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Reinforced Concrete Wall Panel Using Crushed Concrete Waste Aggregate (CCwA)

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Abstract

Steel fabric reinforced concrete wall panel is widely used in low and high rise building construction in Malaysia especially in Klang Valley. The system offers several advantages in construction such as shorter construction time and reduction on the dependency on unskilled foreign workers at construction site. This paper discussed the behaviour of reinforced concrete wall panel using crushed concrete waste aggregate (**CCwA**) as coarse aggregate. This research involved laboratory experimental work testing six (6) samples under static compression test. The samples were prepared using Grade 30 normal Ordinary Portland Cement (OPC) concrete with water cement ratio of 0.55, measuring 75 mm x 1000 mm x 500 mm (Thickness:Length:Height). The aspect ratio (H/L) and slenderness ratio (H/t) of the wall panel are 0.5 and 6.67 respectively. The samples were subjected static compression test with pined-fixed end conditions at upper and lower ends until failure. Result from experiments show that, all samples failed in compression shear with crushing at upper and lower ends edges of wall panels. The average ultimate load for single and double layer steel fabric reinforced concrete wall panel by using **CCwA** is 1349 kN and 1643 kN, respectively. The percentage different between the usage of **CCwA** and NA in wall panel in term of ultimate strength decreased by 5.5 % and 6.6 % for single layer and double layer of wall panels, respectively. A single curvature crushing crack pattern is dominant for all samples with average maximum lateral displacement for single and double layer of steel fabric reinforced concrete wall panel is 2.9 mm and 3.8 mm respectively, occurred at 375 mm (0.7H) wall height. The double layer steel fabric shows 24 % higher lateral displacement than single layer steel fabric sample. Its shows, double layer steel fabric give more ductility in term of prevention of cracking on wall panel. The structural behaviour of reinforced concrete wall panel using **CCwA** as a coarse aggregate is similar with wall panel using Natural Aggregate (NA) in terms of structural strength capacity, displacement profile, and mode of failure. The finding confirmed the performance of **CCwA** is as good as NA. This helps to reduce unnecessary wastages and also prevent depletion of natural resources.

Keywords
Reinforced Concrete Wall Panel, Steel Fabric, Crushed Concrete Waste Aggregate (**CCwA**), Crushing Failure

1. Introduction

Transformation of construction industry in Malaysia especially in building construction was increase drastically recently, where more low and high rise buildings were constructed. In 1999, Construction Industry Development Board (CIDB) launched IBS Strategic Plan to promote modern construction industry using Industrialised Building System (IBS). IBS was approved by Malaysian Government Cabinet in 2003 to realize the intention of CIDB for quality construction practices in Malaysia. The shift to IBS is to ensure high level of quality, productivity, safety and reduce the dependency on unskilled workers (CIDB, 2003). Since the IBS construction is expanding fast for low and high rise building, in Malaysia the production of precast concrete element such as precast beams, columns, slabs, walls, staircases, parapets and drains increased drastically. Currently, most of structural wall panel component system are made of precast component since these systems provide quality construction, save cost, create safer and cleaner working environment as well as reduce the dependence of foreign workers (IBS Digest, 2005). In conventional building construction method, wall is not popular as load-bearing wall element because all loadings from top of the building are directly transfer through the column to the foundation. Steel fabric reinforced concrete wall panel is commonly used as load bearing and infill wall. In this method, normal bar is substituted by steel fabric as this type of reinforcement produce fast installation and cost effective when compared to conventional wall system. The conventional infill wall using bricks and mortar in framed construction require longer time and man-power to install. The cost of the construction furthermore increases when compared to the usage of the precast wall panel. Recently, construction industry in Malaysia used steel fabric reinforced concrete wall panel to improve the construction technology which directly promotes IBS method in construction (Siti Hajar *et al*., 2008). Reinforced concrete wall panel offers efficient means of enclosing and wide space to building with thinner walls reduce the cost of building (Ruzitah and Siti Hawa, 2010). This research used crushed concrete waste aggregate (**CCwA**) as coarse aggregate replacing natural aggregate (NA) in concrete mix. In Malaysia, most of the construction waste industry especially reinforced concrete from old building is directly disposed to open landfill without undergoing any treatment or separation between concrete and reinforcement. Continuous industrial development produces serious problems of construction and demolition waste disposal (Akash *et al*., 2006). There is an increasing shortage of natural aggregates (NA) for production of new concrete for new structural construction project. The way to solve this problem is to reuse this concrete waste material as new aggregate in new construction (Khalaf *et al*., 2004). Reuse of concrete waste as recycled aggregate in new concrete is beneficial from the view point of environmental protection and resources reservation (Xiao *et al*., 2006).

