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POLYMER MATRIX COMPOSITE (PMC) INFILL WALLS FOR SEISMIC RETROFIT

WOOYOUNG JUNG

Ph.D. candidate, Department of Civil Structural and Environmental Engineering, University at Buffalo

Background/Motivation

Civil engineers have recognized the potential of advanced polymer composites as an alternative material for construction. Driven in particular by the recognition that composites can offer improved advantages over traditional materials such as steel and concrete, attempts to use composites for buildings and bridges are on the rise. While it is apparent that fiber reinforced polymer (FRP) composites play an increasingly important role in civil engineering applications, there is even a greater promise for the new concept of joining composites with traditional materials to form hybrid structures. In recent years, PMC materials have been selectively used to retrofit structural elements such as wrapping of concrete columns to enhance strength and ductility. However, the use of such material in a large-scale structural system to resist seismic excitations has been very scarce. The limited use is mainly due to economical factors, lack of standards for PMC wall design and questions related to longevity. Our goal in this research is to study the effective application of composite material when combined with steel frames and to generate optimum seismic retrofit strategies using PMC infill walls.

Previous Research

Typically, some low and middle rise building frames have infill wall systems. The infill walls have been built after the frame is constructed as partitions and in some cases infill walls are parts of the structural system. As a matter of fact, there is no resemblance between the response of the infilled frame and the bare one, as the former is substantially stronger and stiffer than the latter. Around 1950's, the behavior of infilled frames had been investigated by Benjamin and Williams (1957, 1958). Since that time, Mainstone (1971), Liauw et al. (1985) and White et al. (1997) studied the role of infill walls in strengthening and stiffening the structure as a whole. As a result, the effects of neglecting the infill walls are accentuated in high seismic regions where the frame/wall interaction may cause substantial increase of stiffness resulting in possible changes in the seismic demand, and the infilled frame structure typically exhibits changes in the magnitude and distribution of stresses in the frame members. For the infill wall system with composite material, Gasparini, Curry and Debchaudhury (1981) presented the damping of frame with visco-elastic infill panels for increasing damping and minimizing vibration. Recently, Haroun, Ghoneam, and Essam (1997) studied the effects of strengthening and repairing masonry infilled reinforced concrete frames by fiberglass composite.

Justification & Objective

This research addresses the design, fabrication and testing of polymer matrix composite (PMC) infill walls for use as a seismic energy dissipation strategy. For the proposed technique, we have introduced a multi-layer system allowing in plane shear and therefore sliding along specific layers to take place upon loading the frame. Finally, we anticipate the damage to be controlled in such layers, thereby, allowing us to reuse the wall components. In order to meet the best result, we plan to consider several design cases to increase the capacity of the damaged layers by utilizing a combination of (1) visco-elastic and Honeycombs, and (2) visco-elastic and thermoplastic polymer materials.

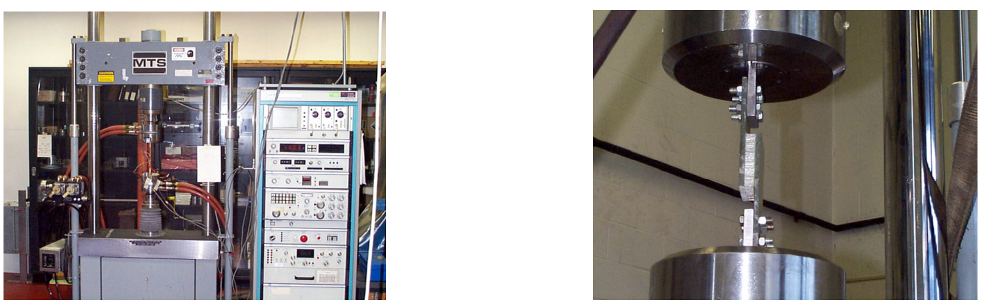
Practically, the new infill PMC wall system may lend itself to the application in seismic areas for three reasons. First, the material has a high stiffness-to-weight and strength-to-weight ratio. The addition of infill walls into an existing building will not significantly alter the weight of the structure; therefore, existing foundations will remain sufficient to carry the gravity loads. Secondly, due to the lightweight of the walls combined with the idea of prefabrication, rapid construction will be achieved and interruption to the occupancy of the structure will be minimal. Third, polymers have good damping characteristics. In designing the walls, polymers that exhibit significant visco-elastic behavior can be utilized in specific layers of the wall.

