14TH CANADIAN MASONRY SYMPOSIUM
MONTREAL, CANADA
MAY 16TH – MAY 20TH, 2021

SPLITTING AND DIRECT TENSILE TESTS COMPARISON IN HOLLOW CONCRETE BLOCKS

Álvarez, José[1]; Mesa, Milena[2] and Chávez, Jorge[3]

ABSTRACT

In this research, an experimental study is conducted on masonry units of hollow concrete blocks. The blocks were tested under direct tensile tests in two directions, *x* and *y,* orthogonal to the extrusion-direction. Splitting tests from ASTM-C-1006 were carried out, also in the *x* and *y* directions. A test procedure was implemented for testing the blocks under the direct tensile test with the aim of obtaining a reliable relationship of hollow concrete blocks in tensile stress. The tensile strength of masonry units could be a decisive parameter in masonry behavior when it is subjected to certain load conditions. One-hundred fifty blocks from the same lot were tested, taking into account compression tests, direct tensile tests, and splitting tests. Either with the splitting or direct tensile test, the tensile strength has a significant statistical difference between both directions (*x* and *y*), verifying the non-isotropy from of hollow concrete blocks. Results in the *x*-direction by applying the splitting method were significantly smaller than by the direct method, contrary to the y-direction. A statistical analysis of parametric and non-parametric hypothesis tests was used to determine the significance levels between both test procedures. In addition, a discussion about compressive and tensile strength relationships was carried out.

KEYWORDS: *direct tensile test, splitting test, hollow concrete block, masonry, tensile strength*

[1] Professor Ph.D., Structural Department, Universidad Autónoma de Nuevo León, Av. Universidad S/N, Ciudad Universitaria, San Nicolás de los Garza, Nuevo León, C.P. 66455, México, jose.alvarezpe@uanl.mx

[2] Professor Ph.D., Structural Department, Universidad Autónoma de Nuevo León, Av. Universidad S/N, Ciudad Universitaria, San Nicolás de los Garza, Nuevo León, C.P. 66455, México, mmesal@uanl.edu.mx

[3] Professor Ph.D., Head of Structural Department, Universidad Autónoma de Nuevo León, Av. Universidad S/N, Ciudad Universitaria, San Nicolás de los Garza, Nuevo León, C.P. 66455, México, jorge.chavezg@uanl.mx

INTRODUCTION

Hollow concrete blocks (HCB) masonry, is well accepted in many countries nowadays. Many authors [1-4], currently studied the units like bricks and blocks. Numerical modeling offers a viable alternative to physical-experimental modeling, where different solution techniques can be used to simulate the linear and non-linear behavior of HCB [1, 3, 5, 6]. Regardless of the implemented numerical model, their tensile strength (blocks/bricks) is usually estimated by a unifactorial correlation with their compressive strength [1, 3, 5, 6]. The tensile strength of HCB could be a decisive parameter in masonry behavior when it is subjected to axial compression (Figure 1, a) or lateral loads (Figure 1, b).

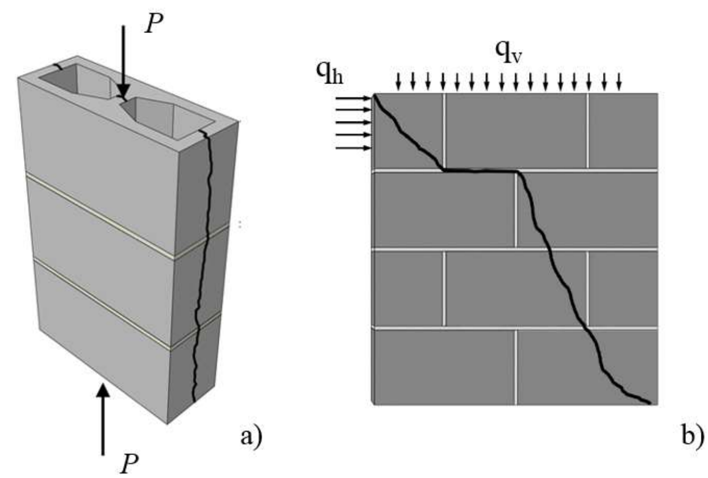


Figure 1: Typical cracking in HCB masonry by tensile stress a) prism under axial compression, b) wallette under lateral loads

Previous investigations [7-11] on the tensile strength of masonry units have focused on their experimental and theoretical aspects (constitutive models). However, the authors consider that there is insufficient research about the tensile testing (direct and indirect) of HCB.

