Elastic Constants of Grout by Ultrasound

Gisleiva C. S. Ferreira, Luis Guilherme A. Favarin, and Gabriella Macedo

***Abstract*—The deformation of grout is a very important property because of demands that this material is subjected when applied to façades. To set such parameter, compression tests are needed to determine the elasticity modulus or the ultrasound technique might be applied, which is a non-destructive test that allows the determination of the flexibility material matrix and therefore the elastic constants such as longitudinal elasticity modulus (*E*), transversal elasticity modulus (*G*) and Poisson's ratio (*ν*). The aim of this study was to obtain the grout elastic constants with ultrasound tests. For this purpose, we selected three colors and two manufacturers for grout, totaling six samples. The results indicated that the elastic constants determined with ultrasound are equivalent to values obtained for destructive tests.**

***Index Terms*—Elasticity modulus, nondestructive test.**

I. Introduction

The most important aspect for the performance of grout, bearing efforts from the movement of ceramic tiles and base, is to provid a strength relief on the ceramic coating during the building's lifetime. In this case, the stiffness and resilience of grout are important factors. Other aspects, like flexibility and adhesion are closely related, since the appearance of cracks by adhesion loss leaves a clear path for the penetration of water and other harmful agents, not only to the grout, but also to the ceramic coating [1].

The Brazilian standard (regulation) NBR 14992 (2003) [2] defines the grout's properties through six tests (determination of water retention, determination of dimensional variation, determination of the compression strength, determination of tensile strength in bending, determination of water absorption by capillarity and determination of permeability), but that standard does not cite any tests to determine elastic properties of this material. Other standards also do not include this type of test because the destructive tests required obtaining the elastic properties (elasticity modulus and Poisson's ratio) are complex and expensive. Therefore, these values are adopted as standards and researches made [3]-[5].

There are specific standards for determining the dynamic elasticity modulus in laying and coating mortar [6], [7], however, these standards adopt a value for Poisson's ratio (0.2), the same as the concrete which cannot be generalized because specific properties for each types of mortar.

For determining the elastic constant by means of ultrasound it is necessary to perform measurements of propagation time on longitudinal and transversal waves. In the case of direct measurements (compression waves), the wave path is the distance between the transducers. Having the distance and propagation time, the speed of wave propagation is determined. The frequency of the transducers is adopted based on the analyzed sample size as well as the anatomical structure of the material. Gonçalves *et al.* [8] determined by means of ultrasound test the longitudinal and transversal elasticity modulus and the Poisson's ratio for a 35-MPa-strength-compressive concrete. The frequency of longitudinal and transversal transducers used by these authors was 100 kHz.

The generalized Hooke's law [9] allows the correlation of materialstrength (*F*), deformation (ΔL) and *K* (coefficient) by means of stiffness matrix components (Equation 1).

$$F = k \times \Delta L \tag{1}$$

Non-destructive methods using wave propagation can be used for obtaining the stiffness matrix [*C*] in which the number of independent components is associated with the complexity of the material to be evaluated [10]. In the case of mortar, considered isotropic, the matrix is composed of only three independent elements (Equation 2).

$$\left[C\right] = \begin{bmatrix} C_{11} & C_{12} & C_{12} & 0 & 0 & 0 \\ C_{12} & C_{11} & C_{12} & 0 & 0 & 0 \\ C_{12} & C_{12} & C_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{44} \end{bmatrix} \tag{2}$$

Having the terms of the stiffness matrix [*C*], by inversion, the flexibility matrix [*S*] is obtained, which makes possible to determine all the elastic constants of a material, ie, the longitudinal and transversal elasticity modulus and the Poisson's ratio. Equation 3 shows the flexibility matrix of isotropic materials.

$$[\mathrm{S}] = \begin{bmatrix} \frac{1}{\mathrm{E}} & -\frac{\nu}{\mathrm{E}} & -\frac{\nu}{E} & 0 & 0 & 0 \\ -\frac{\nu}{\mathrm{E}} & \frac{1}{\mathrm{E}} & -\frac{\nu}{E} & 0 & 0 & 0 \\ -\frac{\nu}{\mathrm{E}} & -\frac{\nu}{\mathrm{E}} & \frac{1}{\mathrm{E}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G} \end{bmatrix} \tag{3}$$

On the other hand, by using Newton's second law for the movement of bodies ($F = m \times a$) it may be associated stresses on the movement in the internal structure of the material. In

Manuscript received April 15, 2014; revised June 20, 2014.

The authors are with College of Technology, State University of Campinas, Campinas, SP, 13484-332, Brazil (e-mail: gisleiva@ft.unicamp.br, luis.favarin@feagri.unicamp.br, gabi.macedo@live.com).

