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Original Article

Mechanical Properties of Brick Masonry Reinforced with Wire Mesh: Advancing Sustainable and Resilient Construction

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Abstract *- Damage to masonry is influenced by the materials and mixture variations of bricks and mortar. This study investigates the mechanical performance of red Brick Masonry Reinforced with wire mesh layers embedded in each course of bricks as internal Reinforcement. The experimental program involved constructing masonry specimens with wire mesh diameters of 5 mm, 6 mm, and 8 mm. The research focuses on compressive, shear, flexural strength, ductility, stiffness, and dissipated energy. Results show that adding wire mesh layers significantly improves masonry performance. Compressive strength increased by 50%, 68%, and 43% for 5 mm, 6 mm, and 8 mm wire diameters, respectively. Shear strength increased by 16%, 60%, and 32%, while flexural strength gains of 402%, 1100%, and 1237% for the same diameters. Furthermore, applying wire mesh can increase the masonry's ability to dissipate energy. This technique demonstrates a promising approach for improving structural performance without changing the wall's external appearance, providing a practical method for reinforcing masonry structures.*

Keywords *- Wire Mesh, Compressive Strength, Shear Strength, Flexural Strength, Dissipation Energy.*

1. Introduction

The most commonly used wall construction material is red brick, made from molded clay and fired at high temperatures until dry and reddish. Red brick is widely used because of its affordability, wide availability, fire resistance, and weather resistance, and it is designed to withstand water exposure without disintegration [1]. Masonry is often used in residential and low-rise buildings, serving as interior and exterior partitions for weather protection [2-4]. However, national regulations classify masonry as a non-structural element, resulting in inadequate planning. Consequently, masonry is susceptible to damage due to inadequate support against lateral forces during earthquakes that cause significant damage to the masonry [5].

The damage commonly seen in brick masonry is typically marked by cracks or fractures that run diagonally. This damage can be affected by the masonry's mixture and materials (bricks and mortar). Efforts to mitigate damage to masonry structures exhibiting cracks are generally undertaken by enhancing the bearing capacity of the structure, repairing cracks, and addressing geometric deficiencies. To ensure the success of any maintenance plan, a thorough understanding of mechanical and structural dynamics, assessment methods, and masonry repair and strengthening techniques is essential. Effective prevention and rehabilitation can only be achieved if structural damage conditions are properly assessed, ensuring the building's structural integrity, aesthetic appeal, and functionality are maintained [6-8]. Masonry repairs can be categorized as aesthetic or structural repairs. Aesthetic repairs, such as mortar and joint renewal, primarily improve the appearance of the structure and restore the non-structural features of damaged components. Meanwhile, structural repairs can be carried out using several methods, such as filling cracks through injection techniques, replacing damaged elements with new ones, or strengthening structural components to increase their bearing capacity [6, 9].

Various masonry wall strengthening methods have been developed by researchers as an alternative to prevent wall damage due to lateral loads such as earthquakes. Wall reinforcement methods have been studied include external Reinforcement, such as the use of polypropylene band mesh by Meguro (2012) [10], Fiber Reinforced Polymer and Polypropylene Composite by Umair (2015) [11], Fiberglass and Polypropylene Fiber Paint Coating by Eka (2024) and Reinforcement of masonry using Jute fiber by Stochino (2025) [12]. In addition, internal wall reinforcement has also been carried out using interlocking methods, such as

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interlocking using reinforcement bar by Regis (2022), and Cement Clay Interlocking Masonry Strengthened with CFRP and Cement-Sand Mortar by Joyklad (2023) [13].

External Reinforcement by Meguro et al. used a Polypropylene band (PP-band) installation on the surface of the wall as Reinforcement. Despite having no significant effect on the initial strength, the use of the PP-band greatly enhanced the masonry wall's ductility and energy dissipation. Furthermore, the failure of URM walls exhibited a more brittle behavior compared to walls with a PP-band.

Overall, the application of the PP-band improved the performance of the walls [10]. Research by Umair et al. on masonry walls strengthening using FRP and PP-band composites showed that the combined FRP + PP-band system not only increased the peak strength but also significantly improved the ductility of masonry walls. This type of Reinforcement can serve as a potential solution for seismic retrofitting of Unreinforced Masonry (URM) structures [11].

Eka et al. have also conducted research on external Reinforcement of masonry by applying a fiber paint coating on the surface. Two types of fiber paint were used in the study: a mixture of waterproof paint with polypropylene fibers and waterproof paint with fiberglass fibers. The fiber paint layers are applied with different thicknesses, namely 1 mm, 2 mm, and 3 mm. The tests carried out included compression and shear testing, and the results showed an increase in compressive strength of up to 82.16% in samples with polypropylene fiber paint and up to 105.91% in samples with fiberglass fiber paint.

Furthermore, internal wall reinforcement methods, such as the interlocking technique investigated by Regis et al., examined the strengthening of brick walls using reinforcing bars as interlocking materials. Their findings showed a substantial increase in both shear and compressive strength; however, its application is quite challenging. In the study by Joyklad et al., Cement Clay Interlocking Brick (CCIB) was used. CCIB is an innovative example that has now been widely adopted in Thailand as a replacement for conventional masonry. Many researchers have investigated the behavior of the CCI brick.

However, the behavior of the CCI brick is not found to be effective under lateral, tensile, and diagonal compressive loads. Therefore, in the study by Joyklad et al., external Reinforcement with CFRP and cement-sand mortar was applied. The experimental results indicated that CFRP combined with Cement-Sand mortar (CS) is an effective way to increase the strength and deflection of CCIB walls. The wall reinforced with two layers of CFRP strips and 10 mm thick CS mortar has an ultimate load-bearing capacity of 171%, and axial deformation is 190% greater than that of the unreinforced CCIB wall [13].

Previous studies on masonry wall strengthening have primarily focused on external reinforcement techniques, such as the use of Fiber Reinforced Polymer (FRP), PP-band, and fiber paint surface coatings. Although these methods are effective in improving strength and ductility, they often alter the surface appearance, require additional finishing work, and may reduce the aesthetic quality of the masonry surface. Furthermore, interlocking Reinforcement is more difficult to apply, as it requires drilling holes to insert interlocking materials such as steel, bamboo, and others. In this study, wire mesh was selected as the internal reinforcement material due to several advantages, including high tensile strength, high elastic modulus, lightweight, corrosion resistance, easy installation without special procedures, minimal cross-sectional changes, cost-competitive performance, and low requirement for skilled labor [14].

Wire mesh is a construction material composed of various combinations of metal bars, such as aluminum or steel, assembled in large quantities and interconnected to form sheets [14-16]. Several previous studies have been conducted on the potential application of wire mesh as Reinforcement, including masonry reinforcement using Wire Reinforced Cementitious Matrix by Tripathy and Singhal (2021) [17]; masonry wall reinforcement with Welded Wire Mesh (WWM) by Syiemiong and Marthong (2020) [18]; research by Marbaniang et al. on out-of-plane bending of masonry walls with Welded Wire Mesh (WWM) (2021) [19], and Warjri et al. (2022) who examined the in-plane behavior of masonry walls reinforced with steel Welded Wire Mesh (WWM) and re-coated with mortar [20]. The use of wire mesh in previous studies has shown quite satisfactory structural behavior results. However, most previous studies used external reinforcement methods. In contrast, research on internal reinforcement methods, particularly the use of wire mesh embedded in mortar joints, is still limited. Therefore, a research gap still exists in understanding how internal wire mesh reinforcement enhances the overall seismic performance of masonry walls without affecting their architectural appearance. The novelty of this study lies in the introduction of an internal reinforcement technique using embedded wire mesh layers within red brick masonry, without altering the wall's surface appearance. The study aims to investigate the mechanical performance of red brick masonry reinforced with wire mesh layers, particularly focusing on its compressive, shear, and flexural strength.

The use of wire mesh as Reinforcement is an effective method because it is not only simpler to implement, but it is also readily available at many building supply stores, facilitating research and application. Within the framework of the Sustainable Development Goals (SDGs) established by the United Nations (UN) in 2015, there are 17 interrelated goals that work together to address various global challenges. [21]. Civil engineering plays a crucial role in achieving these goals, particularly in the effort to provide reliable and robust

buildings as a foundation for sustainable growth. Strengthening brick masonry will be one of the solutions to protect cities by improving the performance of existing buildings and housing, while contributing to the achievement of the SDGs.

From 17 SGDs, reinforcing brick walls directly contributes to SDGs 11 by enhancing building safety, SDGs 12 (Sustainable Construction Method), and SDGs 8, which improve the development of the economy in some ways. However, the brick strengthening shows an important connection to SDG 11, which is to achieve Sustainable Cities and Communities, providing secure and long-lasting cities by enhancing the strength and durability of masonry structures [20, 21]. Researchers find that brick strengthening methods are crucial to provide seismic-resistant buildings [22, 24]. Moreover, seismic-proof structures help cities become safer and economically stronger due to cost-effective construction plans that choose durability, long-life buildings, and the promotion of local materials and technology [25].

Using the wire mesh strengthening approach is in line with the Sustainable Development Goals in real ways, such as heritage preservation initiatives. The restoration of the Al Jahili mosque demonstrates that the structural Reinforcement of old masonry buildings is in line with SDG 11 by protecting cultural heritage while ensuring structural integrity [26, 27]. The Green Building Minimum Compliance System in Rwanda [28] shows how sustainable building solutions like masonry reinforcement can help meet several Sustainable Development Goals while also lowering greenhouse gas emissions. Disaster Risk Reduction: Strengthening masonry buildings in places that are prone to earthquakes helps to achieve SDG 11 right away by lowering the risk of disasters to life and livelihoods [22, 29, 30].

2. Material and Methods

This research examines the mechanical performance of red brick walls reinforced with wire mesh layers, specifically assessing their compressive, shear, and flexural strength. The experimental program was carried out by constructing wall specimens in which a wire mesh sheet was embedded within each course of red bricks, serving as an internal reinforcement system. The primary objective was to characterize how the inclusion of wire mesh alters the structural response of the masonry under different loading conditions. The research procedure is summarized in the flow diagram presented in Figure 1.

2.1. Material

The initial stage includes testing the mechanical properties of red brick material, fine aggregate (sand), and mortar used in red brick masonry construction, along with evaluating the wire mesh material, which functions as Reinforcement in this study.

2.1.1. Red Brick

The red bricks that will be used are the ones that are generally sold in Padang City building shops. Bricks must have sharp and angled ribs, their sides must be flat, they must not show excessive cracks or deformation, they must not easily crumble or break, have a uniform color, and make a loud sound when hit [1].

SNI 15-2094-2000 explains the definition of red brick, which is a construction material in the form of an elongated rectangular prism, solid or hollow, used to construct building walls, made of clay with or without additional materials, and fired at a temperature of 8000°C so that it does not crumble when soaked in water.

2.1.2. Sand

The sand used is black and has a fine texture. It is sieved before being used to separate the coarse grains left in the sand. Sand must be free from organic substances because organic substances will slow down cement bonding and the development of the concrete mixture.

2.1.3. Mortar

Mortar is a mixture of cement, sand, and water in different percentages. The appropriate mass ratio of cement, sand, and water for species that meet the requirements is 1:2.75:0.5. This standard will help assess mortar strength, so it can withstand the working load's compressive force. What needs to be considered when making mortar are the material specifications of cement, sand, and water quality [31].

2.1.4. Wire Mesh

Wire mesh is a series of high-quality steel (with a characteristic yield stress of up to 5,000 kg/cm²) in the form of a net, which is made of welded steel wire and has a uniform distance between the wires, and is used in strengthening concrete. In Indonesia, it is better known as woven wire. Wire mesh can be used for Reinforcement. Wire mesh wire used for Reinforcement must be clean and free from dust, rust, layers of paint, oil, or similar substances [14, 15, 32].

