An experimental study of coconut fibre reinforced concrete under impact load

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2014 NZSEE Conference

ABSTRACT: Devastating impact, e.g. due to falling parapet, during a strong earthquake can greatly damage surrounding structures. This has been observed in many major earthquakes, especially in the case of unreinforced masonry structures. To prevent damage resulting from such an impact loading mitigation measures need to be developed. In this study protective structures made of natural fibre reinforced concrete are considered. The selected fibre is coconut fibre, because it has a high energy absorption capability in comparison with other natural fibres. The inclusion of coconut fibre in the concrete will also enhance the damping of the composite. In this preliminary study, coconut fibre reinforced concrete (CFRC) cylinders with 100 × 200 mm were considered. The corresponding plain concrete specimens were used as references. Coir with a length of 50 mm and 0.4% weight content of plain concrete is selected. The impact behaviours of plain concrete and CFRC were investigated. The results showed that CFRC can absorb more impact energy in comparison with plain concrete. CFRC under impact loading has more small cracks, while plain concrete shows brittle failure. The study also defined the influence factor that controls the energy dissipation of the composite which will be used for developing future protective structures in earthquake regions.

1 INTRODUCTION

Impact load can cause extreme stress condition of the structural members due to the application of the high intensity force generated within a short duration (see e.g. Fujikake, 2009). Impact loads induced during a strong earthquake such as that resulting from falling weight can significantly damage lower structures. To protect people e.g. under a canopy in a walkway, suitable impact-resistant structures need to be developed.

In recent years, study on the impact behaviour of fibre reinforced concrete has become increasingly popular in civil engineering. Different types of fibre reinforced concrete composites have been studied, e.g. Mindess and Bentur (1984) compared the fracture toughness of steel fibre reinforced concrete (SFRC), glass fibre reinforced concrete (GFRC) and plain concrete using photographic record. The results indicated that the cracking process under impact loading was not substantially different from that under static loading. Wang et al. (2013) studied destructive impact of steel fibre reinforced concrete (SFRC). The results indicated that the steel fibre content of SFRC is the main factor to affect the damage to SFRC structure under a blast loading. Xu et al. (2012) conducted drop weight impact on seven different shape steel fibres to study dynamic compressive properties of fibre reinforced concrete (FRC). The experimental results indicated that the spiral steel fibre proposed in the study provides a better dynamic resistance and energy absorption capacity (toughness). Tabatabaei et al. (2012) discussed the development of long carbon fibre and conducted a full-scale test on long fibre reinforced concrete (LCFRC). The investigations revealed that carbon fibre can increase resistance of concrete against spalling. In addition, the impact behaviour of natural fibre reinforced concrete composites has been studied due to their environmental and economic aspects. Impact properties of short discrete jute fibre reinforced concrete (JFRCC) investigated by Zhou et al. (2013) showed that fibre pull-out occurs in JFRCC during impact loading. Wang et al. (2013) performed an impact experiment on bamboo fibre reinforced concrete slab. The impact resistance of the four natural fibre reinforced cement mortar slabs were considered by Ramakrishna and Sundararajan (2005). Their works indicated that coconut fibre reinforced mortar slabs have the highest capability to absorb impact energy in comparison with other types of fibres.

