Development of Green Concrete using Solid Residues from Biomass Gasification

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Abstract:

Biochar and ash are the solid residues from biomass gasification which require a large storage area and lead to environmental pollution such as land pollution. Utilization of these solid residues is an alternative method to solve this problem. These materials can be used as aggregate in concrete due to their compositions. Hence, this research carried out to produce eco-friendly concrete blocks by replacing these residues varied from the 5, 10, 20 and 30%. The experimental results showed that the compressive strength of the concrete decreased with the increase in the amount of the replacement. The compressive strength with the replacement of 30% solid residues in the concrete showed no significant difference when the sample was aged at longer time. From this study, the compressive strength of the concrete substituted by biochar and ash were varied in the range of 3.3-14.3 MPa which is higher than 2.5 MPa of hollow non-load bearing concrete masonry units standard. Therefore, the use of a mixture of biochar and ash in concrete can produce eco-friendly concrete for structural materials.

Keywords: Biochar; Ash; Concrete; Biomass; Residues

1. Introduction

Biomass gasification is a thermos chemical process that produces synthetic gas such as CO, H₂, CH₄ and other lighter hydrocarbons by converting biomass such as sawdust, bark, wood, agricultural residues to synthetic gas under the presence of a restricted air supply. This synthetic gas can be used as an alternative method for generate electricity.¹-³ Although, the solid residue of biochar and ash from the biomass that produced beside the synthetic gas is very large and required a landfill. This leads to an environmental pollution. Utilization of these solid residues in useful application is sustainable for solve this problem. However, solid residues and content depend on feedstock, operation condition and gasifier type. Ash is solid residue that composes of inorganic elements (minerals and metals with minimal carbon). Biochar or char is solid residue that composes of high carbon and content of ash.²-⁴-⁵ Most of ashes from solid residues obtained from biomass gasification process are composed of silica (SiO₂) and calcium oxide (CaO) as the major mineral phases.⁶-⁸

Many researchers have been studied to use of solid residues from biomass gasification process as aggregates in concrete blocks for building materials due to their porous structure and light weight. This results in lightweight concrete blocks which is increased the thermal insulation property of materials.⁸-⁹ Berra et al., illustrated that woody biomass fly ash can be used in cement replacement for 15 wt% or 30 wt%.⁹ Ettu et al., investigated the replacement of Portland cement with corn cob ash at various percentage from 5 % to 25%. They found that the compressive strength of samples with 5-15% replacements at 90 days of curing were higher than the control samples.¹⁰ Raheem et al., also studied the replacement of Portland cement with saw dust ash. The tests showed that the compressive strength value of 23.26 N/mm² can be obtained with 5% saw dust ash replacement.¹¹ These recent studies provide
the promising solution for using solid residues in the cement production.

The present study aims to characterization and utilization of solid residues from biomass gasification process in order to use as aggregates in concrete blocks.

2. Materials and Methods
2.1 Materials
Solid residues consist of biochar and ash from biomass gasification power plant (KP Energy Group Co., Ltd., Chaiyaphum, Thailand) and crushed stones were used as an aggregate to produce concrete blocks. The maximum size of aggregate was not greater than 2 mm. Type I Portland cement was used as binder, harden and adhere to other compositions.

2.2 Preparation of green concrete blocks
The mix proportion of concrete blocks was cement and aggregate mixture with a weight ratio of 1:6. The effect of blending both crushed stones and solid residues in the aggregate on the properties of the concrete blocks were studied. The solid residues were used to replace 0, 5, 10, 20 and 30% crushed stones in the aggregate as shown in Table 1. The moisture in all specimens was controlled at 8% by weight.

The concrete blocks were pressed by molding 50 mm x 50 mm x 50 mm using manual hand press machine. Then, the concrete blocks were de-molded and aged for 7, 14 and 28 days.

Table 1. Percentage solid residues replacement of crushed stone in green concrete blocks

<table>
<thead>
<tr>
<th>Concrete block</th>
<th>Replacement (%)</th>
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<tbody>
<tr>
<td>Control</td>
<td>0</td>
</tr>
<tr>
<td>SR5</td>
<td>5</td>
</tr>
<tr>
<td>SR10</td>
<td>10</td>
</tr>
<tr>
<td>SR20</td>
<td>20</td>
</tr>
<tr>
<td>SR30</td>
<td>30</td>
</tr>
</tbody>
</table>

2.3 Characterizations
Solid residues from biomass gasification power plant
Physical, morphology and chemical properties of solid residues were observed. The density of solid residues was determined by tap density tester (TAP-2SP, Logan Instruments Corp.) for 500 cycles with rotary motion 250 rpm. The average pore sizes and surface area were measured using surface area and pore size analyzers (Autosorb-1, Quantachrome) followed as The Brunauer-Emmett Teller (BET) method. Total carbon (C) and chemical composition were characterized with multiphase carbon and hydrogen/moisture analyzer (RC612, Leco Corp.) and X-ray fluorescence spectrometry (XRF, S8 Tiger, Bruker), respectively. The mineral composition of solid residues was observed using X-ray diffractometer (XRD, Smartlab, Rigaku). The morphologies of solid residues were also investigated by Field Emission Scanning Electron Microscope (FE-SEM, JSM-6304F, JEOL).