There are two types of wire mesh: sheets with a standard size of 2.1 m x 5.4 m and rolls that are 2.1 meters wide and can be up to 54 meters long. When referring to its size, wire mesh is often referred to using the term "M." For example, if they identify wire mesh with the code M10, then the iron has a diameter of 10 mm.

Usually, sizes M8, M9, and M10 are used for multi-story buildings, and for houses, it is enough to use M4, M5, and M6. Wire mesh types with hexagonal and square openings are the most commonly used Reinforcement. Figure 2 shows the types of wire mesh. For details of the size and weight of wire mesh wire according to SNI 07-0663-1995 [33], see Table 1.

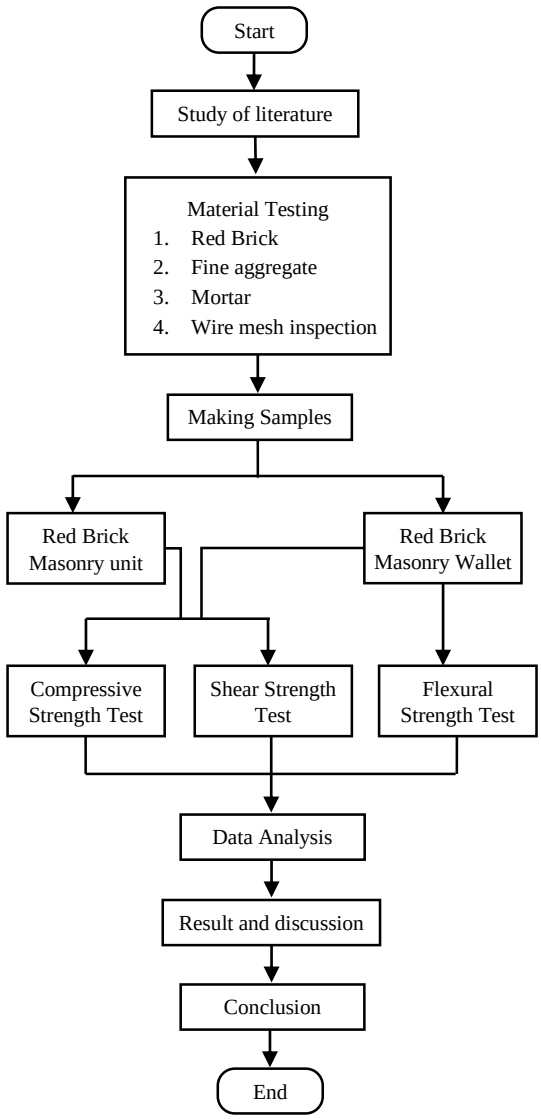


Fig. 1 Research process flowchart

2.2. Masonry

Masonry consists of non-structural elements in a building that serve as fasteners for columns and beams. Another benefit of walls is that they act as room dividers and protect the inside of the building from external influences.

The collapse of red brick masonry due to earthquakes is the main cause of injuries and even fatalities. When an earthquake occurs, the normal brittle nature of masonry increases the possibility of shear and flexural failure.

Therefore, efforts are needed to increase the specific strength while simultaneously improving the compressive capacity of the masonry. In this case, the strength of the mortar used influences the compressive capacity of the masonry [5].

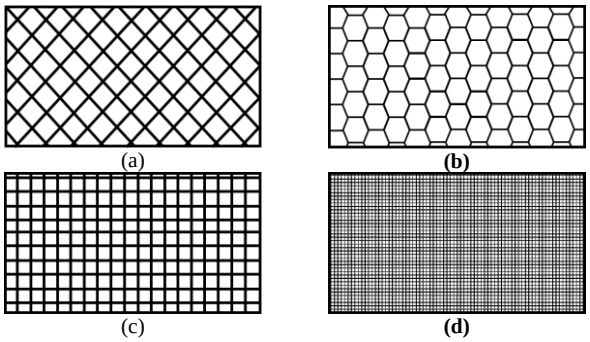


Fig. 2 Various forms of wire mesh

Table 1. Wire mesh wire size and tolerance details

Wire Type	Diameter (mm)	Tolerance (±mm)	Weight (kg/m)
M4	4	0.10	0.099
M5	5	0.10	0.154
M6	6	0.10	0.222
M7	7	0.13	0.302
M8	8	0.13	0.395
M9	9	0.13	0.499
M10	10	0.13	0.617
M11	11	0.13	0.746
M12	12	0.13	0.888

2.3. Fabricated Samples

2.3.1. Compressive Test Unit

The design of the compressive brick unit with a wire mesh layer (

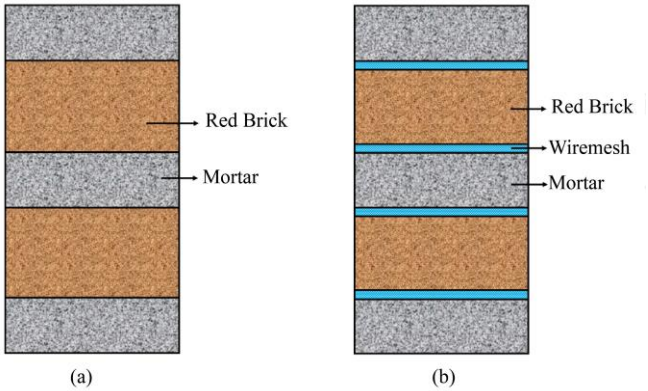


Fig. 3) involved cutting the red brick into two equal parts, which were then bonded together using a mortar mixture.

Wire mesh layers with diameters of 5 mm, 6 mm, and 8 mm were positioned between the brick layers and the mortar (

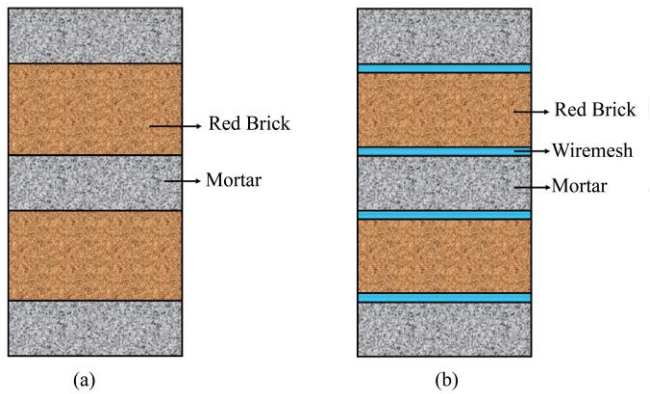


Fig. 3 3(b)) to assess the impact of the wire mesh on the compressive strength of the brick unit. (

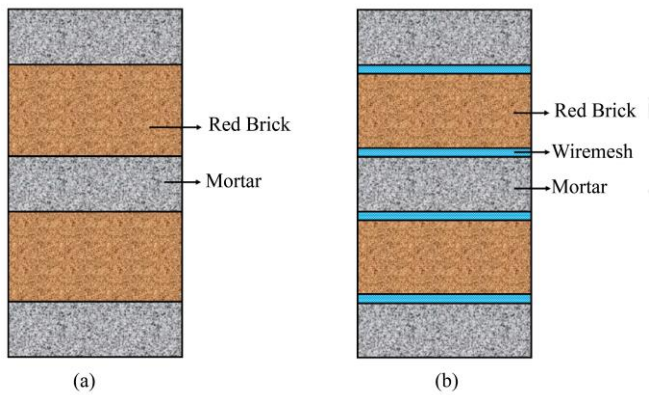


Fig. **3**(a) shows a brick unit that does not have a wire mesh layer applied.

Meanwhile, the manufacture of compressive brick wall unit samples follows the same procedure as the typical creation of red brick walls. Each sample measures 40 x 40 cm. The wire mesh is cut to match the length and width of the bricks and is then positioned between the brick-and-mortar layers, as illustrated in Fig. 5. The control sample is depicted in Fig. 4.

2.3.2. Shear Test Unit

The design of the shear brick unit sample involved arranging three bricks into a single unit bonded with mortar, as shown in the

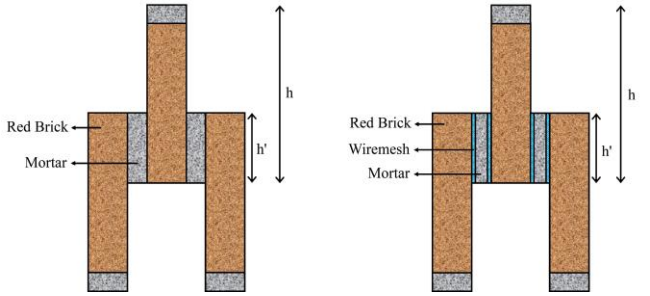


Fig. 6. The wire mesh was then placed between the bricks and the mortar, as depicted in

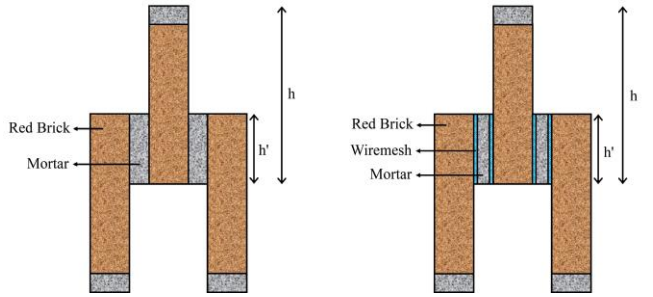


Fig. 6(b). Meanwhile, the sample design of the shear brick wall unit is the same as the design of the compression unit in Figures 4 and 5.

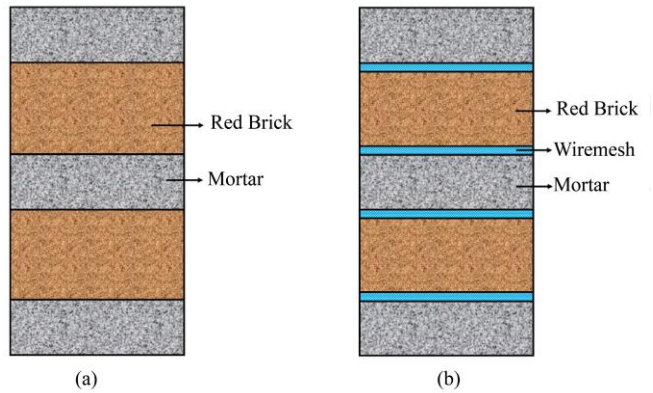


Fig. 3 Compressive Red Brick Samples: (a) Control Sample of brick unit, and (b) Brick unit with wire mesh layer

2.3.3. Flexural Test Unit

Flexural testing was conducted solely on the red brick wall. The design of the flexural brick wall unit is the same as the design of the compression unit in Fig. **4** and 5.

