# THE INFLUENCE OF SHORT FIBRES IN MORTAR ON MASONRY BOND STRENGTH

**Dariusz Alterman[1], Adrian W. Page[2] and Timothy Gray-Thompson[3]**
[1] Research Fellow, The University of Newcastle, Priority Research Centre For Energy,
dariusz.alterman@newcastle.edu.au
[2] Professor Emeritus, The University of Newcastle, Priority Research Centre For Energy,
adrian.page@newcastle.edu.au
[3]Undergraduate student, The University of Newcastle, Discipline of Civil Engineering,
timothy.gray-thompson@uon.edu.au

## ABSTRACT

This paper presents the results of an investigation into the influence of the addition of short steel fibres to mortar on masonry bond and direct shear bond strength. Previous tests of fibre reinforced mortars have indicated that higher mortar tensile and flexural strengths can be achieved. The investigation extends this to the unit-mortar interface. Bond wrench tests to determine masonry bond strength were carried out in accordance with AS3700-2011. Since the Australian standard does not contain a shear strength test, triplet tests in accordance with European Standard EN1052-3 were used to determine the shear strength. Mortar-to-masonry bond is a critical component that affects not only the strength of the masonry construction but also its durability. While traditional mortar uses fine sand only, this investigation examines whether the addition of small steel fibres to the mortar mix increases the masonry shear and bond strength, especially for cored masonry units.

To gain a greater understanding of the effects that the fibres may have on mortar properties, a range of variables were considered, including the extruded clay brick patterns (coring percentage), the proportion of fibres, the mortar water-cement ratio as well as the presence of lime. Image analysis techniques and microscopic examination were also conducted to examine failure surfaces as well as the mortar-brick interface to better understand the bond phenomenon.

**KEYWORDS**: bond strength, direct shear strength, fibre reinforced mortar, image analysis technique

## INTRODUCTION

Sufficient bond strength is an essential component of masonry construction, particularly in unreinforced applications. Wind forces, settlement of foundations, applied loads and occasionally more severe loads such as those imposed during an earthquake may all be experienced by masonry construction during its service life. Whilst masonry construction performs well when these loads induce compression, it is much weaker under shear and flexural loads. In such cases if the bond strength is insufficient the mortar joints will commonly develop cracks, thus reducing the masonry capacity and potentially leading to the failure of the weakest elements. The out-of-plane mode of failure in particular can lead to the collapse of the entire structure. Even if total collapse does not occur, cracked mortar joints can result in decreased durability and lifespan of the structure.

Masonry is a composite material in which both the brick and mortar components contribute to its strength and serviceability. The prime function of the mortar is to bond the masonry units together and at the same time accommodate the inherent dimensional variations of the fired clay units. The mortar is usually weaker than the brick, but there is some potential to increase masonry strength by also increasing the strength of the mortar. The bonding mechanism between mortar and masonry units is a complex phenomenon, affected by many factors such as cement type, admixture type, aggregate size, masonry unit type and its surface characteristics which have been an extensively studied in the past [e.g.: 1, 2, 3, 4]. In general, bond is created by the absorption of cement paste into the pores on the surface of a masonry unit and the subsequent hydration of the cement; however the influence of other factors is also very significant [1].

Experimental studies have shown that the addition of fibres to the mortar helps in the development of bond in masonry construction. Zhu and Chung [5] recorded a 50% increase in bond strength under tension whilst Gupta et al [6] found similar increases when studying the impact of micro and macro fibres on bond performance. Although these studies showed experimentally the potential for fibres in mortar in relation to bond strength, neither was explicit in providing a link to the associated theory and there are no other studies pertaining to mortar in masonry reported in the literature. However in studies related to concrete, fibre additives have been used widely to improve tensile and bending strength [7, 8, 9, 10].

Against this background, the experimental program was planned to investigate the impact of the addition of short steel fibres to the mortar on the flexural bond and shear strength of masonry construction. A mortar composition with two water-cement ratios and the presence of lime was used in conjunction with two different clay brick patterns (coring percentage). In particular, the investigation aimed to assess if the main source of the strength came from the interlocking effect of the mortar filling the cored sections of the bricks creating significant "interlock" for the whole cross-section. This would be particularly relevant for the shear strength, as in addition to the normal brick-mortar adhesion at the interface, the interlock provides a potentially strong resistance against a shearing force within the section, see Figure 1.

