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Mechanical Behaviour Slenderness Ratio of 13 Solid Wall Panels Under Uniformly Distributed Load

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ABSTRACT

Recently, there has been a lot of research in the concrete industry on a sustainable approach using concrete waste as a substitute for natural aggregates. The reason for this is that the quantities of construction and demolition waste generated today pose a significant threat to the environment but can be used as a useful concrete material in the construction industry. The aim of this study is therefore to investigate the mechanical behaviour of solid concrete wall panels containing recycled concrete aggregates as a partial substitute for natural fine aggregates. Mortar cubes and wall panels with dimensions of 50 mm x 50 mm x 50 mm and 1000 mm x 300 mm x 75 mm, respectively, were produced. The wall panels were made from a 1:4 concrete mix consisting of 50% recycled concrete and 5% perlite (to reduce the weight of the concrete, and improve its workability), and 1% superplastizer, while the control wall was made with 100% natural fines. The wall panels were subjected to a compression test under uniformly distributed load. The cube samples were tested at 28 days of age. Mortar cubes with RCA achieved the highest compressive strength of 16.27 MPa compared to the control sample. The control wall panel has a higher ultimate load of 147.51 kN compared to the sample that contains RCA and perlite, which has an ultimate load of 128.68 kN. By 2030, our country needs to achieve sustainable management and efficient use of natural resources. By recycling this solid waste through separating, cleaning and crushing the concrete waste into small particles so that it can be used as a building material to replace sand. This shows that recycled concrete aggregate can be a potential material for making wall panels.

Keywords: Mortar; Recycled concrete aggregate; Wall panel; Slenderness ratio; Perlite

INTRODUCTION

Wall panel is one of the important elements in the building, functions to support and dividing building components such as room, roofs, floors, and ceilings to provide shelter and security to home occupants. It can be classified as load bearing and non-load bearing wall panel. Many types of materials have been used in constructing wall panel such as concrete, metal, clay, and other composites. In Malaysia, traditionally wall panel for local houses are generally made by using clay brick or concrete block that is heavy and function only as separation or partition wall i.e., non-load bearing wall. Without load supporting functionality, the application of this wall has become impractical, as well as increase the loading imposed to beam, column and other supports, hence it will ultimately increase cost of construction.

Nowadays, the use of raw material to fabricate wall panel increase along with the population growth. Therefore, cost cutting based on selection of material is one of the significant concerns. This concern has shifted conventional materials usage towards alternative materials, primarily should be more cost-effective, innovative and human-environment friendly (Correia Lopes et al. 2018) to align with sustainable development concept (Klemun et al.

2022). To advocate this approach, this paper will emphasize the use of recycled materials to produce lightweight fabricated wall panel that adheres to with the required structure standard. While rapid development is inevitable, the construction and deconstruction of existing buildings has produced construction and demolition waste (C&DW) (Nawaz et al. 2022). Consequently, this led to problems in clearing, managing, and disposing waste generation, locally and globally, hence demands intermediate intervention (Bao, 2023). In fact, these C&DW can be reused as a recycled construction material as a new concept of engineering material footprint obtained from siliceous, limestone and lightweight concrete waste (C. Zhang et al. 2023). However, currently, the application of C&DW in construction still far behind due to very limited processing facilities (Abera, 2022), industries awareness and comprehensive research data.

One of the common materials that can be recycled is known as Recycled Concrete Aggregate (RCA) as coarse and natural fine aggregate (NFA) replacement (Cabral et al. 2010) and suggested the use of fine aggregate to increase strength of concrete. Natural Fine Aggregate (NFA) refers to natural sand that is commonly used as a component in concrete mixtures. Recycled Concrete Aggregate (RCA) is a type of material made by crushing and reprocessing old concrete into a new usable material. It can replace natural fine aggregates in various construction applications such as road base, structural fill, and new concrete. The utilization of RCA is not recent, it has been in research interest since 1990 (Hansen, 1990) with a huge number of publications have been published by researchers afterward. The research on the RCA as construction materials have focused more on load bearing applications in column (Knaack & Kurama, 2020), beam (González-Fonteboa & Martínez-Abella, 2007) and slab (H. Zhang et al. 2022) however less was conducted in non-load bearing wall panel applications. To add more economical and environmental approach, the suggestion was to combine RCA and perlite in formulation of concrete mix (Abed et al. 2022). The addition of perlite is common to reduce the density (Panagiotopoulou et al. 2022) likewise enhances the fire resistive (Lanzón et al. 2022).

