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BEHAVIOUR OF DRYSTACK MASONRY WALLETTES UNDER AXIAL COMPRESSION

M.Ferozkhan[1] R.Dhanasekar[2] , W.Holt[3] and M.Dhanasekar[4]

Abstract

Dry-stack masonry (DSM) systems developed in response to raising labour costs achieve structural integrity using different methods of construction. Fibre reinforced cement composite (FRCC) is used as surface rendering for the imparting strength and stiffness to the DSM system constructed using special blocks consisting of tongue and groove joints in this research. The FRCC is a patent pending product (the details of which are therefore not provided in this paper) that sandwiches a fibreglass mesh within the fibre cement – polymer matrix. To examine the behaviour of this DSM system under compression, twelve wallettes of various configurations were constructed and tested under vertical compression under face shell loading. The results are compared with wallettes of similar DSM configurations without the FRCC rendering. This paper discusses the strength and deformation characteristics of the DSM wallettes.

Key Words

dry stack masonry; fibre reinforced cement composite; compressive strength; deformation characteristics

1 Introduction

With a view developing a better understanding of the composite dry stack masonry (DSM), a research project on the assembly properties of DSM wrapped within Fibre Reinforced Cement Composite (FRCC) render was carried out. In this paper, the behaviour of FRCC wrapped and unwrapped wallettes under axial compression is discussed. Parameters such as the compressive strength and the stress strain relationship of the wallettes are evaluated and presented. Twelve wallettes with different combinations of 1/3, 2/3 and full blocks (1/3 block contains single core, 2/3 block contains two cores and the full block contains triple cores) wrapped with FRCC were constructed in a controlled environment room (CER) where the temperature and

[1] Postgraduate Student, CQU Australia, m.Ferozkhan@cqu.edu.au
[2] Lecturer, CQU Australia, r.dhanasekar@cqu.edu.au
[3] Engineering Mgr, Besser Masonry Australia, wayne.holt@pioneer-international.com
[4] Associate Professor, CQU Australia, m.dhanasekar@cqu.edu.au

humidity were maintained at $20^{\circ} \pm 3^{\circ} c$ and $60 \pm 5\%$ respectively. These wallettes were tested under monotonically increasing uniform axial compressive load applied through the face shells of the wallettes. The ultimate failure load as well as the axial and the lateral deformations were recorded for all wallettes. The strength of these wallettes is compared with the DSM wallettes unwrapped with FRCC. The deformation and ultimate load of the DSM wallettes are described and discussed in this paper.

2 Experimental program

2.1 Construction of DSM Wallettes

DSM Wallettes of various lengths with 600 mm height were constructed using different combinations of 1/3, 2/3 and full blocks wrapped with the FRCC as shown in Fig1.

