15th Canadian Masonry Symposium
Ottawa, Canada
June 2-5, 2025

Evaluating the Bond Strength in Mortarless Masonry

Yehia Aboziada[i], Belal AbdelRahman[ii], and Khaled Galal[iii]

Abstract

Masonry construction has been a reliable method that offers cost-effectiveness and strength for decades, particularly mortarless block systems. These systems have gained popularity due to their reduced cost and construction time compared to conventional masonry. Understanding the mechanical properties of the dry-stack interlocking masonry (DSIM) blocks is important for designing masonry structures, particularly those subjected to horizontal forces such as wind. Among these properties is the bond strength, which is considered the key parameter in the design. Numerous studies and standards investigated and suggested different methods of testing to evaluate the tensile bond strength between the blocks. This paper presents an experimental investigation focused on determining the flexural bond strength normal to bed joints in a specific dry stacking system known as a Sparlock block. The test was conducted to assess the bond strength using a bond wrench according to ASTM C1072-22. The effect of adding grout to the empty cells was studied. The findings were compared to the allowable bond stresses stated in CSA 304-24 and other results from the literature. The experimental results showed that the tensile bond strength of the Sparlock blocks is comparable to that of the conventional block, as the interlocking mechanism compensates for the missing mortar layer between the blocks. Also, the flexural bond strength obtained from the joint of the Sparlock grouted prism was 2.86 times greater than that of the ungrouted ones.

Keywords

Masonry, Mortarless, bond Wrench, Interlocking, Flexural strength

[i] Ph.D. student, Department of Building, Civil and Environmental Engineering, Concordia University, 1515 St. Catherine West, Montreal, QC, Canada, Yehia.aboziada@mail.concordia.ca
[ii] Postdoctoral Fellow, Department of Building, Civil and Environmental Engineering, Concordia University, 1515 St. Catherine West, Montreal, QC, Canada, belal.abdelrahman@concordia.ca
[iii] Professor, Department of Building, Civil and Environmental Engineering, Concordia University, 1515 St. Catherine West, Montreal, QC, Canada, khaled.galal@concordia.ca

INTRODUCTION

Masonry, one of the earliest known building materials, continues to be a popular choice in modern construction. The fundamental technique involves stacking stones, bricks, or blocks, either using mortar for bonding or laying them dry. This simple yet effective method has endured through the ages, demonstrating its reliability since ancient times.

Globally, significant efforts have been made to advance mortarless masonry in construction. These initiatives aim to lower labor costs, enhance automation, reduce construction time, and boost efficiency in masonry projects [1–3].

Traditional masonry construction heavily depends on the skill level of masons, whose expertise can vary in aligning blocks and accurately applying mortar at both bed and head joints. Moreover, mortar-based construction is prone to shrinkage cracks, particularly in hot climates [4]. As a result, developing an alternative system to address these limitations became a priority. Eliminating mortar addresses these issues and significantly reduces construction costs, a critical factor in selecting building materials. This innovation has achieved cost savings of up to 27% compared to conventional masonry methods, largely due to faster construction processes and the removal of bonding materials [5,6].

Edwards et al. [7] compared the cost to highlight the benefits of DSIM blocks on conventional blocks. A typical commercial building in Edmonton with dimensions 15 m in width, 40 m in length, and 4m in height was used in this comparison, and the type of DSIM concrete block was the Azar block. Although the conventional system was grouted every three courses, it was still more expensive than the DSIM system, which was grouted and reinforced every course. Figure 1 shows the cost comparison between both systems based on material and labor expenses. It is worth mentioning that the construction duration was reduced from 34 weeks in the conventional method to 12 weeks in the DSIM method.

The use of DSIM offers several advantages, particularly in terms of cost-effectiveness. Construction expenses are significantly reduced by eliminating the need for mortar and its specialized labor. Additionally, this method speeds up the construction process, allowing for faster project completion. Furthermore, DSIM is environmentally beneficial, as it lowers the carbon footprint associated with cement production.