Tensile strength of fragile materials is a difficult property to measure in direct tensile tests, therefore, indirect tensile tests have been used by researchers, such as the splitting test [10, 12], bending test (rupture modulus) [13] and recently, tests based in HCB compressive tests with force parallel to their bed joints [9] (Figure 2). Several researchers [7-9, 14, 15] have reported the results of these testing procedures (direct and indirect) and have discussed their advantages and disadvantages for the characterization of the constitutive laws for masonry units and their component materials.

First experimental studies related to direct tensile tests in masonry units were reported by McBurney [11] in the early 1900s, later, several researchers [7, 9, 10, 16] have been reported its results from direct tensile tests in bricks. In reference [8], hollow clay blocks were tested by direct tensile test, where the authors implemented a testing procedure. The results from the authors [8] highlight the dispersion of the masonry units in the structural tensile response . Despite the difficulties involved in setting up a direct tensile test of HCB units [8, 10], the test is considered the best currently available method to obtain their tensile strength of HCB [8, 17].

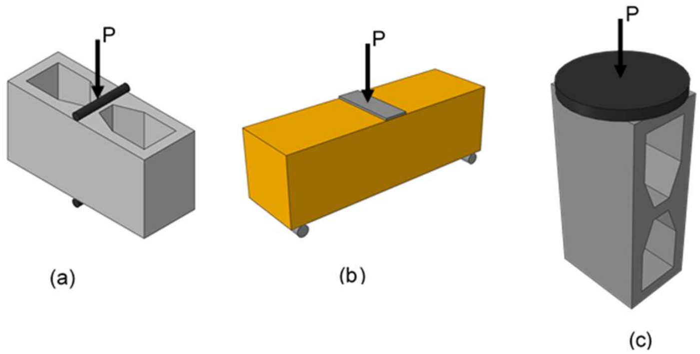


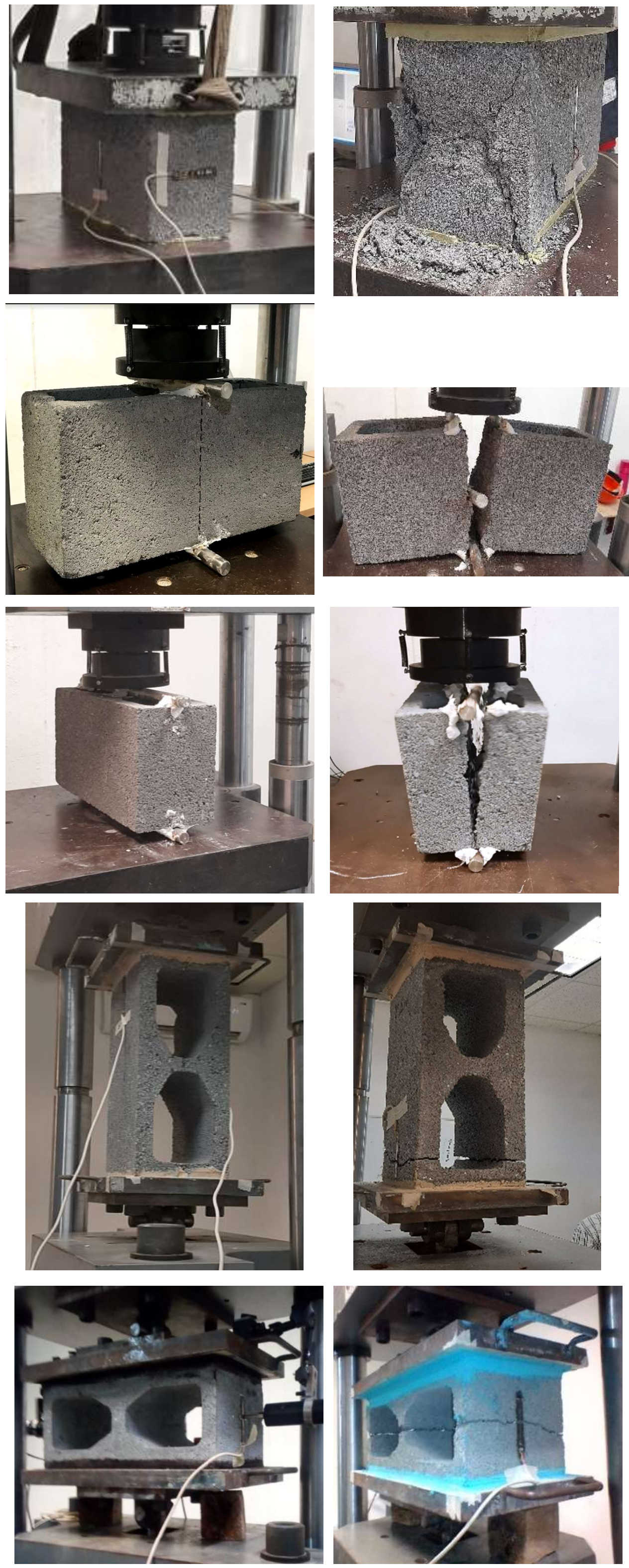
Figure 2: Indirect tensile tests of masonry units: (a) splitting test, (b) flexure test and, (c) compressive test into the parallel direction to the bed joints

