Jurnal Kejuruteraan 36(4) 2024: 1423–1435
https://doi.org/10.17576/jkukm-2024-36(4)-08

Analysing the Influence of Recycled Concrete Aggregate and Expanded Perlite on Mortar Performance

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Received 22 September 2023, Received in revised form 25 November 2023
Accepted 25 December 2023, Available online 30 July 2024

ABSTRACT

With population growth and rapid urbanisation leading to excessive waste generation in the construction sector and the scarcity of natural resources, such as natural fine aggregates, the demand for recycled alternatives has increased. In exploring the potential of recycled materials for construction materials, the present study investigated the performance of recycled concrete aggregate (RCA) and expanded perlite in mortar as a partial replacement for fine aggregates. Different percentages of RCA and expanded perlite were used. A consistent percentage of perlite was used: 0%, 10%, 15%, 20%, 25%, 30% and 35%. The RCA and expanded perlite were then mixed with other materials such as cement, water and fine aggregate. Flowability, compressive strength and flexural strength tests were carried out. It was found that a 90% replacement of RCA for each increasing percentage of perlite in the mortar mix resulted in a significant reduction in flow diameter. The compressive and flexural strength of the mortar increased with age. However, the flexural strength of the control mortar, which contained neither RCA nor perlite, consistently exceeded that of the mortar with these additives. The results provide valuable insights for the production of new materials in the construction industry, for waste management and for lightweight yet durable construction solutions.

Keywords: Recycled concrete aggregate; expand perlite; flexural strength; flowability; compressive strength

INTRODUCTION

In this fast-growing construction industry, many older building structures need to be demolished to make way for new upcoming buildings. This is important to cope with the ever-increasing population growth. As a result, natural resources are being devoured at an unsustainable rate, leading to the depletion of their sources. Natural aggregates are one of the natural resources that are in high demand but are said to be dwindling fast enough (Letelier et al. 2021). The decline of natural aggregates such as sand is of great concern as almost all construction projects, from infrastructure to building structure, use a high percentage of natural resources for on-site construction. This has become a sublimating part of our developing country. The high demand and the speed at which concrete buildings are being constructed have led to the question of how to conserve the natural resources of the mainland. Sand, which is a natural aggregate, can be used as part of concrete construction and especially in mortar.

Mortar is a mixture of sand, cement and water. Mortar is mainly used in the construction of buildings as it acts as a workable paste that then hardens to join civil structures such as column blocks. It is also used to fix bricks and stones, as well as to fill and seal uneven joints and add ornamental colours or patterns to a wall.

The increasing use of concrete and mortar leads to a greater demand for natural aggregates. Therefore, many researchers have been looking for a way out to address the huge shortage of natural aggregates by replacing natural aggregates with recycled concrete aggregates (RCA) in the mix to produce concrete and mortar. For instance, Ruslan et al. (2024) used RCA for the construction of wall panels. Jamaludin et al. (2024) and Jamaludin et al. (2023) have developed an innovative wall-to-wall connection made of RCA. Md Nor et al. (2023) used RCA for construction of interlocking concrete block. The reason of using RCA is that RCA can be converted into small-sized aggregates by crushing and breaking old building materials such as concrete cubes, concrete walls and other structures originally made of concrete containing cement, sand and stone (Zhao et al. 2015). In addition, RCA can help to replace natural aggregates in the use of in-situ concrete and mortar, which could counteract the shortage of natural aggregates. RCA can also help to reduce the amount of construction and demolition waste.

However, RCA is a material with a lower strength. This is due to the adherent residual mortar, which consists of hydrates and makes RCA porous and highly absorbent (Makul et al. 2021). To ensure that RCA can be used as a recycled material, expanded perlite can be used to form a lighter structure. Expanded perlite consists of silicate volcanic rock mixed with six per cent water. The size of perlite can be expanded to 15 times its original shape. You can use expanded perlite to make lightweight insulating concrete, plaster and wall insulation at low temperatures. Due to its low density, expanded perlite is excellent for the production of lightweight concrete and mortar and can also be used as a mineral additive due to its pozzolanic activity. Pozzolanic is a chemically reacting silicate material that reacts with slaked lime at normal temperature and with the inclusion of moisture, contributing to the formation of strong and slow-setting cement.

RCA and perlite clearly play a crucial role in the construction industry. Many structures are very heavy and difficult to assemble and erect. Therefore, a material such as perlite is needed to reduce the weight while ensuring good strength. Therefore, RCA and expanded perlite can be a great alternative to ensure sustainable construction and better utilisation of construction and demolition landfills. The present study therefore investigated the performance of RCA and perlite as partial substitutes for natural fine aggregates in mortar as sustainable building materials.

METHODOLOGY

MATERIALS

The mortar was made of RCA, expanded perlite, natural fine aggregate, cement and water in varying proportions. The maximum size of the RCA was 5 mm. The RCA was made from the concrete cube tests (Figure 1), which came from the construction and demolition waste and test cube facility, where they were used to replace the natural aggregates. In this study, the test cubes were manufactured by Macro Dimension Sdn. Bhd. with a specific strength of 20-25 MPa were collected. The percentage of RCA substitute used is shown in Table 1.

Expanded perlite aggregate was used as insulating and lightweight mortar material. Lightweight aggregates such as expanded perlite have been used in mortars to replace or combine with cement. Expanded perlite is a silicate-containing volcanic substance made from perlite rock that has been heated in kilns. When raw perlite rock is heated to 870 °C, it expands to 35 times its original volume, creating a large number of bubbles that are responsible for its exceptionally low density. Expanded perlite resembles a chemically inert white granulate (Figure 2). The percentages of perlite were 10%, 15%, 20%, 25%, 30% and 35% of the cement weight.

The natural fine aggregates used in this study were collected from the river with a maximum size of 5 mm. The natural fine aggregates were first kiln dried for 24 hours to remove moisture and water that could affect the weight and texture of the mortar according to ASTM C230 (2021). The cement was Portland cement (OPC), which is used as a binder to bind aggregates and other materials together. The water came from the tap and was clean.

All materials were mixed with natural fine aggregates, cement, recycled concrete aggregates and perlite. They were put into the drum mixer and mixed well. Water was then slowly added until the mortar mixture was thickened and well mixed. Each batch of the mixture yielded 3 cube samples and 3 prism samples. The size of the cube mould used was 50 mm x 50 mm x 50 mm, while the size of the prism mould was 40 mm x 40 mm x 160 mm.

