Masonry Shear Triplets Coated with Fiber Reinforced Mortars

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Abstract— Unreinforced brick masonry walls (URM) have been widely used in construction for centuries and represent a large part of building heritage. However, these walls are prone to cracking and failure under certain loading conditions. Addressing this issue requires a comprehensive understanding of URM structures and the implementation of effective retrofitting techniques to enhance their structural integrity. wherefore, researchers have proposed the use of thin Fiber reinforced mortar coating as a reinforcement technique. This experimental study aims to investigate the effectiveness of this approach in improving the behavior of perforated brick masonry walls. To carry out this investigation, a shear triplets test under uniaxial loading has been conducted to evaluate the performance of the reinforcement technique. A series of shear triplets were built with perforated masonry of dimensions (220 x110 × 55) using bastard mortar (1: 1: 5). These specimens were coated with a thin layer of polypropylene fiber reinforced mortar. The test results of the reinforced and unreinforced specimens were compared to analyze the effectiveness of this technique of reinforcement. The test results showed that the application of fiber reinforced coating significantly increased the deformation ability and improved the stiffness and the bond strength of the masonry walls.

Index Terms— *Unreinforced brick masonry walls, Fiber reinforced mortar coating, shear triplets test, polypropylene fiber.*

I. INTRODUCTION

The strength and stability of masonry walls is crucial for the structural integrity of a building. However, perforated brick masonry walls are known to be susceptible to cracking and failure under certain conditions due to lack of their ductility capacity and shear resistance. In order to enhance the seismic performance of load-bearing masonry walls and preserve these cultural heritages, rehabilitation and retrofitting of unreinforced masonry structures should be a substantial subject in structural engineering. Several new techniques have been developed to extend the life of such structures by strengthening or repairing them. To address this issue, engineers and researchers have explored various methods to strengthen these walls, Many of these strengthening techniques, including the use of advanced materials such as fiber-reinforced polymer and (FRP) composites, and other materials [1]-[2]-[3]. however, this technique became costly for strengthening people housing in certain countries. The need to find an efficient and economical way to improve the structural response of these buildings has led to the development of various strengthening techniques, and one promising solution is the use of fiber reinforced mortar. By incorporating fibers into the mortar mix, the resulting composite material exhibits improved tensile strength and crack resistance. The masonry wall in the construction work is always coated with mortar to increase the masonry's strength. Hence, the use of fiber-reinforced mortar coating as a reinforced technique can be an effective solution with less pricey for retrofitting the masonry walls.[4]-[5]-[6]-[7]-[8]-[9]-[10]. Different types of fiber reinforcement were used in the URM walls retrofitting mortar such as steel fibers [26–34], glass fibers [35,36], natural fibers [37–39], polypropylene fibers [29], and polyethylene fibers. A few studies have demonstrated the effectiveness of this technique for the reinforcement of masonry walls. Basically, the effectiveness of these techniques results from the high tensile strength of the fibers embedded in the coating, which increases the shear and bending capabilities of the masonry walls in terms of strength and displacement capacity. Using lime-based mortar for repointing or surface treatment would be ideal, but it is unsuitable for retrofitting due to its low tensile strength and high brittleness. The introduction of fibres in the mortar paste has been proposed very recently for retrofitting of masonry walls. This relatively new retrofitting method involves coating masonry elements with a thin mortar and reinforcing them with short fibers. There are several experimental studies about the effectiveness of FRCM reinforcements applied to masonry walls. a few researchers also proved that TRM systems can be effective against in-plane bending failure[4].This paper presents an experimental study into the shear response of strengthened brick masonry triplet prisms by using a thin Fiber reinforced mortar coating as a reinforcement technique. The masonry triplets were constructed with two types of mortar compounds and tested at three different levels of axial

pre-compression to evaluate the main brick–mortar interface characteristics under different levels of precompression.

II. MATERIAL AND METHOD

2.1. Material tests

The masonry units used to construct the triplet prisms required in this research present nominal dimension of 220mm x 210mm x 55mm ; they were tested in compression and bending according to BS EN 771-1 [11]. Three brick were tested in compression to obtain the average compressive strength and elastic modulus (see Table).