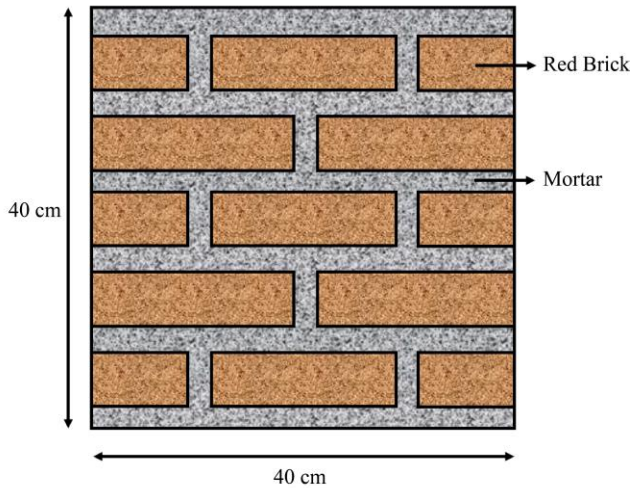


Fig. 4 Control sample of Masonry

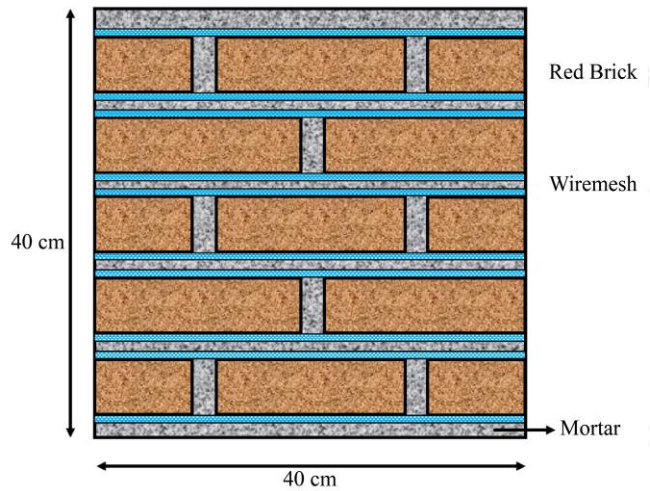


Fig. 5 Masonry with wire mesh layer

2.4. Method

This study was conducted using an experimental method, involving direct experiments to gather results related to the variables under investigation. The experiment will be displayed on red brick and red brick wall samples. Specimens will be categorized into four types: control specimens, specimens with a 5 mm diameter wire mesh layer, specimens with a 6 mm wire mesh layer, and specimens with an 8 mm wire mesh layer. The control sample was not given a wire mesh.

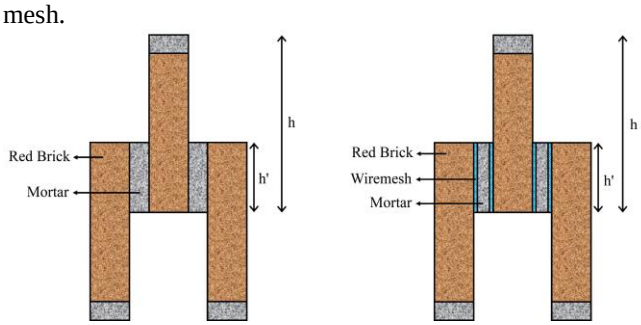


Fig. 6 Shear Red Brick Samples: (a) Control Sample of brick unit, and (b) Brick unit with wire mesh layer.

All sample variations underwent testing to assess the compressive strength and shear strength for both red brick unit and red brick wallet samples. Furthermore, the experiment was conducted to measure the flexural strength of red brick wall samples. Each type of test object comprised three samples per test. Table 2 displays the total count of test samples.

Table 2. Number of test samples

Sample	**Diameter Wire Mesh**	**Compressive Test**	**Shear Test**	**Flexural Test**
Masonry Unit	Control	3	3	-
	5 mm	3	3	-
	6 mm	3	3	-
	8 mm	3	3	-
Total	24 samples			
Masonry Wallet	Control	3	3	3
	5 mm	3	3	3
	6 mm	3	3	3
	8 mm	3	3	3
Total	36 samples			

Each sample to be tested will be assigned an initial to aid in research and data processing. The initials for the samples are as follows: Control Red Brick (PBK), Compression Test Red Brick (PBT), Shear Test Red Brick (PBG), Control Red Brick Wall (DBK), Compression Test Red Brick Wall (DBT), Shear Test Red Brick Wall (DBG), and Red Brick Wall Flexural Test (DBL). Each initial will be accompanied by a number based on the diameter of the wire mesh to distinguish the test object samples. For example, the Red Brick Wall Compression Test with a diameter of 5 will be denoted as DBT D5.

2.5. Experimental Design

2.5.1. Compressive Strength Test

The process of testing the compressive strength of red brick refers to SNI 15-2094-2000 [1], where the surface of the test object is loaded until it reaches the maximum load at a speed of 2 kg/cm²/sec. Equation 1, used to determine the compressive strength of red brick, is expressed as follows [2, 3].

$$F = \frac{P}{A_c} \tag{1}$$

Here, F is the compressive strength (kg/cm²), P represents the maximum load (kg), and A_c refers to the compression area (cm²).

The compressive test of the masonry unit was conducted in the laboratory using a Universal Testing Machine (UTM). Set up for the compressive strength test of the red brick unit as shown in Figure 7 (a). The compressive strength test of red brick walls requires steel material with a U-channel profile with a length of 50 cm, a width of 12 cm, and a thickness of 0.3 cm, which functions so that the load received by the test object is an even load and not a concentrated load. Fig. **8** is the setup for the compressive test of the masonry wallet.

2.5.2. Shear Strength Test

Shear strength is the maximum shear stress that a plane (in the soil) can withstand under certain conditions. The shear strength test of red brick masonry aims to determine the capacity of the mortar to withstand shear force on the masonry wall when it receives a load or force that acts in the longitudinal direction or the length of the masonry wall. Equation 2, which calculates the shear strength of red brick mortar, is formulated in accordance with ASTM 155207 (Standard Practice for Capping Concrete Masonry Units) and is presented as follows [34].

$$V = \frac{P + w}{2(b \times h)} \quad (2)$$

Where V is shear strength, P is the maximum test load, b is the width of the red brick (cm), h' refers to the length of the shear plane (cm), w is the test object weight, and h denotes the height of the masonry unit.

The shear test for the masonry unit was conducted in the same manner as the compressive red brick unit, specifically in the laboratory using a Universal Testing Machine (UTM). The setup for the shear test of the masonry unit is illustrated in Figure 7.(b).

To evaluate the shear strength of a masonry wall, the sample is placed diagonally. Equipped with extra testing accessories, steel angles measuring 6 cm on each side were placed at the diagonal corners of the red brick wall, as illustrated in the Fig. . This setup is intended to stabilize the top and bottom corners of the wall, facilitating the testing process.

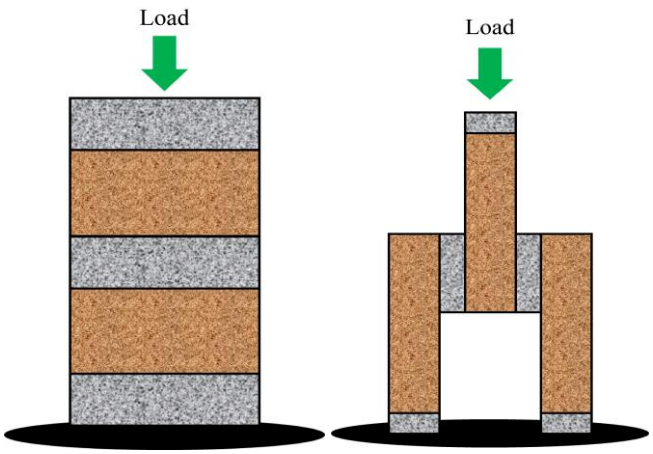


Fig. 7 Red brick test set-up: (a) Compressive test set-up, and (b) Shear test set-up.

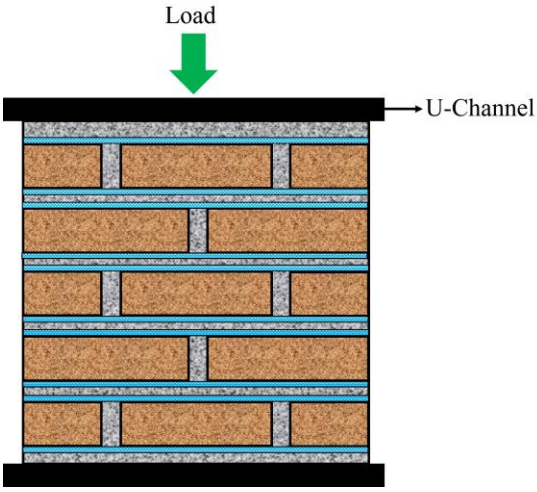


Fig. 8 Red brick walls compressive strength test set-up

2.5.3. Flexural Strength Test

Based on SNI 03-4165-1996, the flexural strength of red brick walls is the bending force acting on a pair of walls per unit cross-sectional area of the wall that flexes. The specimen will be tested until it cracks or reaches the maximum load of the testing machine, and a stress and strain relationship graph will be obtained, as shown in the Fig. [35].

Based on the maximum load value obtained through graphical analysis, the flexural strength of the wall can be determined using Equations 3 and 4.

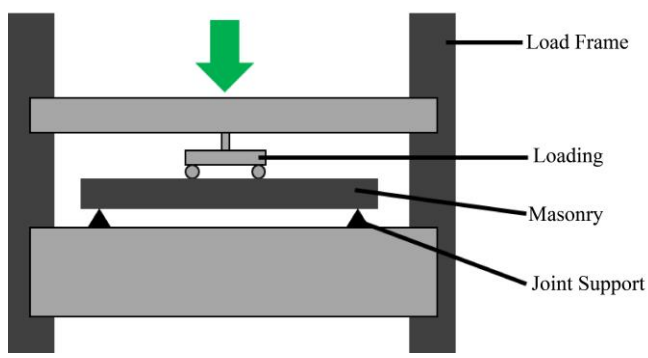
$$flt = \left(P_u + \frac{W}{2}\right) \times \left(\frac{1}{4}\right) \times \left(\frac{c}{I}\right) \quad (3)$$

$$I = \frac{1}{12} Bt \quad (4)$$

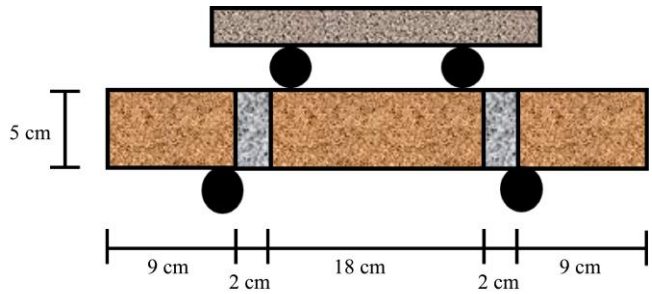
Where, *flt* is flexural strength of red brick masonry walls; P is maximum load; W is weight of tool; c is the distance between the neutral line and the surface (mm); I is the moment of inertia of the bending section (mm²); H is the height of the test object; B is width of the test object (mm); t is the thickness of the test object (mm).

The flexure test was carried out in accordance with SNI-03-4165-1996. The specimen will be tested until it cracks or reaches the maximum load with a loading level of 1 N/mm²/minute using a Universal Test Machine (UTM).

The test is carried out where the fracture plane is located in the central area.



(a)



(b)

Fig. shows the setup for testing the flexural strength of masonry.