2. Material and Methodology

In this section, the detail of **CCwA** reinforced concrete wall panel samples and the experimental set up are described.

2.1 Wall Panel Construction

The experimental work involved construction of six (6) samples of steel fabric reinforced concrete wall panel of size 75mm x 500mm x 1000 mm (Thickness:Height:Length) with aspect ratio (h/L) of 0.5 and slenderness ratio (h/t) of 6.67. The properties of the material used have been confirmed earlier before preparation of the wall sample by conducting cube and steel fabric strength tests. Figure 1 shows the process of preparing the wall panel. The structural behaviour of wall panel in term of ultimate strength load and mode of failure were determined. The wall panels were constructed using concrete Grade 30 by using Ordinary Portland Cement (OPC) and using Crushed Concrete Waste Aggregate (**CCwA**) as a coarse aggregate, totally replacing Natural Aggregate (NA) in concrete mix with water cement ratio of 0.55. The sizes of **CCwA** used were of 10 mm and 20 mm, similar to natural aggregate sizes and steel fabric type B385 (B7) with f_y of 485 N/mm^2 was used as reinforcement. The **CCwA** was crushed using jaw crusher and sieved into the desired sizes as according to the design mix. The detailing dimension of reinforced concrete wall panel is shown in Figure 2. This study was conducted with support condition considered as pinned at the upper end and fixed at the lower end. The wall panel was tested subjected to static compression test until wall panel failure at ultimate load.

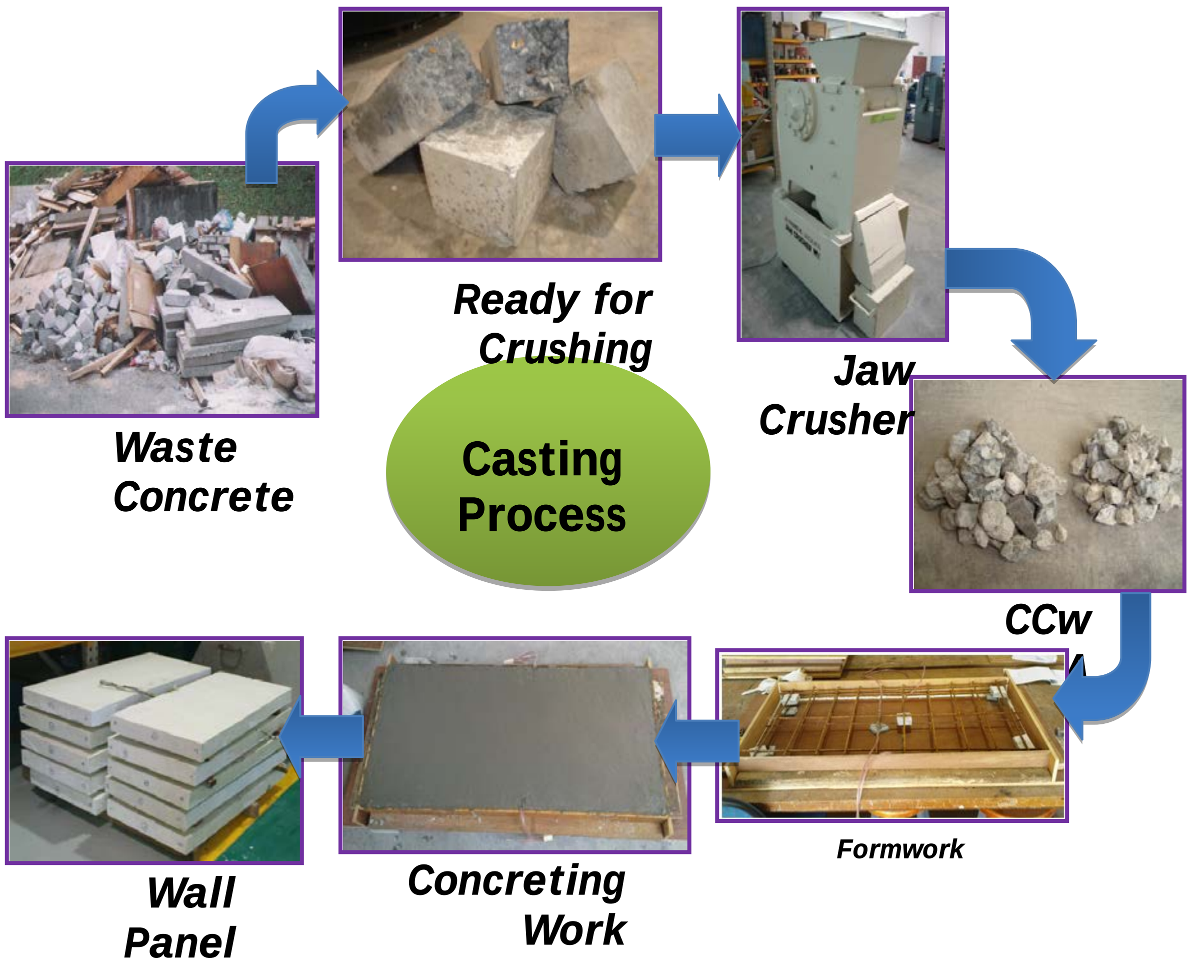
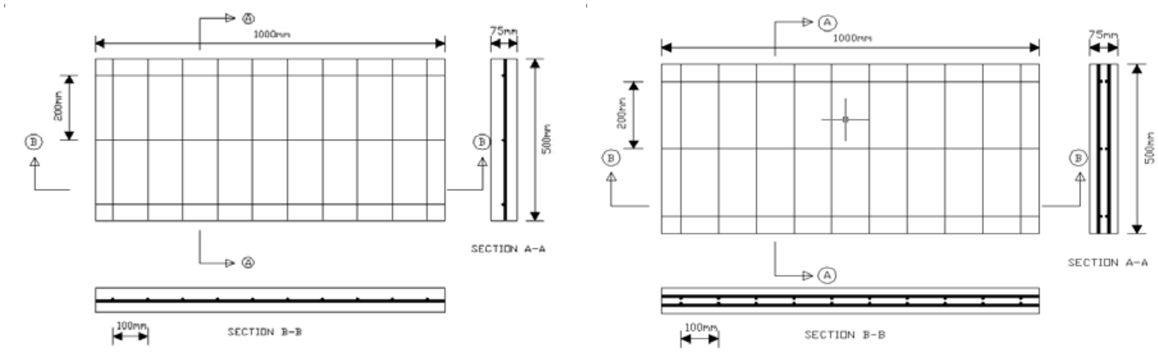