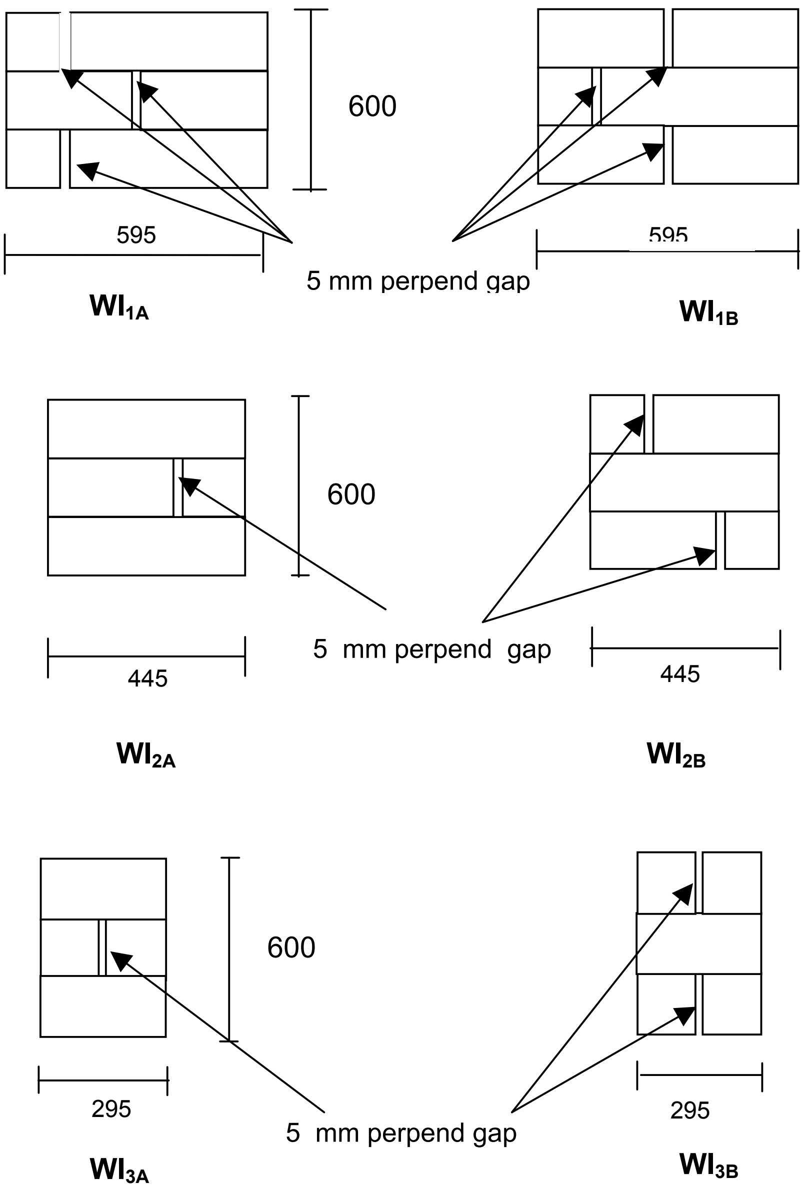


Figure 1 Configuration of Wallette assemblies

To represent the field practice and to understand the behaviour of DSM under compression, three course hollow block wallettes were constructed. Some basic data of these wallettes are provided in Table1 vide column 1 to 7. The 2/3 and Full blocks are grouped as “lower strength blocks” (column 4 of Table1) since their strength is lower (25.5 MPa) relative to the 1/3 block strength (32 MPa). The strength of individual blocks was determined from dry stack bonded prism tests, the results of which are shown in Table 2 (the strength properties are shown in column 3 of Table 2)

Table 1 Geometric Details of DSM wallette specimens

Designation of wallettes	Size l×h (mm x mm)	Number of blocks			Lower strength blocks (%)	Number of dry perpend joints	Number of wallettes tested	
		1/3	2/3	Full			FRCC wrapped	FRCC unwrapped ⊗
(1)	(2)	(3)			(4)	(5)	(6)	(7)
Wl_{1A}	605 X 600	2	2	2	67%	3	2	-
Wl_{1B}	605 X 600	1	4	1	83%	3	2	2
Wl_{2A}	455 X 600	1	1	2	75%	1	2	-
Wl_{2B}	455 X 600	2	2	1	60%	1	2	2
Wl_{3A}	305 X 600	2	2	-	50%	1	2	-
Wl_{3B}	305 X 600	4	1	-	20%	1	2	2

⊗ - Unwrapped wallet sizes are 595 X 600, 445 X 600 and 295 X 600respectively

Table 2 Strength of Blocks

Designation of dry stack bonded blocks	Size l×h (mm x mm)	Mean strength (MPa)	Number of Samples	C.O.V
(1)	(2)	(3)	(4)	(5)
1/3	145 X 600	32.0	3	2
2/3	295 X 600	26.0	3	4
Full	445 X 600	25.0	3	7

