Structural Behavior of Small Scale Masonry Elements Strengthened with Engineered Cementitious Composites

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SUMMARY:
This experimental study aims at investigating the behavior of masonry elements strengthened by engineered cementitious composites (ECC). ECC is a special class of fiber-reinforced cement-based composite materials (FRCC) micromechanically designed to achieve strain-hardening and multiple cracking in tension. A version of ECC suitable for troweling on masonry was developed and material tests were carried out to assess its distinctive mechanical properties. Furthermore, different experiments were performed on masonry elements to investigate the influence of ECC overlay on the masonry behavior. The effect of the thickness of ECC layer on the shear bond strength between ECC and masonry was investigated by a series of triplet tests. Also, direct tension tests using pull-off method were carried out to determine the tensile bond strength between ECC overlay and brick units. The obtained results indicate that the proposed ECC-strengthening technique can effectively increase the shear capacity of masonry elements, improve their ductility, enhance their energy absorption capacity, and prevent the brittle failure mode.

Keywords: Composites, ECC, Strengthening, Masonry elements, Multiple cracking

1. INTRODUCTION

A number of methods were proposed in the literature to strengthen masonry infill or bearing walls by enhancing the in-plane and out-of plane behavior of these elements. Examples of proposed methods include the use of monolithically cast or precast RC infill walls and shotcreting masonry walls which can increase the stiffness and lateral load capacity of the assembly and reduce the lateral drift at the ultimate load (Higashi et. al, 1980; Canbay et. al., 2003). Although experimental investigations have shown the efficiency of these techniques, it seems their application to the inhibited existing structures is not feasible. A more recent strengthening technique being developed is the use of fiber reinforced polymer (FRP) reinforcement. Experimental studies have been conducted extensively to understand the behavior of FRP-strengthened infilled RC frame (Nateghi and Dehghani, 2008). The test results exhibited that significant improvement of strength and energy absorption capacity can be achieved if adequate anchoring is provided for FRP sheets. However, FRP materials generally behave elastically up to the point of failure and potential debonding failure is likely to take place through FRP debonding from the masonry infill wall (Dehghani and Nateghi, 2010). Furthermore, the need for surface preparation and the high retrofitting cost of FRP-strengthening systems made it more or less impractical and uneconomical for civilian structural applications especially in the case of masonry buildings. The objective of this study is to demonstrate the possibility of using a more effective and economical method for strengthening such systems.

In recent years, some research studies have been focused on the use of new strengthening materials with ease of installation to enhance simultaneously the shear resistance of masonry walls and the overall ductility of the system (Prota et. al., 2006; Lin et. al., 2009; Balsamo et. al. 2011). Cement-based composite materials are suitable for strengthening concrete and masonry structures due to their mechanical and physical properties (e.g. coefficient of thermal expansion, fracture energy, and small

shrinkage deformation after installation), as well as other important considerations such as cost, availability, constructability, and ease of installation.
Engineered cementitious composites (ECC) are a special class of fiber-reinforced cement-based composite materials (FRCC), typically reinforced with polyvinyl Alcohol (PVA) fibers, which is micromechanically designed to achieve strain-hardening and multiple cracking in tension. ECC exhibits tensile strain-hardening behavior with strain capacity in the range of 3-7%, yet the fiber content is typically 2% by volume. The ultra-high ductility is obtained by optimizing the micromechanical models that account for the mechanical interactions between the fiber, matrix and interface (Li, 1998).In recent years, the field application of this material has been increased. ECCs has been effectively used for dam repairing, coupling beams in high-rise buildings, bridge deck link slabs, and other structural elements and systems (Kim et. al., 2003; Fischer and Li, 2003). The use of ECC as a strengthening material has been proposed by some researchers (Kim et. al., 2004; Maalej and Leong, 2005; Shin et. al., 2007).Their studies revealed that superior tensile strain capacity of this material can provide significant enhancement of the performance of strengthened structural systems resulting in high delamination resistance, high ductility and increasing load carrying capacity of the structural system.

The main objective of this experimental study is to investigate the influence of ECC ductility on the behavior of masonry elements. After adjusting the weight proportions of matrix ingredients in such way to obtain suitable ECC for plastering onto the masonry walls, a series of experiments were conducted on the retrofitted masonry elements, including prism, beam, and triplet specimens.

