A Study of Stiffness and Strength of a Mixture of RAP and Powdered Rock with Cement Blends

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ABSTRACT

The Brazilian highways are fundamental to the productive chain once promote the integration of states, ports, railways, waterways and airports. One way to correct the defects in the pavements is the restoration, currently being used the pavement milling (cold planing, asphalt milling, or profiling). This operation produces a waste, called Reclaimed Asphalt Pavement (RAP). This paper aims to evaluate the viability of using RAP and powdered rock mixture chemically stabilized with Portland cement, for layers in flexible pavements, correlating the porosity/cement ratio (η/Civ) with stiffness and resistance parameters of the mixtures. All the specimens were prepared in proportions of 70%/30% (RAP/PR). The chemical stabilization was carried out with high early strength Portland cement, contents of 3%, 5% e 7%, all specimens cured for 28 days. Were performed unconfined compressive and splitting tensile tests for strength and resilient modulus and dynamic modulus for stiffness. The results showed that both, strength and stiffness increase linearly with increasing amount of cement and exponentially with decreasing of the porosity. Also, shows that cement-treated material exhibits viscoelastic behaviour. The relationship between the porosity/cement ratio adjusted by a coefficient [$\eta/(Civ)^{0.41}$] proved adequate in predicting strength and stiffness for all studied mixtures.

Keywords: RAP, chemical stabilization, porosity/cement ratio.

1. INTRODUCTION

The Brazilian highways are fundamental to the productive chains once they promote the integration of regions, states, ports, railways, waterways, and airports. According to the Confederação Nacional do Transporte (CNT, 2017 [1]), sixty-two percent of the Brazilian highways extension have shown defects such as pot holes, shoving, rutting. These defects and/or irregularities affect the operating costs, fuel and tires consumption, increase of travel times, among others (CNT, 2017 [1]). Pavement milling is a procedure that can correct such defects, but which produces a waste called Reclaimed Asphalt Pavement (RAP).

The same materials used to build the highway can be reused to repair, reconstruct, and maintain them according to the recycled materials policy from the Federal Highway Administration's -FHWA (Wright Jr., 2001 [2]). The reuse of RAP through recycling has been the subject of countless researches in the world. In Europe and the United States, the main focus is the use in hot asphalt mixtures (Hajj et al., 2009 [3]; Daniel et al., 2013 [4]; Lo Presti et al., 2013 [5]; Mangiafico et al., 2013 [6]). However, it is also possible to reuse RAP as a construction material, in road bases and sub-bases, as aggregates of asphalt concrete, slopes and embankments fill (Wright Jr., 2001 [1]; ARRA, 2006 [7]; Huang et al., 2005 [8]; Huang et al., 2006 [9]; Bilodeau et al., 2011 [10]; Hoyos et al., 2011 [11]; Bilodeau et al., 2012 [12]; Puppala et al., 2012 [13]; Dong and Huang, 2013 [14]; Arulrajah et al., 2014 [15]; Pasche et al., 2014 [16]; Dalla Rosa et al., 2015 [17]; Pires et al., 2016 [18]; Nguyen et al., 2017 [19]).

Although, careful consideration should be given to the viscoelastic behavior in RAP. This is because RAP, which is a bituminous materials, exhibit a strong dependency to temperature and loading time and this behavior cannot be overlook (Di Benedetto et al. 2001 [20]; Di Benedetto and Corté, 2005 [21]). Some works have been done approaching RAP materials using linear viscoelastic approach and carrying out different complex modulus tests, measuring dynamic modulus (or norm of complex modulus) and phase angle; (Bilodeau et al., 2011 [10]; Bilodeau et al., 2012 [12], Dong and Huang, 2013 [14]; Nguyen et al., 2017 [19]), but no one showed the existence of a relationships between viscoelastic behavior and an index, such as η/Civ.

This paper aims to evaluate, through laboratory testing, the viability of using a mixture of RAP and powdered rock (PR) chemically stabilized with high early strength Portland cement for layers in flexible pavements correlating the porosity/cement ratio (η/Civ) with stiffness and resistance parameters of the mixtures. From the proper manipulation of such index intended to achieve objectively and reliability the required strength and stiffness properties.

