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Small Element Paving Technologists (SEPT)

IMPLEMENTATION OF THE FLEXURAL STRENGTH TEST FOR CONCRETE PAVERS

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Note: The following is the notation that is uses in this paper: (.) for decimals and ( ) for thousands.

Summary

This work presents the evolution of the IRAM 11656 Standard regarding the evaluation of the mechanical strength. In 2006 appeared the need for the revision of this standard, changed for the first time in 1998 in the testing method and requirement, passing from the determination of the axial compressive strength over samples extracted from the pavers to the testing of the complete unit between pressure plates whose size depends on its thickness.

Within the framework of this review, the Argentinean Portland Cement Institute (ICPA) proposed to study the Colombian Standard NTC 2017 in order to replace the test for the compressive strength to one for the flexural strength, considering it is more representative of the role played by pavers in the pavement. To assess the feasibility of the method, INTI CONSTRUCCIONES replied the testing device and proceeded to his calibration.

Some variables of the test were studied, like the suitability of the bending device introduced by the NTC 2017 Standard, the use of rubber bands between the supports and the pavers, the influence of the drying prior to the mechanical testing, and the correlations between compression, absorption, density and flexion.

An inter-laboratory comparison was coordinated to validate the results with another laboratory interested in the development of the test. The analysis of the obtained values corroborated the validity of the methodology and the requirement, and produced a database of repeatability and reproducibility of the test method.

The carried-out laboratory study allowed to progress in the correction process of the Standard. After its approval, it will be applied for the Voluntary Certification Program of this product, taking a further step into the quality warranty for the construction materials.

1. INTRODUCTION

The Argentinean paver standard has been modified from its creation trying to adapt the test to the prevailing forces for the use of the units and to make the testing procedure easier, in aspects like the preparation for the loading faces, the repeatability and reproducibility, better working condition, etc.

In 2006 the ICPA and the Argentinean Concrete Block Association (AABH) presented the proposal for a new approach of the Standard, changing the way of assessing the mechanical strength. Considering that the concrete block pavements have a flexible behavior, the flexural strength test would be the main solicitation of each unit. Table 1 compares the existing requirements and those raised by the new project.

Table 1. Compared requirements.

	REQUIREMENTS			
TYPE TESTING	**IRAM 11656: 1998 STANDARD**		**PROJECT IRAM 11656 STANDARD**	
	Average	**Individual value**	**Average**	**Individual value**
Absorption	≤ 5 %	≤ 7 %	≤ 5 %	≤ 7 %
Compression (Rc)				
Pavers Type I	>45 MPa	>40 MPa	---	---
Pavers Type II	>35 MPa	>30 MPa	---	---
Flexion (Mr)	---	---	≤ 4.2 MPa	≤ 3.8 MPa

The National Institute of Industrial Technology (INTI), through its Constructions Center, as an active agency in the standardization and implementation of the Pavers Certification Program, participated in the study on the feasibility of this change and analyzed the main factors influencing the test.

Based on foreign standards, mainly the NTC 2017, the test was developed to take into account the opportunities to improve it and to adapt it to the Argentina reality. Based on the previous premises, tests were conducted on all existing shapes of pavers in the market, as well as an inter-laboratory test and the correlation of variables as absorption, density and bending.

2. EXPERIMENTAL WORK PLAN

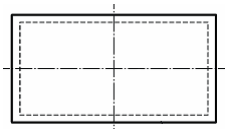
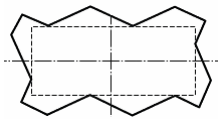
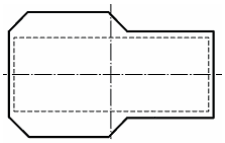
The NTC 2017 flexion test is made with a simple device: two (2) support bars and one bar for the application of the loads. The operator must ensure the parallelism between the three elements. One of them has a pivot allowing to be placed it in the same plane as the fixed one and avoiding the introduction of torsion stresses, not foreseen in the determination of the Modulus of rupture.