2. THE EXPERIMENTAL PROGRAM

A new version of ECC with the ability of troweling on masonry walls was developed. To evaluate the mechanical properties of this ECC, material tests including compression test, uniaxial tension test, flexural test, and single crack test were carried out. Then small scale tests were conducted on masonry elements to investigate the influence of a thin layer of ECC on plain masonry elements in terms of changing stiffness, strength and ductility. Furthermore, a series of direct tension test by use of pull-off method was carried out to determine the tensile bond strength between ECC and clay brick units with and without using two types of commercial adhesives.

2.1. Materials

2.1.1 Masonry units and cement mortar
Solid clay bricks with a dimension of 225mm$\times$105mm$\times$40mm were used to construct masonry elements. The masonry bricks were stacked clear of the ground and covered to protect them from contamination. Due to high water absorption capacity, pre-wetting of the brick units was carried out prior to construction in order to prevent the mortar drying out rapidly, which could lead to a weak bond between mortar and clay bricks. The mixture proportion of mortar used to make the masonry elements was 1:10 (Portland type II cement: 0 to 4 mm sand) with a water to cement ratio of 1.7. By using this proportion a mortar with an average compressive strength close to that of ordinary cement mortar used in construction of masonry building was achieved.

Twelve full size bricks were tested in flexure using three point bending test according to ASTM C67-09 to measure the average flexural strength of bricks which was found to be 3.6 MPa. The compressive strength of the clay bricks was found to be 47.5 MPa using six specimens with a length equal to one-half the full length of the units (in accordance to the ASTM standard) and 48.7 MPa by use of twenty 40 mm cubes provided from clay bricks. The mechanical properties of mortar, which was used to make the masonry elements, were measured using three different sets of specimens; including a total of thirty 50 mm cubes for compression tests, eleven standard 160 mm$\times$40 mm$\times$40 mm prisms for four point bending tests and five cylinders with a diameter of 60 mm and a length of 120 mm for splitting tests (according to ASTM C348-02 and C109-02). The average compressive strength, flexural strength and splitting tensile strength were found to be 6.3 MPa, 1.2 MPa and 1.4 MPa respectively.

Table 2.1. Weight proportions of the ECC matrix constituents

Cement	Fly ash	Fine Sand	Quartz powder	Water	superplasticizer
1	2	0.35	0.35	0.9	0.00187

Table 2.2. Properties of PVA fiber

Diameter (mm)	Length (mm)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation (%)	Density (gr/cm^3)
39	8	1600	42.8	6	1.3

2.1.1 ECC suitable for troweling and its mechanical properties

The major ingredients used to make the ECC matrix included Type I Portland cement, Class C flyash, fine silica sand (max. grain size 0.180 mm) and quartz powder (max. grain size 0.09 mm). Superplasticizer and cellulose (HPMC) were used as chemical admixtures to enhance the fresh properties of the mixture. Table 2.1 shows the weight proportions of the ECC mixture constituents suitable to apply on the masonry wall by trowel. PVA fiber, tailored based on micro mechanical principles, at a volume of 2% with the geometrical and mechanical properties given in table 2.2 was adopted. In practice, dry ingredients including cement, fly ash, sand, quartz powder and superplasticizer were first dry mixed using a Hobart type laboratory mixer for about 1 minute. Then water was added and mixed for 4 to 5 minutes. At this point, obtained ECC matrix showed adequate flowability and viscosity which were essential for the good workability and uniform fiber distribution. Finally, PVA fibers were added gradually and mixed for another 4 minutes.

The mechanical properties of obtained ECC in hardened state were measured in various experiments. The stress-strain behavior of ECC in compression was obtained using six cylinder specimens with a diameter of 100 mm and a height of 200 mm loaded at a constant rate of 0.5 mm/min. The compressive displacement between two points on the cylinder was measured by an extensometer with a gage length of 100 mm attached to the middle of the cylinder height. The obtained compressive behavior, as shown in Fig. 2.1a, exhibits an average compressive strength of 47 MPa at a strain level of 0.55%. In compression, ECC shows a lower elastic stiffness compared to concrete, as well as larger strain at reaching its compressive strength, due to the lack of large aggregates. Beyond the maximum point (f'c), the compressive stress drops to approximately 0.5f'c with subsequently descending stress at further increasing deformations (see Fig. 2.1a) (Fischer and Li, 2003). Furthermore, as a simple compression test, a total of ten 40 mm ECC cubes were tested under compression. For these specimens the average compressive strength was found to be 50.6 MPa which is larger than that of cylindrical specimens. This difference can be attributed to the specimen size effect.

