COMPRESSIVE BEHAVIOUR OF TIN SLAG POLYMER CONCRETE CONFINED WITH CARBON FIBRE REINFORCED EPOXY

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ABSTRAK

Terak timah adalah hasil sampingan proses peleburan. Tujuan kajian ini adalah untuk mengkaji tingkah laku mampatan kolum konkrit polimer (PC) berisi terak timah yang dibalut dengan polimer diperkuat fiber karbon (CFRP). Kajian ini dijalankan dengan tiga bilangan lapisan CFRP yang berlainan. Ciri-ciri mekanikal sampel seperti tekanan maksimum (maximum stress), ketegangan (strain) dan modulus keanjalan (elasticity modulus) ditentukan oleh ujian mampatan. Tekanan mampatan maksimum meningkat dengan ketara kepada 103% untuk PC yang tidak terkurung berbanding PC terkurung. Sementara itu untuk satu lapisan hingga dua lapisan hanya meningkat 14.9% dan kes yang sama untuk dua lapisan hingga tiga lapisan hanya mendapat peningkatan kira-kira 13.6%. Modulus mampatan meningkat kira-kira 26% hingga 39% untuk PC yang tidak terkurung berbanding satu lapisan PC terkurung. Modulus mampatan untuk PC yang satu lapisan, dua lapisan dan tiga lapisan hampir sama iaitu perbezaan tidak lebih daripada 10%. Nisbah pemanjangan bagi PC yang tidak terkurung berbanding dengan PC berkurung satu lapisan menunjukkan penurunan yang besar. Bilangan lapisan dua dan tiga menunjukkan penurunan nisbah kemuluran yang sedikit berbanding satu lapisan. Kekuatan satu lapisan PC terkurung meningkat dengan ketara kira-kira 104.8% berbanding PC yang tidak terkurung. Sementara itu, untuk bilangan lapisan terkurung yang lebih dari satu hanya meningkat sedikit. Keberkesanan pengurungan meningkat sebanyak dua kali untuk satu lapisan PC terkurung berbanding PC yang tidak terkurung. Sementara itu, bilangan lapisan terkurung yang lebih dari satu, keberkesanan pengurungan hanya meningkat sedikit. Kesimpulannya, peningkatan jumlah lapisan terkurung lebih dari satu tidak memberikan perubahan yang signifikan terhadap sifat mekanik.

Kata Kunci: terak timah, konkrit polimer, CFRP, konkrit berbalut, konkrit terkurung.

INTRODUCTION

Over the years, polymer concrete was introduced in civil engineering for alternative material in construction. The development in the field of polymer concrete back date to the late 1950’s when these materials where developed as replacement of cement concrete in some specific application (Raman Bedi et al. 2013). Nowadays polymer concrete is very pronouns in engineering field due to the rapid setting characteristic, high strength-to-weight ratio and ability to withstand a corrosive and aquatic environment (Asif Ali et al. 2013). Polymer concrete (PC) is a composite material that consists of aggregate, filler, and polymeric binder (Asif Ali et al. 2013). The properties of polymer concrete differ greatly depending on may factor such as, condition of preparation, binder content, aggregate types and size distribution (Raman Bedi et al. 2013).

A lot of variations in type of aggregate has been use in polymer concrete such as blasting sand, foundry sand, gravel, granite and etc. Each types of aggregate gives different desired mechanical properties. For the time being, very few studies being done on utilizing by-product material as an aggregate in polymer concrete (Mansor,
One of potential by-product is tin slag. Tin slag is a molten by-product of high temperature process that is primary used to separate the metal and non-metal constituents contained in the tin ore. When cooled, the molten tin slag converts to a rocklike or granular material as shown in Figure 1 (Mohd Abd. Wahab, 2005).

Background Study

The current construction industry revolution offers opportunity for the use of PC as a potential material (Ali and Ansari, 2013). Like other materials, polymer concrete also need to be analyzed in term of the mechanical properties in order to predict the maximum strength and mode of failure. As a composite material, the main problem of PC is the strength and ductility are various depending on many factors such as type of resin, aggregate etc. (Kostiha et al. 2016). Many efforts from previous studies on polymer concrete (PC) focused on the optimum content of polymer resin. Most authors mentioned the optimum amount of resin ranges from 10 to 20% by weight of polymer concrete (Bedi et al. 2013). The choice of resin type also depends on several factors like cost, desired properties, chemical and weather resistance required.

In this study, tin slag will be used as aggregate in PC and high strength carbon fibre reinforced polymer (CFRP) was used as confinement to improve the strength and ductility of this PC.

