THE USE OF CEMENT LEFTOVERS FROM THE HOLLOW OF SPUN PILES AS AN ADDITIVE IN SELF-COMPACTING CONCRETE

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Abstract
Spun piles have been used widely by developing countries, including Malaysia, to construct the foundation of most construction projects. A spun pile is a reinforced precast and prestressed concrete that is compacted in a mould through spinning compaction. The spinning compaction produces cement leftovers in the hollow part of spun piles that can be added to concrete mixtures as an additive. The cement leftovers of spun piles were used as an additive in cement in range of 0%, 10%, 20% and 30% (equal percentages). The resulting compressive strength after curing periods of 7 days and 28 days were presented to investigate the properties of self-compacting concrete containing cement leftovers from the spun piles. Other properties investigated include the physical properties of fresh concrete and water absorption. The results indicated that higher compressive strength and lower water absorption were achieved by the concrete samples containing cement leftovers compared to controlled concrete.

Keywords: spun pile, cement leftover, additive, compressive strength, water absorption

INTRODUCTION

According to the United Nation Sustainable Development report by United Nations (1987), the concept of sustainable development is defined as “development that meets the needs of the present without compromising the ability of the future generations to meet their own needs.” In the field of practicing, sustainability does not stop at the development of new and environmentally friendly materials for construction purposes, but also the reuse of materials that were previously considered as waste by-products of industrial processes. According to Ramme & Tharaniyil (2004) during the last few decades, these “waste” materials have seen a transformation to the status of “by-products” and more recently, “products” that are sought for construction and other applications.

Cement leftovers (CL) of spun piles refers to cement that is produced from the process of compacting and compressing concrete materials inside moulds during the manufacturing process. It possesses cavities or porous layers that contain a large percentage of hollow particles and air voids which have a lower apparent specific gravity compared to mostly solid particles. It can simply turn into dust when it is pressed. The cement leftovers of spun piles can be categorized as a part of non-hazardous construction waste because it is considered as unused residue that remains within the hollow of spun piles. The cavity layer of the cement leftovers will be destructed, crushed into dust and mixed with soil when the spun pile is installed during the construction of piled foundations. Figure 1 (a) shows the cement leftover layer in the hollow of a spun pile and leftovers from a spun pile that has a
thin cavity layer on top of a solid layer while Figure 1 (b) shows a sample of cement leftovers.

Self-compacting concrete (SCC) is considered as a type of concrete which can be placed and compacted under its own weight with little or no vibration without segregation or bleeding. It is used to facilitate and to ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. It has gained significant importance in recent years because of the advantages it offers (Ozawa, et al., 1989; Okamura, 1997; Zhu and Bartos, 2003; Okamura and Ouchi, 2003). Such concrete requires a high slump that can easily be achieved by the addition of superplasticizers to a concrete mix where special attention has to be given to mix proportioning (Mahesh, 2014).

Spun piles are deep foundations that are produced from precast reinforced concrete in cylindrical shapes. A spun pile has a diameter size of 250 mm or 500 mm with a length of 6 m up to 12 m. It is known as a spun pile because the reinforcement of the spun pile and the precast concrete placed into the mould undergo stress during the spinning process to compress and compact the concrete materials inside the mould properly.

The spinning process was executed in four different speeds of rotation per minute controlled by a computer programming system. The first spinning speed distributes the concrete mixture thoroughly inside the mould while the second spinning speed prevents the segregation of concrete materials through further mixing. The third spinning speed starts the compression process to compact the concrete mixture through centrifugal force. It also eliminates excessive air cavities that might weaken the bond between concrete materials. Then, the fourth spinning speed carries out further compaction for concrete grade 30 and above to squeeze out excess water in order to produce high-strength concrete spun piles. As the result of the spinning process, cement leftovers (CL), is produced. Cavities or porous layers that contain a large percentage of hollow particles and air voids are formed in the hollow core of the spun pile. The cement leftover cavities with extremely fragile and thick layers can be turned into fine cement particles when they are pressed. In this study, the cement leftovers of the spun pile is used as an additive for concrete mixtures.