The procedure requires a series of previous measurements to obtain the dimensions of the pavers and to determine the geometric characteristics to be used in the calculations of the Modulus of rupture, according to the formulas in Table 2. Figure 1 shows a series of Uni-Stone pavers, with the inscribed rectangle already drawn, according with the procedure included in the Standard.

Specimens must be tested once saturated, in order to standardize the conditions of the test and to establish a level for equivalent comparison. However, a complete saturation is not always reached since it depends of the porosity of the element. It can be seen in Figures 2 and 3.

The first stage consisted of replicating the testing device, according to the one in the NTC 2017, conducting comparative flexion test with 40 mm x 40 mm x 160 mortar bars. It is done according with the project for the IRAM 11656 standard and the IRAM 1622: 2006 standard, whose methodology is accepted unanimously at international level, carrying out the analysis of the results associated with the effectiveness of both loading patterns.

Table 2. Module of rupture for different forms of pavers.

PAVER TYPE	PAVER SHAPE	Mr CALCULATION FORMULAS
Dutch		$M_r = \frac{3 \cdot C_{max} \cdot L_e}{2a_r \cdot e_r^2}$
Uni-stone		$M_r = \frac{3 \cdot C_{max} \cdot L_e}{(a_r + a_i) \cdot e_r^2}$ **Under revision**
Uni-decor		$M_r = \frac{3 \cdot C_{max} \cdot L_e}{2a_{rs} \cdot e_r^2}$ **Rupture by the greater width**
		$M_r = \frac{6 \cdot C_{max} \left(\frac{L_e}{4} - \frac{x}{2} \right)}{a_{ri} \cdot e_r^2}$ **Rupture by the lesser width**

M_r	Modulus of rupture under flexion (MPa)	a_i	Width of the inscribed rectangle (mm)
C_{max}	Maximum rupture load (N)	a_{rs}	Larger real width of the specimen (mm)
L_e	Testing span (mm)	a_n	Smaller width of the specimen (mm)
A_r	Real width of the specimen (mm)	e_r	Real thickness of the specimen (mm)



Figure 1. Pavers with the inscribed rectangle marked for bending test.



Figure 2. Incomplete saturation after 24 h of immersion in water.



Figure 3. Complete saturation after 24 hours of immersion in water.

The next step consisted of tests overt the currently produced pavers. The results were correlated with the compression test according with the IRAM 11656 standard. Several producers sent a set of pavers taken from the same lot to ensure homogeneity of the samples. In Argentina the most common pavers are Uni-Decor and Uni-Stone (rectangular angular) and Holland (rectangular straight), this last being single or double layered.

The next step was the evaluation of the validity of the theory of bars, used for calculation of Module of rupture. For this purpose, many pavers were tested with different span/thickness relations.

The NTC 2017 allows performing the mechanical tests on the same specimens that underwent the density and absorption test, after being exposed to 100°C to 115°C drying temperatures. The hypothesis of the possible creation of micro-cracks in concrete was formulated as a possible source of modification of the flexural tests and its respective dispersion. For this purpose, tests were made on dried and saturated paves and over saturated only samples.

The correlation between the physical parameters such as water absorption and density with flexural strength, were analyzed for information on the general situation of the precast units, with respect to the requirements formulated by the project for the IRAM 11656 standard.

The benefit of placing neoprene strips between the supports and the paves was studied through comparative tests of similar units with and without the strips.

The experimental plan included inter-laboratory tests with the Structures Department of the National University of Córdoba (NUC), where the device was also developed to compare the results.

3. RESULTS

3.1 Evaluation of the testing device

To assess the suitability of the new bending test, comparative tests were run with the equipments in IRAM 1622: 2006 standard, based on the EN 196-1 standard, and the project for IRAM 11656 standard. They appear in Figures 4 and 5. Table 3 details their similarities and differences.