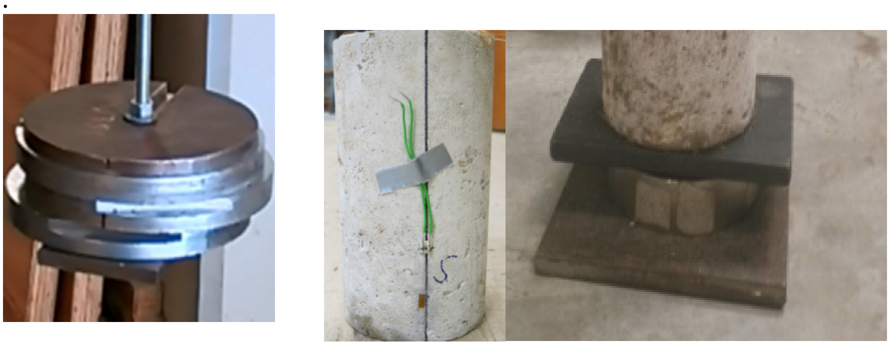
Properties of coconut fibre reinforced concrete composites have been studies in past decades (e.g. Slate 1976; Das Gupta 1978; Paramasivam 1984). Baruah and Talukdar (2007) investigated the effect of coconut fibre volume and fraction on the CFRC overall static performance. Asasutjarit et al. (2007) studied coir-based lightweight cement board by investigating the physical, mechanical and thermal properties. Ali (2012) studied both static and dynamic properties of CFRC composites. However, studies on the impact properties of CFRC are unknown. The purpose of this study is to investigate the impact behaviours of coconut fibre reinforced concrete (CFRC) cylinders under impact loading to evaluate the applicability of CFRC as construction material of protective structures. The corresponding plain concrete specimens will be used as references.

2 MATERIALS AND EXPERIMENTAL PROCEDURES

Both plain concrete and coconut fibre reinforced concrete cylinders of 100 mm × 200 mm were prepared. Ordinary Portland cement, sand, aggregate and coconut fibres were used. The mix design by weight was 1:4:4 for cement: aggregate: sand, respectively. The fibre length was 50 mm and fibre weight content was 0.4% of plain concrete.

The impact tests were conducted by a falling weight. The drop weight system was achieved by a trip mechanism to ensure that the weight drops accurately on the specimens. The drop weight was made of steel plates. The impact face of the falling weight was covered with a flat layer of steel (Fig. 1a). The selected impact weight was 20 kg, and the impact height was 500 mm. Single impact tests were conducted both on plain concrete and CFRC cylinders.

Strain gauges (Fig. 1b) and load cell (Fig. 1c) were used to measure the transmitted forces. Two strain gauges were attached vertically close to the bottom edge of the cylinder. The cylinder was placed on a flat steel plate, which was fixed to a load cell. The load cell was used to measure the force at the base of the cylinder.



(a) (b) (c)

Figure 1. Impact test set up: (a) Drop weight; (b) strain gauge and (c) load cell

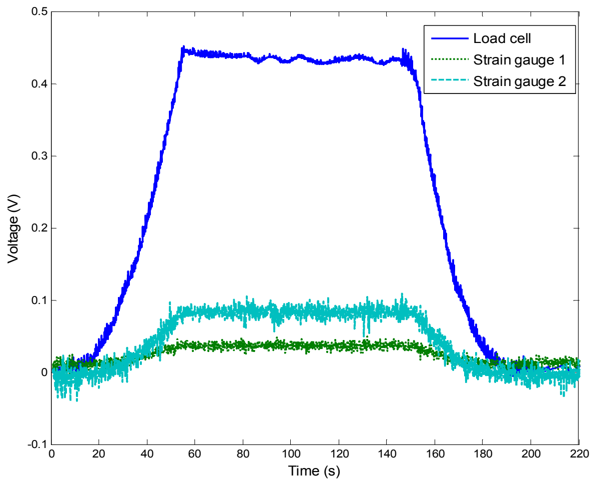
3 RESULTS AND DISCUSSION

3.1 Transmitted forces

A single impact from the drop weight was applied at the centre of concrete a cylinder specimen from a height of 500 mm, giving the corresponding impact velocity of 3.1 m/s. For each test, three samples were considered. Figure 2 describes the calibration method used for the tests. Load cells and strain gauges were calibrated using a compressive machine (Fig. 2a). A measured static load was applied and released gradually as shown in Figure 2b. The recorded voltage difference represented the load difference:

$$\text{Calibration factor} = \frac{\text{Applied load(kN)}}{\text{Recorded voltage(V)}} \tag{1}$$