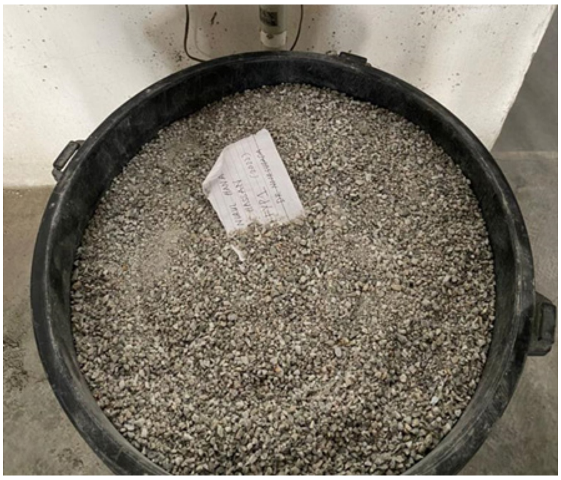

FIGURE 1. The RCA with the maximum size of 5 mm

FIGURE 2. The expanded perlite

DETERMINATION OF THE WORKABILITY OF THE FRESH MORTAR

The flowability test was carried out to determine the workability of the fresh mortar. The flowability test was conducted in accordance with ASTM C230 (2021). A layer of fresh mortar approximately 25 mm thick was placed in the mould and tamped down 20 times with a tamper. The tamping pressure must be just high enough to ensure uniform filling of the mould. The mould was filled with mortar for another layer and tamped down 20 times. The mortar was trimmed to a flat surface flush with the top of the mould by dragging the ruler of the trowel across the top of the mould in a sawing motion. The table top was wiped clean and dry to remove any water from the edge of the flow mould. The mould was lifted off 1 minute after the mixing process was completed. The table was immediately dropped 25 times in 15 seconds. The diameter of the mortar was measured with a tape measure.

COMPRESSIVE STRENGTH TEST

The compressive strength test was conducted to determine the compressive strength of the hardened cube specimen. The test was carried out following ASTM C109 (2020). A mortar layer of approximately 25 mm (half the depth of the mould) was placed in the mould in all cube chambers. The mortar was tamped down 32 times in each cube chamber in about 10 seconds. The remaining mortar was poured into the mould and tamped down another 32 times. The remaining mortar was smoothed with the spatula. After pouring, the specimen was kept in a humid room for 20 to 72 hours. Then the specimen was cured in a water tank for 3, 14, 28 and 54 days.

To test the compressive strength, a load was applied to the surface of the specimen on each day. The specimen was placed in the testing machine below the centre of the upper bearing block (Figure 3). The load was applied at a relative rate of movement between the top and bottom plates of 900 to 1800 N/s. A compressive load (typically from a hydraulic machine) was applied to the specimen until it failed. This loading sequence was allowed to last no longer than 80 seconds and no shorter than 20 seconds. The data were recorded.

TABLE 1. Percentages of the material used for production of mortar

Designation	RCA (%)	Natural fine aggregate (%)	Expanded perlite. (%)
Control	0%	100%	0%
0R0N10P	90%	0%	10%
0R90N10P	0%	90%	10%
50R40N10P	50%	40%	10%
85R0N15P	85%	0%	15%
0R85N15P	0%	85%	15%

continue ...

... cont.

50R35N15P	50%	35%	15%
80R0N20P	80%	0%	20%
0R80N20P	0%	80%	20%
50R30N20P	50%	30%	20%
75R0N25P	75%	0%	25%
0R75N25P	0%	75%	25%
50R25N25P	50%	25%	25%
70R0N30P	70%	0%	30%
0R70N30P	0%	70%	30%
50R20N30P	50%	20%	30%
65R0N35P	65%	0%	35%
0R65N35P	0%	65%	35%
50R15N35P	50%	15%	35%

FIGURE 3. Compressive strength test of cube

FLEXURAL STRENGTH TEST

The flexural strength test was performed by three-point loading, as shown in Figure 4. The test was performed for the age of the prism cured in water of 3, 14, 28 and 54 days. ASTM C348-21 (2021) was used to test the flexural strength of the 40 mm x 40 mm x 160 mm mortar prism.

FIGURE 4. Flexural strength test of the prism

RESULTS AND DISCUSSION

WORKABILITY OF THE FRESH MORTAR

The flowability was carried out to determine the workability of the fresh mortar. Figure 5 shows the flowability of the fresh mortar with different proportions of RCA, natural fine aggregates and expanded perlite. It is clear from Figure 5 that the flowability of the mortar decreases with the reduction of natural fine aggregate in the mortar mix. The results varied between 120 mm and 190 mm diameter.

It is expected that an increasing proportion of RCA and perlite in the mortar will lead to a reduction in the diameter of the mortar flow. It can be seen that a 90% replacement of RCA for each increasing percentage of perlite in the mortar mix results in a significant reduction in the diameter of the flow. The flowability of the mortar designated 90R0N10P reached the lowest value, 120 mm, which is probably due to the highest percentage of RCA. Mortar 0R90N10P has the highest flow value of 190 mm, which is due to the highest percentage of fine natural sand.

However, when RCA was partially replaced, as observed with mortar 50R40N10P, the flow diameter increased more than when 90% RCA was used. The control sample shows that the flowability of the fresh mortar obtained was 185 mm in diameter, which is within an acceptable range according to ASTM C1437 (2020). Saifuddin et al. (2011) found that RCA leads to a decrease in slump, which results in lower workability at a higher RCA content. More specifically, the irregular shape and rough surface of RCA can lead to grain jamming and resistance to movement in concrete and mortar (Hu et al. 2022). The main reason for this is the high water absorption of RCA, which leads to a significant loss of free water in the cementitious materials and a remarkable loss of settlement over time (Fan et al. 2020). They also found that the rough texture of the RCA particles increased the hardness of the mixture. It can be seen that RCA contributes to lower workability when a higher percentage was used but improves greatly when half the percentage of RCA was used. This is because RCA and perlite absorb more water in the mortar mix than when natural sand is used.

