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Journal homepage: http://journal.unj.ac.id/unj/index.php/jpensil/index

THE PERFORMANCE OF MASONRY BRICK WITH CALCIUM HYDROXIDE AS MORTAR

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P-ISSN: 2301-8437
E-ISSN: 2623-1085

ARTICLE HISTORY
Accepted:
15 Agustus 2023
Revision:
28 September 2023
Published:
29 September 2023

ARTICLE DOI:
10.21009/jpensil.v12i3.37905

Abstract

This study aims to determine the shear strength and flexural strength of red brick masonry, determine the effective thickness of calcium hydroxide mortar with a mixture ratio of 1Kp:2Ps, and determine the failure pattern of red brick masonry due to the load received during the direct shear strength test and flexural strength test. The research was conducted by experimental method. The tests carried out were the direct shear and flexural strength tests. Variation of successive mortar thickness of 10mm, 15mm, and 20mm. The test object is 18 (eighteen), the thickness variation consists of 3 test objects. Data analysis used descriptive quantitative by finding the average value of the shear strength and flexural strength. Based on the test results, the average compressive strength and splitting tensile strength of the mortar were 0.613 MPa, 0.0414 MPa. The average shear strength with a 10mm; 15mm; and 20mm is 0.025 MPa; 0.020 MPa; and 0.016 MPa, respectively. The flexural strength of mortar thickness with 10mm, 15mm, and 20mm are 0.034 MPa; 0.045 MPa; and 0.041 MPa, , respectively. In the masonry shear test, the effective thickness of the mortar was found at 10mm with a maximum shear strength of 0.025 MPa, while in the flexural test, the effective thickness of the mortar was found at a thickness of 15mm with 0.045 MPa. The pattern of failure in red masonry's shear strength and flexural strength tests is the mortar failure.

Keywords: Mansory, Calcium Hydroxide, Experiment test

Introduction

Mortar has been widespread and used in cultural heritage built thousands of years ago in various corners of the country, one of which is Indonesia. Indonesia has various historical heritage buildings that must be maintained and preserved (Mashari et al., 2021; Parracha et al., 2020). The heritage of historic buildings in Indonesia is quite a lot and varied. The number of forts in Indonesia ranges from 442.9 forts in an unformed condition, 64 forts in ruins, 143 forts damaged, and 226 forts intact (Rinandi & Suryaningsih, 2015).

Conservation actions on historic buildings must be carried out to prevent sustainable damage and protect the preservation of cultural heritage buildings from being destroyed (Bülbül Bahtiyar & Dişli, 2022; D'Alpaos & Valluzzi, 2020; Mekonnen et al., 2022; Prabowo & Karsono, 2020). Reconstruction and conservation actions must be carried out according to the conditions in each building to prevent damage and maintain the authenticity of heritage buildings (Rahardjo, 2013).

In most historical buildings in Indonesia, the walls are composed of red bricks and glued together with lime mortar (Alecci et al., 2013; Mydin, 2017). Indonesia has an abundant lime supply, making it possible to use it as a substitute for some of the cement needs in mortar making (Riyanto et al., 2021). To conserve damaged mortar, the composition of the mortar must be suitable and similar to the original mortar so that it does not damage other parts and affect the strength of the building. In the restoration of Captain Liem's house, an artificial mortar with a mixture of 1Kp:2Ps was used. The lime used was quicklime which had been soaked in water. The compressive strength of mortar with the age of quenched lime and mortar specimens for 28 days each is 0.21 MPa (Swastikawati, 2022).

Lime has also been widely used in Indonesia to conserve cultural heritage buildings. Some researchers (Fitri et al., 2015; Safiera et al, 2016; Swastikawati, 2022) have applied this material for building improvement by adding adhesives such as cement, sand, and water additives. The problem is the degradation of the quenched lime material, which requires special handling when making the mortar mixture (Karatasios et al., 2008). The mixture's reliability has been tested through physical and mechanical characteristics approaches, limited to the compressive and tensile tests of the binder (Demiral et al., 2022; Hajj & Bhasin, 2018; Jiang et al., 2023; Zdeb et al., 2022; Y. Zhang et al., 2021).