![Figure 1(a). The cement leftover layer in the hollow core of spun piles and from a spun pile that has a thin cavity layer on top of the solid layer](image1)

![Figure 1(b). A sample of cement leftovers](image2)
MATERIALS AND EXPERIMENTAL PROCEDURES

Materials

The cement used in this research is Lafarge Phoenix, a Portland Composite Cement (PCC) brand which satisfied the specifications for ordinary Portland cement, OPC MS EN 197- 1:2007. It is an eco-friendly building material with a minimum of 20% recycled content in its chemical composition. Concrete made from this type of cement releases low levels of hydration heat in the early stages of the hydration process. The CL of the spun pile was obtained from a spun pile production factory called CAPCO Berhad in Rawang. The cement leftover samples were taken directly from the hollow part of the spun piles and placed into sacks or containers.

Mix Proportion

A control mix consisting of PCC, natural sand and crushed rock aggregate was designed with an SCC compressive strength of 30 MPa after a curing period of 28 days and a slump flow range of 500 mm to 700 mm within 5 to 9 seconds. A non-air entrained concrete used the ACI Method of mix design. The PCC was then partially replaced with cement leftovers from the spun piles in the range of 0%, 10%, 20% and 30%. The water-to-cementitious ratio, w/c ratio (cement + cement leftover), was kept constant at 0.50 with many trial mixes conducted to ensure that the workability was in the range of the designed slump flow. The mix proportions of SCC mix design incorporated with 0% 10% 20% and 30% of cement leftovers are shown in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cement (kg/m³)</th>
<th>CL* (kg/m³)</th>
<th>Water (kg/m³)</th>
<th>Coarse Aggregate (kg/m³)</th>
<th>Fine Aggregate (kg/m³)</th>
<th>SP** (kg/m³)</th>
<th>w/c*** Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% CL</td>
<td>460</td>
<td>–</td>
<td>230</td>
<td>589</td>
<td>913</td>
<td>11.00</td>
<td>0.50</td>
</tr>
<tr>
<td>10% CL</td>
<td>460</td>
<td>46.00</td>
<td>253</td>
<td>589</td>
<td>913</td>
<td>11.00</td>
<td>0.50</td>
</tr>
<tr>
<td>20% CL</td>
<td>460</td>
<td>92.00</td>
<td>276</td>
<td>589</td>
<td>913</td>
<td>11.00</td>
<td>0.50</td>
</tr>
<tr>
<td>30% CL</td>
<td>460</td>
<td>138.00</td>
<td>300</td>
<td>589</td>
<td>913</td>
<td>11.00</td>
<td>0.50</td>
</tr>
</tbody>
</table>

*CL : cement leftover  
**SP : superplasticizer  
***w/c : water-cement

Preparation and casting of the specimens

To prepare the mix proportions, the required quantities of materials were weighed. Then, the mixing process was conducted using a mechanical tilting mixer and the procedure was similar as the mixing of normal weight concrete. Seventy two (72) 100 mm × 100 mm × 100 mm of concrete cube samples were casted. Three concrete cubes of each mix proportion were tested for compressive strength and water absorption after curing periods of 7, 14 and 28 days. Before the SCC was ready to be casted into the mould, each side of the inner surface of the mould was greased to facilitate the removal of hardened concrete from its mould. The casting immediately followed mixing, after carrying out tests on the fresh properties of concrete.
The fresh concrete was casted into a plastic mould without heavy tamping. Each side of the inner surface of the mould was filled with fresh concrete and rodded with a steel ruler to avoid the formation of honeycombs. The top surface of the specimens was scraped to remove excess material and to achieve a smooth finish. The casted specimen was placed in the laboratory for 24 hrs at 27+/−1°C in accordance with MS 26: Part 1:2009 until the testing day. Immediately after being removed from the mould, the samples were weighed before being fully immersed in a curing tank.

**Fresh Concrete Test**

The slump flow test was carried out in accordance with BS EN 12350-8:2010. Meanwhile, the sieve segregation test and J-ring test were conducted according to BS EN 12350-11:2010 and BS EN 12350-12:2010 for the testing of fresh SCC respectively.