1877, by using complex mathematical models and procedures, Chistoffell [11] obtained relations between the stiffness matrix coefficients (C_{ii} and C_{ij}) and the ultrasound waves propagation speed (V_{ii} and V_{ij}), according to Equations 4 e 5, where are necessary the material density (ρ), the transducers distance (L) and the propagation time of the ultrasonic wave (t).

$$C = \rho \times V^2 \tag{4}$$

$$V = \frac{L}{t} \tag{5}$$

The objective of this study was to determine as elastic constants of grout samples from the ultrasound technique, which are longitudinal elastic modulus (E_{us}), transversal elasticity modulus (G_{us}) and Poisson's ratio (ν_{us}). These properties will be obtained from the matrix of calculated flexibility with ultrasound data, which could be to realize the technological control of batches and manufactures of the grouts.

II. Materials and Methods

In this study, six colors of grout from three different manufacturers were used, as well as it was adopted two similar colors for each manufacturer. The colors for grout were identified by acronyms as shown in Table I. Monocomponent samples were used, i.e., dry mixture which only needs the addition of water. For characterization, tests of water retention, workability (Flow table), dimensional variation, tensile strength in bending, compressive strength, absorption by capillarity and permeability were performed [2].

TABLE I: Grout's Colors*

Grout	Color
A1	White
A2	Autumn Gray
B1	Bright White
B2	Platinum Gray
C1	White Plus
C2	Light Gray

*Brazilian industry

It was molded prismatic specimens with section 25 × 25 mm and length of 250 mm (Fig. 1), which were subjected to the ultrasound tests [8]. For the ultrasound test, Epoch 4 (Panametrics, USA) was used with two types of flat face transducers (compression and shear wave) and at 1 MHz frequency. It was determined the compression and shear ultrasonic wave speed (Equation 5) as well as the stiffness coefficient of the grouts samples (Equation 4). Based on the data obtained from the two types of transducers, the stiffness matrices were determined and with the inverse of these, the flexibility matrix was obtained (equations 2 and 3) and consequently the elastic constants (E_{us}, G_{us} and ν_{us}).

Tensile strength in bending and compressive strength tests [2], which was based on the American standard [3] were made. For the stage of destructive testing an EMIC universal testing machine model DL 30000 was used and such tests were carried out at 7 days of age. The tensile strength in bending (S_T)was obtained according to equation 6 (Fig. 2), using the applied load in N (P), the distance between the supports (L) and the cross section of the specimen in mm (b and d). Cylindrical specimens (50 mm × 100 mm) were made for compressive strength test (S_C) [2], obtained according to equation 7 (Fig. 3), using the applied load in N (P) and cross section area in mm (A). Results of these tests were statistically analyzed with Statigraphics Centurion software (version XV).

$$S_T = \frac{3 \times P \times L}{2 \times b \times d^2} \tag{6}$$

$$S_C = \frac{P}{A} \tag{7}$$

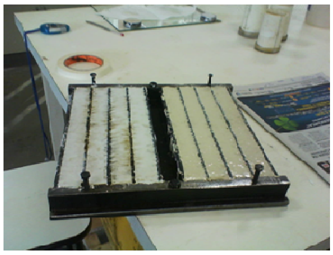

Fig. 1. Prismatic specimens of the grout.

Fig. 2. Tensile strength in bending test for prismatics specimens.

Fig. 3. Compressive strength test for cylindricals specimens.

III. Results and Discussion

Table II shows values of ultrasonic wave speed for the grouts studied herein. Table III shows values obtained for the elastic constants (E, G, ν) to grouts tested.

TABLE II: Average Bulk Density (ρ), Propagation Speed Average Values of Ultrasound Wave (V) and Stiffness Coefficient (C_{LL}) Obtained for Prismatic Samples (25 × 25 × 250 mm)

Grout	ρ (kg/m^3)	V (m/s)	C_{LL} (MPa)
A_1	1,800	1,900	6,500
A_2	1,800	1,500	4,000
B_1	1,850	2,750	13,500
B_2	1,860	3,150	17,800
C_1	1,800	2,900	15,500
C_2	1,780	2,700	13,000

The values obtained for the ultrasonic pulse speed obtained for manufacturers B and C were consistent with the literature [11] which had average values of 3,000 m/s for samples of cement mortar. However, the manufacturer A showed significantly lower results. This result may indicate a lower quality for this sample. For C_{LL} observed values near to those obtained for the longitudinal elasticity modulus (E), however, can't be considered equal.