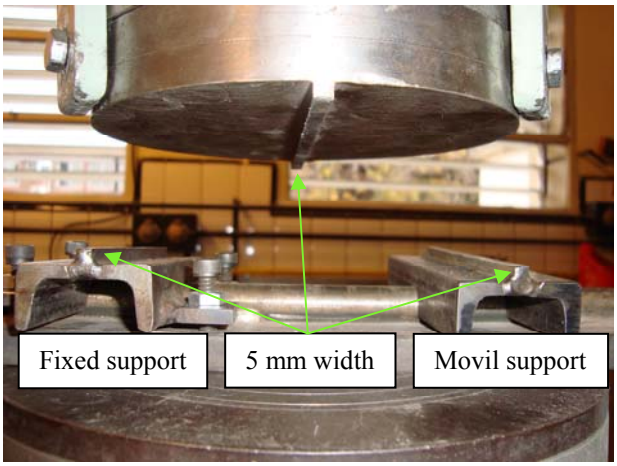


Figure 4. Adopted flexion device by INTI CONSTRUCCIONES according to project IRAM 11656 standard.

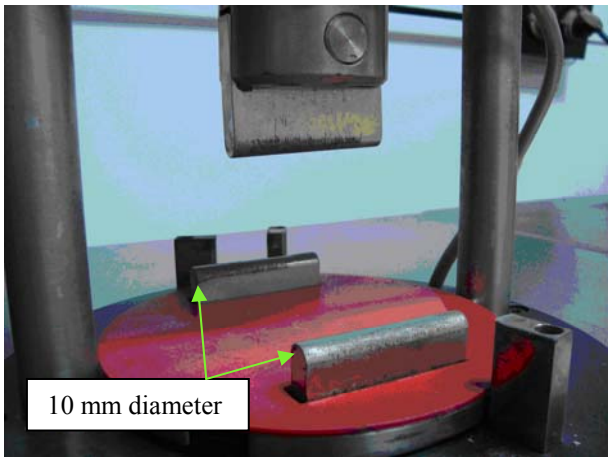


Figure 5. Flexion device according IRAM 1622: 2006 standard.

Table 3. Summary of key features of the load two arrangements.

	DEVICE STANDARD IRAM PROJECT 11656	DEVICE STANDARD IRAM 1622: 2006
Supports and load application element	Cylindrical Diameter: 12 ± 0.5 mm Prismatics Sides: 5 ± 0,0394 in	Cylindrical Dameter: 10.0 ± 0.5 mm Length: 45 to 50 mm
Types of support	1 Mobil in the vertical plane 1 Fixed	2 Fixed
Light between support	Adjustable	Fixed: 100 mm
Load speed control	Manual	Constant equal to 50 kN/s

For the test the samples were prismatic mortar samples, 40 mm x 40 mm x 160 mm, molded according to the IRAM 1622: 2006 standard. Two (2) sets of three (3) specimens were tested with their own testing equipments. The average results and the standard deviation were determined for the Modulus of rupture. Figures 6 and 7 show the tests described with a span/thickness relationship was 2.5.

The tests were performed after 28 d and each of the two resulting halves after the flexural test was tested under compression as indicated in IRAM 1622: 2006 standard, ensuring the uniformity of samples and the validity of the trial.

Although the absolute values of the Flexural strength are not comparable because the load application rate, the support and load-application devises are different, the testing method is the same, since both test a simply supported bar.



Figure 6. Flexural test of mortar samples according to the proposed IRAM 11656 Standard.