To verify the tensile strain-hardening behavior of this ECC and to compare it with that of normal cast ECC, a series of uniaxial tensile tests and flexural tests was carried out. Uniaxial tension tests were performed on dog-bone shaped specimens from both types of ECC (at the age of 28 days) under displacement control loading with a rate of 1 mm/min. The strain of the dog-bone specimens was calculated by taking the average of the readings of two Linear Variable Displacement Transducers (LVDTs), attached to the opposite sides of the specimen, divided by the specimen gauge length which was 191 mm. The thickness and the width of the specimen in the gauge length region were 24.8 mm and 50 mm respectively. The obtained tensile stress-strain curves are presented in Fig. 2.1b. The average first crack strength was found to be 3.25 MPa and all ECC specimens showed strain hardening behavior with a strain capacity of 2.2 to nearly 3.7%. It can be seen that the tensile strength and ductility of troweled ECC is comparable with those of normal cast ECC specimens.

Flexural behavior of ECC was evaluated by performing the four-point bending tests on the ten prism specimens each having a dimension of 160 mm$\times$ 40 mm$\times$ 40 mm. The test setup is shown in Fig.2.2a. The specimens were loaded until complete failure with a constant crosshead speed equal to 0.1 mm/min. The load, head displacement of the machine, and deflection of the specimens at the midspan were recorded in each test. The flexural stress-deflection curves for five specimens are shown in Fig.2.2b. The average first crack strength of ECC prism specimens were found to be 6.5 MPa while the flexural strength ranged from 9.7 to 12.3 MPa. During the tests, ECC demonstrated a high

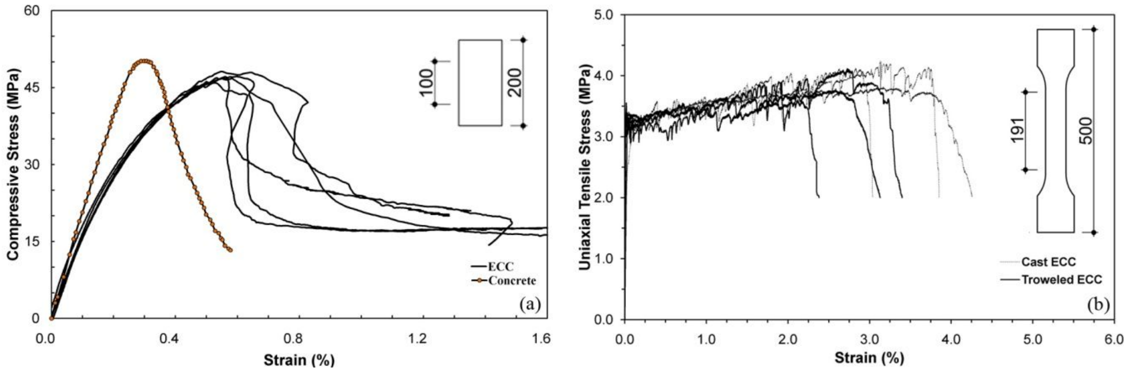

Figure 2.1. Stress-strain behavior of (a) ECC and concrete in compression (b) ECC in tension

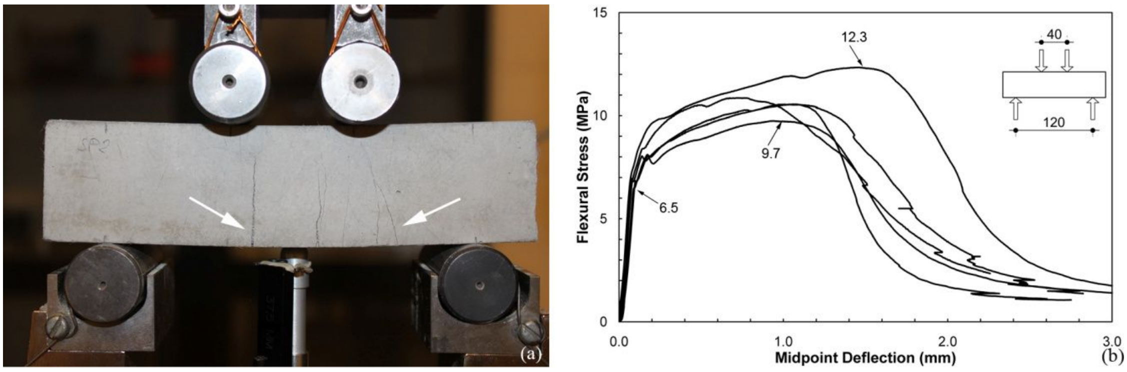

Figure 2.2. (a)Four point bending test setup and multiple cracking of ECC (b) ECC flexural Stress-deflection behavior

deformation capacity due to the successive crack initiation. After elastic behavior, the first visible crack initiated and the load dropped slightly before increasing. New cracks then initiated consecutively and distributed along the tensile surface. By increasing the applied displacement, one of the cracks turned into a localized crack accompanied by overall load decay and then strain softening was started.