One type of mortar was used for construct the triplet prisms. The mortar consisted of 1:1:5 (Portland cement: hydrated lime: sand by volume, and w/c ratio of 0.5; its mechanical properties were determined according to BS EN1015-11[12]. The same mortar was mixed with 1% of polypropylene fiber for making fiber reinforcement mortar coating. Universal testing machine was used to test the flexural strength of specimens shaped like a prism (40mmx40mmx160mm). The two half-prisms obtained after breaking the specimen into two parts during the flexural test were tested after 28 days in compression (show Fig.1). Three specimens from each mix were tested to obtain their average value. The mechanical properties of the plaster mortar obtained from the experiments are shown in Table II.

Fig.1. Three-point bending test and compressive test for mortar prisms and brick units

Table I: compressive strength and young modulus of brick units

Materials	Stress (MPa)	Young's modulus E(MPa)
Brick	14.53	10000

Table II: The mechanical properties of control mortar and plaster mortar obtained from the experiments

Age	Mortar	Maximal Flexural Force (KN)	Flexural Strength (Mpa)	Maximal compressive force (KN)	Compressive stress (Mpa)
7j	Mortar (1:1:5)	0.64	1.5	3.78	2.36
	FRM mortar (with polypropylene)	0.8	1.87	5.72	3.57
28j	Mortar(1:1:5)	0.75	1.75	7.73	3,64
	FRM mortar (with polypropylene)	0.98	2.29	7.86	4.91

2.2. Shear Triplet Tests Setup and Procedure

One type of mortar was used in the construction of the specimens having mix ratio of 1:1:5 of (Portland cement: hydrated lime: sand). In the reinforced plaster mortar, 2% of polypropylene is added to the mortar. Three specimens were tested at each level of pre-compression stress; with each specimen consisting of three 210 mm × 105 mm × 55 mm perforated bricks bonded by 10mm thick mortar joints. To assess the initial strength and friction angle of the unit–mortar interface, four levels of normal compressive stress (0, 0.2, 0.6, and 1.0 MPa) were used in accordance with BS EN1052-3[13]. A vertical load-controlled cylinder has a force capacity of 100 kN and a loading rate of 1.5 mm/min. was applied perpendicularly to the triplet specimens to investigate the failure behavior of the two mortar joints under shear stress. Each specimen was centered in a vertical position in a hydraulic compression testing machine and then a shearing load was gradually applied (see Fig.2). Triplet shear tests were conducted on perforated brick blocks with and without retrofitting. To provide the stability of the test setup, the outer two bricks were also supported by two steel profiles. The test setup was fabricated to accommodate different pre-compressive levels of normal stress for shear triplet specimens; it consists of top and bottom steel plates connected by bolts at each end. A pre-compressive normal stress was applied and it remained constant throughout the test.

The shear capacity was investigated without applying any plaster which was defined as the reference specimen of the unreinforced masonry specimen. To describe this case, the unreinforced control specimens are called CST. Due to the fact that there are three specimens for each experiment set, each specimen in the set is designated as CST0, CST04, CST06 and CST1, respectively.

Table III presents the specification of brick masonry specimens, including their dimension, joint mortar thickness, and plaster thickness. There are three samples for each type of specimen. In this research 24 specimens were tested to find the shear behavior of each sample and find the effect of polypropylene fiber reinforced mortar coating that applied to the brick masonry prisms. 12 sets of triplet specimens were strengthened by using Fiber reinforced mortar coating (show fig.4), each specimen in the set is designated as RST0, RST04, RST06 and RST1, respectively. In this experimental study, the thickness of the plaster layer for each surface was considered as 1cm. The masonry shear triplets test is carried out on the 7th day after the sample is coated. The unreinforced specimens named as reference samples are also examined and the results of these tests are compared with those of reinforced specimens in terms of stress vs strain relationships, ductility coefficients, and bond strength of interface.