Range of RCA in the formulation is suggested from 0 to 100% (Ouyang et al. 2023) however many findings suggest best comprehensive mechanical properties will be achieved when the replacement rate is between 40% to 50% (Mehari & Chen, 2022; Sajan et al. 2022; Zhu et al. 2022). Experimental result also suggests the partial replacement of perlite should no more than 15 % to avoid decrease in concrete strength up to 13% (Ragul et al. 2022) and particularly not more 25% to avoid risk of segregation (Hamidi et al. 2022). Overall performance of RCA has been reviewed comprising the analysis of fresh and hardened concrete on workability, air content, compressive strength, tensile and flexural strength, and compressive strength (Kim, 2022; Şimşek et al. 2022).

The compressive strength of the wall panels is a crucial factor in determining their load-carrying capacity. The study investigates the compressive strength of both the wall panel samples with RCA and perlite and the control samples made with only NFA. The deflection of the wall panels is also an important factor, as it affects the structural stability of the wall panels. Therefore, the study analyzes the deflection of the wall panels and compares it between the samples made with RCA and perlite and the control samples. Finally, the study examines the crack formation in the wall panels, as this can affect the overall durability and service life of the panels. The research compares the crack length between the wall panels made with RCA and perlite and the control samples.

In summary, the main point of this research is to investigate the mechanical behavior of wall panels made with RCA and perlite subjected to uniformly distributed loading, with a focus on compressive strength, deflection, and crack formation, and compare the performance of these panels with control samples made with only NFA. This paper will consider the application of RCA in fabricated wall panel by replacing the fine aggregate with the 50% RCA and 5% perlite. The test results obtained will form a better understanding of the fundamental behavior of the wall panel incorporating RCA and help promote the implementation of the RCA in construction industries. This study aims to assess the behavior of solid concrete wall panel incorporating recycled concrete aggregates and perlite as a partial replacement of natural fine aggregate

METHODOLOGY

MATERIALS

Figure 1 depicts the process flow of this study. The process began with the preparation of the materials, which included recycled concrete aggregate, natural fine aggregate, cement, perlite and superplastizer. This was followed by the preparation of samples for both mortar cubes and wall panels. The hardened mortar cubes and wall panels were then subjected to compressive strength under uniform distribution of load. Consequently, compressive strength, stress-strain, maximum load, deflection, crack propagation was determined. Finally, the effects of using recycled concrete aggregate and perlite in the production of mortar cubes and wall panels as partial fine aggregate replacement were investigated. The recycled concrete aggregate and perlite was utilized in place of some of the fine aggregate in the mortar mix as presented in Table 1. The percentage of the recycled concrete aggregate was based on the total natural fine aggregate volume. A constant water-cement ratio of 1.0 was used to produce the mortar containing the recycled concrete aggregate, perlite, and Portland cement.

TABLE 1. Designations and percentages of the recycled concrete aggregate and perlite in the mortar mix

Sample	Materials		
	Perlite (%)	Recycled concrete aggregate (%)	Natural fine aggregate (%)
RCA	5	50	45
Control	0	0	100

