A COMPARATIVE STUDY OF FOUR BOND WRENCHES WITH RECOMMENDATIONS ON CHANGES TO ASTM C1072

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ABSTRACT
Bond wrenches form the core element of a sound quality control program for masonry construction. These instruments measure a critical element in the manufacture of masonry, achieving an acceptable level of flexural strength. All major masonry codes include design elements for a bond wrench. The major problem for comparison of flexural strength results is the significant variations in the design of bond wrenches. A secondary problem is one of the construction issues for each type of wrench. The objective of this paper is a comparison of flexural results from four bond wrenches, with the additional objective of providing a comparison of the design and construction issues for the four bond wrenches. The test results from a set of 11 prisms, tested using the four bond wrenches in turn, showed a difference between the flexural results for the American bond wrench and the other three bond wrenches using a standard t Test that was significant at the five per cent level. The prisms came from a single pallet of bricks, made with a 1:1:6 mortar at the same time and then stored for more than twelve months at the same location. The relative difficulty of construction of the ASTM C1072 bond wrench may point to the reason for the relative paucity of bond wrenches in the USA. The paucity of bond wrenches means an effective quality control plan is difficult to implement for flexural strength testing, even one based in a university testing laboratory. Suggested changes to ASTM C 1072 are to reduce the mass of the bond wrench and to increase the length of the lever arm. It is finally suggested that a full study of the differences in the results from the

KEYWORDS: masonry bond wrench, flexural bond testing

INTRODUCTION
Borchelt [1], in commenting on a previous paper about the design of two new bond wrenches, asked why the published flexural results [2] were not compared to flexural results using the ASTM standard bond wrench [3, 4]. The purpose of this paper is to compare the results obtained from testing masonry prisms using four different bond wrenches, including the ASTM standard wrench. The clear purpose is to answer this question of J.G. Borchelt.

In setting aside a semester for the construction of the ASTM wrench and the flexural testing, a competent student was not able to complete the ASTM wrench by the required submission deadline for this paper. The student encountered many difficulties in constructing the ASTM wrench. One of the revised objectives of this paper is to review the construction of four wrenches in terms of fabrication issues for a small workshop. Test results are included for the four bond wrenches.

LITERATURE REVIEW

The development of the bond wrench in Australia in the 1960s provided one technique to measure the flexural strength of single wythe masonry piers. Figure 1 shows a typical arrangement sketch for a bond wrench [2].

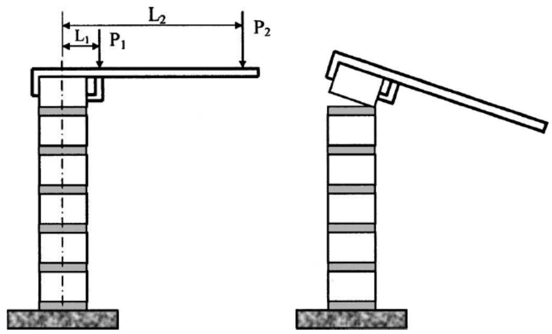

Figure 1: Bond Wrench Schematic Loading System (after Chaudhari, 2010)

Figure 1 shows the standard techniques used for a bond wrench test. The techniques are:

1. T1: Manufacture a set of standard prisms of single wythe construction
2. T2: Allow for the differences in construction between a wall and a prism
3. T3: Develop a bond wrench that will provide a moment to the upper brick whilst holding the second brick in an immovable grip – relatively speaking of course
4. T4; Determine the mass of the bond wrench, m_1 and length from the centroid of the mass relative to the centre of the prism, L_1 and determine $P_1 = m_1 g$, where g is the acceleration due to gravity being 9.806 m/s^2
5. T5: Measure the Force P_2 used to fracture the bond and the offset distance, L_2 and determine the total moment, M_u
6. T6: Repeat the tests to provide a statistically acceptable set of results, generally considered ten results [5]

The total moment applied to the bond will then be as shown in Equation (1)

$$M_u = P_1 L_1 + P_2 L_2 \tag{1}$$

The pertinent observation at this stage in the development of an international standard for a bond wrench or set of bond wrenches is that the key players meet every year or so at one of the four major masonry conferences, yet limited discourse occurs on the development of standard tests. The development of an international standard for bond wrench testing is long overdue coupled with a need for published inter-laboratory test results akin to the seminal work of Baker [6].