All the wallet specimens were constructed using either four or six concrete interlocking blocks dry stacked, aligned and interlocked vertically along the web shell as shown in Fig2(a). Fibre reinforced cement (FRC) mortar of a pre-defined rheological consistency was used in surface rendering. Fibreglass mesh was sandwiched in the FRC matrix to wrap the wallettes as shown in Fig 2(b). The DSM was thus sandwiched in a 5mm thick composite render FRCC on all four sides. The gross thickness of the wallettes thus constructed was 160 mm providing a height to thickness ratio of 3.75. The wallettes were thus considered as “short” with no potential for buckling under axial compression. A minimum of two specimens was constructed for each category with the configurations shown in Fig 1. It should be noted that the difference between the “A” and “B” type wallettes shown on the left and right columns respectively of Fig 1 is that the interchanging of the middle course with the top and bottom courses (and vice-versa).

The width of the perpend joints varied from 4 to 6 mm for different lengths of the wallettes according to the size of the base course. A professional tradesman

constructed specimens. All specimens were built over the visqueen polythene sheet kept on a wooden pallet in the CER chamber of Central Queensland University (CQU) Laboratory where a temperature of $20 \pm 3^{\circ}c$ and a relative humidity of $60 \pm 5\%$ were maintained. The wallettes were cured for 28 days. The composite wrapped specimens were carefully transported after 28 days of curing to the testing lab from the curing chamber without distressing any part of the sandwiched blocks of the encapsulated composite.

(a)Prior to composite wrapping *(b) After composite wrapping*

Figure 2 Construction of the Wallettes

2.2 Instrumentation

In instrumenting the wallettes, it was decided to examine the integrity of the composite action of the DSM-FRCC assembly when subjected to compression on the face shells. For this purpose, the linear variable differential transducers (LVDTs) used to measure linear deformation were either glued (G-series) on the surface of the FRCC or drilled (D-series) into the blocks using a mild steel galvanized plate with threaded screw arrangements fitted with mild steel rod attached to the transducers as shown in Fig 3. The axial and lateral strains of the composite and blocks of the wallet were thus recorded. Six of the twelve wallettes belonged to G-series and the rest D-series.

Three pairs of linear strains were measured on each side of the wallettes and averaged to account for any marginal eccentricity in loading in the thickness direction. Each strain was measured using LVDTs mounted on a lug positioned at the centre of the block. Care was taken not to position the lug in the dry joint (gap) between blocks. This has necessitated the gauge length of each LVDT be varied. The gauge length and the direction of each measured linear deformation were carefully recorded.

(a)FRCC Wrapped DSM *(b)DSM without FRCC wrapping*

Figure 3 Instrumentation of the Wallettes

2.3 Testing of wallettes

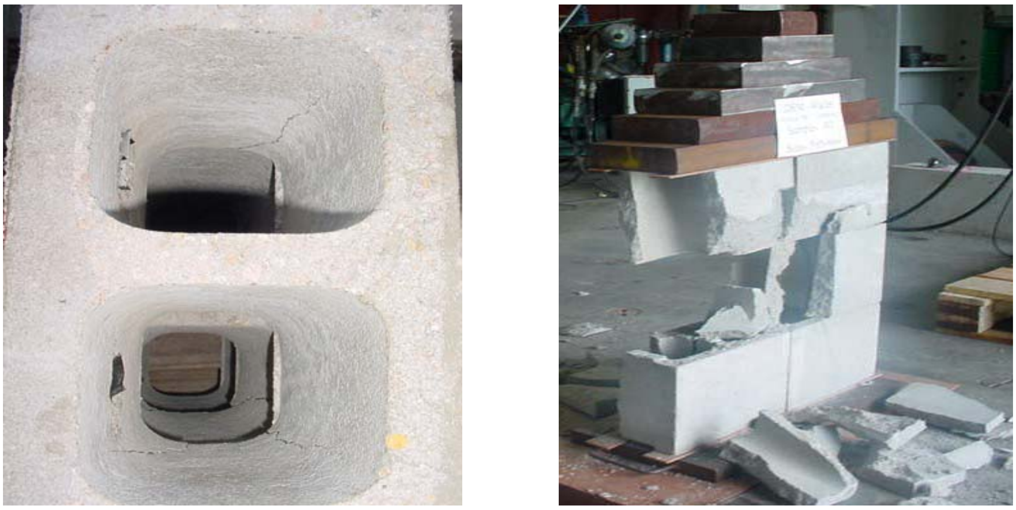
All the twelve FRCC wrapped wallettes (six each of “D” and “G” series) and four unwrapped wallettes were tested under a 2000kN hydraulic actuator attached to a stiff loading frame. The load was applied in the vertical direction and transferred to the face shells of the wallettes. A 4 mm thick plywood capping was used as bearing strips along the face shell between the wallet and the steel platens for this purpose. Both the top and the bottom faces of the wallettes were placed on the plywood bearing strips along the face shell and centered for loading on the strong floor. A data acquisition system was set up to record the load applied using a displacement control of 0.5 mm/min connected to the LVDTs and the deformation as shown in Fig 4(a). The data were analysed carefully and any noise in the data was filtered out. The failure pattern and the ultimate load for both the wrapped and the unwrapped wallettes were recorded.