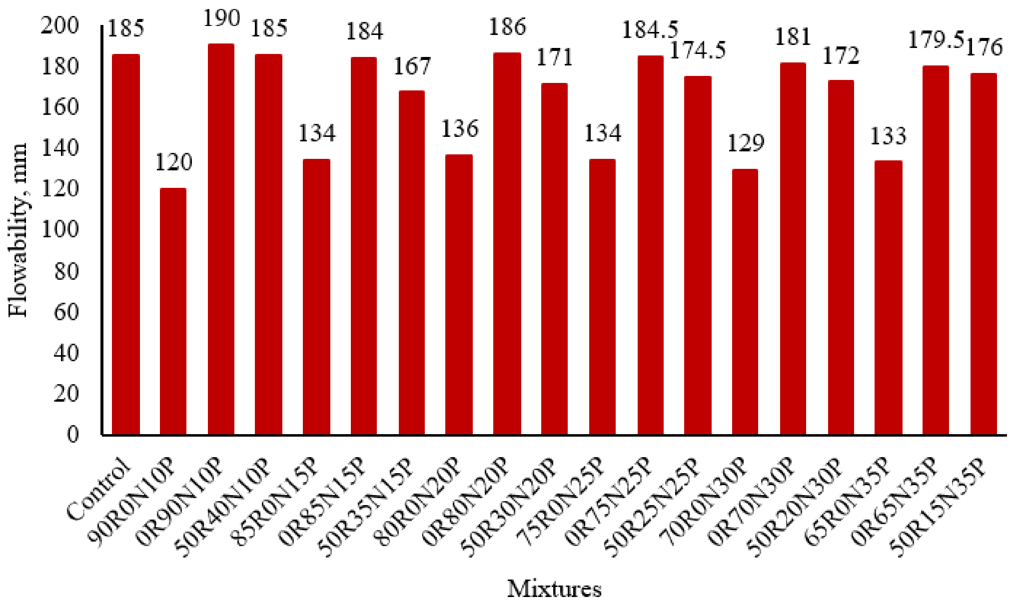

FIGURE 5. Workability of the fresh mortar containing various percentages of expanded perlite and RCA

COMPRESSIVE STRENGTH OF CUBES

The properties and quantity of RCA can have an influence on the compressive strength of RCA in mortar and concrete. The ratio of water to cement (w/c), the percentage of fine aggregate replaced by RCA and the amount of mortar adhering to the RCA are some of the variables that can affect the compressive strength of RCA mortar. Several cube mortar samples measuring 50 mm x 50 mm x 50 mm were cast and prepared for the specified curing time and tested for each sample. The results were evaluated after 3, 14, 28 and 54 days.

Figure 6 shows the compressive strength of mortar cubes with partial replacement of RCA at 0%, 50% and 90% and a constant percentage of perlite at 10%. The figure shows that the control mortar cube, which consists of 100% natural fine aggregates, has the highest compressive strength compared to the other mortar compositions with the value of 28.41 N/mm^2 and 30.31 N/mm^2 at 28 and 54 days, respectively. The compressive strength of mortar 90R0N10P shows the lowest strength compared to mortars 0R90N10P and 50R40N10P. 50R40N10P shows the highest compressive strength from day 3 but starts to decrease from day 28. The lowest strength for mortar 90R0N10P was 3.42 N/mm^2 and 4.16 N/mm^2 at 28 and 54 days, respectively. This could be due to the fact that the workability of the mortar was increased as in conventional mortar mixes. A higher water-cement ratio was used. The addition of water is quite necessary due to the high water absorption of RCA. The addition of water should lower the compressive strength.

Figure 7 shows the result of the compressive strength test of a partial replacement of RCA at 0%, 50% and 85% with a constant perlite content of 15%. The trend line for the 50R35N15P mortar containing 50% RCA shows an increase in compressive strength up to 28 days with a value of 6.81 N/mm^2. However, the strength decreases after 54 days with a value of 8.87 N/mm^2. With 15% perlite in the mortar volume, the highest strength was measured for mortar 0R85N15P, which contained no RCA in the mortar mix. The value increased continuously from day 3 to day 54, reaching a compressive strength of 10.08 N/mm^2. With increasing RCA content, the strength would decrease as RCA absorbs more cement paste compared to natural aggregates, leading to a reduction in the effective volume of cement paste available for hydration. This can lead to insufficient cement hydration and lower strength development of the mortar. In addition, the weak aggregate-cement paste interface of RCA leads to a reduction in the compressive strength of the mortar. This is because the weak aggregate surface is mainly due to the fact that the RCA has been coarsely prepared (Ruslan et al. 2024).

When the percentage of perlite in the mortar mix is increased to 20 %, a remarkable change in the compressive strength pattern can be observed. Figure 8 clearly shows that the mortar containing 50 % RCA together with 30 % natural aggregates and 20 % perlite has a higher compressive strength compared to the other mixes. From day 3 to day 54, the compressive strength of the 50R30N20P mortar increases significantly, reaching 12.15 N/mm^2 and 19.33 N/mm^2 respectively. This result indicates that the addition of perlite at a concentration of 20% increases the compressive strength of the mortar with a significant amount of RCA, possibly due to improved particle packing, lower density or other positive effects resulting from the addition of perlite to the mix. A similar pattern of higher compressive strength can be seen in Figure 9. There is a consistent trend towards higher compressive strength, particularly in the period from day 28 to day 54, after 25% perlite was added to the mortar mix. In particular, the mortar with 50 % RCA and 25 % perlite (50R25N25P) shows a significantly higher compressive strength compared to other mixes. After 54 days of curing, the compressive strength of the 50R25N25P mortar reached 18.45 N/mm^2, exceeding that of the other mixes. This observation indicates that the incorporation of 25 % perlite into the mortar composition contributes positively to its compressive strength, especially when a significant amount of RCA is used. Possible reasons for this improvement include improved packing efficiency, lower overall density or other beneficial effects resulting from the inclusion of perlite in the mix, leading to improved strength properties over time.

When 30% perlite is added to the mortar mix, there is a remarkable deviation from the observed trends, as can be seen in Figures 10 and 11. In particular, when no RCA is included in the mix, the compressive strength exceeds that of the other mixes. This result indicates that a higher concentration of perlite has a negative effect on the compressive strength of the mortar, especially in the absence of RCA. Several factors could contribute to this phenomenon. Firstly, a higher perlite content may disrupt the optimal particle packing within the mortar matrix, resulting in lower interlocking and cohesion, thus weakening the strength of the mortar. In addition, a higher perlite content can lead to greater porosity in the mortar, which can compromise its structural integrity and reduce compressive strength. In addition, too high a perlite content can hinder effective bonding between the cement paste and aggregates, which in turn contributes to lower strength. Overall, the negative effect of increased perlite content on compressive strength, particularly in the absence of RCA, emphasises the importance of carefully balancing the proportions of materials in mortar mixes to ensure the desired mechanical properties. This is supplemented by Demirboga et al. (2001) to the effect that the compressive strength value decreases with increasing proportion of expanded perlite due to the low strength of perlite and the increasing porosity of its structure. In addition, perlite is very susceptible to severe crushing under load (Jamei et al. 2011).