Dry Stacked Interlocking Masonry (DSIM) presents several challenges. One significant issue is maintaining consistent unit height and dimensional accuracy, which is essential for proper interlocking. However, achieving precise tolerances increases manufacturing costs. Additionally, transporting these units can be difficult due to their specialized shapes. The absence of bedding mortar makes load transfer more sensitive to block irregularities, reducing resistance to bending stresses. Moreover, incomplete geometric interlocking may require external bracing during construction. Finally, the limited research on DSIM behavior, particularly under seismic forces, highlights the need for further experimental studies to enhance its performance and reliability.

Generally, DSIM systems rely on different geometry factors to provide alignment and resilience for different load types. For example, Sparlock systems depend on a shear key that allows for stacking the blocks on each other. Another system named Azar had a mechanical interlocking in both directions for interlocking. Putra block systems used protrusions and grooves in the webs. Figure 2 shows different systems of the interlocking blocks. In contrast, Table 1 shows the history of the DSIM systems in the world, along with the interlocking mechanisms and the accommodation for vertical or horizontal reinforcement.

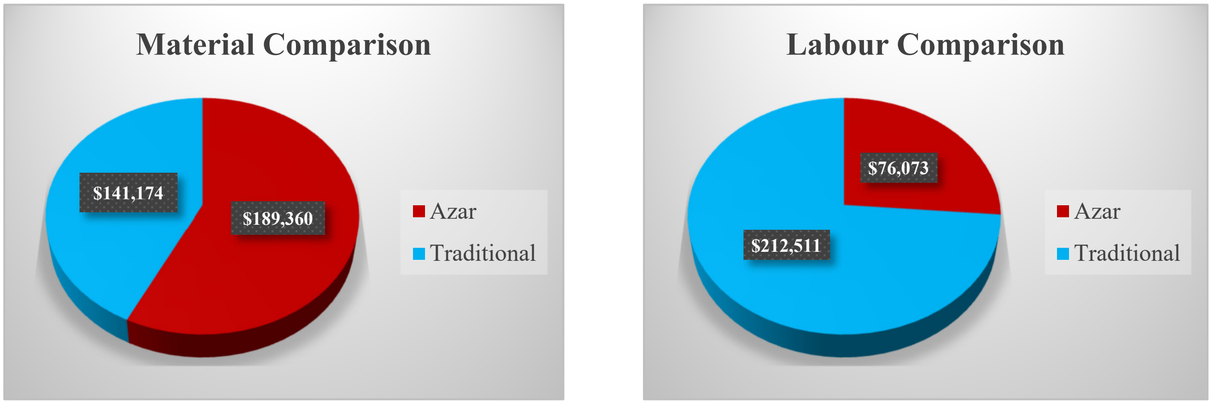
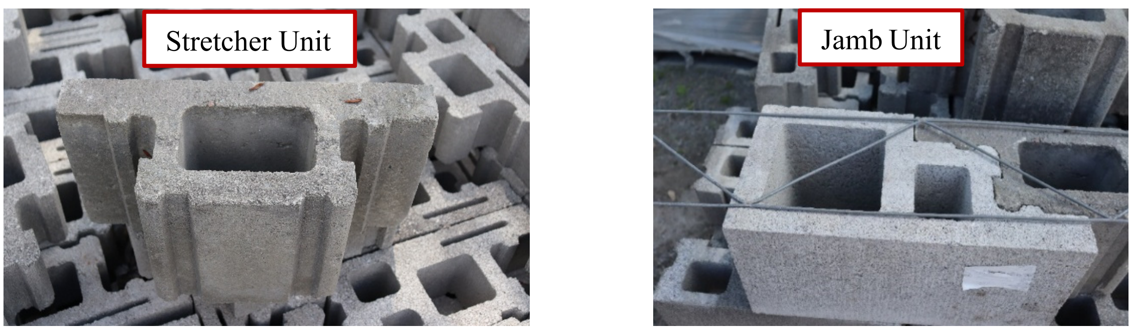
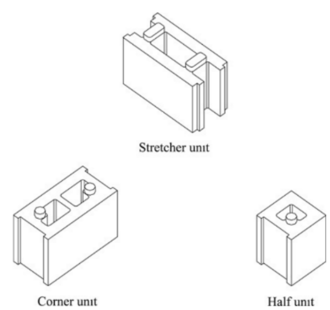