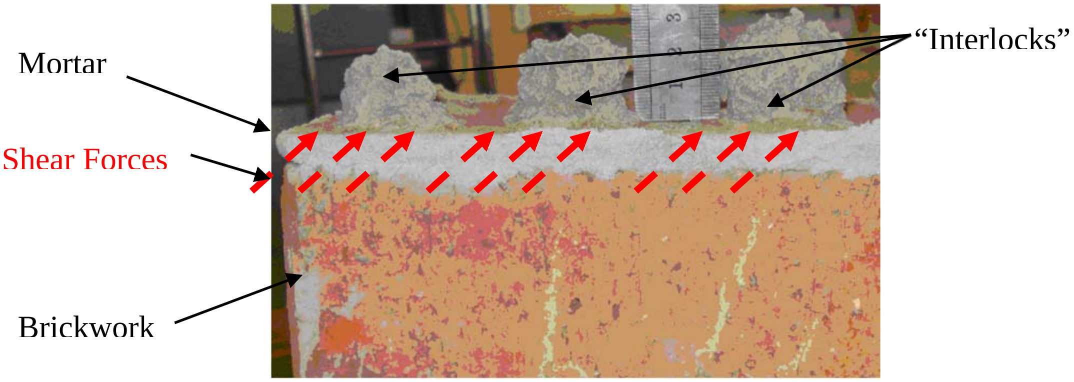

**Figure 1: View of the interlocks**

Additional analysis was performed applying image analysis techniques to examine the dispersion of fibres and the nature of the brick-mortar interface.

## OVERVIEW OF TESTING PROCEDURES

Direct tensile test procedures are relatively difficult to perform and the flexural test procedures are generally preferred to determine the flexural tensile strength using a bond wrench. As there is no method to perform a direct shear test specified in the Australian Standard [11], the European Standard EN1052-3 [12] was adopted and the direct shear test outlined in the Triplet Test procedure was used.

The bond wrench testing apparatus (see Figure 2) is a mechanically operated device which applies an eccentric load which induces flexural failure. The pier is securely clamped into place using the apparatus stand and the bottom joint of the top brick is secured slightly above the clamp (approximately 20 mm). The stand is a hydraulically based mechanism which both secures the pier as per AS3700 and provides an adjustable platform to raise and lower the pier accordingly. The data tracker was then set to record the highest force (N) required to break the bond and converted into a flexural strength of each specimen. Due to the mechanical nature of the bond wrench test procedure, both flexure and compression are exerted on the joint, and this is taken into account in the calculation of the flexural bond strength.

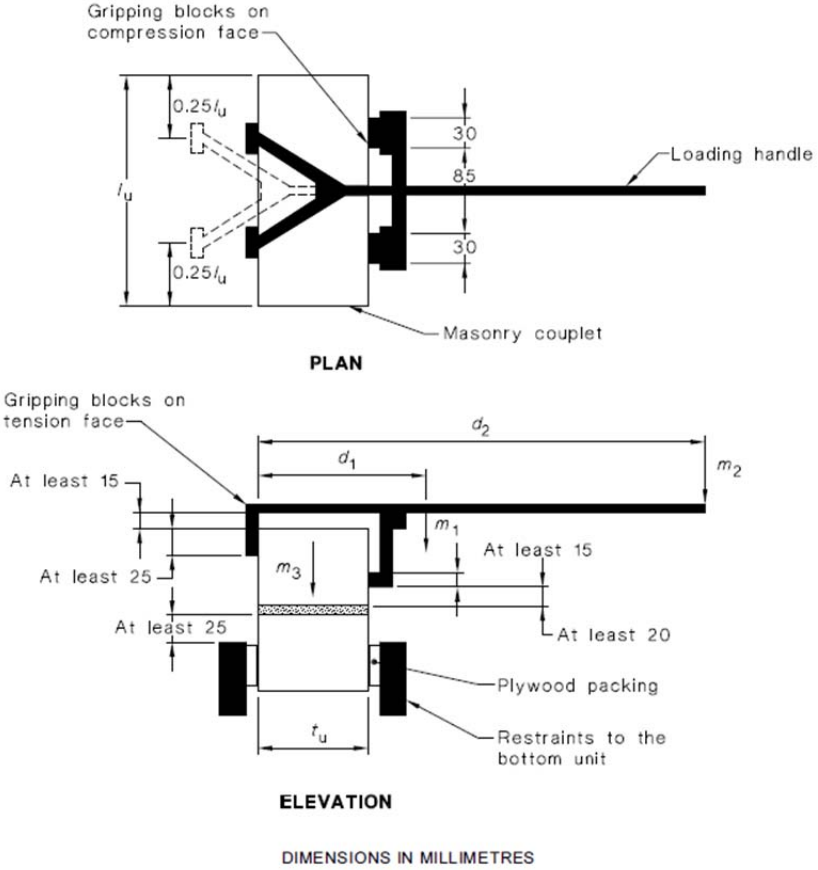

**Figure 2: Schematic apparatus for bond wrench testing [11]**

Due to the difficulties associated with achieving a representative shear test, the Australian standard for masonry [11] does not provide a test method to determine shear bond strength, but directly relates the shear bond strength to the flexural bond strength [13]. For this experimental study, the European shear triplet test was adopted. This test, which is outlined in the EN1052-3

[12], provides two testing procedures, one with a pre-compression stress being applied to the mortar joints and the other with no pre-compression stress. The second test procedure was utilised in the current investigations. The triplet test, presented in Figure 3, incorporates a 3 brick high pier laid with the selected mortar which is placed in an appropriate testing apparatus and load applied. The load is applied to the middle brick from the top with the two loading points located at the same distance from the mortar bed centrelines as the two bottom supports.

