Experimental Investigation Of Infill Walls Strengthened By Cementitious Matrix-Fabric Compsites

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SUMMARY: (10 pt)
In this experimental study, six identical infill wall specimens (755mmx755mm) were constructed. Infill wall specimens having the same mortar ratios were divided into 3 groups, each group being consisted of 2 specimens. Two groups were strengthened by applying single layer and double layer of cementitious matrix-fabric (CMF) system on the surface of infill walls. The third group was prepared without any strengthening material, in order to be used as control specimens.
Diagonal tension tests for all groups were conducted in order to determine the contribution of CMF system to the strength and ductility of infill walls. Test results were evaluated considering experimental parameters such as shear stress, shearing strain, and modulus of rigidity. Results showed that CMF system considerably improved the experimental parameters for the infill walls.

Keywords: Infill wall, cementitious matrix-fabric (CMF), alkali resistant-glass fibers (AR-glass fibers)

1. INTRODUCTION

Masonry infill walls were usually neglected as structural elements in building analysis. Under lateral loads that were developed in moderate seismic regions, infill walls dramatically increased the stiffness of RC frames by acting as diagonal struts. Pujol and Fick (2010) conducted experiments using a full-scale building structure and invesitgated the effect of infill walls in the case of a strong earthquake. They concluded that the masonry infill walls of the structure actually increased the stiffness and the strength. Additionally Prota et al. (2006) proposed to implement cementitious composite materials on infill wall panels in order to improve strength and ductility. Also for the study of improved shear strength and deformability Lignola et al. (2009) used a cementitious reinforcement system on wall panels and thus achieved better stress redistribution. In a study conducted in (2005) Aldea et al. showed that the cementitious material improved the strength of walls and was better in performance in comparison with fiber reinforced polymer (FRP) counterparts.

This study discussed the potential of an innovative strengthening technique consisting of a cementitious matrix-fabric (CMF) composites that were externally applied to the masonry infill walls in reinforced concrete (RC) frame buildings.

2. TEST SPECIMENS

In this experimental study, six infill wall specimens of 755mmx755mmx135mm (widthxheightxthickness) dimensions were constructed using bricks with cement based mortar binders. Dimensions for brick were 190mmx190mmx135mm and the compressive strength in the direction of the holes of brick was measured to be approximately 7.0 MPa. The void ratio of bricks was around 60%. All wall specimens had plaster on both sides. The thickness of plaster was approximately 10mm on each side. As a common practice in Turkey mortar binder and plaster were prepared using the same materials, namely water, cement, and sand. The water:cement:sand volumetric mixture proportions for mortar binder and plaster were 1:1:4 with a measured compressive strength of 7.0 MPa.

Infill wall specimens were divided into 3 groups and each group had 2 specimens. Two groups were strengthened by using cementitious matrix-fabric (CMF) system in varying number of layers on the surface of infill walls. The third group was not strengthened and used as control.

CMF was a structural composite material consisting of a glass fiber mesh, which acted as continuous reinforcement, and a stabilized inorganic matrix, which bound mesh to the infill walls. The glass fiber mesh used for this study was shown in Fig. 2.1.

Figure 2.1. Glass fiber mesh

Mesh had an alkali resistant AR-glass coated grid, SRG 45 (structural reinforcing grid) and mechanical properties of glass grid was given in Table 2.1.

Table 2.1. Properties Of AR-Glass Mesh

Alkali–Resistant Reinforcement Grid (For use in cementitious matrices)	
Tensile Strength	1276 N/mm^2
Maximum Elongation	1.78%
Modulus of Elasticity	72000 N/mm^2
Roll Width	910 mm
Grid Size	25 mm x 25 mm

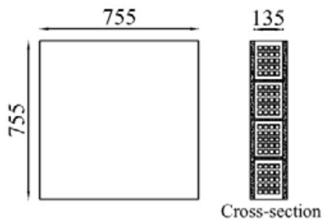
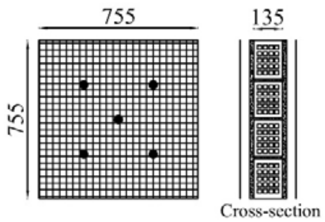
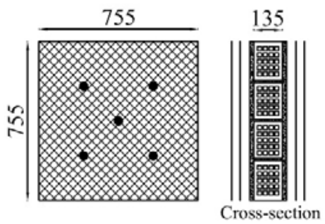
Inorganic matrix was consisting of a silica fume modified cement based mortar that was chemically, physically, and mechanically compatible with the masonry support. Water:cement:sand:silica fume:plasticizer mixture proportions in weight for mortar was prepared to be 0.4:1:1.5:0.1:0.005. Compressive strength of mortar was measured as approximately 20 Mpa.

