SHEAR DUCTILITY OF FIBER-REINFORCED LIGHTWEIGHT-AGGREGATE CONCRETE MASONRY

F. M. Tehrani¹, S. Rico², and R. Farshidpour³

ABSTRACT

Reinforcing concrete masonry walls intends to create selective ductile elements to control the overall response of the building, rather than addressing the brittleness of masonry units. The quality control and assurance of this standard practice requires additional technological and financial resources. As a result, this paper aims to enhance the ductility of masonry units as a means to improve the response of concrete masonry systems. The proposed methodology includes a combination of fiber reinforcement and replacement of conventional coarse aggregates with lightweight expanded shale aggregates. Previous studies indicate fiber reinforcement enhances the flexural strength, toughness, and ductility of concrete. Existing literature also confirms that expanded shale aggregates reduce the applied seismic load due to their lighter weight and lower modulus of elasticity. This paper incorporates a series of experimental studies on the shear behavior of masonry assemblages with zero to two percent of steel fibers by volume. Testing plans included the standard application of diagonal shear loads on masonry piers with type-N normal mortars. Results confirmed that fiber-reinforced lightweight-aggregate concrete masonry (FRLWACM) have a higher capacity for energy absorption with a clear indication of enhanced ductility in shear behavior. Observation of load-deflection curves indicate that such enhancement is achieved through incorporating a small fraction of fiber content. Thus, FRLWACM is a practical and applicable approach in respect to the unit manufacturing process in industry.

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Shear Ductility of Fiber-Reinforced Lightweight-Aggregate Concrete Masonry

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ABSTRACT

Reinforcing concrete masonry walls is intended to create selective ductile elements to control the overall response of a building, rather than addressing the brittleness of masonry units. The quality control and assurance of this standard practice requires additional technological and financial resources. This paper aims to enhance the ductility of masonry units as a means to improve the response of concrete masonry systems. The proposed methodology includes a combination of fiber reinforcement and replacement of conventional coarse aggregates with lightweight expanded shale aggregates. Previous studies indicate fiber reinforcement enhances the flexural strength, toughness, and ductility of concrete. Existing literature further confirms expanded shale aggregates reduce the applied seismic load due to their lighter weight and lower modulus of elasticity. This paper incorporates a series of experimental studies on the shear behavior of masonry assemblages with zero to two percent of steel fibers by volume. Testing plans included the standard application of diagonal shear loads on masonry piers with type-N normal strength mortars. Results confirmed that fiber-reinforced lightweight-aggregate concrete masonry (FRLWACM) contain a higher capacity for energy absorption with a clear indication of enhanced ductility in shear behavior. Observation of load-deflection curves indicate that such enhancement is achieved through incorporating a small fraction of fiber content. Thus, FRLWACM is a practical and applicable approach in respect to the unit manufacturing process in industry.

Introduction

Application of lightweight aggregate concrete and fiber-reinforcement is widely accepted in numerous construction practices [1-2]. Existing literature indicates the effectiveness of fiber-reinforcement in the enhancement of shear ductility and toughness of concrete [3-4]. Furthermore, application of lightweight concrete has a key impact on the reduction of inertia forces during seismic events [5]. These benefits are an indication of the desired characteristics of fiber-reinforced lightweight concrete in seismic regions, where combinations of lightness and toughness enhance the performance of structures in response to dynamic loads [6-10]. Concrete masonry construction, in particular, benefit from these advantages by incorporating fiber reinforcement in the manufacturing process of masonry units in addition to in-situ mixture of grout and mortar.

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Conventional lightweight aggregate concrete may not only address strength requirements of masonry construction, but also incorporate fiber reinforcement processes during unit manufacturing eliminating concerns regarding the workability of fiber-reinforced concrete during in-situ placement [11]. Thus, fiber-reinforced lightweight-aggregate concrete masonry (LWAFRCM) is a practical alternative to conventional concrete masonry in respect to means and methods of production and construction.

Methodology

The scope of this research concentrates on the post-peak strength and behavior of the fiber-reinforced concrete masonry assemblages subject to shear diagonal loadings similar to the ASTM E519 in order to evaluate the effects of steel fiber on the ductility index [12]. The concrete mix contained Portland cement type II, water, normal-weight fine aggregate, lightweight expanded clay coarse and fine aggregates, and steel fibers at zero, one, and two percent volumetric contents. Steel fibers were plain with 0.2 mm diameter and 13 mm length (Fig. 1 and 2).