Other mechanical parameters must be met to achieve the minimum standards for classifying mortar coating materials, including flexural and shear strength (Abdollahnejad et al., 2021; Binda et al., n.d.; Reza Nadi Abiz et al., 2023). This needs to be done to provide information related to the quality of the mixing material using certain formulations to obtain optimal proportions that can be recommended for repairing cultural heritage buildings (Arioglu & Acun, 2006; Pacheco-Torgal et al., 2012; Válek et al., 2019) especially since Indonesia is a country with high earthquake intensity, so it requires special handling. Handling in terms of strength, rigidity, and comfort of the building. Reviewed. Based on this, it is expected that the study of physical characteristics will impact product standardization, especially related to the effective thickness of the mortar layer, which can affect the performance of the reviewed structure.

Research Methodology

This research was conducted at the Building Materials Laboratory, Faculty of Engineering, Universitas Negeri Yogyakarta. The method used is the experimental. The specimens were red brick masonry with lime mortar tested for direct shear test with triplet method and flexure tested using three-point bending. Data analysis was carried out using descriptive quantitative by using the average value of shear strength and flexural strength.

Preliminary test in this study is quicklime with a water factor of 1.9; 2.0; and 2.1. The use of this variation aims to find the optimal water ratio for masonry with lime mortar.

Testing the specific gravity of quicklime is carried out to determine the amount of weight per volume. The specific gravity of quicklime is calculated using Equation (1)(SNI 03-1970, 1990).

Water is the basic material needed to trigger a hydraulic reaction process, which is a chemical reaction in the lime binder (Alvarez et al., 2021; Forster & Scottish Lime Centre Trust., 2004; Lanas et al., 2004; Santoso et al., 2017; Sinka M et al, 2015). Lime immersion with a water factor of 1.9, 2.0, and 2.1 by weight of lime. Tests were carried out on hardened lime mortar to determine the optimum compressive strength and splitting strength based on the water factor used. The amount of water used must be precise because water affects the compressive strength of the mortar (Aldabagh et al., 2022; Nugroho et al., 2022; Widiantoro & Ma'arif, 2014; X. Zhang et al., 2021). The compressive strength of lime mortar can be calculated using Equation (2) (SNI 03-6825, 2002).

$$\sigma = \frac{P}{A} \quad (2)$$

Notes: σ = compressive strength (MPa); P = axial load (N); A = areas (mm2)

The splitting tensile test is calculated with Equation (3).

$$F_t = \frac{2.P}{\pi.L.D} \quad (3)$$

Notes: F_t = Splitting tensile test (MPa); P = load (N); L = height (mm); D = Diameter (mm)

Testing the shear strength and flexural strength of the red brick masonry with lime mortar adhesive is used to test the wall masonry in receiving lateral forces due to the earthquake. Masonry with a relatively smaller height-to-width ratio will behave strongly in resisting shear. In contrast, if the height-to-width ratio is relatively larger, the masonry will behave strongly in resisting bending.

Testing the shear strength of the masonry was carried out using triplet specimens with a testing mechanism as shown in Figure 1.

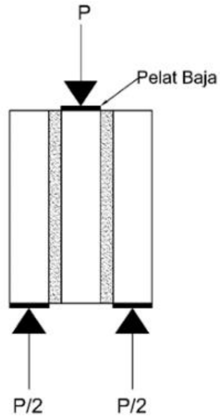

Figure 1. Direct test (Istegun & Celebi, 2018)

The shear stress of masonry can be calculated using Equation (4)(SNI-03-4164, 1996).

$$\tau = \frac{P+W}{2.b.h} \quad (4)$$

Notes: τ = shear stress (MPa); P = load (N); W = weight of plate (N); b = width (mm); h = height (mm)

The flexural strength test of the masonry was carried out using the three-point bending method. The location of the test object, the supports, and the loading points for the flexural strength test of the masonry are presented in Figure 2.

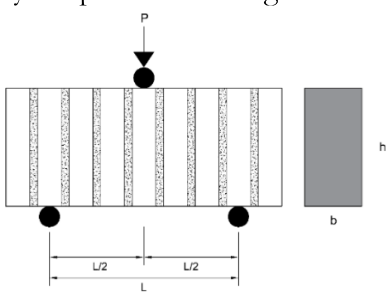

Figure 2. Flexural test (SNI 4154, 2014)

The flexural strength of masonry can be calculated using Equation (5).

$$R = \frac{3.P.L}{2.b.h^2} \quad (5)$$

Notes: R = flexural strength (MPa); P = Load (N); L = distance between support (mm); b = width (mm); h = height (mm)

The brick masonry test specimens in this study were made using quenched lime mortar based on the most optimum compressive and splitting strength values and with a variation of mortar thickness of 1 cm, 15mm, and 2mm. The use of thickness variations aims to obtain the most optimal mortar thickness for red masonry with lime mortar. Figure 4 shows the relationship between variables.