Figure 1: Casting of reinforced concrete wall panel



(a) Single layer steel fabric **(b) Double layer steel fabric**

Figure 2: Reinforced concrete wall panel detailing

2.2 Experimental Set-up

The testing of reinforced concrete wall panels was conducted in the Heavy Structure Laboratory, Faculty of Civil Engineering UiTM Shah Alam. Experimental work involved the testing of six (6) reinforced concrete wall panels. The test was conducted in the heavy structure laboratory set up to 2000 kN reaction frame of Universal Testing Machine. The load cell has a maximum capacity of 2000 kN capacity and were placed at the upper end of the samples. Hydraulic jacks are fixed to the main testing frame to allow the load to be transferred using hydraulic system.

The samples were tested to identify the behaviour of reinforced concrete wall panel under static compression test. The wall panel was placed vertically on C-channel, with the lower end support fixed accordingly in the centre of the reactions frame. The boundary condition is set to allow for rotation and to prevent the lateral deformation at the top of the wall, and to prevent both the rotation and lateral deformation at the lower part of the wall. The steel support was used to prevent the movement of reinforced concrete wall during the testing. U-Channel and rubber pad was used at the lower ends for purpose of fixing the wall panel. The steel base was fixed clamped to the strong floor. The load was applied until ultimate load, the displacement began to increase drastically, and then the test was stopped. The detail of the front view and side view of the experimental set-up for static compression testing are shown in Figure 3.

