Increasing Soil Bearing Capacity and Shear Modulus with Recycle Concrete Aggregate

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ABSTRACT

Soil is an important component in building construction because it supports the structure. Clay soils often pose problems due to their high potential for swelling and shrinkage, which can result in cracking and building settlement. Stabilization of clay soil is an important solution. This research aims to evaluate the effect of recycled aggregate concrete (RCA) from laboratory construction waste on the characteristics of clay soil. The research method involved laboratory experiments, with a mixture of clay and RCA at 5%, 10%, and 15% variations. Testing includes Atterberg Limit, Standard Proctor Test, and Unconfined Compressive Strength (UCS). The results showed that adding RCA increased clay soil's bearing capacity and shear modulus. The peak bearing capacity was achieved by adding 5% RCA, with a Qu value reaching 265.24 kN/m². The shear modulus also increased from 41.63 MPa to 62.442 MPa with the addition of 5% RCA. Thus, the addition of RCA from laboratory construction waste can increase the bearing capacity and shear modulus of clay soil to support construction safety and the principles of sustainable development.

Keywords: clay; recycled concrete aggregate; shear modulus; UCS

1. INTRODUCTION

Soil is important in various construction works (Bhat et al., 2019). Soil acts as a support for building structures. Therefore, the soil must have adequate strength and stability (Karkush &
A good understanding of soil characteristics and their management is key to ensuring the success of construction projects (R. Islam et al., 2019). In this research, clay soil is the main focus. This soil has unfavorable properties, such as the potential for high expansion and shrinkage due to changes in water content (Sharma & Sharma, 2020). So, it has the potential to cause cracks and a significant decline in the building above (Sharma & Sharma, 2019). Therefore, stabilization is needed to improve the characteristics and strength of this clay soil (Tavakol et al., 2020).

In recent decades, soil improvement techniques have been widely applied in various geotechnical fields. Soil improvement is often more economical and profitable than replacing with fill (Shourijeh et al., 2022). Engineers have devised various ways to improve soil, such as dynamic compaction and mixing additives with the soil (S. Islam et al., 2022). This research focuses on using fine-grained concrete waste, known as Recycled Concrete Aggregate (RCA). Soil improvement using RCA has become common practice. Dobrescu and Calarasu indicated that RCA is a promising option for improving the geotechnical properties of low-strength soils (Dobrescu & Calarasu, 2020). Arulrajah also recognized the potential for soil improvement with RCA in the geotechnical field (Kianimehr et al., 2019). The use of RCA in soil improvement has been proven to increase bearing capacity through UCS tests (Zhang et al., 2019). However, additions need to be paid attention to optimal limits so as not to decrease carrying capacity (Sharma & Sharma, 2020). This increase in value gives RCA-soil greater strength and lower permanent deformation compared to ordinary soil (Kianimehr et al., 2019).

Furthermore, the addition of RCA can reduce the Atterberg Limit value. This value affects the level of consistency, such as the ability to withstand water and plastic deformation (Sharma & Sharma, 2020). Lowering the Atterberg Limit value can produce more stable soil and more resistance to changes in volume due to changes in water content (Sosahab et al., 2023).

In terms of compaction, adding RCA can increase the dry volume weight and water content of RCA-soil until it reaches a certain percentage, then decreases (Cabalar et al., 2019). However, the addition of RCA reduced the water content in the soil, which impacted the soil’s physical and mechanical properties (Abd-Allah et al., 2021). The higher the percentage of RCA addition, the more significant the decrease in optimal water content and increase in dry volume weight (Oskooei et al., 2022).

The addition of RCA can also affect the soil shear modulus value. RCA can increase the shear modulus value and reduce permanent deformation. Research by Katarzyna Gabry shows that RCA increases the value of soil shear modulus, influencing resistance to shear forces and soil structure stability (Gabryś, 2023). Increasing the shear modulus value makes the soil more able to withstand shear forces and maintain the stability of the related construction (Mohammadinia et al., 2019).

Previous research shows that adding RCA from construction waste, including pavement waste, can increase soil’s bearing capacity and shear modulus through laboratory tests. However, there is no information regarding the effect of RCA from laboratory waste, especially whether it can increase or decrease the bearing capacity and shear modulus. So, this research focuses on the effect of RCA from laboratory waste. This research aims to fill this gap by exploring the use of laboratory RCA on soil characteristics, especially the impact of variations in RCA particle size on soil's bearing capacity and shear modulus. The results are expected to not only provide solutions to environmental problems but also provide solutions for handling clay soils using RCA to increase bearing capacity and shear modulus, thereby reducing the possibility of damage or failure as well as structural degradation in the future.