3 Failure of wallettes

Failure occurred in FRCC wrapped wallettes soon after the ultimate load was reached, and the final failure was associated with noisy explosion although the peak load attained in each test was small (a maximum of 965kN) compared to the design capacity of the loading frame. The first shear cracks developed initially from the centre of the face shell approximately at 40% to 60% of the ultimate load diverging to ends and then followed by rapid failure for all specimens. The tensile splitting caused by the lateral strain along the edge of the face shells and end shells leading to spalling of surface render as shown in Fig 4.

A closer look at the cracking in the blocks reveal the effectiveness of the FRCC wrapping in minimising the damage of the blocks as shown in Fig 5(a). As minimal damage of the block improves the structural integrity of the wall, this aspect of reduced crack width at the ultimate stage of the wallet is important for the limit state of design of this type of construction. To effectively compare the failure of DSM with and without the FRCC wrapping, Fig 5(b) presents the failure of unwrapped DSM wallettes. Significant reduction in crack width at the ultimate stage due to FRCC wrapping is thus obvious.

Figure 4 Splitting of FRCC render along the corner edge of face and end shells



(a)Minor cracking in blocks of FRCC Wrapped DSM

(b) Sudden Collapse of blocks in the DSM without FRCC wrapping

Figure 5 DSM wallet failure modes

Another matter to be observed is that whilst the web shell failure leading to sudden collapse of wallettes (and dry stack bonded prisms) without FRCC wrapping, both the web and the face shells cracked in the presence of the FRCC wrapping. This shows that the FRCC wrapping has mobilized distribution of the load more uniformly thus modifying the failure mode. Page and Shrive (1988) explained that shell bedded hollow concrete wallettes under uniaxial compression fail by web splitting for the full length as all the cross webs were subjected to deep beam action.

Although the DSM specimens (wallettes and dry stack bonded prisms) with and without FRCC wrapping exhibited noisy failure, the fact that the blocks in the FRCC wrapped specimens retained their shape without disintegration proves that the FRCC wrapping improves the integrity of structures of this form at ultimate limit state of collapse.

4 Strength and stiffness of wallettes

The compressive strength of FRCC wrapped and unwrapped DSM wallettes are summarised in Table 3 and 4 respectively. The mean strength of the different categories of the wallettes and prisms are shown in column 2 and the co-efficient of variation in column 3 of these tables. The strength of the wallettes and prism is calculated by dividing the ultimate load by the face shell area and the values of the two series were averaged out to get the mean strength. From the linear portion of the stress strain curve the modulus of elasticity (E) and Poisson's ratio (ν) were calculated.

There was no significant difference in E and ν between the G and D series and hence they were averaged out. The value of E ranges from 12,540MPa to 14,370MPa. This shows that E is a true material property not affected by the geometry of the wallet. The average E value for the FRCC wrapped wallettes is thus worked out as 13,330MPa. The Poisson's ratio ν for both series was found to range from 0.17 to 0.26. Once again, due to reasonably consistent values, an average ν was worked out as 0.21.