In terms of the third technique, T3, two of the nationally based bond wrench standards took a different approach to the design and development of the bond wrench. ASTM C 1072 provides a relatively heavy bond wrench closer to the original Australian design as shown in Figure 2. Table 1 summarizes the materials list for the ASTM bond wrench. Item numbering matches the ASTM standard [4]. All units are SI rounded to 0.01 or 0.1 millimetres as appropriate.

Table 1: Material List and Comments

Item	Part	Number	Specification (All dimensions are millimetres.)
4	Steel Spacer	2	25.4 by 25.4 by 9.25
5	Sliding Tube	1	508 by 38.1 by 2.03 steel square tube
6	Lower Clamp Bracket	1	Assembly
7	Support	2	266.7 by 101.6 by 6.35 flat bar stock
8	Brace	2	139.7 by 6.35 by 6.35 flat bar stock
9	Brace	2	1270 by 38.1 by 2.03 steel square tube
10	Neoprene Insert	1	304.8 by 19.05 by 3.18
11	Tube	1	1270 by 38.1 by 2.03 steel square tube
12	Neoprene Insert	1	304.8 by 25.4 by 3.18
13	Tube	2	457.2 by 38.1 by 2.03 steel square tube
14	Brace	2	604.8 by 38.1 by 2.03 steel square tube
15	Tube	2	876.3 by 38.1 by 2.03 steel square tube
16	Prism Base Support	1	Assembly
17	Tube	2	901.7 by 38.1 by 2.03 steel square tube
18	Upper Clamp Bracket	1	Assembly
19	Neoprene Insert	1	254 by 38.1 by 3.18
20	Hex Bolt (zinc plated)	2	Ø12.7 – length 254 pitch 2.954
21	Flat washer 9701-0039	4	Suit item 20
22	Plate	1	371.5 by 203.2 by 6.35
23	Tube	2	457.2 by 38.1 by 2.03 steel square tube
24	Hex nut	2	Suit item 20
25	Hex Bolt (zinc plated)	2	Suit item 26
26	Hex Bolt (zinc plated)	2	Ø12.7 – length 203.2 pitch 2.954
27	Side	1	355.6 by 76.2 by 12.7 bar stock
28	Floating Plate	1	190.5 by 50.4 by 12.7 bar stock
29	Roll Pin	2	Ø12.7 by 50.4
30	Slide	1	381 by 50.4 by 25.4 Aluminium
31	Side	2	250.8 by 76.2 by 12.7 flat bar stock
32	Top Plate	1	355.6 by 50.8 by 12.7 flat bar stock
33	Side	1	304.8 by 53.98 by 12.7 flat bar stock
34	Plate	2	304.8 by 50.8 by 12.7 flat bar stock
35	Socket Head Cap Screw	2	Ø6.35 – 1 pitch by 25.4
36	Holder	2	50.8 by 12.7 by 12.7
37	Loading Block	1	(ASTM calls for Steel)
38	Joint	1	50.8 by 25.4 by 6.35

McGinley completed excellent work on calibration of the ASTM standard bond wrench. As noted in McGinley's abstract [7], "*This calibration device was designed to simulate a standard brick couplet specimen and was instrumented with linear strain gauges which were monitored and recorded during loading. The results of these tests were compared and discussed in an effort to determine what attributes of the testing apparatuses can significantly affect the stress distribution in masonry couplet specimens*."

Similar work completed in Australia reviewed the design of the Australian standard bond wrench using finite element studies [8]. These studies led to a modified design, [9], for the bond wrench as shown in Figure 3. The basic mechanics of the bond wrench is understood and the bond wrench provides an excellent quality control tool for masonry construction as applied on Catholic Churches after the 1989 Newcastle earthquake [10, 11].

