FULL BOTTOM STRENGTHENING OF RC BEAMS WITH CFC PANELS FOR IMPROVED IMPACT RESISTANCE

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1. INTRODUCTION

A reinforced beam is one of the reinforced concrete structural components which is possibly subjected to impact load during its service life. Many researchers studied RC beams under impact load (Hughes 1982) in order to enhance their impact resistance by using strengthened material, including fiber-reinforced polymer (Pham TM 2017) and carbon fiber-reinforced polymer (Al-Farttoosi 2014). In this study, we proposed a methodology to improve the impact resistance of RC beams by attaching continuous fiber composite (CFC) panels to the bottom surface. The experimental tests and numerical analysis were conducted to investigate the impact resistance. The repeated constant-speed drop-weight test was carried out in the experiment to compare the impact resistance of conventional RC beams with a full bottom strengthening of RC beams with CFC panels, bonded by soft epoxy. In the analytical program, the smoothed particle hydrodynamics (SPH) methodology was applied to simulate the behavior of RC beams reinforced with CFC panels under impact load, the adhesive particles which considered its mechanical properties were placed between concrete and CFC particles.

2. METHODOLOGY

2.1. Experimental program

The drop-weight impact test was set up as shown in Fig. 1, 100 kg mass of steel hammer repeatedly dropped at an impact velocity of 3.0 m/s until the cumulative residual displacement reached 1% of the span. The compressive strength of the concrete was 45.5 MPa, longitudinal rebars were SD295A 2D10 at the bottom, 2D6 rebars at the top, and D6 stirrups spaced at 100 mm. The dimensions and material properties are presented in Fig. 2 and Table 1, respectively.

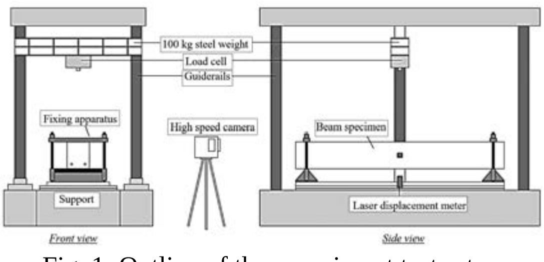
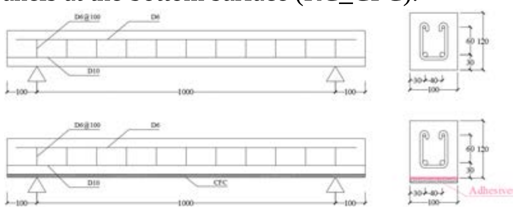


Fig. 1: Outline of the experiment test setup

As shown in Fig. 2, there are two different types of beam specimens including RC and RC fully reinforced with CFC panels at the bottom surface (RC_CFC).



RC

RC_CFC

Fig. 2: Types of specimens (unit: mm.)

Table 1: Material properties

	Continuous fiber composite panel		Adhesive
	Flexible board	Carbon fiber sheet	
Density [kg/m^3]	1600.0	1818.0	1170.0
Young's modulus [N/mm^2]	13000.0	245000.0	1500.0
Poisson's ratio	0.15	0.10	0.35
Compressive strength [N/mm^2]	47.2		85.1
Tensile strength [N/mm^2]	18.5		55.6
Yield strength [N/mm^2]		3400.0	

The strengthening material such a CFC panels had a sandwich structure, consisted of 1.0-mm-thick carbon fiber core dovetailed by 3.0-mm-thick flexible boards, as shown in Fig.3

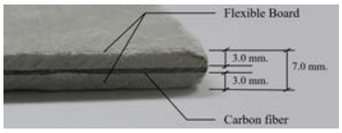


Fig. 3: CFC panel

2.2. Analytical program

A SPH was introduced to simulate the repeated constant-speed drop-weight impact test, consisted of impactor and beam. The half model with a particle size of 6.0 mm. was used with the same dimension as the experimental condition. The linear Drucker-Prager criterion was employed to model concrete particles as an elastoplastic material, together with a tensile softening response that corresponds to the bilinear function developed by Hillerborg (Hillerborg A. 1976). The reinforcement was modeled as an elastoplastic material that conforms to the von Mises yield condition with a simple bilinear stress-strain relationship with 1/100 of the initial stiffness was set for hardening stiffness, in both compression and tension.

The von Mises criteria was applied in modeling the CFC panels as an elastic-plastic material, along with a multi-linear elastic-plastic stress-strain relationship, which was demonstrated from the results of CFC panel testing, as shown in Fig. 4.

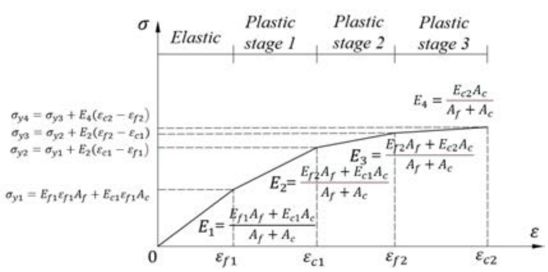


Fig. 4: Multi-linear stress-strain relationship for the CFC panel

Where ε_{c1} , ε_{c2} are the strains of carbon fiber, ε_{f1} , ε_{f2} are the strains of flexible board, E_{c1} , E_{c2} are the Young's modulus of