Table 3 Strength and elastic properties of FRCC wrapped wallettes

FRCC Wrapped DSM wallet Designation (1)	Mean comp. strength (*MPa*) (2)	C.O.V (%) (3)	No. of samples (4)	Mean *"E"* (*MPa*) (5)	Mean "ν" (6)
WI_{1A}(D) WI_{1A}(G)	27.0	0	2	13,840	0.26
WI_{1B}(D) WI_{1B}(G)	22.0	6	2	13,320	0.25
WI_{2A}(D) WI_{2A}(G)	29.0	0	2	13,250	0.21
WI_{2B}(D) WI_{2B}(G)	30.0	9	2	14,370	0.22
WI_{3A}(D) WI_{3A}(G)	30.5	12	2	12,540	0.17
WI_{3B}(D) WI_{3B}(G)	31.5	2	2	12,650	0.17

From the results shown in Table 3 it can be seen that the wallettes WI_{3B} constructed with less number of low strength blocks (20% in Table1) pronounced the highest strength (31.5MPa) amongst all the wallettes tested; the wallettes WI_{1B} that have the higher number of low strength blocks (83% in Table 1) recorded the lowest strength (22.0MPa). Therefore it is clear that in a composite like DSM wall where there is a mix of lower and higher strength blocks randomly positioned, the % of lower strength blocks appear to determine the strength of the composite. The COV of the results is very low, which shows the consistency in the testing and procedure.

Table 4 Strength of unwrapped DSM Wallettes

Unwrapped DSM wallet Designation (1)	Mean Comp. strength (MPa) (2)	C.O.V (%) (3)	No. of samples (4)
WI_{1B}	20.5	3	2
WI_{2B}	26.0↑	↑	2
WI_{3B}	26.0	5	2

↑ One of the two samples tested failed due to local stress concentration

Four unwrapped wallettes were also tested. The strength of these wallettes is presented in Table 4. No deformation measurement was taken on these wallettes and hence the elastic properties of the DSM without FRCC wrapping are not reported. Once again WI_{1B} wallette that had 83% of lower strength blocks failed at the lowest stress level (20.5MPa) compared to the WI_{3B} wallette that had only 20% of low strength blocks. Similar finding is also reported by Fudge and Sargeant (1992). Ramamurthy et al (2000) investigated compressive strength of dry stacked masonry from three course high wallettes and reported wallettes to block strength ratio of 0.77. In the test reported here the ratio of the unwrapped wallette strength (Table 4) to the block strength (Table 2) varied from 0.64 to 0.81 when 1/3 block strength was used in the calculation. If the full block strength is used in the calculation, the ratio varied from 0.82 to 1.0.

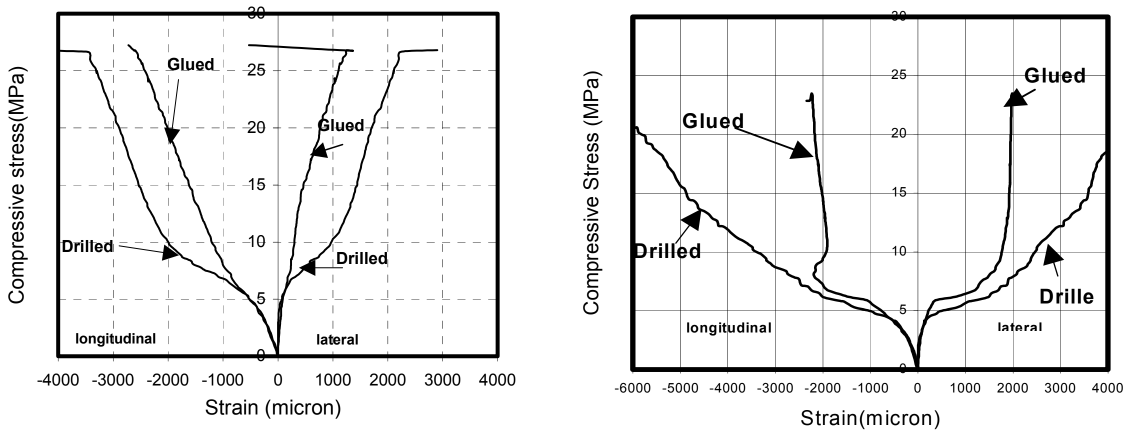
A comparison of the strength of the wallettes with and without FRCC wrapping reveals that where the weaker blocks do not dominate (Wl_{2B} and Wl_{3B}), the FRCC wrapping increase the compressive strength by approximately 20%. However if the weaker blocks dominate the composition, the increase in compressive strength due to FRCC is only marginal (approximately 7%).