2. EXPERIMENTAL PROGRAM

The experimental program has been carried out in distinct segments. First, tests were performed to characterize the materials used (RAP, PR and Portland cement). Next, compaction curves, through the Proctor test (NBR 7182, 2016 [22]), considering three distinct energies , standard (600 kN.m/m^3), intermediate (1,650 kN.m/m^3), and modified (2,700 kN.m/m^3), were established to target a dry unit weight for a given specimen. It was then established through the dry mass of RAP-PR-cement divided by the total volume of the specimen. Porosity (η) is defined as the ratio of voids (in volume) over the total volume of the specimen (V). As shown in Eq. (1) (Consoli et al. 2011) [23], porosity (η) is a function of dry unit weight (γd), high early strength Portland cement (C), crushed RAP content and PR content (S). Each material (RAP, PR and cement) has a unit weight of solids (γs_{RAP}, γs_{PR} and γs_{C}), which also needs to be considered for calculating porosity.

$$\eta = 100 - \frac{100\left\{\left(\frac{\left[\frac{\gamma_d V}{1+\frac{C}{100}}\right]\left[\frac{RAP}{100}\right]}{\gamma s_{RAP}}\right)+\left(\frac{\left[\frac{\gamma_d V}{1+\frac{C}{100}}\right]\left[\frac{PR}{100}\right]}{\gamma s_{PR}}\right)+\left(\frac{\left[\frac{\gamma_d V}{1+\frac{C}{100}}\right]\left[\frac{C}{100}\right]}{\gamma s_{C}}\right)\right\}}{V} \quad (1)$$

Following, a number of tests to characterize the strength across the unconfined compression tests, (NBR 5739, 2010 [24]; ASTM C39 ,2010 [25]), split tensile tests (NBR 7222 , 1983 [26]; ASTM C496, 2011 [27]) and tests to determine the Resilient modulus, (DNIT-ME

135 ,2010 [28]; ASTM D4123, 1995 [29]) and the complex modulus (dynamic modulus and phase angle), (AASHTO T 342 ,2011 [30]), considering sinusoidal load amplitude was adjusted to obtain axial strains between 50 and 75µm/m (Linear Viscoelastic Domain) and a range of temperatures (4, 21, 37 and 54°C) and loading frequency (0.01, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20 and 25 Hz).

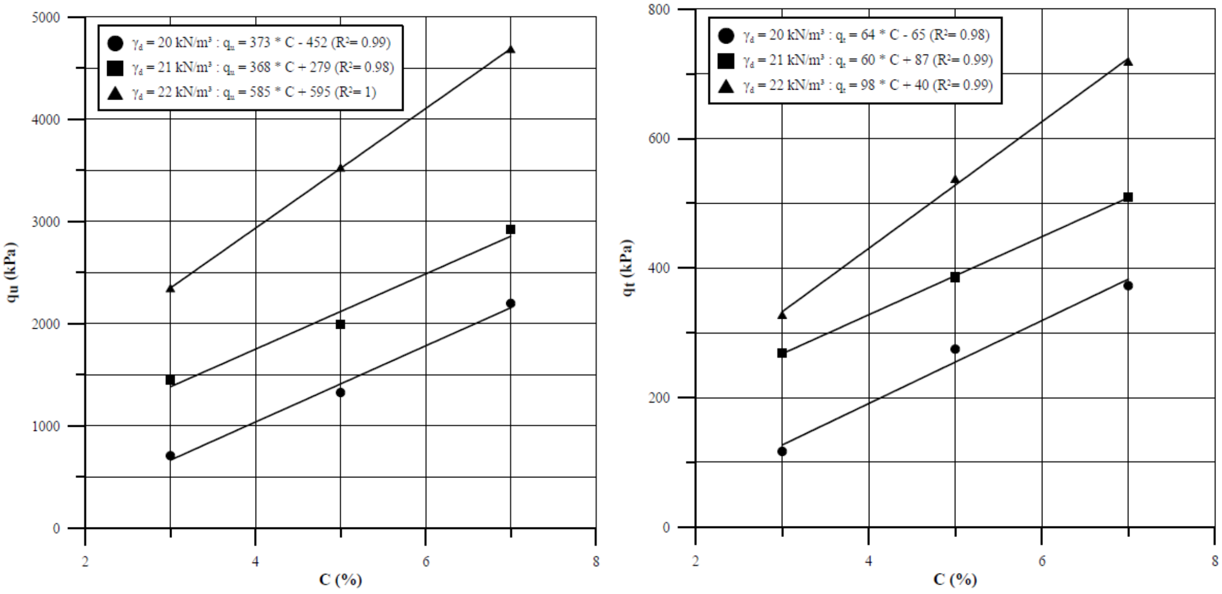
All the specimens were prepared in proportions of 70%/30% (RAP/PR), as indicate on previous experiences (Specht *et al.*, 2013 [31]; Pasche *et al.*, 2014 [16]), distinct amounts of high early strength Portland cement, Type III (ASTM C150, 2017 [32]) (3, 5 and 7%). The molding points had a moisture content of about 8% and dry unit weights (20, 21 and 22 kN/m³). The specimens were cured for 28 days in a room at 21º±2ºC and relative humidity above 95%.

