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Experimental Test of Masonry Wallets Retrofitted by ABACA Fiber Reinforced Mortar

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***Abstract*— Unreinforced masonry (URM) houses are very weak against earthquake and many of them were collapsed or heavily damaged and killed many people during past large earthquakes, such as 2015 Nepal earthquake, 2010 Haiti earthquake, 2009 Padang earthquake, etc. Most URM buildings are built with little deliberation of seismic loading, and so these are not capable of resisting the seismic ground motion, which caused damage and collapse of the buildings. Based on these circumstances, retrofitting of URM structures is the prominent issue for earthquake disaster mitigation, especially for reducing human casualty. For this reason, there are many kinds of retrofitting materials and methods have been developed and used to strengthen the URM houses, such as Fiber Reinforced Polymers (FRP), steel mesh cage, surface treatment using Shotcrete, post-tensioning using rubber tires, etc. They can contribute somehow to increase strength and modulus for structural applications. However, they are relatively expensive and not available in many parts of the world, which is of prime importance in the third world countries. Therefore, in this paper, a new retrofitting material that is Abaca Fiber Reinforced Mortar (FRM) will be proposed. Abaca fiber, which is known as a natural material and available in local community, is used as a reinforcement in cement lime mortar. The experimental method used in this research consists of the tensile test of Abaca fiber, the in-plane and out of plane method. Based on the experimental test results, FRM methods have high potency to be used as retrofitting method of URM houses, due to its bigger deformation capacity and ease on application.**

***Keywords*— Masonry structures; Retrofitting; Abaca fiber; deformation capacity.**

I. INTRODUCTION

URM houses are popular because of their inherent advantages, such as low cost, need of less skilled labor, use of locally available materials, eco-friendly, heat and sound insulation and fire proof, etc. On the other hand, because of their low seismic capacity, many URM houses were damaged or collapsed during past earthquakes in many countries [1]. The recent earthquakes in the past decades, such as the 2006 Java Earthquake in Indonesia, the 2008 Wenchuan Earthquake in China, the 2009 Padang Earthquake in Indonesia, the 2010 Haiti Earthquake, and so on, have demonstrated the seismic vulnerability of masonry structures. This is because of poor lateral load carrying capacity of masonry, especially URM walls.

Earthquakes typically strike without warning and after only tens of seconds, bring a large number of casualties and damage. The principal threat to human life and safety is the shaking damage and the collapse of buildings and other structures that have been inadequately designed or poorly constructed [2]. According to Meguro et al., retrofitting of low earthquake-resistant masonry structures is the key issue for earthquake disaster mitigation, especially for human casualty reduction [3]. Based on this reason, some retrofitting materials, such as fiber reinforced polymer, steel fiber-reinforced polymer and glass fiber-reinforced polymer, etc., have been developed and tested, but these materials are generally high in cost. Therefore, we propose to use Abaca fiber, which is easily available and has a high tensile strength. Abaca fibers are cut in the different length and then mixed in mortar as reinforcement. Use of fiber as reinforcement is a common strategy to increase the mechanical properties of mortar because fibers reduce the crack growth [4]. Recent studies also show that the basic role of fiber when added is to produce a fiber reinforced concrete (FRC) which bridges across the cracks that develop in concrete either as it is loaded or as it is subjected to environmental change [5]. But, related to the application on composite, fiber has a disadvantage in compatibility with hydrophobic matrix due to hydrophilic behavior [6]. To solve this problem, a modification is needed, such as proper surface modification of natural fiber can increase the interfacial fiber-matrix bonding [7]. In this paper, the purpose of the study is to develop a new retrofitting material which is Abaca fiber for URM houses in view of mechanical aspects and also social aspects. Abaca fiber is known as one of the strongest natural fibers, native to the Philippines and widely distributed in the humid tropics countries including Indonesia. In the last years, natural fibers reinforced composites have received high attention due to their low density, excellent thermal properties, low cost, biodegradability, availability, non-toxicity and absorbing CO2 during their growth [8-11].