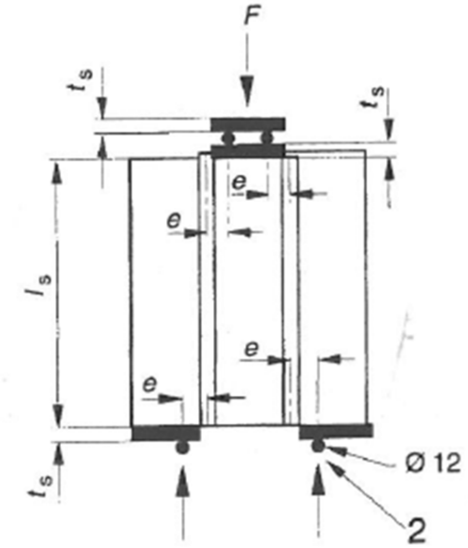

**Figure 3: Schematic apparatus for Triplet Test [12]**

## OVERVIEW OF MATERIALS

This investigation focused on the steel fibres which were 6 mm long with a diameter of 0.16 mm, imported from Dramix in Belgium and shown in Figure 4a. The extruded clay bricks used were 110 mm (wide) x 230 mm (long) and with 20% and 40% cored area as shown in Figure 4b.

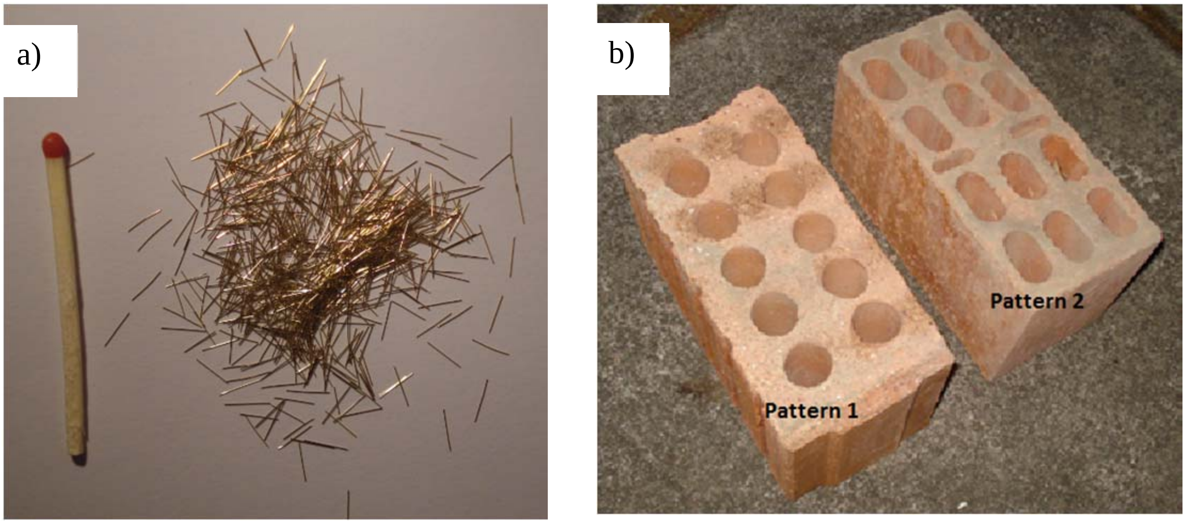

**Figure 4: Picture of Steel Fibres (a) and Masonry Units (b)**

The tests also investigated the effects of hydrated lime on the bond strength. A standard 1:1:6 (cement: lime: sand) by volume mortar, classified as M3 in accordance with the Australian Standard [11] was used. The sand was Newcastle beach sand, and the cement and lime were from the same batch throughout. The mortar compositions and compressive strength results are shown in Table 1. All brickwork specimens were constructed in the laboratory by an experienced mason. Note that due to the perforations in the units, a significant proportion of mortar flowed into the perforations during construction.

