URM WALLETS RETROFITTED WITH FIBER REINFORCED MORTAR (FRM) AND ABACA ROPE MESH (ARM) SUBJECTED TO DIAGONAL COMPRESSION TEST

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ABSTRACT: Unreinforced masonry (URM) walls have been constructed for long time and are still widely used today. However, the past large earthquakes have repeatedly shown the vulnerability of URM walls, as it have been reported that many of URM walls were collapsed and killed many people. Therefore, retrofitting of existing URM walls is urgently needed to reduce the casualties in the future. In this paper, we propose URM wallets retrofitted with a new material that is Abaca fiber, in the form of Fiber Reinforced Mortar (FRM) and Abaca Rope Mesh (ARM) subjected to diagonal compression test. Abaca fiber is a locally available natural material and it has high tensile strength. Based on the results of in-plane tests, FRM and ARM can increase strength and deformation capacity of masonry wallets.

Key Words: Unreinforced masonry, retrofitting, Abaca fiber, strength, deformation capacity

INTRODUCTION

Unreinforced masonry (URM) buildings have been known as popular building structures because of their inherent advantages, such as low cost, need of less skilled labour, use of locally available materials, eco-friendly, heat and sound insulation and fire proof, etc. However, most of URM buildings are built with little or no consideration of seismic loading, and these are not capable of resisting the expected seismic ground motions. Due to their low seismic capacity, many URM houses were damaged or collapsed during the past earthquakes in many countries around the world. The URM buildings have been the major cause of human and economic losses during earthquakes, as observed during the 2001 Gujarat Earthquake in India, the 2003 Bam Earthquake in Iran, the 2005 Kashmir Earthquake in Pakistan, 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. 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 (1). It caused the poor lateral load carrying capacity of masonry, especially URM walls. URM walls have low shear and flexural strength to withstand in-plane and out-of-plane loads generally caused by earthquakes (2). A masonry wall subjected to diagonal compression can fail by

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shear sliding, shear friction, diagonal tension, or toe crushing, depending on its material properties, height-to-length ratio, and applied force (3).

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 (4). 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. However these materials are generally expensive and are not available in many parts of the world. Therefore, we use a natural fiber called Abaca fiber, which is locally available and has high tensile strength, as a reinforcement in cement lime mortar (FRM) and as a mesh (ARM). Natural fiber reinforced cement composites have been getting attractive during last years, especially for low cost building construction in developing countries (5, 6). It has been reported that natural fibers, such as Sisal, Roselle, Coconut, Sugar cane bagasse, Hemp, and Jute, etc. improve the compressive and tensile strength of the cement based composites (7-12). 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 CO_2 during their growth (13-16). It has been reported that Abaca fiber is resistant to rotting and has a high tensile strength, and a specific flexural strength comparable to that of glass fiber (17). Only a few research has been done using Abaca fiber as a retrofitting material of unreinforced masonry (URM) houses. This paper is an attempt to contribute to the development of a new retrofitting material for URM houses strengthened with FRM and ARM subjected to diagonal compression test, considering both mechanical aspects (high strength, large deformation and energy dissipation capacities), and social aspects (local availability, easy applicability, and affordability).

Figure 1. Abaca fiber before cut (left), after cut (middle), and mixed in mortar (right)

Figure 2. Abaca fiber in the form of Abaca rope before separation (left) and after separation (right)

EXPERIMENTAL PROGRAM

Abaca fibers used in this study were obtained from Asapack Company in Japan. The mechanical and chemical properties of Abaca fiber are given in Tables 1 and 2 (18). There are two type of retrofitting methods, they are FRM and ARM. For the FRM retrofitting, Abaca fibers were cut into two different lengths as of 30 mm and 80 mm (Figure 1). The fiber content used was 1% of total weight. Abaca fibers were mix with cement lime mortar manually before applying to the wallets (Figure 3). While for ARM retrofitting, Abaca fiber were cut and separated become three tiny Abaca rope with the thickness around 2-3 mm (Figure 2). Then, Abaca rope were meshed vertically (six Abaca rope) and horizontally (six Abaca rope) to the wallets prior to plastering, with spacing 40 mm (Figure 4). Abaca rope were meshed vertically first and then horizontally. Twelve samples of wallets were prepared in this research for the in-plane diagonal compression tests. The wallets without retrofitting (URM wallets) and with retrofitting by Fiber Reinforced Mortar (FRM wallets) and Abaca Rope Mesh (ARM) were tested to evaluate effects of the FRM and ARM retrofitting.