The behaviour of reinforced shear triplets was studied by calculating the shear strength after finding the ratio between the load and the area parallel to the mortar joint, as follows:

The shear strength, f_v is calculated according to EN 1052-3 [13] as given in (1).

$$f_v = \frac{f_{max}}{2A} \qquad (1)$$

Where Fmax is the maximum value of the shear force and A is the cross sectional area of the joint. Additionally, characteristic value of the shear strength fvk is calculated with (2):

$$f_{vk} = 0.8 * f_v \qquad (2)$$

Fig.2: Test setup of shear triplet test

Table III: specification of brick masonry specimens

Type of Mortar	joint mortar thickness	Thickness of Reinforced Mortar coating	Number of specimens		Total of specimens
Mortar (1 :1 :5)	10 mm	------------	Without plaster	12	24
Mortar with 2% of polypropylene	10 mm	10 mm	With plaster	12	

The amounts of energy consumed by the samples during the experiment were calculated using the area below theload-displacement curves of the specimens (show fig.3).

$$\mu = \frac{\delta_u}{\delta_e} \qquad (3)$$

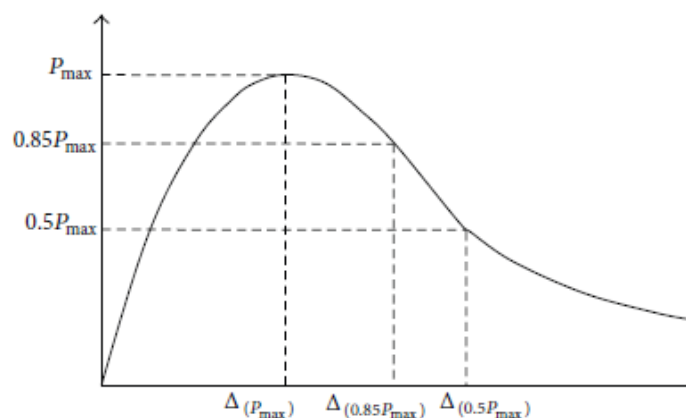$$\mu_{0.85} = \frac{\Delta_{0.85pmax}}{\Delta_{pmax}} \qquad (4)$$

Fig.3: the deformation ability of the samples

Fig. 4: Application of FRMC strengthening to shear

III. RESULTS AND DISCUSSION

3.1. Unreinforced shear triplet

The failure of the unit-mortar interface of masonry under shear can be characterised by the Coulomb friction criterion for lower levels of normal compressive stress to the joint (2MPa).

$$r_u = c + \mu * \sigma_n \qquad (5)$$

$\mu = tan\ \varphi$: coefficient of friction between the unit and the mortar

$C = r_0$: the shear strength under zero compression loads that represents the cohesion (bond shear stress).

$\sigma_n = \sigma_0$: the normal stress

The maximum shear stress for these specimens is obtained as 1.23Mpa. The attained stress-strain relationship is illustrated in Fig. 5. These curves represent the behavior of stress-strain for four levels of compressive normal stresses applied initially. From this figure, it is noticed that maximum stress increases with increasing of compressive normal stress. As shown in this figure, due to lack of ductility, the shear strength of the brick units suddenly decreased and brittle fractures occurred rapidly under stress.

Fig. 6 shows the relationship between the shear strength and the normal stress for all the specimens. These results show there is an almost linear relationship between the shear and normal stresses (σ-τ), as represented by the linear relationships:

$$r = 0.815\sigma + 0.418 \qquad (6)$$

This formula indicates that the coefficient of friction (μ) is 0.815 and the coefficient of cohesion (c) is 0.41 MPa. Similarly, Paulay and Priestley [14] determined that the cohesion of the masonry should be equivalent to 3% of its compressive strength and its coefficient of friction should range from 0.3 to 1.2.[14].
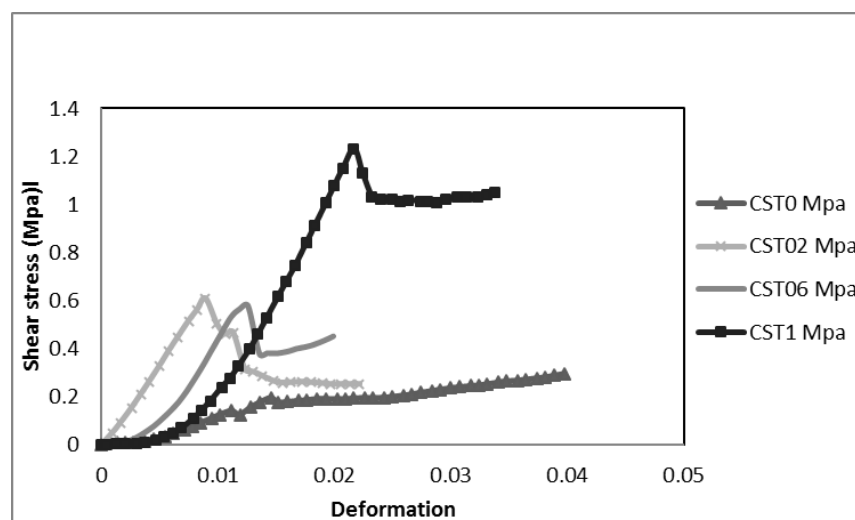