**Table 1: Batch composition and compressive strength**

| Batch No | Composition | W/C Ratio | Fibre Content [%] | Compressive Strength [MPa] |
|---|---|---|---|---|
| 1 | 1:1:6 | 1.68 | 0 | 1.97 |
| 2 | 1:1:6 | 1.68 | 1 | 2.79 |
| 3 | 1:1:6 | 1.68 | 2 | 3.54 |
| 4 | 1:0:6 | 0.98 | 0 | 6.33 |
| 5 | 1:0:6 | 0.98 | 1 | 6.39 |
| 6 | 1:0:6 | 0.98 | 2 | 7.82 |

Note: The average compressive strength given in the table was obtained from 3 samples for every batch at 7 days from 70 mm cubes. The specimens were cured in the laboratory fog room for 7 days before testing.

As would be expected, the mortar without lime is much stronger than the mortar with lime due to its lower water-cement ratio. The increase of strength of the mortar with no lime ranged between 120% and 220%.

Note: the higher interlocks due to the flow of mortar into the perforations (to a depth of approximately of 20-35 mm) occurred on the lower side of the joints during the laying process, with the degree of penetration being affected by the consistency of the mortar and the compression force applied during laying. Lower interlocks (of about 10-15 mm) were created on the top side of the mortar joint. These interlocks subsequently provided resistance against shearing forces within the section for both the bond wrench and triplet tests

## FLEXURAL STRENGTH RESULTS FOR BOND WRENCH TESTS

The bond wrench tests were performed after 7 days of curing on 9 joints for every combination. As required in this test, two masonry piers, built from 6 units and thus containing 5 joints, were constructed. The maximum force required to break the bond was recorded and used for further analyses. Generally the failure under flexural or tensile forces occurs at the mortar-brick interface [12] and this was also observed throughout these tests. The results from the bond wrench test are presented in Figures 5 and 6.

With the exclusion of lime from the mortar, there was an increase in flexural strength of approximately 61% and 105% which directly relates to the higher water-cement ratio for both brick patterns. For the mortar without lime, an increase in mean flexural strength was observed as the percentage of fibres increased from zero to 2%. This is correlated with the corresponding increase in mortar compressive strength. However, the lime mortar experienced no significant improvement in mean strength with the increased proportion of fibres from 1% to 2%, particularly for brick pattern 2 with 40% coring area. The influence of both lime and fibre content was also confirmed through multi-variance statistical analysis using Tukey's HSD (honestly significant difference) test; performed in JMP [14].

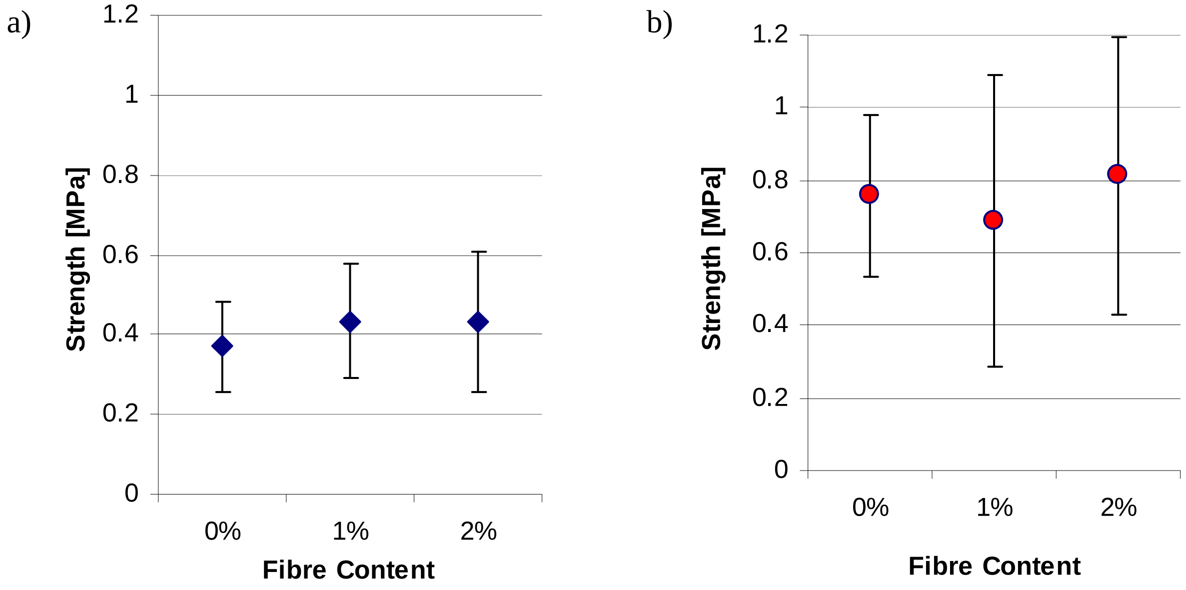

**Figure 5: Mean Flexural Strength Results for Brick Pattern 1 (20%coring area) with lime (a) and without lime (b). Note: One standard deviation for every combination is also shown.**

