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Flexural and Shear Bond Strength of Sediment Brick Masonry

L W Ean, M A Malek, B S Mohammed, Chao-Wei Tang, M T Tamunif

Abstract: ***This paper presents an experimental investigation of shear and flexural bond strength of masonry prisms for newly developed sediment masonry bricks. The masonry prisms were constructed in three levels stack-bonded prisms for shear bond strength test and five levels stack-bonded prisms for flexural bond strength test using cement mortar and cement-lime mortar with pre-wetted and dry masonry units. The bond strengths of sediment brick masonry were tested accordance with RILEM TC 127-MS and ASTM E518 for shear and flexural bond strengths respectively. The results were compared to clay brick and cement-sand brick masonry. The results show that pre-wetted sediment brick masonry exhibits higher flexural and shear bond strengths of about 1.5 times and 5 times respectively compared to dry (non-wetted) sediment brick masonry. Using cement-lime mortar in pre-wetted sediment brick masonry leads to increment of the bond strengths and pre-wetting action is essential for sediment brick masonry to prevent failure of shear bond strength.***

Keywords: Bonding strength, Experimental and Sedimentation

I. INTRODUCTION

Masonry brick is one of the important constituents in construction industry since 8000 BCE [1]. Traditionally, masonry bricks were produced by fired or unfired method, using earth materials such as clay and sand. Although earth have been abundantly available in nature, it may lead to depletion of natural resources in the future. Efforts have been made around the globe to utilize waste from various industries in brick production as alternative building materials in order to conserve the natural resources[2]–[4]. Bricks utilizing these wastes have different characteristics. Therefore, studies of these newly developed bricks are essential, especially on the compatibility of these materials with commonly used mortars for developing appropriate structural performance.

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* Correspondence Author
L W Ean, Institute of Sustainable Energy, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
M A Malek, Institute of Sustainable Energy, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
B S Mohammed, Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.
Chao-Wei Tang, Department of Civil Engineering and Geomatics, Cheng Shiu University, No. 840, Chengching Road, Niaosong District, Kaohsiung Country, Taiwan.
M T Tamunif, Institute of Sustainable Energy, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

Measurement of bond strength in masonry is substantially important when subjected to in-plane and out-of-plane bending [5]. Bond strength of the masonry developed from penetration of hydration product in the form of calcium-silicate-hydrates (C-S-H) from the mortar into the masonry units through the surface pores. Prime factors influencing bond strength of the masonry regardless of using conventional (10 mm thick) or thin mortar layers (1-4 mm thick) are the type of mortars, the type of masonry unit and workmanship [6].

Sarangapaniet. al. [7] found that high-cement mortar or mortar with plasticizing additives produced better bonding in conventional masonry. Besides that, surface structure of masonry bricks is also one of the important aspects in developing bond strength of the masonry. In fact, earlier study conducted by Grandetet. al. (1972) [8] showed that coarser pores results in better bond strength and pore size on masonry bricks of greater than 0.05μm improved bond development. Groot (1993) [9] showed that rough surface texture provides better bond strength compared to smooth surfaces. However, Reddy and Gupta (2006) [10] found that masonry brick with many fine pores lead to increment of bond strength due to uniform coating of mortar on fine pores compared to surface with larger pores, although the surface porosity remained the same. In 2007, the same author Reddy et. al.[5] tested on rough surface texture bricks by filling a layer of gravel-cement mixture on top and bottom surface of the masonry bricks and found that masonry bricks with rough textured bedding face increased the bond strength compared to plain bed surface masonry units.

In contrary, Thambooet. al (2013) [6] agreed to [10] that smooth surface texture of masonry bricks displayed higher flexural and shear bond strength as compared to rough surfaces for concrete masonry constructed with thin layer polymer cement mortar. The polymer cement mortar has different characteristics as compared to pure cement and cement lime mortars. It was stated that flexural tensile strength of the polymer mortar is 50% more than its compressive strength whereby conventional mortars have flexural strength that is 10% of its compressive strength. It was claimed that the rough surface specimens exhibited lower bond strength due to the stress concentration created on the 'Valleys' at the rough surface interface when the loading is applied. Based on the above reviews, different arguments on the effects of surface texture on the bond strength made it remained as an area to be explored further for future research. In addition, moisture content also shows a great impact to the bond strength. Reddy et al [5] reported that soil-cement masonry constructed with bricks of 75% of saturation exhibited optimum moisture content as compared to dry or fully saturated bricks that showed poor bond strength. Meanwhile, dry cured masonry exhibited higher bond strength as compared to the wet cured masonry [11].