Fig.5: shear stress-strain relationship of unreinforced shear triplets with different value of pre-compression
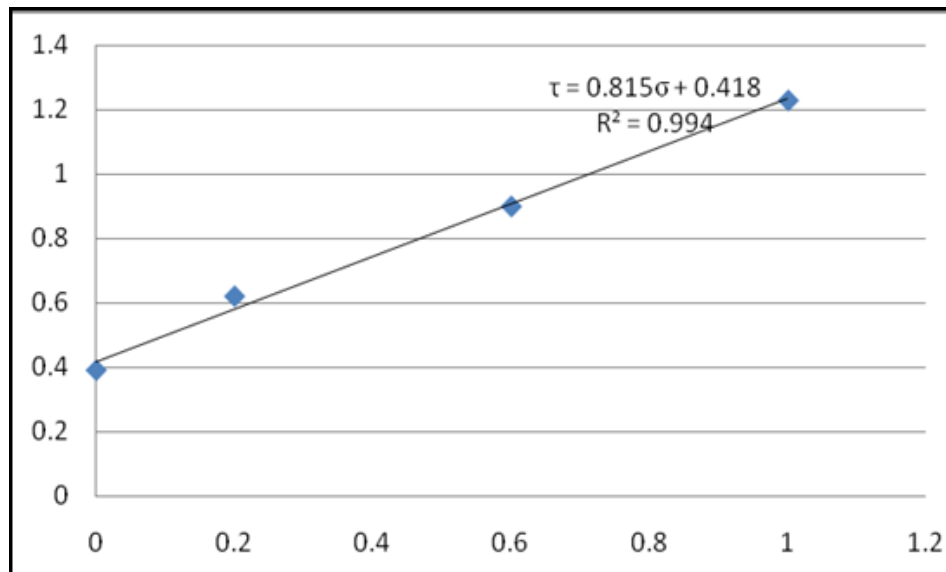
$$\tau = 0.815\sigma + 0.418$$
$$R^2 = 0.994$$

Fig.6: Maximum shear stress versus normal stress for unreinforced shear triplet test

Mode of failure

Fig. 7 shows the final states of failure under triplet shear tests for CST under different values of pre-compression, the result shows that three failure modes were found during the shear tests, i.e.:

- Sliding at the brick-mortar interfaces (Fig.7. a).
- Sliding at the brick-mortar interfaces accompanied by a diagonal shear crack at the mortar joint (**Error! Reference source not found.**Fig. 7. b).
- Shear crack at the mortar joint accompanied by splitting cracks followed by brick crushing (Fig. 7. c).

(a)Sliding at the brick-mortar interfaces

(b)Sliding at the brick-mortar interfaces accompanied by a diagonal shear crack at mortar joint