II. Material and Method

Abaca fibers used in the study were obtained from Asapack Company in Japan. Tables 1 and 2 show the mechanical and chemical properties of Abaca fiber [12]. For the experiment of Abaca reinforced composite, Abaca fibers were cut into five different lengths as of 10 mm, 30 mm, 80 mm, 100 mm, and 300 mm. Since cement lime mortar is not popular, it depends on country, some country used lime and some are not. We used cement lime mortar in our research in order to improve the bond strength. We used very weak mortar due to strong bricks used as masonry unit. When we used weak mortar shear and flexural strength become very weak. Therefore we used lime to improve that. The fiber content used was 1% of total weight. Abaca fibers were mixed with cement lime mortar manually before applying to the wallets. Retrofitting using fiber reinforced cement will not contribute to significant increment of the building weight, since Abaca fiber is light material. Fifteen and twelve samples of wallets were prepared in this research for the in-plane diagonal compression test and the out-of-plane test, respectively. The wallets without retrofitting (URM wallets) and with retrofitting by Fiber Reinforced Mortar (FRM) were tested to evaluate effects of the FRM retrofitting.

TABLE I
ABACA FIBER MECHANICAL PROPERTIES [12]

Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)	Specific modulus (approx.) (GPa)	Elongation (%)
1.5	400-980	6.2-20	9	1.0-10

TABLE II
ABACA FIBER CHEMICAL PROPERTIES [12]

Cellulose (wt.%)	Hemi-cellulose (wt.%)	Lignin (wt.%)	Pectin (wt.%)	Waxes (wt.%)	Moisture content (wt.%)
56-63	20-25	7-13	1	3	5-10

TABLE III
PROPORTION OF MORTAR MIX FOR THE IN-PLANE WALLET

Cement (gr)	Lime (gr)	Sand (gr)	Water (gr)	c/w ratio
140	1,110	2,800	1,000	0.14

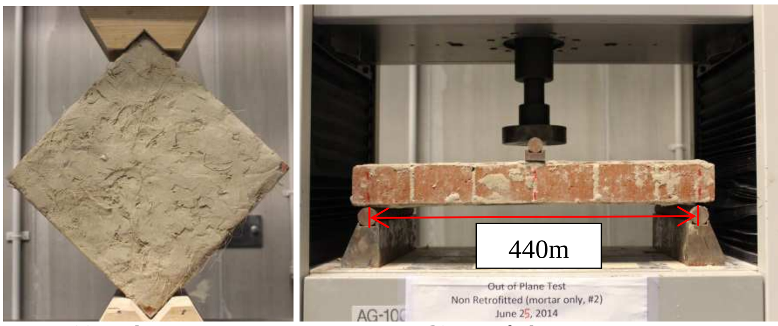
The composition of mortar for in-plane wallet is given in Table 3. Cement water ratio of mortar was kept 0.14. The wallet dimensions were 275×275×50 mm^3 and consisted of 7 brick rows of 3.5 bricks each as shown in Figure 1 (c), while the dimension for out-of-plane wallet were 475x235x50 mm^3 and consisted of 6 brick rows of 6 bricks each as shown in Figure 2. The out-of-plane wallets were simply supported with a 440 mm span. Steel rods were used to support the wallets at the two ends. The masonry wallets were tested under a line load which was applied by a 20mm diameter steel rod at the wallet mid-span (Figure 3(b)). The thickness of mortar with Abaca and mortar joint thickness were 5 mm. Specimens were tested 28 days after construction under displacement control condition (Figure 3). Autograph Shimadzu 10 T was used for the in-plane diagonal compression test. The loading rate for in-plane wallets was 0.15mm/min for URM cases and 0.25mm/min for retrofitted cases, respectively. The reason of change of loading ratio is to shorten the time of experiment and we checked that there was no difference between behaviors of the specimens when we applied 0.15mm/min and 0.25mm/min. The loading rate for out-of-plane wallets was 0.15mm/min for both cases.

(a) Abaca fiber (b) Abaca fiber after cut (c) Wallet with (left) and without (right) FRM

Fig. 1 Photos of specimens (in-plane wallet)

Wallet with (left) and without (right) FRM

Fig. 2 Photos of specimens (out-of-plane wallet)