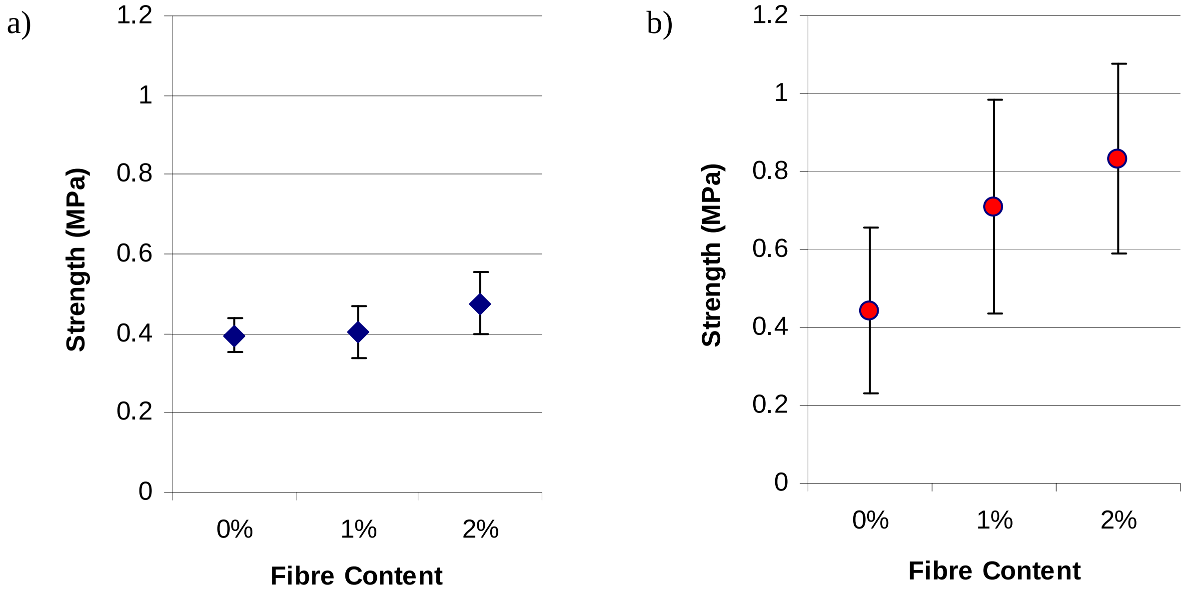

**Figure 6: Mean Flexural Strength Results for Brick Pattern 2 (40%coring area) with lime (a) and without lime (b). Note: One standard deviation for every combination is also shown.**

Surprisingly, no significantly different trends were observed between the two brick patterns; with only a slight increase of joint flexural strength for mortar without lime. Before firm conclusions can be drawn on the influence of fibre content and coring area on the flexural strength, a larger scale investigation would be required.

## SHEAR STRENGTH RESULTS FOR TRIPLET TESTS

The shearing tests on 6 joints for every combination were performed after 7 days of curing. Note: the piers for the shear tests were 3 bricks high; this means there were 2 joints for every pair. The shear strength results are presented in Figures 7 and 8. In general, for both brick patterns the inclusion of fibres for both mortars with and without lime increased the shear strength. However, from the limited results available it appears that may be an upper limit on the percentage of fibres needed to optimize the shear strength. This trend was not reflected for one batch for the mortar without lime for brick pattern 1, where the fibreless mortar was the strongest as shown in Figure 7. The reason for this apparent anomaly is still being investigated. As noted previously, the mean strength for mortar without lime was stronger than for the mortars with lime however not as significantly as for bond wrench tests. This was observed for 5 out of 6 comparisons.