(c)Shear crack at mortar joint accompanied by splitting cracks followed by brick crushing
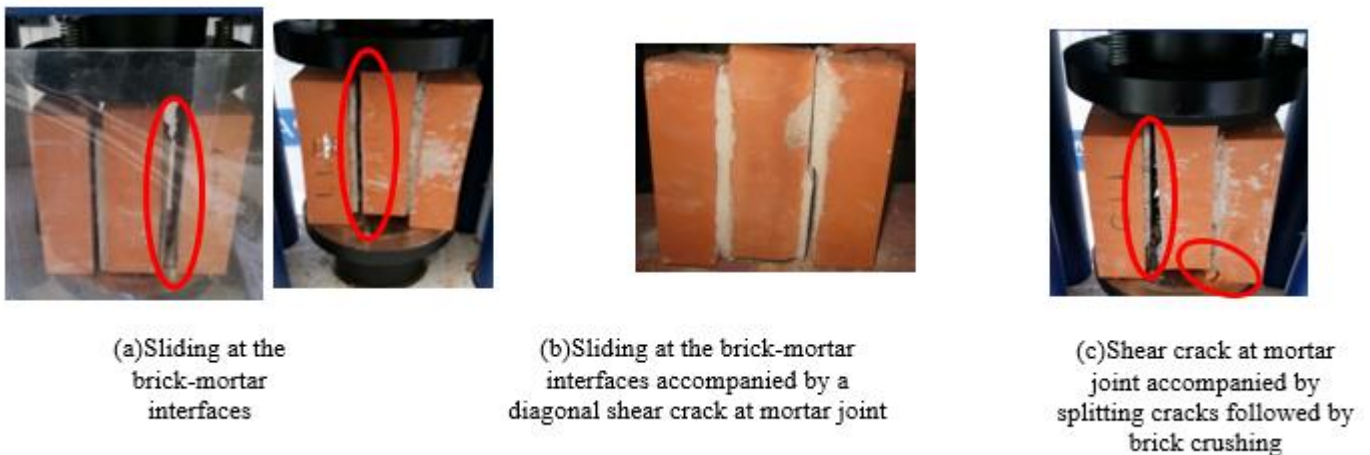
Fig.7: Final states of failure under triplet shear tests for unreinforced shear triplets (CST)

3.2. Reinforced shear triplet with FRMC (PP fiber reinforced mortar coating)

The reinforced shear triplet was subjected to the same pure shear loading. Figure 8 shows the final states of failure of reinforced specimens (RST) under different values of pre-compression, the result shows that the failure modes of all plastered specimens were similar due to a diagonal or vertical crack in the direction of loading, which followed the interface between the bricks and joint mortar. Through the application of reinforced plaster, the samples were able to deform more easily and were covered by not leaving the samples after the experiment. As a result, rupture of the samples was prevented and ductile behavior was achieved. Fig.9 represent the behavior of stress-strain for reinforced shear triplets under four levels of pre-compression applied initially. From this figure, it is noticed that maximum stress increases with increasing of compressive normal stress.

Fig.8: Final states of failure for triplet shear tests under different value of pre-compression for reinforced sheartriplets (RST)
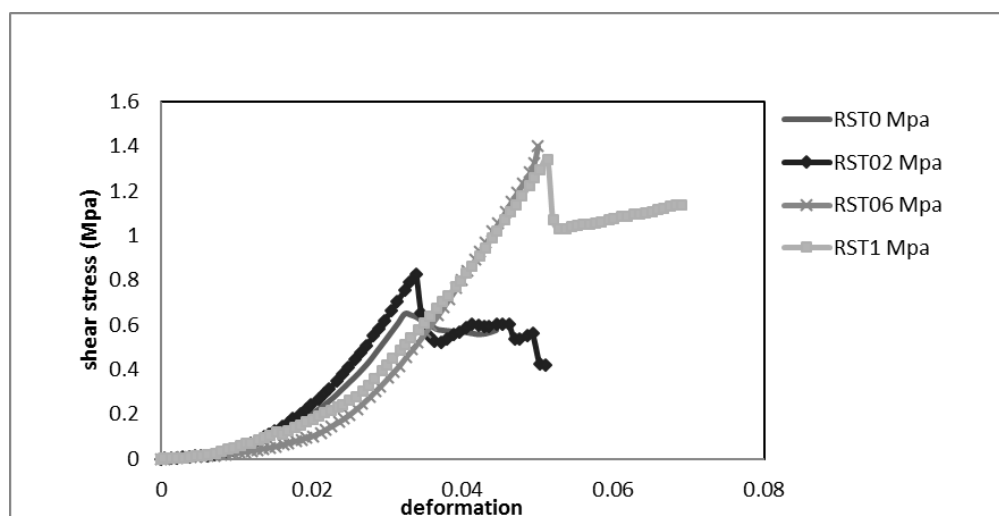

