CFRP-CONFINED EXPANSIVE CRUMB RUBBER CONCRETE

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ABSTRACT

The behaviour of carbon fibre-reinforced (CFRP)-confined expansive rubberized concrete was examined in this research by experimental testing of 9 rubberized concrete-filled fibre-reinforced polymer (FRP) tube (CFFT) columns under axial compression. The effect of rubber content was examined by manufacturing test specimens with 0%, 20%, and 40% volume replacement of sand in the concrete mix designs. The influence of CFRP confinement condition was also examined with specimens prepared with either 1 or 2 layers of CFRP plus confining plates attached to specimen ends during curing. All specimens were cylinders with 100 mm diameter and 200 mm height and confined by CFRP. Axial and lateral strains were monitored during concrete curing, as lateral pre-stress developed in the FRP shell, plus during the application of axial compression. Pre-stress development over the initial 2-3 days of curing has been reported and axial stress-strain curves during compression have been provided. The results of this study indicate the addition of crumb rubber to pre-stressed CFFTs results in a noticeable loss in the columns’ axial stiffness and strength. However, the pre-stress development during the curing stage for the expansive mixes were found to be considerably higher in rubberized concrete specimens compared to the conventional concrete specimens, indicating that expansive agent is more effective in rubberized concrete.

KEYWORDS

Rubberized concrete, expansive agent, concrete-filled FRP tubes, pre-stressed FRP, confined concrete.

INTRODUCTION

Due to the cost and technology limitation, the majority of the used tires are disposed into landfill, and only a small fraction is recycled. By engineering waste materials, targeting appropriate applications and finding smarter solutions, tires can be used effectively in civil engineering applications, such as aggregates in concrete. Rubber particles can be replaced with the natural aggregates in concrete. Adding rubber to concrete has both positive and negative impacts on its properties. For example, it reduces its strength and stiffness (Ganjian et al. 2009; Khatib and Bayomy 1999; Youssf et al. 2017a,b); however, it improves its energy dissipation, ductility, damping, and impact resistance (Atahan and Yücel 2012; Hassanli et al. 2017a). To mitigate the adverse effect of rubber on the mechanical properties of rubberized concrete, different mixing proportion and procedures, as well as rubber treatment methods have been studied (Eldin and Senouci 1993; Raffoul et al. 2016; Su et al. 2015; Turatsinze et al. 2007; Youssf et al. 2019). In addition, previous studies have shown that the effect of confinement is higher in crumb rubber concrete (CRC) compared to conventional concrete (CC) (Gholampour et al. 2017; Hassanli and Youssf 2016; Hassanli et al. 2017b; Hassanli et al. 2017c; Gholampour et al. 2019).

The main deficiency of concrete-filled fibre-reinforced polymer tube (CFFT) columns is that the FRP-confinement effect is only activated when a considerable lateral hoop strain is developed in the FRP
shell. Due to concrete shrinkage, gaps can develop at the FRP/concrete interface, which reduces the confinement effectiveness. As a result, the substrate concrete may lose substantial integrity before the FRP jacket is fully utilized or even before it is activated. This is more critical in concrete with higher levels of shrinkage, such as self-consolidating concrete. To overcome this drawback, the FRP jacket can be pre-stressed. Expansive agent (EA) can be added to concrete to provide pre-stressing of the FRP jacket in confining column members. Expansion in concrete due to added EA, mitigates the effect of contraction due to shrinkage. It has been shown that restricting concrete expansion improves microstructure densification and hence, enhancement to mechanical properties (Mo et al. 2014).

This research aims to utilise the near-incompressible property of rubber to improve the strength properties of CRC by confining rubberized concrete in CFRP tubes and using an expansive agent to provide a level of lateral pre-stress.

EXPERIMENTAL PROGRAM

Material properties

Three concrete mixes were prepared with rubber contents of 0%, 20%, and 40% as volume replacement of sand, with all mixes having EA content of 15% as the weight replacement of cement. Styrene-butadiene rubber (SBR) was used which was obtained from wastes tires. As shown in Table 1, all mixes had a water-to-cement ratio (w/c) of 0.5 and were identical apart from their rubber content. To remove dust and impurities from the rubber particle surfaces, they were first washed using tap water, and then air dried in the lab environment (Yousuf et al. 2019). To examine the influence of confinement condition 3 specimens were prepared with 1 CFRP layer, while a further 3 specimens were prepared with 2 CFRP layers whereas the final 3 specimens were prepared with 1 CFRP layer as well as confining plates installed at the specimen ends.