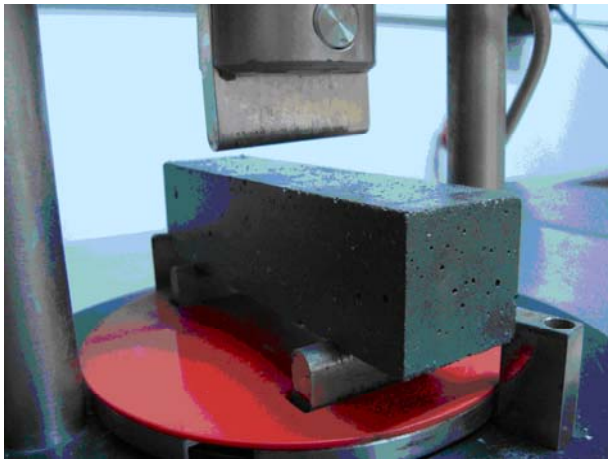


Figure 7. Flexural test of samples according to IRAM 1622: 2006 Standard.

Table 4 shows the values for the Modulus of rupture obtained in each case, and the respective values for compression strength. The standard deviation obtained with both methodologies on homogeneous samples are equivalent, therefore, it can be concluded that the new devise do not introduce any abnormalities to the outcome of the test.

Table 4. Results of flexural and compression strengths with each device.

DEVICE	MOULD NUMBER	FLEXION (MPa)		COMPRESSION (MPa)	
		AVERAGE	STANDARD DEV.	AVERAGE	STANDARD DEV.
IRAM 1622 standard	1	8.0	0.6	45.0	0.7
	2	7.8	0.5	45.5	1.4
Project IRAM 11656 standard	3	6.6	0.6	45.8	0.6
	4	7.2	0.1	44.3	1.3

After of the reception in the Concrete Technology Laboratory of the Constructions Center INTI, the samples were separated in lots of 10 units. Five (5) were tested under compression and five (5) under flexion, to compare the average strength, forming 10 sets. The characteristics of the pavers and the obtained results are seen Table 5. It can be noticed a great variability introduced by the compression tests in the results, attributable to the preparation of the bases with thermoplastic sulfur and graphite, and the application of loads by pressure plates.

Figure 8 shows a growing trend line between the values of compression strength and Modulus of rupture under flexion.

Table 5. Compression and flexural tests on pavers.

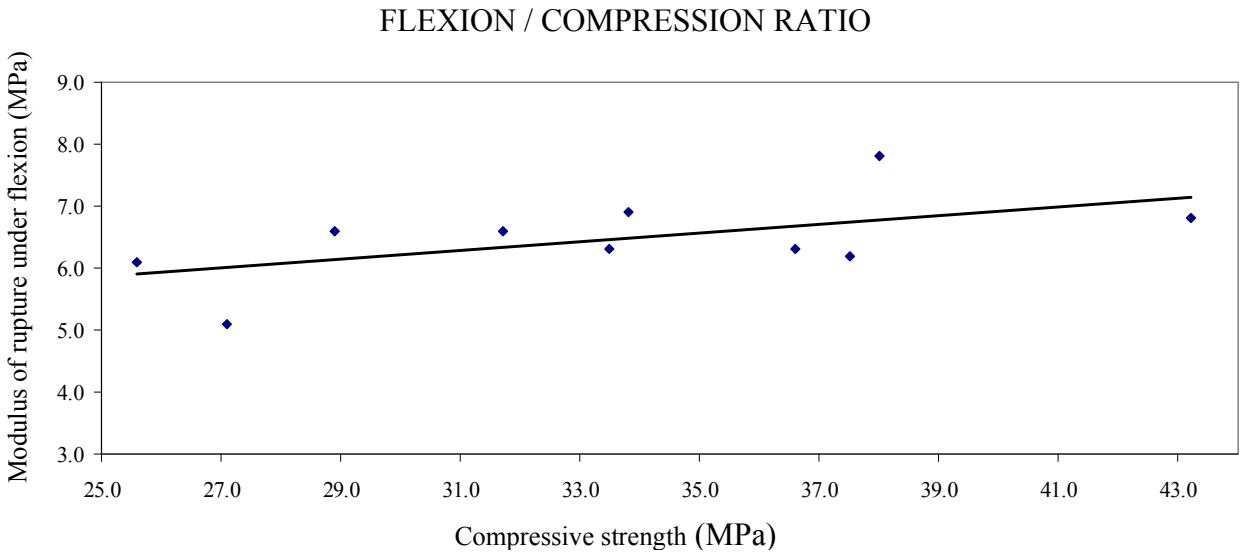
SAMPLE	TYPE	THICKNESS (mm)	STRENGTH			
			Compression (MPa)	Standard Dev. (MPa)	Flexural (MPa)	Standard Dev. (MPa)
1	**Uni-Stone**	**60**	25.6	7.6	6.1	2.1
2	**Uni-Stone**	**60**	27.1	5.2	5.1	0.9
3	**Uni-Stone**	**80**	28.9	4.0	6.6	0.7
4	**Uni-Stone**	**80**	31.7	11.8	6.6	0.5
5	**Uni-Stone**	**80**	33.5	10.3	6.3	0.8
6	**Uni-Stone**	**80**	33.8	3.1	6.9	0.7
7	**Uni-Stone**	**60**	36.6	3.2	6.3	0.3
8	**Holland 2 layer**	**60**	37.5	4.6	6.2	1.0
9	**Uni-Stone**	**80**	38.0	12.7	7.8	0.7
10	**Holland**	**80**	43.2	6.8	6.8	0.9