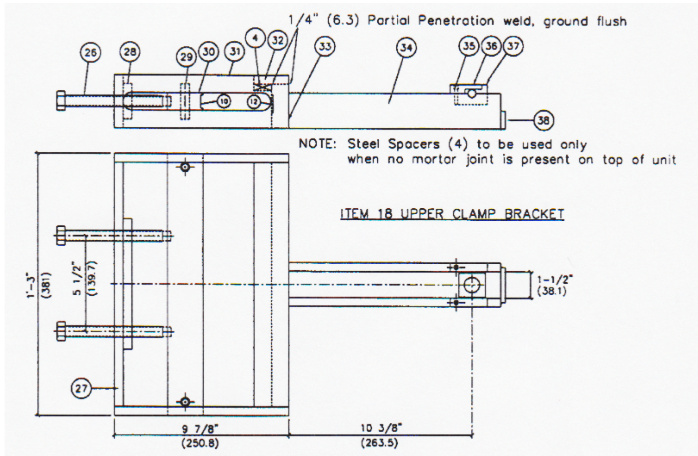

Figure 2: ASTM C1072 Bond Wrench Drawing Clamp Bracket

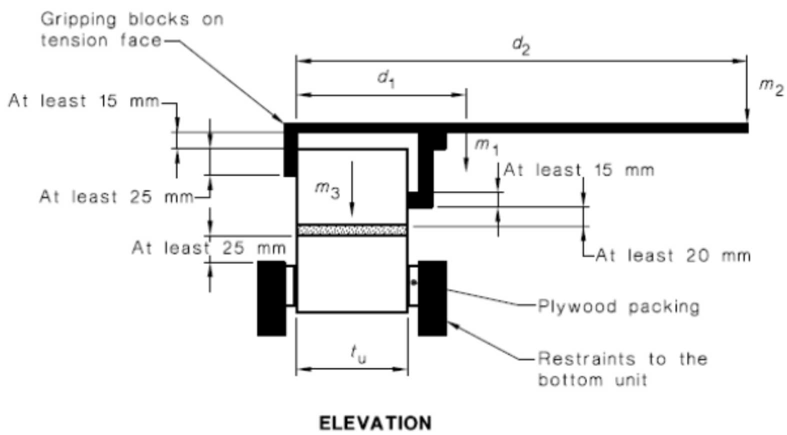

Figure 3: AS 3700 Bond Wrench Schematic Diagram

The Australian Standard uses different symbols for the distances and forces applied to the bond wrench, the symbols used in Equation (1) are the symbols used in this paper. There are significant differences for the two wrenches, but it is clear that the design of both wrenches was by highly competent teams of engineers who sought to measure the flexural strength of the masonry joint.

Baronio, Binda and others [12, 13] working in Italy dealt with the problem of soft historic mortars with very low flexural strengths. The conceptual idea advanced by Binda was the balanced bond wrench, where L_1 is zero. This definition of a balanced bond wrench immediately classifies the previously described bond wrenches as unbalanced; as these wrenches impart a moment to the interface at the start of each flexural test. This moment depends on the mass of the bond wrench and the centre of gravity, but for the US bond wrench and to a less extent the Australian wrench this is moment is significant. Figure 4 shows the balanced bond wrench developed at TAMU for testing the differences between balanced and unbalanced bond wrenches. The unbalanced wrench is similar.

Figure 4: TAMU Balanced Bond Wrench (after Chaudhari 2010)

Figure 5 shows one of the two ACME brick types used for the testing work at Texas A&M University. This is a common brick used in South Western USA.