Research Objective

The objective of this research is to determine the mechanical behaviour of tin slag polymer concrete short column that is confined with CFRP under compression loading. A fine size (<1mm) of tin slag was use for casting PC column with the weight ratio between resin and tin slag aggregate is 30:70. Confinement for the PC was done with CFRP wrap at 1, 2 and 3 layers. Compressive behaviour of PC between confined and unconfined was analyzed.

LITERATURE REVIEW

The stress state of confined column by FRP is develop from axial compression load. Under loading, the lateral pressure exerted and react uniformly in radial of confinement circular column and develop a tensile stress on hoop direction. When the column confined by FRP is subjected to axial compression load, the internal column expands laterally, and this expansion is restricted by the FRP. For circular column, the confining action and reaction of free body diagram as Figure 2. The maximum confining pressure, \( f_i \) provided by FRP maximum stress (ultimate tensile),
thickness of FRP, \( t_{frp} \) and diameter of confined circular column core, \( d \) (Habib-Abdehak Misbah et al. 2017).

![Free body diagram of confining action and reaction](image)

This confinement pressure can be written as:

\[
f = \frac{(2 \cdot t_{frp} \cdot f_{frp})}{d}
\]  

[1]

**RESEARCH METHODOLOGY**

Fabrication involves two stages, where the first stage is casting of polymer concrete column and second stage is the wrapping process of the polymer concrete with the CFRP layer for confinement as depicted in Figure 3 (a) and (b). The casting of tin slag polymer concrete was fabricated in accordance to ASTM C192/470. The specimen size of PC column that was casted is 50 mm in diameter and 100 mm in height. In the beginning, mould for casting of PC need to be pre-coated with release agent. Past research done by Yusuff et al. (2018) reported that optimum ratio for this polymer concrete is 70% of tin slag aggregate and 30% of resin. Therefore, the resin-to-tin slag weight ratio selected is 70:30. Tin slag and resin was mixed using a heavy duty mixer. Then, methyl ethyl ketone peroxide as curing agent was added at about 1% of the resin weight. Before the resin starts to gel, the mixture of polymer concrete was poured into the mould. The mixture inside the mould was compressed to remove entrap air. Curing take place at room temperature with minimum curing time of 24 hours.

![Figure 3. (a) Casting of tin slag PC (b) CFRP wrapping on tin slag PC](image)

For PC confinement process, fabrication was prepared in accordance to ACI 440-08. First, the unidirectional carbon fibre fabric was cut into the size of PC column for 1 ply, 2 ply and 3 ply confinement. Next step was Sikadur 330 epoxy preparation. As per manufacture recommendation, the mix ratio between part A and B is 4:1. The
epoxy was applied to the carbon fibre fabric and wrapped onto the PC column with the carbon fibre positioned on the lateral direction of the PC column. Each layer of wrapping includes an extra 5 cm as an overlap. Last step is curing process, as per manufacturer recommendation a 30 days of curing at room temperature condition was required. The compression test follows ASTM C579-01 standards. The test was conducted using a 600kN load capacity Instron universal testing machine with loading rate set at 1 mm/min. The test specimens need to be mounted precisely on the centre of compression plate to avoid load imbalance during testing. For strain measurements, strain gauge was installed at mid span of the specimens (Figure 4). An average reading of three specimens was recorded for each sample.

RESULT AND DISCUSSION

The result of test is shown in Table 1. The test was conducted on four group of tin slag polymer concrete column. One group for unconfined column (UNC) and another three group is confined with CFRP with different numbers of layer (L1, L2 and L3). Average value was calculated for each group of samples. From compression test of unconfined tin slag polymer concrete column, shown that the tin slag polymer concrete column had an average compressive stress of 59.21MPa and with the average maximum load 103.5kN.
Table 1. Compression properties of confined and unconfined PC

