폴리머 복합재료로 코팅된 손상 철근콘크리트 보의 성능평가

Evaluation of the Performance of Pre-cracked RC Beams Coated with Polymeric Composites

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ABSTRACT

This paper summarizes the results of a series of numerical evaluations (Lee et al., 2004, 2005) on the performance of pre-cracked reinforced concrete (RC) beams coated with polymeric composites. It was intended to numerically show the superior characteristics of the polymeric composites for enhancing the strength and ductility of existing concrete structures. Further, the predicted load-carrying and energy absorbing capacities of the beams were compared with previous experiments to verify the predictive capability of implemented computational model.

1. Introduction

Bridges like many other concrete structures suffer the impact of environment, daily use, and other unexpected effects day after day. This daily exposure deteriorates concrete, creating loss in strength and durability. Different methods of strengthening back concrete structures have been in use over the years. Using concrete and steel to accommodate losses in strength and ductility has been a reliable and quantifiable method. On the other hand, the use of composite materials has been widely used in other structures (e.g., aerospace and automotive structures). Due to the amazing qualities found on these materials, the construction industry finally saw an application in design and building.

A new technology using sprayed fiber reinforced polymeric composites has been introduced as a reliable solution to deteriorated concrete structures. This technology promises an easy application on concrete, a more affordable price and equal or better results than other composites technologies (Banthia et al., 2002; Harries and Young, 2003; Lee and Hausmann, 2004). More detailed description on the characteristics of the polymeric composites can be found in Young and Harries (2000).

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Finite element codes have shown their great capabilities in predicting the behavior and evaluating the performance of conventional engineering materials such as metal (Biggs et al., 2000). However, predictions of the performance of the system composed of concrete and new composite materials are rather complex since the new materials exhibit a less straightforward damage constitutive behavior.

The primary objective of this numerical study is to develop a reliable and accurate computational model for simulating the retrofit and strengthening performance of the polymeric composites. It is also intended to study the capability of the polymeric composites in increasing the bending and shear capacities of reinforced concrete (RC) beams. A computational model is developed by implementing the damage constitutive model proposed by Lee (2001) and Karihaloo and Fu (1990) into the finite element code ABAQUS to simulate the performance of concrete structures retrofitted with the polymeric composites. The accuracy of the computational model is evaluated by comparing the present numerical predictions with experimental data. The details of the computational model used in this simulation and simulation results are described elsewhere (Lee et al., 2004, 2005).

2. Simulation of performance of RC beams coated with polymeric composites

A series of numerical three-point bending tests are conducted on the undamaged and damaged (pre-cracked) RC beams with and without the polymeric composites to predict load-displacement curves from which the increase in load-carrying and energy absorption capacities is evaluated. For all beam models, the energy absorbed by the beams prior to failure is calculated by taking the area under the loading curve. This area is calculated using Simpson's integration method in conjunction with MATLAB. This failure energy is used to quantify the ductility of the beams. To assess the potential of the present computational model, we compare our predictions with experimental data reported by Lee and Hausmann (2004). The material properties of concrete, steel and the polymeric composites used in these simulations are summarized in Table 1. The damage parameters involving in these simulations are summarized in Table 2.

While the 3D, 8-node linear brick solid element C3D8 in ABAQUS is utilized for modeling the concrete beam and the polymeric composites coating, the 2-node linear truss element T3D2 in ABAQUS is used for modeling the rebar. The RC beam are loaded proportionally with the rate of 0.015 mm/sec at the center of the beam corresponding to the head-loading rate of the MTS testing machine used in experiments (Lee and Hausmann, 2004). To model the damage (pre-crack) in RC beams, a small and very thin notch was modeled at the mid span so that it acts as a crack trigger for the failure of the beams. The length and width of the notch are 10 mm and 0.1 mm, respectively. The main advantage of this modeling approach in comparison with most computational damage modeling techniques is that the damage evolution given material degradation is fully coupled with the constitutive equation by incorporating damage laws into the constitutive model.

Comparisons of peak load and energy absorbed during the three-point bend tests between the present prediction and experiments (Lee and Hausmann, 2004) are summarized in Tables 3 and 4, respectively. The details of numerical simulations and experimental comparison are described in Lee et al. (2004, 2005).

Table 1. Material properties used in the simulation

	Concrete	T-310 Resin	E-glass fiber	Rebar
Tensile Modulus (GPa)	29.0	1.3	69.0	200.0
Poisson's Ratio	0.17	0.35	0.17	0.30

Table 2. Damage parameters used in the simulation

Parameters	S_o	M	ε^{th}	$c1$	$c2$
	2.25E+07	4.0	0.20E-05	0.95	10.80

Table 3. Summary of simulation results compared with experimental data for peak load of RC beams

Specimen	Peak Load (KN)Percent of Prediction / Test Data		Percent of Prediction / Test Data
	Prediction	Test Data	
Undamaged RC beams without the polymeric composites coating	18.64	11.90	156.64
Undamaged RC beams with thin the polymeric composites coating	20.84	15.47	134.71
Undamaged RC beams with thick the polymeric composites coating	24.90	24.20	102.89
Pre-cracked RC beams without the polymeric composites coating	11.68	10.64	109.77
Pre-cracked RC beams with thin the polymeric composites coating	14.12	11.28	125.18
Pre-cracked RC beams with thick the polymeric composites coating	16.52	14.91	110.80

Table 4. Summary of simulation results compared with experimental data for energy absorption

Specimen	Energy Absorbed (J)Percent of Prediction / Test Data		Percent of Prediction / Test Data
	Prediction	Test Data	
Undamaged RC beams without the polymeric composites coating	9.91	11.89	83.35
Undamaged RC beams with thin the polymeric composites coating	15.28	13.65	111.94
Undamaged RC beams with thick the polymeric composites coating	27.94	25.73	108.59
Pre-cracked RC beams without the polymeric composites coating	8.71	14.56	59.82
Pre-cracked RC beams with thin the polymeric composites coating	14.03	12.18	115.19
Pre-cracked RC beams with thick the polymeric composites coating	20.41	23.11	88.32

3. Summary

A computational approach to the evaluation of retrofit and strengthening performance of polymeric composites was presented. The outcome from the numerical study can be summarized as follows: 1) The coating thickness has a significant influence on the load-carrying and energy absorption capacities of the beams. 2) The peak load and energy absorbed prior to the failure are shown to be greater for the beams with a thick coating in comparison with those for the beams with a thin coating.

This study, in conjunction with the previous experimental observations (Banthia et al., 2000; Lee and Hausmann, 2004, etc.), will accelerate the introduction of the polymeric composites to infrastructure rehabilitation. However, long term tests should be performed to evaluate the lasting performance of the polymeric composites under harsh environments.

4. References

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