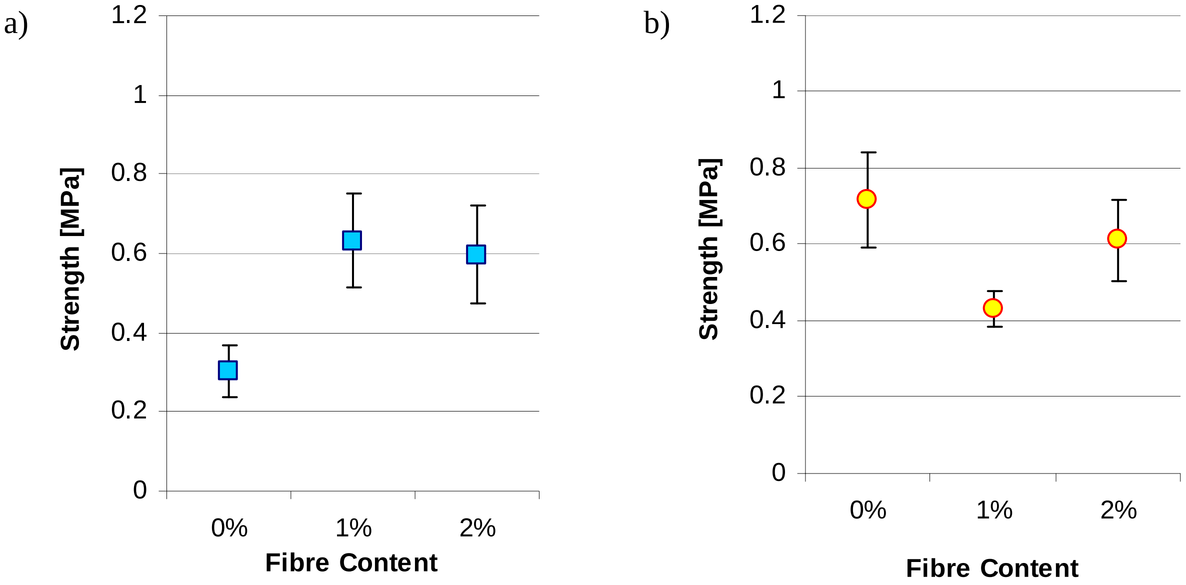

**Figure 7: Mean Shear Strength Results for Brick Pattern 1 (20%coring area) with lime (a) and without lime (b). Note: One standard deviation for every combination is also shown.**

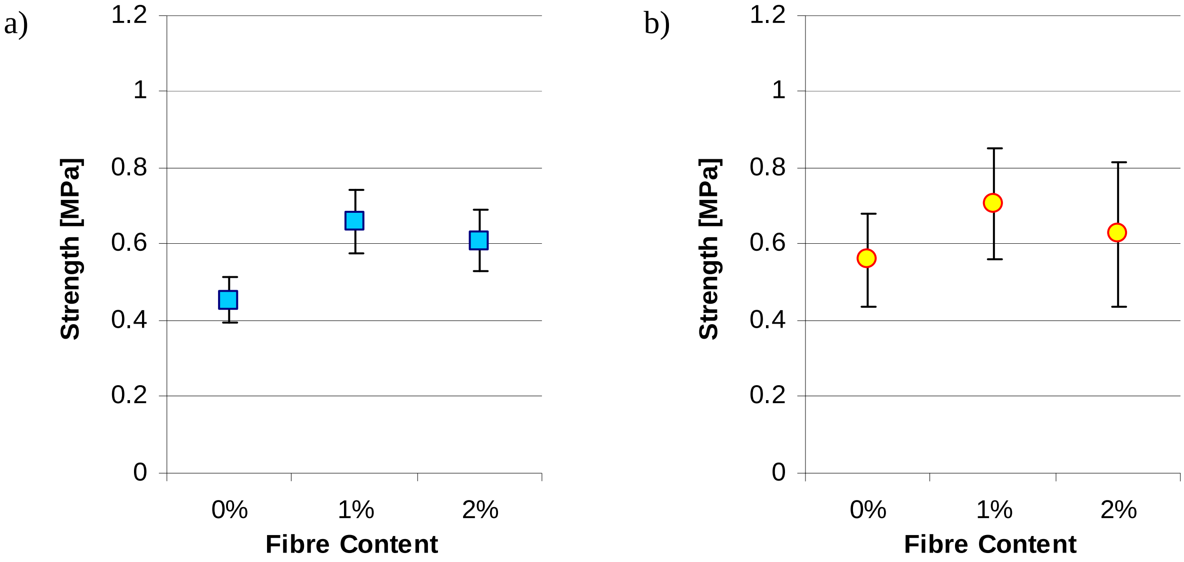

**Figure 8: Mean Shear Strength Results for Brick Pattern 2 (40%coring area) with lime (a) and without lime (b). Note: One standard deviation for every combination is also shown.**

All failures occurred at the masonry unit-mortar interface with the mortar around the area of coring being sheared to a smooth face in line with the mortar-brick interface as shown in Figure 9. When a specimen was loaded, cracks along the interface appeared gradually and with the increase of load, they widened and lengthened until the maximum load was reached and sections began to spall and fall off the specimen. Some specimens had cracks appear along the mortar interface before the failure occurred where an obvious separation between the mortar and the brick was visible.

**Figure 9: Typical failure mode for triplet tests. Note: the penetration of mortar into the cores was greater onto lower bricks (bottom of joints); however there was no trend observed with regard to which surface actually failed in shear (roughly half for each surface)**

The crack propagation started at the bottom support roller and slowly propagated along the interface gradually becoming wider and longer. The specimen did not fail until the mortar in the cores was sheared off. This suggests that the main source of the strength in these tests was from the strength of mortar filling the cored sections of the bricks creating the significant interlock for the whole cross-section. The specimens with the higher mortar compressive (and tensile) strengths would therefore be expected to have a higher capacity.

