IN-PLANE AND OUT-OF-PLANE STATIC FAILURE TEST OF MASONRY WALLET RETROFITTED BY ABACA FIBER REINFORCED CEMENT COMPOSITES

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Abstract

Masonry structures, especially unreinforced masonry (URM) ones are very weak against earthquake and many of them were collapsed and/or heavily damaged and killed many people during past large earthquakes. Therefore, retrofitting of URM houses is the key issue for reducing casualties. In this paper, we will propose a new retrofitting material that is Abaca fiber reinforced cement composites. Abaca fiber, which is a locally available natural material and has high tensile strength, is used as a reinforcement in cement lime mortar. Based on the results of in-plane and out-of-plane static failure tests, Abaca fiber reinforced cement composites can increase strength and deformation capacity of masonry wallets.

Key Words: Masonry, Retrofitting, Abaca fiber, Strength, Deformation capacity

1. INTRODUCTION

URM houses are popular 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. On the other hand, because of their low seismic capacity, many URM houses were damaged or collapsed during the past earthquakes in many countries [7]. The recent earthquakes in the past decades, such as, 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, have demonstrated the seismic vulnerability of masonry structures. This is because of 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].

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 [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 [13]. 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 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, mixed in mortar as reinforcement. Abaca fiber is 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 [5,8,9,19]. 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 [10].

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In recent years, natural fiber reinforced cement composites have been getting attractive, especially for low cost building construction in developing countries [15,16]. 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 [1,6,11,12,14,17]. It is also reported that natural fibers, as reinforcing agent in cement or cement concrete composites, serve as crack arrestor that eventually retard the crack propagation to lead non-catastrophic failure [18]. Only a few research has been done using Abaca fiber as a retrofitting material of unreinforced masonry (URM) houses.

The purpose of the study is to develop a new retrofitting material for URM houses considering both mechanical aspects (high strength, large deformation and energy dissipation capacities, and long durability), and social aspects (local availability, easy applicability, and affordability).

2. EXPERIMENTAL PROGRAM

Abaca fibers used in the study were obtained from Asapack Company in Japan. The mechanical and chemical properties of Abaca fiber are given in Tables 1 and 2 [4]. 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 wallets) were tested to evaluate effects of the FRM retrofitting.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Tensile strength (MPa)</th>
<th>Tensile modulus (GPa)</th>
<th>Specific modulus (approx.) (GPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>400-980</td>
<td>6.2-20</td>
<td>9</td>
<td>1.0-10</td>
</tr>
</tbody>
</table>

Table 1 Mechanical properties of Abaca fiber [4]

<table>
<thead>
<tr>
<th>Cellulose (wt.%)</th>
<th>Hemi-cellulose (wt.%)</th>
<th>Lignin (wt.%)</th>
<th>Pectin (wt.%)</th>
<th>Waxes (wt.%)</th>
<th>Moisture content (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56-63</td>
<td>20-25</td>
<td>7-13</td>
<td>1</td>
<td>3</td>
<td>5-10</td>
</tr>
</tbody>
</table>

Table 2 Chemical properties of Abaca fiber [4]

Table 3 Proportion of mortar mix for the in-plane wallet

<table>
<thead>
<tr>
<th>Cement (gr)</th>
<th>Lime (gr)</th>
<th>Sand (gr)</th>
<th>Water (gr)</th>
<th>c/w ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1,110</td>
<td>2,800</td>
<td>1,000</td>
<td>0.14</td>
</tr>
</tbody>
</table>

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 275x275x50 mm³ 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 mm³ 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

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

Wallet with (left) and without (right) FRM

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

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

Figure 3. Testing of specimens

3. RESULTS AND DISCUSSION

3.1 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 4 (a). 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 4 (b) 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.
3.2 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 a 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 it can be seen in Figures 5 (b) to 5 (f), there were 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 a slightly higher strength and clearly 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 increase deformation capacity.
Figure 5. Load-deformation curves of URM and FRM wallets (in-plane test)

3.3 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 case of FRM wallets, ductile failure could be observed after the peak load. The wallet specimens could have deformation capacities up to 10 mm - 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 are 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. For the fiber length 30 mm and 100 mm, the out-of-plane tests are still ongoing. The effectiveness of Abaca fiber reinforced cement composites in the out-of-plane tests still needs to be tested and evaluated.

4. CONCLUSIONS

Based upon the experimental results, it can be concluded that Abaca fiber reinforced cement composites have high potential for retrofitting URM houses in developing countries. FRM wallets by Abaca fiber reinforced cement composites showed a slightly higher strength, because using Abaca fiber as reinforcement in cement composites does not contribute to increase the strength and bigger deformation capacities than those of URM wallets. Following researches regarding out-of-plane test, shaking table tests, and durability of this composites will be reported in other papers by the authors.

5. REFERENCES


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Etri Suheilmidawati, getting Ahli Madya (A.Md) degree from Department of Civil Engineering, Polytechnic State of Padang in 1999, Sarjana Teknik (ST) degree from Department of Civil Engineering, Andalas University in 2003, Master of Engineering (M.Eng) degree from Department of Civil Engineering, Toyohashi University of Technology, Japan in 2006, Doctor of Engineering (Dr.(Eng)) degree from Department of Civil Engineering, The University of Tokyo, Japan in 2015. Now, work as lecturer at Department of Civil Engineering, Polytechnic State of Padang.