Fig.9: shear stress-strain relationship of reinforced shear triplets with different value of pre-compression
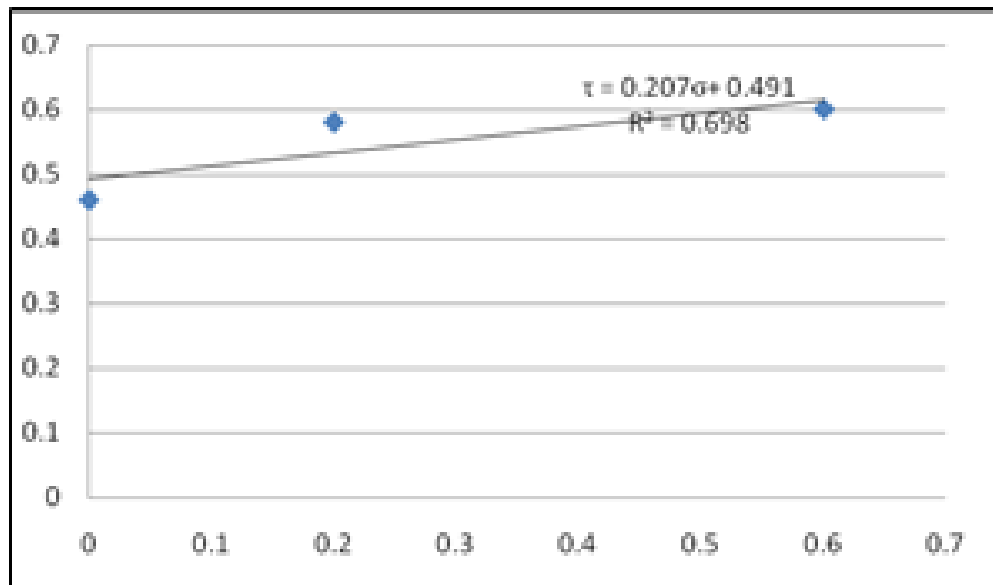
Fig.10: maximum shear stress versus normal stress for reinforced shear triplet test

According to the vertical and horizontal components of the load applied. The results give almost a linear relationship between shear and normal stresses (σ-τ) which was represented by the linear relationships:

$$r = 0.207 * \sigma + 0.491 \qquad (7)$$

In the shear failure equations obtained from fig.6 and fig.10, the smallest friction force was 0,21 in unreinforced sample and the largest was 0,81 in N sample. The largest adherence was 0,49 in reinforced sample and the smallest adherence was 0,42 in N sample.
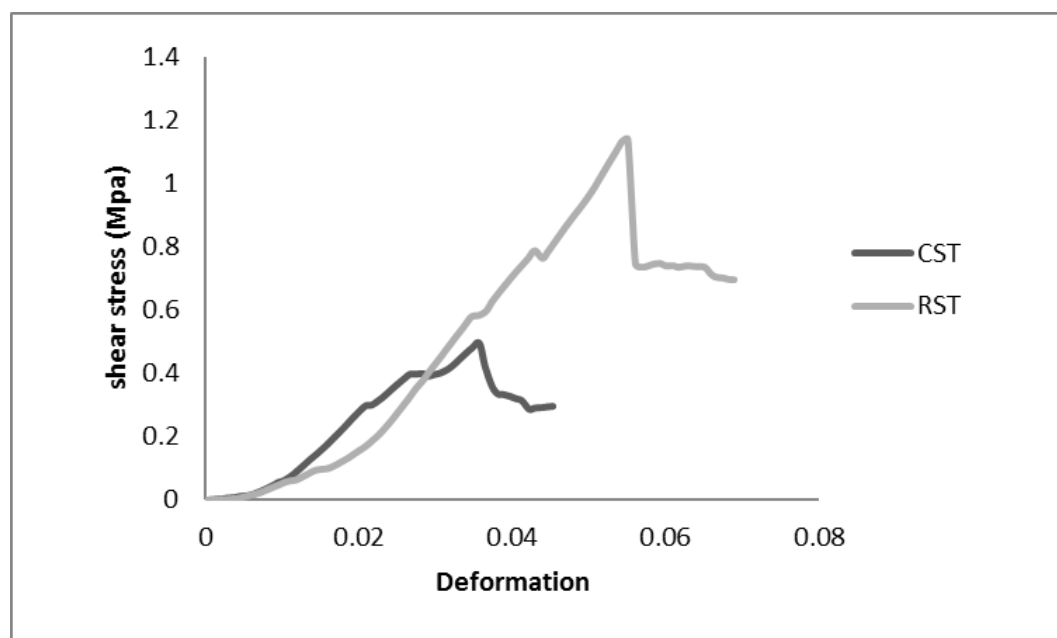