In this paper, the tensile strength is evaluated in HCB, taking into account a new procedure, based on the test procedure from reference [8]. Another goal of this research is to validate the current test available from ASTM C-1006-13 for HCB and to evaluate the assumed relationship between tensile and compression strength of 10%-15%.

TEST PROCEDURE

One-hundred fifty blocks were selected from the same lot randomly (Figure 3). Five series of 30 HCB were tested: S-1 for the compressive test of HCB; S-2 for the ASTM tensile test, or splitting test, in x-direction; S-3 for the splitting test in y-direction; S-4 for the direct tensile test in the x-direction and; S-5 for the direct tensile test in the y-direction (see Figure 4). The HCB are manufactured in the State of Nuevo Leon, Mexico, with a double cell and of cement and aggregate up to a size less than 10 mm. Their nominal dimensions are: 397 mm x 197 mm x 147 mm (length x height x thickness) and have a net to gross area ratio of about 0.555. The S-1 series was tested to determine HCB compressive stress-strain curves and their maximum compressive strength according to standards [18, 19]. The S-2 and S-3 series were tested following the ASTM C-1006-13 [12]. The S-4 and S-5 series were tested with the procedure presented as follows, based on reference [8].

Figure 3: Random selection of HCB within the same block production



S-1. Compressive test

S-2. Splitting test in x-direction

S-3. Splitting test in y-direction

S-4. Direct test in x-direction

S-5. Direct test in y-direction

Figure 4: Series for testing the blocks

Direct tensile test procedure

The direct tensile tests were divided in two series S-4 and S-5. A different set of supporting steel plates (A-36 steel) were created for each direction: a pair of plates with dimensions of 460 mm x 250 mm x 25.4 mm (length x height x thickness) for S-4 and, for S-5 a pair of 230 mm x 250 mm x 25.4 mm (length x height x thickness). Both pairs of plates are hinged with the purpose of distributing the tensile force as uniformly as possible, minimizing the bending effects. Other advantages of using hinged connections can be found in [8]. The setup for a direct tensile test is composed of several steps:

- Cleaning, leveling, and preparation of the plates
- Preparation of the epoxy resin
- Placement of the resin on the bottom plate with a thickness of 6 mm
- Placement and leveling the block
- Placing the resin on the top of the block
- Placement and leveling of the upper plate

The general arrangement for the S-5 series is presented in Figure 5. The tests were carried out in a servo-hydraulic machine (Instron-600DX), by a controlled displacement of 0.0005 mm/sec (0.5 µm/sec) [7].