**Compressive Strength Test**

This test was conducted according to BS EN 12390-3:2002.

**Water Absorption Test**

This test was conducted according to BS 1881: Part 122.

**RESULTS AND DISCUSSION**

**Properties of fresh concrete**

The properties of fresh SCC mix proportions tested by the slump flow test (slump flow diameter and T500 mm) of filling ability, J-ring test of passing ability and sieve segregation test of concrete segregation resistance ability are shown in Table 2. Nagataki and Fujiwara (1995) suggested a slump flow value ranging from 500 mm to 700 mm for concrete to be classified as self-compacting concrete. At a slump flow of >700 mm, the concrete might segregate whereas at a slump flow of <500 mm, the concrete might have insufficient flow to pass through highly congested reinforcement. All the mixes in the study conformed to the above range. The slump flow diameters of all mixes were in the range of 545 – 660 mm. All mixes could be designated as SCC mixes.

The J-Ring diameter and the difference in concrete height inside and outside the J-Ring were in the range of 555 – 637 mm whereas the difference in height was less than 40 mm. The specimen containing 10% CL showed the finest J-ring result among the other design mixes in terms of mobility through narrow sections where the value was 1.125 cm. The segregated portion in percentage must be ≤ 20% as that is the requirement that needs to be fulfilled by SCC mixes. The lowest segregated portion value of 8.00% was recorded by the mix design containing 30% CL whereas the highest segregated portion value of 11.78 % was recorded by the control mix design.
Table 2. Properties of Fresh SCC mix design

<table>
<thead>
<tr>
<th>Samples</th>
<th>Slump Flow Test</th>
<th>J-ring Test</th>
<th>Sieve Test</th>
<th>Segregation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slump Flow, SF (mm)</td>
<td>Flow Time, t500 (s)</td>
<td>Inner Flow Height h1 (cm)</td>
<td>Outer Flow Height h2 (cm)</td>
</tr>
<tr>
<td>0% CL</td>
<td>545.00</td>
<td>4.55</td>
<td>4.50</td>
<td>2.125</td>
</tr>
<tr>
<td>10% CL</td>
<td>657.50</td>
<td>6.53</td>
<td>3.00</td>
<td>1.875</td>
</tr>
<tr>
<td>20% CL</td>
<td>590.00</td>
<td>5.75</td>
<td>2.875</td>
<td>1.625</td>
</tr>
<tr>
<td>30% CL</td>
<td>555.00</td>
<td>5.15</td>
<td>4.625</td>
<td>2.375</td>
</tr>
</tbody>
</table>

Compressive strength of SCC

The compressive strength results of SCC are shown in Figure 2. The overall strength of the SCC increased for all specimens. The lowest strength was recorded at day 7 where 29.20 MPa was recorded by the control concrete specimen containing 0% CL whereas the highest strength of 45.70 MPa was recorded by the specimen containing 10% CL at day 28. The highest 7-day strength of 35.40 MPa was recorded by the specimen containing 10% CL while the lowest 7-day strength of 28.10 MPa was recorded by the specimen containing 20% CL.

At day 14, the lowest strength of 32.40 MPa was recorded by the specimen containing 20% CL while the highest strength of 42.00 MPa was recorded by the specimen containing 10% CL. At day 28, the lowest strength of 34.80 MPa was recorded by the specimen containing 20% CL while the highest strength of 45.70 MPa was recorded by the specimen containing 10% CL. Thus, it can be seen that SCC containing 10% CL achieved a higher compressive strength compared to other specimens.
Figure 2. Compressive strength test result of each SCC batch at 7, 14 and 28 days of wet curing

Water absorption by SCC

The water absorption results of all specimens are shown in Figure 3. In general, the water absorption of all specimens showed an increase in value. The lowest water absorption at day 7 was 4.45% by the control specimen whereas the highest water absorption was 12.15% by the specimen containing 30% CL at day 28.