Figure 1: Comparison of the construction costs in both conventional and DSIM systems



a- Sparlock systems

b- Azar block [8]



c- Putra block [2]

Figure 2: Different systems of the interlocking blocks

Table 1: Initial exploration of mortarless interlocked blocks in many countries

Block Name and developer	Country	Material of block	Type of block	Interlocking mechanism	Applicability to have reinforcement
Ytong blocks (Sahlin, 1971)	Sweden	Aerated Concrete	Solid	Tongue and groove	No reinforcement
Hydraform blocks (Jochen Kofahl, 1980)	South Africa	Soil and cement	Solid	Tongue and groove	No reinforcement
Haener unit (Haener,1984)	North America	Concrete	Hollow	Nibs projecting above the two webs	Vertical and horizontal
Whelan unit (Whelan, 1985)	North America	Concrete	Hollow	Dove-tailed end web	Vertical
Sparlock system (Hatzinikolas, 1986)	Canada	Concrete	Hollow	Through geometry and stacking pattern	Vertical
Faswall and Durisol (Hans and Leni Walter,1987)	U.S.A.	Cement and mineralized-wood fiber	Hollow	Through geometry and grouting.	Vertical
Mecano system (Gallegos, 1988)	Peru	Sand-lime	Hollow	Interlocking through grouting only	Vertical and horizontal
Sparfil (Gazzola and Drysdale, 1989)	Canada	Concrete	Hollow	No geometric interlocking – used as surface bonded masonry	No reinforcement
TASTA system (Jansma,1991)	Netherlands	Lightweight aerated concrete	Solid	Vertical and horizontal grooves	No reinforcement
TSZ block (Lorenz,1991)	Czechoslovakian	Lightweight concrete	Hollow	Lightweight rings on blocks from concrete	Vertical and horizontal
Modified H-block (Drexel University,1992)	U.S.A.	Concrete	Hollow	Tongue and groove	Vertical and horizontal
Azar block (Azar Building System Inc,1997).	Canada	Concrete	Hollow	Mechanical interlocking in horizontal and vertical directions	Vertical and horizontal
Sillblock (Indian Institute of Technology Madras, 2000)	India	Concrete	Solid	Dove-tail and groove	No reinforcement
Putra block (Malaysian housing research center,2004)	Malaysia	Concrete	Hollow	Protrusions and grooves	Vertical and horizontal

LITERATURE REVIEW

In DSIM systems, various loads induce tensile flexural stress, including lateral forces from wind or earthquakes, direct bending from vertical loads, and eccentric forces acting on the assemblages [9]. Depending on the direction of the tensile load, two types of flexural stress can develop: normal or parallel to the bed joint. Three standardized tests are commonly used to measure the tensile strength of masonry: the bond wrench test, the beam test, and the wall test. The bond wrench test, described in ASTM C1072 [10], AS 3700 [11], and CSA S304 Annex E [12], evaluates the flexural bond strength by applying a moment to individual joints. CSA S304 [12] provides a schematic diagram of the method, as shown in Figure 4. In contrast, ASTM C1072 and AS 3700 describe the clamping system and loading arm, as illustrated in Figure 5, with the primary difference being that ASTM uses a smaller loading arm than the Australian standard. The beam test (ASTM E518 [13]) measures the flexural strength of masonry stacked prisms under four-point loading or uniform loading. The wall test (ASTM E72 [14]) assesses the flexural performance of full-scale walls under simulated lateral loads, offering insights into the system's large-scale behavior.

