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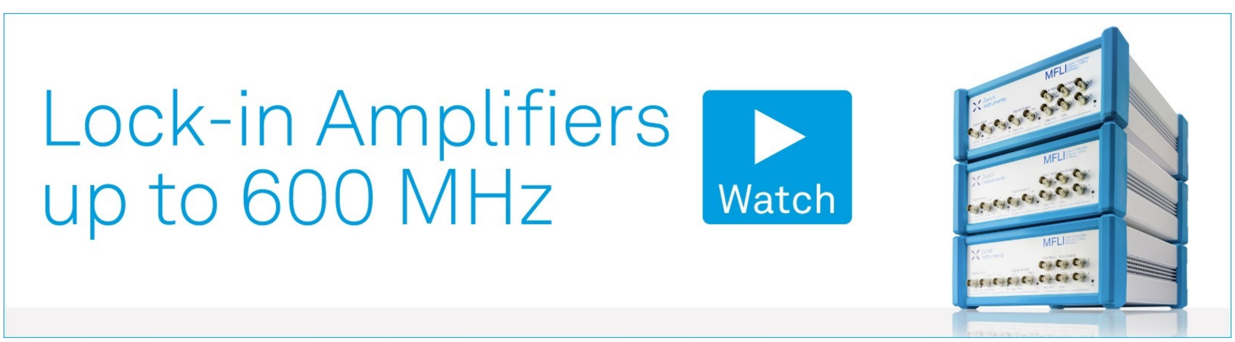

# Experimental Study on Compressive Strength of Sediment Brick Masonry

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**Abstract.** The effects of pre-wetted unit bricks, mortar type and slenderness ratio of prisms on the compressive strength and failure mode of newly developed sediment brick have been evaluated and compared to clay brick and cement-sand bricks. The results show that pre-wetted sediment brick masonry exhibits higher compressive strength of up to 20% compared to the dry sediment masonry. Using cement- lime mortar leads to lower compressive strength compared to cement mortar. However, the sediment brick masonry with the cement lime mortar exhibit higher compressive strength in comparison with cement mortar masonry. More of diagonal shear cracks have been observed in the failure mode of the sediment bricks masonry compared to clay and cement-sand bricks masonry that show mostly vertical cracks and crushing. The sediment unit bricks display compressive strength in between clay and cement-sand bricks.

## INTRODUCTION

Recycling of industrial by-products or waste has been a popular alternatives in producing sustainable green construction building materials [1-2]. Many researches have been conducted to evaluate the properties of clay bricks masonry under compression [3-10]. Studies for a newly developed material such as fly ash bricks also have been carried out to study its properties compared to clay bricks [11-12].

The compressive strength of a masonry composite is not linearly dependent on either of its constituents, i.e. bricks and mortar. Among other factors, it is also influenced by brick-mortar bond strength which is affected by the mortar water retentivity and roughness or the open pore structure of the brick surface. In addition, masonry is constructed from local available bricks which have various properties and may produce masonry with stiff brick and soft mortar or vice versa. Evaluation of the nonlinear properties of the clay masonry, including brick-mortar bond and the failure mode have been reported in the literature [11, 13].

The initial moisture of the brick plays an important role as the moisture transport between the mortar and brick effects the hydration of the cementitious products of the mortar. In this case, cement-lime mortar seems to have good water retention and flow properties that finally led to a better bonding with the bricks [4]. Highly absorptive brick units are pre-wetted prior to laying to avoid the water suction effects [11]. However, too high or too low initial rate of absorption (IRA) is unfavourable to the brick-mortar bond. Low-suction bricks tend to flow on mortar in the

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case of damp bricks, while highly absorptive bricks result in weak brick-mortar bond because of the rapid suction effects [3].

In [14] found that IRA less than 0.25 kg/m$^2$/min is low suction bricks and IRA more than 1.5 kg/m$^2$/min is a highly porous and absorptive bricks, whereby IRA ranging from 0.25 to 1.5 kg/m$^2$/min provides good bond strength.