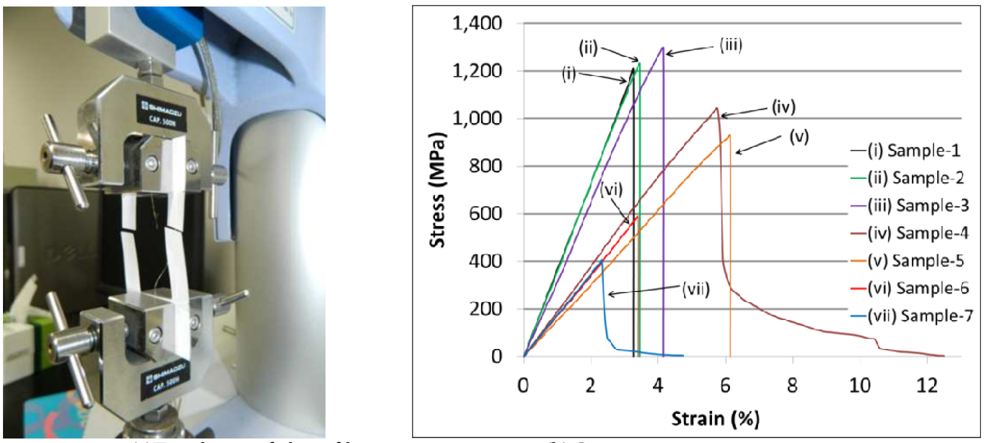
(a) In-plane test (b) Out-of-plane test

Fig. 3 Testing of specimens

III. Results and Discussion

A. Tensile Strength Test of Abaca Fiber

The Universal Testing Machine (UTM) Shimadzu EZ-L 200 N is used to conduct the tensile strength test of Abaca fiber. There were seven samples with 40 mm in length were used in this test. These fibers then were pasted by glue to the paper as shown in Figure 4(a). The diameter of Abaca fibers used in this test were varied in between 0.13 mm to 0.2 mm. The results of the tensile strength test of Abaca fibers are shown in Figure 4 (b). From the experimental test, it is obtained that most of fibers showed a brittle failure, whereas some samples still have some deformation capacities. The average of tensile strength test was 957 MPa. These fibers showed average strain as much as 4.3%.