<table>
<thead>
<tr>
<th>Sample</th>
<th>Maximum Load (kN)</th>
<th>Compressive Stress at Maximum Load (MPa)</th>
<th>Deformation (mm)</th>
<th>Compressive Strain at Maximum Load (mm/mm)</th>
<th>Maximum value of strain gague</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNC-S1</td>
<td>100.500</td>
<td>57.52</td>
<td>3.112</td>
<td>0.03112</td>
<td>14090</td>
</tr>
<tr>
<td>UNC-S2</td>
<td>110.000</td>
<td>62.86</td>
<td>3.023</td>
<td>0.03023</td>
<td>14108</td>
</tr>
<tr>
<td>UNC-S3</td>
<td>100.000</td>
<td>57.24</td>
<td>2.987</td>
<td>0.02987</td>
<td>18136</td>
</tr>
<tr>
<td>AVG-UNC</td>
<td><strong>103.500</strong></td>
<td><strong>59.20</strong></td>
<td><strong>3.041</strong></td>
<td><strong>0.03041</strong></td>
<td><strong>15445</strong></td>
</tr>
<tr>
<td>L1-S1</td>
<td>222.000</td>
<td>119.53</td>
<td>3.899</td>
<td>0.03899</td>
<td>262844</td>
</tr>
<tr>
<td>L1-S2</td>
<td>228.000</td>
<td>121.93</td>
<td>4.693</td>
<td>0.04693</td>
<td>28298</td>
</tr>
<tr>
<td>L1-S3</td>
<td>222.000</td>
<td>119.10</td>
<td>4.331</td>
<td>0.04331</td>
<td>45144</td>
</tr>
<tr>
<td>AVG-L1</td>
<td><strong>224.000</strong></td>
<td><strong>120.19</strong></td>
<td><strong>4.307</strong></td>
<td><strong>0.04308</strong></td>
<td><strong>112095</strong></td>
</tr>
<tr>
<td>L2-S1</td>
<td>269.000</td>
<td>135.50</td>
<td>4.204</td>
<td>0.04204</td>
<td>35407</td>
</tr>
<tr>
<td>L2-S2</td>
<td>275.000</td>
<td>139.30</td>
<td>5.671</td>
<td>0.05671</td>
<td>139163</td>
</tr>
<tr>
<td>L2-S3</td>
<td>276.000</td>
<td>139.42</td>
<td>5.544</td>
<td>0.05544</td>
<td>311380</td>
</tr>
<tr>
<td>AVG-L2</td>
<td><strong>273.333</strong></td>
<td><strong>138.07</strong></td>
<td><strong>5.140</strong></td>
<td><strong>0.05140</strong></td>
<td><strong>161983</strong></td>
</tr>
<tr>
<td>L3-S1</td>
<td>352.000</td>
<td>167.12</td>
<td>5.759</td>
<td>0.05759</td>
<td>379456</td>
</tr>
<tr>
<td>L3-S2</td>
<td>315.000</td>
<td>150.01</td>
<td>5.493</td>
<td>0.05493</td>
<td>20113</td>
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<tr>
<td>L3-S3</td>
<td>320.000</td>
<td>153.50</td>
<td>5.709</td>
<td>0.05709</td>
<td>45957</td>
</tr>
<tr>
<td>AVG-L3</td>
<td><strong>329.000</strong></td>
<td><strong>156.88</strong></td>
<td><strong>5.654</strong></td>
<td><strong>0.05654</strong></td>
<td><strong>148509</strong></td>
</tr>
</tbody>
</table>

As shown in Figure 5, stress-strain curve of confined concrete with the any type of FRP normally consist with two main regions. At the beginning of stress-strain curve linear region (elastic region), the confinement effect of FRP is still not active. Therefore, the behaviour of confined polymer concrete column with CFRP for group sample layer-1, layer-2 and layer-3 is similar to unconfined Tin slag polymer concrete column. As a stress reach at maximum compressive stress of unconfined polymer concrete column, the confined polymer concrete column reaches at state of unstable volumetric due to increasing of confinement pressure. At this point the effect of confining jacket are active and strain rapidly increase with the increase of compressive stress. And this region also calls as transition zone in stress-strain model of confinement concrete column (Lam and Teng, 2003). At the second region, respond from stress-strain curve shown exhibit of a second linear region with the slope a little bit smaller that from the first region. At this point confining jacket of tin slag polymer concrete with CFRP are fully activated.
Figure 5. Stress – strain curves for unconfined and confined tin slag polymer concrete

The confinement effect is sufficient to restraint the effect of the deteriorated condition of the tin slag polymer concrete and allow a greater compressive stress to be applied. At the end of this stress-strain curve shown very sharp transition for all group of confined samples where is the test sample was fail and CFRP jacket burst (Figure 6).

Figure 6. Failure mode of (a) unconfined and (b) confined tin slag polymer concrete

CONCLUSION

Based on the result and discussion, the objective of research was achieved. Mechanical behaviour of tin slag polymer concrete confined with CFRP was determined. From the data gained it can be concluded as per follow:

a. Maximum compressive stress significantly increases to 103% for unconfined PC to confined PC, meanwhile for one-layer to two-layer only increase 14.9% and same case for two-layer to three-layer only gain about 13.6%

b. Ductility ratio decreases with increasing number of layer confinement. Ductility ratio of unconfined to one-layer confined PC significantly decrease. Others layer confinement shows a slight deceased in ductility ratio.

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c. Confinement effectiveness increases twice for one-layer confined PC from the unconfined PC. Meanwhile for others layer of confinement increase slightly.

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