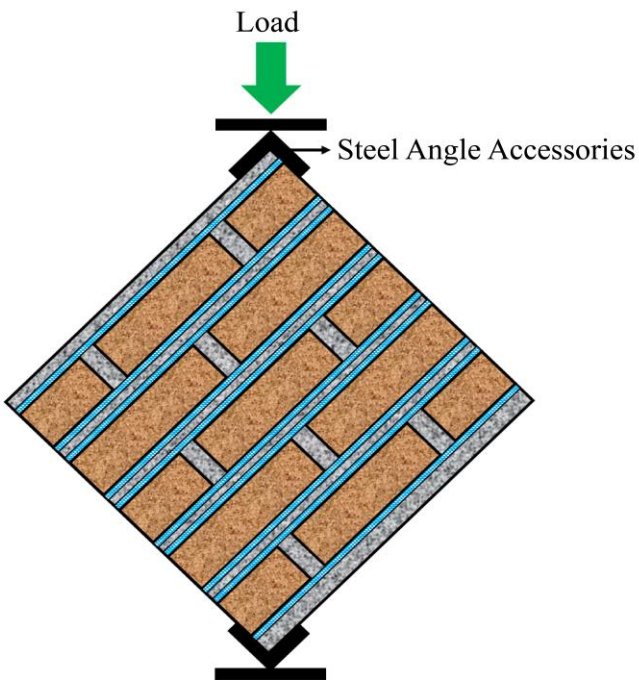


Fig. 9 Red brick walls shear strength test set-up

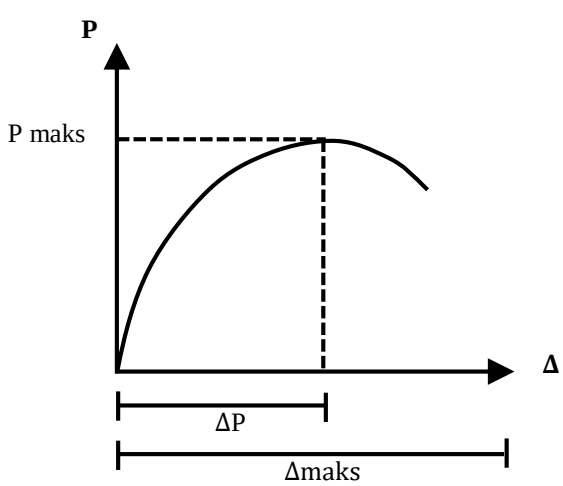
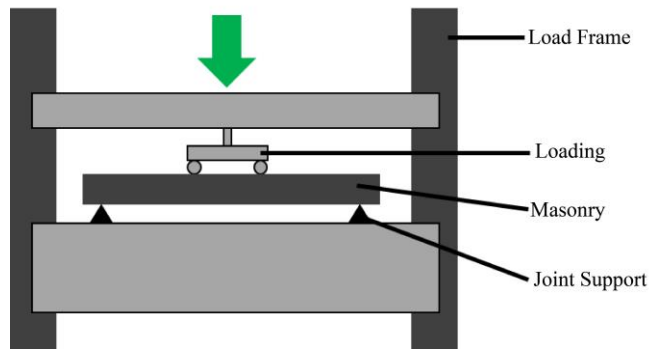
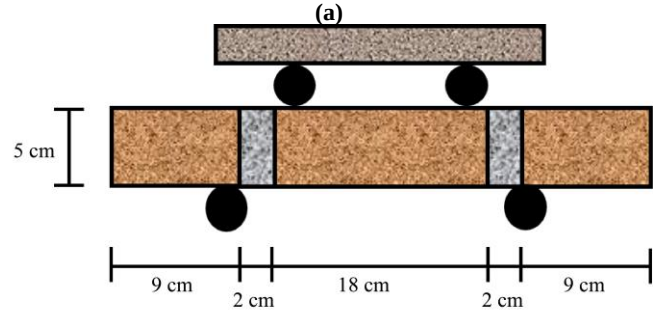


Fig. 10 Stress-Strain graph



(a)



(b)

Fig. 11 The setup for the flexural strength test of walls

2.6. Energy Dissipation

The energy dissipation capacity is obtained by calculating the hysteretic energy of masonry specimens under cyclic loading [36]. In simple terms, the area under the curve is used to calculate the dissipation energy. The curve describes the relationship between the applied force and the deformation (Δ) in the structure or structural element, as in Figure 12.

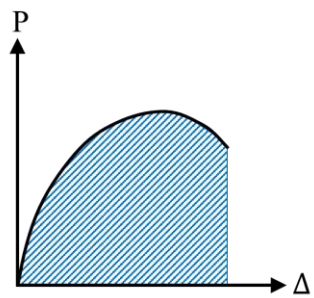


Fig. 9 Area under the curve using the multi-segment trapezoid method

The area can be calculated using the multi-segment trapezoid method approach [37, 38], formulated in Equation 5.

$$A = \sum_{i=1}^{n} \Delta_i \frac{f(x_i) + f(x_{i-1})}{2} \tag{5}$$

Energy Dissipation (E) can be calculated using the following equation 6.

$$E = \sum_{i=1}^{n} E_i \quad (6)$$

Where Ei is the trapezoid segment area of *i*.

3. Results and Discussion

This section discusses the results and observations of the compressive, shear, and flexural strength of red brick and red brick masonry without a wire mesh layer, as well as testing samples with a wire mesh layer.

3.1. Compressive Strength

Tables 4 and 5 present the compressive strength results for the masonry unit and masonry wallet. It shows that the average compressive strength of masonry with the addition of wire mesh has increased successively at diameters of 5mm, 6mm, and 8mm. Table 3 and 4 also show the percentage increase in the compressive strength of bricks with wire mesh compared to control bricks (without wire mesh).

Table 3. Compressive Strength Percentage of Red Brick Masonry Unit

Sample Type	Average Compressive Strength (kN)	Compressive Strength control (kN)	Percentage Increase
PBT D5	5.129	1.755	192%
PBT D6	8.550	1.755	387%
PBT D8	8.111	1.755	362%

Table 4. Compressive Strength Percentage of Red Brick Masonry Wallet

Sample Type	Average Compressive Strength (kN)	Compressive Strength control (kN)	Percentage Increase
DBT D5	65.23	43.58	50%
DBT D6	73.34	43.58	68%
DBT D8	62.51	43.58	43%

Fig. demonstrates the increase in the compressive capacity of the masonry unit, and Fig. shows the increase in the compressive capacity of the masonry wallet. The addition of 5 mm, 6 mm, and 8 mm diameter wire mesh to the masonry unit experienced a significant increase in the compressive strength of 5.129 kN, 8.550 kN, and 8.111 kN (see Table 4), respectively, while the compressive strength of the control unit (without wire mesh) was 1.755 kN. The percentage increase with wire mesh was 192%, 387%, and 362%, respectively, against the control unit (Without Wire Mesh). The highest capacity was found in the masonry unit with a 6 mm wire mesh, which increased by 387%.

Meanwhile, in a study conducted the compressive strength of the control masonry unit was 25.89 kg/cm², and the use of polypropylene fiber coatings with thicknesses of 1 mm, 2 mm, and 3 mm produced compressive strengths of 30.32 kg/cm², 31.16 kg/cm², and 47.16 kg/cm², respectively. Application of fiberglass fiber coatings with the same thicknesses yielded compressive strengths of 30.1 kg/cm², 31.22 kg/cm², and 53.31 kg/cm², respectively. From this comparison, it can be seen that the most significant improvement was achieved by Reinforcement using 3 mm thick fiberglass fiber paint with a percentage of 105.9%. From the comparison, it can be seen that with wire mesh reinforcement, the percentage increase was highest, namely, 387%. This shows that the internal reinforcement method in this study and the fiber paint layer by Eka with an optimal thickness can significantly increase the compressive strength of the masonry.

