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Mechanical properties of seashell concrete

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Abstract

Blood clam or cockle (*Anadara granosa*) shell is a type of marine by-product that can be used to replace aggregate or cement partially in concrete. In this research, the ground cockle seashell was used as a partial cement replacement. The ground seashells were prepared by burning, crushing, grinding and filtering the cockle using no #200 sieve. The mechanical properties studied were compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of seashell concrete. These properties were compared with those of a control Ordinary Portland Cement (OPC) concrete. Based on the trial mixes using the ground seashell with proportion of 2, 4, 6 and 8% by weight of cement, the optimum compressive strength was achieved for the mix that replaced cement by 4%. The seashell concrete yielded less compressive strength and modulus elasticity compared to the OPC concrete. It is noted that the tensile strength and flexural strength were higher than those of the OPC concrete, which is advantageous to increase concrete tension properties.

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1. Introduction

Seashells of various molusks such as oyster, clam, mussel and scallops, are available abundantly along coastal areas in Indonesia. Based on a report from Ministry of Marine and Fisheries Indonesia, production of pearl oysters, green mussels, and blood cockles in 2007 were 64,641 tons, 420 tons, and 205 tons, respectively [1]. Various physical, mechanical and chemical properties of shells, such as cockle or blood clam (*Anadara granosa*), oyster, periwinkle shells, mussels, scallops, crepidula shells, and conk shells as a sand replacement, a partial and total...
coarse aggregate replacement, filler, and cement replacement, in form of complete, crushed, ground or powder have been studied previously. As a sand replacement, the waste oyster shells filled material pores, reduced the absorption rate and produced a comparable strength with the normal controlled concrete mix. The replacement of 5% seashell was recommended to avoid further reduction in compressive strength [2]. Another study was conducted by Safi, et al. [3] concluded that mixing the oyster shell did not cause a reduction in the compressive strength significantly due to a good adhesion between seashell and cement paste. The crushed shells have better permeation properties than the concrete without seashells. This is partly because the shapes and configuration in the mixture could reduce the tortuosity of pores in concrete.

The crushed seashells as a coarse aggregate replacement produced low strength and lightweight concrete that is more suitable for low strength application such as concrete paver [4,5]. A recent study by Cuadrado-Rica et al. [6] concluded that the use of crushed queen scallop shells as the aggregate replacement could decrease the mechanical properties and increase the porosity because of an increase of entrapped air in concrete. Uncrushed cockle shells could replace aggregate partially up to 20% with an increase in compressive strength than normal concrete. However, it has a low workability because of the size, shape and texture of the shells [7].

The use of ground seashells as a partial cement replacement is less favourable in application, since the production of shell powder requires intensive energy to burn and grind the shells as fine grain powder. Until recently, there are not many studies reported the influence of ground seashells on the mechanical properties of concrete. In one study, cement was partially replaced by the ground cockle by 5-50%. The ground cockle shells have 95-99% by weight of Calcium Carbonate (CaCO₃) that is suitable as a filler in concrete. However, a replacement above 15% by weight of cement could decrease strength, permeability and porosity of concrete up to 28 days [8]. This paper provides an experimental study to measure the mechanical properties of seashells concrete, such as compressive strength, tensile strength, flexural strength and modulus of elasticity.

2. Materials and Method

The Ordinary Portland cement type I was used as a main binder. Fine aggregate with specific gravity of 2.68, fineness modulus of 2.86, and water absorption of 1.24% was used. Coarse aggregate with specific gravity of 2.7, and water absorption of 1.08% was incorporated as the main component of concrete. The sea shells were collected from local seafood vendor. The shells were cleaned, dried, burnt at brick furnace, crushed into small pieces using Los Angeles machine, then grounded with a blender, and sieved using #200 sieve to produce seashell powder. The shells were burnt at high temperature of 500°C for 3 days. The chemical composition of seashell powder is shown in Table 1.