Table 1. Mechanical properties of Abaca fiber (18)

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 2. Chemical properties of Abaca fiber (18)

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 3. 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 mm³ and consisted of 7 brick rows of 3.5 bricks each as shown in Figure 3. The mortar joint thickness was 5 mm. All wallet specimens were built under same constituent and cured for 28 days under same environmental conditions. Two specially made strong wooden wedges are used to apply diagonal force over the corners of masonry wallets. Wooden wedges are connected with Autograph Shimadzu 10 T top and bottom platens. After 28 days, specimens were tested under displacement control condition (Figure 5). Autograph Shimadzu 10 T was used for the in-plane diagonal compression test. The loading rate for in-plane wallets was 0.15m/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 0.15m/min and 0.25mm/min.

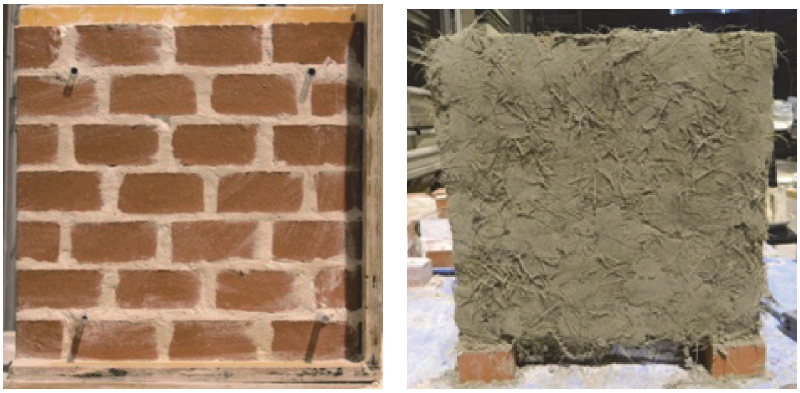


Figure 3. Photos of wallet before and after FRM retrofitting

Figure 4. Photos of ARM wallet before and after plastering

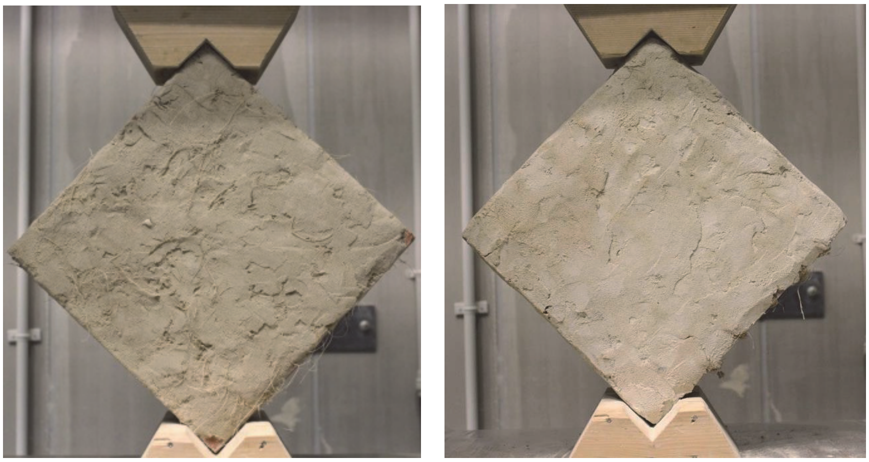


Figure 5. Testing of in-plane specimens, FRM (left) and ARM (right)

RESULTS AND DISCUSSION

Tensile strength test of Abaca fiber

The axial tensile tests of Abaca fiber were conducted by using the Universal Testing Machine (UTM) Shimadzu EZ-L 200 N with constant loading rate (10 mm/min). Seven specimens with 40 mm length single fiber pasted by glue to the paper were prepared as shown in Figure. 6. Diameter of Abaca fiber varies from 0.13 mm to 0.2 mm. The axial tensile tests of Abaca fiber were performed and the results shown in Figure. 7 were obtained. Most of samples showed brittle failure, while some samples still have some deformation capacities. The average tensile strength and strain were 957 MPa and 4.3 %, respectively.