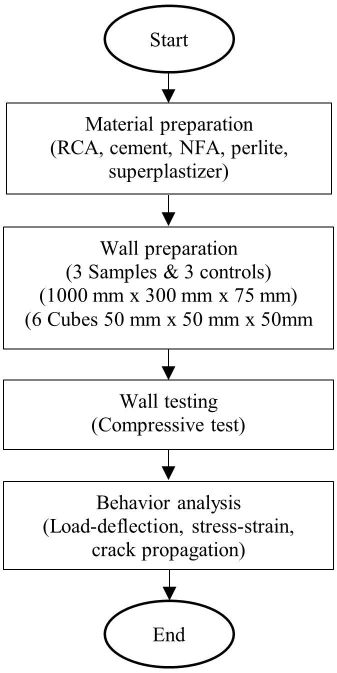


FIGURE 1. Process flow of the behaviour of the wall panel study

FIGURE 2. Process of the preparation of the recycled concrete aggregate

PREPARATION OF CUBES AND WALL PANELS

For the preparation of the mortar cubes and wall panels, the same proportion was used, as presented in Table 1. The sample designated as Control sample was prepared with a mortar mix design of 1: 4 for OPC: NFA. Meanwhile, for RCA samples, the mortar mix design was 1: 2 : 1.8 : 0.2 for mixture of cement : NFA : RCA: perlite. For each proportion, all the materials were mixed and cast. For the fresh mortar, the flowability test for each mix was conducted. For the RCA sample mixture, the water cement ratio of 1.0 were utilized. The mortar cubes were cured for 28 days. The curing process for the wall panels was carried out by covering the wall with thick gunny and watering it daily. Wall panels measuring 300 mm in width, 75 mm in thickness, and 1000 mm in height were cast vertically. They were supported by heavy duty clamps at the bottom of the wall to prevent movement. Figure 4 shows the size and location for LVDT and strain gauge of the prepared wall panels.

Linear vertical displacement transducers (LVDTs) were applied at selected locations, as shown in Figure 5. The LVDTs were applied to determine the deflection of the wall at these locations. Two LVDTs were located at mid-height of the wall and one LVDT was located at 250 mm from the top of the wall, as shown in Figure 5. A data acquisition system was used to store the data collected from the tests.