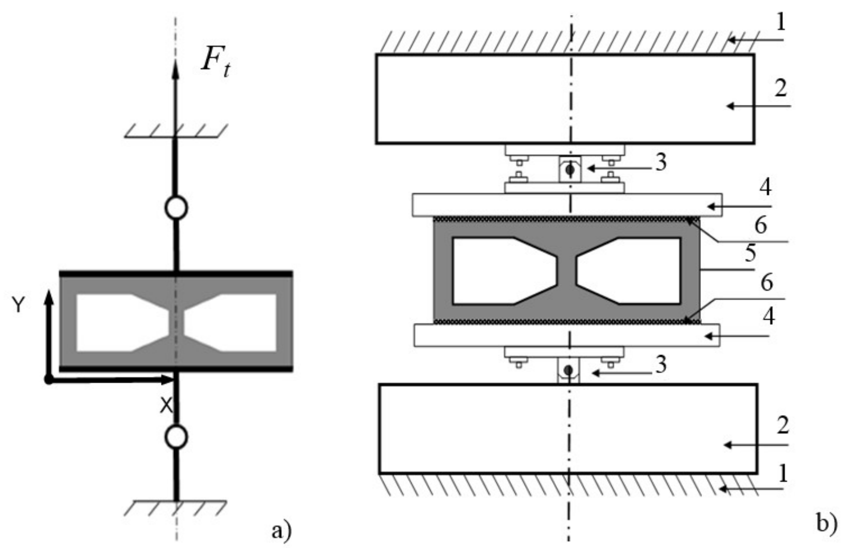


Figure 5: Test setup for S-5 series: (a) schematic arrangement, (b). Front view. Where: 1. Machine support frame, 2. Upper and lower clamps, 3. Hinged elements for transmitting the load, 4. Plates, 5. Specimen, 6. Epoxy resin

Strains gauges were used to measure the strains in these tests. The Linear Variable Differential Transformer (LVDT) transducers capture the displacement of the epoxy resin and this distorts the results, so the LVDT were not used in the tests.

RESULTS AND DISCUSSION

The experimental results from the S-1 series are shown in Figure 6. From these results, a mean compressive strength over the gross area of $f'_{C_g} = 16.02\,MPa$ was obtained. For both direct and splitting tests, the specimens had a brittle mode of failure (Figure 4). The splitting test applied to S-2 and S-3 computes the tensile strength $\left(f_{ti}\right)$ of the specimens by Equation 1[12]. The results of the mean values for S-2 and S-3 are shown in Table 1.

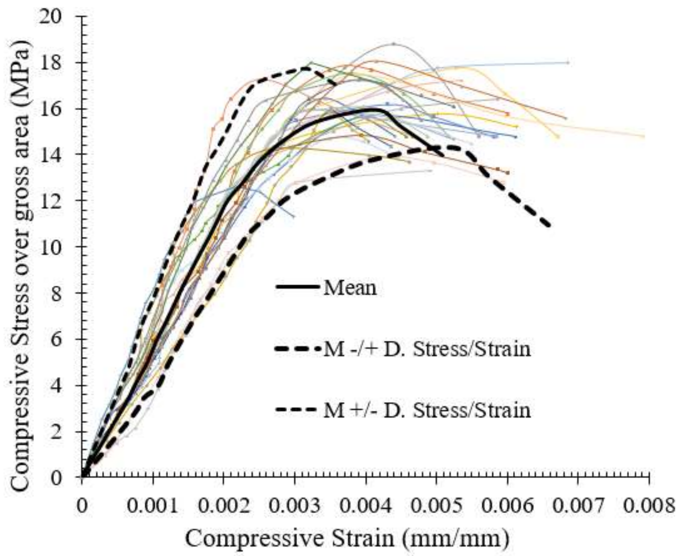


Figure 6: Experimental axial compression stress-strain relationships $\left(\sigma\, vs\, \varepsilon\right)$ of HCB

$$f_{ti} = \frac{2P}{\pi LH} \tag{1}$$

Where: f_{ti} : splitting tensile strength (MPa); P : maximum applied load indicated by the testing machine (N); L : split length, gross length minus the length of any voids along the failure plane of the bearing rods (mm); H : distance between rods (mm), the height of the HCB.

Table 1: Splitting results for S-2 and S-3 series

S-2 series				
Specimens	$H(mm)$	$P(kN)$	$L(mm)$	$ft_{S-2}(MPa)$
Mean	144.91	68.24	145.38	1.52
Deviation	0.124	12.174	0.480	0.269
COV	0.09%	17.84%	0.33%	17.66%
S-3 series				
Specimens	$H(mm)$	$P(kN)$	$L(mm)$	$ft_{S-3}(MPa)$
Mean	144.94	24.13	79.41	0.99
Deviation	0.237	4.319	6.581	0.189
COV	0.16%	17.90%	8.29%	19.07%

Results of the S-4 and S-5 series were obtained by applying the procedure described before, (section: Direct tensile test procedure). Figure 7 and 8 illustrate the stress-strain curves for S-4 and S-5 series respectively. In addition, Table 2 shows other results: direct tensile force (Ft_D); direct tensile strength over the gross area $\left(ft_{DG_i}\right)$; direct tensile strength over the net area $\left(ft_{DN_i}\right)$; direct ultimate tensile strain $\left(\varepsilon_{D,U_i}\right)$; direct tensile modulus over the gross area $\left(Et_{DG_i}\right)$ and; direct tensile modulus over the net area $\left(Et_{DN_i}\right)$.