Researches were conducted on the bond characteristics in conventional masonry. Various tests have been conducted for characterization of flexural and shear bond behavior of the unit-mortar interface, such as uniaxial tensile test on couplets, four-point beam test and bond wrench pier tests [6]. However, behavior of newly developed bricks may differ from the conventional clay bricks, hence study needs to be carried out for the performance of the masonry constructed by the newly developed bricks. Christy et. at [12] and Basha et. al.[13] have conducted research on bond strength of fly ash masonry and found that fly ash masonry behaves differently compared to clay masonry as fly ash masonry units are highly water-absorbent and weaker than clay masonry units. More research are needed for such new emerging engineering materials.

II. METHODOLOGY

The sediment masonry bricks of size 210 x 100 x 65 mm were developed by mixing 90% of reservoir sediment and 10% of OPC with water content of 10% from total dry mix, compressed with a pressing load of 220 kN [14]. The properties of sediment masonry units were tested accordance with the requirements of the ASTM C140 and ASTM C67 and compared to clay and cement-sand masonry units, as shown in Table 1 [15]. Sediment masonry prisms were constructed with cement-lime mortar (M1) and cement mortar (M2) with water-cement ratio 0.8 as shown in Table 2. 70 mm cubes mortar were tested for compressive strength on the testing day of masonry.

Table. 1 Properties of masonry units [15]

Type of Masonry units	Density (kg/m^3)	Water Absorption (%)	Initial Rate of Absorption (g/min/194cm^2)	Compressive Strength (MPa)
Sediment	1635.47	12.53	34.05	6.202
Clay	1831.69	11.47	45.63	14.143
Cement-sand	1889.69	10.68	126.90	5.607

Table. 2 Mix proportion for mortars by volume

Mix	Average compressive strength (MPa)	Mix Proportion (by volume)		
		Cement	Hydrated lime	Fine sand
M 1	7.89	1	0.5	4.5
M 2	15.29	1	0	3

The masonry prisms were constructed with dry and pre-wetted units. Pre-wetted units were emerged in water for 15 minutes prior to construction. The excessive water after pre-wetting were drained before used. The stack-bonded-masonry-prisms were constructed with mortar thickness within 10 to 12 mm and leveled vertical and horizontally. The flow of mortars were monitored by using flow table and maintained in the range of 130 to 150%. The prisms were air cured and tested after 28 days. The dry clay brick indicated by RD, wet clay brick is RW, dry sediment brick is SD, wet sediment brick is SW, dry cement-sand brick is CD and wet cement brick is CW. 5 samples were tested for each categories.

Shear strength of the prisms were tested in accordance with RILEM TC 127-MS. It is a method of measuring an index of shear strength on the interface between masonry unit and the mortar. Five specimens prism of three layers were tested as shown in Figure. The prisms were placed in such a way that the applied load is acting parallel to the mortar joint. The load was applied as near as possible to the joints. Supports were applied below the prisms at both end units. The testing speed applied was 0.06 mm/s. The adhesive shear strength is calculated using Equation 1. Where F is the ultimate load, A_1 is the area of the upper joint and A_2 is the area of the lower joint.

$$\tau_0 = \frac{F}{(A_1 + A_2)} \tau_0 = \frac{F}{(A_1 + A_2)} \qquad (1)$$

Fig. 1 Setting up for masonry shear test

The specimen with shear strength lower than 0.3 N/mm^2 was classified as "not successful test". Failure modes for the prisms were also identified with reference to RILEM TC 127-MS. The position of cracks were studied, whether it is predominantly at the upper or lower masonry unit or mortar interface or through the mortar.

Flexural strength of the prisms placed on simply supported beam with third point loading were determined in accordance with ASTM E518.