Many research studies have been carried out to establish a correlation between the three methods. McGinley and Greenwald [15] conducted experimental work to obtain the bond strength using the wrench and beam method. The tested prisms consisted of two height courses for the wrench apparatus, while the prism for the beam method consisted of four height courses. Two types of conventional blocks and three different types of mortar were examined in this study. Figure 6 shows the construction procedures of the prisms along with the tests using both methods. The authors sorted the failure of the test into three categories. Typically, the separation occurs at either the mortar joint's top (T) or bottom (B). In some cases, the mortar joint may separate at both the top and bottom (T/B). Table 2 summarises the average test results for the three types of mortar, along with the coefficient of variation. It can be concluded that the bond wrench has high coefficients of variation. The results obtained using the hollow unit with a width of 150 mm are higher than those with 200 mm. The bond wrench testing apparatus yields lower flexural tensile bond strengths compared to the beam method, with values being about half of those from the beam test. R. Thomas et al. [16] tested both full-scale walls from concrete masonry in flexure and correlated the results with the data from testing prisms using a wrench apparatus. It was found that the correlation factor between the flexural strength of the wall and the bond strength of the prism was 1.11.

Hamid and Hakam[17] conducted experimental tests on seven grouted four-height blocks using the wrench method and compared the results with the flexural strength obtained from the walls. The grouted prisms' failure was observed through cracks at the interface of the mortar, then tension failure inside the grout core. Finally, the authors found that the bond wrench method is appropriate for determining the modules of rupture of grouted masonry walls. The results were similar between the wall and wrench tests for different thicknesses of conventional masonry blocks.

Based on the above, the bond wrench apparatus offers the advantage of testing each joint individually within a single specimen. It can be performed both in the field and in the lab, with prisms either prepared beforehand or extracted from existing structures. Unlike the beam test, which may be influenced by the weakest joint, the bond wrench test provides a more consistent assessment by evaluating each joint separately. While extensive research has investigated the flexural bond strength of conventional masonry using bond wrenching, no studies have specifically examined its application to mortarless systems.

This research aimed to determine the flexural bond strength of ungrouted and grouted prisms for a specific DSIM system called Sparlock. The results were then compared with data from the literature review on conventional concrete masonry blocks.

Table 2: Flexural bond strength for the ungrouted prisms tested by McGinley and Greenwald [15]

Mortar type	Width of conventional block	Average Peak stress (MPa)	COV (%)
Type N (Portland cement lime)	203 mm	0.292	37.9
Type S (Portland cement lime)	203 mm	0.336	51.6
Type N (Masonry cement mortar)	152 mm	0.263	39.1
	203 mm	0.133	53.8

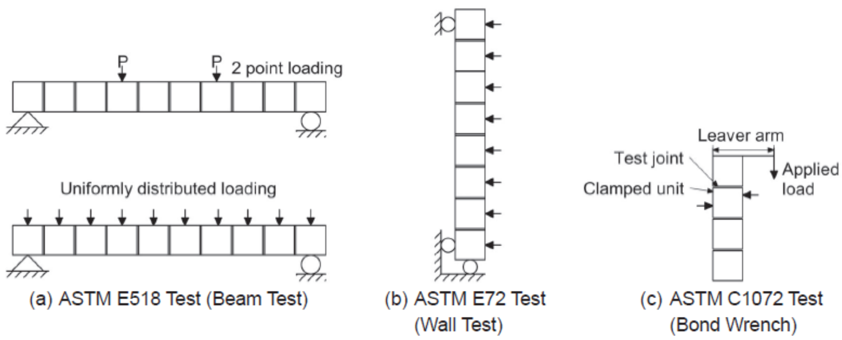


Figure 3: Different methods to obtain the flexural strength normal to bed joints [9]