5 Stress strain relationships

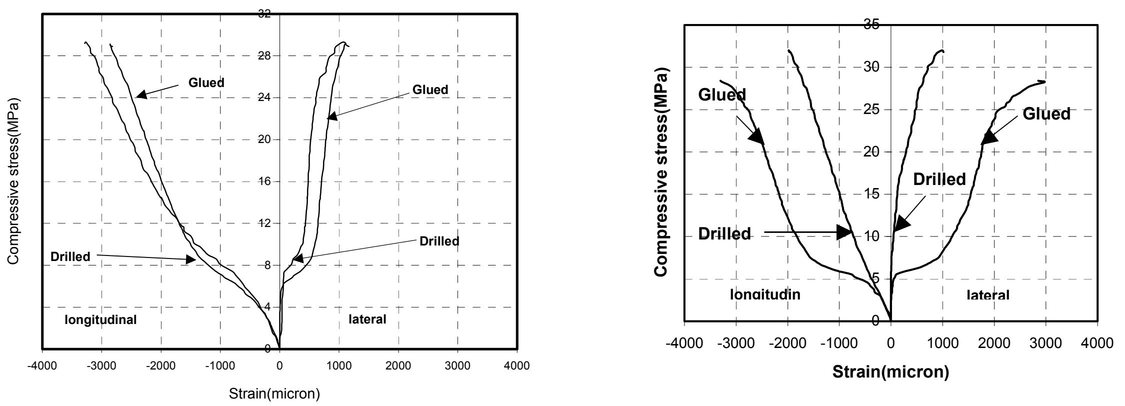
Three linear strains ($\varepsilon_a, \varepsilon_b, \varepsilon_c$) on both sides of FRCC wrapped DSM wallet were recorded. The average values of $\varepsilon_a, \varepsilon_b, \varepsilon_c$ and their corresponding angles (θ_a, θ_b, θ_c) were used to convert the measured linear strains into normal and shear strains $\varepsilon_x, \varepsilon_y, \gamma_{xy}$ from the following equation.

$$\varepsilon_{a/b/c} = \varepsilon_x Cos^2\theta_{a/b/c} + \varepsilon_y Sin^2\theta_{a/b/c} + \gamma_{xy} Sin\theta_{a/b/c} Cos\theta_{a/b/c} \quad (1)$$