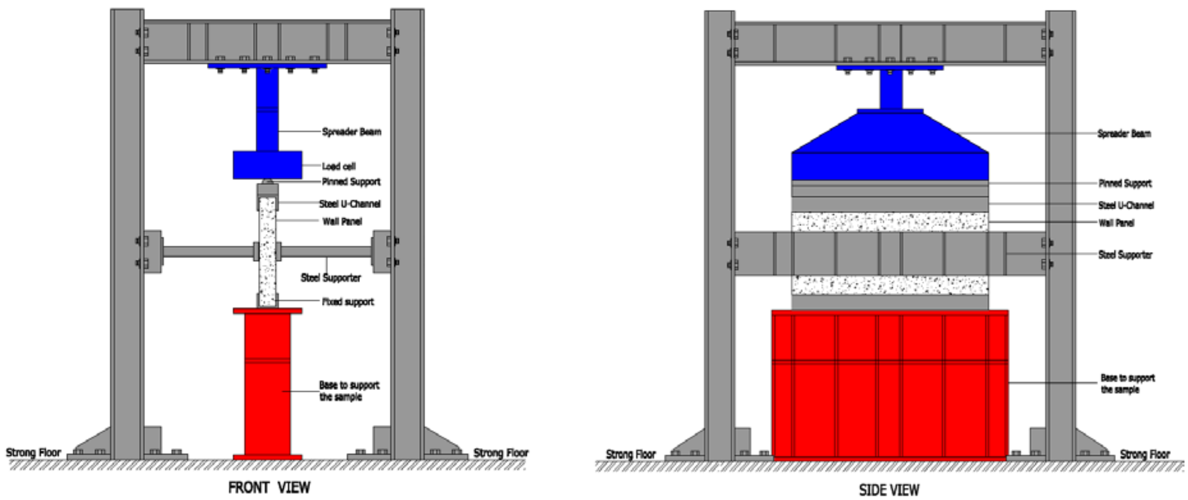
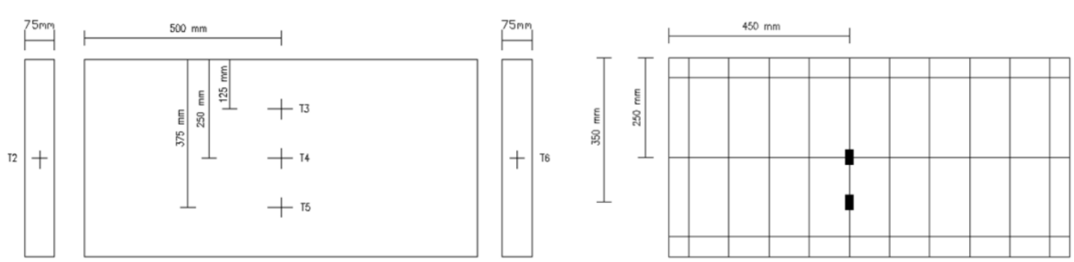


Figure 3: Experimental set up for static compression testing

Linear variable differential transducers (LVDT) were used to measure displacements, perpendicular to the height, and any small movement of the wall panels. They were placed at various locations on the front surface of wall panel as shown in Figure 4 (a). The magnitude of displacement was measured by using three (3) transducers (T3 – T5). The function of transducers 3, 4, and 5 is to measure the lateral profile of wall panel during testing and to monitor any twisting of wall panel. The load cell and the transducers were connected to a portable digital electronic data logger. In this experiment, four (4) strain gauges were placed on the steel fabric at the front and rear sides of wall panel, two (2) on each layer of the steel fabric whereas two (2) strain gauges were placed on the steel fabric for single layer steel fabric. Strain gauges were used to identify the strain in the steel fabric during testing. The position of strain gauges placed on the steel fabric of the wall panel, located at 0.5L and 0.7L at 250 mm and 375 mm of the height of the wall panel as shown in Figure 4 (b). Instruments should be installed properly before starting applying the load to the wall panel. The wall panel was loaded up until failure. At each load increment, mode of failure and displacement were recorded. The pattern of cracks was recorded and width and length of the crack were measured. The data from strain gauge and LVDT were record automatically by data logger which was connected to the computer. Every load increment, deflection or deformation has been recorded. Figure 5 shows final set-up for static compression testing.



(a) **(b)**

Figure 4: Arrangement of LVDT and Strain Gauge

Figure 5: Final set-up of wall panel

3. Result and Discussion

The result presented herein is according to ultimate strength, deflection profile, crack pattern, stress and strain relationship of wall panel under static compression test.