Actually, there are several technical and economical challenges associated with the use of PMC in structural applications such as buildings. Some of the most serious questions surrounding the viability of PMC structures relate to the availability of tested PMC structural systems to resist seismic loads, the cost of their construction, availability of standards for their design, practical connection details, and the feasibility of their construction. In the design process, there were many design variables that affected both the performance and cost of the infill wall. Having a large number of design variables and a wide range of materials that can be used presented a great challenge. In this research, a conceptual optimum design of an infill wall is presented using the finite element analysis. As mentioned above, the conceptual design is based on using a multi–layer system and allowing for in plane shear deformations to be concentrated in specific layers. Thereby, damage in such layers will provide the energy dissipation in the system. Also, the other aspects of the PMC infilled frame system are considered: (1) studying of properties of FRP and visco–elastic materials, (2) manufacturing the structural PMC walls, and (3) testing the wall systems when incorporated in a steel frame having semi–rigid bolted connections.

Progress of Research

1. Material Testing

Fiber reinforcing polymer (FRP) materials were tested to evaluate the mechanical properties that are needed for analysis and design. The evaluation of the mechanical properties of composites includes their strength and stiffness characteristics. For tension and compression test, each ultimate tensile, compression strengths, Young's modulus and Poison's ratios were obtained by testing longitudinal (0°) and transverse (90°) specimens according to the ASTM D3039 standard test method for tension and ASTM standard D3410 for compression. For evaluating in–plane shear properties, the 2–rail shear test method, as described in ASTM D4255, was used in this research. Also, the visco-elastic material was tested in this research. It is composed of H8–PP Polypropylene Honeycomb produced by Nida–Core Corp, FL, combined with a resin–rich layer on each surface of the honeycomb. This is a hexagonal cell honeycomb extruded from polypropylene. In our research of the honeycomb and resin–rich layers, the energy dissipation was expected to be through in–plane shear deformation. To investigate the behavior of honeycomb materials, pure shear test was considered as depicted in Figure 1.



(a) FRP Material Test (b) Visco-elastic Material Test

Figure 1: The Configuration of the Material Tests

2. Design and Construction of Composite Panel

In this section, we present one conceptual application of the PMC wall system. First, a sandwich construction was considered as a main concept to reduce the weight, sound and vibration as well as to improve structural rigidity. Based on this concept, the wall system was designed with three panels forming the entire wall thickness as shown in Figure 2(a). Second, we approached the optimum design of inner and outer layers composed of laminates based on structural performance. Design of each laminate layer includes (1) selecting a material system or a group of material systems, (2) determining the stacking sequence for the laminate based on applied loads, (3) some of the constraints include cost, weight, and stiffness. For optimum design based on the cost and performance, we have relied on detailed 3–D finite element models using ABAQUS. Eight node linear brick elements (C3D8) were used to model both the steel frame and honeycomb materials. Four node shell elements (S4R5) were used to model the composite laminate wall components. The interface between infill and frame members was modeled with gap–friction elements which provided gap between the nodes of frame and the wall along the perimeter. The finite element analysis is used to (1) design the optimum composite panel (2) develop proper simplified analytical model for composite infill wall frame system (3) predict the type of anticipated failure mode for subsequent experiments having various visco-elastic layers and new conceptual wall designs.