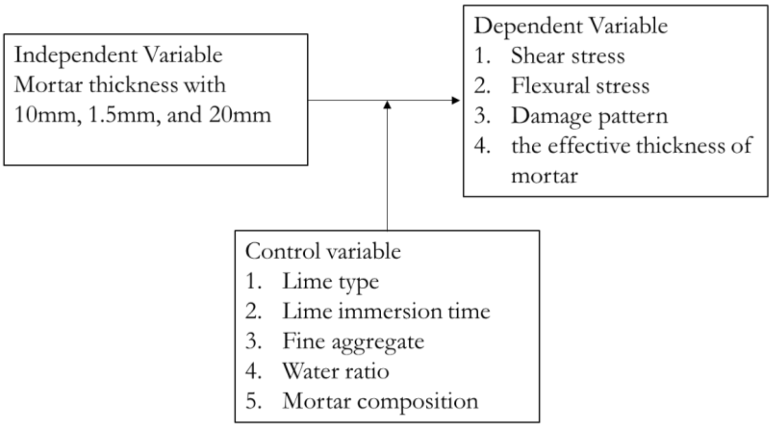

Figure 3. Reseach variable

The independent variable in this study is the thickness of the mortar layer on the brick masonry, with the direct shear and flexure test scheme on the specimen. Each composition value is determined by mixing quicklime and fine aggregate. The research was carried out in stages as shown in Figure 5.

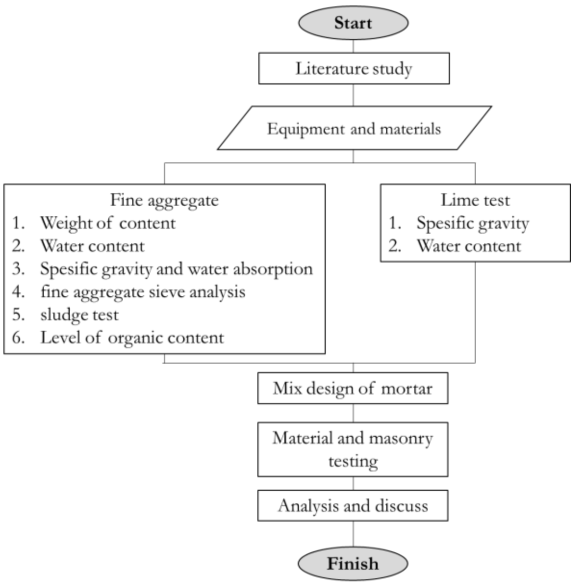

Figure 4. Research flow

Research Results and Discussion

Compressive Strength of Mortar

The compressive strength test was carried out on cube specimens with dimensions of 50×50×50mm, which were 28 days.

Table 1. Compressive strength of mortar

Code of specimens	Mass (kg)	Dimension (mm)		P Max (N)	Compressive strength (MPa)	Compressive strength averages (MPa)
		b	h			
K1VA190	0.220	49.5	49.7	1670	0.679	0.547
K2VA190	0.224	50.0	50.0	1530	0.612	
K3VA190	0.220	49.6	50.5	1090	0.435	
K4VA190	0.221	50.8	49.7	1170	0.463	
K1VA200	0.220	49.7	49.0	2020	0.829	0.613
K2VA200	0.222	49.8	49.7	1300	0.525	
K3VA200	0.220	49.2	49.9	1380	0.562	
K4VA200	0.224	50.0	49.5	1320	0.533	
K1VA210	0.207	48.3	59.2	1250	0.437	0.461
K2VA210	0.208	48.5	49.7	1010	0.419	
K3VA210	0.209	49.6	48.7	1410	0.584	
K4VA210	0.213	49.0	49.0	970	0.404	