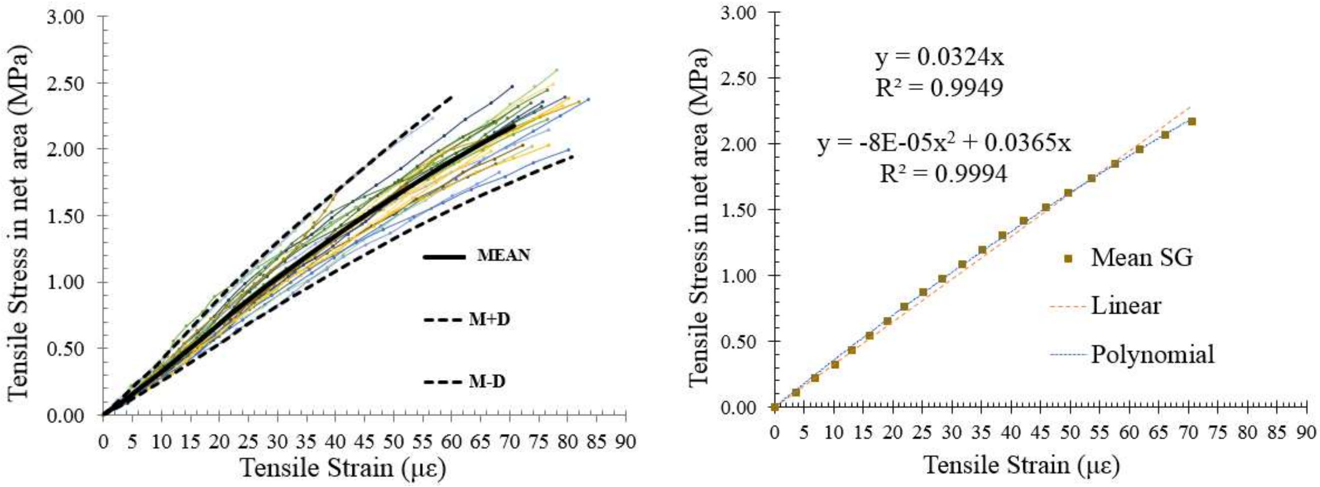


Figure 7: Stress-strain relationships from the S-4 results

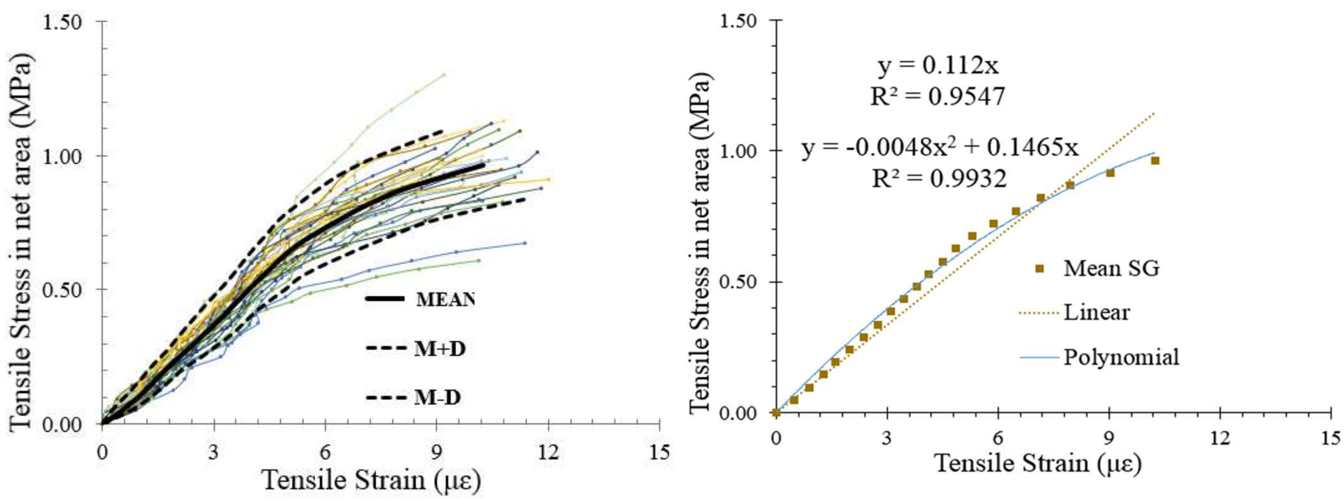


Figure 8: Stress-strain relationships from the S-5 results

Table 2: Direct tensile test results for S-4 and S-5 series

S-4 series						
Specimens	$Ft_D\left(kN\right)$	$ft_{DG_{S-4}}\left(MPa\right)$	$ft_{DN_{S-4}}\left(MPa\right)$	$\varepsilon_{D,U_{S-4}} *10^{-6}$	$Et_{DG_{S-4}}\left(MPa\right)$	$Et_{DN_{S-4}}\left(MPa\right)$
Mean	21.44	0.74	2.18	70.64	12223.33	35936.60
Deviation	2.336	0.081	0.237	10.070	1506.919	4430.342
COV	11%	11%	11%	14%	12%	12%
S-5 series						
Specimens	$Ft_D\left(kN\right)$	$ft_{DG_{S-5}}\left(MPa\right)$	$ft_{DN_{S-5}}\left(MPa\right)$	$\varepsilon_{D,U_{S-5}} *10^{-6}$	$Et_{DG_{S-5}}\left(MPa\right)$	$Et_{DN_{S-5}}\left(MPa\right)$
Mean	14.25	0.18	0.96	10.24	24650.47	130483.13
Deviation	1.907	0.024	0.129	1.089	4573.124	24207.072
COV	13%	13%	13%	11%	19%	19%

Statistical analysis

Statistical analysis was carried out, first for S-2 and S-3 series and later for S-4 and S-5. Normal distribution tests, Levene, t-Student, and Mann-Whitney U tests were implemented in SPSS software. First, the normality and Levene tests were applied to know and prove normality and homogeneity of variance. For splitting tests comparison, S-2 and S-3, the t-student test was used due to the sample passing the normality and Levene tests ($P > 0.05$) (Table 3). However, the t-student test did not pass the homogeneity of variance (Table 4), evidencing the non-isotropy in the HCB mechanical behavior.

Table 3: Levene test for S-2 and S-3

Variance hypothesis	**Test of Levene for the Equal Variance**		**Power (1-β err prob)**
	F	Sig.	
Equal variances assumed	3.645	P = 0.061	1.000
Equal variances not assumed	-	-	

Table 4: T-Student test of independent samples for S-2 and S-3