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Percentage (%)</th>
</tr>
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<tbody>
<tr>
<td>SiO₂</td>
<td>1.60</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.92</td>
</tr>
<tr>
<td>CaO</td>
<td>51.56</td>
</tr>
<tr>
<td>MgO</td>
<td>1.43</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.08</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.06</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.31</td>
</tr>
<tr>
<td>LOI</td>
<td>41.84</td>
</tr>
</tbody>
</table>

The control mix consisted of cement (505 kg), water (179.35 kg), fine aggregates (642.22 kg) and coarse aggregates (969.52 kg). The expected compressive strength at 28 days is 35 MPa. In order to obtain the optimum cement replacement, the cement was replaced by 2, 4, 6 and 8% by weight with the ground sea shells. The optimum cement replacement of 4% was used to investigate the mechanical properties of the seashell concrete.
The seashell concrete was prepared by mixing dry materials and water in the pan mixer. The dry materials consisted of cement, fine and coarse aggregates, and ground seashells. The mixture blended continuously until it was well combined. The specimens were cast in 150x300mm cylinders for compressive strength, splitting tensile strength and Young’s Modulus of Elasticity. Specimens of 100x100x400mm were used for flexural strength. The seashell concrete were cured for 28 days at water pond before left to air dry until the testing date. The strength properties were determined by conducting tests for compressive strength (SNI 03-1973-1990), splitting tensile strength (SNI 03-2491-2002), flexural strength (SNI 02-4431-1997) and Young’s Modulus of Elasticity (ASTM C469).

3. Results and Discussion

3.1. Compressive strength

Compressive strength was used as evaluation criteria for the trial mixes. Table 2 displays the compressive strength of mixes with cement replacement of 2, 4, 6, and 8% by weight. The proposed optimum mixture was the mixture with ground seashell content of 4% with has the highest strength of 32.24 MPa at 28 days. The mix was used for further investigation on mechanical properties of seashell concrete.

<table>
<thead>
<tr>
<th>Ground seashell percentage</th>
<th>Compressive strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>30.84</td>
</tr>
<tr>
<td>4%</td>
<td>32.24</td>
</tr>
<tr>
<td>6%</td>
<td>28.86</td>
</tr>
<tr>
<td>8%</td>
<td>30.56</td>
</tr>
</tbody>
</table>

The compressive strength of mixture using 4% ground seashell is shown in Fig. 1. There was an increase of compressive strength of all samples at 7, 28 and 91 days for both type of concrete. The OPC concrete samples showed a slightly higher strength than the seashell concrete. The influence of the ground seashell on the compressive strength could reduce the early strength of concrete. This was likely due to a decrease of the cement content that could reduce the rate of hydration in concrete at early ages. Similar findings were reported by Lertwarttanaruk et al. [9]. The ground seashell has less calcium content (CaO) than cement that causing a slow hydration because of disruption of the process. However, after 28 days, the increment in strength was quite significant for the seashell concrete.

![Fig. 1. Compressive strength of OPC and seashell concrete at 7, 28, and 91 days.](image-url)
There was a gradual increase in tensile strength for both OPC and OPC seashell in Fig. 2. The increment of tensile strength of seashell concrete was relatively higher than the OPC after 28 days. It was reported that addition of 5% cockle ash has increased the tensile strength significantly [8]. This high tensile strength was likely due to an improved bonding at the interface of the cement paste and aggregates. The addition of the ground seashell could increase the density of the concrete, thus could change the Interfacial Transition Zone (ITZ) phase between the aggregate and cement paste.

### 3.3. Flexural strength

The average flexural strength of OPC and seashell concrete is presented in Fig. 3. Overall the values varied in the range of 4.5-6.75 MPa. It can be seen that the flexural strength of seashell concrete tend to increase at 28 and 91 days. A considerable strength gained after 28 days was probably due to calcium content in the cement that produced a better bonding between paste and aggregates. The bonding has also influenced the tension properties such as tensile and flexural strength. This additional increase in tension properties is beneficial to enhance composite action between steel reinforcement bars and concrete.
3.4. Modulus of Elasticity

The average Young’s Modulus of elasticity at 7, 28 and 91 days for the OPC and seashell concrete is shown in Fig. 4. The Young’s Modulus of Elasticity of the seashell concrete was lower than the OPC. However, the increment of Young’s Modulus of Elasticity of seashell concrete was higher than the OPC. The modulus of elasticity of concrete mostly relies on the interfacial transition zone between the aggregate and cement paste. A better bond between the both phases could lead in better tension properties, thus the modulus of elasticity of seashell concrete.

4. Conclusions

In this study, the effect of replacing cement by ground seashell on the mechanistic properties of concrete was examined. Replacement of the cement with the ground seashell led to a decrease of compressive strength of seashell concrete compared with the control OPC concrete. The tensile and flexural strength of the seashell concrete were higher than the control concrete. The Young’s Modulus of Elasticity of seashell concrete increased with the age of concrete. It can be concluded that the concrete containing ground seashell yielded relatively better tension properties, but lower compressive strength and modulus of elasticity than the control concrete.

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References