The five levels prism were placed horizontally on the support as simply supported beam. The setting up of the test is shown in Figure 2 and Figure 3 shows the loading condition of the test. The loading speed used was 0.06 mm/s. The flexural strength for the prism is calculated using Equation 2, where R is the gross area modulus of rupture in MPa, P is the maximum applied load in N, P_s is the weight of the prism in N, L is the span in mm, b is the average width of the prism in mm, and d is the average depth of the prism in mm. Prism which has failure occurred in a joint located outside of the middle third of the span length were discarded.

$$R = \frac{(P+0.75P_s)L}{bd^2} R = \frac{(P+0.75P_s)L}{bd^2} \quad (2)$$

Fig. 2 Setting up for prism flexural test

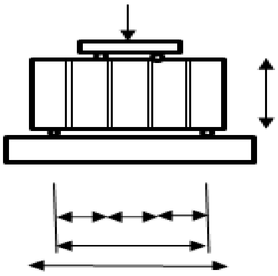


Fig. 3 Loading method for three point load flexural test

III. RESULTS AND DISCUSSIONS

This section presents results on flexural bond strength and shear bond strength of sediment masonry prisms with and without pre-wetted condition and compared with clay and cement-sand masonry prisms, tested at the same conditions. The application of pre-wetted condition is to fulfil the requirement of ASTM C67 for conventional clay brick. Since the sediment brick is newly developed, hence this study attempts to see whether there is any difference in their mechanical properties based on pre-wetted condition.

Figure 4 shows average results of shear bond strength for masonry triplets for all three types of bricks, with or without pre-wetting (dry), for M1 and M2 mortars. All the samples showed shear bond strength of more than 0.3 MPa which satisfies RILEM TC 127-MS, except for SDM1.

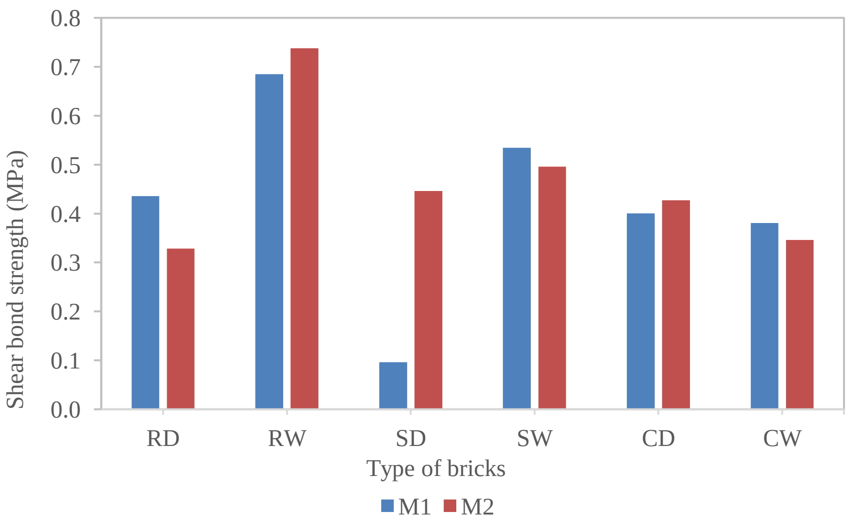


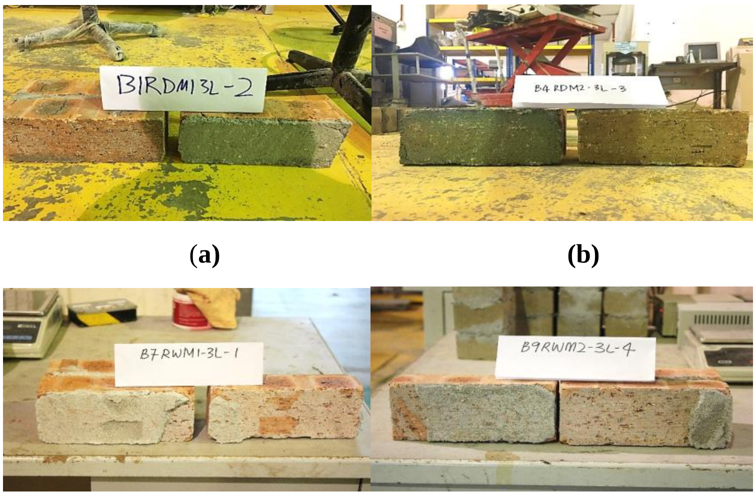
Fig. 4 Shear bond strength for the masonry prisms.