2.2. MASONRY COMPONENT TESTS

2.1.1 Workability test of ECC

As mentioned earlier, the objective of this study is to strengthen masonry walls or panels by troweling a thin layer of ECC onto their surfaces. Therefore it is necessary to adjust the amount of water and chemical admixtures to avoid the fresh mix running off the wall. In order to confirm this possibility, a series of masonry prism specimens, each having five bricks and four mortar bed joints, was constructed and left intact for 7 days. Afterwards, a wood frame was installed around the specimens to control the thickness of strengthening layer during installation (see Fig.2.3 a). Fresh ECC mixtures with different weight proportions of water and superplasticizer were made and applied on the surface of specimens in 20 to 30 mm thicknesses while the specimen were positioned vertically. When the proportions of water and superplasticizer were set to 0.9 and 0.00187, respectively, no falling down of the fresh mix occurred and a smooth surface of ECC without bumps and dips in the hardened state was achieved (see Fig. 2.3c). It is worth to emphasize that the flow properties of fiber-free mix should be in such way to completely disperse the fiber through the mix, which is essential for ECC to show strain-hardening and multiple cracking behavior in the hardened state. In the present study the mechanical properties of hardened ECC investigated by different experiments confirmed good fiber dispersion.

2.1.2 Tensile bond strength between ECC and Clay bricks

The bond strength of ECC material to the clay brick was measured by direct tension test (i.e. pull-off method) in accordance to ASTM C1583-04 with some modifications. In order to prepare the test specimens, a number of pre-wetted bricks were cut into half of their length and a 20 mm layer of ECC was cast on top of them and cured for 28 days. For some specimens, before applying ECC, a thin layer of commercial adhesives (VINNAPAS EF and SAF54) was painted on the surface of the bricks

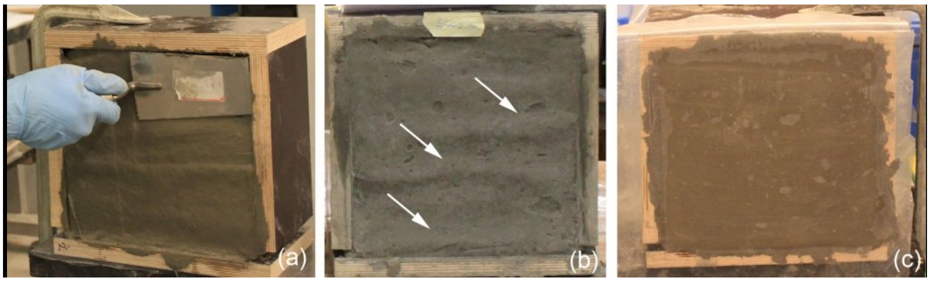

Figure 2.3. (a) Applying ECC layer (b) ruffled surface of hardened ECC (c) flat surface of hardened ECC after adjusting water and superplasticizer

Figure 2.4. **(a)** Test setup (**b)** the test specimens after failure in tension

to study their effects on the bond strength. Then a circular cut with a diameter of 50 mm perpendicular to the top surface was drilled to at least 10 mm below the ECC-brick interface and the obtained ECC core was left intact, attached to the brick. Finally, a steel disk with a threaded hole in its top face was bonded to the top surface of the ECC core using a very strong epoxy adhesive. Special care was taken to ensure that the disk is centered with the test specimen and that the axis of the disk is parallel to the axis of the test specimen. A steel rod tied up to the steel disc was used for applying tensile load to the specimen symmetrically supported by three screws with rounded ends, as shown in Fig. 2.4a. The failure load and the failure mode were recorded. It should be noted that a box shaped formwork was used for casting ECC to provide a completely smooth and flat finished surface of ECC layer. This is essential to avoid applying moments while the specimen is loaded in direct tension.