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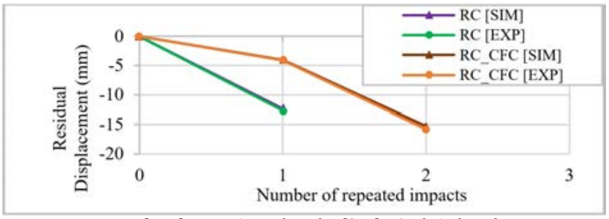
carbon fiber, E_{f1}, E_{f2} are the Young's modulus of flexible board, E_1, E_2, E_3, E_4 are the Young's modulus, σ_{y1}, σ_{y2}, σ_{y3}, σ_{y4} are the stresses, A_f is the area of carbon fiber, A_c is the area of flexible board

Among the strengthened specimen, adhesive particles were presented as bonding judgment in middle of concrete and CFC particles. The constitutive law of the adhesive material and the von Mises equivalent failure criterion were subsequently employed to determine the stress of the adhesive particles to be able to simulate the interfacial debonding of CFC panels. In addition, the tensile cracking of concrete was calculated using the anisotropic damage law. The CFC panel particles split from the concrete particles when either the adhesive particles reached the yielding condition, or the strain exceeded the strain limit of the CFC panel.

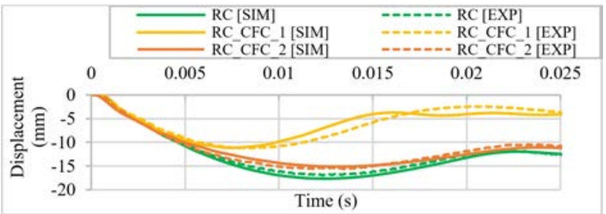
3. Results and discussion

The experimental results confirmed that the impact resistance and the number of repeated impacts allowable tended to increase by CFC strengthening. Using the proposed analytical program, the repeated drop-weight impact test was well-simulated. Fig. 5 shown the accurate estimation of the repeated impact number that each specimen can withstand before reaching the failure condition, validated by experimental results. As shown in Fig. 6, it can confirm that the lower mid-span displacement was achieved, and the number of repeated impacts increased by attaching CFC panels to the bottom surface of RC beams.

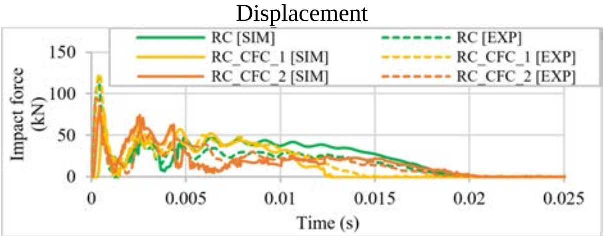


Note: [EXP] – Experimental results, [SIM] – Analytical results

Fig. 5: Relationship between cumulative residual displacement and Number of repeated impacts



Displacement

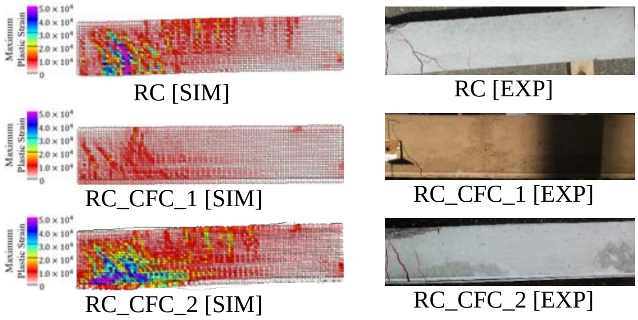


Impact force

Note: [EXP] – Experimental results, [SIM] – Analytical result, 1,2 – Number of repeated impacts

Fig. 6: Displacement and impact force time histories of specimens during repeated impacts

The impact response of full bottom strengthening of RC beams with CFC panels was effectively reproduced by using an elastic-plastic material model and multi-linear stress-strain relationship for the CFC panel. The CFC panel peeling off was observed in the simulation by using the described proposed analytical idea. The flexural cracks were well simulated by applying the anisotropic constitutive law in the tension region. Additionally, the analysis's results indicated that the specimens reinforced with CFC panels had greater impact resistance and bending fractures that occupied a larger region, as shown in Fig, 7.



Note: [EXP] – Experimental results, [SIM] – Analytical result, 1,2 – Number of repeated

Fig. 7: Crack distribution of all specimens during repeated impacts

4. CONCLUSIONS

This research paper presented the experimental tests and numerical analysis in order to investigate the impact resistance of Conventional RC beams and full bottom strengthening of RC beams with CFC panels. During the experimental tests, using drop-weight tests, 3 m/s impact loads subjected to all specimens repeatedly until the cumulative residual displacement reached 1% of the span. It can determine that better impact resistance can be achieved by strengthening of RC beam with CFC panels and the allowable number of repeated impacts increased. The flexural crack was observed in all specimens. In the strengthened specimens, the adhesive failure led the CFC tended to peel off. The proposed analytical program, using smoothed particle hydrodynamics, the results exhibited that SPH particles are capable of simulating the impact behavior of beams reinforced with CFC panels with high accuracy in which CFC panels were modeled as an elastic-plastic material under either a single impact or repeated impacts, and the interfacial debonding of CFC panels were well simulated by using a proposed SPH idea. Moreover, the anisotropic constitutive law in the tension area was successfully used to accurately simulate the displacement response and flexural fracture.

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