3. RESULTS

3.1 Effect of the Cement Content and Porosity on Unconfined Compressive and Split Tensile Strength

The variation of unconfined compressive strength (q_u) and the split tensile strength (q_t) with the amount of Portland (C) is shown in Fig. 1 for a curing period of 28 days. Increasing dry unit weight and increasing cement content end up increasing q_u and q_t. A linear function also fits well for the three dry unit weight studied.

FIGURE 1 Unconfined compressive strength (q_u) (a) and Split tensile strength (q_t) (b) versus high early strength Portland cement content (C)

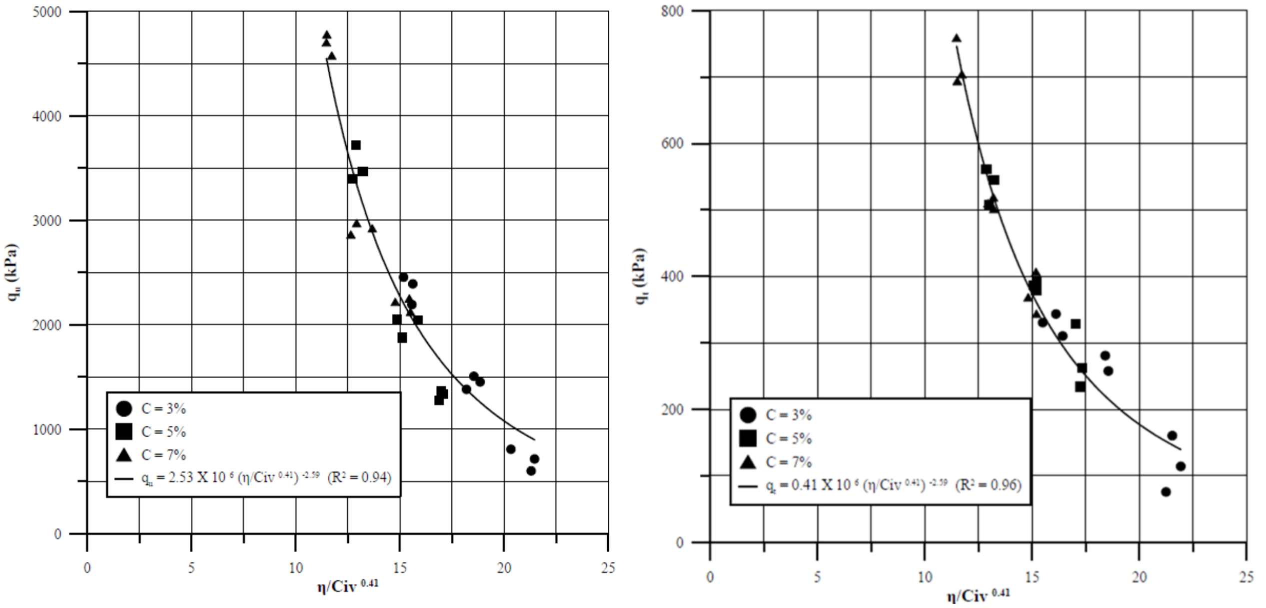


(a) **(b)**

3.2 Effect of the Cement Content and Porosity on Unconfined Compressive and Split Tensile Strength

Figure 2 presents the unconfined compressive strength and split tensile strength as a function of the adjusted porosity/cement ratio $\eta/(Civ)^{0.41}$ [expressed as porosity (η) divided by the volumetric cement content (Civ), the latter expressed as a percentage of cement volume to the total volume of the RAP-PR-cement mix (Consoli *et al.*, 2007 [33]). A simple observation of Fig. 2 suggests that the adjusted porosity/cement ratio is useful in normalizing results for RAP-PR-cement blends. Good correlations (R^2=0.94 and 0,96) can be observed between $\eta/(Civ)^{0.41}$ of the RAP-PR-cement mix studied, respectively for 28 days of curing.