Fig.11: Comparison between the experimental results of unreinforced and reinforced shear triplets test

The experimental shear stress-strain curve for unreinforced and reinforced specimens are illustrated in Fig.10.This Figure show that the Fmax values were determined for these specimens as 27922 N and 14410 N, respectively. The maximum stress on the RST is an average of 1.23 Mpa, while the CST is only 0.28 Mpa. The curves in Fig.11 show that the reinforced specimen is more ductile than the specimens without plaster. When unreinforced shear triplet is taken as reference sample, the unreinforced shear triplet has shown a lesser deformation ability compared to the reinforced specimen. The deformation of RST specimen is also more significant than the CST specimen, which can improve the dissipation energy or the capability of the fiber reinforced mortar coating to reduce the collapse probability of the specimens. This figure shows that the application of fiber mortar coating as a plaster exhibits better the shear behavior with increase of 168% in shear resistance and improvement in deformability and increase in ductility of 46%. The maximum stress on the RST is an average of 1.23 Mpa, while the CST is only 0.28 Mpa. As shown in this figure the addition of PP fiber in mortar plastering enables the masonry shear triplet to absorb loading energy.

CONCLUSION

The aim of this research is to observe the failure mechanism and the shear behavior of perforated brick masonry walls strengthened by using thin layer coatings made of PP fiber-reinforced mortars. For this objective, triplet shear experiments were performed for unreinforced and reinforced test specimens. Test results of both types of specimens were compared with each other in terms of stress-strain relationship and deformation capacity. Once the results have been obtained and examined, the following conclusions can be drawn:

- The values of maximum load, shear strength, and deformation capacity until the break of the uncoated specimens, are significantly lower than those registered in coated specimens.
- The application of PP fiber reinforced mortar coating improves and increases the ductility and the bond strength of the masonry walls. On the other hand, the highest energy consumption was observed in the reinforced specimen.
- reinforcing application provided enhancement in shear resistance of 68% and improvement in deformability and increase in ductility of 46%.
- The PP fiber reinforced mortar coating significantly increases the stiffness of the triplet. Increasing rigidities in reinforced plaster applications may be attributed to a good surface for adherence between the wall and reinforcement.
- The reinforced plasters did not peel completely from the surface throughout the experiment and created a covering effect and increased the deformation ability of the triplet. Thus, the rupturing of the samples was prevented and ductile behavior was obtained.
- In the envelope curves drawn following the experiment, using the σ and r values obtained from the maximum stress, it was observed that the highest adherence was obtained from the reinforced triplets.
- specimens reinforced with mortar coatings present a sharp reduction of the strengths after reaching the maximum load, showing a quasi-brittle break. However, compared to uncoated wallets, they show a better post-cracking behavior.

As conclusion, the experimental results discussed in this work show that the reinforcement of masonry wallets using polypropylene fiber-reinforced mortar coatings is effective, as they improve the shear strength, increase the deformation capacity until the break and slightly improve the post-cracking behavior, although they do not avoid the brittle failure of the wallet. These results show that the PP fiber reinforced mortar that can increase the shear capacity of the masonry wall can be used as the new strengthening method for the brick masonry walls to reduce the vulnerability of this kind of structure during the earthquake excitation. The advantage of this new strengthening method is enabling the constructor to apply this technique of strengthening to their existing or new building in an easy and inexpensive way.

Compliance with ethical standards

Conflict of interest: the authors declare that they have no conflict of interest.

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