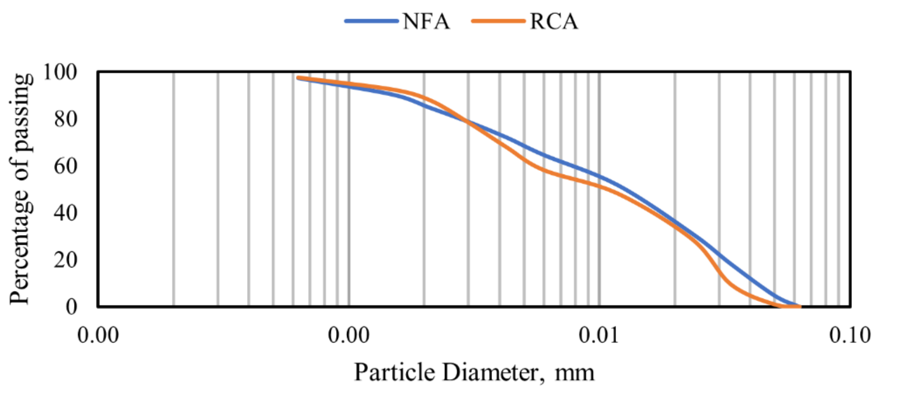


FIGURE 3. Sieve analysis of NFA and RCA aggregates

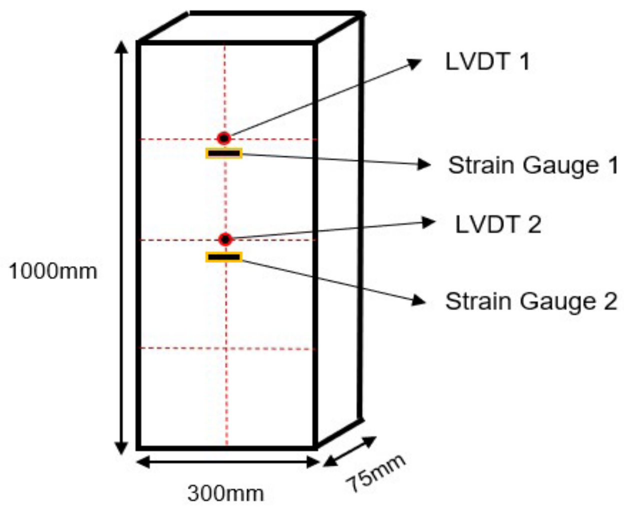


FIGURE 4. Size and location for LVDT and Strain gauge for the wall panel

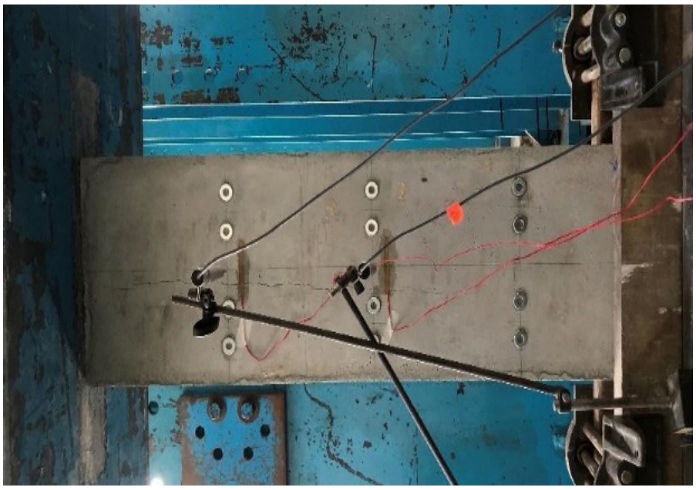


FIGURE 5. Test setup for the wall panel

ANALYSIS

All the data collected from the data acquisition system were analysed. The compressive strength of the cubes was determined at 28 days. The strength effectiveness of recycled concrete aggregate was determined as a partially fine aggregate in mortar. For the wall panels, the relationship between the load and the deflection was developed to identify the ultimate load of each wall panel. A series of tests were conducted to evaluate the effectiveness of using recycled concrete aggregate as a partial replacement for fine aggregate in the production of wall panels.

RESULTS AND DISCUSSION

FLOWABILITY OF THE FRESH MORTAR

The workability of the mortar was assessed using a flow table test, in accordance with ASTM C230 regulations. The flow value was measured using the flow table method. Workability is an important factor in concrete components as it can affect the process of mixing, moving, placing, compacting, and finishing, while minimizing the loss of homogeneity. From the result, the diameter for sample with RCA and additional of perlite is 140.3 mm meanwhile, the diameter for control sample which does not contain RCA and perlite is 162.3 cm with 15.6% difference. From Figure 6, the control sample has higher value than RCA sample. The workability of sample with RCA shows lower performance as compared to sample without RCA concurred with the finding from (Prasad Dash et al. 2022) with slump test result. This is due to the crushed angular shape of RCA and the higher water absorption rate. Furthermore, the incorporation of perlite has exhibited pozzolanic activity and promoted the early hydration process thus increase initial water cement ratio (Wang et al. 2021). Higher surface area and large number of pores in perlite structure increase absorption water content up to 300% (Jamei et al. 2011). The current finding that the sample with a 143 mm spread is within the range of most suitable fluidity and workability at the site is consistent with the suggestion from other studies, such as the study by Gündüz et al. (2007), which also found that a similar flow value was optimal for workability.

