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A data-driven model to predict strengthening performance of fibrous composites for civil infrastructure systems

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ABSTRACT

The deterioration of civil infrastructure systems has called for an immediate remedy in the light of their structural integrity. Fiber-reinforced polymer (FRP) composite materials have been proven for their effectiveness on strengthening performance for reinforced concrete (RC) structures (Ha et al., 2014; Park et al., 2017). Despite their light-weightiness and significantly high elastic properties, they are vulnerable to brittle failure, leading to premature failure (i.e., debonding of FRP composites) of strengthened RC structures. Hybridization of FRP, i.e., use of different types of fibers or fibers being oriented at different directions, is a recently proposed technique, which is capable of further enhancing the engineering properties of FRP composites and potentially improving the ductility, thereby preventing brittle failure. This study presents a data-driven model to predict the hybrid FRP composites, and discusses their potential application for rehabilitation of deteriorated RC structures.

1. INTRODUCTION

Recently, in the face of frequent global disasters such as earthquakes, tsunamis, typhoons, and floods, the possibility of structural collapse is increasing (Park et al., 2017). Accordingly, there is a growing need for securing the structural safety for the protection of civil infra-systems (Lee et al., 2008). A typical repair technique is crack repair methods, achieving the water resistance and material durability by injecting resin or cementitious materials into the cracks (Hosny et al., 2006). In addition, there is a

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fiber-reinforced polymer (FRP) method in which FRP reinforcement is attached to the surface of reinforced concrete to improve structural strength and rigidity (Jonkers, 2008). However, the elastic moduli of the above-mentioned materials are different with that of the conventional concrete material, and thus new cracks may occur near the repairing system when the concrete structure is subjected to external pressure.

Therefore, it is necessary to develop advanced reinforcement technology to overcome limitations of existing methods. In this study, we proposed a reinforcement method using new hybrid materials composed of SFRP composites and carbon fiber cores. The convergence of the SFRP and carbon fiber materials is expected to complement the disadvantages of each method. A data-driven micromechanical model is developed, and the characteristics of the proposed model are analyzed through numerical simulations. In addition, the effectiveness of the model is demonstrated by comparing available experimental data

2. METHODS

The framework of the proposed data-driven model is based on micromechanics, and is considering multi-phase and damage properties. Following Sun and Ju (2004), the constitutive model can be derived as

$$\mathbf{C}^*_{hybrid} = \left\langle \mathbf{C}^*_{SFRP} \right\rangle \cdot \left[\mathbf{I} + \phi_{cf} (\mathbf{S}^{cf} + \tilde{\mathbf{A}}_1)^{-1} \cdot \left\{ \mathbf{I} - \mathbf{S}^{cf} \cdot \phi_{cf} (\mathbf{S}^{cf} + \tilde{\mathbf{A}}_1)^{-1} \right\}^{-1} \right] \tag{1}$$

With

$$\tilde{\mathbf{A}}_1 \equiv \left[\tilde{\mathbf{C}}_1 - \left\langle \mathbf{C}^*_{SFRP} \right\rangle \right]^{-1} \cdot \left\langle \mathbf{C}^*_{SFRP} \right\rangle \tag{2}$$

where $\mathbf{C}_{\mathrm{SFRP}}^*$ and $\mathbf{C}_1$ are the stiffness tensor of SFRP composites and carbon fiber cores, $\mathbf{I}$ is the fourth rank identity tensor, and ϕ_{CF} denotes the volume fraction of carbon fiber cores, respectively. The parameter $\mathbf{S}^{\mathrm{cf}}$ means the Eshelby's tensor, which can be found in Ju and Ko (2008).

3. RESULTS AND DISCUSSIONS

Numerical simulations based on the developed model are conducted to investigate the effect of the model parameters on the mechanical behavior of hybrid composite-reinforced concrete structures. The relations between volume fraction of carbon fiber and strengthening behavior of concrete structure is illustrated in Figure 1. It indicates that the mechanical characteristic of the proposed hybrid composite increases as the volume fraction of carbon fiber core increases.

This is due to the fact that the carbon fiber helps to have greater resistance to the pressure applied to the composite material. The tendency in Figures 1 occurs because the model considers only the elastic region, however, different predictions may appear when the proposed model consider the interaction between the matrix and carbon fiber is taken into consideration.

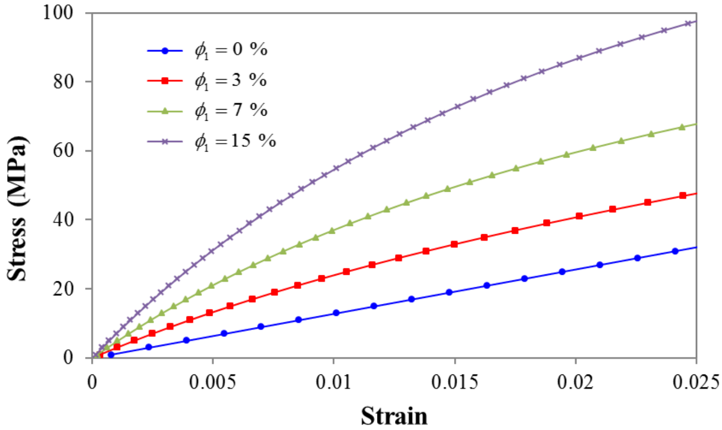

Figure 1. The predicted stress-strain behaviors composites with respect to the volume fraction of carbon fiber

4. CONCLUSIONS

This work examines the influence of model parameters on the mechanical behavior of composites containing carbon fiber and SFRP. The present approach is derived by incorporating the micromechanics-based model into the computational algorithm. Within the present study, the influence of the carbon fiber of CNT is examined via numerical simulations.

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