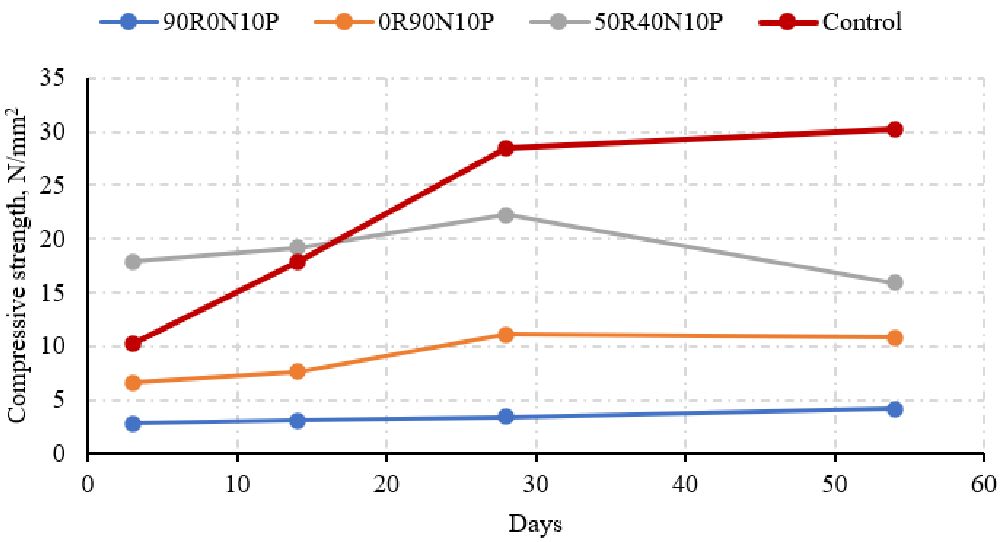

FIGURE 6. Compressive Strength for Mortar with partial replacement of RCA and constant percentage of Perlite at 10%

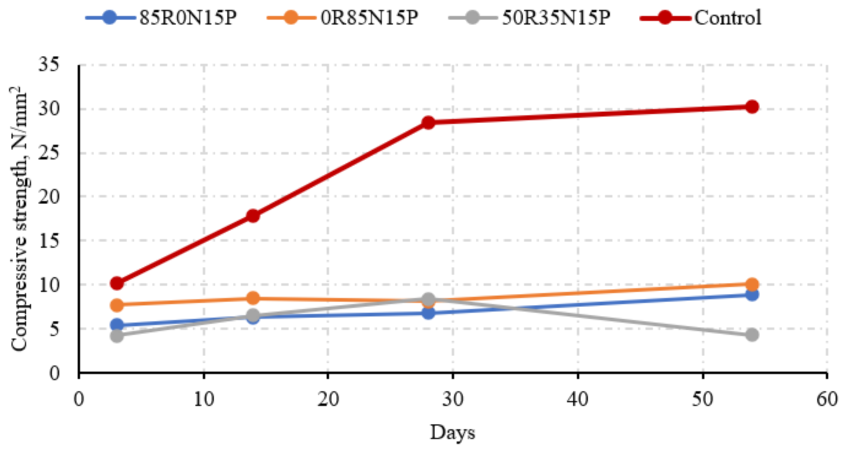

FIGURE 7. Compressive strength for mortar with partial replacement of RCA and constant percentage of perlite at 15%

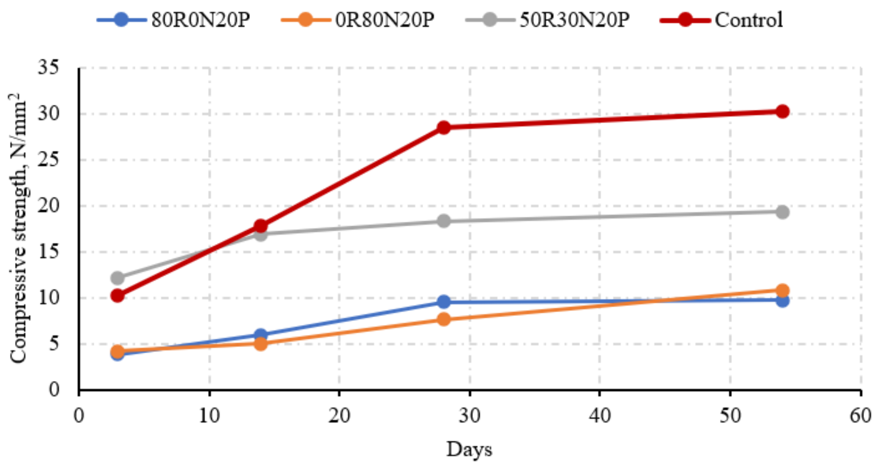

FIGURE 8. Compressive strength for mortar with partial replacement of RCA and constant percentage of perlite at 20%

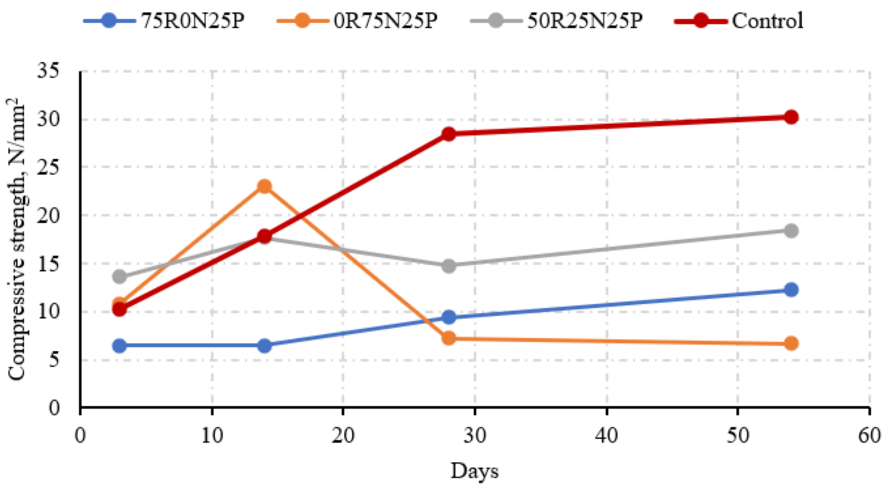

FIGURE 9. Compressive strength for mortar with partial replacement of RCA and constant percentage of perlite at 25%

