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A study on the effects of fiber reinforcement on a concrete material model

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ABSTRACT

This paper introduces a modified Karagozian & Case (K&C) as a plastic-based concrete material model for steel fiber reinforced concrete (SFRC). The effect of the addition of steel fibers in the concrete material model is reflected for strength surfaces, damage function, and dynamic increase factor, and the material model is verified through the comparison with the multi-axial experiments for SFRC. Impact analysis using the modified concrete model is performed in LS-DYNA, and the numerical model is verified through correlation studies between the numerical analysis and the experimental data. The results show that the accuracy of simulation results for SFRC structures is improved by the modified concrete model.

1. INTRODUCTION

A Karagoziam & Case (K&C) model (Malvar et al., 1997) as a plastic-based concrete material model can describe the confinement effect and softening behavior of concrete, so it can be popularly used in blast and impact analyses for concrete structures (Wu et al., 2019, Hong et al., 2017). The K&C model has 49 input parameters, and when unconfined compressive strength is given, the rest of the parameters can be automatically determined. However, since automatically determined parameters are based on plain concrete, these are not appropriate for steel fiber reinforced concrete. This paper reflects the fiber reinforcement effect on the input parameters for strength surfaces, damage function, damage evolution parameters, and dynamic increase factors in K&C model. First, the strength surfaces are modified through uniaxial and triaxial compressive test data for SFRC. And damage function is proposed according to fiber amount in the concrete matrix. Single element analysis is carried out to calibrate the stress-strain relation. Impact analysis for SFRC structures using the modified K&C model is performed to verify the numerical model

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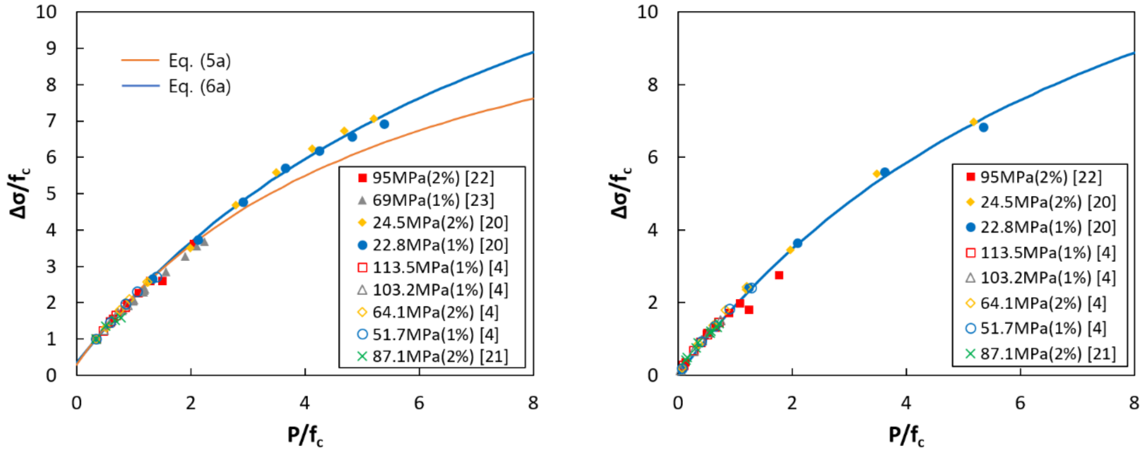
2. MODIFIED MATERIAL MODEL

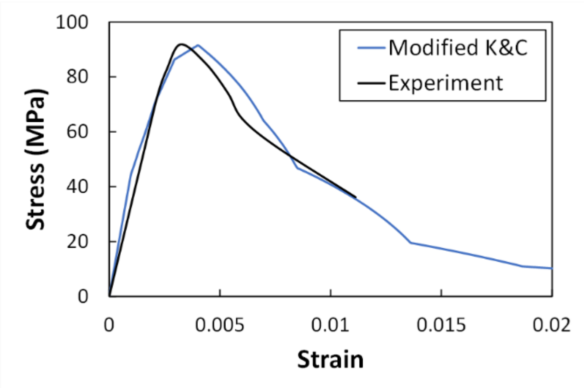
Strength surfaces of the K&C model consists of yield, maximum and residual strength surfaces. Among these surfaces, maximum and residual strength surfaces are modified based on the multiaxial test data for SFRC (see Fig. 1). The yield surface is determined by assuming that the yield strength is 0.45 times the unconfined compressive strength. The current stress state for hardening behavior can be obtained from the interpolation between the yield and maximum surfaces, and the stress state for softening behavior is from the interpolation between the maximum and residual strength surfaces.

