Mechanical and Durability Properties of Lightweight Foamed Concrete Containing Palm Kernel Shell

Hanizam Awang1*, Adebayo Adesina Dauda2, Wenny Arminda3

1,2School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
3Department of Building Technology, Federal Polytechnic Ilora, Nigeria
*Corresponding author E-mail: hanizam@usm.my

Abstract

The research project aimed to investigate the effect of palm kernel shell (PKS) on the mechanical strength and durability of foamed concrete at the level of 10% to 60%. The samples were designed and prepared having a dry density of 1600 kg/m³ with a binder to filler ratio of 1:1.2. Hardened foamed concrete samples were subjected to air cured and tested at the age of 7, 14, 28, 56 and 90 days. Mechanical performance of the PKS foamed concrete was assessed in term of its compressive strength. Durability properties namely water absorption and vacuum porosity were investigated. The result shows that the addition of PKS to lightweight foamed concrete up to 30% significantly improve the mechanical properties and the durability of the foamed concrete.

Keywords: Palm Kernel Shell, foamed concrete, mechanical and durability

1. Introduction

Global Crude palm oil production has increased almost threefold over the past three decades [1] and it is dominated by Indonesia (34 mega tons pa) and Malaysia (19.5 mega tons pa), followed by Thailand (2 mega tons pa), Columbia (1.143 mega tons pa) and Nigeria (0.97 mega tons pa) [2]. From the production chain of palm oil, solid residues have been generated which includes palm pressed fibers, oil palm trunk, empty fruit bunch and roots, and palm kernel shell (PKS). Most of the aforementioned solid residues are usually used as biomass fuel [3], raw material in fertilizer industry, animal feeds industry, paper industry, composite wood industry and pharmaceutical industry [4]. In most cases, due to the high amount of palm oil mill production, many of palm oil waste is not well managed and they were just disposed of uncontrolled in open grounds around the oil mills and leads to the deteriorations of the environment [5]. In Malaysia alone, around 4 million tons of PKS produced annually [3].

To minimize the environmental deterioration effected by the waste, efforts have been made on the possibility of PKS been used as in many fields of production. Initially, PKS was used as bio fuel but when it was discovered that it has characteristics comparable to coarse aggregate then effort began to use it as a replacement for coarse aggregate in the production of concrete. In Africa and South East Asia, since three decades ago, PKS has been used as lightweight aggregate [6], [7]. Although the bonding between PKS and cement matrix is weaker in tension when compared to concrete containing crushed granite [8]. PKS concrete possess a good potential that enables it to be used as structural concrete but the ratio of PKS in the concrete should be a function of the intended application and strength [9],[10],[11]. The quest for environmentally friendly construction materials and low cost of construction has made the consideration of foamed concrete and the use of industrial non-toxic waste such as PKS a better idea in the creation of a sustainable environment [12]. The use of PKS in foam concrete improves its strength and widens its application potentials [7].

This study was conducted to investigate the inclusion of PKS as lightweight aggregate in foamed concrete. The compressive strength and durability properties including water absorption, permeability and porosity of foamed concrete were measured. The microstructure analysis was also conducted using light microscope.

2. Research Method

2.1. Materials

Portland composite cement conforming to MS 522-1:2007 from a single source was used as the main binder. The local sand as fine aggregate was sieved passing through 600 microns sieve with the specific gravity of 2.7 and fineness modulus of 1.35 while PKS with specific gravity of 1.62 passing through 5mm sieve was used as coarse aggregate. To create a better bonding between PKS and the cement matrix interface, silica fume was used in a dry form. A protein based foaming agent (PA-1) diluted with a ratio of 1:30 was used to produce the stable foam using a portable foam machine. Superplasticizer, Conplast SP 1000 (SP) was used to improve the workability of the mix and reduce water requirement of the mix.

2.1. Mix Proportion and Casting

Foamed concrete with a targeted dry density of 1600 kg/m³ was cast in the fix binder to sand ratio of 1:1.2 and binder to water ratio of 1:0.5. PKS in different percentage which ranges from 10-60% was added as an aggregate. Silica fume (SF) and SP were added at 10% and 1% of the weight of the binder, respectively. The mix design for the research work is shown in Table 1.
2.3. Test Procedures

The foamed concrete sample cubes of 100mm x 100mm were cast and air cured until the testing days to determine the compressive strength according to BS EN 12390-3 [15]. The water absorption was measured using foamed concrete cylinder of 75mm in diameter and 100mm in height, which had been air cured for 28 days. The porosity of PKS foamed concrete was determined using the Vacuum Saturation Apparatus. The light microscope examination was performed to assess the microstructure of the specimens.

3. Result and Discussion

3.1. Compressive Strength

Figure 1 shows the overall average results of the compressive strength for all specimens at various ages of tests. The additional PKS up to 30% achieved the highest strength results for every testing ages compared to the control specimen. At the age of 28 days, PKS-10 and PKS-20 gained a compressive strength of 17.9MPa and 16MPa, respectively, or about 33.2% and 19.6% higher than that of the control which obtained 13.4MPa. The PKS-30 slightly increased the strength to 13.4MPa or about 0.15% higher than PKS-0, whilst when PKS are added exceed 40%, the compressive strength decreased significantly. At 90 days, the PKS-10, PKS-20 and PKS-30 obtained a magnificent strength which of 18.0MPa, 17.4MPa and 15.7MPa or about 29%, 24% and 12% higher than the control specimens, respectively. Meanwhile, the decrease in strength also occurs when the PKS was added exceeds 40%.