(a) Compressive machine



(b) Voltage recorded by the load cell and strain gauges

Figure 2. Load cell and strain gauge calibration

Figure 3 shows the force transmitted by a plain concrete cylinder. The load cell and strain gauge were located at the bottom and the lower end of the cylinder, respectively. It can be seen that the maximum force obtained from the load cell and strain gauge was similar. The maximum force recorded by the load cell occurred at the time of about 0.4 ms. The maximum force from strain gauge occurred at the time of 0.5 ms. The peak impact force obtained from the load cell was 72.05 kN and from strain gauge was 69.63 kN. Figure 4 shows the corresponding force transmitted by a CFRC cylinder. The maximum force transmitted was 33.29 kN from load cell measurement and 32.64 kN from strain gauge measurement. A summary of peak impact force results are shown in Table 1. The result shows that the peak force of plain concrete was much larger than the CFRC. The impact force is transferred in the form of waves when a cylinder is impacted by the striker at the top face. During the wave propagation process, part of energy is absorbed by the crack development in the cylinder. Coconut fibre in the CFRC has the capability to distribute cracks over a wider region. Consequently, more energy is absorbed compared to plain concrete. The energy transmitted is reduced and the waves arrived at the bottom load cell in CFRC is significantly less than that in plain concrete. The ductile behaviour of CFRC in comparison with plain concrete can also be seen in the stress-strain relationship in Figure 5 (Yan and Chouw, in print). The result clearly indicates the potential of CFRC composite in resisting impact loadings.