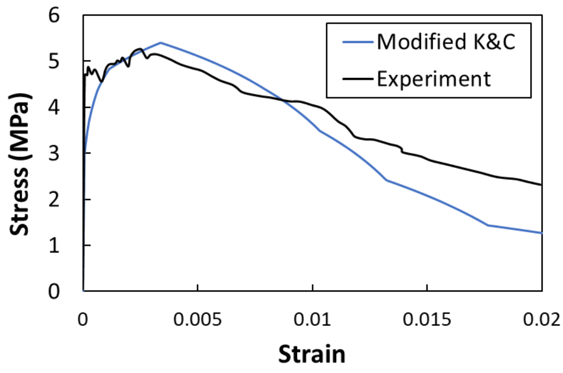


(a) Maximum (b) Residual

Figure 1. Strength surfaces for SFRC

In the interpolation process between surfaces, η represents the relative position of the current strength surface, and η is expressed as a function of λ. $\eta(\lambda)$ means the damage function, and 13 points of (λ_i, η_i) are required for input parameters of the K&C model. The damage function is defined by three factors of λ_m, α_c, and α_d. Since the damage function significantly affects the stress-strain relations for SFRC, the variation of these factors is investigated with various fiber reinforcement amount. The calibration equations for three factors can be obtained through regression analysis, and the factor values depend on the reinforcing index (Lee et al. 2021). Fig. 2 shows the stress-strain relations for SFRC with the reinforcing index of 1.5 %. From comparison with the experimental data, the damage evolution parameters $(b_1,\ b_2)$ are determined. It can be seen that the softening regions for both compression and tension are enlarged, and in particular, the tensile stress-strain relation of SFRC shows the improved energy absorption capacity compared to plain concrete.



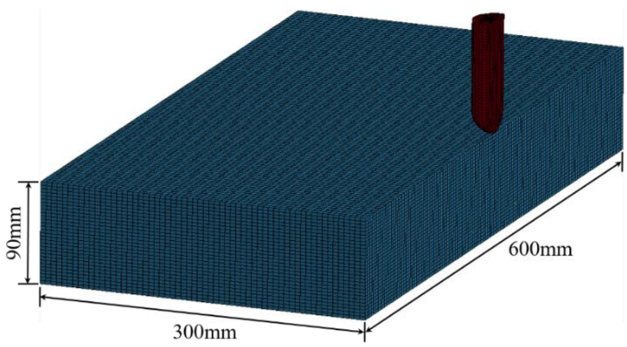


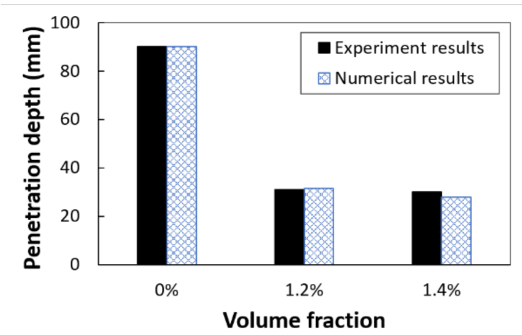
(a) Compression (Abbass et al., 2018) (b) Tension (Kwan et al., 201)

Figure 2. Stress-strain relations (V_f=1.5%)

3. NUMERICAL VERIFICATION

The modified K&C model is used in a numerical model for impact analysis for SFRC in LS-DYNA. To verify the numerical model, projectile experiment conducted by Almusallam (2015) is used for numerical simulations. All slabs have dimensions of $600 \times 600 \times 90$ mm, and the steel bars of 8 mm diameters were used for reinforcing slabs with a spacing of 100 mm. Experiments were conducted with three fiber volume fractions (0%, 1.2%, 1.4%) at the striking velocity of 135.1 m/s. Due to the symmetry of the geometry, the half of the target and projectile is modelled for numerical simulations Fig. 3(a). Figure 3(b) shows that the numerical results show a good agreement with experiment data by reflecting the decrease in the penetration depth with increasing volume fraction.





(a) finite element model (b) penetration depths

Figure 3. Numerical simulation of projectile experiment

4. CONCLUSIONS

This paper introduces the modified K&C model for SFRC. The proposed model deals with strength surfaces, damage function, damage evolution parameters for SFRC, and strain rate effects for SFRC and steel are also taken into account. The modified model is verified through a comparison between the experimental data and numerical results obtained from single element analysis for stress-strain relations. Furthermore, the numerical simulation of SFRC slabs subjected to projectile impact have been compared with experimental results to testify the accuracy of the numerical model. As a result, the proposed model can accurately consider the fiber reinforcement effect on the nonlinear behavior of SFRC.

Acknowledgements

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