The results showed that pre-wetting is enhancing the bond strength. Pre-wetted samples for sediment masonry with M1 exhibit five times higher of shear bond strength, while clay masonry showed 1.5 to 2 times higher of shear bond strength for M1 and M2 respectively. In contrast, pre-wetted cement sand masonry does not show any improvement in the shear bond strength. Dry cement-sand masonry showed higher shear bond strength for M2 mortar. This is in-line with the open pore structure brick characteristic which improved the interface bonding. Generally, sediment masonry has shear bond strength value in between clay and cement-sand masonry. Pre-wetted sediment masonry constructed with cement lime mortar (SWM1) has shown higher shear bond strength as compared with the one constructed with cement mortar (SWM2). This is in agreement with Sarangapaniet. al. [7] that lime in mortar improved hydration products penetration into the brick pores and led to improvement of interface contact, as well as bond strength. Furthermore, initial moisture content of the sediment bricks has also a significant influence on the bond strength as found by Singh and Munjal [16].

SWM1 showed higher shear bond strength than cement-sand masonry.

Dry sediment masonry constructed with cement lime mortar (SDM1) showed extremely low shear bond strength because of insufficient suction of water for interface bonding due to cement lime mortar water retention.

Figure 5 shows failure mode of clay masonry due to shear load. Dry clay masonry (RDM1 and RDM2) constructed with M1 and M2 showed failure at the upper or lower brick-mortar interfaces. It exhibited failure in one or both unit/mortar interfaces as that listed in RILEM TC 127-MS. Meanwhile, pre-wetted clay masonry (RWM1 and RWM2) also showed the same failure pattern, which is failure at both brick-mortar interfaces.

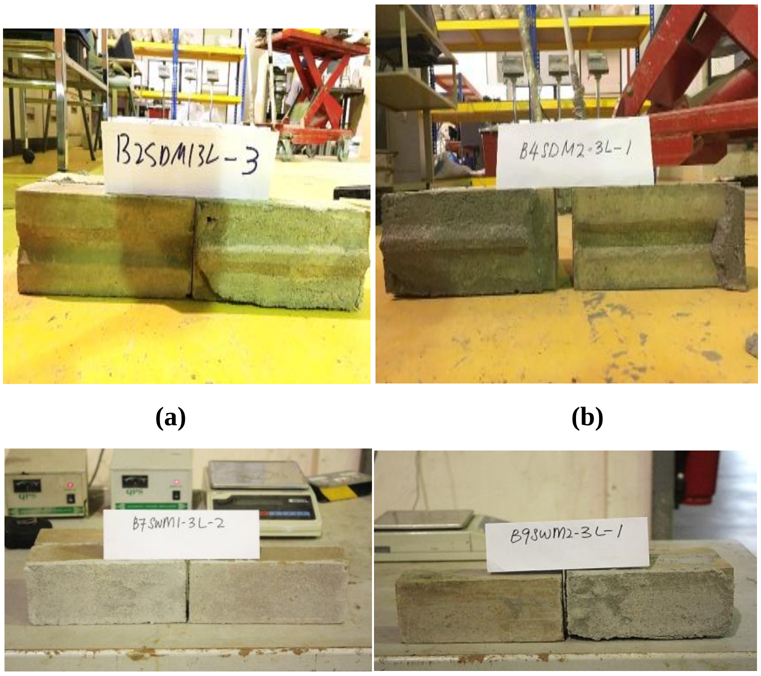


(a) (b)

(c) (d)

Fig. 5 Failure mode of red masonry (a) RDM1, (b) RDM2, (c) RWM1, and (d) RWM2

On the other hand, dry sediment masonry showed weak shear bonding as illustrated in Figure 6(a) and (b). SDM1 and SDM2 failed at the frog (indentation) side of the interface with clean detachment of mortar. Meanwhile, pre-wetted sediment showed better shear bonding especially for SWM1. It failed in mortar only, as shown in Figure 6(c) where some mortar are still attached on the surface of the brick and on the side without frog. This showed that the presence of frog contributed to better bond strength as it increased the contact area at the brick-mortar interface. This is in agreement with findings by Singh and Munjal [16].