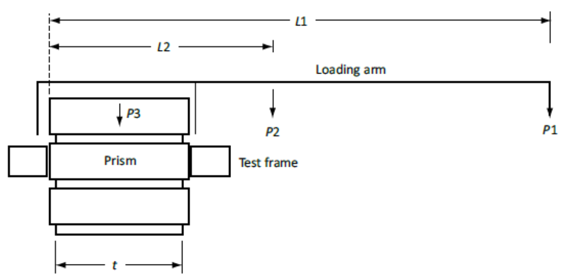
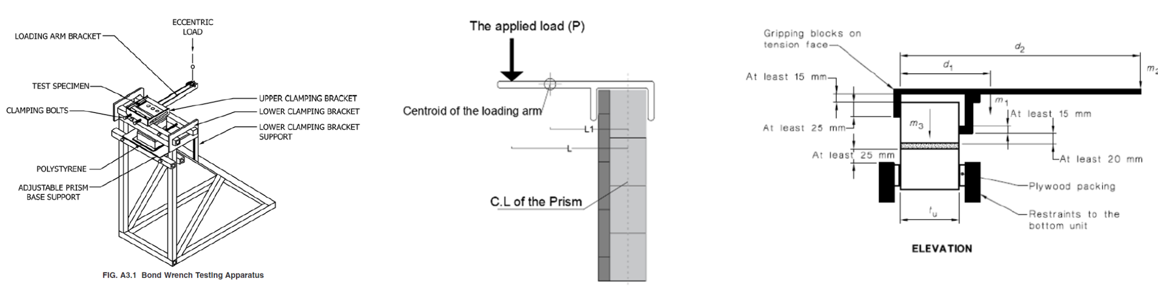


Figure 4: Schematic diagram of bond wrench apparatus according to CSA S304 (Annex E) [12]



ASTM C1072 [10] AS 3700 [11]

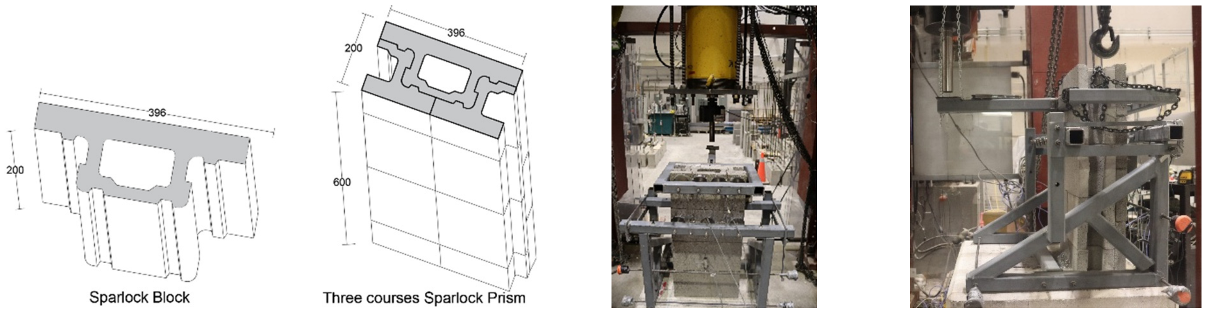
Figure 5: Clamping system and loading arm for the bond wrench

Figure 6: Experimental work conducted by McGinley and Greenwald [15]

TESTING PROGRAM

Five ungrouted and five grouted prisms were prepared for testing using a wrench apparatus, as illustrated in Figure 7. The dimensions of the Sparlock prism and the proposed bond wrench are provided in Figure 8. King Cell Filler E-20 from Sika was utilized in the grouted prisms. Additionally, five cylinders with a diameter of 100 mm and a length of 200 mm were fabricated to determine the compressive strength of the grout. Furthermore, five grouted prisms, measuring 150 mm x 150 mm x 500 mm, were prepared for the rupture test of this material. The compressive strength of the grout was measured at 29 MPa, while the rupture strength was 3.10 MPa. All tested prisms were constructed using stretcher units from the same batch. Five random units were selected to obtain geometric properties, and the average dimensions were used to calculate the flexural bond strength according to ASTM C1072-22 [10]. The load was applied monotonically at the end of the wrench arm using a steel bar connected to a hydraulic cylinder with a high-precision load cell, which has a capacity of 450 kN and an accuracy of ±0.05% of the rated output.

Figure 7: Construction of Sparlock prisms



a- Dimensions of Sparlock block and prism, all dimensions in mm

b- Elevation of the Wrench apparatus

c- Side view of the Wrench apparatus

Figure 8: The proposed Wrench apparatus used in the current study

TEST RESULTS

For the ungrouted prisms, it was found that the joints started to open at an average load equal to 80 N. As the applied load increases, the gab of the dry joint increases, reaching around 5 mm at a load of approximately 800 N. The coefficient of variation (COV) for the ungrouted joints was 6.38 %. The grouted prisms have a higher coefficient of variation equal to 30.7 %. The grouted prism joints experienced a sudden failure, starting with the dry joint opening, followed by the failure within the grout core.