Mix design followed masonry industry recommendations and ASTM C192 standard [13] at various water contents from 10 to 14 percent by volume. The design mix was selected based on initial compressive tests on 15 specimens using ASTM C39 [14], and contained 14% cement, 19.85% coarse lightweight aggregate, 19.85% fine lightweight aggregate, 34% normal-weight sand, and 12% water by volume. The unit weight of the mix was 1522 kg/m$^3$, and the maximum compressive strength was recorded as 3275 kPa. Masonry units were casted in wooden mold at
50% scale (Fig. 3). To facilitate the placement of concrete and imitate the industry practice, the fresh concrete in the mold was subjected to a vertical pressure caused by a 31 kg weight and 15 seconds vibration on a shaker. Specimens were covered with plastic sheeting to be cured at room temperature for 48 hours.

Masonry assemblies composed of four rows of masonry units with 2-unit width at total dimensions of 406 x 406 x 92 mm (16 x 16 x 3.625 in.). The mortar was type N with normal weight. All piers were covered with plastic sheet to be cured for 28 days at room temperature. Fig. 4 displays the setup for diagonal loading test.

Results

Prior to experimentation, two expected failure mores included bond failure at the mortar bed and masonry cracking at the unit. Due to the lower strength of units involved, relatively common in practice, the failure path in experiments conducted occurred within the masonry units as shown
in Fig. 5 and 6. For all specimens, cracking began from the center of specimen in an approximate vertical direction, at an expected 45-degree angle with the layout of the masonry units. Fig. 5 shows the failed specimen without fiber. In this specimen, a wide crack appeared at pick load, immediately followed by total failure. Broken pieces were completely separated upon removal of the specimen from the testing machine. On the contrary, the specimens with steel fibers exhibited slower crack propagation and were more resilient to splitting, as shown in Fig. 6. Steel fibers bridged cracks during crack propagation and were essential in controlling the crack width and enhancing the integrity of the steel fiber-reinforced pier, apparent in Fig. 6.

![Figure 5. Failure of plain masonry pier.](image)

![Figure 6. Failure of fiber-reinforced masonry pier.](image)

Fig. 7 displays the load-displacement relationship for various assemblies. The plain specimen exhibited the most brittle behavior. Displacement at failure was nearly 1.2 times the displacement at peak load for this assemblage. The specimens with 1% and 2% fiber contents reached peak loads nearly 23% and 29% higher than plain concrete, respectively. The displacement at failure for these specimens were 1.77 and 4.26 times their displacement at peak loads, respectively. The initial tangent modulus of elasticity of fiber-reinforced specimens with one and two percent fiber content were also recorded to be 2.2 and 4.0 times the same value for the plain specimen.
Figure 7. Load-displacement response of diagonal shear testing specimens.

Table 1 provides a summary of calculated shear strength, shear modulus of elasticity, and shear ductility for each specimen. The equation used in the calculation of shear strength is presented below:

$$\tau = (0.707P)/A_n$$  \hspace{1cm} (1)

where, $\tau$ is the shear strength (kPa), $P$ is the peak load (kN), and $A_n$ is the net area of the specimen (m$^2$). The shear modulus of elasticity is the slope of the lower third stress-strain relationship. The shear ductility index was measured from the following equation:

$$\mu = \frac{A_1 + A_2}{A_1}$$  \hspace{1cm} (2)

where, $\mu$ is the shear ductility index, $A_1$ is the area covered by the pre-peak stress-strain curve, and $A_2$ is the area covered by the post-peak stress-strain curve up to three times the strain value at the peak stress.

Table 1. Shear strength and shear modulus of elasticity of specimens.

<table>
<thead>
<tr>
<th>Fiber content (%)</th>
<th>Shear Strength (kPa)</th>
<th>Shear Modulus (MPa)</th>
<th>Shear Ductility</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1517</td>
<td>215</td>
<td>1.42</td>
</tr>
<tr>
<td>1</td>
<td>1531</td>
<td>481</td>
<td>2.02</td>
</tr>
<tr>
<td>2</td>
<td>1606</td>
<td>862</td>
<td>4.71</td>
</tr>
</tbody>
</table>

Conclusions

Results of experimental investigations conducted for diagonal shear testing of half-scale masonry specimens, concluded that steel fiber-reinforcement enhances the measured mechanical properties of lightweight aggregate concrete masonry piers. Visual observations indicated that fiber-
reinforcement improved the integrity of the specimen after failure and limited crack width after peak load. The data obtained throughout the course of the experiment also indicated the effectiveness of fiber reinforcement in the increase of the shear strength, the shear modulus of elasticity, and the shear ductility index. The shear ductility index of specimens with one and two percent fiber content were respectively 1.5 and 3.3 times the value of shear ductility within the specimen not containing fiber, respectively.

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References