Relation between modulus of elasticity obtained by ultrasound and for load cycles in the lateritic concrete mixed with lignosulphonate plasticizer

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Abstract. The concrete produced using coarse aggregate originated from basaltic or granitic rocks, commonly becomes expensive due to the shortage of soil deposits of such rocks in some regions of Brazil. Alternatively, there are the lateritic concretions, with no economical value, in exchange of the conventional coarse aggregate in concrete. The lateritic concretions are originated from Tropical Soils that represent 60% of the soils in Brazil. This research presents a study about the concrete mechanical behavior mixed with lateritic concretions as coarse aggregate and lignosulphonate plasticizer. At all, 254 cylindrical and prismatic specimens were produced for develop studies of workability, compression strength, splitting tensile strength, bending tensile strength, elasticity modulus and microstructure analysis. The experimental results of the elasticity modulus, using compressometer/extensometer equipment and a Portable Ultrasonic Non-Destructive Indicating Tester (PUNDIT), were compared with theoretical expressions of the standard ABNT, ACI, CEB and CSA codes. The results indicated that the elasticity modulus measured experimentally were equivalents in both methodologies, increasing the similarity as the concentration of plasticizer grows. However, experimental values were lower than the values obtained by theoretical equations proposed by the national and international codes, presenting maximum variance of 5.53 GPa. Nevertheless, the results obtained for lateritic concrete were higher than those obtained for the reference concrete mixed with ordinary coarse aggregate.

INTRODUCCION

The scarcity of conventional materials to compose the concrete tends to increase costs and stimulates research for alternative supplies. In this paper, it is proposed the substitution of granitic coarse aggregate for lateritic concretions.

In the Brazilian Northeast there are plenty of granitic as well as lateritic rocks. However in the Northern parts of the country granitic rocks are rarely found, which makes the lateritic concretions a feasible alternative for concrete coarse aggregate in that region.

Studies about the use of laterites as aggregate in concrete are not new. Queiroz de Carvalho [1] has published many articles about the properties of the lateritic concrete; Chagas Filho and Barbosa [2,3,4] studied the bending of lateritic concrete beams and possibilities to construct concrete in hot climates; Nichol [5] and Gomes and Pinto [6] studied the possibility of using laterite as coarse aggregate. Liborio and Trigo [7] studied the enhancement of the concrete mechanical properties due to the use of laterites.

Lateritic concretions

Lateritic concretions are concretionary elements formed by the intense lixiviation of latosols, commonly found in tropical regions in which physical and chemical weathering are high. Alternate cycles of drying and humidification cause the silicate particles to chemically react,
creating ions of K⁺, Ca²⁺, Na²⁺, Mg²⁺ and Si⁴⁺, iron, aluminum and silicon. During lixiviation, iron passes from the ferrous to the ferric state (Fe³⁺), initiating a wrapping process that originates concretions.

In the precipitation of the iron oxide hydrated, other particles of soil could be cemented to the coarse aggregate, creating porous granular structures as the process of crystallization happens. When the precipitation occurs around the nucleus, the particles created are called pisolites, concretionated elements similar to pebble with rounded or oblong shapes.

**Modulus of elasticity**

The Modulus of elasticity is a parameter used to design structures that relates applied tensions to its instantaneous deformation. The most accurate way to determine the modulus of elasticity is by testing specimens in the laboratory.

The modulus of elasticity of the concrete does not present a linear behavior after a certain level of tension. Tests with specimens show that the stress-stain diagram for concrete is usually linear for stress 30% lower than the effective strength after which it presents a curved shape. This behavior is the result of the progressive microcracking that happens in the interface between aggregate and mortar, called transition zone.

The transition zone is a natural phenomenon that happens around the aggregate particles inducing them to segregate in different levels of porosity, types of particles and surface areas. Such segregation implies different kinds of envelopment of the mortar around the aggregate.