To determine the unconfined compressive strength of concrete, \( f'_{cu} \), standard 100 × 200 mm cylinders were prepared according to AS1012.1 (AS1012.1 2014) from the same three concrete batches, cured at the same condition as the CFFT specimens and tested (according to AS1012.9) at the same age as the CFFT specimens. The EA was a calcium-sulpho-aluminate (CSA) agent (DENKA CSA#20) with a specific gravity of 2.86 and was added to the dry concrete ingredients alongside the dry cement. The CFFT specimens were made by pouring concrete in prefabricated FRP tubes, with these tubes being manufactured a week before concrete casting. Unidirectional CFRP sheets having a nominal thickness of 0.13 mm were used to manufacture the FRP tubes. Two-part epoxy resin with nominal tensile modulus of 4500 MPa and tensile strength of 30 MPa was used as the adhesion material in manufacturing FRP tubes. According to the manufacturer’s data, the CFRP sheets had ultimate strength, elastic modulus and rupture strain of 4900 MPa, 230 GPa and 2.1%, respectively.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Rubber (%</th>
<th>Cement (kg/m³)</th>
<th>20 mm stone (kg/m³)</th>
<th>10 mm stone (kg/m³)</th>
<th>Sand (kg/m³)</th>
<th>Water (kg/m³)</th>
<th>Rubber (kg/m³)</th>
<th>Expansive agent (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>0</td>
<td>370</td>
<td>865</td>
<td>215</td>
<td>687</td>
<td>200</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>R20</td>
<td>20</td>
<td>370</td>
<td>865</td>
<td>215</td>
<td>549.6</td>
<td>200</td>
<td>44.8</td>
<td>60</td>
</tr>
<tr>
<td>R40</td>
<td>40</td>
<td>370</td>
<td>865</td>
<td>215</td>
<td>412.2</td>
<td>200</td>
<td>89.6</td>
<td>60</td>
</tr>
</tbody>
</table>

Test specimens

A total of 9 CFRP-confined CFFT specimens having 100 mm diameter and 200 mm height were prepared from 3 different concrete mixes. The development of lateral strain in the CFRP tube was recorded during concrete curing to monitor pre-stress development as the concrete hardened and expanded. The hoop and axial strains were measured using strain gauges attached to the mid-height of the cylinders (See Fig. 1(b)). All specimens were then tested at 28 days under monotonic axial compression at a constant loading rate of 0.02 mm/sec.

The test specimens were labelled according to rubber content and confinement conditions. For the first parameter, the letter R is followed by the rubber content of 0, 20, or 40 which is expressed in terms of the percent of sand volume replaced by rubber. Next, the letters A, B, or C were added to distinguish
between the confinement conditions, where type A and B specimens had one and two CFRP layers, respectively, and type C specimens had one CFRP layer as well as confining plates installed at the specimens’ ends. Figure 1 shows examples of these specimens.

![Test specimens](image1.png)

**Fig. 1.** Test specimens a) During concrete curing, b) During axial compressive testing

**TEST RESULTS AND DISCUSSIONS**

**Development of FRP pre-stress during concrete curing stage**

Figure 2 shows the axial and hoop strain development in all specimens during concrete curing. As shown in Figure 2(a), the hoop pre-stress increased to approximately 2000 microstrain for the CC specimens, with up to 7500-8000 microstrain recorded for specimens with 40% rubber. Hence, for the same EA content, CRC develops a higher level of pre-stress compared to CC with this outcome observed for all three confinement conditions.

![Strain development](image2.png)

**Fig. 2.** Strain development during concrete curing a) Type A, b) Type B, c) Type C.

**Axial compression tests**

The stress-strain behaviour of CFFT specimens is shown in Figure 3. As can be seen, an increase in the rubber content results in a loss in axial strength along the full axial stress-strain curve. This observation appears to not be influenced by confinement conditions, with types A, B and C specimens all experiencing a similar trend. On the other hand, a comparison of ultimate strain values for companion specimens with varying levels of rubber content reveals ultimate strain is not noticeably influenced by the amount of rubber. Additionally, a comparison of specimens A and C reveals insignificant influence of confining the specimen ends during concrete curing.

![Axial stress](image3.png)

**Fig. 3.** Influence of rubber content on the stress-strain response a) Type A, b) Type B, c) Type C.

**CONCLUSIONS**

The main findings of this study are summarized in the following points:

- EA is more effective in CRC compared to CC. Additionally, as the rubber content increases, the pre-stress development due to expansion becomes more significant. The stresses developed in
specimens with 40% rubber during concrete curing were approximately twice those obtained for specimens with zero rubber content.

- The addition of CRC to FRP confined concrete results in a loss in axial strength along the full axial stress-strain curve. However, to mitigate this strength reduction due to the addition of rubber to concrete, it is suggested to use CRC with EA added in structural members where a level of confinement is provided.

- Confining of the ends of the concrete during curing time has no effect on the strength.

From the above findings, it can be concluded that although very promising results were obtained from prestressing FRP-confined CRC, more tests are required in order to confirm the obtained results.

REFERENCES
AS1012.1 (2014). "Methods of testing concrete - Sampling of concrete AS 1012.1, Standards Australia.,"