Table 3 provides all specimens' load capacity and flexural bond strength. The peak stress is calculated using Eq. (1) for ungrouted prisms and Eq. (2) for grouted prisms, as specified by ASTM C1072 [10].

(1) $F_n = \frac{pL+P_1L_1}{S} - \frac{P+P_1}{A_n}$

(2) $F_g = \frac{6(pL+P_1L_1)}{bd^2} - \frac{P+P_1}{bd}$

Where F_n is the net area flexural tensile strength in MPa, S is the section modulus of the net bedded area of the prism in mm³, A_n is the net bedded area of the prism in mm², P is the maximum applied load in N, P_1 is the weight of the loading arm in N, L is the distance from the center of the prism to the loading point in mm, L_1 is the distance from the center of the prism to the centroid of the loading arm in mm, F_g is the gross area flexural tensile strength in MPa, b is the prism's width in mm, and d is the depth of the prism in mm.

Table 3: Results of the flexural bond wrench test

Prism ID		The average section modulus $S_{(mm3)} = \frac{I}{y_{tension\ side}}$	The average cross-sectional area of the prism (mm²)	Arm Length (mm)	Peak Load (N)	Peak Stress (MPa)	Average Stress (MPa)	COV (%)
Ungrouted	P_1	2172099	57474.53	600	880	0.23	0.211	6.38
	P_2			594	720	0.19		
	P_3			609	800	0.21		
	P_4			579	860	0.22		
	P_5			549	725	0.206		
Grouted	P_1	2666667	80000	520	1853	0.412	0.599	30.7
	P_2			520	1850	0.411		
	P_3			530	2680	0.61		
	P_4			500	3040	0.65		
	P_5			520	4080	0.91		

DISCUSSION AND COMPARISON

CSA S304 Comparison

The CSA S304 [12] Provides specific flexural tensile strength values for different blocks and bricks based on conventional prisms with 50% running bond courses, as shown in Table 4. The experimental results indicate that the flexural bond strength of ungrouted DSIM Sparlock blocks is lower than that of conventional concrete block prisms using mortar types N or S. However, the flexural bond strength of grouted Sparlock prisms is comparable to that of grouted conventional hollow blocks with Type S mortar and slightly higher than that of conventional prisms using Type N mortar.

Table 4: Specified flexural tensile strength or different units according to CSA S304 [12]

	Normal to bed joints (vertical span), MPa		Parallel to bed joints (horizontal span), MPa	
	Mortar type		Mortar type	
Unit type	S	N	S	N
Clay brick, solid	0.65	0.5	1.3	1
Clay brick, hollow	0.3	0.2	0.55	0.35
Concrete brick and block	0.4	0.3	0.8	0.55
Calcium silicate brick	0.3	0.25	0.55	0.45
Grouted hollow block and brick	0.65	0.5	0.85	0.55

The literature review Comparison

Figure 9 shows the average peak bond strength of conventional prisms with various mortar types from the literature, along with the Sparlock ungrouted prisms. In this study, the flexural bond strength of the ungrouted Sparlock blocks was 0.211 MPa. This value aligns with the range of bond strengths reported in the literature. McGinley and Greenwald [15] observed bond strengths ranging from 0.133 MPa to 0.336 MPa, depending on mortar type and block width, with the highest strength of 0.336 MPa achieved using Type S (Portland cement lime) mortar with 203 mm blocks. R. Thomas et al. [16] reported an even higher bond strength of 1.165 MPa for Type S mortar (COV: 33%), attributed to a saturated curing method. This curing approach involved spraying specimens with water 24 hours after construction and sealing them in bags to retain moisture, ensuring full hydration of the mortar, critical for achieving high bond strength, especially for large hollow CMUs. By contrast, Matthys [18] reported a lower average bond strength of 0.165 MPa (COV: 61.6%) for his specimens that were cured in the air, comparable to the ungrouted Sparlock prism results.