Notes:
K1, K2, K3, K4 = cube specimens
VA190, VA200, VA210 = water contents

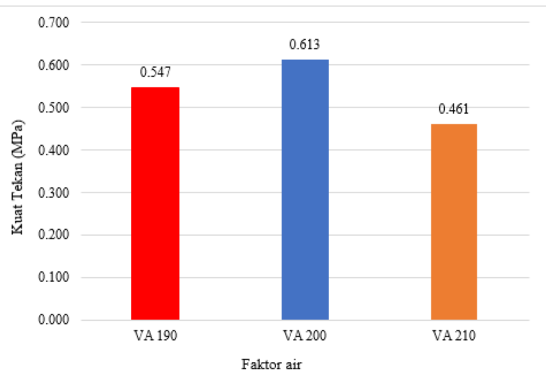

Figure 5. Compressive strength averages

Based on Table 1 and Figure 5, it can be seen that the mortar test object with lime immersion water variations is 1.9; 2.0; and 2.1 produces a strong compressive strength of 0.547 MPa, respectively; 0.613 MPa; and 0.461 MPa. The lowest average compressive strength of mortar is in the water variation 1.9. The most optimal average cube mortar compressive strength is in the water variation 2.0. The results of this study have higher compressive strength and split tensile strength values compared to research (Murty, 2005), which has relatively smaller compressive strength due to the manual-based material mixing process.

Splitting Tensile Test of Mortar

The splitting tensile strength test was carried out on cylindrical specimens with dimensions of 100×200 mm, which were 28 days old. The test results are presented in Table xx, where the specimen with a water content of 200 has a better value compared to other materials.

Adding the water content value does not significantly impact the physical test characteristics. This is because, with the addition of water volume, the quenched lime paste becomes more plastic, affecting the bonding strength between the bricks and the mortar layer. The nature of slaked lime, which is more dominant in Pozoland, causes the treatment time to be longer than ordinary admixtures.

Thus, in subsequent tests, an additional variable is needed, namely the time for curing the test object with a mixture of quenched lime mortar, as a comparison to obtain material characteristic values that have more impact on its mechanical characteristics.

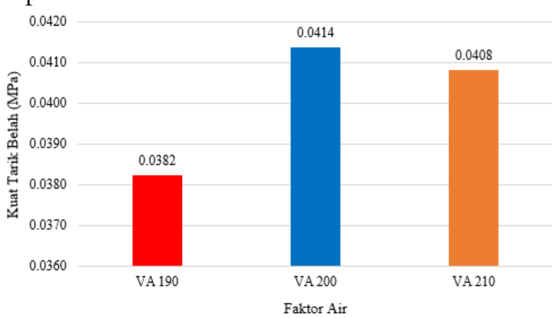

Figure 6. Splitting tensile strength averages

Table 2. Splitting tensile test results

Code of specimens	Mass (kg)	Dimension (mm)		P Max (N)	fts (MPa)	fts (MPa)
		b	h			
SC1WC190	1.97	201.6	83.80	1140	0.0429	0.0382
SC2WC190	1.94	202.6	83.50	960	0.0361	
SC3WC190	1.93	209.0	84.50	980	0.0353	
SC4WC190	1.99	201.7	84.40	1030	0.0385	
SC1WC200	1.96	197.0	82.70	1430	0.0559	0.0414
SC2WC200	1.96	799.3	84.15	1070	0.0101	
SC3WC200	1.94	197.0	84.75	1110	0.0423	
SC4 WC 200	1.97	198.7	73.90	1320	0.0572	
SC1 WC 210	1.87	193.9	83.80	1030	0.0403	0.0408
SC2 WC 210	1.88	196.5	85.10	1100	0.0419	
SC3 WC 210	1.87	194.3	85.10	1090	0.0419	
SC4WC210	7.87	196.1	83.90	1010	0.0391	

Notes:
SC1, SC2, SC3, SC4 = cylinder specimens
WC190, WC200, WC210 = water content

Based on Table 2 and Figure 6, it can be seen that the mortar test object with variations in lime soaking water is 1.9; 2.0; and 2.1 produces a split tensile strength of 0.0382 MPa each; 0.0414 MPa; and 0.0408 MPa so that the most optimal is the water variation 2.0.

Direct Shear Test

The shear strength test was carried out on specimens of triplet masonry bricks with a curing age of 28 days based on (SNI-03-4164, 1996). The specimens consisted of 9 (nine) pieces with each variation having a different mortar thickness.

