Evaluation of the Uniaxial Compression Strength of Expanded Polystyrene at Different Speeds

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ABSTRACT
This work evaluated and compared parameters of resistance to uniaxial compression of expanded polystyrene (EPS), with different densities, when submitted to different execution speeds. These, performed according to ASTM 1621, were executed with samples of four different specific masses (14.5, 18, 28 and 33.5 kg/m³) at speeds of execution equal to 10 and 50 mm/min. The tests were conducted up to 28% deformation. It was possible to obtain and measure the resistance and modulus of elasticity parameters considering deformations at the elastic limit as well as the time of flow and the maximum limit established (28%). Additionally, the cited parameters were analyzed and compared with each other, as well as with the results of the literature (values obtained in research and empirical correlations). The main results show the high EPS strength as a relationship between the deformability and strength of the material with its specific mass (as the density of the material increases, its resistance and deformation properties also increase). In addition, a correspondence was found between the specific deformation in the flow and the test velocity variation. The same was observed with respect to the modulus of tangent elasticity of the material.

1. INTRODUCTION

Expanded Polystyrene (EPS), commonly known as geofoam in geotechnical engineering, has been increasingly applied in the area of civil engineering, as it has positive technical properties such as low specific weight (15 to 40 kg/m³, high strength (70-250 kPa) and low compressibility (modulus of elasticity = 1 to 11 MPa). It has been used in road construction on soft soils, widening of highways, light embankments of bridge/viaduct and rail embankments, pipeline protection, buried pipelines and structures, slope stabilization, stadium / theater seating / bleachers, dams, airports and taxiways in general as well as other specialized applications (Vaslestad 1990; Roh et al. 2000; Yang and Yongxing, 2005; Gu et al. 2005; Zhang et al. 2006; Avesani Neto 2008; Sun et al. 2009; Mcguigan and Valsangkar 2010; Jafari 2010; Stark et al. 2012; Bartlett et al. 2015).

EPS began to be used in 1960, when the Norwegian Road Research Laboratory introduced its use in soft landfill construction. Since then, the material has become a notable option and with increasing use in various geotechnical works (Trandafir et al. 2010). In addition to the characteristics already mentioned, it is worth mentioning that the use of EPS provides great durability to the work, adequate performance and in many cases economy, speed of execution and lower environmental impacts. When applied in geotechnical works, EPS is subject to dynamic, confinement, compression and constant loading actions (Avesani Neto 2008). In order to ensure the safety of the work, it is necessary to carry out the assessment and analysis of the stability of the material. In particular, the behavior of the material in both mechanical and hydraulic terms as well as exposure to hydrocarbons and weathers should be analyzed. Although there is research on the product, it is clear that the wealth of information about EPS is still restricted to the international context, in particular, in soft landfill applications, bridge and viaduct encounters and pavement bases (see for instance, Stark et al. 2012; Bartlett et al. 2015). In Brazil, few works have been developed on the subject (Horvarth 1994; Avesani Neto 2008).

Since EPS has a small elastic limit (deformations about 1-2%) when compared to traditional construction materials, its stress x deformation behavior is directly influenced by the application speed of the loads. In this sense, in order to understand how the material behaves in axial stresses at different loading levels, this work evaluated and compared parameters of uniaxial compression strength (UCS) of expanded polystyrene (EPS) with different densities when submitted to different execution speeds.

2. MATERIALS AND METHODS

Uniaxial compression tests were performed in EMIC universal machine standardized by ASTM 1621 - 2000, in order to

obtain stress versus strain curves (Figure 1). The tests were carried out at the geotechnical laboratory of Bauru School of Engineering (UNESP).
Four different specific masses (14.5, 18.0, 28.0 and 33.5 kg/m^3) of national origin were used and five specimens were used for each test. The specimens used were measured and chosen manually and all had a cubic shape, whose edge was 100 mm. Two different test speeds were used: 10 and 50 mm/min. The parameters of resistance and modulus of elasticity were obtained considering the elastic limit (obtained by the change of inclination of the stress x strain curve) and at the maximum test limit adopted (28%). This strain value (28%) allows a large visualization of the stress x strain curve of the material. The material would continue to deform if an initial value was not established, as shown by Horvath (1994).

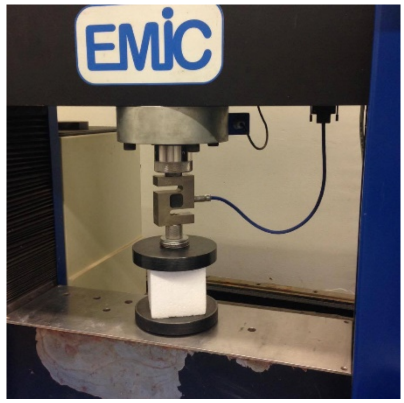

Figure 1. Specimen compressed in uniaxial compression test.

3. RESULTS AND ANALYSES

The results obtained from the stress versus strain curves for the tests performed at 10 and 50 mm/min are shown in tables 1 and 2, respectively.

Table 1. Average values obtained from uniaxial compression tests with 10 mm / min execution speed.