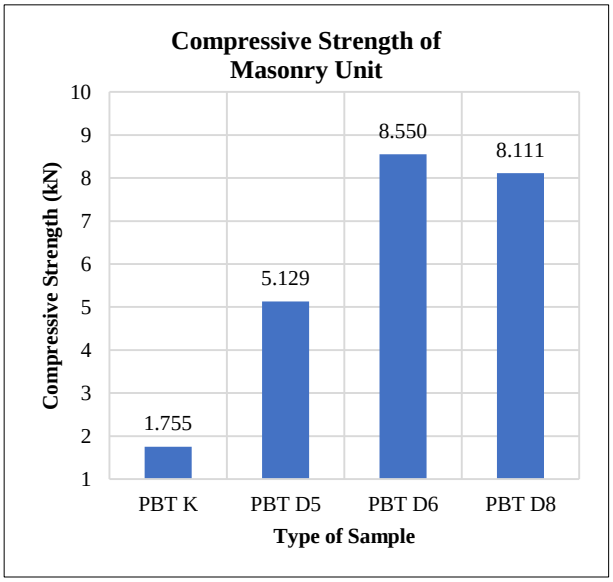


Fig. 13 Average compressive strength of masonry unit

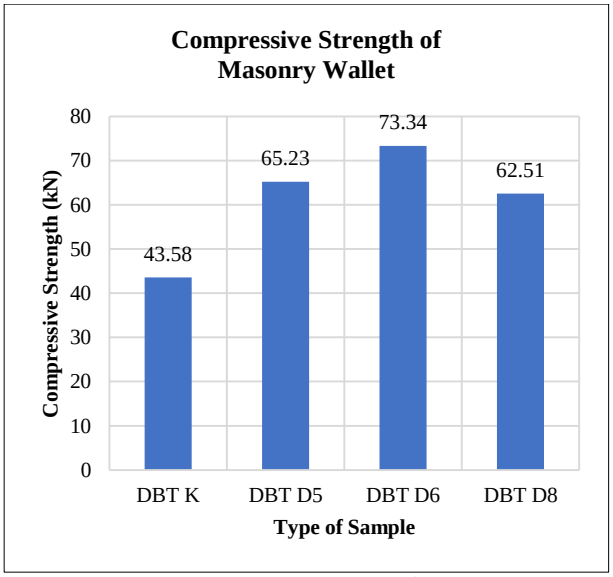


Fig. 14 Average compressive strength of masonry wallet

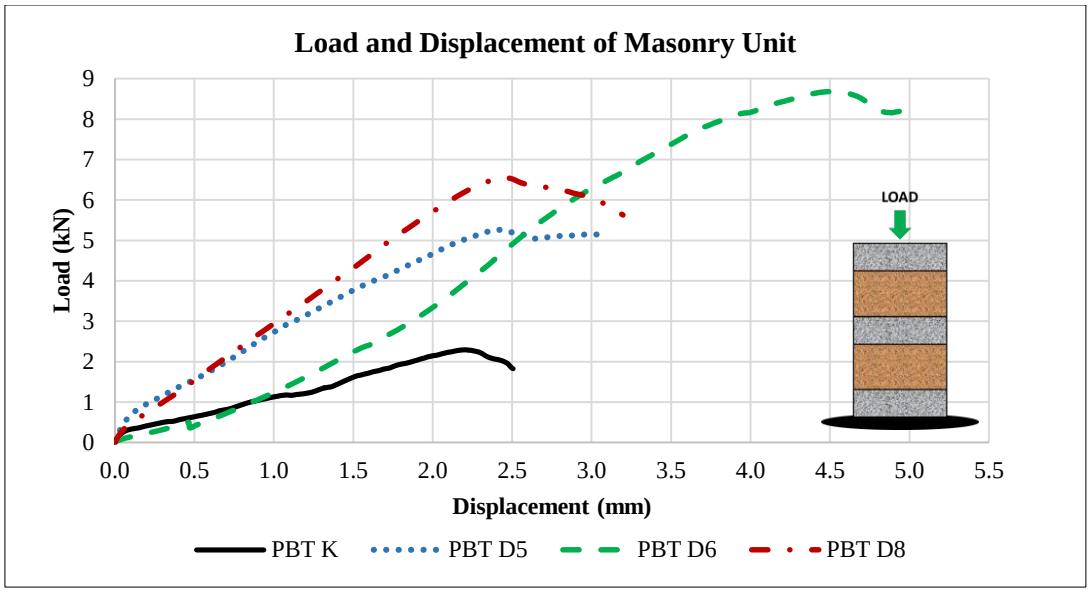


Fig. 15 Load-displacement compressive strength of masonry unit

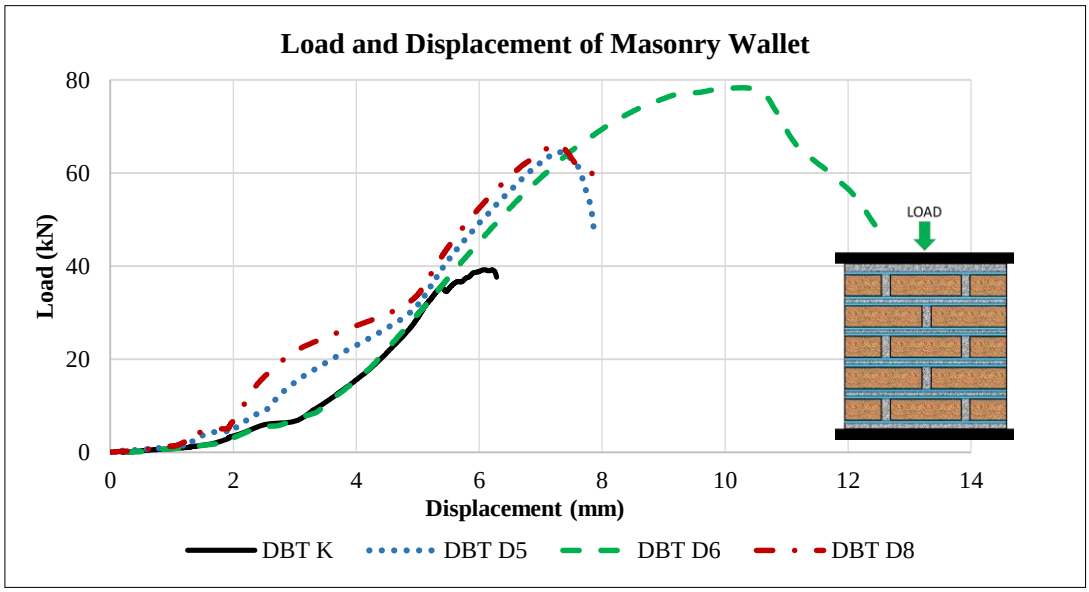


Fig. 16 Load-displacement compressive strength test masonry wallet

From Table 5, it can be seen that the addition of wire mesh with diameters of 5 mm, 6 mm, and 8 mm to the masonry wallet experienced an increase of 50%, 68%, and 43%, respectively. Brick walls with a 6 mm diameter wire mesh layer also exhibited the highest compressive strength value, increasing by 68%.

In the compressive strength test of the masonry unit and wallet, there was also the effect of displacement on the load value. Figures 15 and 16 show the load-displacement graph for the compressive strength test. Based on Fig. and Fig. , it can be seen that the displacement value is directly proportional to the load value, where the greater the decrease, the greater the loading value, and then the graph value drops drastically when the test object has experienced damage/collapse.

The compressive capacity of masonry is limited by the strength of its constituent bricks. If the brick unit already experiences cracks, then the masonry can no longer support the load, and eventually, the collapse occurs. The wire mesh on the brick masonry will transmit the load first before passing it to the brick, so that the masonry will not quickly experience initial collapse. The dissipation energy in the compressive test of the masonry unit and wallet can be seen in Table 5 Table 5and Table 6. The values shown are the energy up to maximum load and the total energy of masonry.

Table 5. Energy Dissipation of Compressive Test Masonry Unit

Sample	Code	Energy up to maximum load	Total Energy
		kNmm	kNmm
Control	PBT K	2.71	3.34
Wire mesh D 5 mm	PBT D5	7.39	10.92
Wire mesh D 6 mm	PBT D6	19.31	23.23
Wire mesh D 8 mm	PBT D8	8.67	13.30

In Table 6 and Fig. , the energy dissipation resulting from the compression test shows an increasing trend with the addition of wire mesh to the layer of masonry unit samples. The total energy in the sample without a wire mesh is 3.34 kNmm. Wire mesh layers with diameters of 5 mm, 6 mm, and 8 mm add 10.92 kNmm, 23.23 kNmm, and 13.30 kNmm, respectively. The highest increase in energy dissipation of the masonry unit is in the sample with a wire mesh diameter of 6 mm. Furthermore, the energy dissipation up to the maximum load in the sample without a wire mesh is 2.71 kNmm. Samples with wire mesh diameters of 5 mm, 6 mm, and 8 mm are 7.39 kNmm, 19.31 kNmm, and 8.67 kNmm, respectively. The analysis indicates that the wire mesh strengthens the bond between materials and increases the material's ability to absorb energy when subjected to compressive loads.

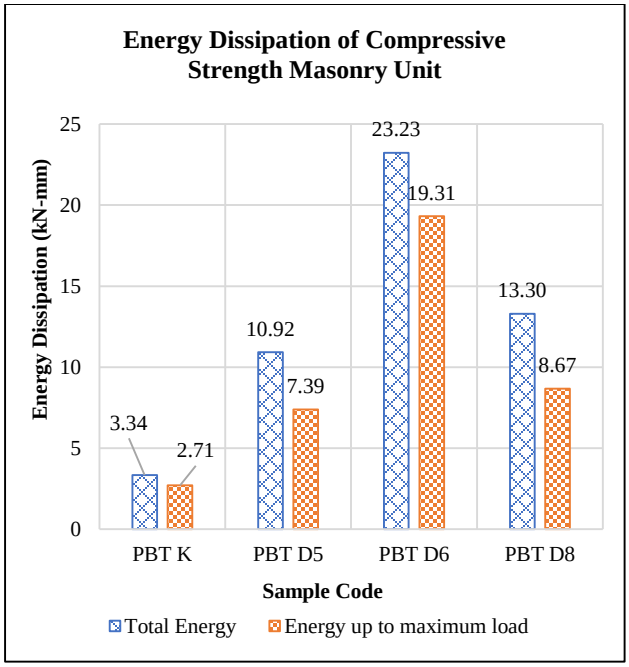


Fig. 17 Energy Dissipation of Compressive Test Masonry Unit

Similar trends were also observed in the compression test of brick walls, as shown in Fig. . From Table 7, the total energy dissipation of the sample without a wire mesh was 86.25 kNmm. When wire mesh was applied with a diameter of 5 mm, 6 mm, and 8 mm, the energy dissipation increased by 209.80 kNmm, 506.45 kNmm, and 231.84 kNmm, respectively. The largest increase in total energy was in the sample with a wire mesh diameter of 6 mm.

Table 6. Energy Dissipation of Compressive Test Masonry Wallet

Sample	Code	Energy up to maximum load	Total Energy
		kNmm	kNmm
Control	DBT K	78.97	86.25
Wire mesh D 5 mm	DBT D5	179.36	209.80
Wire mesh D 6 mm	DBT D6	368.19	506.45
Wire mesh D 8 mm	DBT D8	197.07	231.84

The energy dissipation needed to reach the maximum load on the sample without a wire mesh was recorded at 78.97 kNmm. Along with the increase in the wire mesh diameter, the energy dissipation value to reach the maximum load was 179.36 kNmm at a thickness of 1 mm, 368.19 kNmm at a thickness of 2 mm, and 197.07 kNmm at a thickness of 3 mm. Thus, the application of wire mesh can be considered an effective strategy in material engineering to improve mechanical resistance to deformation and damage due to compressive loads.

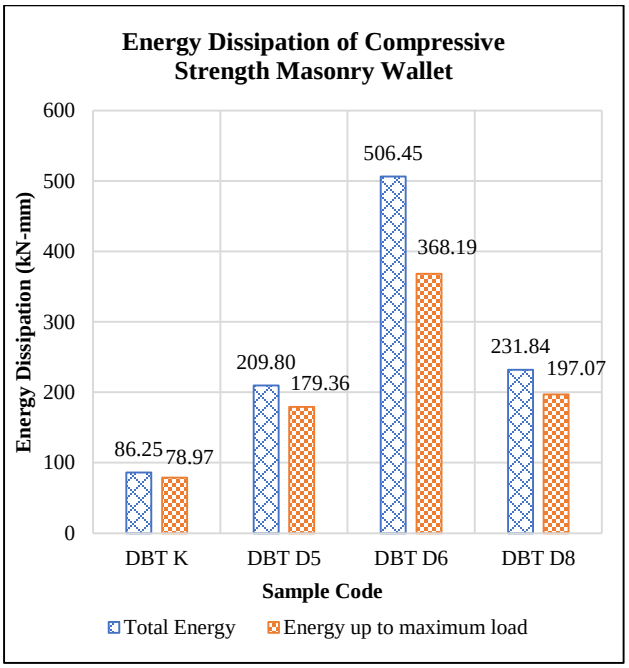


Fig. 18 Energy Dissipation of Compressive Test Masonry Wallet

Ductility and stiffness greatly influence masonry. When an earthquake occurs, the load carried by the structure will experience deformation, and if the force caused by the earthquake is too excessive, then the structure will no longer

be able to withstand the force, and it will be transmitted to non-structural parts, namely the masonry. As a result, the wall will collapse after it receives the compressive load caused by the earthquake. The ductility and stiffness values of the wall can be calculated by looking at the load and displacement graph of the compressive strength of the masonry, with the results in Table 7. Based on Table 7, the results indicate that the ductility and stiffness of the masonry wallet with wire mesh layers have increased compared to the masonry wallet without wire mesh. The ductility value increased with the percentage of wire mesh diameters of 5mm, 6mm, and 8 mm, at 46%, 82%, and 79%, respectively. The stiffness value increased with the percentage of 5mm, 6mm, and 8mm diameter wire mesh, namely 34%, 15%, and 38%. The masonry wallet compression test yielded the highest ductility value of 82% for masonry with a 6 mm diameter wire mesh, and 38% for stiffness.

Table 7. Ductility and Stiffness of the Compressive Test of Masonry Wallet

Sample	Δu (mm)	Δy (mm)	Load Max (kN)	Ductility	Ductility Percentage	Stiffness (kN/mm)	Stiffness Percentage
DBT K	6.10	1.88	39.22	3.24	0%	6.43	0%
DBT D5	7.36	1.56	64.50	4.72	45%	8.76	36%
DBT D6	10.30	1.76	78.34	5.85	80%	7.60	18%
DBT D8	7.30	1.26	66.04	5.80	79%	9.04	41%

3.2. Shear Strength

Table 8 displays the shear strength test results for masonry units, while Table 9 displays the results for masonry wallets. From these tables, it is evident that the average shear strength of masonry units and walls with wire mesh layers of 5 mm, 6 mm, and 8 mm has improved compared to those without wire mesh. The tables also provide information on the percentage increase.

Table 8. Shear Strength Percentage of masonry unit

Sample Type	Average Shear Strength (kN)	Shear Strength control (kN)	Percentage Increase
PBG D5	1.474	0.877	68%
PBG D6	2.102	0.877	140%
PBG D8	1.675	0.877	91%

Table 9. Shear Strength Percentage of Masonry Wall

Sample Type	Average Shear Strength (kN)	Shear Strength control (kN)	Percentage Increase
DBG D5	8.82	7.58	16%
DBG D6	12.10	7.58	60%
DBG D8	10.04	7.58	32%

The diagrams in Figures 19 and 20 show the comparison of shear strength test results for the masonry unit and wall with wire mesh layers. According to Table 8 and Figure 19, the addition of wire mesh with diameters of 5 mm, 6 mm, and 8 mm to the masonry unit resulted in shear strength increases of 1.474 kN, 2.102 kN, and 1.675 kN, respectively, compared to masonry without wire mesh. This represents percentage increases in shear strength of 68%, 140%, and 91%, respectively. In contrast, a study found that the percentage increases in shear strength using polypropylene fiber paint surface coatings with thicknesses of 1 mm, 2 mm, and 3 mm were 5.65%, 24.73%, and 58.33%, respectively. Fiberglass fiber paint surface coatings of the same thickness observed percentage increases of 1.34%, 43.82%, and 35.75%. Comparative analysis shows that internal Reinforcement using wire mesh provides a significantly greater increase in shear strength compared to an external fiber coating. The wire mesh system effectively limits the masonry units and improves the bond between the brick and mortar, resulting in better shear resistance. On the other hand, the fiber paint coating primarily improves surface adhesion and reduces microcracking, but has a limited effect on internal stress distribution. Therefore, the wire mesh reinforcement method demonstrates greater efficiency and reliability in improving the shear performance of red brick masonry.