At 7 days, the lowest water absorption of 4.45% was recorded by the control specimen while the highest water absorption of 8.76% was recorded by the specimen containing 30% CL. At day 14, the highest water absorption of 10.41% was recorded by the specimen containing 30% CL while the lowest water absorption of 4.50% was recorded by the control concrete specimen. At day 28, the highest water absorption of 12.15% was recorded by the specimen containing 30% CL while the lowest water absorption of 5.24% was recorded by the control specimen.

Hence, based on the average water absorption of all specimens, the results showed increasing water absorption with time along with the increasing percentages of the cement leftovers from spun piles for all of the mix designs.
DISCUSSION

The increase in strength of SCC incorporated with cement leftovers from spun piles was directly proportional to the increment in the duration of wet curing. If the cement leftovers are added into SCC in appropriate percentages, the increments in SCC strength would be relatively high compared to other percentages that would only result in a small increment in strength. In this study, the percentage of cement leftovers added to SCC which led to a relatively high strength increment was 10%. Thus, cement leftovers from spun piles are capable of increasing the strength of the SCC when they are added in the right proportions.

The increment in water absorption of SCC was directly proportional to the increase in wet curing days which increased the percentage of cement leftovers added to the SCC mixes. 20% of cement leftovers added to SCC shows moderately low increments in terms of water absorption compared to 30% of cement leftovers which resulted in the highest increment in terms of water absorption of SCC. Hence, suitable percentages of the cement leftovers from spun piles can decrease water absorption.

The increment in terms of SCC water absorption was directly proportional to the increasing percentage of cement leftovers added in SCC mixes. This is due to the physical properties of cement leftovers which are extremely porous. As a result, it absorbs a lot of water and makes the SCC mixes less workable. To overcome the problem, additives are required to be added into fresh SCC mixes during the mixing process to restore its workability. Therefore, superplastizer (SP) type Adva181 was added to control the workability of fresh SCC mixes.
The increment in SCC strength was due to the increase in wet curing duration and the percentage increase of cement leftovers added to SCC mixes. The higher the percentage of cement leftovers added to SCC mixes, the higher the water-cement ratio. Due to the inadequate water-cement ratio of the SCC mixes, the chemical reaction of hydration between the cement and water will be disrupted (Neville, 2012 and Nguyen et al., 2016). This would affect the strength of the SCC produced. Therefore, the appropriate percentage (for example, the proper percentage of LC used in this research was 10%) of cement leftovers from spun piles and the amount of superplasticizers to be added to fresh SCC mixes as an additive need to be considered carefully in order to produce high-strength SCC.

CONCLUSIONS

The conclusions that can be made from this study are as follows:

i. The compression test results shows that the increment in the compressive strength of SCC containing cement leftovers from spun piles was due to the increase in wet curing duration and the increase in the percentage of cement leftovers used compared to the control SCC (no cement leftovers added). After 7 days of wet curing, the compressive strength of all specimens fell within the range of 29 MPa to 34 MPa. After 14 days of wet curing, the compressive strength of all specimens fell within the range of 32 MPa to 42 MPa. Finally, after 28 days of wet curing, all the specimens achieved compressive strength values between 34 MPa to 46 MPa.

ii. From the water absorption test results, it was clear that the increment in water absorption of the SCC added with cement leftovers was due to the increase in wet curing duration and the increase in the percentage of cement leftovers added to the SCC mixes compared to the control SCC. After 7 days of wet curing, the water absorption of all specimens fell within the range of 4% to 9%. After 14 days of wet curing, the water absorption of all specimens fell within the range of 4% to 11% while specimens cured for 28 days had water absorption values between 5% to 12%.

iii. It was found that the percentage of cement leftovers to be used as an additive in SCC should be appropriate in relation to the mass of cement used. If the percentage used is too low, the effects of the cement leftovers from spun piles as an additive in SCC mixes would not be too prominent. Meanwhile if the percentage of cement leftovers used is too high, it will affect the water-cement ratio of the SCC mix and reduce its strength SCC. Based on the results of this study, the appropriate percentage of cement leftovers to be used as an additive in SCC is 10% of the mass of cement used to prepare the SCC mixes.

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