(a)Tensile test of abaca fiber (b) Stress-strain curves

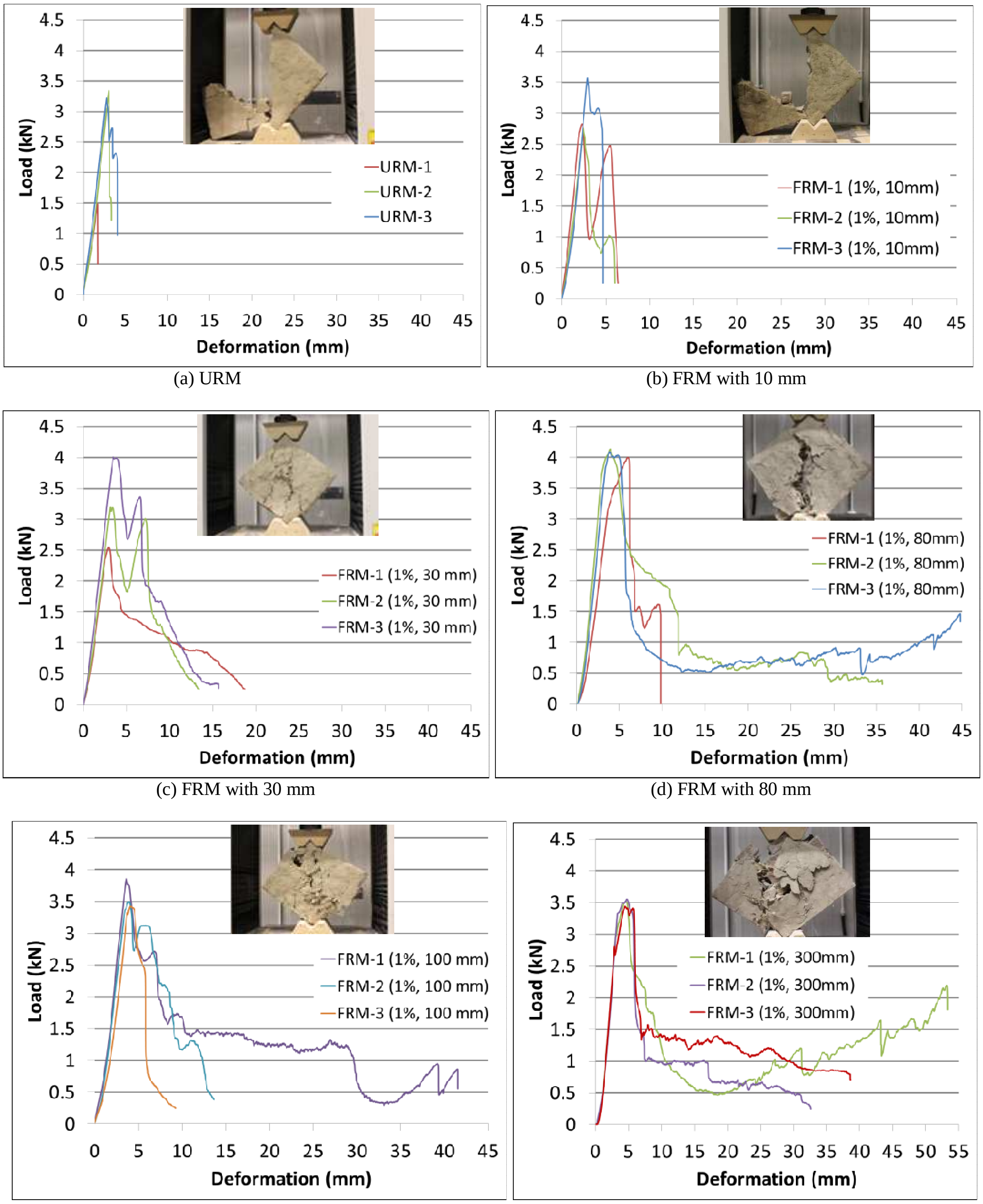
Fig 4. Tensile test of Abaca fiber

B. In-plane Diagonal Compression Test

The in-plane diagonal compression tests using masonry wallets with and without retrofitting were carried out to evaluate the effect of retrofitting by Abaca fiber reinforced cement composite. Three samples for each condition (URM and retrofitted by FRM) were tested. As presented in Figure 5, URM wallets were split into two pieces after the initial diagonal crack occurred, and no residual strength was left. On the other hand, FRM wallets performed with slightly higher strength and bigger deformation than URM, due to the contribution of Abaca fiber inside the mortar as shown in Figures 5 (a) to 5(f). The average strength of URM wallets is 2.7 kN, while those of FRM wallets with fiber length 10mm, 30 mm, 80 mm, 100mm, and 300 mm are 3.0 kN, 3.3 kN, 4.0 kN, 3.6 kN, and 3.5 kN, respectively.

All specimens exhibited linear curves up to the peak load, and then the load decreased due to the initial crack occurred. After the peak load, most of the curves showed decreasing lines as the crack became bigger. As can be seen in Figures 5 (b) to 5 (f), there was a decreasing line after the specimens achieved the initial peak strength. After initial peak strength, the load was transferred to the Abaca fiber, as reinforcement in mortar. Abaca fibers in cement composites played a role as a crack arrester and bridged the cracks on two sides when any crack occurred. Therefore, when the cracks became bigger, longer fiber lengths contributed to give more deformation capacities, as in Figures 5 (d), 5 (e), and 5 (f) up to 15 to 55 mm.

Based on the test results, composites with longer fibers (fiber length 80 mm, 100 mm, and 300 mm) show slightly higher strength and bigger deformation compared to those with shorter fibers and URM wallets. Even though there is no significant strength difference by the length of fiber used; it is clear that Abaca fiber in cement composites contributes to increasing deformation capacity.