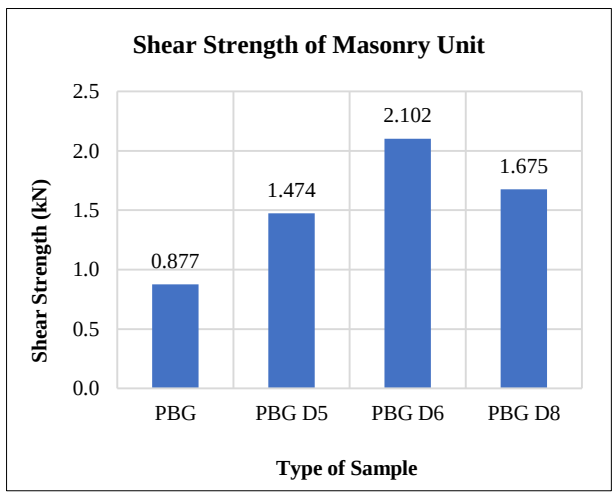


Fig. 19 Average shear strength of masonry unit with wire mesh layer

The highest shear strength value was observed in masonry with a 6 mm diameter wire mesh layer, showing a 140% increase. In Table 9 and Figure 20, the shear strength results for the masonry wallet with the addition of 5 mm, 6 mm, and 8 mm wire mesh increased by 16%, 60%, and 32%,

respectively. Again, the highest shear strength was found in masonry with a 6 mm wire mesh, corresponding to a 60% increase. In testing the shear strength of red brick walls, there was also a displacement effect on the load value. The load-displacement graph of the shear strength test is shown in Figures 21 and 22.

Masonry damage due to shear forces occurs due to horizontal earthquake forces, which result in the release of the red brick's bond or bond with the species, which causes fractures that usually have a diagonal pattern in the red brick masonry. Adding wire mesh between the layers of brick and mortar will reduce fractures caused by earthquakes so that the masonry does not collapse prematurely

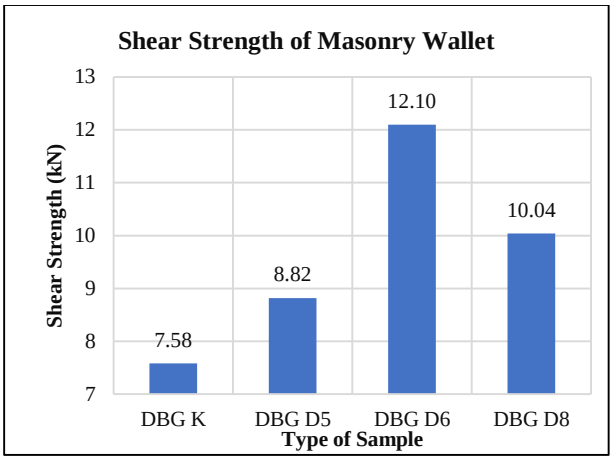


Fig. 20 Average shear strength of masonry wallet with wire mesh layer

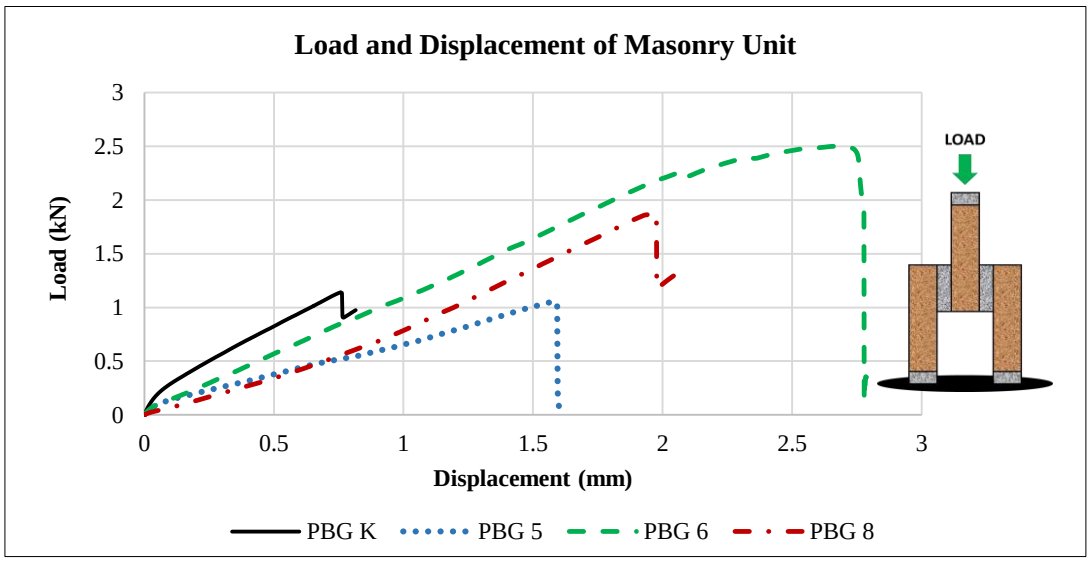


Fig. 21 Load-displacement of Masonry Unit shear strength test

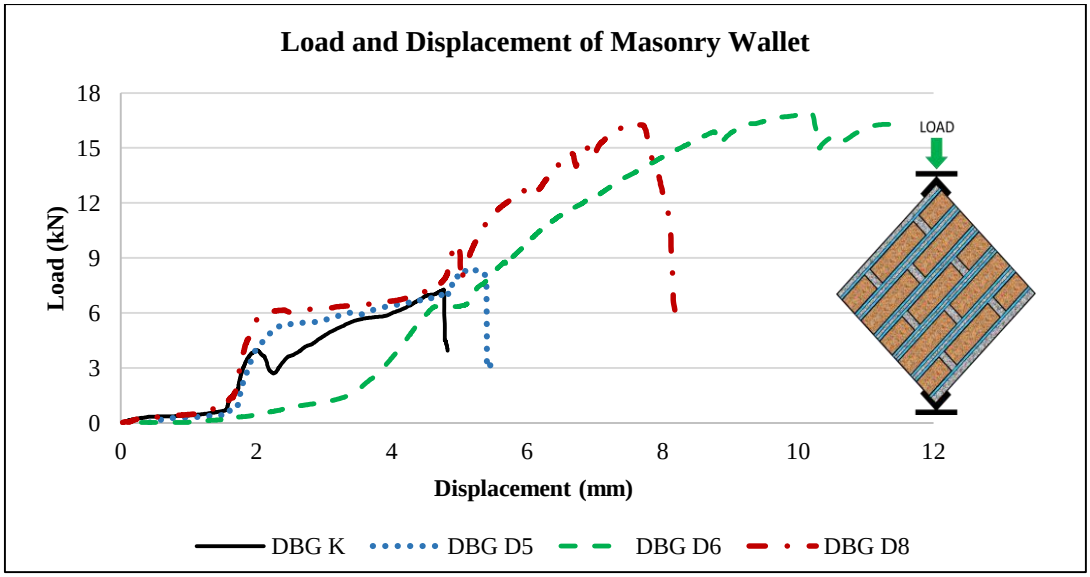


Fig. 22 Load-displacement of Masonry Wallet shear strength test

Tables 10 and 11 display the total energy dissipation capacity of the masonry unit and masonry wallet. Furthermore, Tables 10 and 11 display the energy dissipation value up to the maximum load. In Table 10 and Fig. , the total energy in the masonry unit sample without wire mesh is 0.553 kNmm. In the sample with a wire mesh layer with a diameter of 5 mm, the total energy increases to 0.883 kNmm, then there is a substantial increase in the sample with a wire mesh diameter of 6 mm, namely 4.063, and in the sample with a wire mesh diameter of 8 mm, the increase is not too large, namely 1.778 kNmm.

Table 10. Energy Dissipation of Shear Test Masonry Unit

Sample	Code	Energy up to maximum load	Total Energy
		kNmm	kNmm
Control	PBG K	0.498	0.553
Wire mesh D 5 mm	PBG D5	0.873	0.883
Wire mesh D 6 mm	PBG D6	3.834	4.063
Wire mesh D 8 mm	PBG D8	1.670	1.778

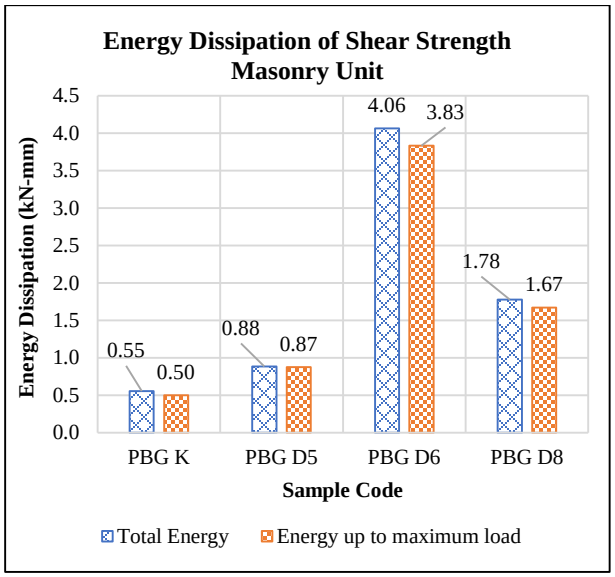


Fig. 23 Energy Dissipation of Shear Test Masonry Unit

Likewise, the energy dissipation up to maximum load increases significantly when the sample is given a layer of wire mesh with a diameter of 6 mm. The energy dissipation at maximum load for the sample without wire mesh, and with wire mesh of 5 mm, 6 mm, and 8 mm, is 0.498 kNmm, 0.873 kNmm, 3.834 kNmm, and 1.670 kNmm, respectively. The energy dissipation in masonry wallets from shear tests is shown in Table 11 and Figure 24. The total energy and energy up to maximum load show similar trends. In the control sample, the total energy was 16.34 kNmm, and the energy up to maximum load was 16.06 kNmm. In the sample with 5 mm wire mesh, the total energy and energy up to maximum load increased by 22.74 kNmm and 20.36 kNmm. The largest energy increase occurred in the sample with 6 mm wire mesh, with a total energy of 96.74 kNmm and an energy up to the maximum load of 76.44 kNmm. Finally, in the sample with 8 mm wire mesh, an increase in energy increases also occurred, but not as significantly as in the sample with 6 mm wire mesh, with a total energy and energy up to maximum load of 64.39 kNmm and 58.16 kNmm.

Table 11. Energy Dissipation of Shear Test Masonry Wallet

Sample	Code	Energy up to maximum load	Total Energy
		kNmm	kNmm
Control	DBG K	16.06	16.34
Wire mesh D 5 mm	DBG D5	20.36	22.74
Wire mesh D 6 mm	DBG D6	76.44	96.74
Wire mesh D 8 mm	DBG D8	58.16	64.39

Figures 23 and 24 show nearly identical energy trends for the masonry units and wallets. Furthermore, when the wire mesh layer is applied to the masonry, the energy trend increases. This indicates that the wire mesh layer can increase the masonry's capacity to dissipate energy. The ductility and stiffness values of the red brick masonry shear strength test can be seen in Table 13.