![Fig. 1: Compressive strength of PKS foamed concrete specimens at various ages](image)

Generally, it was observed that PKS specimens with PKS content up to 30% exhibit the highest compressive strength compared to other specimens. The higher strength value of foamed concrete with additional PKS up to 30% is also affected by the inclusion of silica fume as an additive in the concrete mix. This contributes to the strength of concrete and produces a stronger and denser of concrete as well as improves the durability of concrete.

3.2. Water Absorption

The average test results of all specimens at the 28 days are shown at Figure 2. It was found that PKS-60 has the highest absorption value of 11.2% among other PKS foamed concrete specimens, but slightly lower than the control specimen which has 11.8% or about 5.4% higher than PKS-60. Meanwhile, the lowest water absorption value was recorded by PKS-30 which has only 9.0% absorption. It can be concluded that the additional PKS up to 30% in foamed concrete is able to reduce the percentage of water absorption, but increased when additional PKS exceed 40%. Water absorption in foam concrete is a function of pores or voids in the matrix and also affected by the level of permeability. This also lines with Kong [14] who mentioned that the PKS has a 24hr water absorption capacity of 10.5% (depending on size) which is attributed to its high pore content.

![Fig. 2: Water absorption values of PKS foamed concrete specimens at 28 days](image)

The microstructure analyses obtained through light microscope for the seven foamed concrete mixes with different percentage of PKS including control mix are shown in Figure 4. The inclusion of PKS affected the distribution and size of the pores produced. From Figure-6a, it can be seen that the pores size formed in the control specimens without PKS looks smaller with about 0.034mm pore size and the pores are densely distributed. And also, the gaps in

### Table 1: Mix proportion (kg/m³)

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>Sand</th>
<th>PKS</th>
<th>Water</th>
<th>Foam</th>
<th>SF</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS0</td>
<td>293.5</td>
<td>352.28</td>
<td>0</td>
<td>117.65</td>
<td>183</td>
<td>29.35</td>
<td>2.93</td>
</tr>
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<td>PKS10</td>
<td>293.5</td>
<td>352.28</td>
<td>29.38</td>
<td>117.65</td>
<td>183</td>
<td>29.35</td>
<td>2.93</td>
</tr>
<tr>
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<td>293.5</td>
<td>352.28</td>
<td>58.69</td>
<td>117.65</td>
<td>183</td>
<td>29.35</td>
<td>2.93</td>
</tr>
<tr>
<td>PKS30</td>
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<td>352.28</td>
<td>88.04</td>
<td>117.65</td>
<td>183</td>
<td>29.35</td>
<td>2.93</td>
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<tr>
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<td>117.39</td>
<td>117.65</td>
<td>183</td>
<td>29.35</td>
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<td>117.65</td>
<td>183</td>
<td>29.35</td>
<td>2.93</td>
</tr>
<tr>
<td>PKS60</td>
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<td>352.28</td>
<td>176.08</td>
<td>117.65</td>
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<td>29.35</td>
<td>2.93</td>
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</tbody>
</table>
the interfacial zone between the foam agent, the air contents and the fine aggregate are smaller. The PKS-0 has a more compact microstructure compared to other specimens containing PKS. The above observation accounts for its high porosity and permeability throughout all ages of curing.

- **Fig. 4**: Comparison of pore formation between normal foamed concrete (control) and PKS foamed concrete at the age of 28 days

The PKS-10 and PKS-20 at 28 days (Figure 4(b) and (c)) having pore size with a diameter of 0.071mm and 0.073mm, respectively, are slightly bigger than the pores in the control specimen. The distribution and interconnectivity of pores were reduced by the shell. This is basically responsible for the decrease in percentage of porosity and increase in the compressive and flexural strength of the two mixes (PKS-10 and PKS-20) compared to control specimen. However, the pore size of PKS-30 and PKS-40 increased to 0.081mm and 0.095mm respectively and the pore distribution is also reduced, hence the increase in the percentage of porosity and permeability (Figure 4(d) and (e)) when compared to PKS-10 and PKS-20. This scenario is as a result of increase in the percentage of PKS in the mixes. Nevertheless, additional PKS content of up to 50% and above, makes the foamed concrete obtained the highest percentage of porosity and permeability because it causes increase in the pore size and interconnectivity of voids. This is observed in PKS-50 with pore size 0.144mm and PKS-60 which has 0.158mm pore size (Figure 4(f) and (g)).

4. Conclusion

Incorporation of PKS affects the compressive strength of foamed concrete. PKS-10 recorded the highest strength because of its lesser PKS contents. The PKS inclusion up to 30% increases the strength of the foamed concrete over the time but reduced when the PKS added exceeds 40%. The PKS-10 obtained the highest strength at all the ages with 17.9MPa at 28 days, followed by PKS-20 of 16MPa and PKS-30 of 13.4MPa. These strength values are higher than the control specimen PKS-0 of 13.4MPa at the same age. The presence of PKS in foamed concrete actually increases the pore size and reduces the air void volume; this has a significant effect on the porosity of foamed concrete. The percentage content of PKS affects the sizes and interconnectivity of the pores produced and thereby confirmed the result of the compression strength initially observed. The porosity value of PKS specimens are lesser than that of the control specimen however when additional PKS increased to 50% and 60%, the porosity value are nearly the same value as the control specimen. This justifies the lower strength because of the higher the porosity the lesser the strength. Furthermore, it can be concluded that PKS can be used in foamed concrete up to 30% and perform credibly well, but there will be a decline in strength and durability if this level is exceeded.

Acknowledgement

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[17] British Standards Institution BSI 22472015 World Agricultural Supply and Demand Estimates