(a) (b)

(c) (d)

Fig. 6 Failure mode of sediment masonry (a) SDM1, (b) SDM2, (c) SWM1, and (d) SWM2

Cement-sand masonry in Figure 7 shows weak bonding for pre-wetted masonry bricks (CWM1 and CWM2), as the samples failed at lower brick-mortar interface with clear detachment of mortar. Cement-sand masonry brick has frogs at both sides of the interface, therefore failure occurred at any sides of the interface. Meanwhile, dry cement-sand masonry samples (CDM1 and CDM2) with shear bond strength of 0.400 MPa and 0.427 MPa showed better shear bonding as compared to the pre-wetted units (CWM1 and CWM2) with shear bond strength of 0.381 MPa and 0.346 MPa. Dry cement-sand masonry showed failure in mortar only, some mortar are found to be attached on the brick surface of the failure side.

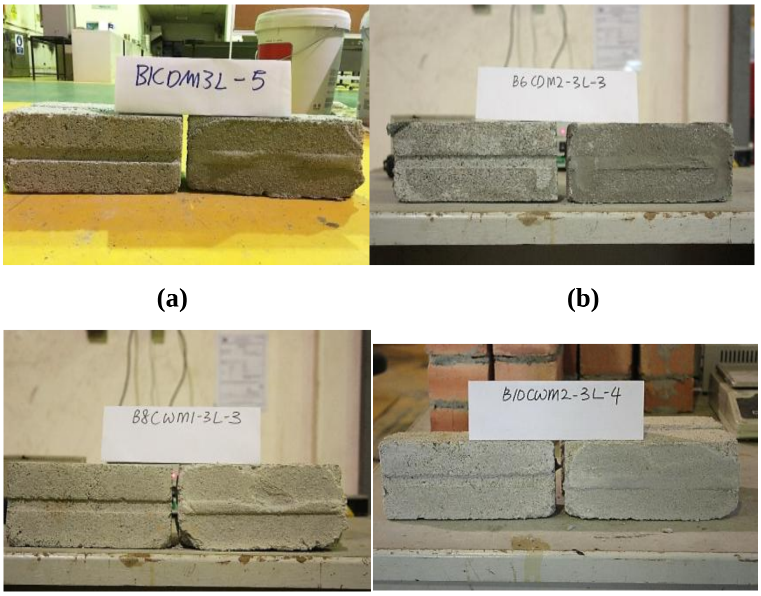


Fig. 7 Failure mode of cement-sand masonry (a) CDM1, (b) CDM2, (c) CWM1, and (d) CWM2

Figure 8 shows flexural bond strengths for the masonry prisms. CDM2 showed the highest flexural bond strength as compared to other types of masonry prisms. Mortar with lime (M1) showed improvement in flexural bond strength as compared to cement mortar (M2), except for cement-sand masonry. Open pore structure of the cement-sand masonry bricks allow higher flexural bond strength when higher compressive strength of mortar is used. SWM1 showed higher flexural bond strength as compared to clay masonry. In general, pre-wetted masonry bricks constructed with cement lime mortar have better flexural bond strength for clay and sediment masonry.