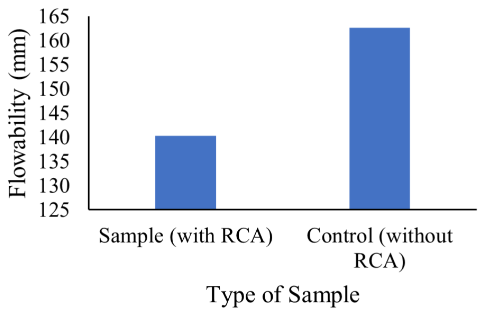


FIGURE 6. Flowability of the mortar

COMPRESSIVE STRENGTH OF MORTAR CUBE

The fresh cement mortar was prepared for a compression test using 50mm x 50mm x 50mm cube. After 28 days of water curing, the cubes were weighed and tested. Figure 7 shows the compressive strength of the mortar for three cube samples labeled as S1 (sample 1), S2 (sample 2), S3 (sample 3), and three control cubes labeled as C1 (control 1), C2 (control 2), and C3 (control 3). The samples with RCA have higher average compressive strength of 16.13 MPa as compared to control sample with 10.53 MPa. The compressive strength of RCA sample was in the range of 10 Mpa to 50 Mpa from several research findings (Etxeberria et al. 2007; Kazemi et al. 2019). In average, the difference shows incorporating RCA and perlite have increased the compressive strength by 53.2%. However, the amount of water in the mortar when it is set affects the compressive strength of the mortar. Control samples typically have a higher water content than samples containing recycled concrete aggregate, as they do not contain additives that can cause water loss during mixing or curing. However, the use of superplasticizer in samples with recycled concrete aggregate can reduce the amount of water loss, allowing them to achieve a water usage rate of 100% compared to the control samples. Lower compressive strength is the result of more water content. In terms of density, average density of RCA samples cube was 6.16 kg/m^3 while for control is 6.24 kg/m^3 with 1.3% difference and shows a small significant comparative density. This is due to characteristic of RCA that has higher volume fraction of low-density C-S-H as compared to natural aggregates (Akono, Chen, et al. 2021; Akono, Zhan, et al. 2021).

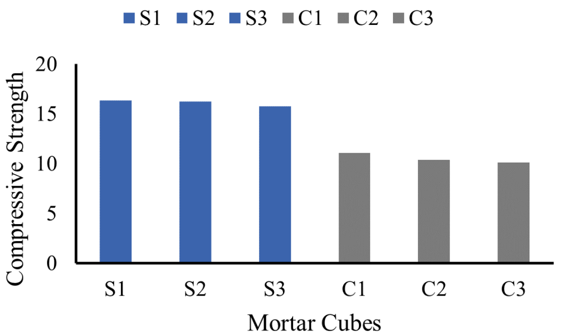


FIGURE 7. Compressive strength of the mortar

BEHAVIOR OF THE WALL PANEL SUBJECTED TO UNIFORMLY DISTRIBUTED LOAD

Figure 8 presents the relationship between load and deflection for the control sample and RCA sample of the wall panels. The result was obtained from the (Linear Variable Displacement Transducers) LVDT 1 which it is located 250mm from the top of the wall. In this testing, it can be analyzed that the deflection increased with the increment of the load.

The maximum deflection for the sample is 0.42 mm and the maximum deflection for control is 0.384 mm with percentage different of 8.57%. This shows that the wall that contain 50% of RCA can support high load with lesser deflection. As mentioned, the control sample have maximum load which is 147.51 kN then the sample wall load is 128.68 kN. Specimens failed with a brittle type of failure, unable to withstand any additional loading after reaching the maximum load. The connection for this testing setup was fixed at the bottom of wall. It will be one of the factors for the small deflection. The connection of the testing setup being fixed at the bottom of the wall can cause small deflection because the wall panel is not completely fixed at the top, allowing for some degree of movement or deformation. When a load is applied to the top of the panel, it can cause the panel to bend or deflect, and the connection at the bottom of the panel will resist this movement, resulting in a smaller overall deflection.

Figure 9 shows the load vs deflection graph for the LVDT point 2 at middle height of the wall which is 500 mm from the top of the wall height. For control wall, the maximum deflection was 2.402 mm and for the sample wall, the maximum deflection was 1.17 mm with percentage different of 51.3%. The ultimate load for the control wall is 147.51 kN and for sample wall is 128.68 kN. The deflection at mid span is higher than quarter of wall indicated wall major deflection and bending. Finding shows the solid wall exhibited better mid wall deflection compared to other sandwich wall such as (A. et al. 2022) with the maximum failure load of 17.97 kN and maximum mid-span deflection of 43.73 mm when incorporating EPS, while (Awan & Shaikh, 2021) recorded 9.75 mm deflection with maximum load of 1215 kN using recycled tyre-bale.

Figures 10 shows graph of stress vs strain from sample and control wall based on strain gauges located at surface of the wall, 170 mm from the top.