Variance hypothesis	**T-test for Equal Means**						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal variances assumed	8.728	58	P = 0.000	0.532	0.061	0.410	0.654
Equal variances not assumed	8.728	51.9	0.000	0.532	0.061	0.409	0.654

From the Levene test of S-4 and S-5, homogeneity hypotheses for the variance should be rejected ($P < 0.05$) (Table 5). The non-parametric test from Mann-Whitney U was applied to compare both samples, and displayed a statistically significant difference in both directions (x and y) ($P << 0.05$) (Table 6). This also shows the non-isotropy in the mechanical behavior of the HCB under direct tensile testing.

Table 5: Levene test for S-4 and S-5

Variance hypothesis	Test of Levene for the Equal Variance		Power (1-β err prob.)
	F	Sig.	
Equal variance assumed	17.036	P=0.000	1.000
Equal variance not assumed	-	-	

Table 6: Non-parametric test for S-4 and S-5

	Groups	N	Mean Rank	Sum of Ranks	Net Tensile Strength	
Net tensile Strength	S-4	30	45.50	1365.00	Mann-Whitney U	0.000
	S-5	30	15.50	465.00	Wilcoxon W	465.00
	Total	60	-	-	Z	-6.654
					Asymp. Sig. (2-tailed)	P=0.000

For S-2 and S-4 comparison, the t-student test can be applied, however, for S-3 and S-5, the Mann-Whitney U test was used (Table 7). The results from the hypothesis test (Table 8) showed that for the x-direction there is a significant difference (P < 0.05). However, in the y-direction the obtained difference by both procedures (S-5 and S-3) is not significant (P >> 0.05). That is, the tensile strength obtained by the S-4 ($ft_{DN_{S-4}} = 2.18$) is significantly greater than the one obtained from the splitting test, S-2 ($ft_{S-2} = 1.52$) (Table 1 and 2). An explanation for the significant difference obtained for S-2 and S-4 is that, in the splitting procedure of S-2, the load is applied over the gross area.