The average value of tensile bond strength at failure obtained from ten test specimens without using the adhesives was found to be 0.68 MPa. This value decreased to 0.2 and 0.25 MPa for the specimens with EF and SAF adhesives, respectively. This reduction can be attributed to the penetration of the water to the adhesive layer. It is worth to emphasize that comparable results obtained when the test was repeated on the dry bricks. In this case due to high water absorption capacity of the clay bricks, the painted adhesive layer dried out rapidly before acting as an adhesive. As presented in Fig. 2.4b, the failure occurred at the bond line between the brick and the ECC layer for all specimens. Furthermore, when the test was repeated for the specimens prepared with dry bricks (without using the adhesives), a tensile stress less than 0.1 MPa was achieved. This reveals that if adequate pre-wetting of the bricks is carried out prior to construction, good bond strength between the clay bricks and ECC material can be expected. It should be noted that these results depend on the type of the bricks.

2.1.1Compression test on masonry prisms

To investigate the effect of ECC overlay on the compressive behavior of masonry elements five series of prism specimens were constructed and tested under axial compression according to ASTM C1314-09. The number of test specimens, thickness of ECC layers and strengthening configurations used in each series are illustrated in table 2.3. The bearing surfaces of the top and the bottom bricks were grinded before prisms construction to avoid premature failure due to the uneven surfaces of bricks. All prisms included five bricks bonded together by a mortar joint with a thickness of around 10 mm. The

Figure 2.5. (a) Test setup, failure mode of the brick prisms: (b) without strengthening layer, (c) with two layers of ECC

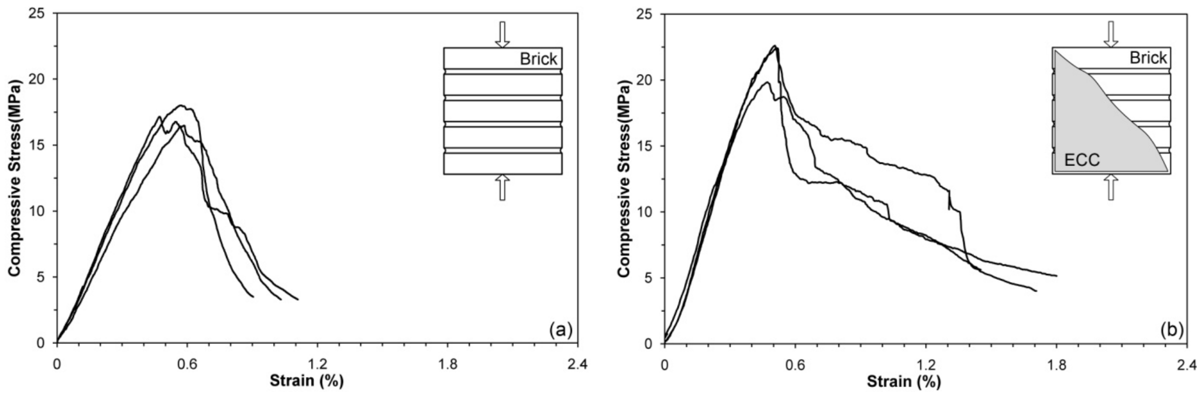

Figure 2.6. Compressive stress-strain relationship for the brick prisms: (a) without strengthening layer, (b) with 10 mm ECC layer on both sides

Table 2.3. Masonry prism specimens and strengthening configurations

	Se.1	Se.2	Se.3	Se.4	Se.5
Number of tests	5	3	5	5	3
strengthening configuration	--	single-face	single-face	double-face	double-face
Thickness of ECC layer (mm)	--	5	10	10	20

ratio of prism height to the least lateral dimension of prism was 2.2. Therefore, height to Thickness correction factors for the compressive strength can be assumed equal to 1. The load was applied by displacement control at a rate of 0.5 mm/min and the compressive displacement of the prism was measured using an extensometer attached to the specimen with a gauge length of 100 mm. The test setup is shown in Fig. 2.5a.

The unretrofitted masonry prisms exhibited typical compression failure modes characterized by vertical splitting, both in-plane as well as out-of-plane, prior to mortar crushing, as shown in Fig. 2.5b. In fact, the vertical splitting of the bricks due to the different material properties of the bricks and mortar leads to a premature failure of the prisms. This is because the higher Poisson ratio of the mortar results in a tendency for lateral mortar tensile strains to exceed lateral brick strains. In contrast, all the retrofitted specimens exhibited one failure mode imitated by vertical tensile cracking on the side faces of the prisms close to the ECC layer, as shown in Fig. 3c. By increasing the load, new cracks occurred and a full separation of ECC layer was occurred at the failure point. Fig. 3c illustrates that the ECC debonding happens due to the development of vertical cracks within the prism, not because of the weak bond between ECC and masonry materials.