The observation after the tests were: The standard deviation is smaller for the flexural tests and the rectangular angular paves or "Uni-Stone", presented different breakage planes, although some broke in a plane perfectly perpendicular to the greater largest axis of the paver (figures 9 and 10), several of them presented a twisted breakage surface in relation to the same axis. In contrast, in reatngular straight or “Holland” pavers and “Uni-Décor”, presented the rupture a plane perpendicular to the axis of the paver. In spite of this difference in the type of breakage plane, the dispersion values were similar.

3.2 Verification of the application of Theory of Bars in the calculation of the module to rupture at bending

For the calculation of Modulus of rupture of the pavers applies the theory of bars. One of its assumptions defines bar as one element in which one of its dimensions is superior to other two, by setting a minimum ratio of 3 to 1.

Figure 8. Modulus of rupture vs. compressive strength.



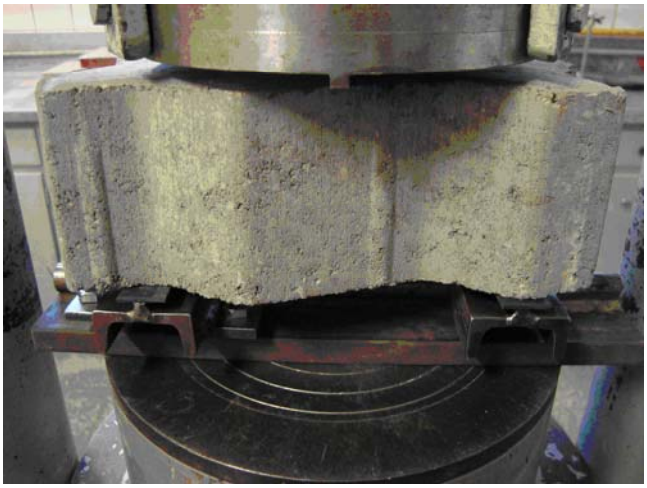


Figure 9. A "Uni-Stone" paver bending test.



Figure 10. Rupture of a Uni-Stone paver under flexion.

To view the influence of the testing span, 10 samples of straight rectangular pavers 60 mm thick were selected. Five (5) were tested with an approximate span of 120 mm (ratio 2 to 1), while the remaining were tested with a span of 180 mm (3 to 1 ratio) resulting in an average Modulus of rupture of 6.1 MPa and 6.3 MPa respectively. Although the relationship between the test span and the thickness/width does not meet the Bars Theory to model the test, it can be concluded that that, in relative terms, it does not significantly influence in the determination Modulus of rupture.