(a) URM

(b) FRM with 10 mm

(c) FRM with 30 mm

(d) FRM with 80 mm

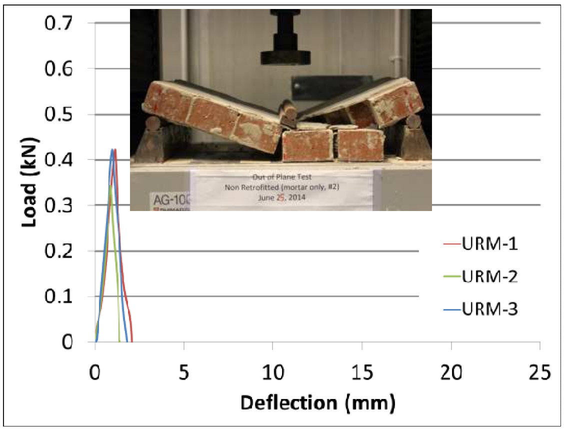
(e) FRM with 100 mm

(f) FRM with 300 mm

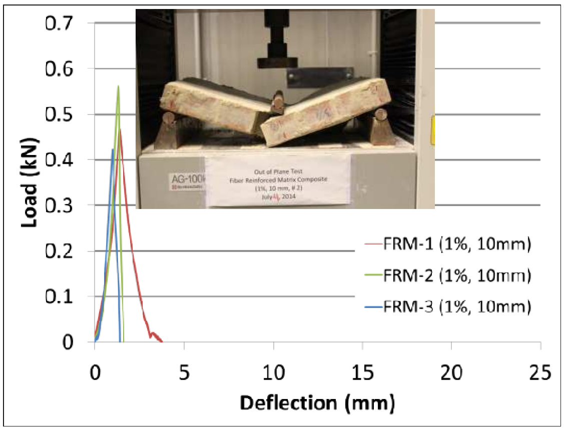
Fig. 5. Load-deformation curves of URM and FRM wallets (in-plane test)

C. Out-of-plane Bending Test

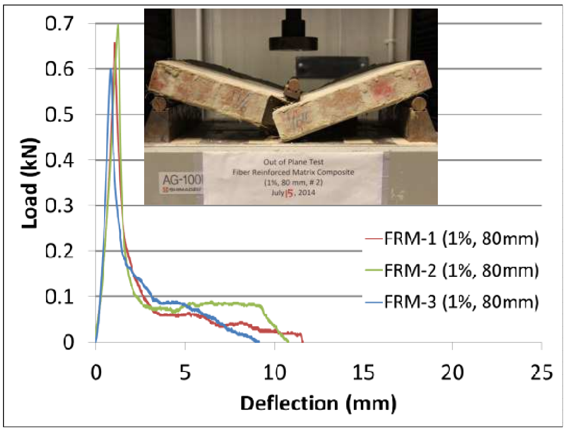
Based on the results of the out-of-plane tests, URM wallets showed a brittle failure after the peak load and the wallet specimens were broken easily into two parts after the initial crack occurred. On the other hand, in the case of FRM wallets, ductile failure could be observed after the peak load. The wallet specimens could have deformation capacities up to 10 mm - to 20 mm in case of fiber length 80 mm and 300 mm, as shown in Figures 6 (c) and 6 (d) as long fibers could prevent cracks from opening. Fiber length 80 mm also showed a higher strength value as of 0.7 kN compared to other fiber lengths. In case of the fiber length of 10 mm, there is no significant difference from URM wallets, while it showed smaller deformation capacity than that of longer fiber cases (Figure 6 (b)). The average strength of URM, fiber length 10 mm, 80 mm, and 300 mm is 0.40 kN, 0.48 kN, 0.65 kN, and 0.45 kN, respectively. The out-of-plane test of Abaca fiber reinforced cement composites showed smaller deformation capacities than those of the in-plane tests, which showed maximum deformation capacities up to 55 mm. The effectiveness of Abaca fiber reinforced cement composites in the out-of-plane tests still needs to be tested and evaluated.