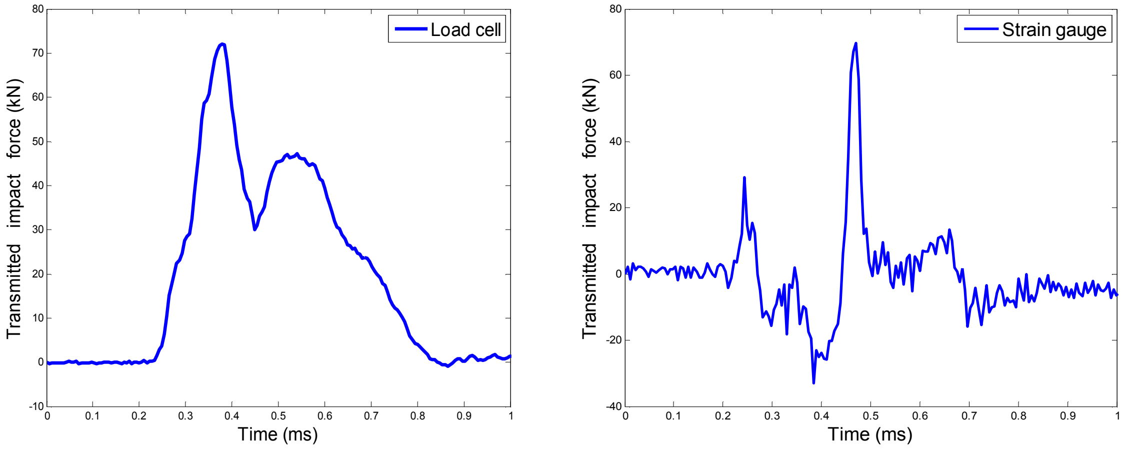


Figure 3. Force transmitted by plain concrete

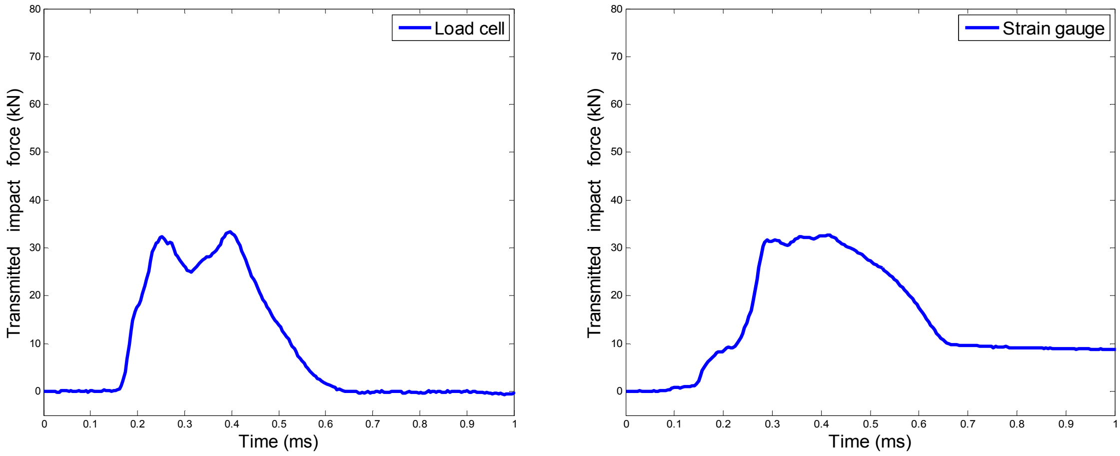


Figure 4. Force transmitted by CFRC

Table 1. Peak force of plain concrete and CFRC concrete

Concrete	Load cell (kN)	Strain gauge (kN)
Plain concrete cylinder	72.05	69.63
CFRC cylinder	33.29	32.64

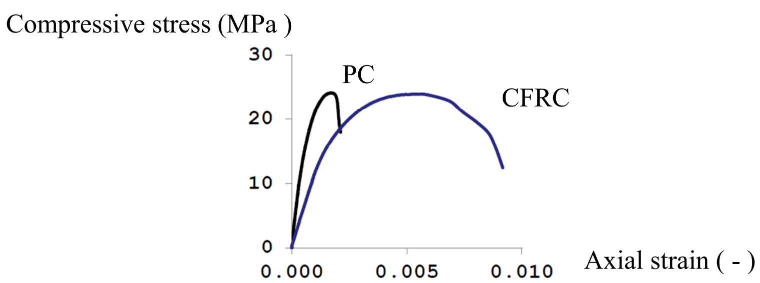
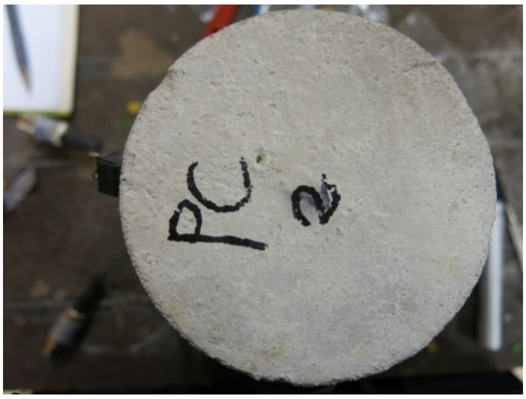


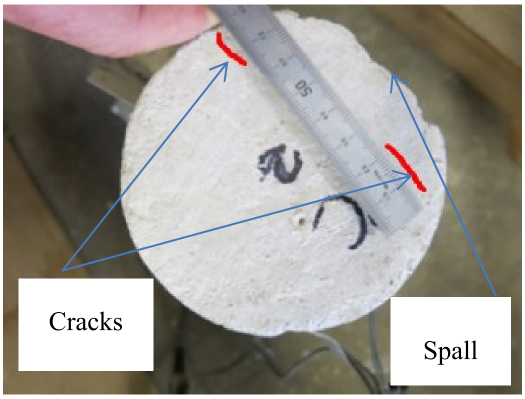
Figure 5. Influence of coconut fibre on the stress-strain relationship (Yan and Chouw, in print)