High modulus bricks undergone lateral tension induced by shear stresses at the brick-mortar interface while the shear stresses at the interface of low modulus bricks is in the opposite direction, induced lateral compression thus postponed the failure of the brick [4]. The bond strength can also be evaluated from the failure mode of the masonry prism. Behaviour of newly developed bricks may differ from the conventional clay bricks, hence study needs to be carried out for the performance of the masonry bricks.

## METHODOLOGY

The sediment 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 [15]. The bricks were tested accordance with the requirements of the ASTM C140 and ASTM C67.

The sediment, clay and cement sand unit bricks were tested on the density, water absorption, initial rate of absorption (IRA) and compressive strength. The properties are listed in Table 1. The mix proportion for the mortars with water-cement ratio 0.8 is shown in Table 2. The 70 mm cubes mortar were tested for compressive strength on the testing day of masonry. The masonry prisms were constructed with dry and pre-wetted units joint with two types of mortars. 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. The pre-wetted masonry units were immersed in water for 15 mins prior to construction. 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 three and five levels prisms were constructed with an average mortar thickness varying from 10 to 12 mm. The compressive strength of the prisms were tested on average of five samples for each type of masonry prism using universal testing machine with capacity of 1000 kN under load-controlled with approximate rate of 0.11 MPa/s. Figure 1 shows the test set-up for the compression test.

**TABLE 1.** Properties of unit bricks

| Type of Bricks | 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 | Cement | Hydrated Lime | Fine Sand |
|---|---|---|---|
| M 1 | 1 | 0.5 | 4.5 |
| M 2 | 1 | 0 | 3 |

**FIGURE 1.** Test set-up for prism compression test

## RESULTS AND DISCUSSION

Initial rate of absorption (IRA) test was conducted accordance to the requirements of ASTM C67 which requires masonry unit with suction less than 30 g/min per 194 $cm^2$ to prevent excessive suction of water from the mortar during construction that could disturb the hydration of cement in the mortar. Sediment bricks show IRA of 34.05 g/min per 194 $cm^2$, which slightly higher than the limit. Figure 2 and 3 show compressive strength of the prisms comparing between M1 and M2 of different mortar mixes for different levels and type of prisms.

In Fig. 2 and 3, compressive strength of the three (H/t = 2.15) and five levels (H/t = 3.65) prisms show reduction of 3% to 42%. For instance, compressive strength for five levels RD prism using M1 decreased by 3% compared to three levels while five levels RD using M2 decreased by 42% compared to three levels. The compressive strength decreased as the sample H/t ratio increased due to the confining stresses [8], therefore prisms for five levels will be used for the discussion below (Fig. 4 and 5). The pre-wetted masonry shows increment of compressive strength compared to the non-wetted masonry. Pre-wetted sediment masonry (SW) shows increment of 5 to 20% higher than the non-wetted sediment masonry (SD). Nevertheless, the non-wetted clay masonry prism shows higher compressive strength compared to its pre-wetted version for M1. RWM2 in five levels prism shows 65% increment of compressive strength compared to RDM2. Compressive strength of clay masonry prism increased with mortar strength, but the failure strain is higher in mortar using lime. Hence, using lime in mortar has a significant improvement in ductility of clay masonry [11]. This condition was observed in samples RWM2. Tests conducted on clay bricks from literature found that an absorptive brick units (IRA more than 30 g/min per 194 $cm^2$) should be wetted prior to laying for better bond strength [11]. Figure 3 shows that cement-lime mortar (M1) increased the prisms strength in five levels prisms because masonry units with high IRA are compatible with high water retentivity mortar. Cement-lime mortar (M1) have better water retention with better flow properties although the compressive strength is much lower than M2. Addition of lime has led to improve the penetration of the hydration products into the brick pores and further improve the contact and bond strength [4].