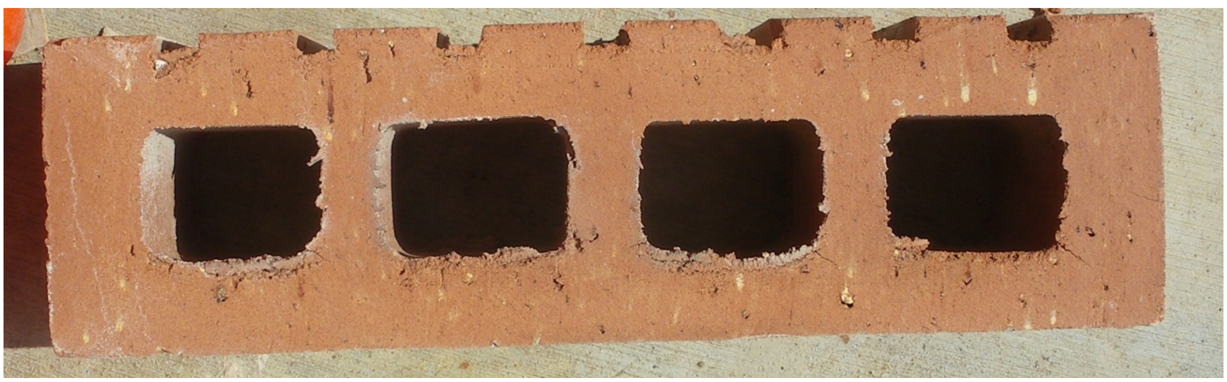

Figure 5: ACME Brick used for the Testing Programs

These bricks are narrow when compared to the average Australian clay brick, with a distinctive ridged pattern on the interior face side of the brick. Figure 6 illustrates the standard measurement gauge used to describe the brick geometry. The number of ridges and grooves on the internal face of the brick can vary, Figure 5 shows a brick with seven grooves and Figure 6 shows six.

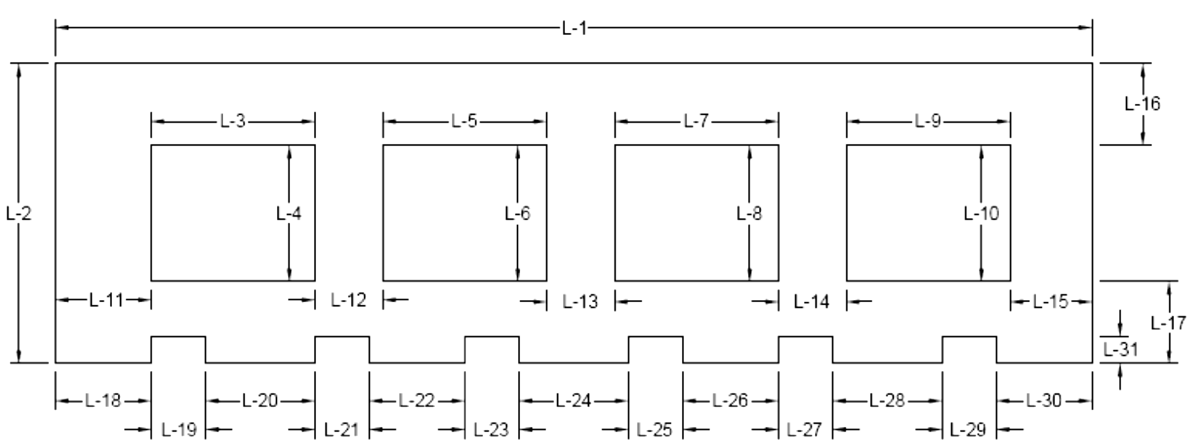

Figure 6: ACME Brick Dimensions Template

This earlier research investigated the difference in flexural test results between a balanced and an unbalanced wrench, with results presented elsewhere [2]. The results did have a low coefficient of variation.

Australian prism practice and at TAMU does not utilize the drop hammer and jig required for the ASTM standard. The construction of single brick stacked prisms, typically five bricks high, have been the subject of significant research. As part of this body of work, some reviewed the difference in the flexural strength with the location of the joint in the stack. The usual finding is that a lower brick in the stack has a higher flexural bond strength [14], although the difference is not generally considered significant. Nichols [14] showed that changing the IRA of the brick by wetting could alter the flexural bond strength be a statistically significant amount at the five per cent confidence level.