TABLE III: ELASTIC CONSTANTS FOR GROUTSOBTAINED BY THE ULTRASSOUND TEST

Elastic Constants	Color grout	Average
E_{us} (MPa)	A_1	5,600
G_{us} (MPa)		2,200
ν_{us}		0.24
E_{us} (MPa)	A_2	3,600
G_{us} (MPa)		1,500
ν_{us}		0.19
E_{us} (MPa)	B_1	7,200
G_{us} (MPa)		2,600
ν_{us}		0.40
E_{us} (MPa)	B_2	7,000
G_{us} (MPa)		2,400
ν_{us}		0.42
E_{us} (MPa)	C_1	7,000
G_{us} (MPa)		2,600
νus		0.38
E_{us} (MPa)	C_2	6,500
G_{us} (MPa)		2,400
ν_{us}		0.39

The results indicated that it is feasible to apply the ultrasound test to determine the grout elastic constants. It was observed that the longitudinal elasticity modulus varied as a function of the mechanical strength, with higher values for the grout with greater tensile strength in bending (C1-S: 3 MPa and E_{us}: 7.1 GPa). These values were consistent with the literature [1], who obtained values for static tests between 5 and 7 GPa. However for Poisson's coefficient(ν_{us})there was a wide variation between the grouts studied, which were quite different from the value adopted in national and international Standards (ν=0.20). Table IV-Table VI show the results from physical and mechanical characterization. Statistical regression analysis between the colors studied (homogeneous groups) and the correlation coefficients obtained between the tensile strength and ultrasonic pulse speed and between the tensile strength and stiffness coefficient obtained in the ultrasound test, respectively (Tables VII and VIII).

By only using S_T to classify for the grouts studied, the manufacturer A was ranked as type I and the other two (B and C) were ranked as type II, according to standard NBR 14992:2003 [2]. In this standard, grouts type I are suitable for indoor and low traffic, type II are recommended for high traffic and outdoor environments. However, this information is not given by manufacturers to consumers. This same classification can be observed for the other parameters considered by standard, except for the absorption for capillarity (all were ranked as type I).

TABLE IV: TENSILE STRENGTH IN BENDING AND COMPRESSION STRENGTH OF THE AVERAGE COLORS OF GROUT(S) OBTAINED FOR 3 DIFFERENT MANUFACTURERS (A, B, C)

Color grout	*S_T (MPa)	*S_C (MPa)
A_1	2.0	6.0
A_2	2.0	4.0
B_1	3.1	11.0
B_2	3.9	15.8
C_1	2.7	11.5
C_2	3.0	10.5

* NBR14992:2003 (S_T: ≤ 2 MPa – type I; ≤ 1 MPa – type II) and (S_C: ≤ 8 MPa – type I; ≤ 10 MPa – type II).

TABLE V: WATER RETENTION AVERAGE OF THE COLORS OF GROUTS OBTAINED FOR 3 MANUFACTURERS (A, B, C)

Color grout	**Water retention (%)
A_1	97
A_2	97
B_1	98
B_2	97.5
C_1	96.5
C_2	97

*NBR14992:2003 (≤ 75%-type I; ≤ 65%-type II)

TABLE VI: DIMENSIONAL VARIATION, CAPILLARY ABSORPTION OF WATER AND PERMEABILITY AVERAGE OF THE COLORS OF GROUTS OBTAINED FOR 3 MANUFACTURERS (A, B, C)

Color grout	*Dimensional variation (mm/m)		**Absorption for capillarity (g/cm³)	***Permeability (cm³)
	length	Cross section		
A_1	1.60	0.05	0.45	0.48
A_2	1.20	0.04	0.45	0.45
B_1	0.20	0.05	0.45	0.40
B_2	0.70	0.05	0.45	0.44
C_1	0.40	0.10	0.45	0.45
C_2	0.70	0.20	0.45	0.44

* NBR 14992 (≤ 2.0 mm/m); **NBR 14992 (≤ 0.60 g/cm³-type I; ≤ 0.30-type II); ***NBR14992 (≤ 2.0 cm³-type I; ≤ 1.0 cm³-type II).

TABLE VII: STATISTICAL REGRESSION ANALYSIS PERFORMED TO DEFINE HOMOGENEOUS GROUPS AMONG THE COLORS OF GROUT ADOPTED IN THIS STUDY

Color grout	Homogeneous groups			
A_2	X			
A_1		X		
B_1			X	
C_1			X	
C_2			X	
B_2				X

TABLE VIII: CORRELATIONS BETWEEN TENSILE STRENGTH (S) AND SPEED (V); CORRELATIONS BETWEEN STIFFNESS COEFFICIENT (CLL) AND TENSILE STRENGTH (S) FOR A PRISMATIC SPECIMEN (25 × 25 × 250 MM)

Test	Correlation model	R*
Ultrasound and Tensile strength in bending	$S_T = 1.33 + 0.1263 \times C_{LL}$	0.85
	$S_T = 0.36 + 0.00098 \times V$	0.82

*R=Correlation Coefficient

To confirm the variability between manufacturers, we carried out a statistical analysis to determine whether there was a statistically significant difference between manufacturers and colors studied. Manufacturers A and B statistically differ in their respective colors of grout, but only manufacturer A was classified as type I (lower mechanical performance). This can be explained by the material permeability [12] and the type of pigment used can also influence (organic or inorganic). The manufacturer C showed no statistical difference for its colors and also with color B_1 (manufacturer B

), which corroborated on their mechanical performance.