FIGURE 2 Variation of unconfined compressive strength (q_u) (a) and split tensile strength (q_t) (b) with adjusted porosity/cement ratio

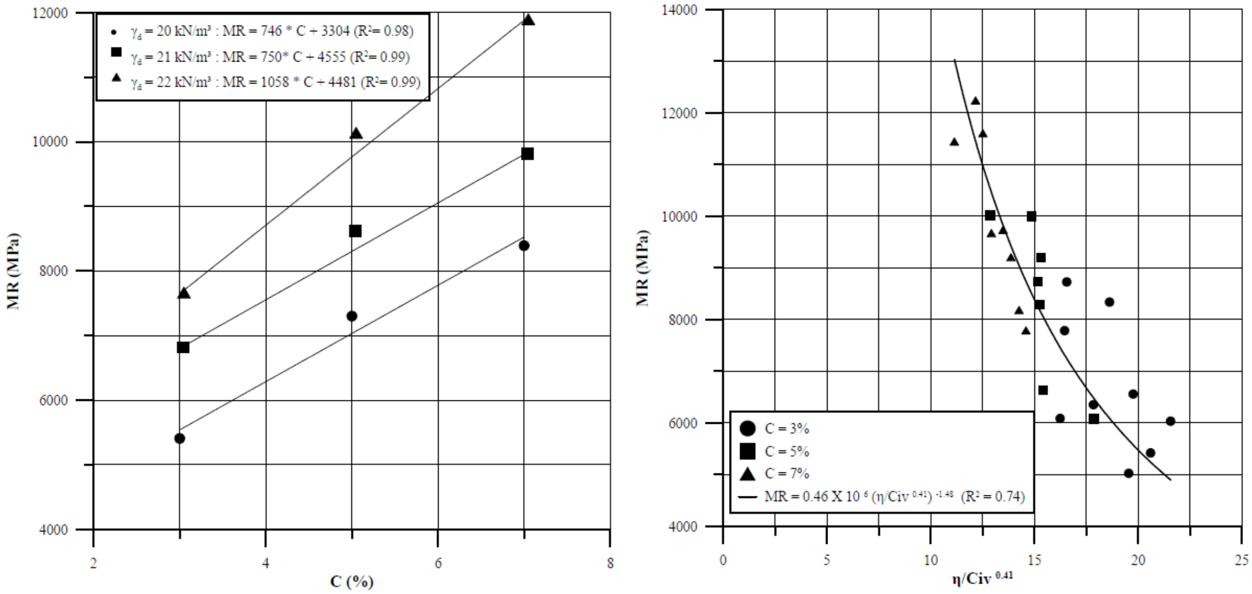


(a) **(b)**

3.3 Effect of the Cement Content and Porosity on Resilient Modulus

The resilient modulus (MR) variation with the amount of Portland cement (C), considering three distinct dry unit weights (20, 21 and 22 kN/m^3) is shown in Fig. 3 (a). Figure 3 (b) presents the resilient modulus as a function of the adjusted porosity/cement ratio $\eta/(Civ)^{0.41}$, a simple observation suggests that the adjusted porosity/cement ratio is useful in normalizing results for RAP-PR-cement blends and acceptable correlation (R^2=0.74) can be observed between $\eta/(Civ)^{0.41}$ and MR of the RAP-PR-cement mix studied.

FIGURE 3 Resilient modulus (MR) versus high early strength Portland cement content (C) (a) and variation of MR with adjusted porosity/cement ratio (b)

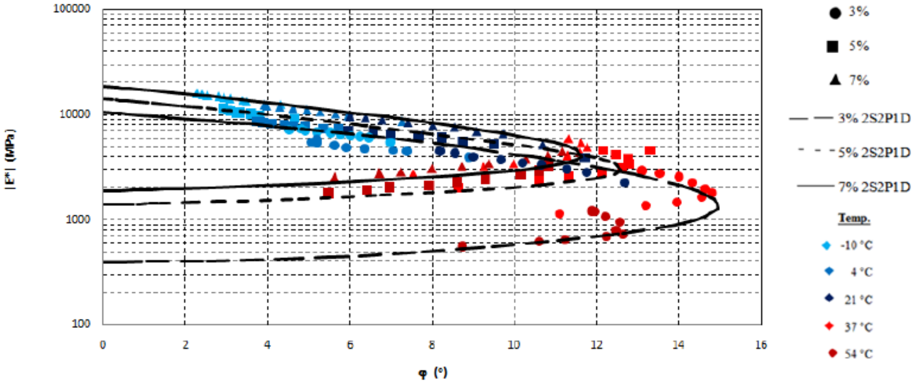


(a) (b)