In developing a certification test for masons, who were repairing the Catholic Churches after the 1989 Newcastle earthquake, the author looked to certify the mason with a standard brick rather than test every constructed wall. This problem arose because of the scattered nature of the construction zones and the range of brick types. The first problem encountered in this test program was that of transporting the prisms to the Newcastle University Laboratory for testing. Significant difficulties exist in testing masons during normal construction operations. The ability to have tests performed improves if the masons see the tests as part of a normal schedule using their standard techniques and not as an academic exercise.

The bond wrench is about fifty years old; it has proven capable of measuring the flexural strength of brickwork and in advancing understanding of the methods of failure of masonry. It is time for the development of an international standard wrench that allows us to compare all results on an equal statistical basis.

COMPARISON OF THE BEAMS AND BEAM CONSTRUCTION ISSUES

One of the objectives of this paper is to review the construction of four wrenches in terms of fabrication issues for a small workshop. Graduate and undergraduate students from Texas A&M University manufactured four bond wrenches over two years. Significant differences are present in the metalwork skills of the four students. The four wrenches are Type 1, a modern balanced wrench, Type 2, a modern unbalanced wrench, Type 3, an Australian standard model and Type 4, an ASTM C1072 Standard bond wrench. Significant differences exist in the design of these bond wrenches. Two Masters Students from India manufactured the Type 1 and 2 instruments. Two skilled undergraduate students manufactured the Type 3 and Type 4 wrenches.

Original plans developed for the Type 1 and Type 2 wrenches required a variation on the Australian standard wrench. The intent was to compare the balanced Type 1 to the unbalanced Type 3. The students clearly lacked the metalworking skills to fabricate the Type 3 wrench or a variation on the wrench. Without reference to their thesis committees, the two students fabricated wrenches as shown in Figure 4, rather than a modified Type 3. Never wanting to limit creativity, the committees permitted the students to proceed. The key difference is the fixed nature of the plate elements that encase the brick, but the simple construction of the bond wrench meant that the build time with scrap steel was a few hours. The design overcame a potential problem with the Type 3 and Type 4 designs and the standard grooves on the ACME bricks. The students obtained a statistically excellent set of results in terms of the coefficient of variation and repeatability with their two fixed wrenches [2].

The Type 3 wrench presented no significant problems except for the locking cam. This mechanism has proved difficult to source and then fit. The following edited comments, provided by Lawrence [15], document the construction issues associated with the Type 4 wrench.

While building the masonry bond wrench, several problems arose.

1. *The main problem I had to face was understanding the drawings. There were several areas in the drawings that were not clearly stated and required a lot of time to figure out. The most challenging drawing was that of the holder/loading block.*
2. *The terminology used, such as "SHCS" was something that I had never heard before. I later figured it out to mean "Socket Head Cap Screw" which instantly made that part of the drawings understandable.*
3. *The other problems were the tools and equipment that were available for making the bond wrench. The welder was not working properly on some days and the oxy-acetylene torch was not allowed to be used for a couple weeks due to the oxygen bottle sealing improperly.*
4. *I believe that the bond wrench, being constructed out of half-inch steel, made it difficult to construct and fabricate because the torch would "wash" to much of the metal away when I had to cut the slide holes for the aluminium bar.*
5. *I believe that it is a great design, but it is difficult, to make because of the half inch and one inch steel used.*
6. *The size of steel involved in making the bond wrench is in my opinion, to large. I understand that it is trying to allow for the most accurate data possible, but if lacking the proper tools and functionality of those tools, the bond wrench is quite hard to fabricate.*
7. *The hardest part of the fabrication, the slide plates for the aluminium bar, my father, was able to use a laser table at his work, Priefert Ranch Equipment. This allowed the slides to be extremely precise and accurate.*
8. *As of now, I have spent around 12 hours on the bond wrench, much more than intended. I believe most of that is due to the tools not functioning properly and resorting to other, more difficult ways of producing the same work such as using a cut-off wheel on the grinder to cut through the half-inch steel when the torch was down.*
9. *The only people that have worked on the bond wrench, beside me, are my father, the laser table operator.*
10. *The only area left is the holder/loading block and it will be finished and ready to use on day one of the spring 2013 semester.*