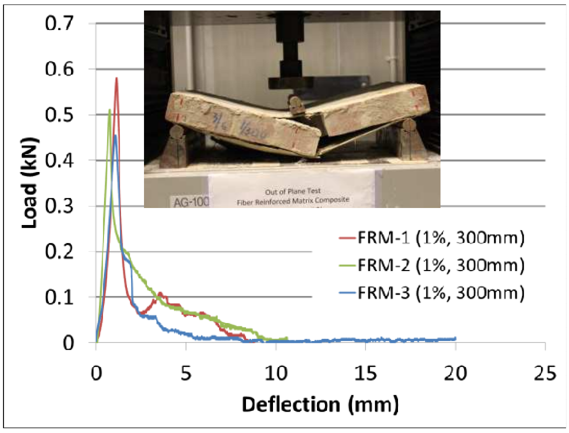
(a) URM



(b) FRM with 10 mm



(c) FRM with 80 mm



(d) FRM with 300 mm

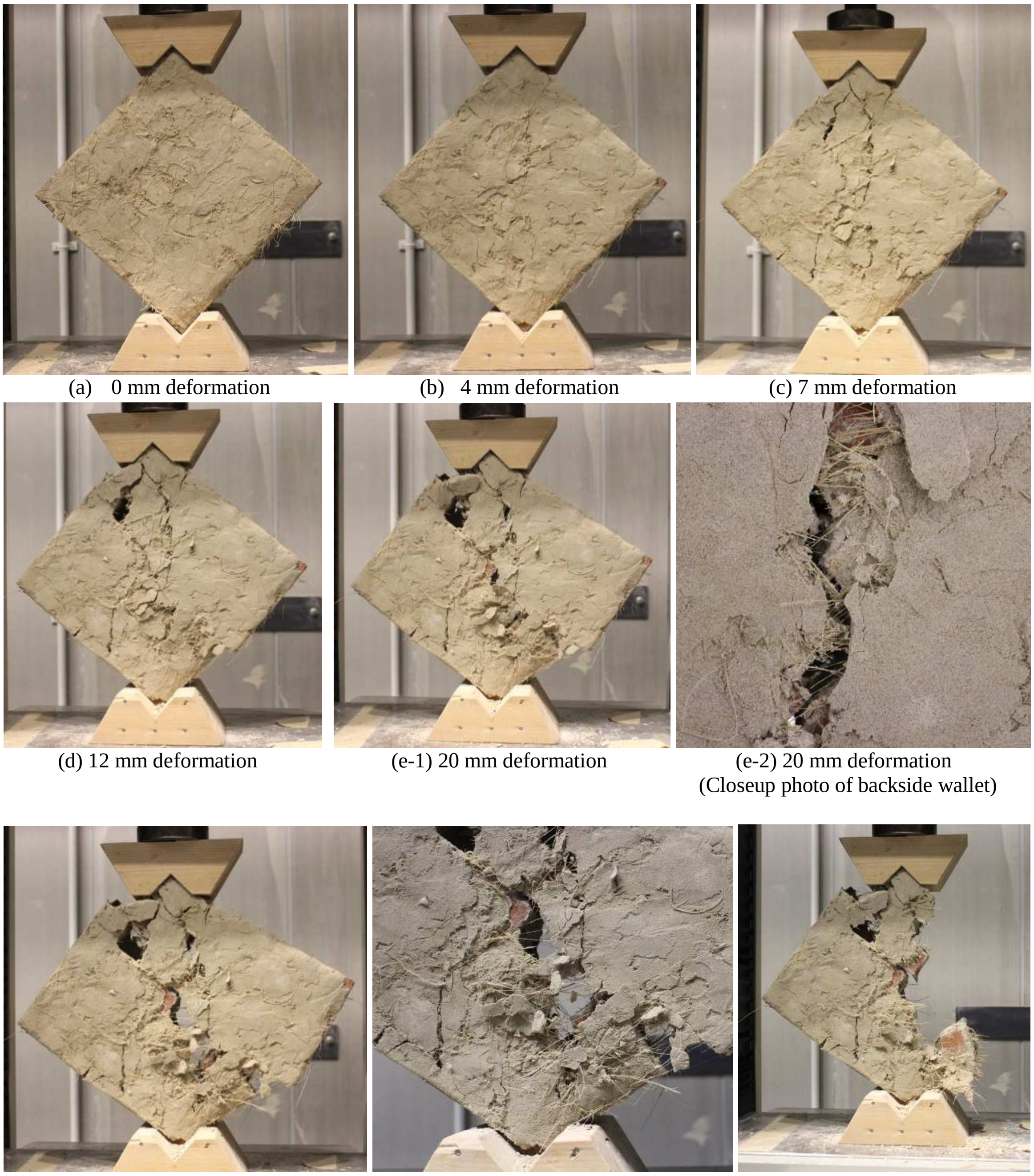
Fig. 6. Load-deformation curves of URM and FRM wallets (out-of-plane test)

D. Failure Patterns of the FRM of the in-plane tests

Fig. 7 shows the failure patterns of FRM of the in-plane tests. The in-plane wallets showed diagonal tension crack first when the initial crack occurred and then became bigger, a shear sliding failure occurred after that, while Abaca fiber played a role as crack arrester and bridge the crack before the wallets collapsed. Shear sliding also observed in the FRM in-plane wallets and caused the wallets collapsed due to no confinement from Abaca fiber. On the other hand, when the crack became bigger and caused shear sliding to ARM in-plane wallets, Abaca rope confined the brick vertically and horizontally.