The compressive stress-strain curves for the plain masonry prisms and the retrofitted ones with 10 mm ECC layer on both sides are shown in Fig. 2.6. A stress-strain behavior more or less similar to that of plain specimens obtained for the prisms with one-side strengthening layer. However, the strengthened prisms with 10 mm ECC layer on both sides of the prism exhibited a relatively small increase in strength, stiffness and energy absorption capacity in comparison to the plain specimens. In fact, due to failure mechanism characterized by vertical cracking on the prism, the strengthening layer has a small effect on the mechanical properties of the prism in compression but can prevent the severe spalling of bricks observed in the control specimens. It seems that a higher stiffness and strength increase can be expected if ECC layer is applied on the prisms constructed using soft clay bricks. When the test was repeated for group 5 specimens, no more increase in the compressive stiffness and strength was observed. In this case, the specimens failed due to vertical cracking through the clay bricks and mortar joints in a plane parallel to the ECC layer, which means that the applied layer is stronger than the basic material (masonry prism). This can be attributed to the ratio of thickness to area of ECC layer. It is worth emphasizing that the main purpose of applying ECC is to increase the shear strength and ductility of the masonry panel under lateral loading which are studied in the following sections.

2.1.1 Four-pint bending test on masonry beams

Flexural tests were carried out on masonry beams under four point bending, according to ASTM E518-10, to evaluate the performance of ECC material on the flexural strength and out-of plane behavior of the masonry walls. Furthermore, these tests can also be used to show the direct tensile behavior of ECC layer plastered to the masonry surface based on the performance of the tensile side of the constant moment region. A total of nine specimens were constructed, including three plain masonry beams as the control beams and six strengthened beams by plastering ECC layer in thickness of 20 mm with and without using the adhesive (SAF54). All masonry beams were vertically constructed with ten bricks and nine 10 mm mortar joints. As described in the aforementioned standard, a wood frame was used to align one face of the specimen to a plane.

Special care was taken during the installation of the bricks which were be loaded in the test. Load bearing faces of the bricks were grinded before the construction of the specimens to obtain full contact between the specimens and the load-applying blocks and supports. This is essential to avoid premature shear failure in the mortar joints close to the loading points and supports due to the load concentration resulting in high shear stresses. The test setup is shown in Fig. 2.7. An Instron testing machine with the capacity of 100 kN was used to apply load under displacement control at a rate of 0.3 mm/min. The midspan deflection of the specimens was recorded by means of two LVDTs located under the both sides of the middle mortar joint. The specimens were loaded until complete failure and the load, head displacement of the machine and deflection of the beams at the midpoint were recorded in each test.

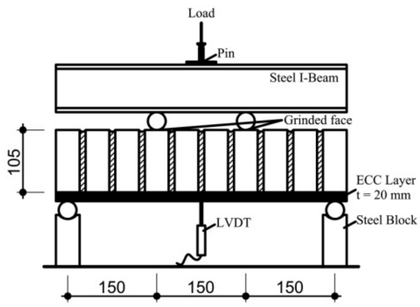

Figure 2.7. (a) Four-point bending test schematic view and dimensions (b) test setup and instrumentation

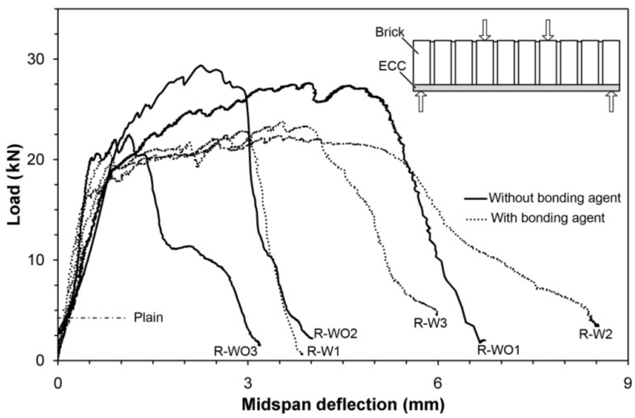

Figure 2.8. Flexural response of the masonry beams

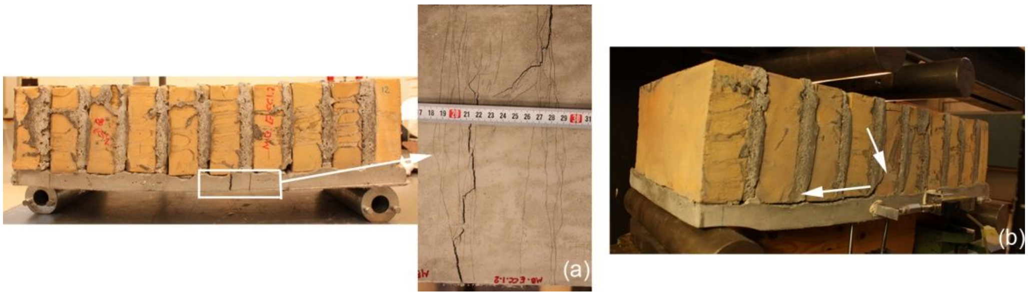

Figure 2.9. Failure mode of retrofitted masonry beams: (a) multiple cracking in the ECC layer (bottom view) (b) ECC debonding in specimen R-WO3