3.1 Compressive Behaviour

In compressive behaviour, the wall panels were tested under compressive load until the wall panels failed at ultimate load. From experimental result, the average ultimate load for SLAL (**CCwA**) and DLAL (**CCwA**) show higher value than the theoretical calculation of about 24% and 30% which is 1349 kN and 1644 kN respectively. From the result comparison, it shows that using double layer steel fabric give 18% more strength to wall panel compared with using single layer of steel fabric. On the other hand, the ultimate load from theoretical calculation for single and double layer steel fabric using NA is 1073 kN and 1197 kN respectively. However, the result for both samples from the experimental shows higher than theoretical calculation of about 25% and 32 % which is 1428 kN and 1760 kN respectively. From result analysis, the percentage of ultimate strength for single and double layer increase significantly. Table 1 shows detail of experimental result and theoretical calculation of wall panel.

Table 1 Experimental and theoretical result

Sample	Ultimate Load (kN) (Experimental)	Ultimate Load (kN) from BS 8110 (Theoretical)	Percentage Differences (%)	Displacement (mm)
SLAL (CCwA) 1	1380	1024	26%	4.30
SLAL (CCwA) 2	1318	1024	22%	1.48
DLAL (CCwA) 1	1598	1149	43%	4.20
DLAL (CCwA) 2	1689	1149	32%	3.30
SLAL (NA)	1428	1073	25%	8.00
DLAL (NA)	1760	1197	32%	6.80

Note: SLAL (CCwA) : Single Layer steel fabric with Axial Load by using Crushed Concrete Waste Aggregate
DLAL (CCwA) : Double Layer steel fabric with Axial Load by using Crushed Concrete Waste Aggregate
SLAL (NA) : Single Layer steel fabric with Axial Load by using Natural Aggregate
DLAL (NA) : Double Layer steel fabric with Axial Load by using Natural Aggregate

As such from this study, the single layer steel fabric wall panel using **CCwA** can be proposed as load bearing wall panel in building construction because of higher ultimate strength result. The comparison of ultimate strength for wall panel by using **CCwA** and NA shows the similar performance, support by Levy and Helene, (2004) in which the compressive strength of concrete made from recycled concrete aggregate with 20%, 50%, and 100% replacement could have equal fresh workability and also can obtained the compressive strength in range 20-40 MPa at 28 days.

3.2 Lateral Displacement Profile

The maximum lateral displacement for all reinforced concrete wall panels occurs at 0.7H of total height of wall panel which is 375 mm from the upper edge with single curvature pattern. It is supported by Suhelmiey *et al*., (2011), in which wall panel under load action without eccentricity load top and bottom of wall deflected with single curvature.

The average maximum lateral displacement for SLAL (**CCwA**) and DLAL (**CCwA**) is 2.90 mm and 3.75 mm, which is 28% and 6% lower than theoretical calculation. However, the maximum lateral displacement for control sample SLAL (NA) and DLAL ((NA) is 7.95 mm and 6.80 mm, which is 50% and 41% respectively higher than theoretical calculation. Figure 6 shows the lateral displacement profile of wall panel. The results show that the maximum lateral displacement for samples with NA is higher than samples with **CCwA** as a coarse aggregate. Therefore, reinforced concrete wall panel more ductility when using NA compared with CCwA in term of lateral displacement. From comparison between single and double layer in term of lateral displacement, the double layer shows higher lateral displacement compared with single layer steel fabric about 23 %. Based on the results, the double layer steel fabric can support the higher load and can be considered good to reduce the propagation of cracks before the structure wall panel failed compared to single layer steel fabric. But from the percentage increase value, the double layer did not prevail higher ultimate load and SLAL could be considered good enough as reinforced concrete wall panel according to British Standard because it reported allowable displacement.