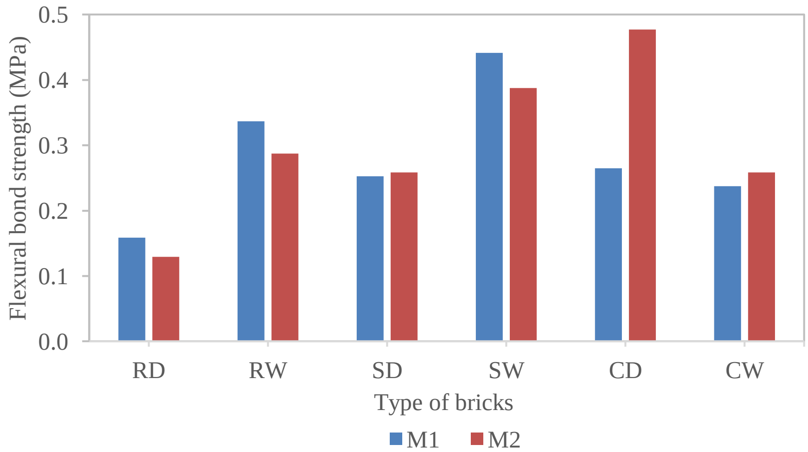


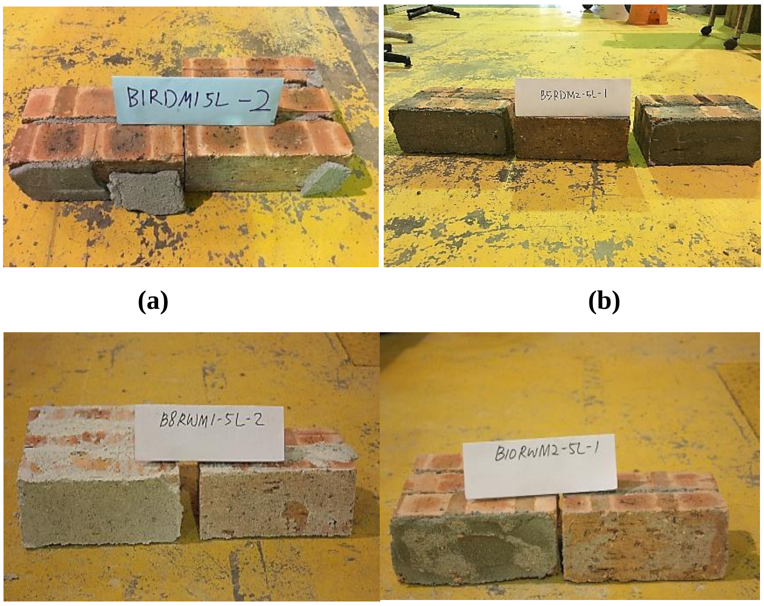
Fig. 8 Flexural bond strength of the masonry prisms

Figure 9 to Figure 11 show failure mode of all the masonry under flexural bond test. All the samples failed at the middle span. The failure mode is analysed in accordance to classification summarized by Lumantarnaet. at. [17]:

- Type A, failure at one brick-mortar interface;
- Type B, failure at both brick-mortar interface;
- Type C, failure within the mortar joint;
- Type D, failure within the brick unit; and
- Type E, combination of failure within the brick unit and mortar joint.

RDM1 in Figure 9(a) showed Type C failure, whereby bond failure in mortar joint is observed; while dry clay masonry in Figure 9(b), (c) and (d) illustrated Type

A failure, which is the failure at one brick-mortar interface as described by Lumantarna et. al [17]. Venkataramaet. al [10] found that failure within the mortar joint normally occurred in weak (soft) mortar masonry while failure at brick-mortar interface is exhibited in masonry constructed using moderately stiff bricks. Although RDM1 is also constructed using the same group of bricks, the compressive strength of mortar M1 for RDM1 is much lower than the compressive strength of clay bricks. Pre-wetted clay masonry (RWM1 and RWM2) showed stronger flexural bond strength as compared to RDM2 when clean detachment of mortar is noticed at both sides of the middle span brick in RDM2 sample, while some brick residue are noticed on the mortar face of RWM1 and RWM2.

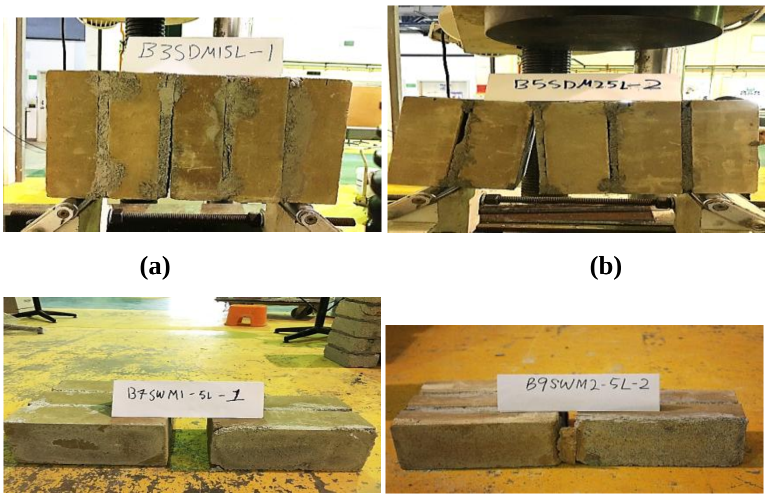


(a) (b)

(c) (d)