Table 7: Levene test for series comparison

	$\left(ft_{DN_{S-4}}\ ;\ ft_{S-2}\right)$		$\left(ft_{DN_{S-5}}\ ;ft_{S-3}\right)$	
Variance hypothesis	**Test of Levene for Equal Variances**		**Test of Levene for Equal Variances**	
	F	Sig.	F	Sig.
Equal variances assumed	0.225	0.637	6.856	0.011
Hypothesis tests used	Parametric (t-Student)		Non-parametric (Mann-Whitney U)	

Table 8: Hypothesis test used for series comparison

t-student test for S-2 and S-4 (x-direction)				**Non-parametric test for S-3 and S-5 (y-direction)**			
Variance hypothesis	t	df	Sig. (2-tailed)	**Groups**	**N**	**Net Tensile Strength**	
Equal variances assumed	9.81	58	P = 0.000	S-5	30	Mann-Whitney U	434.0
Equal variances not assumed	9.81	57.1	0.000	S-3	30	Wilcoxon W	899.0
				Total	60	Z	-0.237
				Asymp. Sig. (2-tailed)			P=0.813

Additionally, the ratio of tensile/compressive strength was calculated (Table 9), where f'_{cg} and f'_{cn} are the compressive strength over the gross and net area respectively. The t-student test was applied for the x and y directions for series S-4 and S-5, over the gross and net area, taking into account a pattern value of 10% assumed for many researchers. A ratio of 10% for tensile/compressive strength of HCB, usually used by many researchers, had a significant statistical difference (*$P = 0.000 < 0.05$*) related to the experimental quotients obtained in the present study.

Table 9. Tensile and compressive relationships of the block

Relationships	$\left(\dfrac{ft_{DN_{S-4}}}{f'_{C_n}}\right)$	$\left(\dfrac{ft_{DG_{S-4}}}{f'_{C_g}}\right)$	$\left(\dfrac{ft_{DN_{S-5}}}{f'_{C_n}}\right)$	$\left(\dfrac{ft_{DG_{S-5}}}{f'_{C_g}}\right)$
Mean	0.075	0.026	0.033	0.011
Deviation	0.008	0.003	0.005	0.002
COV	11%	11%	13%	13%
$E_{MAE} = \dfrac{\sum_{i=1}^{n}\left(\dfrac{0.10 - Q_{n(i)}}{0.10}\right)}{n_p}$	61.08%	29.94%	44.26%	69.04%
Design values $= \dfrac{Mean}{1 + 2.5COV}$	0.059	0.020	0.025	0.008

CONCLUSION

In this paper an experimental and statistical tensile strength study was carried out, and the conclusions are the following. 1) It is confirmed that the HCB have a non-isotropic character under tension. 2) The splitting method underestimates the tensile strength in the x-direction, contrary to the y-direction, because the procedure in the x-direction is over the gross area and, in the y-direction over the net area. 3) The tensile/compressive strength relationship of 10% is not applicable for the HCB masonry presented in this research. For HCB with compressive strength over the gross area (f'_{cg} = 16.02 MPa) the recommended relationship for design is 5.9% for the x-direction, while 3.3%, for the y-direction. 4) The HCB units under direct tensile stress in the x and y directions present behavior that can be analytically modeled in a linear way until a brittle failure occurs. 5) It is confirmed that the most reliable method currently available to determine the tensile strength of the hollow concrete block is the direct tensile test, despite the inconveniences that this entails.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from the School of Civil Engineering (FIC) and the Structural Engineering Department of the Universidad Autónoma de Nuevo León (UANL), as well the PAICYT- IT1350-20 project.