Fig. 2.8. shows the flexural behavior of retrofitted specimens and the load bearing level of plain masonry beams. It can be observed that the strength and more importantly the ductility of the retrofitted masonry beams are increased dramatically by applying a thin layer of ECC. The plain specimens revealed an approximately linear elastic behavior up to ultimate load carrying capacity with an average of 5 kN and a subsequent catastrophic failure at 0.2 mm midspan deflection. The failure occurred in a joint inside of the middle third of the span length. In contrast, the retrofitted specimens exhibited the first crack in the ECC layer at a load of about 20 kN which is five times more than the ultimate bearing load of the plain specimens. For these specimens, the ultimate strength was higher than the first cracking strength. Also, the formation of multiple cracking in the ECC layer was observed during the inelastic deflection process. It is worth emphasizing that the ductility increased by a factor of 25 to 30 and all retrofitted specimens exhibited strain-hardening behavior due to the unique performance of ECC material and failed in a ductile manner. Fig. 2.9a illustrates the typical failure mode characterized by the multiple cracking in the ECC layer in the constant moment region.

By referring to Fig. 2.8, it can be seen that one of the retrofitted beams (R-WO3) exhibits a sharp load drop relatively after the first cracking strength. In this case a wide crack occurred between the ECC layer and bricks around the midspan and propagated to the closer support which led to ECC debonding (see Fig 2.9b). The load-deflection curves for the specimens with bonding agent show a more constant behavior in the inelastic branch. In fact, due to the presence of the adhesive, a more constant tensile stress distribution was achieved in the ECC layer resulting in a more stable inelastic response. However, the curves reveal a reduction of strength in comparison to the retrofitted specimens without the bonding agent. This reduction in strength can be related to the penetration of the wet bonding agent to the ECC, leading to a change in the mechanical characteristic of ECC material.

2.2.4 Triplet tests

The procedure described in BS EN1052-3 was adopted to estimate the effect of ECC strengthening layer on masonry walls in view of shear resistance. Therefore, a series of triplet tests was conducted to evaluate the in-plane initial shear strength of bed joints in masonry using triplet specimens. To prepare the test specimens, a series of triplet specimens was constructed by three full bricks and two mortar joints, leading to a total dimension of 225 mm × 140 mm × 105 mm. The load bearing surfaces of the bricks were grinded before construction of the triplet specimens to avoid premature failure during the experiment. After 7 days, ECC layer was vertically troweled to one side of the specimens with thicknesses of 5 and 10 mm using a wood frame to control the thickness of applied layer. All specimens were tested after 28 days. The name of test specimens and the thickness of applied layers are illustrated in table 2.4.

The test setup is shown in Fig. 2.10a. Two steel rods serving as the supports were fixed 80 mm apart from each other on a stiff steel beam installed on the bottom of an Instron testing machine. Two LVDTs were used on both sides of the specimen and fixed to the machine frame in order to measure the displacement of the bottom face of the middle brick. Also the specimen was restricted by two F-clamps lightly tightened to avoid damage to the test equipments which could occur due to unexpected failure. It should be noted that the F-clamps were not tightened strongly because it would affect the shear resistance of the triplet specimens. The load was applied on the top face of the middle