2. RESEARCH METHODS

This section explains the materials used and the test procedure steps carried out to complete the research, detailed as follows.
Clay

The clay soil used came from the Agricultural Land of Kadiri University, Kediri City, East Java Province. The soil is excavated, dried, and crushed using a hammer until the particle size can pass through the No. sieve, 4 (< 4.75 mm) and No. 40 (< 0.425 mm). The soil is then subjected to physical testing as presented in the following Table 2.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>CL</td>
</tr>
<tr>
<td>Cu</td>
<td>2.66</td>
</tr>
<tr>
<td>Cc</td>
<td>2.06</td>
</tr>
<tr>
<td>Liquit limit</td>
<td>33.65 %</td>
</tr>
<tr>
<td>Plastic limit</td>
<td>22.70 %</td>
</tr>
<tr>
<td>Index plasticity</td>
<td>10.95 %</td>
</tr>
<tr>
<td>Dry volume weight</td>
<td>1.52 gr/cm³</td>
</tr>
<tr>
<td>Qu</td>
<td>168.07 kN/m²</td>
</tr>
</tbody>
</table>

![Figure 1. Clay soil](image)

Recycled concrete aggregate

Recycled Concrete Aggregate is obtained from Kadiri University laboratory concrete waste. The waste is then cleaned so that additional materials do not contaminate it. Concrete waste is crushed using a hammer to produce smaller aggregates to make RCA. Then, the waste is filtered using filter No. 40 (< 0.425 mm).

![Figure 2. Recycled concrete aggregate](image)

Laboratory testing

In this research, clay soil was mixed with RCA with 5%, 10% and 15% variations. Then laboratory tests such as Atterberg Limit, Standard Proctor Test, Unconfined Compressive Strength (UCS) are carried out. Atterberg Limit carried out to observe the liquid limit (LL), plastic limit (PL), and plasticity index (PI) of original soil samples and RCA soil mixtures using...
procedures according to ASTM D-4318 (Standard Test Method, 2000). Standard Proctor test, using ASTM D-698 procedures (Standard Test Method, 2000). This test is used to determine the compaction properties of soil mixed with RCA by knowing the relationship between soil moisture and density, as well as determining the maximum dry density (pdmax) and optimum water content (wopt) for the soil-RCA mixture (Varaprasad et al., 2019). Unconfined Compressive Strength (UCS), using the ASTM D-2166 testing standard. This test was carried out on a cylindrical specimen with a diameter of 41mm and a height of 88 mm at optimum water content, and it was compacted to maximum dry density (ASTM, 2006).

Shear modulus
The shear modulus can be obtained by knowing the Su value from the Unconfined Compressive Strength (UCS) test. This was stated by Locat & Beausejleour (1987). With the following equation 1:

\[ G_{\text{max}} = 0.397 (Su)^{1.05} \]  

(1)

In the equation above is the compressive strength value derived from the Unconfined Compressive Strength test.

3. RESULTS AND DISCUSSION

Liquid limit
The graph shows in Figure 4 the decrease in the original land's Liquid Limit (LL) value as RCA is added. This is caused by adding RCA material, which has non-cohesive properties. Where porosity tends to be lower compared to the original soil. Low porosity indicates the presence of little empty space between the RCA particles. Thus, the ability of the soil-RCA mixture to absorb water decreases (Shourijeh et al., 2022).

![Figure 3. Liquid limit results chart](image)

Plastic limit
From graph in Figure 5, a trend is presented. Where the trend can be seen to be stable, where there is no significant increase or decrease. Therefore, it is difficult to make valid estimates to determine the next value if RCA is added (Gupta & Kumar, 2023).
Increasing Soil Bearing...

Index plasticity

It can be seen from the graph in Figure 6 that there is a decreasing trend in the Plastic Index (PI) value in RCA mixed soil. The most significant decrease occurred at an RCA percentage of 10%. This occurs due to the addition of particles from RCA that have properties different from the original soil. Thus, the soil becomes stiffer and less plastic with increasing RCA percentage (Tavakol et al., 2020).

Standard proctor test

It can be seen in Figure 7, that the dry volume trend does not show a significant increase or decrease. Therefore, the trend equation obtained can less predict the dry volume weight value when further RCA is added (Abd-Allah et al., 2021). Therefore, further research is needed to identify additional variables that can clarify the relationship between adding RCA and changes in dry volumetric weight.
Unconfined compressive strength (UCS)

The graph shows in Figure 8, that the Qu value increases when RCA is added. The Qu value of the original soil was 186.07 kN/m², and increased to 265.24 kN/m² with the addition of 5% RCA. This shows that the presence of RCA influences the increase in soil compressive strength. The increase in bearing capacity is influenced by the soil consistency limit value. When the soil plasticity value is lower, it means the soil has a lower deformation capacity, which can indicate limitations in the movement of soil particles (Perez et al., 2023). This is often related to increased soil strength. Thus, when the soil plasticity value becomes lower, the Qu value (compressive strength) tends to increase. However, it is important to note that there is an optimal limit for RCA addition, which should not exceed the point where soil strength begins to decrease (Sosahab et al., 2023).
A graph shows in Figure 9 and Figure 10, the relationship between Stress and Strain in original soil and soil mixed with RCA at 5%. This graph shows that when pressure begins to be applied to the soil, the stress-strain curve will increase proportionally with the increase in strain. This phenomenon reflects the elastic properties of soil, where deformation occurs proportionally to the applied pressure, and the relationship between stress and strain is linear (Varaprasad et al., 2019). In addition, the graph shows the decline after reaching the peak point of the soil (Ultimate Plastic), where the soil can no longer withstand the axial load applied (Sharma & Sharma, 2020). From this graph, it can also be seen that the mixed soil with 5% RCA has a Qu value that is greater than the original soil. Thus, it can be concluded that the addition of 5% RCA is the most optimal percentage compared to mixing 10% and 15% RCA.