The student proved competent at metalwork. The shop tool issues were outside his control; but are included to provide a clear picture of the problems. The challenge is the comparison of bond wrench results within a country and between countries. The bond wrench is fifty years old, but it has not reached an acceptable standardization level given the very limited number of groups that use any form of wrench. The key challenges in developing an internationally accepted standard are:

1. constructable in a small workshop with limited tools

2. able to handle the various faces used on bricks including the grooved bricks used in the South Western region of the USA, which present a challenge for bolt based loading mechanisms
3. utilize a standard brick, which at TAMU by serendipity rather than any higher purpose has evolved to a standard extruded clay brick from the ACME Plant at Elgin
4. utilize a standard sand, lime, and cement mix, with no doubt this should be the Ottumwa sand first described by Baker [6], to complete an international inter-laboratory study to compare the manufacturing methods in various countries, suggested are, Australia, Canada, China, England, Germany, India, Indonesia, Italy, Slovenia, Switzerland, and USA as a suggested starting basis
5. avoid the use of a clamping mechanism, which may pre-damage the joint leading to a larger coefficient of variation of the results
6. design a simple clamping mechanism
7. develop a testing method that includes moisture limits on the bricks and exact mixture requirements for the mortar and testing schedule

TEST RESULTS

A set of prisms remained after the original testing program for the balanced and unbalanced bond wrench. The brick prisms were manufactured using a one lime to one cement to six sand, were stored under identical conditions and cured for more than one year. There were eleven prisms of differing numbers of bricks. The four bond wrenches were used to test the bonds on the prisms. Each bond wrench was used in turn for a single test. The prisms to be tested were selected at random from the storage location. Figure 7 shows the flexural results for the four wrenches.