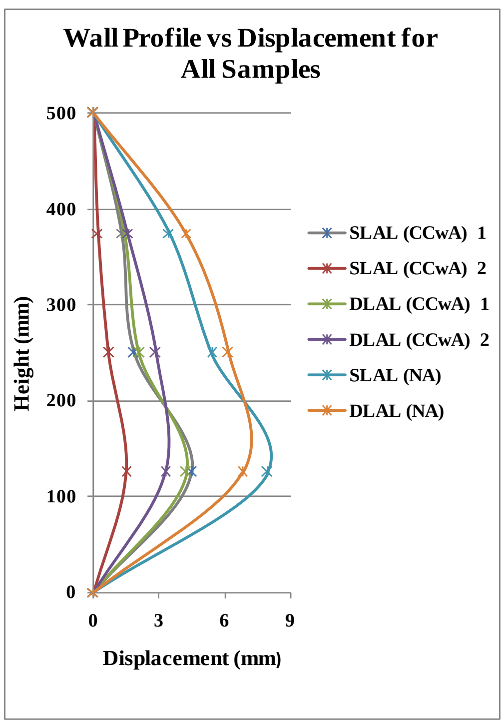


Figure 6: Lateral Displacement profile for all sample

3.3 Crack Pattern

Based on observation during experiment, most of the crushing cracks happened on samples which used single layer steel fabric especially at the top and bottom locations of the wall panel. Experimental results from Ruzitah *et al.*, (2010) also reported that, the wall panel crushed at the base because of the proper load distribution happened within the concrete matrix; it also showed that compression failure at the lower end of wall panel without any major crack on the surface of wall panel except for the SLAL (**CCwA**) which failed totally. Based on graph displacement profile at maximum point T5 above, for single layer samples crack, was initiated at $P_{50\%}$ load and totally failed at P_{ult}. But for the double layer samples, it was difficult to see the crack pattern at $P_{50\%}$ load until major crack occurred at P_{ult} when the samples totally failed. The observation is supported by the graph in Figure 10, the load increased linearly with displacement until failure at ultimate load. Table 2 shows the detail descriptions and location of crushing crack for each sample at ultimate load. According to BS 8110: Part 1: 1997 in clause 3.9.3.5 arrangement of reinforcement for reinforced walls in tension which states that, in any part of reinforced wall where tension occurs under ultimate load, the reinforcement must be arranged in two layer and every layers must be in accordance with the bar spacing requirement. The observation supported the clause in BS 8110 that double layer of steel fabric gave more prevention of cracking to wall panel. Using **CCwA** as a coarse aggregate did not affect the behaviour of reinforced concrete wall panel in term of cracking pattern. Result from experiment shows the similarity in term of cracking by using **CCwA** as a coarse aggregate replacing the NA in concrete mix. Figure 7 shows the typical failure on reinforced concrete wall panel.

Table 2: Description and location of crack at P_{ult} for all samples

Sample	Crack Location	Side Crack	Surface Crack
SLAL (CCwA) 1	Crushed at upper and lower of the wall	Crack at the top wall panel	None
SLAL (CCwA) 2	Crack at bottom of wall panel	Crack on left edge at the bottom wall panel	Crack on front surface at the bottom wall panel
DLAL (CCwA) 1	Crushed at upper and lower of the wall	None	None
DLAL (CCwA) 2	Crushed at upper and lower of the wall	Crushed at left and right side edge wall panel	None
SLAL (NA)	Crushed at upper and lower of the wall	Crack on both side at the top	Crack on front and rear surface at the middle of wall panel
DLAL (NA)	Crushed at upper and lower of the wall	None	None

(a) Front of wall panel

(b) Rear of wall panel

(g) Surface crack on wall panel

(c) Surface failure at the top wall panel

(d) Crushing and crack at the top of wall panel

(h) Crushing failure at the bottom of wall panel

Figure 7: Typical failure on reinforced concrete wall panel

3.4 Stress-Strain Relationship

The stress-strain of longitudinal bars is directly proportional with respect to the increasing load that was applied on the surface of wall panel (Ruzitah and Siti Hawa, 2010). Figure 12 shows the graph of stress versus strain for all wall panel samples. From the graph profile the strain of steel fabric is found directly proportional with the stress. Maximum compressive stress was recorded by DLAL (**CCwA**) with 23464 kN/m^2, however the lowest stress was recorded by SLAL (**CCwA**) 2 with 17575 kN/m^2. This situation was expected because the double layer of steel fabric gives more strength to the wall panel. The average maximum compressive stress for SLAL (**CCwA**) is 18041 kN/m^2. Therefore, the percentage of average maximum compressive stress between experimental and theoretical calculations for single layer steel fabric wall panel using **CCwA** is 24% higher than theoretical calculations. On the other hand, the average maximum compressive stress for DLAL (**CCwA**) is 21915 kN/m^2, but the theoretical calculation shows a 30% lower value than experimental result. Table 3 shows the detail of the stress-strain measurements of steel fabric. From experimental result that is shown in the table, the sample with **CCwA** as a coarse aggregate gives lower compressive stress of about 5.3% for single layer and 6.6% for double layer respectively of the wall panel compared with NA. These shows, NA as coarse aggregate gives more strength to the wall panel. Replacement of 50% and 75% of RCA shows an increased in strength compared with 25 % and 100% replacement of aggregate, replacement 100% of RCA in concrete mix could reduce the strength of concrete by 7.2 % for 7 days and 8% for 28 days (Ahmad *et al*.,2009). In the concrete construction the RCA has similar performance with natural aggregate (Limbachiya *et al*., 2004). The strain gauge result shows the maximum of strain for steel fabric occurs at location 0.7H which is 375 mm from the top of wall panel. All strain gauge were install at steel fabric reinforcement shows increase linearly with respect to the applied load on the top surface of wall panel. The maximum strain was recorded is 5.536 μm for sample SLAL (**CCwA**) 2, it happened because the sample was totally failed at ultimate load with cracking at the bottom of the wall panel at location where strain gauges were installed. During observation also, the cracking of wall panel initiated when the steel fabric started to bend during the loading on the top of the wall panel and automatically cause the samples to fail.