The transition zone is the result of the wall effect. The aggregate is many times bigger than the hydrated grain of cement; the difference of size between the grains gives the aggregate a wall characteristic that affects the position of the cement hydrated grains. Mostly small grains tend to linger around the aggregate creating a space with higher porosity than the rest of the matrix. Such porosity is initially 40% of the total matrix porosity decreasing to 10-20% after the first day. In concretes with j ≥ 365, it tends be equal to the matrix porosity. In the case of concretes mixed with plasticizer the wall effect is reduced, keeping the porosity constant in the interfacial zone.

Experimentally, the modulus of elasticity could be obtained by applying loading and unloading cycles of compression as recommended by the Associação Brasileira de Normas Técnicas, the ABNT NBR 8522: 2003 standard. The prediction of the strains could be done by using “strain-gauges” or a compressometer-expansometer equipment.

Commonly, when it is not possible to determine the elasticity modulus in an experimental way, it could be obtained by equations involving the concrete strenght. The CEB/90 (Comité Euro-International du Béton) uses the Eq. 1 for cylindrical specimens.

\[
Ec= 10,000 \times ((f'c)1/3) \tag{1}
\]

\( Ec = \) Tangent modulus of elasticity for concrete at 28 days (MPa);
\( f'c = \) Average Compression Strength at 28 days (MPa);

The ACI (American Concrete Institute) recommends the Eq. 2 for normal concretes and Eq. 3 for concretes with density different of 2.300 kg/m³:

\[
Ec = 4.37 \times ((f'c)0,5) \tag{2}
\]

\[
Ec= 43 \times [(\gamma)1,5] \times [(f'c)0,5] \times (0,000001)] \tag{3}
\]

Where:
\( Ec = \) Tangent modulus of elasticity for concrete with 28 days (MPa);
\( f'c = \) Average Strenght due compression at 28 days (MPa);
\( \gamma = \) concrete density (kg/m³).
As recommended by the ABNT NBR 6118:2003 standard, the elasticity modulus in the origin could be estimated through many tests by using the Eq. 4 for normal concretes with \( j = 28 \). The elasticity modulus for a \( j \geq 7 \) days concrete could be also evaluated by using the \( f'c \) instead of \( f'cj \). Despite the fact that greater compression strength often implies greater elasticity modulus, there is not a direct proportionality.

\[
E_{ci} = 5,600 \left( f'c \right)^{0.5}
\]

(4)

Where:

\( E_{ci} \) and \( f'c \) in [MPa].

The Canadian Standards Association by the CSA-A23.3: Design of concrete structures standard states that the elasticity modulus for a concrete in which the \( \gamma_c \) lies between 1,500 and 2,000 kgf/cm\(^3\) may be obtained by the Eq. 5. This equation is suitable for concrete specimens with compressive strength greater than 40MPa.

\[
E_c = \{ 3,300 \left( f'c \right)^{0.5} \} + 6,900 \times \left( \gamma_c/2,300 \right)^{1.5}
\]

(5)

For normal density concretes in which the compressive strength lies between 20 and 40MPa it may be obtained by the Eq. 6. This expression is suitable for concretes with low compressive strength and is about 5% lower than the one given by 1999 ACI code.

\[
E_c = 4,500 \times \left( f'c \right)^{0.5}
\]

(6)

**Ultrasound**

The elasticity modulus could be also obtained by using a high frequency emission/reception device. Sound waves spread around the concrete and have their velocity altered depending on the material being crossed. The velocities are brought to a specific abacus that indicates the probable value of elasticity modulus of the concrete.

The PUNDIT (Portable Ultrasonic Non-Destructive Indicating Tester) is a helpful equipment for concrete structure analysis because it is light, non-destructive and could be moved to different parts of the structure to be analyzed. It was initially developed to determine the uniformity of the concrete, the cover thickness, and to detect defects and anisotropy.

The procedure to determinate the dynamic elasticity modulus by ultrasonic technics results in values that are theoretically equal to the ones obtained by loading cycle tests. If the elasticity modulus is computed by the ultrasonic pulse, the equation recommended is the Eq. 7.

\[
E_d = \left( V \right)^2 \times \left( \rho \right) \times \left\{ \left( 1+\mu \right) \times \left( 1-2\mu \right) \right\} / \left( 1-\mu \right)
\]

(7)

Where:

\( E_d \) = dynamic elasticity modulus;
\( V \) = dynamic pulse velocity;
\( \rho \) = concrete density;

During the period in which the concrete strength is increasing significantly, different modulus of elasticity are obtained. For analysis in the first ages, it is necessary to adjust the empirical equations.