3.3 Influence of the drying prior to the flexion test

To study the possible influence of the drying process of the pavers exposed to more than 100°C temperature, prepared two (2) sets 10 pavers each, where only five (5) of each set were exposed at temperatures between 105°C and 115°C. Then all pavers were saturated and tested. The results are included in the Tabla.6. This experience emerged that there are no significant differences between both methodologies.

Table 6. Comparison between pavers dried and not dried before of the bending test.

PAVER TYPE	THICKNESS (mm)	Exposed to laboratory environment		Exposed to more than 100°C	
		AVERAGE	STANDARD DEV.	AVERAGE	STANDARD DEV.
Uni-Decor	60	7.5	0.6	8.7	0.8
Uni-Stone	80	5.9	0.4	6.3	0.9

Since IRAM standards have historically adopted that both tests are made on different samples, it was proposed to the IRAM Subcommittee to maintain this criterion regardless of the influence of drying on the results.

3.4 Correlation between water absorption, density and Modulus of rupture

The relationship between the Modulus of rupture and some physical parameters like water absorption and density was analyzed. As indicated in NTC 2017, the density and the absorption were determined before the flexural text.

To get those values, the pavers are placed first in an oven with forced ventilation at a temperature between 105°C and 115°C until it register a constant mass, in order to get the dry weight. Then the sample is submerged in water until the difference between two consecutive weights, separated by 24 h, is less than 0.2 %, in order to get the saturated weight. With the saturated paver, the suspended weight is determined.

The absorption and the density were calculated according to the following formulae:

$$Absorption\ (Aa),\ (\%) = [(Mh - Ms) / Ms] \times 100 \qquad (1)$$

The density (D) of the dry specimen must calculate as follows:

$$Density\ (D),\ (kg/m^3) = [Ms / (Mh - Ma)] \times 1\ 000 \qquad (2)$$

Where:

Mh: Saturated mass (wet) of the specimen, (g).

Ms: Dry mass of specimen, (g).

Ma: Mass of the specimen immersed in water and suspended, (g).

Once obtained these two physical parameters, the flexural text was made. Figures 11 and 12 show the lines showing the adjustment of the absorption/flexural strength and the density/flexural strength relationships. It should be noted that the values in the Figures are individual values.

Table 7. Tests carried out with and without neoprene strips in the supports.

	MODULUS OF RUPTURE UNDER FLEXION	
SUPPORT	**WITHOUT NEOPRENE**	**WITH NEOPRENE**
Average (MPa)	7.0	6.4

Standard Deviation. (MPa)	0.8	0.4
Standard Deviation (%)	11.4	6.3
Amount of specimens	8	5
Paver type	Uni-Stone, 80 mm	Uni-Stone, 80 mm
Breakage type	Predominantly warped	Predominantly flat

Figure 11. Correlation Modulus of rupture and water absorption.