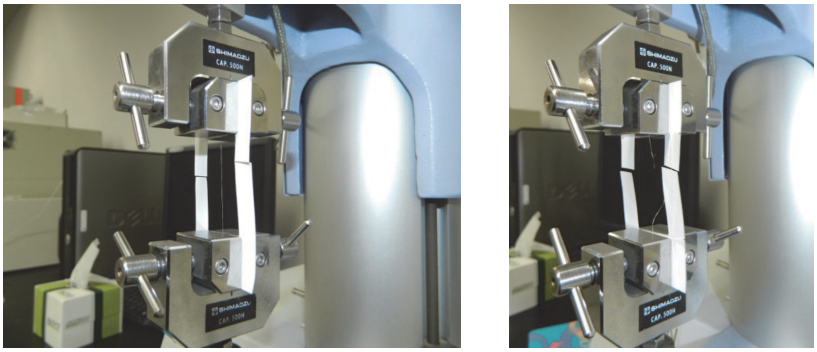


Figure 6. Tensile test of Abaca fiber before test (left) and after test (right)

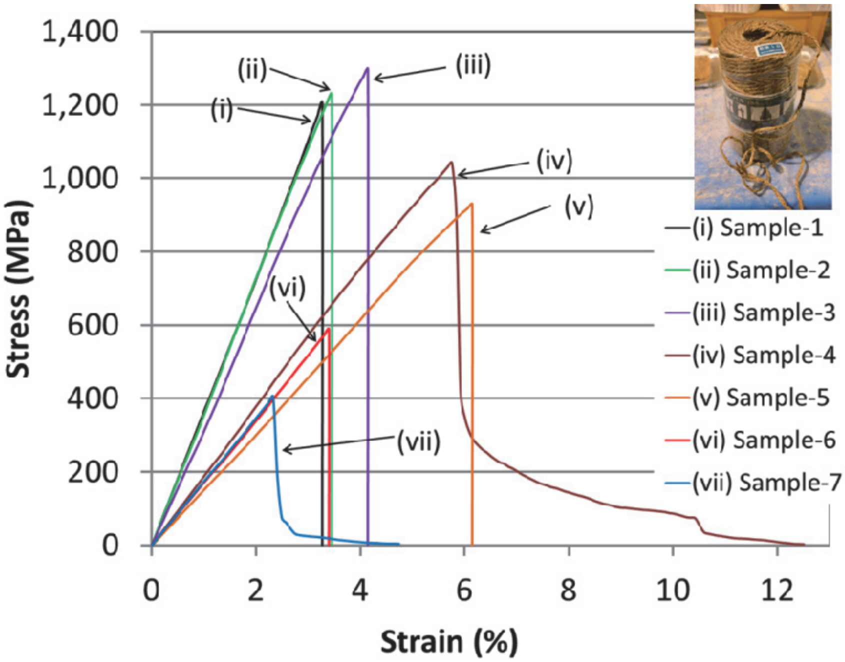
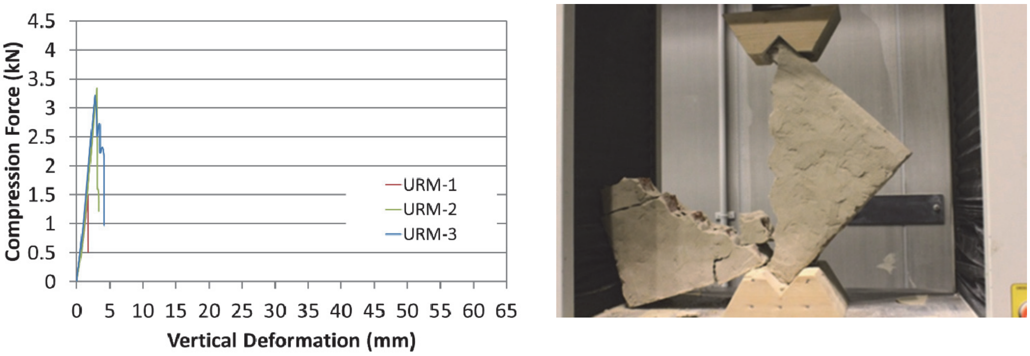


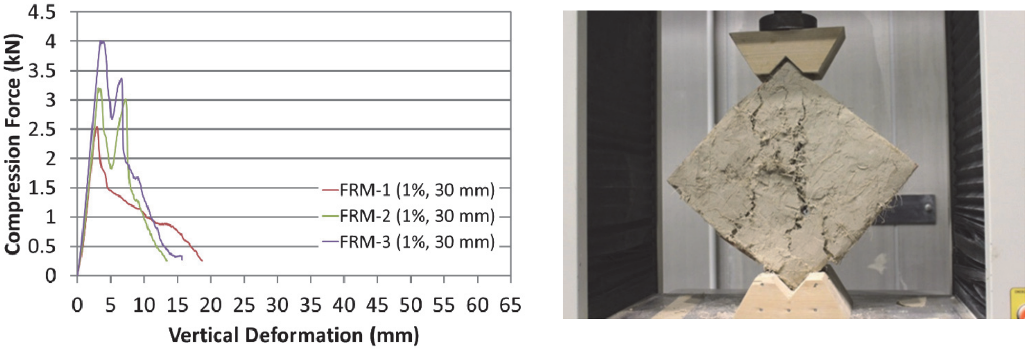
Figure 7. Results of tensile test of Abaca fiber