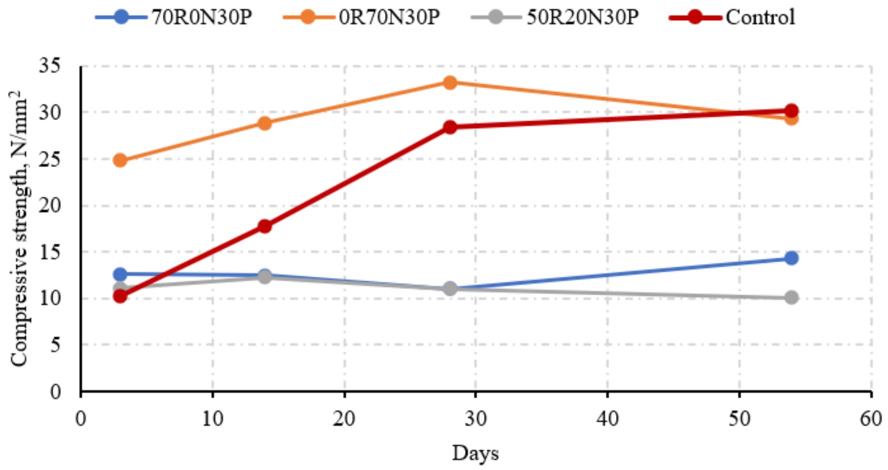

FIGURE 10. Compressive strength of mortar with partial replacement of RCA and constant percentage of perlite at 30%

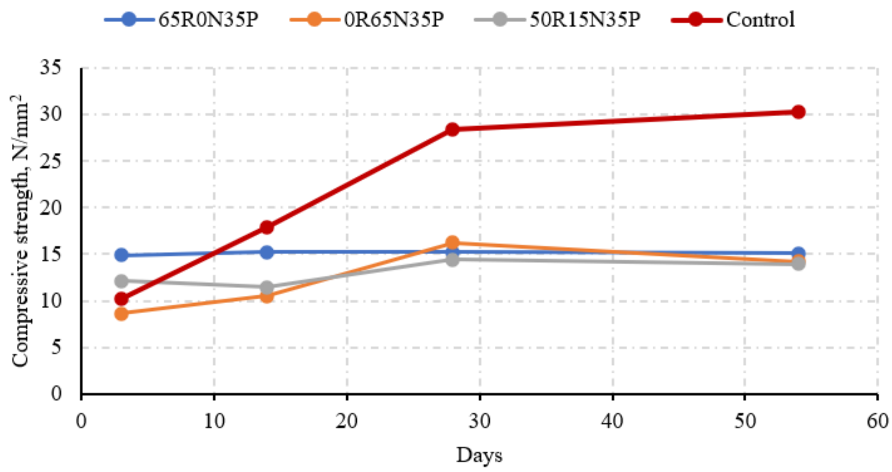

FIGURE 11. Compressive strength of mortar with partial replacement of RCA and constant percentage of perlite at 35%

FLEXURAL STRENGTH OF PRISMS

Figures 12 to 17 illustrate the variations in the flexural strength of mortars containing RCA, natural aggregates and perlite in certain proportions. A consistent trend in the graphs shows that the flexural strength of the control mortar without RCA and perlite tends to be higher than that of the mortars with these additives with the value of 4.93 N/mm^2 and 5.81 N/mm^2 at 28 and 54 days, respectively. Several factors contribute to this observation. Firstly, the absence of RCA in the control mortar potentially leads to a more uniform and compact structure, which allows for better load distribution and higher flexural strength. In contrast, the addition of RCA leads to irregularities in particle size, shape and surface texture, which can create weak points in the mortar matrix and thus compromise flexural strength. Furthermore, while perlite can help to reduce the density of the mortar, an excessive amount of perlite can lead to increased porosity and reduced interfacial bonding between constituents, thus reducing flexural strength. In addition, differences in the mechanical properties of RCA and perlite, such as their modulus of elasticity and tensile strength, compared to natural aggregates may also affect the overall flexural strength of the mortar. Overall, the observed trend underlines the importance of carefully selecting and proportioning the ingredients in mortar mixes to optimise flexural strength while taking into account the potential effects of additives such as RCA and perlite on the structural performance of the mortar.

The presence of RCA in mortar mixes can actually have a detrimental effect on flexural strength due to factors such as irregularities in particle size and shape and can lead to weak points in the mortar matrix. However, when 10 %, 15 % and 20 % perlite are added to the mix together with 50 % RCA and at the same time the proportion of natural aggregates is reduced (from 40 % to 30 %), a significant increase in flexural strength is observed. This phenomenon can be seen in Figures 12 to 14 for the mortar compositions designated 50R40N10P, 50R35N15P and 50R30N20P.

The increase in flexural strength due to the addition of perlite can be attributed to several factors. Firstly, perlite has a lower density compared to natural aggregates (Sengul et al. 2011), which helps to reduce the overall density of the mortar mix. This lower density can improve the workability of the mortar and reduce internal stresses, ultimately leading to improved flexural strength. In addition, the spherical shape and smooth surface texture of perlite can lead to better packing of particles in the mortar matrix, which improves structural integrity and resistance to flexural forces. In addition, perlite's ability to reduce the overall porosity of the mortar can improve interfacial bonding between constituents, further increasing flexural strength. Overall, the combination of RCA with perlite in certain proportions together with a reduction in the content of natural aggregates leads to a synergistic effect that increases the flexural strength of the mortar, as shown by the observed trends in Figures 12 to 14.

Considering at the age of the mortar, there is a significant trend in which the flexural strength of mortars with different proportions of RCA and expanded perlite increases steadily with the age of the mortar from 3 days to 54 days (Figures 12 to 17). This observation indicates that the mechanical properties of the mortar continue to improve over time, which is likely due to ongoing hydration processes and the development of microstructural bonds in the material. As the mortar ages, the cementitious matrix is further hydrated in certain samples, leading to the formation of additional hydration products and a denser microstructure. This densification leads to improved interfacial bonding between the aggregates and the cement paste, thereby increasing the mortar's resistance to bending forces. In addition, any internal voids or defects present in the mortar can be filled or sealed over time, further contributing to the improvement in flexural strength. The cumulative effect of these processes is reflected in the observed trend of increasing flexural strength with increasing age of the mortar. This emphasises the importance of considering the maturity of the material when assessing its mechanical performance. This trend emphasises the potential for continued development of the strength of mortars containing RCA and perlite, making them suitable for applications requiring long-term durability and structural integrity.