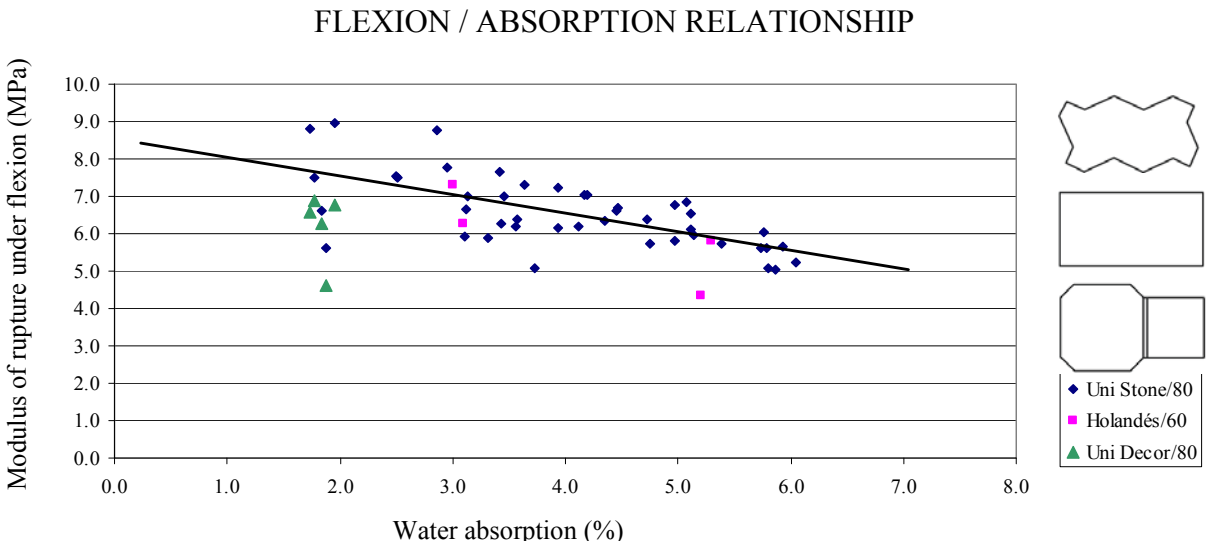
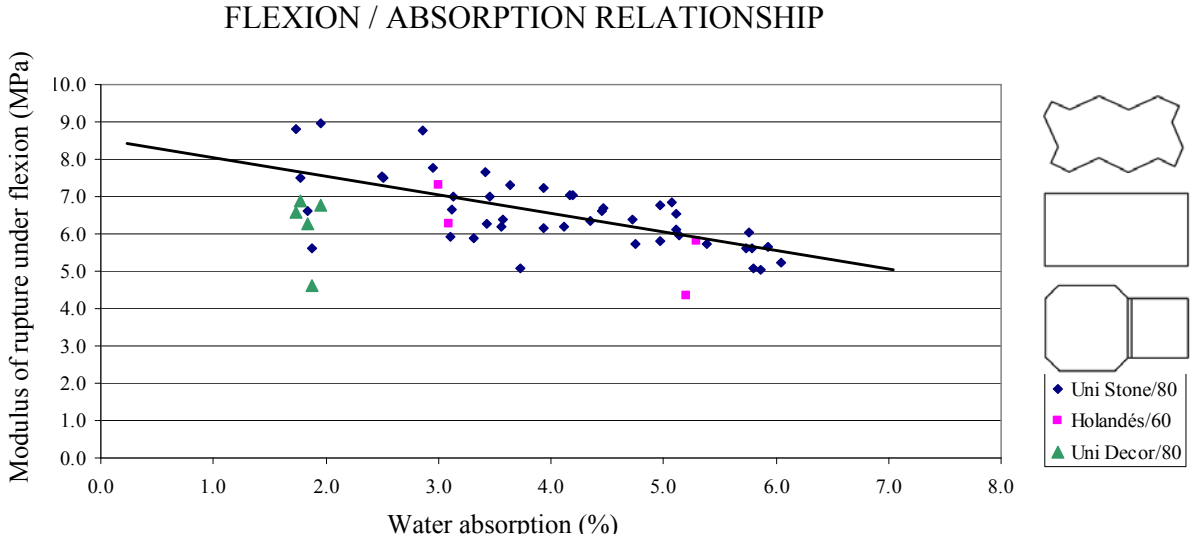


Figure 12. Correlation Modulus of rupture and density.



3.5 Use of neoprene strips between the supports and the specimen

In order to establish the utility of using 2 mm thick neoprene bands between the supports and the specimen, tests were carried out with and without the strips. Table 7 shows that the standard

deviation in percentage increases by not using bands. In addition, the rupture surfaces are predominantly warped, introducing a greater uncertainty in the result.