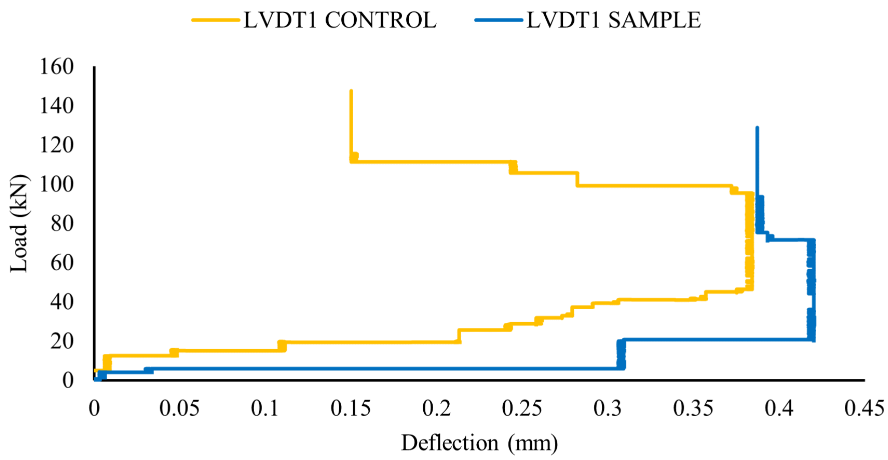


FIGURE 8. Load vs Deflection at ¼ height of wall

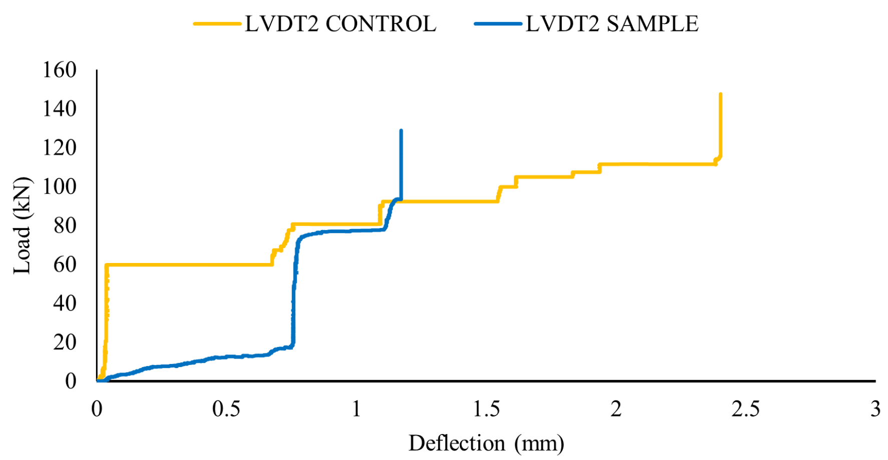


FIGURE 9. Load vs Deflection at Mid Span (500 mm)