## IMAGE ANALYSIS

An image analysis technique, using an Olympus microscope linked with a digital camera, was used to further investigate the failure modes between the masonry units and the mortar. The joints chosen for the analysis were of high and low bond strength to analyse extreme cases. Each sample was selected, cut from a joint and an appropriate surface preparation was carried out including polishing and protecting the surface with a resin with fluorescence dye. This allowed the interface between the mortar and brick to be captured using Image Pro Express software. Of particular interest in viewing these interfaces was the dispersion, orientation and quantity of fibres, see Figure 10. The images taken at 50x magnification were used to look at the overall fibre dispersion and orientation throughout a specimen. It was noted that in all of the samples analysed that there was an even dispersion of fibres. The orientation seemed to be totally random as at the cut and polished surface there were fibres at all angles.

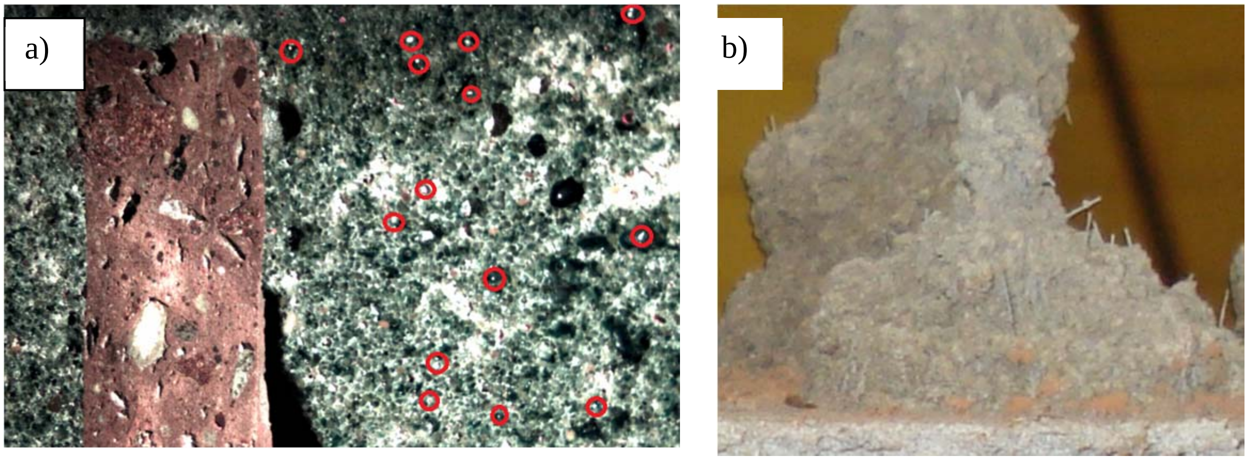

**Figure 10: Orientation and scatter of fibres in a core of a brick a) 50 times magnification, b) picture taken by a digital camera. Note: fibres have been identified and highlighted with red circles**

The brick to mortar bonding interface was investigated with the high magnification of 200x and an example picture can be seen in Figure 11.

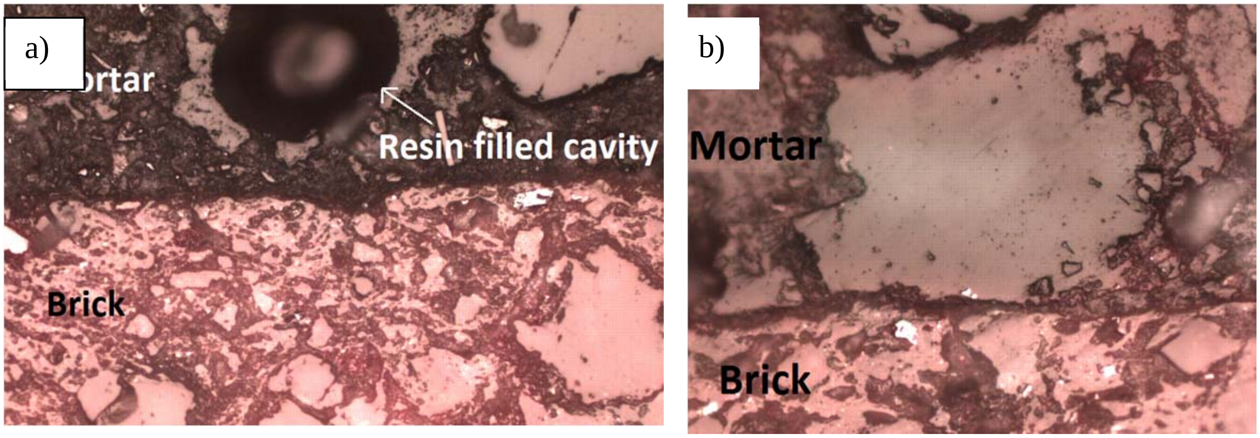

**Figure 11: Typical bonding interface image of 200 times magnification a) 1% fibres and no lime, b) 1% fibres with lime**

Along the interface of each sample, some variability was found with some areas with more cavities. Through the comparison of the interface under ultraviolet light between brick units and mortars with and without lime, there was also a noticeable difference in the number of pores present on each interface, with a significant increase in the number of pores for the mortars with lime.