Correlations obtained from $S_T \times C_{LL}$ (0.85) e $S_T \times V$ (0.82) were close to those found by other authors. This proves the efficiency of ultrasound technique to estimate grouts mechanical strength [1], [13]-[15].

IV. Conclusions

The ultrasound test allowed us to infer quickly and accurately the properties of elasticity in grout, especially in relation to the longitudinal elastic modulus. The ultrasound technique efficiency has been demonstrated to estimate the material strength from the correlation with the ultrasonic speed. The ultrasound test allowed the detection of differences in mechanical properties between the selected manufacturers and it is concluded that the technique can be used in technological control of them.

Acknowledgments

This work was supported by Laboratory of the Nondestructive tests, College of Agricultural Engineering, State University of Campinas.

References

[1] L. V. R. GOMES, "Study of test methods physical and mechanical behavior of grouts," PhD. Dissertation, Dept. Civil Engineering, Federal University of Espiri to Santo, ES, 2008.

[2] *Mortar Based on Portland Cement for Grouting Ceramic Tiles – Requirements and Test Methods*, ABNT Standard NBR14992-2003.

[3] *Ceramic Title Grouts: Specification*, ANSI Standard A-118.6-1985.

[4] *Adhesive for Tiles–Determination of Transverse Deformation for Cementitious Adhesives and Grouts*, DIN Standard EN 12002-2003.

[5] *Adhesives and Grouts for Tile – Part 3 – Determination of Flexural and Compressive Strength*, DIN Standard EN 12808-3-2002.

[6] *Produits de Carrières Pierres Calcaires – Mesure du Module d'élasticité Dinamique*, AFNORStandardNFB 10-511-1975.

[7] *Mortar for Covering Walls and Ceilings – Determination of the Dynamic Elasticity Modulus by Ultrasonic Wave Propagation*, ABNT Standard NBR 15630-2008.

[8] R. Gonçalves, M. Giacon, and I. M. Lopes, "Determination of the stiffness matrix of concrete using ultrasound," *Engenharia Agrícola*, vol. 31, no. 3, pp. 427-437, 2011.

[9] J. J. B. Bodig, *Mechanical of Wood and Wood Composites*, New York: Van Nostrand Reinhold, 1982.

[10] V. Bucur, *Acoustics of Wood*, 2 st ed., New York: Springer-Verlag, 2006.

[11] E. B. Christoffel, "Uber die for tpflanzung von stessen durch elastische feste korper," *Ann Matematical*, vol. 2, 1877, pp. 193-243.

[12] Z. Lafhaj, M. G. Djerbi, and A. M. Kaezmarek, "Correlation between porosity, permeability and ultrasonic parameters of mortar with variable water/cement ratio and water content," *Cement and Concrete Researc*h, vol. 36, pp. 625-633, 2006.

[13] V. C. Campiteli and N. G. Silva, "Correlation between the dynamic elasticity modulus and mechanical strength of cement mortars, lime and sand," *Ambiente Construído*, pp. 21-35, 2008.

[14] Z. Lafhaj and M. Goueygou, "Experimental study on sound and damaged mortar: variation of ultrasonic parameters with porosity," *Construction and Building Materials*, vol. 23, pp. 953-958,2009.

[15] G. C. S. Ferreira, R. Gonçalves, and A. R. Campanholi, "Physical and *mechanical* characterization of grout from ultrasound test," *XSBTA-Brazilian Symposium on Technology of Mortars*, pp. 1-14, 2013.

Gisleiva Cristina Dos Santos Ferreira wan born in 1975, Brazil. She received her civil engineering PhD from State University of Campinas, UNICAMP, and Brazil in 2007.

She is a professor at the Faculty of Technology at Unicamp since July 2011, she is teaching courses of civil construction technology and environmental engineering. At the graduate school (post-degree), she has worked in the areas of materials science and environment and research lines are: mechanical, environmental and economic performance of materials and processes applied to construction with the use of solid waste; microstructure characterization of conventional cementitious matrices and solid waste; inspection and monitoring of buildings in service of cultural and historical interest with non-destructive techniques; evaluation of construction materials mechanical performance used in buildings and in service of historical and cultural interest