Table 3. Direct shear test of mansoory

Code of specimens	Dimension (mm)			P Max (N)	fst (MPa)	fst averages (MPa)
	b	h	l			
1 DST I	111.0	228.1	156.4	765.28	0.015	0.025
1 DST II	112.1	231.7	161.3	2335.28	0.045	
1 DST III	111.8	229.6	157.9	825.28	0.016	
1.5 DST I	110.7	229.7	168.6	645.28	0.013	0.020
1.5 DST II	109.4	227.3	166.4	1225.28	0.025	
1.5 DST III	110.3	228.5	168.2	1185.28	0.024	
2 DST I	110.8	228.6	180.2	715.28	0.014	0.016
2 DST II	110.4	231.9	180.6	775.28	0.015	
2 DST III	112.6	233.5	178.6	1055.28	0.020	

Note:
DST = direct shear test
1; 1.5; 2 = mortar thickness
I, II, III = number of specimens

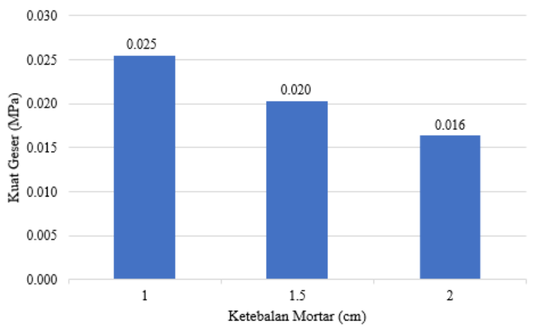

Figure 7. Direct shear test averages

Based on Table 3 and Figure 7, the results of comparing the average shear strength of the masonry for each variation of mortar thickness are 0.025 MPa, 0.020 MPa, and 0.016 MPa. The highest average shear strength occurred in the mortar with a thickness of 1 cm, which was 20.10% greater than the 1.5 cm mortar variant and 35.21% greater than the 2 cm mortar variant. The lowest average shear strength occurred in the 2 cm mortar variant, 18.92% lower than the 1.5 cm mortar variant. The shear strength of the red masonry with a mortar thickness of 1 cm has a higher value than the thickness of the other mortar variants. This is due to the shrinkage properties of the quenched lime material on the brick masonry, affecting the mechanical behavior when a direct shear test occurs. The bonding capacity of quenched lime still needs to be done with a longer age approach, also by adding other additives, namely silica fume material, to increase its shear strength. The thicker the mortar layer, the more brittle it will be and has a small shear value, in addition to the nature of the quenched lime as a pozzolan which takes longer to react with water.

Flexural Test

The flexural strength was carried out for 28-days-on masonry specimens. The flexure tests consist of 9 (nine) specimens, which has a different mortar thickness. The flexural strength test was carried out using the three-point loading method with a controlled loading speed of 0.35MPa/second on the testing machine.

The resulting test results are the maximum load (Pmax) for each test object with dimensions that have been adjusted to the testing machine.

Table 4. Flexural testing specimens

Code of specimens	Dimension (mm)			P Max (N)	fst (MPa)	fst averages (MPa)
	b	h	l			
1 DS_I	110.1	226.3	501	260	0.032	0.034
1 DS_{II}	110.7	227.4	501	200	0.024	
1 DS_{III}	110.7	229.3	503	380	0.045	
1,5 DS_I	111.0	228.4	545	320	0.041	0.045
1,5 DS`$_{II}$	111.7	232.7	540	350	0.043	
1,5 DS_{III}	111.0	229.5	553	400	0.051	
2 DS_I	112.4	229.4	573	410	0.054	0.041
2 DS_{II}	113.0	233.8	587	238.4	0.031	
2 DS_{III}	109.4	227.3	573	270	0.039	

Note:
DS = direct shear test
1; 1.5; 2 = mortar thickness
I, II, III = number of specimens