Table 3: The detail of the stress-strain measurement of steel fabric

Sample	Maximum Stress (kN/m^2) (Experimental)	Maximum Stress (kN/m^2) (Theoretical)	Strain Longitudinal Steel Fabric (μm)	Failure Mode	Remark
SLAL (CCwA) 1	18507	13661	L_{250} = 1.449 L_{350} = 2.128	Crushing at upper and lower	Maximum strain occur at ¾ of wall height
SLAL (CCwA) 2	17575	13661	L_{250} = 1.417 L_{350} = 5.536	Crack at the base of wall panel	Maximum strain occur at ¾ of wall height
DLAL (CCwA) 1	21303	15313	L_{F250} = 0.708 L_{R250} = None L_{F350} = 0.796 L_{R350} = 0.750	Crushing at upper and lower	Maximum strain occur at ¾ of wall height
DLAL (CCwA) 2	22526	15313	L_{F250} = 1.153 L_{R250} = 0.800 L_{F350} = 1.980 L_{R350} = 0.262	Crushing at upper and lower	Maximum strain occur at ¾ of wall height
SLAL (NA)	19046	14301	L_{250} = 0.166 L_{350} = 0.114	Crack at the top and base of wall panel	Maximum strain occur at the middle of wall height
DLAL (NA)	23464	15954	L_{F250} = 0.350 L_{R250} = 0.428 L_{F350} = 0.505 L_{R350} = 0.353	Crushing at upper and lower	Maximum strain occur at ¾ of wall height

4. Conclusion

The average ultimate loads for SLAL (**CCwA**) and DLAL (**CCwA**) under compression load test were found to be 1349 kN and 1643 kN respectively. The percentage comparison of average ultimate strength from experimental shows 24% and 30% higher than theoretical calculation. The result of ultimate load for SLAL (NA) and DLAL (NA) shows 6% and 8% higher values compared with sample using **CCwA**. Most of the major cracking occurs on sample with single layer steel fabric. Maximum deflection for all samples occurs at the same place and location which is 375 mm (0.7H) from the total height of the wall panel. The displacement for wall panel using **CCwA** was recorded to range from 4.31 mm to 1.48 mm. The percentage of average maximum compressive stress between experimental and theoretical calculations for single and double layer steel fabric wall panel using **CCwA** are 24% and 30% higher than theoretical calculations. During analysis, the sample using **CCwA** as a coarse aggregate gives higher stress of about 2.8% for single layer and 6.6% for double layer steel fabric respectively compared with samples using NA as a coarse aggregate. The average maximum compressive stress for SLAL (**CCwA**) and DLAL (**CCwA**) is 18041 kN/m^2 and 21914 kN/m^2 respectively. From experimental result, the samples with **CCwA** as a coarse aggregate shows the lower stress about 5% and 7% for single and double layer steel fabric compared with NA. The experimental results show that, the wall panel using **CCwA** show similar structural behaviour in term of ultimate load, displacement profile, and mode of failure. Based on the result, the reinforced concrete wall panel can sustain higher loading without remarkable failure especially when designed with double layer steel fabric, therefore wall panel also can be promoted as a load bearing unit. When **CCwA** are accepted in present construction method, the cost and the environmental load in term of concrete waste would decrease compared to the construction without the use of recycled material especially for large-scale construction.

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