The ASTM C 597-02 (2002) standard states that results from the ultrasonic tests should not be used to determine the concrete strength nor its elasticity modulus. Such data could only be used to analyze other tests due to the great number of variables that could alter the wave’s propagation velocity. Furthermore, the concrete is a heterogeneous material and its own proprieties could also interfere with the ultrasonic pulse determination.

The concrete structure influence on the ultrasonic pulse variation could be divided in external and internal factors. The great number of variables affecting a structure could lead to
similar elasticity modulus values in different types of structures, which makes this kind of test rather inaccurate.

According to Lorenzi, Tisberek et al. (2007) [8] concretes with the same strength could present different velocities of pulse propagation. Their studies showed that the ultrasonic pulse is more affected by the cure conditions and to the kind of aggregate than the results obtained for load application tests.

OBJECTIVE

This paper will explain the elasticity modulus behavior for a concrete mixed with lateritic coarse aggregate and lignosulphonate plasticizer. The goal is to add technical data to the current knowledge enabling the use of lateritic concretions as growth aggregate in exchange of granitic rocks. The study presented on this paper is part of a deeper research on lateritic concrete. Over 250 specimens were analyzed for their mechanical properties behavior such as compressive strength, splitting tensile strength, bending tensile strength, elasticity modulus and Electric Microscope analysis.

TEST PROGRAM

a) Materials

The materials used to compose the concrete were Portland cement CP II F-32, similar to IP type classified for ASTM C595; Sand from the Paráiba River as fine aggregate; Lateritic concretions as coarse aggregate; Lignosulphonate plasticizer in the proportions of 0.4%, 0.6% and 0.8% of the mass of the cement.

b) Test procedure and results

The test was made with an electric-hydraulic compression machine with a loading capacity of 1,500 kN and an average loading rate of 0.05 MPa/s. The strain on the specimens was measured by using a Maruto compressometer-expansometer with horizontal and vertical gauges which were able to measure strain variations of 0.02mm.

The stress-strain curves for the four mixtures are shown in the Fig.1 and Fig.2. Concretes at 28 days were used for greater data accuracy. The graphics represent only the ascendant part of the curves due to a machine limitation, which stopped automatically after a decrease in the specimen strength. However, all curves present similar behavior to what was expected on the technical references.

![Figure 1: Stress-strain curve of Reference Concrete and for the mix with 0.4% of plasticizer.](image-url)
Figure 2: Stress-strain curve of the mix with 0.6% and 0.8% of plasticizers.

The graphics show regions among the limits of 30% $f'_c$, 50% $f'_c$, 75% $f'_c$ and $f_c$. They represent, respectively, the area in which the concrete has an elastic behavior; the area in which micro fissures envelop all aggregate and the stress in the mortar begins; the area in which fissures start to happen in the mortar; and the area in which fissures in the mortar increase and connect themselves like a net until the collapse.

As we could observe, the presence of the plasticizer represents an important variable to the increasing behavior of the stress-strain curve. The more plasticizer used the more the strength increases, consequently lower strains are obtained. The mixture with 0.8% of plasticizer presents an elastic region that is approximately 1.65 times bigger than the elastic limit obtained for the reference concrete. It could be explained by the fact that the additive in the concrete acts like a surfactant, disaggregating the cement grains and enabling higher levels of hydration. More hydrated grains means a mortar with less porous and, consequently, a more compact matrix. The increase of plasticizer also affects the inflexion point of the curves, leading to an abrupt collapse without creeping.

Comparing all four curves on the same chart, Fig. 3, we could see that despite the fact that the addition of 0.8% of plasticizer caused higher concrete strength than the others concretes, it also led to an increase on the strain when compared to the other mixtures.