E. Failure Pattern of FRM Wallets of the out-of-plane wallet

Whereas for the out-of-plane wallets (Fig.8), the initial crack occurred around mid-span, became bigger, and then continued to another span along the mortar joint. The failure along the mortar joint caused the bricks collapsed in a shorter time for FRM out-of-plane wallets

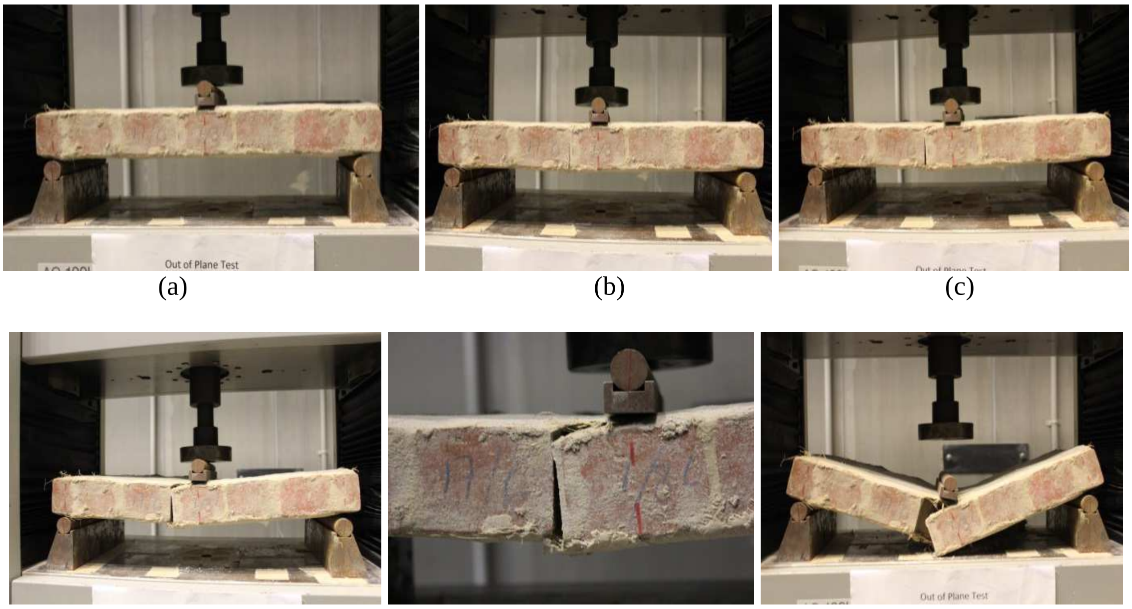


(a) 0 mm deformation (b) 4 mm deformation (c) 7 mm deformation

(d) 12 mm deformation (e-1) 20 mm deformation (e-2) 20 mm deformation (Closeup photo of backside wallet)

(f) 28 mm deformation (g) 38 mm deformation (h) 41.5 mm deformation

Fig. 7 In-plane testing of FRM wallet with 100 mm fiber length (FRM-1 in Fig. 4 (e)) from (a): the beginning, (b): initial diagonal crack occurred, (c~f): the crack became bigger and other cracks appeared, (d~g): Abaca fiber bridges the crack, and (h): collapsed wallet



(a) (b) (c)

(d) (e) (f)

Fig. 8 Out-of-plane test using FRM wallet with Abaca fiber length 80 mm from the beginning (a), initial diagonal crack occurred (b), the crack became bigger (c, d), Abaca fibers bridge the crack (e), collapsed wallet (f)

IV. Conclusions

Based on the results of the experimental tests, Abaca fiber-reinforced mortar have a high potential for retrofitting Unreinforced Masonry houses, especially in developing countries. FRM wallets by Abaca fiber-reinforced mortar showed a slightly higher strength because using Abaca fiber as reinforcement in cement composites does not contribute to increasing the strength and bigger deformation capacities than those of URM wallets. FRM with longer fiber (fiber length 80 mm) showed the highest strength as of 4.0 kN and also biggest ductility up to 45 mm, compared to URM and FRM with shorter fibers and FRM with fibers longer than 80 mm.

The effective fiber length in FRM reached the optimum value at fiber length 80 mm. As it is observed in the case of fiber with 100 mm length, the strength and the ductility became smaller. In case that fiber with the length of over 80 mm is used, it showed less workability due to the fiber balling during a mix with mortar. Variability of the fibers (as it is a natural fiber) and the workmanship contribute to the variability of performance of retrofitted specimen.

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