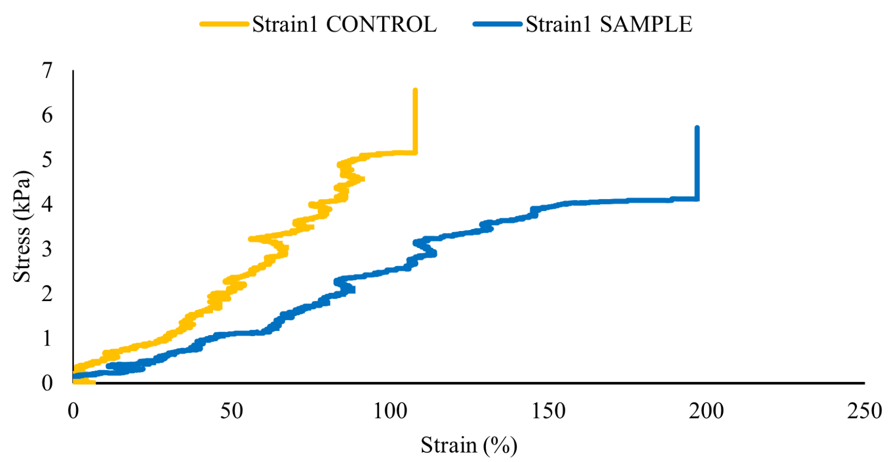


FIGURE 10. Stress vs Strain at 170 mm from the top of the wall panel

The maximum strain was on sample wall which is 197 µm/m and for control wall, the strain was 108 µm/m. It can be observed that the line initially linear and became non-linear at the end and registering large strains for small increases in stress. In tension, the stress-strain behavior supposedly should be like that in compression thus the relationship between the shear strain at failure and the effective stress is linear (Genov, 2020). Non-linearity was caused primarily by the coalescence of microcracks at the paste aggregate interface. This happened when the walls were subjected to applied load and then stress concentration occurs at the weak aggregate–cement paste interface, leading to the formation of microcracks (Chandra & Berntsson, 2002). The weak aggregate interface was mainly due to the RCA has gone through the rough preparation process. As comparison, the wall panel containing RCA and perlite was 45% strain decrement as compared to the control sample that only contain NFA. The maximum stress of the wall before failure was registered at 5.23kPa for the control wall, and 4.12kPa for the sample wall. After it reached ultimate stress, the structure will be in necking process and will fail at fracture point. This demonstrates that the wall panel with RCA has a lesser buckling effect in comparison to that of the wall panel without RCA, which has a greater tendency to deflect when the load is applied. The necking process refers to the reduction in cross-sectional area of the wall that occurs when it is subjected to a compressive force. This occurs as the wall begins to deform under the applied force, causing the cross-sectional area to decrease. As the deformation continues, the area of the material decreases even further until it reaches a minimum point known as the "neck." At this point, the material begins to experience a rapid increase in stress, leading to ultimate failure. It was observed that when the ultimate stress had been reached, large crack network within the wall surface, consisting of dense and compact microcracks and cracks in the cement paste matrix, were formed.

Figures 11 shows graph of stress vs strain from sample and control wall based on strain gauges located at surface of the wall, 520 mm from the top.

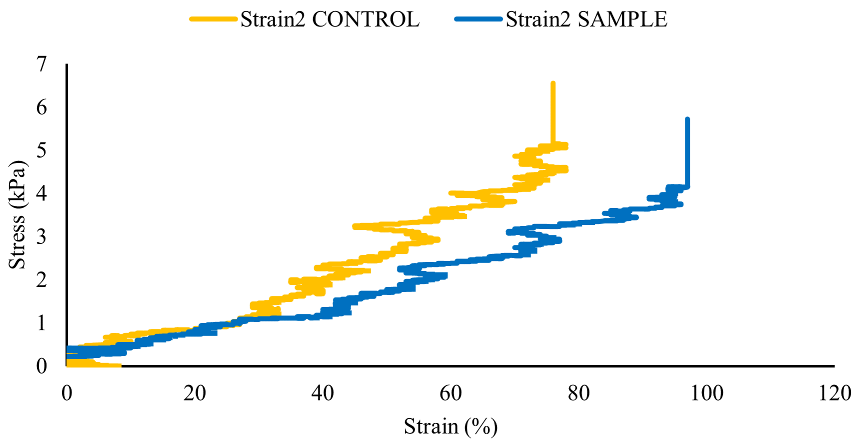
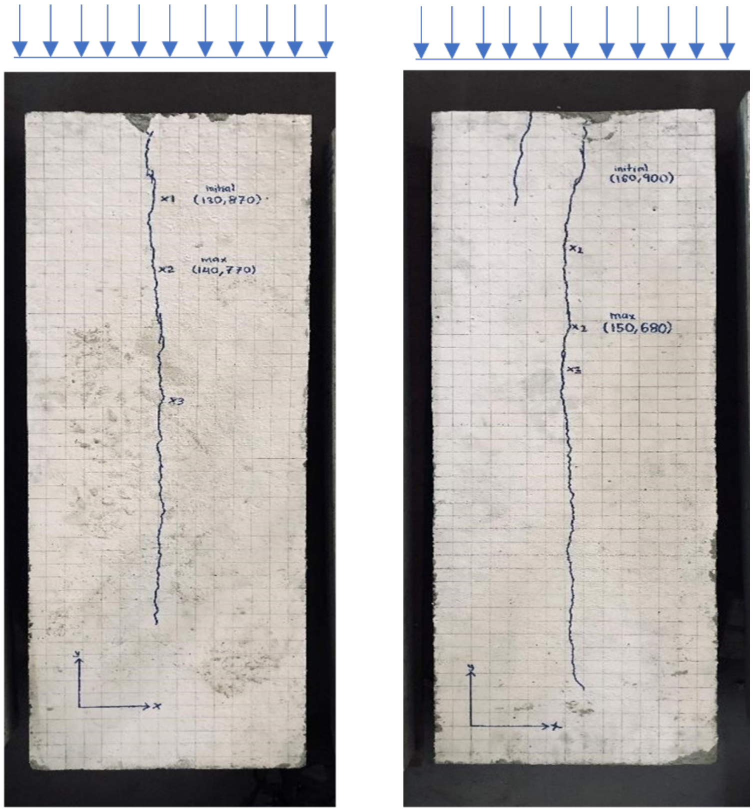