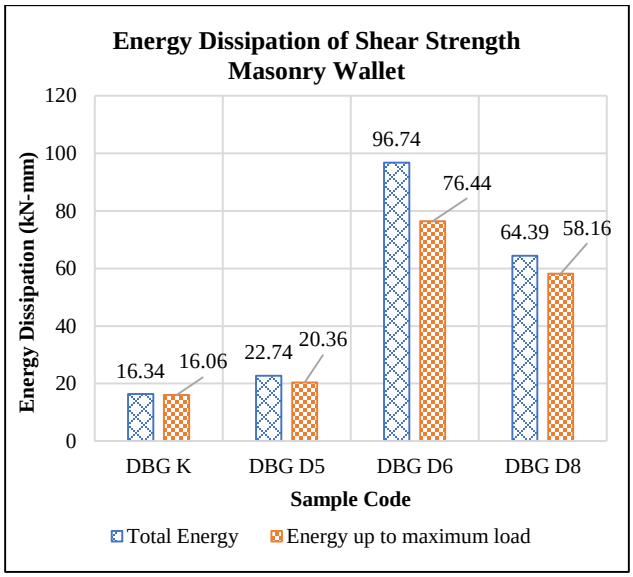


Fig. 24 Energy Dissipation of Shear Test Masonry Wallet

Based on Table 12, the results indicate that the ductility and stiffness of the masonry wallet with wire mesh layers have increased compared to normal masonry. The ductility

value increased with the percentage of wire mesh diameters of 5mm, 6mm, and 8 mm, namely 12%, 29%, and 23%. The stiffness value increased with the percentage of 5 mm, 6 mm, and 8 mm diameter mesh, namely 3%, 5% and 33%. The highest ductility value from the shear strength test was for masonry with 6 mm wire mesh, with a percentage of 29%, while for stiffness, it was for masonry with 8 mm wire mesh, with a percentage of 33%.

Table 12. Ductility and Stiffness of Shear Test of Masonry Wallet

Sample	Δu (mm)	Δy (mm)	Load Max (kN)	Ductility	Ductility Percentage	Stiffness (kN/mm)	Stiffness Percentage
DBG K	4.6	1.56	7.26	2.95	0%	1.58	0%
DBG D5	5.11	1.55	8.32	3.30	12%	1.63	3%
DBG D6	10.16	2.67	16.9	3.80	29%	1.66	5%
DBG D8	7.72	2.12	16.26	3.64	23%	2.11	33%

3.3. Flexural Strength

Testing for the flexural strength of masonry is carried out using a Universal Testing Machine (UTM). This test is carried out in accordance with SNI-03-4165-1996, where the wall will be tested in cross-section until it cracks in accordance with Figure 10.

Table 13 contains the results of the flexural strength test. From Table 13, it can be seen that the flexural strength that can be carried by the control specimen with the specimen adding wire mesh diameters of 5mm, 6mm, and 8mm is 4.38 kN, 24.25 kN, 57.95 kN, and 64.57 kN.

Table 12. Flexural Strength Percentage of Masonry Wallet

Sample Type	Average Flexural Strength (kN)	Flexural Strength control (kN)	Percentage Increase
DBL 5	24.25	4.83	402%
DBL 6	57.95	4.83	1100%
DBL 8	64.57	4.83	1237%

The comparison for the flexural strength of the masonry wall is in Fig. . From Table 13 and Figure 25, it can be concluded that the flexural strength test of masonry walls with the addition of the wire mesh layer experienced a significant increase with the percentage of diameters of 5mm, 6mm, and 8mm, namely 402%, 1100%, and 1237%. The greatest flexural strength was observed in the masonry wallet with an 8 mm wire mesh, showing an increase of 1237%. In testing the flexural strength of red brick walls, there was also a displacement effect on the load value in Fig. .

Based on Fig. , in the flexural strength test, the masonry with a wire mesh layer with a diameter of 8mm has the highest value. In contrast to the compressive strength and shear strength tests, the highest values were for walls with 6mm diameter wire mesh. This occurs because the flexural strength test applies a perpendicular load from the central axis of the wallet, causing a masonry wallet with brittle properties to fracture immediately when subjected to that load.

In the flexural strength test, wire mesh acts as Reinforcement because it can withstand deflection in the wallet before breaking. The larger the diameter of the wire mesh, the greater the maximum stress it has, so that when it reaches the maximum bending load, the brick wall does not immediately break. Therefore, the masonry wallet with wire mesh with a diameter of 8mm has the highest flexural strength values.

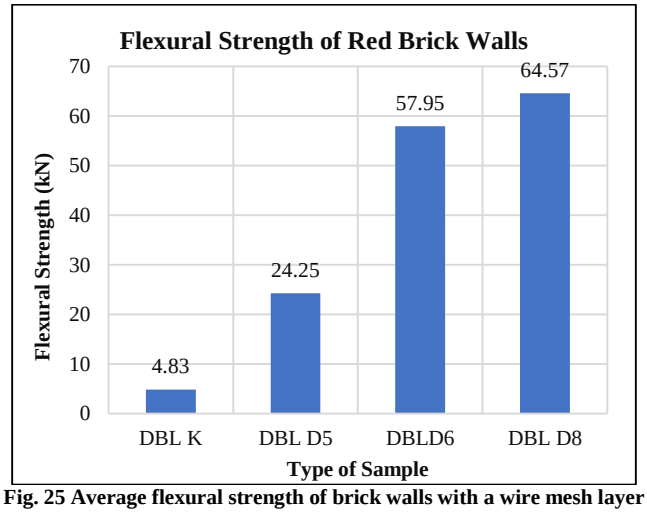


Fig. 25 Average flexural strength of brick walls with a wire mesh layer

The dissipation energy in flexural tests can be seen in Table 14 and Figure 27. The trend of increasing dissipation energy from the flexural test is different from the trend of dissipation energy produced from the compression and shear tests; namely, the largest increase occurs in samples with 6 mm of wire mesh, and dissipation energy does not increase with the wire mesh diameter. Meanwhile, in the flexural test, energy increases with the wire mesh diameter, and the largest increase is in samples with 8 mm wire mesh. The total energy values of the control samples, with wire mesh of 5 mm, 6 mm, and 8 mm, are 10.47 kNmm, 126.81 kNmm, 318.08 kNmm and 1009.26 kNmm. The control, with wire mesh sizes of 5 mm, 6 mm, and 8 mm samples, energy up to maximum load, are 10.24 kNmm, 119.50 kNmm, 311.38 kNmm and 892.46 kNmm, respectively.

Table 14. Energy Dissipation of Flexural Test Masonry Wallet

Sample	Code	Energy up to maximum load	Total Energy
		kNmm	kNmm
Control	DBL K	10.24	10.47
Wire mesh D 5 mm	DBL 5	119.50	126.81
Wire mesh D 6 mm	DBL 6	311.38	318.08
Wire mesh D 8 mm	DBL 8	892.46	1009.26

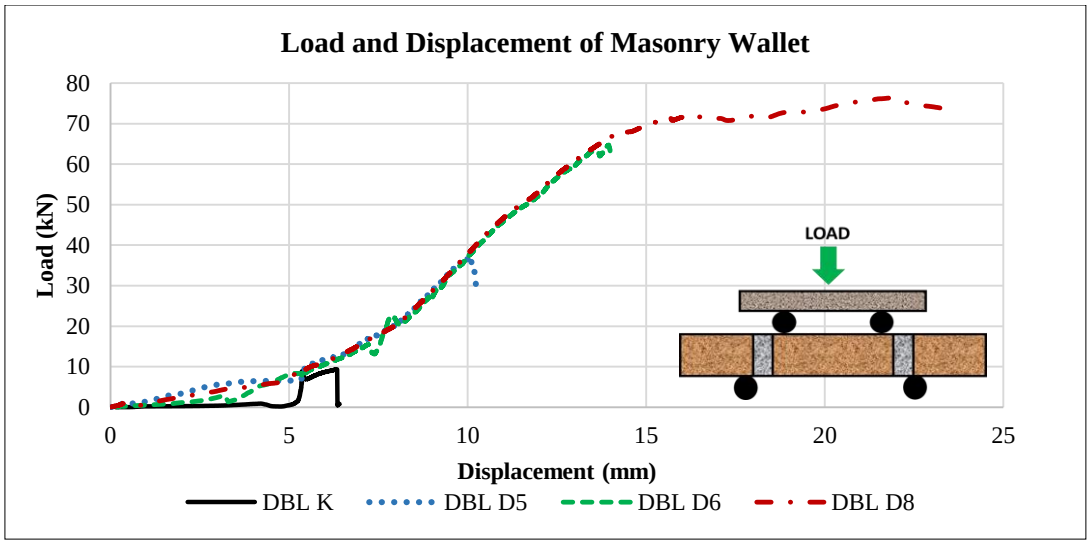


Fig. 26 Load-displacement of the flexural strength test of the masonry wallet

Table 15. Ductility and Stiffness of the Flexural Test of Masonry Wallet

Sample	Δu (mm)	Δy (mm)	Load Max (kN)	Ductility	Ductility Percentage	Stiffness (kN/mm)	Stiffness Percentage
DBT K	6.32	4.18	9.36	1.51	0%	1.48	0%
DBT D5	10.05	3.14	37.3	3.20	112%	3.71	151%
DBT D6	13.92	3.27	64.76	4.26	182%	4.65	214%
DBT D8	21.88	4.75	76.32	4.61	205%	3.49	136%

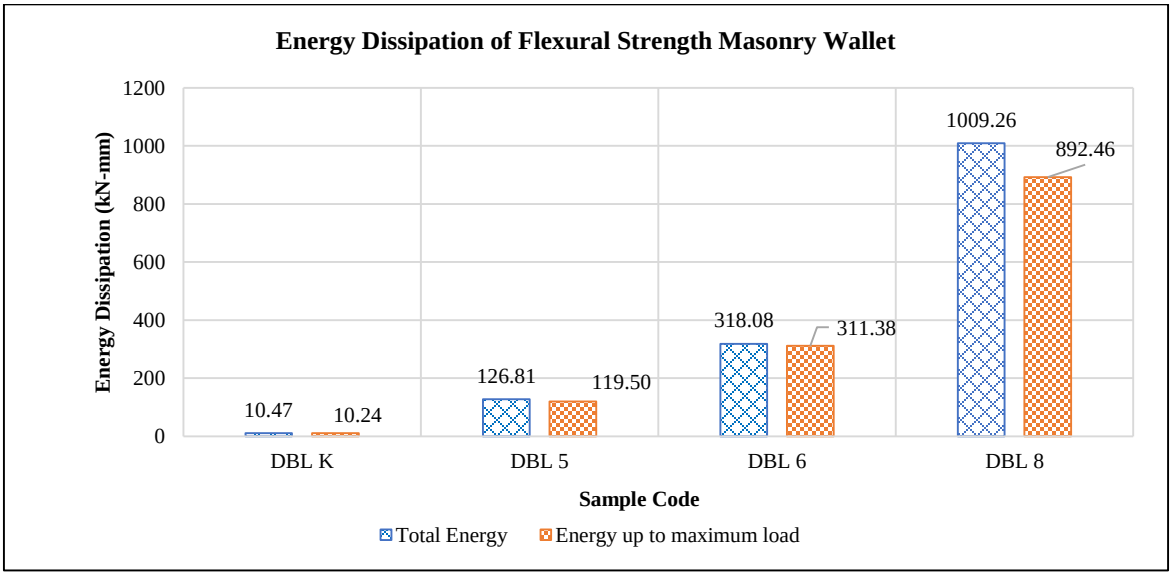


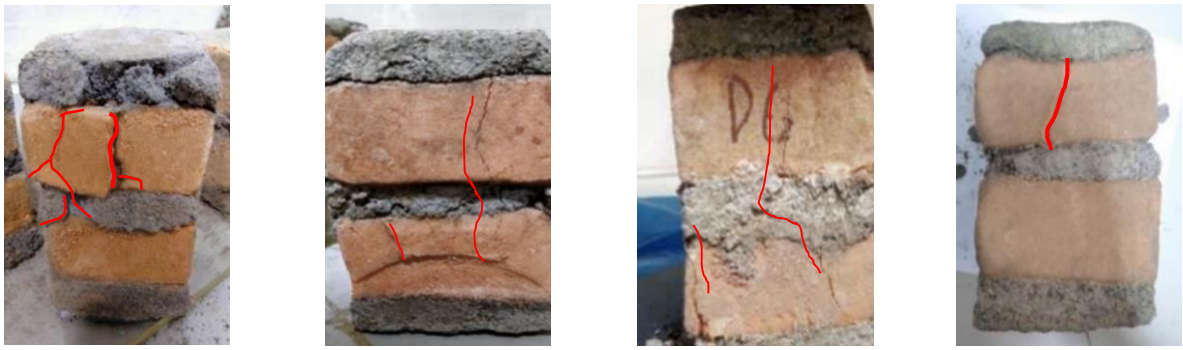
Fig. 27 Energy Dissipation of Flexural Test Masonry Wallet

Based on Table 15, the research results indicate that the ductility and stiffness of the masonry wallet with wire mesh reinforcement increased compared to unreinforced masonry. The ductility values increased with wire mesh diameters of 5 mm, 6 mm, and 8 mm by 112%, 182%, and 205%, respectively. Meanwhile, the stiffness values increased by 151%, 214%, and 136% for the same wire mesh diameters. The highest ductility value from the flexural test was obtained in the masonry with 8 mm wire mesh of 205%, while the highest stiffness value was found in the masonry with 6 mm wire mesh of 214%.