Control specimens consisted of infill wall specimens only with plasters on both sides. For other specimens CMF system was easily applied over plastered wall surfaces, which also facilitated practical strengthening applications on existing buildings. In total two different types of applications of CMF system were used in strengthening. First one was applying single layer of CMF system over both faces of plastered wall and the second one was utilizing double layer of CMF system on both faces.

Strengthening application was consisted of four stages in total. Initially wall surfaces were wetted. Then the mortar layer was troweled onto the wall surface with a 2mm width. Glass fiber mesh was placed on mortar layer with the fiber orientation on the wall being 0^0-90^0. Finally the mortar layer was troweled again onto the glass fiber mesh. This procedure was repeated for the second layer. All strengthened specimens were prepared with simple pultrusion technique. This technique was applied by clamped wooden panels, which applied pressure to the wall surface during curing period for perfect bonding between CMF system and wall substrate.

Strengthened groups had anchorages as shear connectors for better bonding between mesh and wall substrate. Five holes were drilled on wall specimens for this application. Anchorages were cut from glass fiber mesh with dimensions of 20cmx45cm. SRG 45 fabrics were stowed into these holes in a way that approximately 15 cm long ends of anchorages were protruding from the wall surface. Fibers of these ends were separated and bonded on the wall with mortar. All types of experimental groups were explained in Table 2.2.

Table 2.2. Specimen Groups

Specimen Group	Specimen Code	Strengthening Type	Dimensions (mm)
I	C	Plastered wall	
II	S-2-1	Single layer of CMF over both faces of plastered wall with anchorages	
III	S-2-2	Double layer of CMF over both faces of plastered wall with anchorages	

3. EXPERIMENTAL SET-UP

Diagonal tension tests were performed using a similar experimental technique to the one that described at ASTM E519/E519M-10 (2010) on 6 wall specimens. Wall specimens, having dimensions of 755mmx755mmx135mm were rotated for 45° and were loaded until failure was reached. Schematic of the testing system was presented in Fig. 3.1.

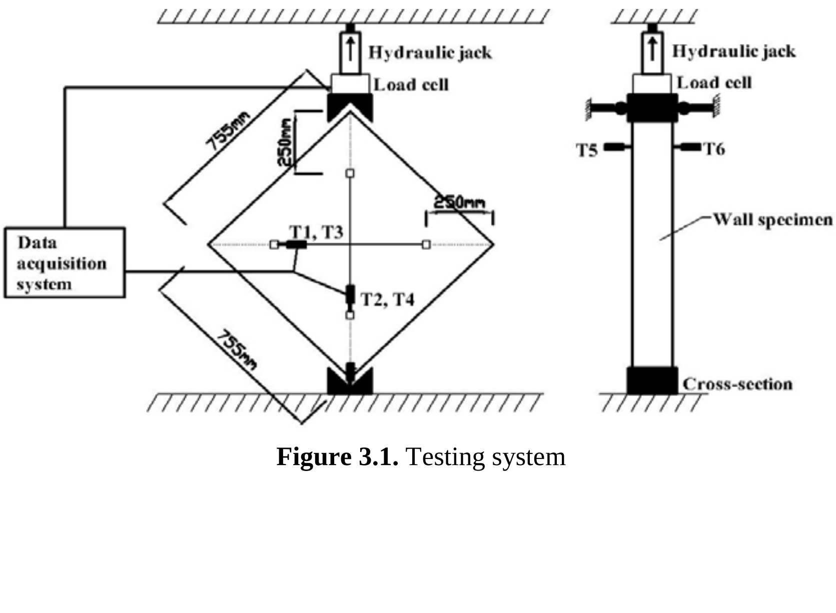


Figure 3.1. Testing system

A force controlled testing technique was used with the intention of keeping the loading speed constant. 10 kN load increments were chosen for the loading steps. Loading increments were repeated twice until the 30% of expected ultimate load was reached and specimens were loaded until failure was reached at the third cycle.