Fig. 9 Failure mode for clay masonry under flexural bond test (a) RDM1, (b) RDM2, (c) RWM1, and (d) RWM2

Similar to clay masonry, sediment masonry in Figure 10(a), (b) and (c) also showed Type A failure, which is failure at one brick-mortar interface that generally occured at moderately stiff bricks as studied as Venkatarama Reddy et. al. [10] and poor bond strength as discovered by Lumantarnaet. al. [17] and Sarangapaniet. al [7]. The failures are noticed on the side without frog. This is in-line with the findings by Sarangapaniet. al. [7] in shear bond strength that bond strength is enhanced by introducing frog. Pre-wetted sample SWM2 in Figure 10(d) shows better bonding when combination of brick failure and bond failure is noticed (Type A and D) [7], [16]. Besides failure of brick, a small amount of brick residue has been observed on the mortar surface of the failure interface.



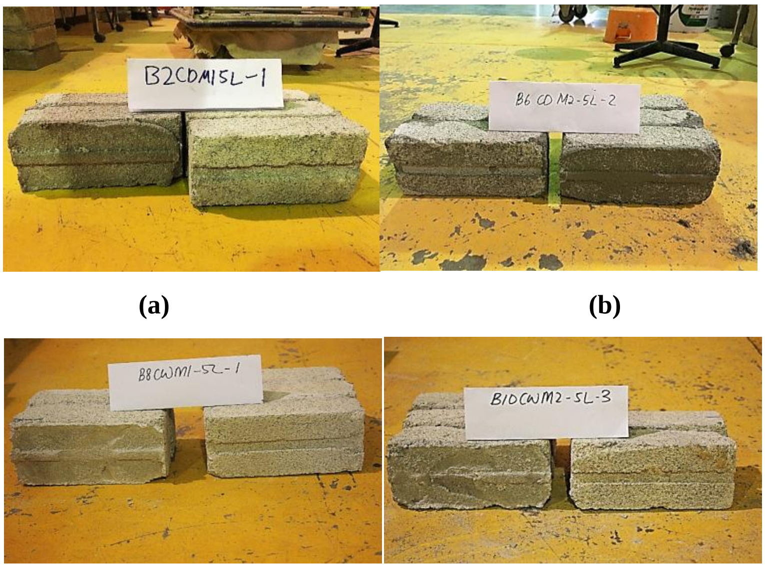
(a) (b)

(c) (d)

Fig. 10 Failure mode of sediment masonry under flexural bond test (a) SDM1, (b) SDM2, (c) SWM1, and (d) SWM2

Cement-sand masonry is found to be different from sediment and clay masonry. Dry cement-sand masonry bricks formed a better flexural bonding composite masonry because of the open pore structure. CDM1 in Figure 11 (a) showed a combination of failure at brick-mortar interface and failure within the brick unit (Type A and D). Other than detachment of the mortar, a crack on the brick is noticed. On the other hand, CDM2 in Figure 11(b) showed failure within brick unit (Type D) when some brick residue can be seen on the mortar surface.

These failures are frequently observed in masonry constructed using weak brick units, which is in agreement with Lumantarnaet. al. [17]. Pre-wetted cement-sand masonry (CWM1 and CWM2) in Figure 11(c) and (d) illustrated failure at one brick-mortar interface (Type A) with clean detachment of mortar is noticed. It indicated a weak brick-mortar bonding.



(a) (b)

(c) (d)

Fig. 11 Failure mode of cement-sand masonry under flexural bond test (a) CDM1, (b) CDM2, (c) CWM1, and (d) CWM2

IV. CONCLUSIONS

This study shows that sediment masonry prisms constructed with cement lime mortar performed a good shear and flexural bonding with pre-wetted condition. It can be concluded that, although pre-wetting action seemed to increase only 3% in compressive strength of sediment masonry constructed with cement-lime mortar as presented in [18], it is an essential action for shear bond and flexural bond strengths. Sediment masonry constructed with cement-lime mortar without pre-wetted failed in shear bond strength (i.e. 0.096MPa). Sediment masonry exhibited shear bond strength in between clay and cement-sand masonry but better flexural bond strength as compared to clay masonry.

