well proven by the scientific community, so the model results are in line with the previous research.

3. Conclusions

The approach to characterize the fracture behavior of concrete under cyclic loading using energy dissipation is very well suitable for distinguishing the crack propagation stages. This energy dissipation model very well explained the different stages, stable and unstable crack propagation, and the reason behind it. It also helps to identify the size effect behavior of concrete.

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