## CONCLUSION

The aim of the study was to observe the influence of steel short fibres on masonry bond strength with a view to improving the strength of masonry constructions. Testing undertaken to examine the relationship between strength, mortar composition and unit coring area was performed and a significant improvement of the bond and shear strength of the mortars with higher content of fibres was observed in most cases. In particular, the following conclusions can be drawn:

1. The mortars without lime exhibited an increase of up to 100% higher flexural strength than those incorporating lime. This was most evident for the mortar compression and masonry flexural tests with the same trends being observed in the direct shear tests. Since the interface strength was influenced by the contribution of the mortar filled cores, the higher strength mortars should therefore be expected to produce higher shear and tensile strengths. This may not be the case for solid units without perforations.
2. The mortar with the fibres was found to produce higher joint strengths in comparison to no-fibre mortar, the higher the content the higher the mean flexural strength. A similar trend was observed for the joint shear strength; however there may be an upper limit to the strength enhancement as the result of the addition of fibres. This was also pointed as a major difference attribute among various variables through the statistical analysis.
3. Image analysis showed that the fibres were evenly distributed throughout the mortar with random orientations. More effective contributions from the fibres could probably be obtained if their orientation could be controlled and located in the shear plane. This area should be further studied to properly adjust the direction of fibres.

The addition of fibers in concrete materials is well recognized as a means of improving concrete tensile strength in many applications; however, little has been done to transfer this approach to mortar in masonry applications. This preliminary research indicates that there is some potential for the use of fibers in masonry mortar, but further research is required.

## ACKNOWLEDGEMENTS

This research has been supported by Think Brick Australia and Civil Engineering laboratory staff. Their support and the assistance are gratefully acknowledged.

## REFERENCES

1. Sugo H.O., Page A.W., Lawrence S.J. (2007), Influence of age on masonry bond strength and mortar microstructure, Canadian Journal of Civil Engineering, Vol 34, pp. 1433 ‐ 1442
2. Sugo H.O., Page A.W., Lawrence S.J., (2001), The Development of Mortar/Unit Bond, in Proc. 6th Australasian Masonry Conference, Adelaide
3. Sugo H.O., Page A.W., Lawrence S.J. (1997), Characterisation and Bond Strengths of Mortars with Clay Masonry Units, in Proc. 11th IB2MC, Shanghai, China, pp. 59 ‐ 68
4. Vladimir G. Haach, Graça Vasconcelos, Paulo B. Lourenço (2011), Influence of aggregates grading and water/cement ratio in workability and hardened properties of mortars, Construction and Building Materials, 25, pp. 2980–2987
5. Zhu M. and Chung D.D.L (1997), Improving Brick-to-Mortar Bond Strength by the Addition of Carbon Fibers to the Mortar, Cement and Concrete Research, Vol 27, No. 12, pp. 1829-1839
6. Gupta R., Brzev, S. and McEwen W. (2009), Bond Performance of Conventional and High Performance Fiber‒Reinforced Mortars, in Proc. 11th Canadian Masonry Symposium, Toronto, Canada.
7. Tugçe Sevil, Mehmet Baran, Turhan Bilir, Erdem Canbay (2011), Use of steel fibre reinforced mortar for seismic strengthening, Construction and Building Materials, 25, pp. 892–899
8. Md. Toihidul Islam, Vivek Bindiganavile (2011), The impact resistance of masonry units bound with fibre reinforces mortars, Construction and Building Materials, 25, pp. 2851–2859
9. Berndt M.L. (2010), Strength and Permeability of Steel Fibre Reinforced Grouts, Construction and Building Materials, Vol 24 (9), pp. 1768 ‐ 1772
10. Liang N., Zhang X., Sun, L. and Li F. (2011), Effects of Polypropylene Fiber on Shrinkage of Masonry Cement Mortar, Advanced Materials Research, Vols. 295 ‐ 297, pp 1138 ‐ 1141
11. Australian Standard, AS 3700 – 2011, (2011), Masonry Structures, Standards Australia
12. European Standard, DIN EN 1052-3 (2002), Methods of test for masonry, Part 3: Determination of initial shear strength
13. Masia J. M., Simundic G., Page W. A. (2012), Assessment of the AS3700 relationship between shear bond strength and flexural tensile bond strength in unreinforced masonry. in Proc. 15th International Brick and Block Masonry Conference, Florianópolis – Brazil, 3-6 June 2012.
14. SAS Software Version 9.2, SAS Institute Inc.; Cary, NC: 2008.