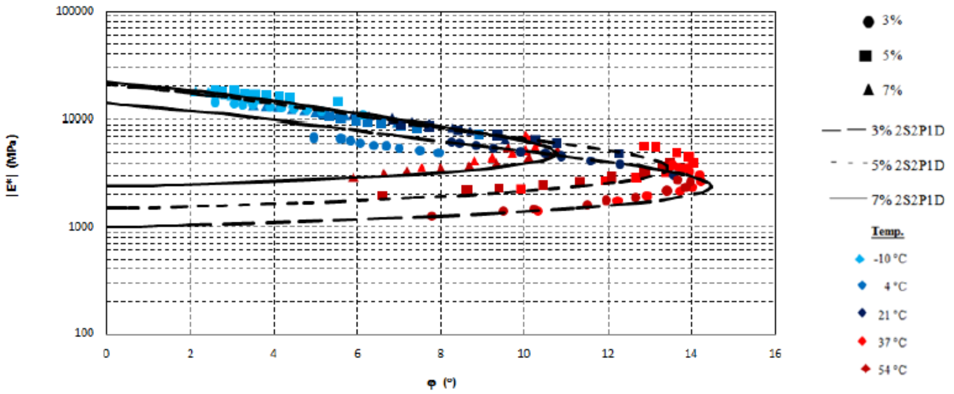
3.4 Effect of the Cement Content on Dynamic Modulus considering Four Distinct Curing Testing Temperatures and Ten Loading Frequencies

The Black diagram allows understanding the behavior of the material at different temperatures, comparing the dynamic modulus with the phase angle. The figure 4 shows, for all mixtures, the experimental and 2S2P1D modeling results. The 2S2P1D model was developed by Di Benedetto *et al.* (2004) [34], to simulate linear viscoelastic properties of binders and/or asphalt mixtures.

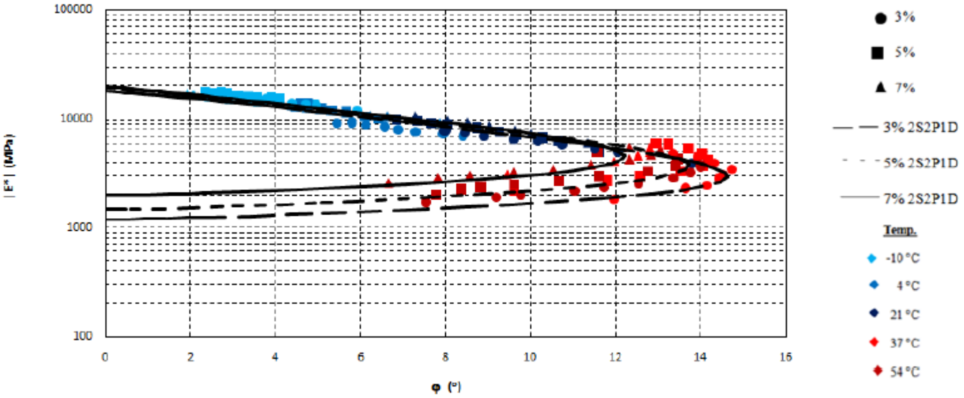
FIGURE 4 Black diagram



a) γ_d 20 kN/m³



b) γ_d 21 kN/m^3



c) γ_d 22 kN/m^3

4. CONCLUDING REMARKS

From the data presented in this manuscript, the following conclusions can be drawn:

- Increasing dry unit weight and increasing cement content end up increasing strength and the stiffness, for 28 days of curing, for all the blends studied .
- Regardless of the amount of cement added in the blends, the reduction of the porosity for the compacted material promoted significant gains in strength and stiffness. It was found that the values potentially increased with the reduction of the porosity of the compacted blend.
- The porosity/cement ratio (η/Civ) shown to be an appropriate index parameter to assess q_u and q_t of the compacted RAP – PR – Portland cement blends studied.
- The black diagram shows an increase of the phase angle for high temperature conditions, from 37 ° C, and a decrease from 54 ° C. This happens because the binder in the RAP begins to softening, losing the viscoelastic feature, resulting only in stress mobilization in the mineral skeleton. Also, mixtures with a lower content of cement have the highest values of phase angle, in other words, these mixtures have a more important viscous portion, in relation to the elastic portion. Based on that, it is possible to infer that these mixtures would present, in field, more plastic deformations when compared to other mixtures. Besides, through the results of the black diagram, it is clear that cement-treated material exhibits viscoelastic behaviour.

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