FIGURE. 11 Stress vs Strain at 520 mm from the top of the wall

This figure shows that at low stress, the concrete behavior begins to become nonlinear. The maximum strain for was in sample wall which is 97 µm/m and for control wall, the strain was 76 µm/m. The maximum stress before its failure was at 5.24 kPa for control wall, and 2.32 kPa for the sample wall. Considering the stress, RCA with a lower elastic modulus value as material in wall particularly slender wall, with a lightweight property normally tends to have a lower axial capacity (Rahman et al. 2021).

Figure 12 depicts the crack patterns observed on the faces of wall panels following the failure. The one-way action solid panel deflected vertically in a single curvature, with maximum deflection along center of the wall. The crack patterns were perpendicular to the loading direction and horizontal indicating bending failure. For the sample wall, the crack has start at coordinate (130,870) of the wall extended to the mid and lower part of the wall. The maximum width of crack was at (140,770) with the crack length of 76 mm. As comparison, the control wall began the crack at (160,900) with the maximum crack width at (150,680) with the crack length of 89 mm. The crack pattern on the RCA sample was found to be spread under the load, and the direction of the crack was vertical, perpendicular to the loading surface concurred with findings from Xie et al. 2022.

The crack patterns of panels on the tension face were vertical which is perpendicular to the direction of loading and failure occurred towards the center of wall panels (Guan et al. 2010). J. Zhang et al. 2022 found that the initial cracks grew wider and expanded obliquely towards the middle of the wall as the loading displacement increased



(a) (b)

FIGURE 12. Crack Pattern of the samples (a) wall panel containing perlite and RCA, (b) control wall panel

CONCLUSION

This article discusses the effects of employing recycled concrete aggregates and perlite as part of the fine aggregate replacement for the formation of wall panels. Considering the findings, it is possible to conclude that: i) The flowability for control sample which 22% higher than RCA sample that contain 50% of RCA and 5% of perlite. ii) The RCA sample mortar cubes represent the highest compressive strength, compared to the control samples with average value 16.13MPa. iii) The ultimate load for the control wall panel at 147.51kN, is higher than wall with RCA at 128.68 kN. iv) The smallest deflection is 0.42mm found to be with the panels with inclusion of RCA and perlite. v) Crack length of wall panels incorporating RCA and perlite is smaller than that control wall.

Based on the results presented in the study, the performance of the wall panel incorporating RCA and perlite was generally comparable or superior to that of the control wall panel made only with NFA. The use of RCA and perlite resulted in a mortar with higher compressive strength, smaller crack length, and reduced deflection under load. However, the control wall panel had a higher ultimate load capacity than the RCA panel. Overall, the findings suggest that the use of RCA and perlite could be a viable option for sustainable construction, with potential benefits in terms of material efficiency, waste reduction, and improved performance in certain aspects.

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DECLARATION OF COMPETING INTEREST

None

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