For the grouted masonry prisms, limited data are available from the literature. However, Hamid and Hakam [17] investigated the modulus of rupture of grouted concrete masonry using bond wrench tests. Their study, which utilized Type S PCL mortar, reported an average peak stress of 1.98 MPa—substantially higher than the 0.599 MPa measured for grouted Sparlock prisms in this study.

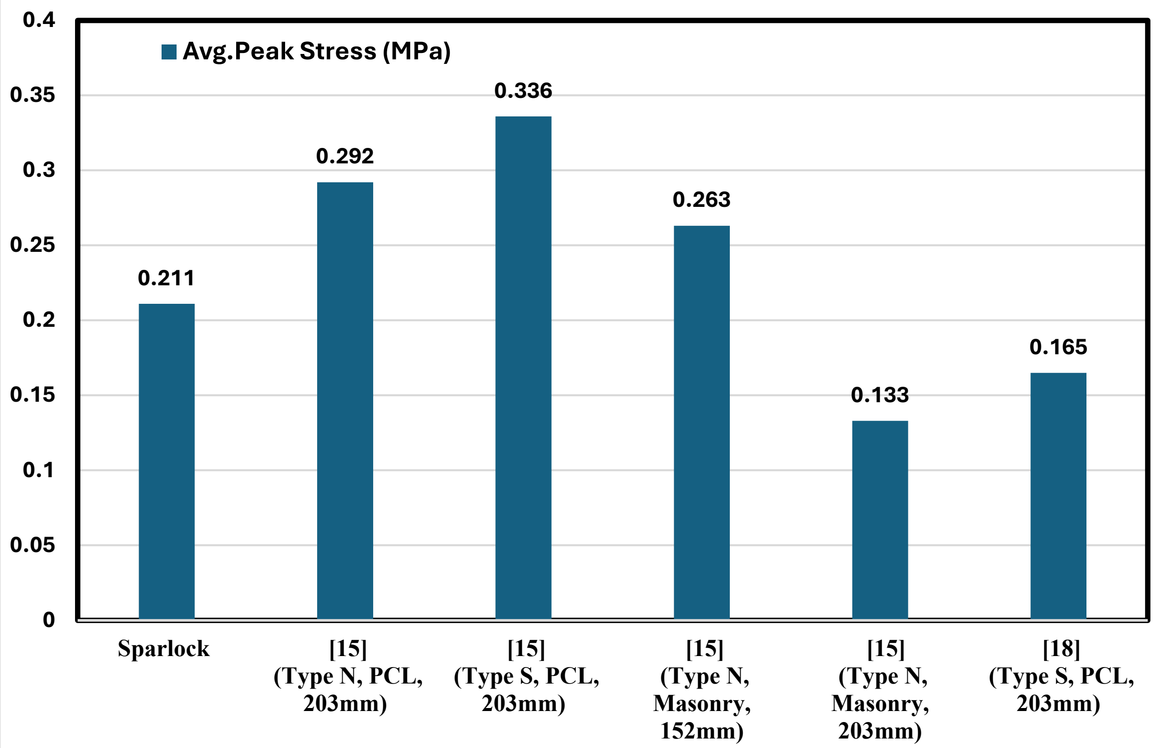


Figure 9: Comparison of flexural bond strength across the studies

CONCLUSIONS

This study examined the flexural bond strength of the DSIM system, specifically the Sparlock configuration, and compared its performance with that of conventional masonry systems. Five joints were tested for each configuration (ungrouted and grouted). The findings are summarized as follows:

1. The average peak flexural bond stress for the Sparlock ungrouted prisms was 0.211 MPa, while the grouted prisms exhibited an average flexural bond strength of 0.599 MPa.
2. The ungrouted Sparlock prisms displayed a failure mode characterized by an opening in the dry joint followed by cracking in the web of the stretcher block. In contrast, the grouted Sparlock prism experienced sudden failure, beginning with an opening in the dry joint and progressing to tension failure within the grout core.
3. The average peak bond stress of the Sparlock grouted prisms was 2.86 times higher than that of ungrouted prisms, demonstrating the significant improvement in bond strength provided by grouting.
4. The bond strength of ungrouted Sparlock prisms aligns with the lower range of values reported in the literature and falls below the CSA S304 recommendations for conventional masonry with mortar.
5. Grouted Sparlock prisms exhibited flexural bond strength comparable to conventional grouted masonry using Type S mortar but lower than the higher values reported in the literature for the grouted conventional specimens.