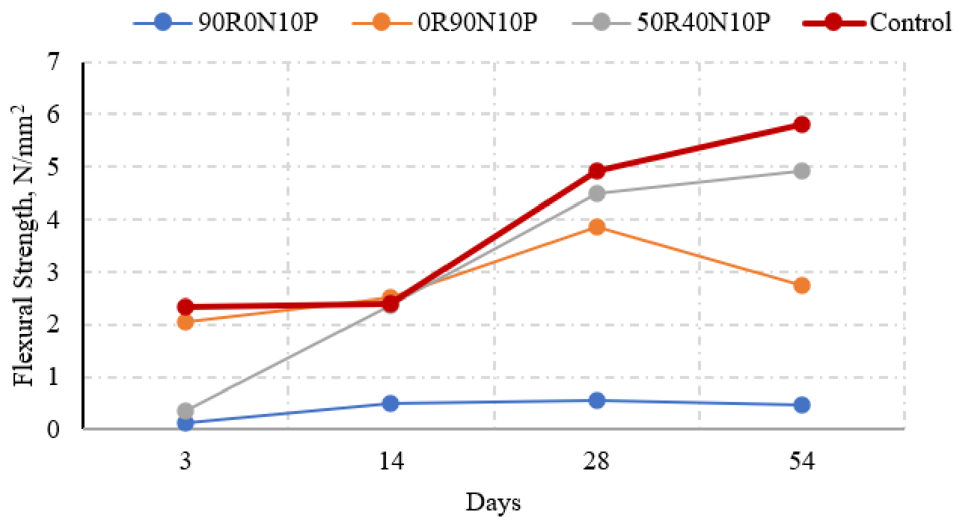

FIGURE 12. Flexural strength of mortar with partial replacement of RCA and constant percentage of perlite at 10%

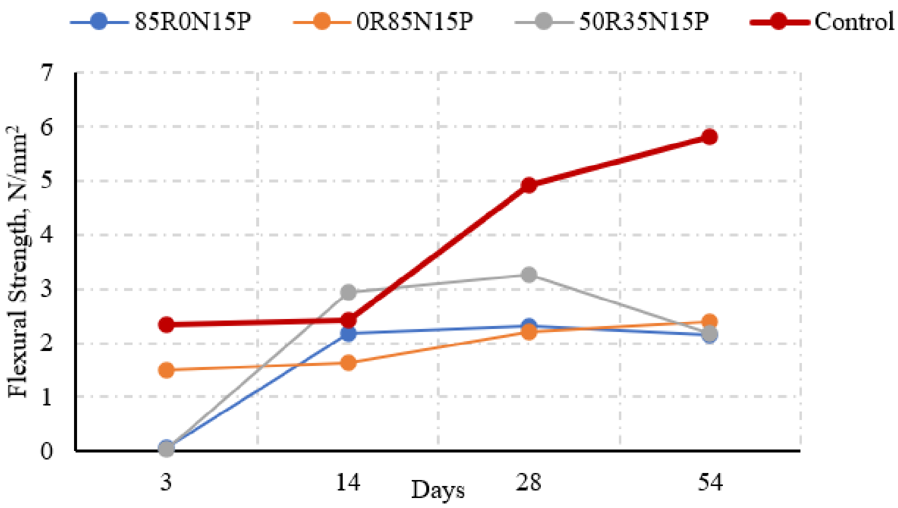

FIGURE 13. Flexural strength of mortar with partial replacement of RCA and constant percentage of perlite at 15%

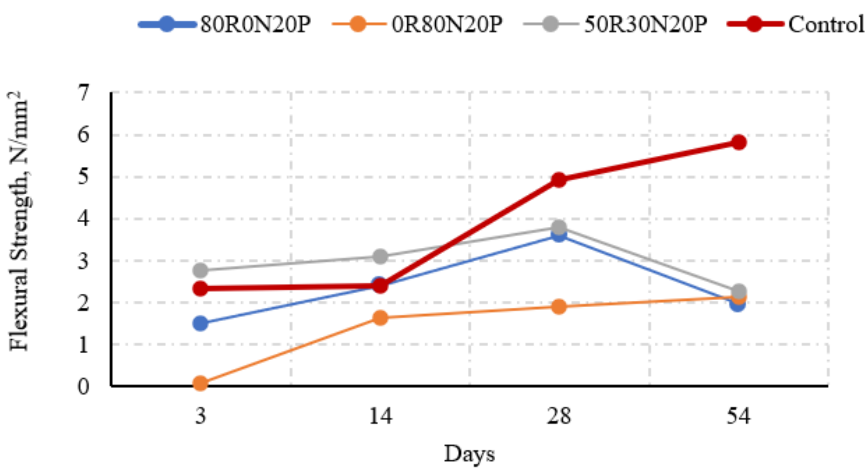

FIGURE 14. Flexural strength of mortar with partial replacement of RCA and constant percentage of perlite 20%

Overall, the highest flexural strength after 28 days when the mortar contains 50% RCA, 40% natural aggregates and 10% perlite is 4.49 N/mm^2 with the designation 50R40N10P. The highest flexural strength after 54 days is achieved if the mortar mixture contains 0% RCA, 65% natural aggregates and 35% expanded perlite (designation 0R65N35P) with the strength of 6.1 N/mm^2.

The observed variation in flexural strength between different mortar samples over time illustrates the complex interplay of factors that influence the mechanical properties of the material. While some mortar samples show an increase in strength between 3 and 28 days, indicating progressive hydration and development of structural integrity, others show a decrease in flexural strength when they reach an age of 54 days. In particular, certain mortar compositions such as 0R90N10P, 50R35N15P, 50R30N20P, 80R0N25P, 75R0N25P, 0R75N25P, 50R20N30P and 0R70N30P show a decrease in flexural strength with an increase in perlite content (Figures 12 to 17). For example 0R90N10P, the flexural strength fell from 3.87 to 2.75 N/mm^2 at 28 and 54 days respectively. The difference is approximately 33.87 %.

This result indicates that although perlite can initially contribute to an improvement in flexural strength, an excessive amount of perlite can have a detrimental effect on the mechanical properties of the mortar during prolonged curing. The addition of perlite, particularly at higher concentrations, can disrupt the optimal particle packing within the mortar matrix, resulting in increased porosity and reduced interfacial bonding between constituents. As a result, the mortar's resistance to flexural forces can be compromised, leading to a decrease in flexural strength over time. These results underline the importance of carefully controlling the proportion of perlite in mortar mixes to optimise mechanical performance and ensure long-term durability. Furthermore, they emphasise the need for further investigation into the optimum perlite content for specific mortar compositions in order to achieve the desired strength properties over different curing times.