Concrete blocks
Morphology of concrete blocks was observed using FE-SEM. The compressive strength of three aged cubes at 7, 14, and 28 days were determined with constant applied load at 0.1 MPa/s. The density and fracture surface of cement blocks which that aged for 28 days were calculated from weight and volume of concrete blocks and investigated by FE-SEM, respectively.

3. Results & Discussion
3.1 Properties of solid residues
Morphologies
Fig 1 illustrates a SEM micrograph of solid residues from biomass gasification power plant. The various shapes and sizes of solid residues can be observed such as elongated and irregular-shaped particles. Furthermore, the rough surface and porous structure can be clearly seen.
Physical properties

Physical properties of solid residues are shown in Table 2. The density, surface area and pore size of solid residues were 3740 kg/m$^3$, 106.5 m$^2$/g and 34.64 Å, respectively.

Table 2. Physical properties of solid residues

<table>
<thead>
<tr>
<th>Density (kg/m$^3$)</th>
<th>Surface area (m$^2$/g)</th>
<th>Pore size (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3740</td>
<td>106.5</td>
<td>34.64</td>
</tr>
</tbody>
</table>

Element composition

The chemical composition of solid residues is presented in Table 3. The main components were CaO, C, K$_2$O and SiO$_2$ in amount of 64.1, 11.11, 11.1 and 10.3%, respectively. This result was consistent with mineral composition as shown in Fig 2, which was composed of calcite (CaCO$_3$) as a major phase and a presence of other compounds (i.e. quartz (SiO$_2$) and larnite (Ca$_2$SiO$_4$)). Therefore, it is most likely can be reused as a raw material in concrete blocks.

3.2 Concrete block properties

Fig 3. shows the aged concrete block specimens. The color of green concrete blocks was darkened with increase in the replacement of solid residues. This might be due to the high content of C in the solid residues.

The compressive strengths of concrete blocks at various aging are illustrated in Fig 4. Overall, the compressive strength of the green concrete blocks decreased with the increase in the amount of the replacement. Although the compressive strengths of specimens were not significantly changed at aging time for 7 and 14 days, the strengths were highly increased at aging time for 28 days. However, the compressive strength results with the replacement of 30% solid residues in the concrete blocks showed no significant difference even the specimens were aged until 28 days. The green concrete blocks with replacement of 5% solid residues (SR5) presented the maximum strength, which was 14.3 MPa at aging time for 28 days. The minimum strength was occurred in aged concrete blocks with replacement of 30% solid residues (SR30) for 7 days, which is higher than 2.5 MPa of hollow non-load bearing concrete masonry units standard.

The density of concrete blocks with aged for 28 days decreased as increased the solid residues replacement (Fig 5). The densities were gradually decreased from 2.1 to 1.4 kg/m$^3$ when the solid residues were added up until 30%. These results can be related to their microstructures as shown in Fig 6. The SEM micrograph of control specimen without the solid residues illustrates the tightly pack of particles. In the specimen with 5 and 10% replacement of solid residues, the pieces of biochar and ash particles can be observed. This result in the materials being loose and less compacted in the specimens due to the higher solid residues presented more amount of large biochar and ash particles.

4. Conclusion

This investigation has demonstrated that solid residues (biochar and ash) from biomass gasification process can be used as aggregates in building materials to develop of green concrete blocks. The green concrete blocks were lightweight and high compressive strength of hollow non-load bearing concrete masonry unit standard.
Table 3. Chemical composition of solid residues

<table>
<thead>
<tr>
<th>Compound (%)</th>
<th>CaO</th>
<th>K₂O</th>
<th>SiO₂</th>
<th>MgO</th>
<th>P₂O₅</th>
<th>Fe₂O₃</th>
<th>Cl</th>
<th>BaO</th>
<th>SO₃</th>
<th>Al₂O₃</th>
<th>Na₂O</th>
<th>MnO</th>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>11.11</td>
<td>64.1</td>
<td>11.1</td>
<td>10.3</td>
<td>5.14</td>
<td>3.08</td>
<td>1.57</td>
<td>1.25</td>
<td>1.15</td>
<td>0.8</td>
<td>0.79</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Fig. 2. XRD pattern of solid residues.

Fig. 3. Green concrete block specimens.

Fig. 4. Compressive strength of concrete blocks at various aging times.

Fig. 5. Densities of concrete blocks

Fig. 6. Fracture surface of concrete blocks: (a) Control, (b) SR5 and (c) SR10
Acknowledgements

The authors would like to acknowledge KP Energy Group Co., Ltd. for solid residues that we used as raw material in this study. And we would like to grateful National Research Council of Thailand (NRCT) and Thailand Institute of Scientific and Technological Research (TISTR) for financial support.

References