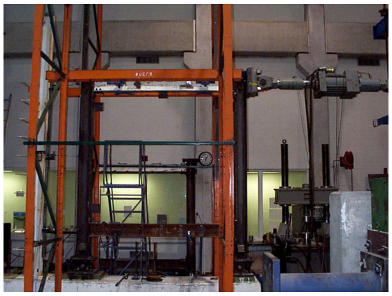
Detailed design drawings were delivered to a local PMC manufacturer (AN–COR Industrial Plastics, Inc., Tonawanda, NY) to construct the PMC infill wall. The PMC wall as shown in Figure 2(b) was constructed considering the most practical and commercial conditions. After manufacturing, the wall was installed in a frame (2500x2400 mm, W8x24 column and W8x21 beams) having semi–rigid bolted connections to be tested.

(a) Multi-layer System (b) Constructed Wall Shape

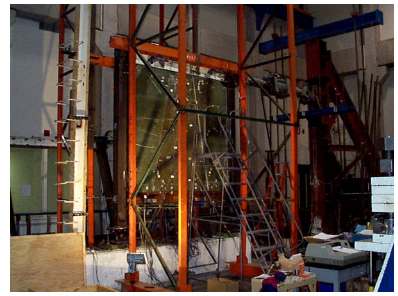
Figure 2: The Configuration of the PMC Infill Wall

3. Description of the Experiments

In the experimental phase, testing of steel frame with and without composite infill wall is planned as shown in Figure 3. Steel frame and composite infilled frame specimens were tested under monotonic and cyclic in–plane loading. To apply lateral force, a 250–kips MTS hydraulic actuator with a stroke of ±4 inch was used. All cyclic tests were performed under displacement control.



(a) Steel Frame Test Setup



(b) The PMC infilled Frame Test Setup

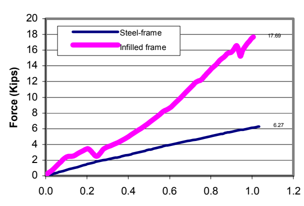
Figure 3: The Configuration of the Bare Frame and PMC Infilled Frame

Various instruments were attached to the specimen to capture key quantities to characterize the structural response of the composite infill wall and steel frame. These key quantities include the following: (1) longitudinal and transverse strain at critical point on the composite infill panel, (2) the shear deformation of the visco-elastic material using linear potentiometers, (3) the hysteretic behavior and the corresponding strength deterioration and stiffness degradation of steel frame and composite infilled frame using displacement transducers, and (4) buckling of the PMC inner panel.

Conclusions

Several important results concerning composite energy dissipation of infill panel may be stated. Based on numerical and experimental results so far, the main conclusion may be drawn as follows:

- Initial stiffness of the PMC infilled frame is 3 times that of the steel frame. And, the load-carrying capacity of the PMC infilled frame is 4 times that of the steel frame.



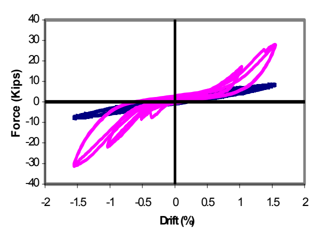


Figure 4: The Results of the PMC Infilled Frame Test (Monotonic & Cyclic loading)

Table 1: The Comparison of Each Component

	Infilled Frame	Steel Frame	PMC Infill Wall
Stiffness (Kips/in)	15.65	5.55	10.1

- The total energy dissipation capacity of the PMC infilled frame subjected to small deformation of visco-elastic layers is 3 times that of the steel frame. The contribution of the PMC infill wall is 65% of overall energy dissipation performance without significant degradation for the stiffness and strength. It is evident that energy dissipation capacity of the PMC infilled system may be larger where the visco-elastic layers contribute a relatively large deformation.