3.4. Failure Modes

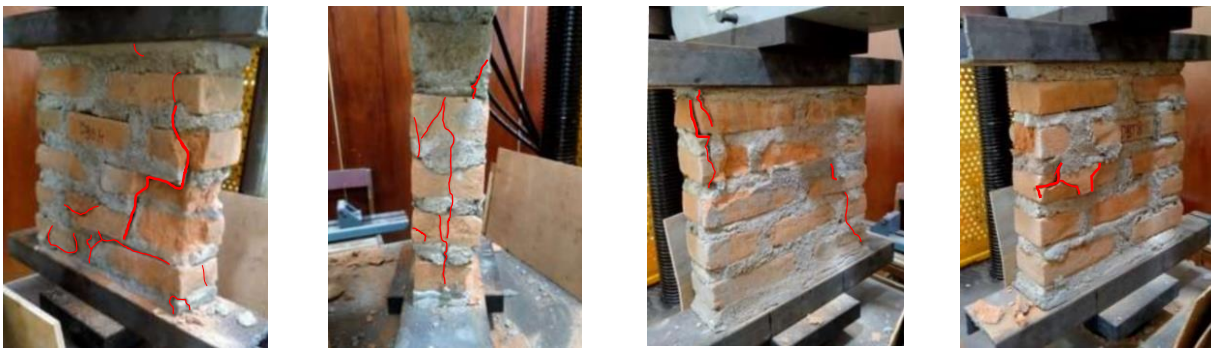
3.4.1. Due to Compressive Loads

From the pattern of damage that occurs on masonry with the addition of a layer of wire mesh whose compressive strength has been tested, the damage that occurs in each type of sample can be seen in Fig. and Fig. . Damage to the control brick in the compressive strength test is shown in Fig. (a), where the brick appears cracked and broken after experiencing compressive force, with visible cracks in the area between the mortar and the brick. In Fig. (b), the brick with a 5 mm wire mesh layer shows cracks, but the brick remains intact because the wire mesh supports the load before it reaches the brick. Fig. (c) depicts damage to the brick with a 6 mm wire mesh layer. Although cracks appear on the edges and slightly in the middle of the brick, the wire mesh prevents it from breaking by holding the load. Finally, Fig. (d) illustrates damage to the brick with an 8 mm wire mesh layer, where cracks are visible in the middle. The brick fails to withstand the load transmitted by the wire mesh, resulting in immediate cracking. From the damage pattern in Fig. (a), it can be seen that the brick wall, which was not reinforced with a layer of wire mesh, immediately cracked and was destroyed after receiving the existing compressive load. The wall fell apart because the strength of the brick wall only rested on the mortar bond. In Fig. (b), the damage pattern that occurs on a red brick wall with a 5mm diameter mesh layer after being given a compressive load is that cracks occur on the side of the wall. The cracks that occurred did not cause the bricks to crumble because the wire mesh layer held the wall ties and mortar so that the walls did not collapse. The damage pattern that occurred on the red brick wall with a wire mesh layer with a diameter of 6 mm (Fig. (c)) after being given a compressive load was that cracks occurred at the edge of the wall. On the wall, they can see the bricks are cracked and destroyed, but only on the surface and not deep inside. Finally, in Fig. (d), the damage pattern that occurs on a red brick wall with a wire mesh layer with a diameter of 8mm after being given a compressive load is that cracks occur on the sides and surface of the wall. The wire mesh between the brick and mortar withstands the compressive load, preventing the cracks from penetrating the wall.



(a) (b) (c) (d)

Fig. 28 Damage Patterns of Compressive Red Brick: (a) Control; (b) With wire mesh layer diameter 5mm; (c) With wire mesh layer diameter 6mm; and (d) With wire mesh layer diameter 8mm.



(a) (b) (c) (d)

Fig. 29 Damage Patterns of Compressive Red Brick Masonry: (a) Control; (b) With wire mesh layer diameter 5mm; (c) With wire mesh layer diameter 6mm; and (d) With wire mesh layer diameter 8mm.

3.4.2. Due to Shear Loads

Figures 30 and 31 show the pattern of damage that occurs on bricks and brick walls with the addition of a layer of wire mesh whose shear strength has been tested, so the damage that occurs in each type of sample can be seen.

The control shear brick masonry test object shown in Figure 30(a) exhibited damage, characterized by the separation of the bond between the brick and mortar after applying force. This separation occurred due to the lack of a wire mesh layer to support the load on the mortar layer.

In Figure 30 (b), the shear brick masonry test object with a D5 wire mesh layer shows damage where the bond between the brick and mortar has released only at the top; the bond remains intact at the bottom. For the shear brick masonry with a 6 mm diameter wire mesh layer, illustrated in Figure 30 (c), the damage consists of cracks and fractures at the bottom of the masonry. However, the bond between the brick and mortar is preserved because the wire mesh effectively supports the shear load. Finally, Figure 30 (d) displays damage to the shear brick masonry test object with an 8 mm diameter wire mesh layer. Similar to the previous case, cracks and fractures occur at the bottom of the masonry, but the bond between the brick and mortar remains intact due to the wire mesh's ability to hold the shear load.

The damage pattern seen in Figure 31 (a), a brick wall that was not reinforced with a layer of wire mesh, experienced fractures in the brick and mortar after receiving the existing shear load. Based on Figure 31 (b), it can be seen that the damage pattern that occurred on the brick wall with a 5mm diameter wire mesh layer after being subjected to a shear load experienced cracks in the brick and mortar, but did not break. Figures 31(c) shows the damage pattern that occurred on a brick wall with a 6mm diameter wire mesh layer after being given a shear load. The wall developed cracks in the brick section, while the mortar section remained intact because the wire mesh maintained the bond between the brick and mortar, preventing fractures in the wall.

Damage patterns that occur on brick walls with a wire mesh layer with a diameter of 8mm, Figure 31(d), after being given a shear load, there were small cracks in the brick and mortar. Walls that are coated with wire mesh do not experience fractures because the wire mesh inside the wall withstands the shear load received, so that the wall does not experience fractures at the brick-and-mortar bond.

(a) (b) (c) (d)

Fig. 30 Damage Patterns of Shear Red Brick: (a) Control; (b) With wire mesh layer diameter 5mm; (c) With wire mesh layer diameter 6mm; and (d) With wire mesh layer diameter 8mm.

(a) (b) (c) (d)

Fig. 31 Damage Patterns of Shear Red Brick Masonry: (a) Control; (b) With wire mesh layer diameter 5mm; (c) With wire mesh layer diameter 6mm; and (d) With wire mesh layer diameter 8mm.

3.4.3. Due to Flexural Loads

The pattern of damage that occurs on brick walls with the addition of a layer of wire mesh, whose flexural strength has been tested, shows the damage that occurs in each type of sample. This damage can be seen in Figure 32. Based on Figures 32 (a) above, it can be seen that the red brick wall, without the addition of the wire mesh layer, was immediately fractured and destroyed after being given a bending load. Damage pattern on red brick wall with 5mm wire mesh layer Figures 32 (b), after being given a bending load, it experienced cracks but did not break down because the wire mesh withstood the bending load, so that the brick-and-mortar bonds did not come loose. Meanwhile, in Figure 32(c), the damage pattern on a red brick wall with a 6mm wire mesh layer after being given a bending load shows cracks in the middle of the red brick wall. The crack did not cause the brick wall to collapse because the wire mesh inside it resisted the deflection load on the wall. In Figures 32 (d), it can be seen that the damage pattern on the red brick wall with an 8mm wire mesh layer, after being given a bending load, experienced cracks in the middle of the red brick wall, and the wall did not collapse.

(a) (b) (c) (d)

Fig. 32 Damage Patterns of Flexural Red Brick Masonry: (a) Control; (b) With wire mesh layer diameter 5mm; (c) With wire mesh layer diameter 6mm; and (d) With wire mesh layer diameter 8mm.

4. Conclusion

Based on the results of research, it can be concluded that adding a wire mesh layer to a masonry can increase its compressive strength, shear strength, and flexural strength.

In the compressive strength test, the addition of the wire mesh layer significantly increased the compressive capacity of the red brick masonry compared to normal masonry. The percentage increases in compressive strength for masonry units with 5 mm, 6 mm, and 8 mm wire mesh are 192%, 387%, and 362%, respectively. The highest compressive strength was achieved with the 6 mm diameter wire mesh, showing a 387% increase.

The percentage increase in compressive strength of masonry wallets with wire mesh layers of diameters of 5mm, 6mm, and 8mm, respectively, is 50%, 68% and 43%. The highest compressive strength value was found in masonry with a 6mm diameter wire mesh layer, which increased by 68%.

Ductility and stiffness of the masonry wallet with wire mesh layers have increased compared to the control masonry. The highest ductility value from the masonry compression test was a masonry with 6 mm diameter wire mesh with a percentage of 82%, while for stiffness, it was a masonry wallet with 8 mm diameter wire mesh with a percentage of 38%.

For the shear strength test, the percentage increases for units with 5 mm, 6 mm, and 8 mm diameter wire mesh layers are 68%, 140%, and 91%, respectively. The highest shear strength value was found with the 6 mm diameter wire mesh, corresponding to a 140% increase. The percentage increase in masonry wallets with wire mesh layers of diameters 5mm, 6mm, and 8mm was, respectively 16%, 60% and 32%. Again, the highest shear strength value was found in the masonry wallet with a 6mm diameter wire mesh layer, which increased by 60%. The highest ductility was a wallet featuring 6 mm wire mesh at 29%, while for stiffness it was with 8 mm wire mesh at 33%.

Furthermore, in the flexural strength test, masonry wallets with the addition of the wire mesh layer experienced a significant increase compared to the control wallet. The percentage increase in the flexural strength with wire mesh layer diameters of 5mm, 6mm, and 8mm, respectively, is 402%, 1100%, and 1237%.

The greatest flexural strength was observed in the wallet with an 8 mm diameter wire mesh layer, increased by 1237%. The highest ductility was a wallet with 8 mm diameter wire mesh with a percentage of 205%, while for stiffness, it was with 6 mm diameter wire mesh with a 136% increase. In terms of energy dissipation, although the compression, shear, and flexural tests showed different increasing trends, the masonry energy dissipation increased after the wire mesh layer was applied.

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