3.6 Inter-laboratory tests

To assess the reproducibility of the test, pavers were tested in the laboratories of INTI CONSTRUCCIONES and the National University of Córdoba. The last laboratory developed the testing devise in a parallel way during the study of the standard. It meant to count in the country with another qualified laboratory to apply the method. This provision of an equal amount of pavers for each laboratory was requested from several companies, with the proposal of testing them in close dates. The results reported in Table 8 showed a good reproducibility, taking into account that it was the moment of the implementation to point of the method. This type of comparison must be repeated periodically to assess the relative positioning of laboratories and guarantee the comparability of results.

Table 8. Comparisons between laboratories.

	INTI LABORATORY		UNC LABORATORY	
PAVER TYPE	**M_R (MPa)**	**STANDARD DEVIATION (MPa)**	**M_R (MPa)**	**STANDARD DEVIATION (MPa)**
Uni-stone, 80 mm	5.2	1.1	5.0	0.7
Uni-stone, 80 mm	7.5	1.4	7.8	1.5
Uni-decor, 60 mm	6.2	0.9	5.5	0.7
Amount of samples	10		10	

4. FINDINGS

The following observations come from the analysis of the results obtained for each evaluation.

- The proposed testing devise for the modification of IRAM 11656 standard does not introduce abnormalities to the flexural test. It presented acceptable results for the standard deviation, compared with the ones of a testing devise with a proven behavior.
- While the model applied for the calculation of the Modulus of rupture, according to the theory of bars, is not valid for the relations between the test span and the thickness of pavers, it showed no significant influence in the results.
- Even though the drying at temperatures between 105°C and 115°C, necessary to determine the absorption of water and the density, are reached prior to the flexural test, it does not significantly affects the results of the Modulus of rupture. It is proposed to use different specimens for the implementation of both tests, according with the criterion adopted in the IRAM 11561 standard for concrete blocks
- The compression test introduces greater uncertainty duet to the need for the treatment of the bases for the application of the loads with the pressure plates. Likewise, it means more complications to set-up a self-control in the plant laboratory, due to the toxicity of the required composite of sulfur and the special working conditions required.
- According to the flexion and compression values obtained in the INTI CONSTRUCCIONES laboratory, the requirement for the flexural Modulus of rupture adopted in the project for the IRAM 11656 standard would seem appropriate although the standard deviation of this test is lower than the one obtained under compression.
- For the proposal for the standard, it is possible to get reference values from the correlations obtained for absorption/flexure and density/flexure obtained.

- The use of 2 mm thick neoprene bands between the pavers and the support appears to decrease the variability of the tests.
- The broken surface for the Holland and Uni-Decor pavers is flat and perpendicular to the axis of the paver, while in the Uni-Stone pavers it is perpendicular or diagonal.
- Comparative tests between the two participating laboratories in the studies are consistent.
- The results and observations of this work let to conclude that for the usual requirements, the new test model would be appropriate to assess the quality of the pavers.

5. REFERENCES

ARGENTINEAN CONCRETE BLOCK ASSOCIATION (AABH) - NATIONAL INSTITUTE OF INDUSTRIAL TECHNOLOGY (INTI) - ARGENTINEAN PORTLAND CEMENT INSTITUTE (ICPA). (2005). Certification program. Certification of Concrete Blocks and Pavers. Technical Regulation.

ICONTEC. (2004). Colombian National Standard (NTC) 2017:2004 Concrete Pavers for Pavements.

IRAM (1995). IRAM Standard 11656: 1995 Concrete pavers for block pavements. Requirements and test methods.

IRAM (1998). IRAM Standard 11656: 1998 Concrete pavers for block pavements. Requirements and test methods.

IRAM (2009). IRAM Standard 11656 Project under discussion. Scheme A6. Concrete pavers for block pavements. Requirements and test methods.

TIMOSHENKO, S. (1957). Resistencia de materiales" Primera parte. Teoría elemental y problemas. ESPASA-CALPE S. A, MADRID.

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