![Figure 8. Soil UCS results chart](image)

![Figure 9. Pure soil UCS results chart](image)
Mechanical testing relationship

The graph shows in Figure 11, that the Qu value peaks at adding 5% RCA, namely 265.24 kN/m². The Qu value also affects parameters such as Atterberg Limit, Standard Proctor, and UCS (Yang et al., 2020). Although values such as LL, PL, Plasticity Index, and dry unit weight are lowest at adding 5% RCA, the Qu value, or soil bearing capacity, reaches its peak at that percentage. So, it was concluded that adding RCA increased the bearing capacity of clay soil, indicating that RCA could strengthen the soil structure (Chmielewska & Gosk, 2022).

![Graph showing mechanical testing relationship](image)

Figure 10. Relationship graph for each test

Visual

The image in Figure 12 to Figure 15, shows variations in failure patterns in the RCA mixed soil. 10% RCA soil mix shows the most fatal failure compared to other mixtures because a higher proportion of RCA can change the interactions between particles, affecting the strength and failure pattern (O’Kelly, 2021).

![Visual examples of mechanical testing](image)

Figure 11. Pure soil
Figure 12. RCA 5%
Figure 13. RCA 10%
Figure 14. RCA 15%
From the image in Figure 16 to Figure 19 of the sample fraction, it can be seen that there is a different distribution for each RCA percentage. The most even distribution is found in the 5% RCA sample. Even though there is an even distribution at 10% and 15% RCA, there are several points of RCA lumps. Therefore, the carrying capacity of 10% and 15% RCA is not higher than 5% RCA. RCA 5% shows an even and proportional distribution, thereby significantly increasing the bearing capacity of the soil (Zhou et al., 2023).

**Correlation of shear modulus and UCS**

Table 3 shows the $Su$ values obtained from the UCS test for each mixture percentage. Based on equation (1) correlation of shear modulus and $Su$ by Locat & Beausejoux (1987), the resulting shear modulus values are as follows in Table 4 (Locat & Beausejoux, 1987).

<table>
<thead>
<tr>
<th>Mixture</th>
<th>$Su$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Soil</td>
<td>84,036</td>
</tr>
<tr>
<td>RCA 5%</td>
<td>132,618</td>
</tr>
<tr>
<td>RCA 10%</td>
<td>86,534</td>
</tr>
<tr>
<td>RCA 15%</td>
<td>49,802</td>
</tr>
</tbody>
</table>

**Table 3. Shear modulus calculation**

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Equation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Soil</td>
<td>$= 0.397 (84,036)^{1.05}$</td>
<td>41,637 Mpa</td>
</tr>
<tr>
<td>RCA 5%</td>
<td>$= 0.397 (132,618)^{1.05}$</td>
<td>67,224 Mpa</td>
</tr>
<tr>
<td>RCA 10%</td>
<td>$= 0.397 (86,534)^{1.05}$</td>
<td>42,927 Mpa</td>
</tr>
<tr>
<td>RCA 15%</td>
<td>$= 0.397 (49,802)^{1.05}$</td>
<td>24,038 Mpa</td>
</tr>
</tbody>
</table>

*Source: Locat & Beauserjoux, 1987*

From the calculation in Table 4, it can be seen that the shear modulus (Gmax) value increases when RCA is added. The original land value, 41,637 MPa, increases to 67,224 MPa with the addition of 5% RCA. However, there was a significant decrease with the addition of more RCA. The increase in shear modulus is caused by the cement component in RCA, which has a lower specific gravity than ordinary soil so RCA can reduce the soil's lateral pressure.
RCA also forms a dense structure between soil particles, binding between particles and preventing relative movement, thereby increasing density and reducing soil porosity (Petcherdchoo et al., 2023). As a result, the soil has a higher shear strength / shear modulus than the original soil (He & Senetakis, 2016; Mohammadinia et al., 2019).

4. CONCLUSION

Adding 5% RCA increases the bearing capacity of the original soil by 168.07 kN/m² to 265.24 kN/m². The shear modulus of the soil increased from the original soil of 41.637 Mpa to 67.224 Mpa with 5% RCA mixing, and RCA can change its physical and mechanical properties. The presence of RCA increases soil density and load-bearing ability. Using RCA as an additive in soil mixtures has great potential to improve mechanical performance and soil stability. An increase in shear modulus indicates that the soil can withstand lateral shear forces, reducing the risk of soil settlement or structural failure. Thus, increasing the shear modulus of the soil after using RCA can improve the overall safety and reliability of the construction and reduce the possibility of future structural damage or failure. In addition, using RCA supports sustainable development principles by reusing existing materials rather than extracting limited natural resources.

REFERENCE