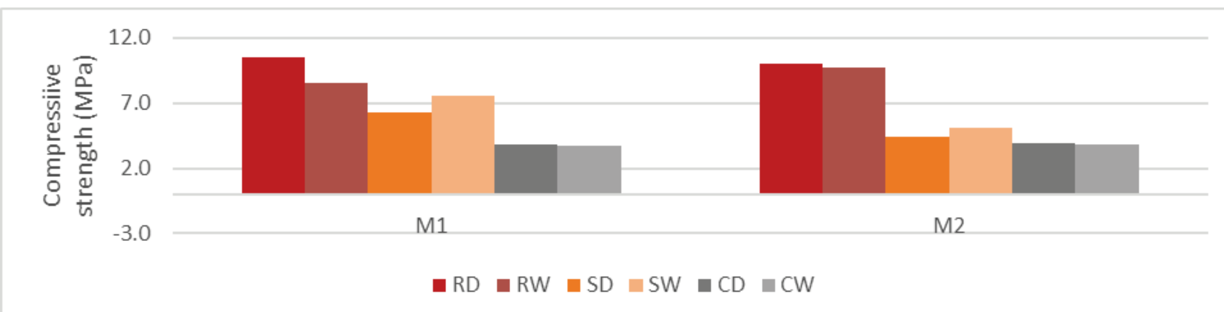


**FIGURE 2.** Compressive strength for three levels masonry prisms

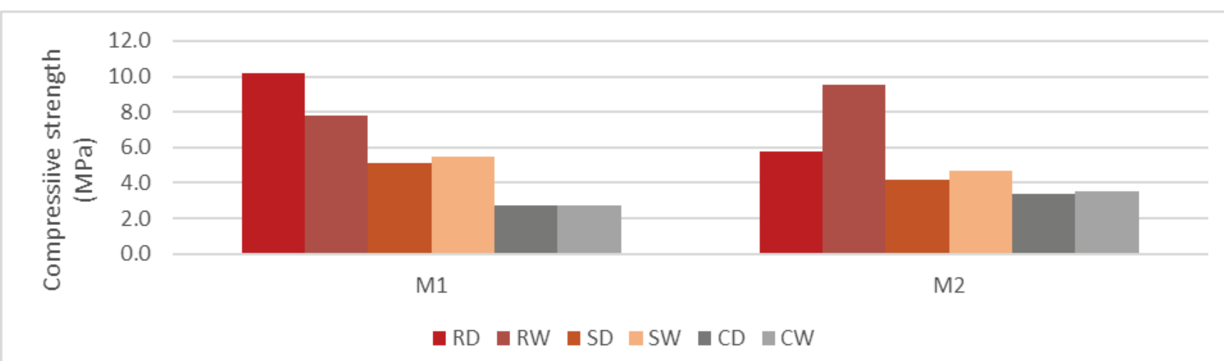


**FIGURE 3.** Compressive strength for five levels masonry prisms

Fig. 4 and 5 show the compressive strength of five levels prisms and its mortar strength. RWM1 is an example of stiff brick soft mortar masonry that shows brittle and crushing upon failure [16]. Figure 6 shows the failure mode of RWM1 that initiated from the middle of the masonry. On top of that, vertical tensile breaks were observed on the RWM1 samples. Clay masonry prisms fail in face shell separation. The sediment masonry shows the case of masonry with soft bricks and stiff mortar that experienced triaxial compression in the bricks, uniaxial compression and bilateral tension in mortar until the interface bonding failed. Failure is initiated by the tensile splitting of the mortar and later extended to the bricks [17]. The failure mode of the sediment masonry prisms are shown in Fig. 7. The sediment prisms fail in shear break mode. Pre-wetted cement sand masonry shows not significant effects on the compressive strength. It only shows up to 3% difference on the compressive strength because of the open pore structure of the bricks.

The failure patterns are associated with the elastic properties of the masonry components in the case of the brick-mortar interface bond is remained intact until failure. Vertical splitting cracks followed by crushing of bricks are associated with strong mortar (M2), while diagonal shear cracking and vertical splitting are predominant failure modes for prisms with intermediate (M1) and weak mortar [4, 11, 17]. However, the bond strength of the prism should be further investigated and verified by bond strength test.