3.2 Damage observed

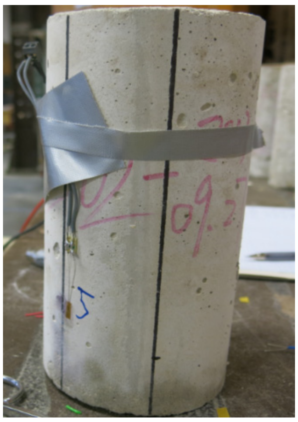
Figures 6 and 7 display the plain concrete cylinder and CFRC cylinder before and after impact, respectively. After being impacted by the drop weight, plain concrete and CFRC showed significant differences in failure patterns. Figure 6 shows the failure pattern of plain concrete in form of spalling at the edge of the concrete cylinder with only few cracks at the impact face. In contrast, more cracks were observed both at the contact face and at the perimeter of the CFRC cylinder (Fig. 7). This distribution of small cracks is due to the bridging effect of the coconut fibre in CFRC that also enhances the tensile property of the fibre-concrete composite. Coconut fibre enhances the ductile behaviour of CFRC (Fig. 5) and also enables a wider distribution of cracks during impact. These two properties make CFRC able to avoid brittle failures that are observed in the plain concrete. Instead of crushing the concrete, the induced energy is absorbed by the large number of minor cracks.



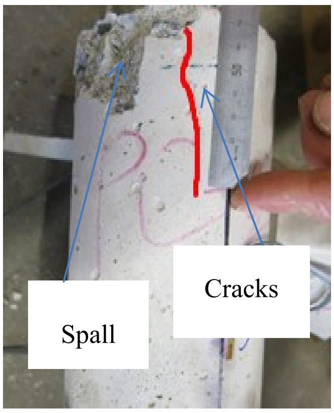
(a) Before impact: top view



(b) After impact: top view

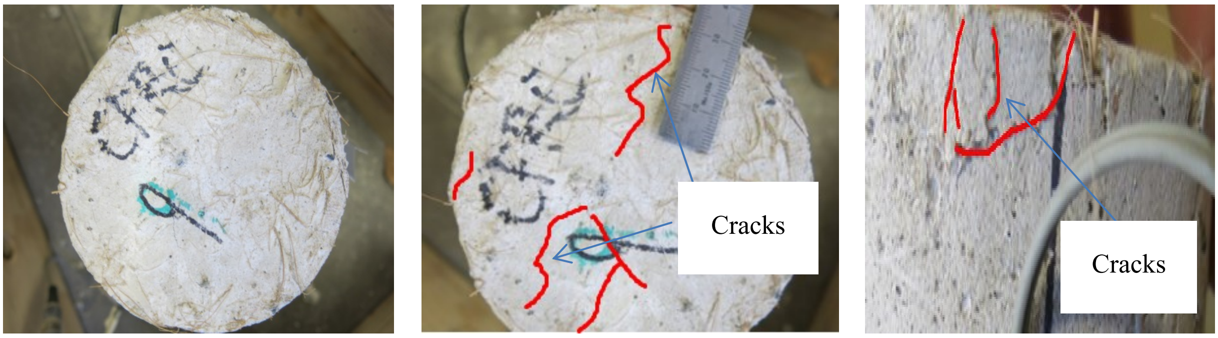


(c) Before impact: side view



(d) After impact: side view

Figure 6. Views of plain concrete before and after impacting



(a) (b) (c)

Figure 7. Influence of coconut fibre on the fibre-concrete composite behaviour: (a) Before impact and after impact (b) top view (c) side view

4 CONCLUSIONS

The impact properties of plain concrete and coconut fibre reinforced concrete (CFRC) were studied. The investigation revealed that:

Under an impact loading, the damage to plain concrete is characterized by concrete spalling, while as anticipated the CFRC specimens experience distributed cracks.

With regard to the impact load transfer, in comparison to plain concrete, significant less impact force is transmitted by CFRC. More impact energy is absorbed by coconut fibre in CFRC. This indicates that CFRC composite has a good impact resistance and thus has a potential to be used in future protective structures in earthquake regions.

For the application of CFRC in protective structure, more investigations are necessary to understand the overall impact behaviour of CFRC structural members.

5 ACKNOWLEDGEMENTS

The authors would like to thank all people for their supports throughout the research. The authors also wish to thank China Scholarship Council for supporting the PhD study of the first author at the University of Auckland.

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