REFERENCES

[1] Z. Fei, Z. Qiang, W. Fenglai, and Y. Xu, "Spatial variability and sensitivity analysis on the compressive strength of holow concrete block masonry wallettes," *Construction and Building Materials,* vol. 140, pp. 129-138, 2017. http://dx.doi.org/10.1016/j.conbuildmat.2017.02.099

[2] Y. Zhao and F. Wang, "Experimental studies on behavior of fully grouted reinforced-concrete masonry shear walls," *Earthquake Engineering and Engineering Vibration,* vol. 14, pp. 743-757, 2015/12/01 2015. 10.1007/s11803-015-0030-5

[3] K. F. Abdulla, L. S. Cunningham, and M. Gillie, "Simulating masonry wall behaviour using a simplified micro-model approach," *Engineering Structures,* vol. 151, pp. 349-365, 2017/11/15/ 2017. https://doi.org/10.1016/j.engstruct.2017.08.021

[4] J. Álvarez-Pérez, J. H. Chávez-Gómez, B. T. Terán-Torres, M. Mesa-Lavista, and R. Balandrano-Vázquez, "Multifactorial behavior of the elastic modulus and compressive strength in masonry prisms of hollow concrete blocks," *Construction and Building Materials,* vol. 241, p. 18, 2020/04/30/ 2020. https://doi.org/10.1016/j.conbuildmat.2020.118002

[5] A. Drougkas, P. Roca, and C. Molins, "Numerical prediction of the behavior, strength and elasticity of masonry in compression," *Engineering Structures,* vol. 90, pp. 15-28, 2015/05/01/ 2015. https://doi.org/10.1016/j.engstruct.2015.02.011

[6] E. Moradabadi, D. F. Laefer, J. A. Clarke, and P. B. Lourenço, "A semi-random field finite element method to predict the maximum eccentric compressive load for masonry prisms," *Construction and Building Materials,* vol. 77, pp. 489-500, 2015/02/15/ 2015. https://doi.org/10.1016/j.conbuildmat.2014.12.027

[7] J. C. Almeida, P. B. Lourenço, and J. A. O. Barros, "Experimental investigation of bricks under uniaxial tensile testing," *Masonry International,* vol. 18, pp. 11-20, 2005.

[8] N. Mojsilović, "Tensile strength of clay blocks: An experimental study," *Construction and Building Materials,* vol. 25, pp. 4156-4164, 2011/11/01/ 2011. https://doi.org/10.1016/j.conbuildmat.2011.04.052

[9] V. G. Haach, G. Vasconcelos, and P. B. Lourenço, "DEVELOPMENT OF A NEW TEST FOR DETERMINATION OF TENSILE STRENGTH OF CONCRETE BLOCKS," presented at the 12th Canadian Masonry Symposium, Vancouver, British Columbia, June 2-5, 2013.

[10] K. Thomas and D. O. O'Leary, "Tensile strength tests on two types of brick " in *Proceedings of the Second International Brick Masonry* Conference held in Stoke-on-Trent, England, 1970.

[11] J. W. McBurney, "STRENGTH OF BRICK IN TENSION," *Journal of the American Ceramic Society,* vol. 11, pp. 114-117, 1928/02/01 1928. 10.1111/j.1151-2916.1928.tb16864.x

[12] ASTM-C-1006, "Standard Test Method for Splitting Tensile Strength of Masonry Units," ed, 2013, p. 3.

[13] ASTM-C67, "Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile," p. 17, 2017.

[14] P. Schubert, "Tensile and flexural strength of masonry - influences, test methods, test results," presented at the Proceedings of the 10th International brick/block masonry conference, Calgary, Canada, 1994.

[15] A. A. Hamid and R. G. Drysdale, "Flexural Tensile Strength of Concrete Block Masonry," *Journal of Structural Engineering,* vol. 114, pp. 50-66, 1988. doi:10.1061/(ASCE)0733-9445(1988)114:1(50)

[16] S. Rosenhaupt, A. C. Van Riel, and Wyler, "A new indirect Tensile test for Concrete Theoretical Analysis and Preliminary Experiments," *Bulletin of Research Council of Israel,* vol. 6C, p. 13, 1957.

[17] R. L. Mayes and R. W. Clough, "A literature survey – compressive, tensile, bond and shear strength of masonry," University of California, Berkeley1975.

[18] NMX-ONNCCE-C-036, "RESISTENCIA A LA COMPRESIÓN DE BLOQUES, TABIQUES O LADRILLOS Y TABICONES Y ADOQUINES– MÉTODO DE ENSAYO," ed, 2013, p. 10.

[19] ASTM-C-140, "Standard test methods for sampling and testing concrete masonry units and related units," ed, 2018, p. 17.