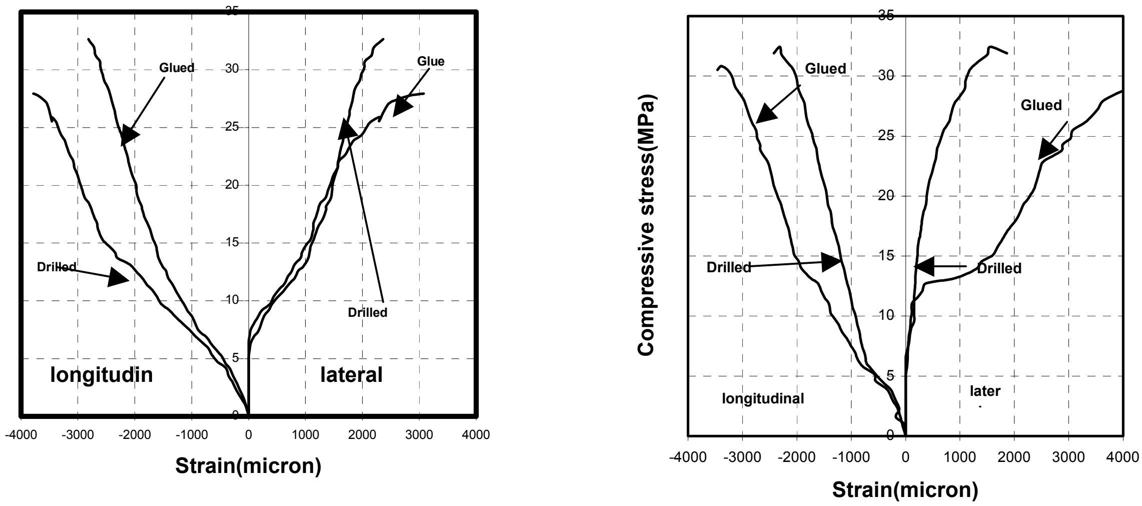
The normal strains ($\varepsilon_x, \varepsilon_y$) were plotted against the applied compressive stress for the pair of D and G series in a single graph for all wallettes tested as shown in Fig 6 (a) to 6(c).



(a) Wallettes Wl_{1A}(D); Wl_{1A}(G); Wl_{1B}(D) & Wl_{1B}(G)



(b) Wallettes Wl_{2A}(D); Wl_{2A}(G); Wl_{2B}(D) & W



(c) Wallettes WI_{3A}(D); WI_{3A}(G); WI_{3B}(D) & WI_{3B}(G)

Figure 6 Stress – Strain Relations of the DSM wallettes wrapped with FRCC

All wallettes exhibit similar shape of the stress-strain diagram. The graphs are presented only up to the maximum load as the post failure occurred suddenly.

Up to approximately 25% of the ultimate load (here compressive strength) both the glued and drilled specimens have exhibited identical stress-strain response. At stresses higher than 25%, the glued and drilled series exhibit varying response. This has occurred consistently in all the 12 wallettes tested.

Under face shell bedding compression, it appears that delamination occurs at around 25% of compressive strength when the material remains linear. Delamination induces local nonlinearity leading to the FRCC composite (from glued specimens) behave different to the dry stacked blocks (from drilled specimens). After delamination, a complex behaviour is exhibited in which either the glued specimens or the drilled specimens recorded higher strains at any given stress level. No consistency in the behaviour is observed after delamination with the behaviour be best defined as complex and random. Careful numerical modelling and further testing would be required if one is interested in examining the delamination induced nonlinearity of the DSM wallettes.

6 Conclusions

Behaviour of the dry stacked masonry wrapped within a patent-pending FRCC under axial compression was examined experimentally. The following conclusions are made from the analysis of data obtained from the experiments:

1. The FRCC wrapping has the potential to modify the mode of failure of DSM assembly from complete collapse of blocks to fine, uniformly distributed cracked blocks. The FRCC wrapped wallettes showed much improved structural integrity even after attaining the ultimate load.

2. In the test reported here the ratio of the unwrapped wallette strength to the block strength varied from 0.64 to 0.81 when 1/3 block strength was used in the

calculation. If the full block strength is used in the calculation, the ratio varied from 0.82 to 1.0.

3. The FRCC wrapping has increased the compressive strength of the wallette by about 20% relative to the strength of the corresponding unwrapped wallettes when the configuration of the wallettes was not dominated by low strength blocks. However, when the low strength blocks dominated the configuration of the wallettes, the beneficial effect of the FRCC wrapping is less dramatic (7%).

4. The stress-strain curves of the wallettes exhibited the occurrence of delamination of the FRCC wrapping at about 25% of the ultimate stress.

5. The mean value of the Young's modulus E of the wallet is 13,300MPa; and the mean value of the Poisson's ratio ν of the wallet is 0.21.

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