Vertical and horizontal displacements, namely shortening and extension, were measured by four displacement transducers (LVDT) with 10mm capacity at each side of wall panel. Two more displacement transducers with 10mm capacity were used in order to control the out of plane displacements. Data were collected through the load cell and LVDTs during tests using a data logger and the collected data were transferred to a computer.

4. TEST RESULTS

Test results of the infill wall specimens were tested under monotonic diagonal loads and results were evaluated using applied load (P), shear stress (S_s), shearing strain (γ) and modulus of rigidity (G). According to the ASTM E519/E519M-10, shear stress was calculated by Eqn.4.1.

$$S_s = 0.707P/A_n \tag{4.1}$$

In the shear stress formula given above A_n was the net cross-sectional area of the wall specimens. Shearing strain, γ, was determined from changes in the distance between gages and was calculated using the ASTM equation Eqn.4.2.

$$\gamma = [(\Delta V + \Delta H)/g] \tag{4.2}$$

In Eqn. 4.2 ΔV and ΔH were the average changes in gage length taken on both sides of the wall specimens in the vertical and horizontal direction, respectively.Also g was the average distance between gages, and it should be noted that gages on the same axis were placed at equal distances from each other. Modulus of rigidity, G, was calculated by Eqn.4.3.

$$G = S_s / \gamma \tag{4.3}$$

In this study, modulus of rigidity was calculated by dividing the difference between the 5% and 30% of maximum shear stress, which was at the initial linear region of shear stress-shearing strain curves, by the difference of the corresponding shearing strain values. Mean values of experimental parameters were given in Table 4.1.

Table 4.1. Experimental Parameters

Specimen Code (Group)	Experimental Parameters (Mean Values)			
	S_{smax}(MPa)	γ_{max} (mm/mm)(%)	G(MPa)	P_{max}(kN)
C (I)	0.94	0.24	944.00	250.50
S-2-1 (II)	1.32	0.31	1215.73	328.50
S-2-2 (III)	1.56	0.47	1283.74	389.00

Displacement values from both sides of the specimens were recorded at every load increment and the average of recorded measurements were used in presenting the S_s-γ curves for all wall specimens. S_s-γ curves for wall specimens were given in Fig. 4.1.

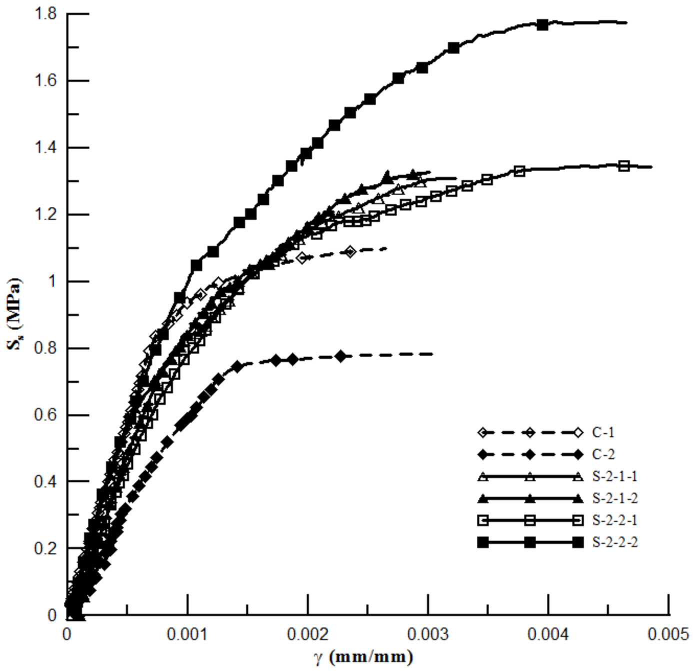


Figure 4.1. Shear stress-shearing strain diagram

Failure modes and crack patterns were recorded manually during testing. Also vertical cracks and their widths were observed and recorded at every loading step. Failure at the specimens occurred suddenly and in a brittle mode. During failure vertical cracks developed predominantly. Diagonal cracks along with horizontal cracks developed for specimens, which were strengthened on both sides with double layer (S-2-2). Also for those specimens (S-2-2) there were cases where the anchorages were torn apart (Figure 4.2).