Figure 3: Relation of the Stress-Strain curves of all mixtures.
The evolution of the elasticity modulus was determined for all four mixtures at ages of 3, 7 and 28 days, as shown in the Fig. 4. For the reference concrete and the mixtures with 0.4% and 0.6% of plasticizer the behavior of the elasticity modulus was similar over time, although the reference concrete presented lower values as expected.

Figure 4: Evolution of the modulus of the elasticity along the time.

At the firsts ages, the concrete with 0.8% of plasticizer presents lower results, however it tends to increase as the time goes on. Monteiro, Helene and Kang (1993) [9] said that the elasticity modulus depends mostly on the matrix strength and the bound with the aggregate. While the water/cement ratio and the dry material quantity is kept constant, the elasticity modulus is a function of the matrix. In that case, the large addition of plasticizer, without exudation, could have retarded the increase of strength in the transition zone during the first ages, causing a slower crystallization process. This process could justify a lower strength in this zone during the first days and, therefore, the elasticity modulus for the 0.8% of plasticizer concrete.

The Fig. 5 presents all the average values from the tests developed for prediction of the modulus of elasticity obtained in laboratory tests and for analytical expressions.

The ultrasonic test presents different results for the mixtures when compared to the tests with cycle loads. As for the ultrasonic test there is a nonlinear behavior, which increases substantially after the first additions of plasticizer and decreasing abruptly with the addition of of 0.8% of plasticizer. As seen in the review, the data from ultrasonic analysis is very sensible to variations in the matrix such as surface humidity, aggregate, presence of air, specimens’ age, etc. Indeed, while mixing the concrete and the plasticizer, especially the 0.8% of plasticizer mixtures, it was verified the presence of air bubbles. High levels of lignosulphonate plasticizers tends to produce air bubbles in the mixture, and the 0.8% concentration is higher than the recommended by the plasticizer’s producer. This little hollows in the concrete matrix could have interfered with the ultrasonic tests causing the wave’s velocity to decrease pointing to lower elasticity modulus values.

Comparing the results of the destructive and the nondestructive tests, a great variance of values could be observed. However, such discrepancy did not happen with the reference concrete, which presented coherent values throughout the tests. Apparently the plasticizer interfered with the elasticity modulus evaluation in a way that could not be thoroughly explained due to the low number of specimens tested.

The elasticity modulus values obtained experimentally by loading cycles and ultrasonic tests are lower than the ones given by the ABNT, ACI and CEB equations. However, the conservative expression adopted by CSA presented values close to the ones given by load cycles for the reference concrete and concrete with 0.4% of plasticizer.
Figure 5: Modulus of elasticity for all methodologies in concrete with $j = 28$. 

Methodology adopted to predict the modulus of elasticity

Experimental data

Analytical data

Curve $\sigma \times \varepsilon \ (30\%C)$

Load cycles

Ultrasonic pulse (15x30)cm

Ultrasonic pulse (15x15x75)cm

NBR

ACT

CEB

CSA

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<tr>
<th>Methodology adopted to predict the modulus of elasticity</th>
<th>Experimental data</th>
<th>Analytical data</th>
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<tr>
<td>CR 0.40%</td>
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0 5 10 15 20 25 30 35 40

Modulus of elasticity (GPa)

0 5 10 15 20 25 30 35 40

Modulus of elasticity (GPa)
CONCLUSIONS

1. During the tests to determine the stress-strain curves the addition of lignosulphonate plasticizer developed low strains, except for the 0.8% concentration;
2. The values predicted by ultrasound and load cycles, presented a maximum difference of 5.53GPa and a non-constant behavior, despite accurate values for the reference concrete;
3. The elasticity modulus values obtained experimentally were lower than the ones proposed by the ABNT, ACI and CEB equations but close to the conservative values presented by the CSA equations;
4. The use of the PUNDIT to determine the modulus of elasticity demonstrated irregular results possibly caused by the air bubbles, which tend to appear in the mixture as the addition of lignosulphonate plasticizer increased. For a plasticizer addition equal to 0.8% of the cement quantity, the modulus of elasticity tends to decrease.

REFERENCES