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REFERENCES

1. L. Zhang, "Production of bricks from waste materials - A review," *Constr. Build. Mater.*, vol. 47, pp. 643–655, 2013.
2. A. Al-Fakih, B. S. Mohammed, M. S. Liew, and E. Nikbakht, "Incorporation of waste materials in the manufacture of masonry bricks: An update review," *J. Build. Eng.*, vol. 21, pp. 37–54, Jan. 2019.
3. Y. Meng, T.-C. Ling, and K. H. Mo, "Recycling of wastes for value-added applications in concrete blocks: An overview," *Resour. Conserv. Recycl.*, vol. 138, pp. 298–312, Nov. 2018.
4. A. L. Murmu and A. Patel, "Towards sustainable bricks production: An overview," *Constr. Build. Mater.*, vol. 165, pp. 112–125, Mar. 2018.
5. B. V. Venkatarama Reddy, R. Lal, and K. S. Nanjunda Rao, "Enhancing Bond Strength and Characteristics of Soil-Cement Block Masonry," *J. Mater. Civ. Eng.*, vol. 19, no. 2, pp. 164–172, 2007.
6. J. A. Thamboo, M. Dhanasekar, and C. Yan, "Flexural and shear bond characteristics of thin layer polymer cement mortared concrete masonry," *Constr. Build. Mater.*, vol. 46, pp. 104–113, 2013.
7. G. Sarangapani, B. V Venkatarama Reddy, and K. S. Jagadish, "Brick-Mortar Bond and Masonry Compressive Strength," *J. Mater. Civ. Eng.*, vol. 17, no. 2, pp. 229–237, 2005.
8. J. Grandet, R. Javelas, B. Perrin, and B. Thenoz, "Rôle de l'ettringitedans la liaison de type mécanique entre la terrecuite et la pâte de ciment-portland," *Rev. Terre Cuite (French)*, vol. 48, pp. 21–28, 1972.
9. C. Groot, "Effects of water on mortar-brick bond," 1993.
10. B. V. Venkatarama Reddy and A. Gupta, "Tensile Bond Strength of Soil-Cement Block Masonry Couplets Using Cement-Soil Mortars," *J. Mater. Civ. Eng.*, vol. 18, no. 1, pp. 36–45, 2006.
11. J. A. Thamboo and M. Dhanasekar, "Characterisation of thin layer polymer cement mortared concrete masonry bond," *Constr. Build. Mater.*, vol. 82, pp. 71–80, May 2015.
12. C. Christy, D. Tensing, and R. Shanthi, "Experimental study on compressive strength and elastic modulus of clay and fly ash brick masonry," *J Civ. EngConstrTechnol*, vol. 4, no. 4, pp. 134–141, 2013.
13. S. H. Basha and H. B. Kaushik, "Evaluation of Nonlinear Material Properties of Fly Ash Brick Masonry under Compression and Shear," *J. Mater. Civ. Eng.*, vol. 27, no. 8, pp. 04014227-1–11, Aug. 2015.
14. J. L. Ooi, L. W. Ean, B. S. Mohammed, M. A. Malek, L. S. Wong, C. W. Tang, and H. Q. Chua, "Study on the Properties of Compressed Bricks Using Cameron Highlands Reservoir Sediment as Primary Material," *Appl. Mech. Mater.*, vol. 710, pp. 25–29, Jan. 2015.
15. E. L. Woen, M. A. Malek, B. S. Mohammed, T. Chao-Wei, and M. T. Tamunif, "Experimental study on compressive strength of sediment brick masonry," in *AIP Conference Proceedings*, 2018, vol. 1930.
16. S. B. Singh and P. Munjal, "Bond strength and compressive stress-strain characteristics of brick masonry," *J. Build. Eng.*, vol. 9, pp. 10–16, 2017.
17. R. Lumantarna, D. T. Biggs, and J. M. Ingham, "Compressive, Flexural Bond, and Shear Bond Strengths of In Situ New Zealand Unreinforced Clay Brick Masonry Constructed Using Lime Mortar between the 1880s and 1940s," *J. Mater. Civ. Eng.*, vol. 26, no. 4, pp. 559–566, 2014.
18. E. L. Woen, M. A. Malek, B. S. Mohammed, T. Chao-Wei, and M. T. Tamunif, "Experimental study on compressive strength of sediment brick masonry," in *AIP Conference Proceedings*, 2018, vol. 1930, no. 1, p. 020017.