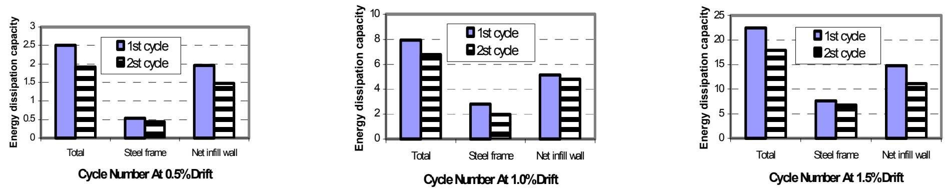


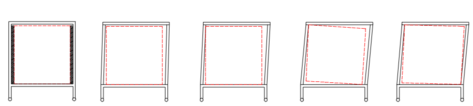
Figure 5: The Energy Dissipation Capacity for the PMC Infilled Frame (Kips-in)

- Main damage of the PMC infill wall is elastic buckling of the inner part at high drift values (3%). It is recommends that a stiffer strong core material for the design and construction should improve the performance of the PMC infill wall.
- Initial gaps affect the behavior of the PMC infilled frame. Like infilled frame with traditional material, the stiffness of the PMC infilled frame is reduced through the introduction of initial gap. However, to approach an ideal construction with no initial gaps, it is preferred to reduce the size of the initial gap as much as possible in the PMC infill wall.

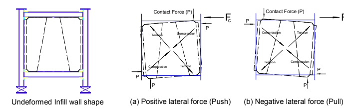
Table 2: The Results of Initial Gap Effect for the PMC Infill Wall

	No side Gap	Initial Gap (0.05 in)
Stiffness (Kips/in)	18.3	16.2

- Based on analytical modeling of the PMC infill wall, considerable stiffness as well as acceptable strain in the energy dissipation material have been considered. However, from the experiments, it is evident that visco-elastic layers provide a large fraction of the total lateral stiffness in the PMC infill wall system. Thus, more studies for the visco-elastic layers are still needed.
- At high drift value, local crushing failure took place at wall corner, a better detail will be needed to overcome this kind of failure.

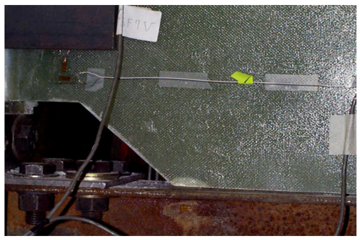


(a) Behavior of the PMC Infill Wall

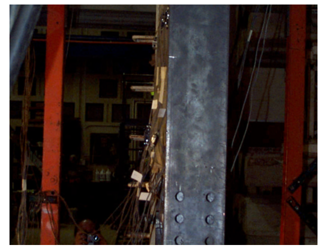


(b) Failure Modes of the PMC Infill Wall

Figure 6: The Behavior and Failure Modes of the PMC Infill Wall



(a) Corner Crushing Damage



(b) Elastic Buckling of the PMC Infill Wall

Figure 7: The Damages of the PMC Infill Wall

Future Study

Additional research is required based on the first test. Especially, advanced modeling related to the structural performance and economic application will be needed. Practically, light and flexible building systems often require specific design features for limiting structural damage, structural control for the vibration, and maximizing occupant comfort and safety. Consequently, our research plans include the following:

- Study the behavior of several composite infill wall systems from the experiment.
- Develop simplified analytical modeling from the experimental results.
- Study and test advanced interfacing materials under seismic excitation.
- Redesign an advanced composite infill panel considering performance and cost.

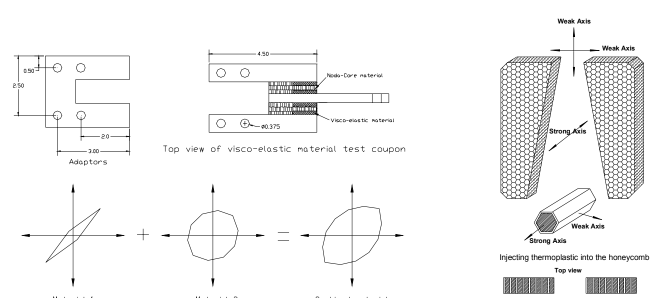


Figure 8: The Examples of the Advanced Interfacing System

- Dynamic analysis and testing of the composite infill wall system