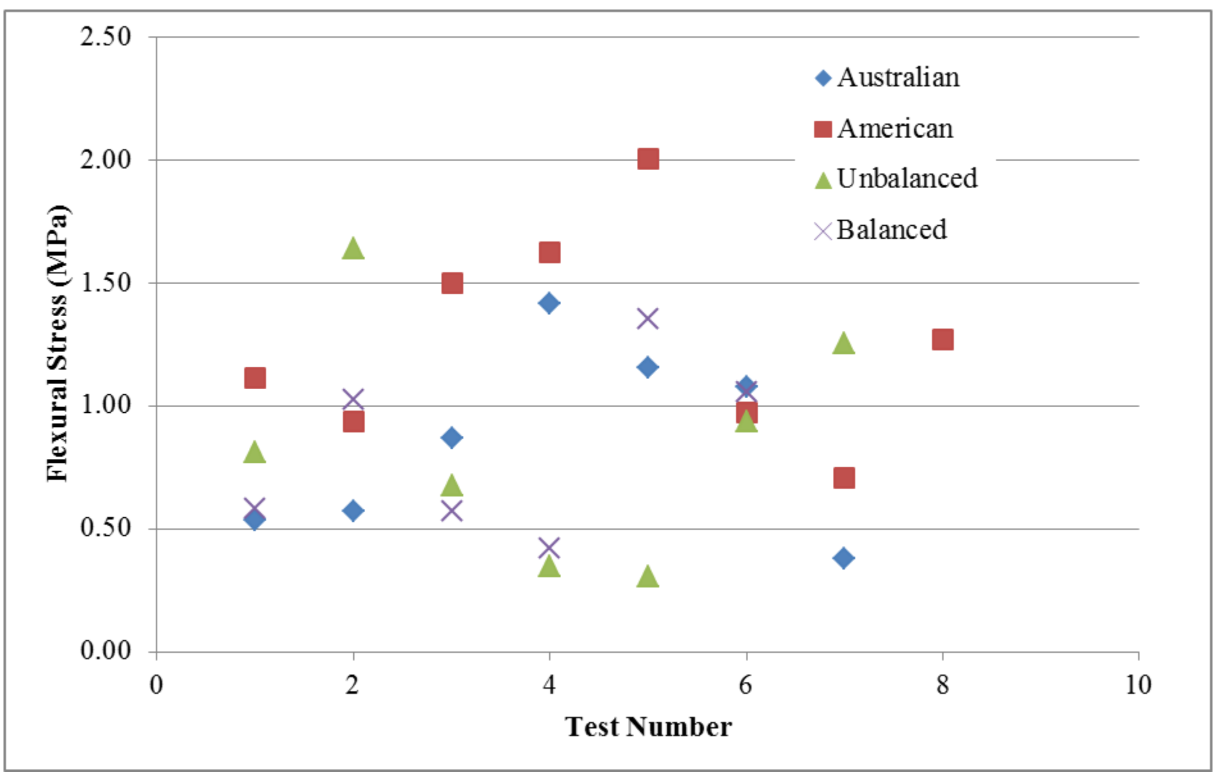

Figure 7: Test Results for the Flexural Tests

Table 2 shows the test results for the bond failure loads and peak stress.

Table 2: Test Results – Failure Load and Peak Stress (MPa)

Prism/Brick	Test Wrench	Failure L (kg)	Stress (MPa)
1-1	Australian	9.97	0.55
1-2	American	34.53	1.14
2-1	Unbalanced	25.36	0.81
2-2	Failed in setup	0	0
2-3	Failed in setup	0	0
2-4	Balanced	17.45	0.58
3-1	Australian	10.72	0.59
4-1	American	26.42	0.96
4-2	Unbalanced	51.28	1.63
4-3	Balanced	30.73	1.02
5-1	American	52.25	1.53
5-2	Australian	17.09	0.90
5-3	Balanced	17.07	0.57
5-4	Unbalanced	21.00	0.63
6-1	American	57.87	1.65
6-2	Australian	28.65	1.46
6-3	Unbalanced (smooth bond failure)	10.80	0.38
7-1	Balanced	12.58	0.42
7-2	American	75.35	2.03
7-3	Australian	23.12	1.19
8-1	Unbalanced	9.43	0.30
8-2	Balanced	40.71	1.35
8-3	Failed in American Setup	0	0
9-1	American	28.28	1.00
9-2	Australian	21.42	1.11
10-1	Unbalanced	29.25	0.94
10-2	Balanced	31.65	1.05
11-1	American	16.09	0.74
11-2	Australian	6.64	0.39
11-3	Unbalanced	39.14	1.21
11-4	American	41.73	1.30

The sets of results for each type of bond wrench were compared using Student's t Test. The tested hypothesis was that the difference in the mean results between each set and the other three sets was zero. The Student's t Test results show that at the five per cent acceptance the unbalanced, balanced, and Australian wrenches the test cannot distinguish the means with the other three sets. The American wrench results show that the mean is distinct and different from the other three sets and the complete set. The American results are on average fifty per cent higher than the other three tests. The tests failures at setup were ignored.

Figure 8 shows the average stress results for each prism.