The flexural strength of mortar depends not only on the percentage of perlite in the mortar, but also on the composition of the RCA in the mix. In Figure 13, for example, the flexural strength is lowest for mortar with 85% RCA (85R0N15P), followed by mortar 50R35N15P and the highest flexural strength for mortar 0R85N15P after 3 days. However, the flexural strength of mortar 50R35N15P increases from day 14 to 28 before decreasing again. This is due to the fact that the strong water absorption capacity of RCA and its comparatively weaker adhesive mortar in contrast to the new cement paste could be the reason for the decrease in flexural strength (Suman & Rajasekaran, 2016).

Figure 14 shows the flexural strength for mortar 80R0N20P, 50R30N20P, 0R80N20P and the control. The result shows that the flexural strength for mortar 50R30N20P reaches the highest value on day 3 to day 54, as can also be seen in Figure 15. Figure 15 shows that the mortar with 50% RCA has the highest flexural strength at day 3 and day 54. This is likely due to the fact that in combination with the new aggregates, the old adhering mortar is reduced, which may result in higher water absorption, lower density and crushing strength, and lower abrasion resistance, which in turn results in a decrease in flexural strength (Singh, 2021).

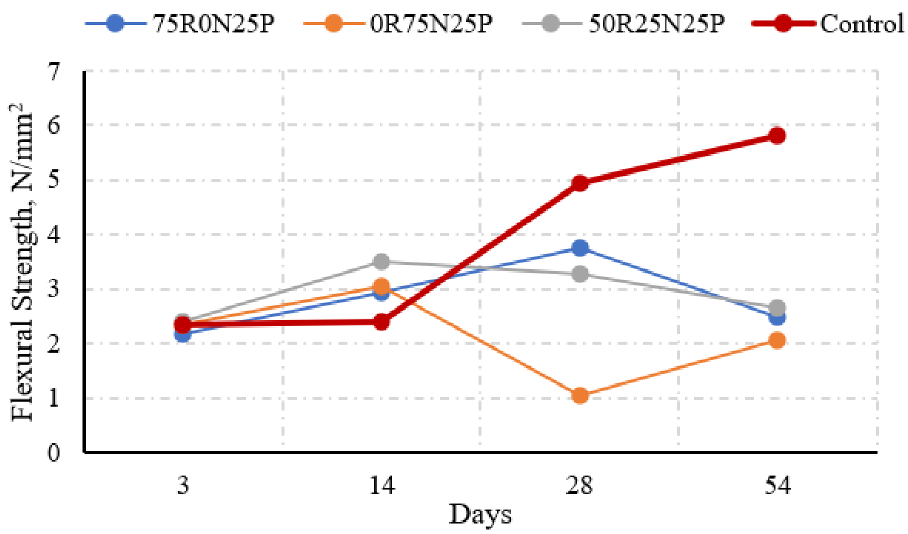

FIGURE 15. Flexural strength of mortar with partial replacement of RCA and constant percentage of perlite at 25%

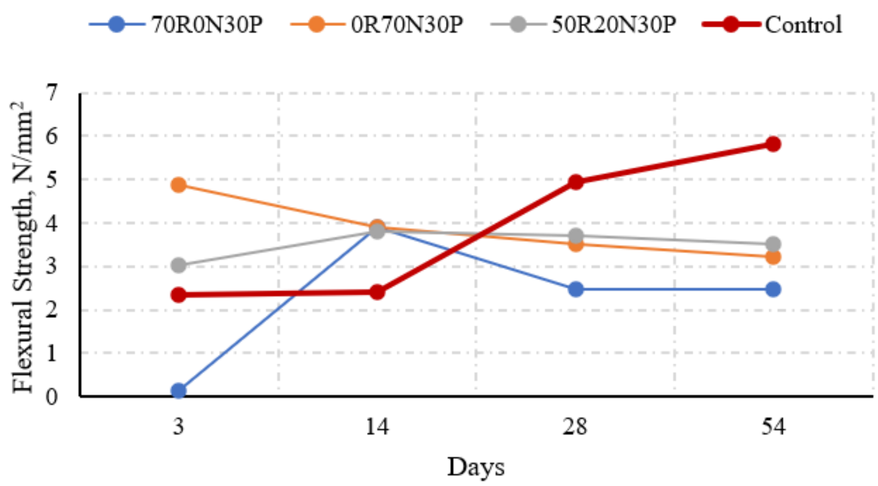

FIGURE 16. Flexural strength of mortar with partial replacement of RCA and constant percentage of perlite at 30%

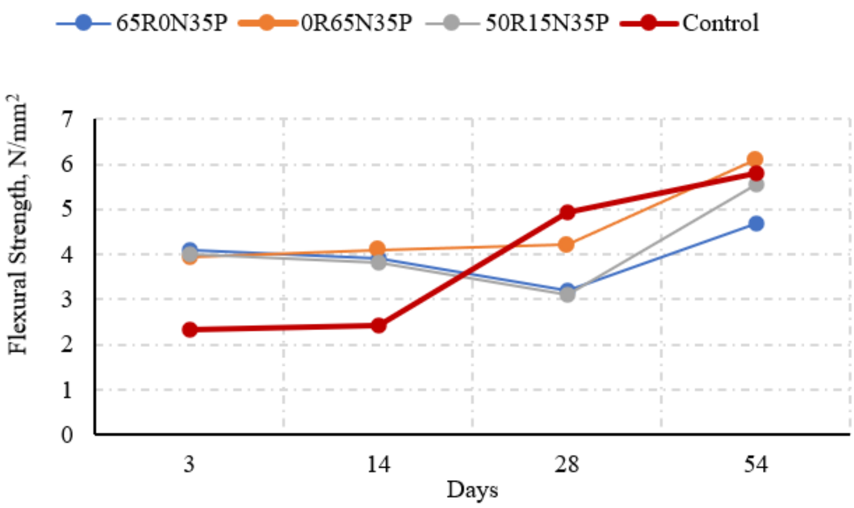

FIGURE 17. Flexural strength of mortar with partial replacement of RCA and constant percentage of perlite at 35%

Figure 16 and Figure 17 show that the strength of mortar with partial replacement of RCA decreases compared to mortar with only natural aggregates and perlite. This is probably due to the fact that in mortar 50R15N35P the proportion of expanded perlite increases and the proportion of natural aggregates decreases. The low density of the hardened mortar was undoubtedly influenced by the expanded perlite. When it is added to an aggregate, its flexural strength is reduced. In addition, the porous structure of expanded perlite contributes to its high water absorption capacity. The water absorption capacity increases as the volume of expanded perlite increases. The structure of expanded perlite is porous and its flexural strength is low.