ρ (kg/m³)	$\sigma_{esc.}$ (kPa)	$\varepsilon_{esc.}$ (%)	E_{tang} (kPa)	σ_{final} (kPa)	ε_{final} (%)
14.5	60.65	6.00	1010.87	96.48	27.95
18	77.41	4.88	1585.63	112.4	28.03
28	179.59	6.24	2876.02	248.1	27.16
33.5	185.69	5.15	3603.26	274.8	25.99

ρ = specific mass; σ_{esc} = yield stress; ε_{esc} = specific yield strain; E_{tang} = tangent or initial modulus of elasticity; σ_{final} = stress obtained at the end of the test; ε_{final} = specific deformation at the end of the test.

Tabela 2. Average values obtained from uniaxial compression tests with 50 mm / min execution speed.

ρ (kg/m³)	$\sigma_{esc.}$ (kPa)	$\varepsilon_{esc.}$ (%)	E_{tang} (kPa)	σ_{final} (kPa)	ε_{final} (%)
14.5	56.28	3.29	1710.49	106.60	33.41
18	99.31	3.76	2637.93	161.10	31.06
28	151.72	4.00	3793.10	230.80	31.53
33.5	182.07	3.76	4836.21	269.90	31.81

ρ = specific mass; σ_{esc} = yield stress; ε_{esc} = specific yield strain; E_{tang} = tangent or initial modulus of elasticity; σ_{final} = stress obtained at the end of the test; ε_{final} = specific deformation at the end of the test.

Analyzing the data in table 1, we notice an increase in yield stress (σ_{esc}) and stress at the end of the test as the specific mass of the sample increases. The same behavior occurs for the modulus of elasticity of the material (E_{tang}). On the other hand, a pattern cannot be perceived linking the flow (ε_{esc}) and final (ε_{final}) deformations and the specific masses.
Analyzing the stress x strain curves (see for instance, Figure 2) it is verified that the studied material presents an elastic phase about to 5-6% average deformations. These values are larger than the common values reported in the literature (e.g., Horvath 1994, Avesani Neto 2008, Stark et al. 2012 and Bartlett et al. 2015). It is probably that the difference is due to the fact that these values are obtained directly from the curve. Then, we notice a plastic behavior that reaches deformations of 28% (reference value for measurements above the plastic limit of the material, which in this case occurs after 5-6% of deformation). A fixed deformation value is adopted since the plastic phase ends only when the load application is ceased.

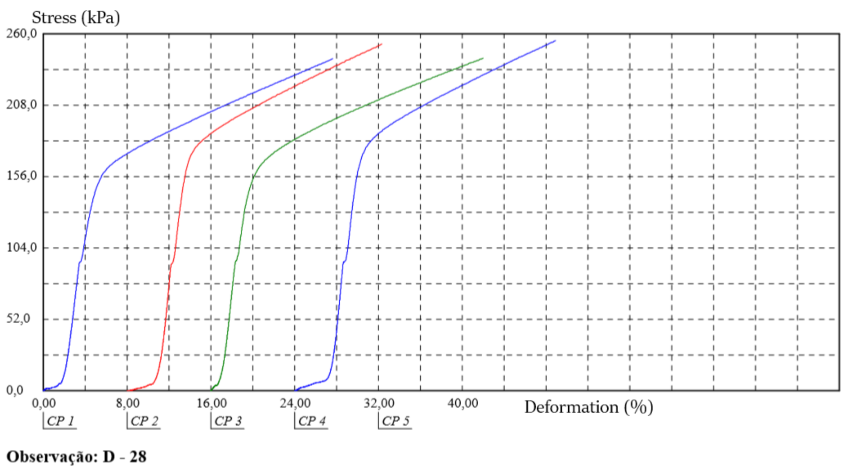

Figure 2. Stress *versus* strain curves - 28 kg/m^3.

The same behavior observed in the v = 10 mm/min test is also observed in the v = 50 mm/min test. The proportional relationship between yield and final stresses as well as the modulus of elasticity with the specific mass of the material remains the same. Regarding the yield and final deformations, they still do not have a direct relation with the EPS density. In general, when making a comparative analysis between the tests performed at different speeds, we notice a variation between the values obtained from the resistance parameters, however, it is not possible to establish a pattern between them. In general, the values of yield stress (σ_{esc}) and final stress (σ_{final}) of 14.5 and 18 kg/m³ increased comparing the tests with v = 10 mm/min and v = 50 mm/min, except of the σ_{esc} of 14.5 kg/m³, which had its value slightly reduced. For the 28 and 33.5 kg/m³ the yield stress, final stress and yield strain values (ε_{esc}) were relatively reduced. The tangent modulus of elasticity (E_{tang}) showed a standard behavior. When increasing the speed of the test, its value showed slight increases for the four densities. All these results are in agreement with the current literature (see for instance Horvath 1994 and Avesani Neto 2008).

4. FINAL REMARKS

In summary, the main conclusions of this article were:

• There is a proportionality relationship between the EPS specific mass and its strength considering yield and final stress, i.e., as density increases, resistance also increases;
• From the values obtained from the modulus of elasticity in the elastic limit, EPS can be considered a high strength material;
• EPS rigidity is related to its specific mass. The higher the density the greater the stiffness of the material;
• As the speed of running the uniaxial compression test increases, the initial modulus of elasticity of the material also increases and,
• In general, the test speeds used in this study presented little influence on the values of the strength parameters of the single compression test.

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