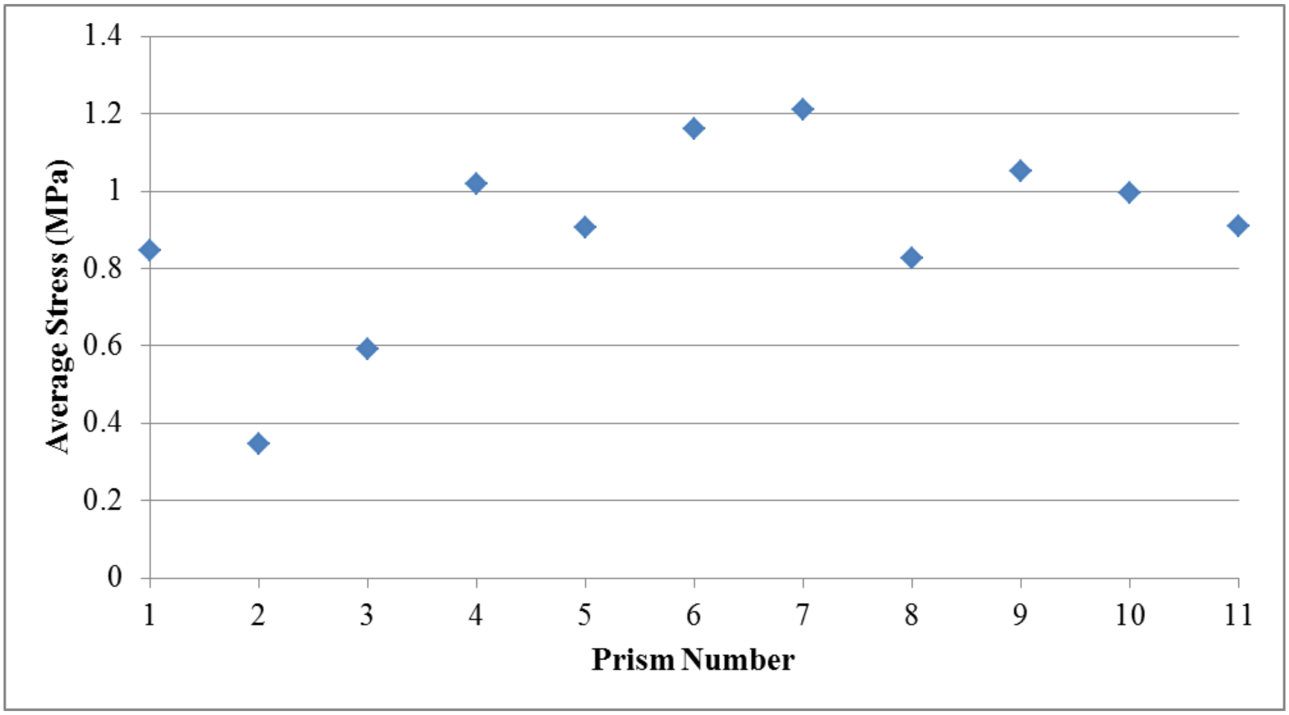

Figure 8: Prism Average Test Results for the Flexural Tests

The objective of making suggested changes to the ASTM standard to address the observed construction issues has morphed into a broader suggested international experiment to allow a comparison between all testing methods, existing wrenches and previous published results for these different existing wrenches. The ultimate objective is a simple wrench that improves the quality of masonry on construction throughout the world and provides a consistent set of answers. The results used a standard set of prisms constructed at the same time with the same materials and methods. One set of results is not conclusive, but do point to the need for further testing to determine if the result is consistent with other bricks and mortar types.

CONCLUSIONS

Masonry testing is challenging under all circumstances, without the self-imposed differences in the various national standards, particularly allowing for the very small size of the masonry community interested in testing standards. Borchelt's specific question about a comparison of the Type 4 ASTM C1072 Bond Wrench results to the Type 3 Australian standard wrench and the Type 1 and Type 2 wrenches developed at TAMU led to a broader question about the comparison of all bond-wrench results and the possible need for an internationally accepted wrench. Comparison of test results for a set of eleven prisms manufactured with one brick type, a 1:1;6 mortar type, laid by the same mason and stored in identical conditions for more than a year showed that the American wrench yielded results for the peak flexural strength that were fifty per cent higher than the other three wrenches.

The paper's objective was to provide a set of suggested changes to bond wrench standards, mainly the ASTM C1072 Standard, to provide a suitable device that is easier to construct, whilst retaining the underlying statistical requirement of obtaining repeatability in measured results. In reality, the paper's objective morphed into considering the problem of comparing all bond wrench results and developing a simple system for encouraging a broader adoption of the bond wrench on all masonry construction. The suggested need is simple wrench usable with a standard brick and mortar mixture to compare existing wrench results and compare results from different laboratories around the world. The American wrench at 16.6 kilograms and with a very short moment arm that requires significant loads to cause failure, up to 75 kilograms, is difficult to place and tends to fly about at the time of failure. A longer moment arm and lower mass would reduce the danger inherent in this testing. The Newcastle University Masonry groups use of strain gauges to calibrate the wrench improves the safety significantly and should be required.

ACKNOWLEDGEMENTS
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