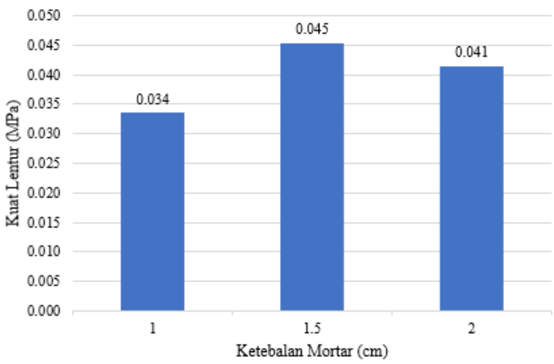

Figure 8. Flexural test averages

Based on Table 4 and Figure 8, the comparison results of the average flexural strength of the masonry for each variation of mortar thickness are 0.034 MPa, 0.045 MPa, and 0.041 MPa. Flexural strength with the highest value occurred in the mortar with a thickness of 1.5 cm, which was 25.84% greater than the 1 cm mortar and 8.91% greater than the 2 cm mortar variant. Red brick's lowest average flexural strength occurred in the 1 cm mortar variant, 18.58% lower than the 2 cm mortar variant. This is due to the sticky power of the extinguished lime, which will be brittle if it has larger dimensions. In addition, its higher shrinkage will impact its mechanical characteristics; a faster drying process in this masonry requires stable moisture to maintain the properties of quenched lime, which requires longer react with other connecting components (Lumantarna et al., 2012; Pozo-Antonio, 2015; X. Zhang et al., 2023).

Failure Pattern of Mansory Brick

The failure pattern of the masonry due to the applied load is explained as follows.

Direct shear test

The specimen of masonry has different thickness in Figure 9 up to Figure 11.

Figure 9. Failure pattern of 1 UGPB

The masonry suffers type A damage, namely the bond failure between the mortar and the masonry (slip) with a 100-mm, 150-mm, 200-mm in thickness.

Figure 10. Failure pattern of 1.5 UGPB

Figure 11. Failure pattern of 2 UGPB

The damage that occurred to the specimens with various mortar thicknesses had similar characteristics, this was because the slaked lime had a longer setting time due to its pozoland-like nature. There is a slip failure at the interface due to the imperfect bonding process, improper installation conditions, and smooth brick surface conditions.

Flexural test

Various patterns of brick masonry failure are presented in Figures 12 to Figure 1. Each test characteristic has similar failures. This indicates that the quenched lime mortar has a special effect on the variety of failure patterns in masonry (Bompa & Elghazouli, 2020; Chase, 1983; Elghazouli et al., 2021; Gil, 2016; Sathiparan et al., 2013).

Figure 12. Failure pattern 1 ULPB

Each specimen with a thickness of 10 mm has a type A failure pattern, namely the failure of the mortar at one brick-mortar interface.

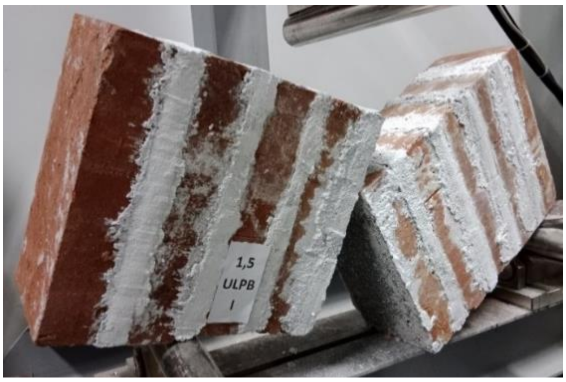

Figure 13. Failure pattern 1.5 ULPB

Each specimen with a thickness of 15mm has a type A failure pattern, namely the failure of the mortar at one brick-mortar interface.

Figure 14. Failure pattern 2 ULPB

Each specimen with a thickness of 2 cm has a type A failure pattern, namely the failure of the mortar at one brick-mortar interface. It can be concluded that all ULPB specimens failed in the mortar because the bonds produced by the mortar and the bricks were smaller than the bonds between the mortar and the mortar.

Conclusion

In the direct shear test, the calcium hydroxide mortar with a thickness of 10mm, 15mm and 20mm had uniform failures, namely slippage between the mortar and the bricks. While in the flexure test, the main failure also occurred in the mortar with an effective thickness of 15mm. As for the flexural strength of the red bricks with a variation of 1 cm mortar thickness; 1.5cm; and 2 cm respectively of 0.034 MPa; 0.045 MPa; and 0.041 MPa experienced a failure pattern in the mortar. (3) The thickness of the effective mortar in the shear strength test is red masonry with a mortar thickness of 1 cm. The thickness of the effective mortar in the flexure test is masonry with a mortar thickness of 15mm.

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