In-plane diagonal compression test

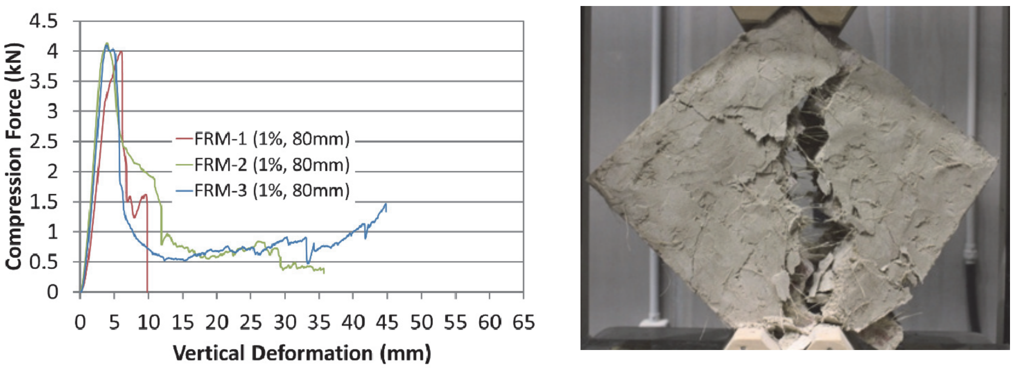
The in-plane diagonal compression tests using masonry wallets with and without retrofitting were carried out to evaluate the effect of retrofitting by FRM and AFM. Three samples for each condition (URM and retrofitted by FRM and ARM) were tested. As presented in Figure. 8 (a), URM wallets were split into two pieces after the initial diagonal crack occurred and no residual strength was left. On the other hand, FRM and ARM wallets performed with a slightly higher strength and bigger deformation than URM, due to the contribution of Abaca fiber. The average strength of URM, FRM (fiber length 30 mm and 80 mm), and ARM wallets are 2.7 kN, 3.3 kN, 4.0 kN, and 1.5 kN, respectively. For FRM retrofitting, all specimens exhibited linear curves up to the peak load and then decreased due to the initial crack occurred. After the peak load, most of the curves showed decreasing lines as the crack became bigger. Some specimens have a second peak as shown in Figure. 8 (b), due to good workability of fiber inside mortar and well distribution on the wallets surface. The well distribution of fiber inside mortar contributed more to bridge the cracks so the strength increase up to second peak. 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 up to 10 – to 45 mm. ARM retrofitting showed a lower initial peak strength than those of FRM, but it has a higher residual strength due to the confining effect of Abaca rope mesh on both sides of wallets. ARM wallets showed a higher residual strength than their initial peak strength almost two times per each specimen. It also contributed to the bigger deformation capacities up to 65 mm (Figure. 8(d)). FRM retrofitting has an advantage on ease in application and bigger deformation capacities than URM, whereas ARM retrofitting has a higher residual strength and bigger deformation capacities than those of URM and FRM.



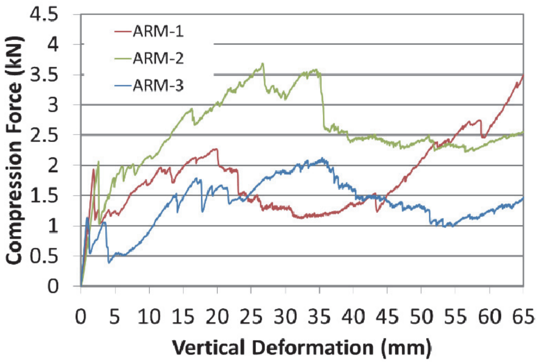
(a) URM



(b) FRM with 30 mm



(c) FRM with 80 mm



(d) ARM

Figure 8. Load-deformation curves of URM, FRM, and ARM

CONCLUSIONS

Based upon the diagonal compression test results, Abaca fiber performed a high tensile strength of 957 MPa. It can be concluded that FRM and ARM retrofitting have high potential for retrofitting URM houses in developing countries. For both retrofitting FRM and ARM wallets showed a slightly higher strength and bigger deformation capacities than those of URM wallets. FRM retrofitting have an advantage on easily application and bigger deformation capacities than those of URM, while ARM retrofitting have a higher residual strength and bigger deformation capacities than those of URM and FRM due to the holding effect of Abaca rope mesh. ARM retrofitting also have a lower risk of falling down brick and mortar spalling, because of attaching Abaca ropes to the mortar. Following researches regarding out-of-plane test, shaking table tests, and durability will be reported in other papers by the authors.

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