It is important to note that this is part of an ongoing study, and more testing is necessary to verify the obtained results.

ACKNOWLEDGEMENTS

This investigation was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), MBM Groupe, and Mitacs. All testing and research efforts were made possible through their generous support. These contributions are gratefully acknowledged.

REFERENCES

[1] Drysdale, R. G., and Guo, P. (1995). "Strength characteristics of interlocking dry-stacked concrete block masonry." Proc., 7th Canadian Masonry Symposium, Saskatoon, Canada, 160–171.

[2] Thanoon, W. A., Jaafar, M. S., Abdul Kadir, M. R., Abang Ali, A. A., Trikha, D. N., and Najm, A. M. S. (2004). "Development of an innovative interlocking load-bearing hollow block system in Malaysia." Constr. Build. Mater., 18, 445–454. https://doi.org/10.1016/j.conbuildmat.2004.03.013

[3] Al-Fakih, A., Mohammed, B., and Liew, M. S. (2018). "Behavior of the dry bed joint in the mortarless interlocking masonry system: An overview." Civ. Eng. Res. J., 4(5), 555639

[4] Beall, C. (2000). "New masonry products and materials." Prog. Struct. Eng. Mater., 2(3), 296–303. https://doi.org/10.1002/1528-2716(200007/09)2:3

[5] Uzoegbo, H. C., and Ngowi, J. V. (2003). "Structural behavior of dry-stack interlocking block walling systems subject to in-plane loading." Concr. Beton, 103, 9–13

[6] Anand, K. B., and Ramamurthy, K. (2003). "Laboratory-based productivity study on alternative masonry systems." J. Constr. Eng. Manag., 129(3), 237–242. https://doi.org/10.1061/(ASCE)0733-9364(2003)129:3(237)

[7] Edwards, J., Gayed, M. P., and TR, Department. (2010). "Design and construction of interlocking mortarless block masonry." Mason Chair Rep. No. 101, Proc., 2nd Mason Mini Symposium, 44–93

[8] https://windsorstar.com/news/azar-supplies-foundation-blocks-for-mississippi-home, accessed on January 28, 2025

[9] Drysdale, R. G., and Bennett, R. M. (2020). Masonry Structures: Behaviour and Design. 2nd Ed., Canada Masonry Design Centre, Mississauga, ON, Canada

[10] ASTM C1072-22. (2022). "Standard test methods for measurement of masonry flexural bond strength." ASTM International, West Conshohocken, PA. https://doi.org/10.1520/C1072-22

[11] Standards Australia. (2018). "AS 3700-2018: Masonry structures." Sydney, Australia

[12] Canadian Standards Association (CSA). (2024). "CSA S304: Design of masonry structures." Mississauga, ON, Canada

[13] ASTM E518-22. (2022). "Standard test methods for flexural bond strength of masonry." ASTM International, West Conshohocken, PA. https://doi.org/10.1520/E0518

[14] ASTM E72-22. (2022). "Standard test methods of conducting strength tests of panels for building construction." ASTM International, West Conshohocken, PA. https://doi.org/10.1520/E0072-22

[15] McGinley, W. M., and Greenwald, J. (2005). "Hollow unit bond wrench test trials." Proc., 10th Canadian Masonry Symposium

[16] Roberts, T., Samblanet, P., and Hogan, M. (1995). "Research evaluation of the flexural tensile strength of concrete masonry." Proc., 7th Canadian Masonry Symposium, 513–524

[17] Hamid, A. A., and Hakam, R. Z. H. (1998). "Modulus of rupture of concrete block." Proc., 8th Canadian Masonry Symposium, 29–39

[18] Matthys, J. (1990). "Concrete masonry flexural bond strength: Prisms versus wall tests." Proc., 5th North American Masonry Conference, Univ. of Illinois, Urbana-Champaign