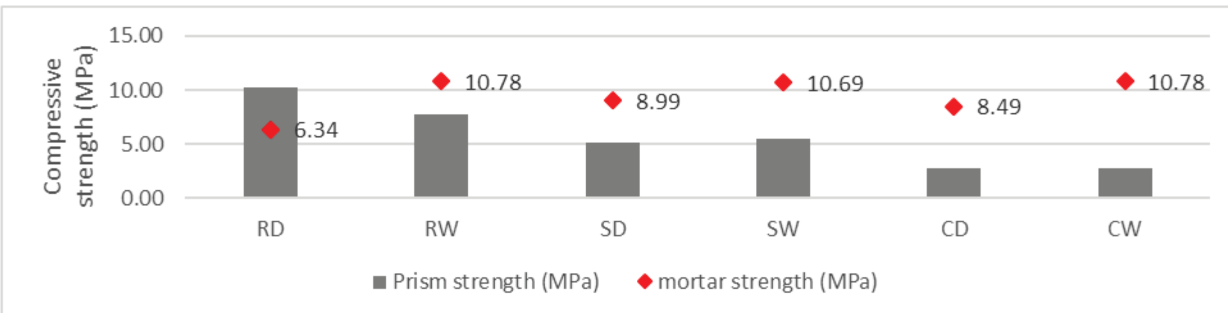


**FIGURE 4.** Compressive strength of five levels masonry prisms with M1 mortar strength

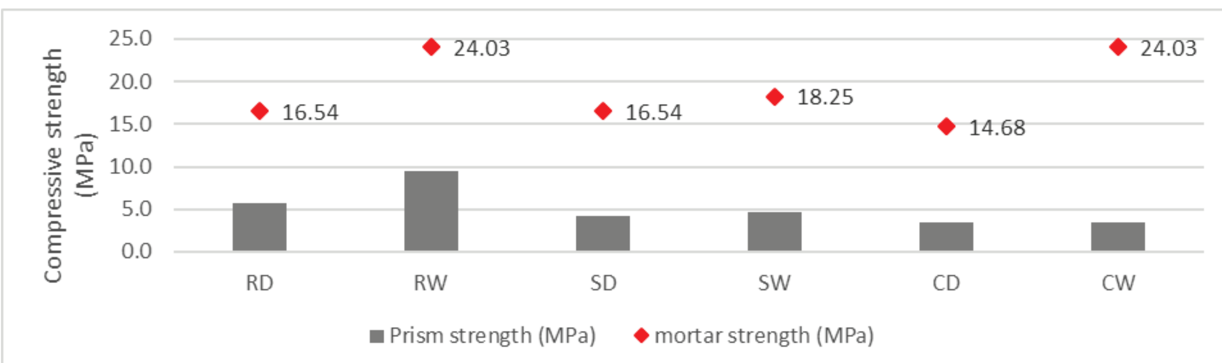


**FIGURE 5.** Compressive strength of five levels masonry prisms with M2 mortar strength

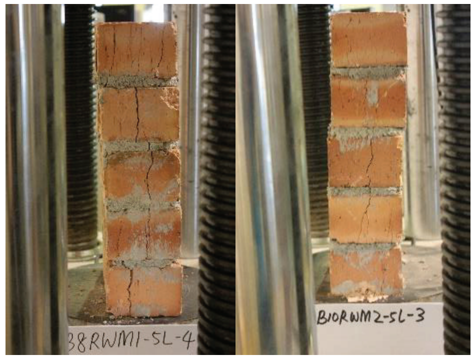


**FIGURE 6.** Failure mode of pre-wetted clay masonry prisms


**FIGURE 7.** Failure mode of pre-wetted sediment masonry prisms


**FIGURE 8.** Failure mode of pre-wetted cement-sand masonry prisms

## CONCLUSION

Conclusions can be made as follows:

1. Sediment bricks unit and prisms compressive strength fall in between clay bricks and cement-sand bricks.
2. Pre-wetted masonry units for IRA more than 30 g/min per 194 $cm^2$ has led to increase masonry prisms compressive strength. Pre-wetted sediment prism has showed increased strength up to 20% for cement-lime mortar (M1) and 16% for cement mortar (M2), although IRA of the sediment bricks just slightly exceeded the specify limit by ASTM. However, the pre-wetted effects are lower as the H/t increased.
3. Cement-lime mortar exhibits better bonding in sediment masonry although the compressive strength is lower than the cement mortar. This can be observed from the failure mode when diagonal shear cracks are visible on the samples. The high water retentivity mortar is adapted well to the sediment bricks.

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