Figure 4.2. Failure modes

4.1. Discussion of test results

Test results were evaluated for maximum shear stress developed at specimens under diagonal pressure effects and for the corresponding shearing strain and modulus of rigidity values. These parameters for each specimen in comparison with the control specimen were given in Table 4.2.

Table 4.2. Observed percent increases in parameters measured during experimental study

Specimen Group	S_{smax} (MPa)	γ_{max}(mm/mm)(%)	G(MPa)
S-2-1 (II)	%40	%29	%29
S-2-2 (III)	%66	%96	%36

There were significant increases observed in maximum shear stress, shearing strain and modulus of rigidity. When the damage was evaluated it was observed that specimens failed due to vertical cracks that were developed at stress levels approaching maximum shear stress values.

Double layer two-face strengthened S-2-2 specimens demonstrated a more ductile behavior, when compared with single layer two-face strengthened S-2-1 specimens. Until the moment of failure, wall and CMF stuck to each other and worked together. At the moment of failure horizontal anchorages snapped and therefore failure was observed.

All CMF strengthened specimens demonstrated improvements considering test parameters in comparison with the un-strengthened control specimens. Specifically mean maximum shear stress for all strengthened specimens were found to improve significantly (Figure 5.1.).

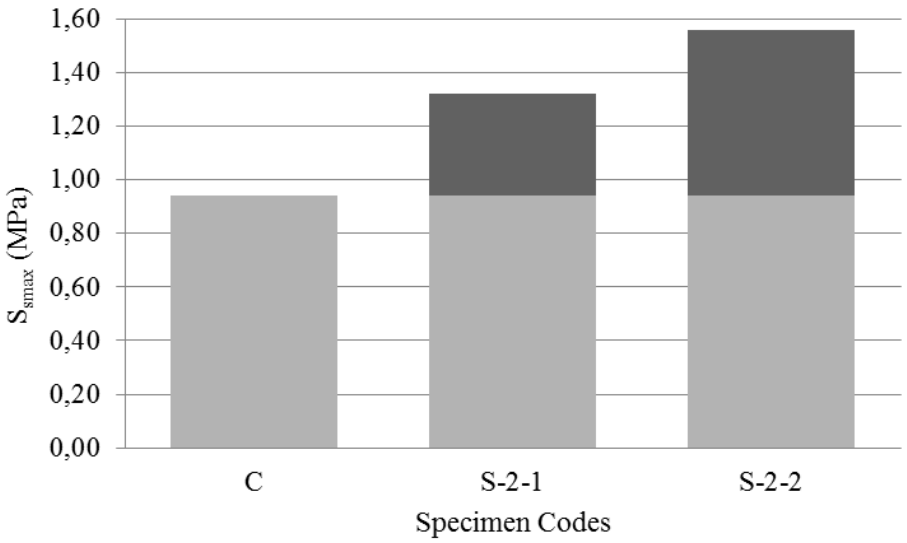


Figure 5.1. Shear stress comparison between test groups

Shearing strain at the maximum shear stress (γ_{max}), maximum shear stress, and modulus of rigidity (G) increased by 29%, 40% and 29%, respectively on average for single layer two-face strengthened CMF applications (S-2-1) when compared to control specimens. However double layer two-face anchoraged specimens (S-2-2) demonstrated 96%, 66% and 36% increases for the tested parameters, $\gamma_{max,}$ S_s, and G, respectively.

When the strengthened groups were compared there were not any significant difference between single layer and double layer applications. On the other hand a significant difference was observed in shearing strain values. Double layer strengthened specimens showed a more ductile behavior than single layer strengthened specimens. Anchorages at double layer two-face specimens (S-2-2) worked at full capacity and facilitated a significant increase in the failure load until rupture.

Initial stiffness values for all specimens, with only one control specimen exception, were measured to be approximately same.

Results showed that strengthening with CMF on two faces of specimens (S-2-1, S-2-2) were successful when evaluated in terms of parameters used in this study.

5. CONCLUSIONS

Strengthening of infill walls were known to affect the stability of rc buildings, especially in the case of strong ground motions. In this study, CMF strengthening systems for infill walls were investigated using maximum shear stress, shearing strain and modulus of rigidity parameters. Different modes of application such as single layer versus double layer were studied by constructing masonry walls. The most important outcome of this study was that the ductility of the double layer strengthened specimens increased significantly. Over all the tested parameter values for double layer strengthened specimens were better when compared to control specimens.

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