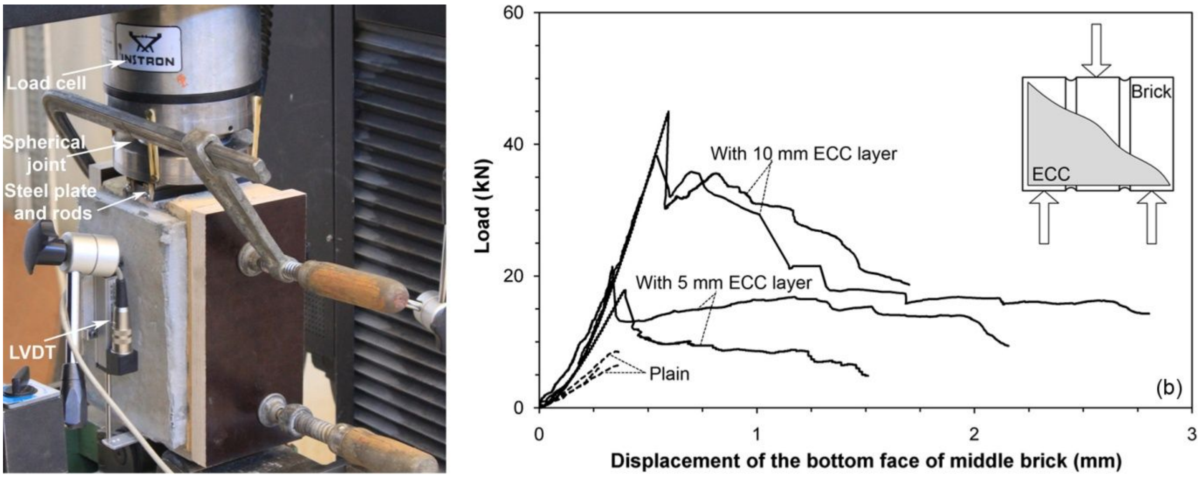

Figure 2.10. (a)Triplet test setup (b) Load-displacement curves obtained from the triplet tests

Table 2.4. Experimental results of triplet shear tests

Specimen name	strengthening configuration	Thickness of ECC layer (mm)	Maximum load (kN)	Deflection (mm)
CT1	--	--	6.2	0.2
CT2	--	--	8.1	0.17
CT3	--	--	5.9	0.23
ST5-1	Single-side	5	21.4	2.15
ST5-2	Single-side	5	18.1	1.51
ST10-1	Single-side	10	38.2	2.8
ST10-2	Single-side	10	45.0	1.7

brick under displacement control at a rate of 0.5 mm/min.

The values of maximum load and displacement of the middle brick at failure are listed in Table 2.4. It can be seen that both parameters were increased by an order of magnitude due to the presence of ECC layer. The shear load versus displacement curves are shown in Fig. 2.10b. It is obvious that by applying a thin layer of ECC, the shear load carrying capacity of the tested specimen as well as its energy absorption capability was increased dramatically because of the action of ECC material. However, a more stable behavior after peak shear load was achieved when the thickness of reinforcement layer was set to 5 mm. In fact, the development of cracks in ECC material and therefore achieving a good ductile behavior of retrofitted masonry elements depends on the thickness to area ratio of the ECC layer. It should be noted that when the test was repeated for masonry elements with a reinforcement layer of 20 mm, the specimens exhibited, in contrast, a rather brittle behavior characterized by the limited shear failure of the bricks and debonding of ECC layer.

After collapsing one of the mortar joints in retrofitted specimens, the shear load was transferred to the ECC layer and a sudden loss in strength occurred (see Fig. 2.10b). Beyond this point the specimens showed a ductile behavior up to failure. First cracks appeared in the ECC layer around the collapsed joint and by increasing deformation, debonding of reinforcement layer started from this area. In higher deformations, the number and width of cracks increased and the specimens failed because of the collapse of the second mortar joint.

3. CONCLUSIONS

To demonstrate the possibility of retrofitting brick infill panels or bearing walls by troweling ECC onto the outside surfaces of the bricks, tensile bond strength tests using pull-off method, compression tests on masonry prisms, flexural tests on masonry beams, and shear tests on triplet specimens were performed. Furthermore, tensile, compressive and flexural properties of ECC which was suitable for troweling were determined. The following conclusions can be drawn from the current experimental results:

1. By selecting a reasonable weight proportion of the ECC matrix ingredients, uniform fiber dispersion through the mixture and a smooth surface of plastered ECC after hardening were achieved. In addition, the hardened mechanical properties of plastered ECC were measured to be comparable to those of normal cast ECC.

2. Due to the failure mechanism characterized by vertical cracking in the prisms, the strengthening layer has a small effect on the compressive strength and stiffness of the masonry prisms but can prevent the severe spalling of the bricks.

3. The strength and more importantly the ductility of the retrofitted triplet specimens and masonry beams increased dramatically by applying a thin layer of ECC. This increase shows that the proposed technique can be effectively used to enhance shear load carrying capacity as well as energy absorption capability of masonry infill or bearing walls and also to prevent out-of plane catastrophic failure of these elements which usually occur even in moderate earthquakes.

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