CONCLUSIONS

From the analysing of the influence of RCA and expanded perlite as partial natural fine aggregate replacement on mortar performance, several conclusions can be addressed:

1. The use of RCA in the mortar mixture makes the mortar less workable. The higher the percentage of RCA, the lower the flowability of the mortar with the diameter of 120 to 190 mm. The mortar flow diameter is expected to decrease as the amount of RCA and perlite in the mortar increases. The flow diameter is significantly smaller when RCA is replaced by 90% for each additional percentage of perlite in the mortar mix. It is because it contained the most RCA, the mortar labelled 90R0N10P had the lowest value for flowability at 120 mm. However, the angular shape and rough texture of the RCA particles make the mix harder.
2. The compressive strength and flexural strength increased with increasing age of the mortar. However, the flexural strength of the control mortar without RCA and perlite tended to be higher than that of the mortar with these additives, with a value of 4.93 N/mm^2 and 5.81 N/mm^2 after 28 and 54 days respectively.
3. At the age of 54 days, mortars containing more than 50% RCA had lower compressive and flexural strength. It is because the RCA had lower strength than natural aggregate.
4. This result indicates that although perlite can initially improve the flexural strength, an excess of perlite can have a negative effect on the mechanical properties of the mortar over longer curing times.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknologi MARA, Cawangan Pulau Pinang (100-TNCPI/PRI 16/6/2 (022/2021) and Pusat Kecemerlangan Kejuruteraan dan Teknologi JKR (CREaTE) (Grant No. JAR 2001) for financially supporting this research. Special thanks to Ir. Dr Sherliza Zaini Sooria, Professor Dr Azmi Ibrahim, Ir Dr Sarina Ismail, Ir. Dr Thong Jia Wen, Fatma Sakinah Razali, Muhammad Afiq Tambichik, Nor Azlina Kasim, Noor Azlan Abdullah, Ir. Muhamad Yusri Zainal and Zainun Tamby.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

ASTM C109. 2020. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), ASTM International.

ASTM C1437-20. 2020. Standard Test Method for Flow of Hydraulic Cement Mortar, ASTM International.

ASTM C230 (2021) Standard Specification for Flow Table for Use in Tests of Hydraulic Cement, ASTM International.

ASTM C348-21 (2021) Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars, ASTM International

Demirboga, R., Orung, I., Gul, R. 2001. Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes. *Cement and Concrete Research* 31(11):1627-1632.

Fan, Y., Niu, H., & Zhang, X. 2020. Impact of the properties of old mortar on creep prediction model of recycled aggregate concrete. *Construction and Building Materials* 239: 117772.

Hu, J., Cavalline, T., Mamirov, M., Dey, A. 2022. ACI CRC 2019 P0027: Effective Characterization of Recycled Concrete Aggregate (RCA) for Concrete Applications, ACI Foundation.

Jamaludin, A.H., Md Nor, N., Ruslan, A.K., Mat Saliah, S.N., Abi Suhaimi, N.A.S., Md Hassan, A.S., Fauzi, M.A., & Razali, F.S. 2023. Structural performance evaluation of horizontally light reinforced dapped for vertical wall-to-wall connection of precast wall panel. *Jurnal Kejuruteraan* 35(6): 1455-1465

Jamaludin, A.H., Md Nor, N., Ruslan, A.K., Mat Saliah, S.N., Ahmad, N.A, Md Hassan, A.S., Fauzi, M.A., & Aziz, N.A. 2024 Structural performance evaluation of cross dapped connection for vertical wall to-wall connection of precast wall panel. *Jurnal Kejuruteraan* 36(1): 307-315.

Jamei, M., Skandaji, H.G., Chtourou, Y., & Kallel, A. 2011. Water retention properties of perlite as a material with crushable soft particles. *Engineering Geology* 122(3): 261-271

Letelier, V., Bustamante, M., Muñoz, P., Rivas, S., & Ortega, J. M. 2021. Evaluation of mortars with combined use of fine recycled aggregates and waste crumb rubber. Journal of Building Engineering, 43(March), 103226.

Makul N, Fediuk R, Amran M, Zeyad AM, Murali G, Vatin N, Klyuev S, Ozbakkaloglu T, Vasilev Y. 2021. Use of recycled concrete aggregates in production of green cement-based concrete composites: A review. *Crystals* 11(3): 232. https://doi.org/10.3390/cryst11030232

Md Nor, N., Setiawan A.F., Hamizah, N. E., Zaini, M.N., Mat Saliah, S.N., Md Nujid, M., Ismail, S.I. 2023. The behaviour of one-hollow interlocking concrete block made from recycled concrete aggregate under flexural loading. *Procedia Structurak Integrity* 47: 732-743.

Ruslan, A.K., Md Nor, N., Ramle, M.A., Jamaludin, A.H., Mat Saliah, S.N., Fauzi, M.A., Md Hassan, A.S., Tambichik, M.A., & Kasim, N.A. 2024. Mechanical behaviour slenderness ratio of 13 solid wall panels under uniformly distributed load. *Jurnal Kejuruteraan* 36(1): 09-19.

Safiuddin, M., Alengaram, U.J., Salam, M.A., Jumaat, M.Z., Jaafar, F.F., Saad, H. 2011. Properties of high-workability concrete with recycled concrete aggregate. *Journal of Materials Research* 14 (2).

Sengul, 0., Azizi, S., Karaosmanoglu, F., & Tasdemir, M.A. 2011. Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. *Energy and Buildings* 43 (2-3): 671-676.

Singh, G. 2021. Materials today: Proceedings. *Materials Today: Proceedings* 37: 2432–2438.https://doi.org/10.1016/j.matpr.2020.08.276

Suman, S. & Rajasekaran, C. 2016. Mechanical properties of recycled aggregate concrete produced with Portland Pozzolana Cement. Advances in concrete construction. 4. 27-35. 10.12989/acc.2016.4.1.027.

Zhao, Z., Remond, S., Damidot, D., & Xu, W. 2015. Influence of fine recycled concrete aggregates on the properties of mortars. *Construction and Building Materials* 81: 179–186. https://doi.org/10.1016/j.conbuildmat.2015.02.037.