SHEAR TESTS ON EPS BLOCKS JOINT TO GEOTECHNICAL USE

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Abstract: Expanded polystyrene (EPS) has been recently introduced in Brazil as lightweight material for construction of embankments on soft soils and bridge abutments. Despite this fact there is no consolidated experience in testing of this product from a geotechnical point of view in this country. This paper presents the first research data on joint shear laboratory tests. The samples had densities of 10, 20, 30 and 40 kg/m³ for virgin material and 10 kg/m³ for recycled material. The joint direct shear tests show that the samples have a significant value of peak and residual friction angle, variable with the density and distinct behaviours with this variable.

Keywords: EPS geofoam, laboratory tests, properties, shear behaviour, friction.

INTRODUCTION

The application of expanded polystyrene (EPS) and extruded polystyrene (XPS) in civil engineering has a wide acceptance in building by its high thermal capacity, acoustic insulation and absorption of impacts and settlements. But its use as a geosynthetic (on and in the ground) has just a recent application.

In geotechnical engineering this material, manufactured in prismatic blocks called geofoam, has properties that allow its use in many applications. The low density EPS (density about 100 times lower than the density of soil, as a result of its manufacturing process) and a relatively high mechanical strength, offers the geofoam a big variety of applications in embankments, especially in areas with soft soils consisting of a low bearing capacity. Consequently, it is expected that the geofoam can resist loads, for example in landfills, and does not affect the foundation soil. Besides this "classic" application, the EPS geofoam can also be used as a base and sub-base of road pavements, for the alleviation of pressures on walls and slopes, for infrastructure protection and for bridge abutments.

In these applications, the EPS blocks can have a range of properties. Thus, it is necessary to study the response of the material used in each application.

There are two modes of shear that are of interest regarding the EPS blocks. Internal block shear, to ensure that there is no collapse of the blocks, which is not frequent, and the shear of the interface between blocks (joint), which is an important factor of stability in works with horizontal foundations (Horvath 1994).

Thus, an experimental program was performed. The response of EPS was assessed through joint direct shear testing. With this procedure, there was a comparative study of the shear behaviour dependent on the density of the EPS geofoam, with the objective of determining possible relationships to predict the behaviour of the material, expanding its study and improving to understand the behaviour of EPS.

LABORATORY TESTS

Samples

The EPS blocks used in this research had been chosen in accordance with its density to enclose most of the values used in practice (between 10 and 30 kg/m³). It was carried out testing also EPS blocks containing recycled materials and EPS blocks of a higher density in order to study materials with properties that may have future utility.

All samples were placed in a acclimatized room with a temperature of 23 °C and relative humidity of the air of 50% for a period of at least 24 hours. After this acclimatization, all the samples had been weighed with a precision of a thousandth of gram and duly measured for the determination of the volumes and densities in accordance with norm ASTM C 303, 1996. The Table 1 displays all statistics of the measurements made for all tested samples. Note that the values of density have a small variation between samples. This variation is perfectly acceptable in the conduction of the tests.

Table 1. Statistics of EPS samples

Nominal density (kg/m³)	Density (kg/m³)			S. D.	C.V. (%)
	Max.	Min.	Aver.		
10 (recycled)	15.40	12.00	13.03	0.58	4.42
10	13.10	10.30	11.69	0.65	5.58
20	25.50	20.70	22.18	1.18	5.34
30	38.60	30.30	33.19	1.95	5.88
40	43.70	38.60	41.03	2.03	4.95

Joint Direct Shear

The Direct shear testing of soils described in the standard ASTM D 3080 (1998), however, some changes were made in these tests.

For the realization of the joint direct shear test, two plates of the material were put in contact with a confining stress on top of the upper plate. For the execution of the test, a shift between the plates was applied. The simultaneously measuring of the strength and the displacement was made. This test was performed with the typical equipment for testing of soils. Figure 1 shows the equipment used.

Figure 1. Direct shear test equipment

Figure 2 shows the sequence of the tests sample installation: The box for the test (a), the sample of EPS placed on the bottom of the box (b), the top of the box for the application of displacement with the EPS sample (c), the rod for the implementation of the confining stress (d), with the test ready to start.

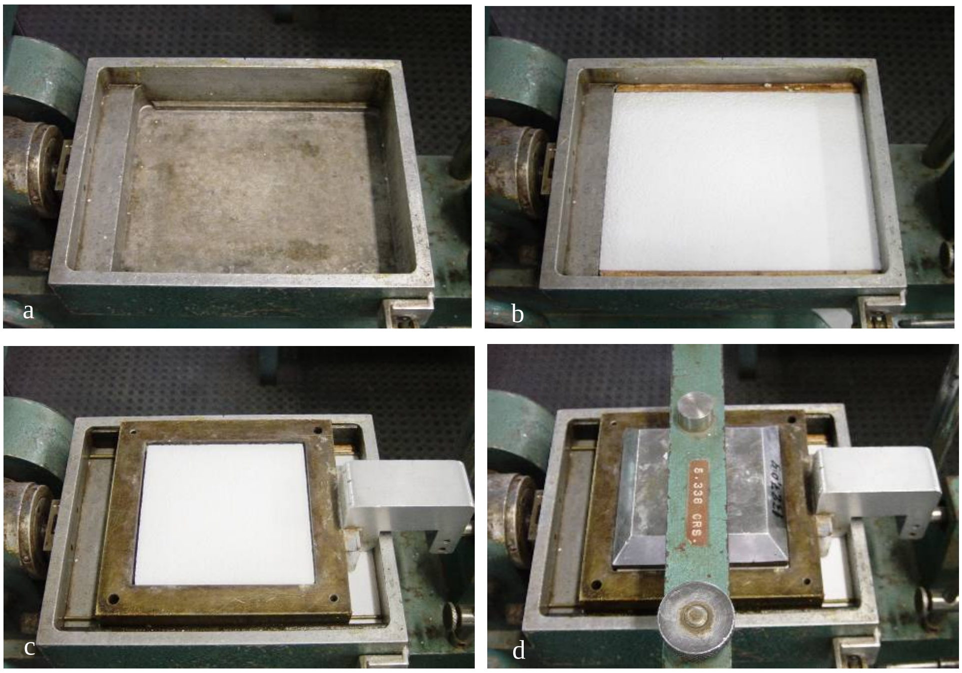

Figure 2. Steps of the shear test installation

The confinement tensions used had been chosen (10, 20, 30, 40, 50 and 60 kPa) in order to represent the field situations. The speed of the test was 0.50 mm/min, which is identical with the speed used for the shear tests of soils.

The samples used in the testing of the joint direct shear and the loads of confining stress are represented in **Table 2**.

Table 2. Density of the samples and confining stress

Nominal density (kg/m³)	Confining stress (kPa)
10	10, 20, 30 and 40
20	10, 20, 30 and 40
30	10, 20, 30, 40, 50 and 60
40	10, 20, 30, 40, 50 and 60

10 (recycled)	10, 20, 30 and 40

RESULTS

The results obtained with the joint direct shear testing in EPS samples of 10 (with virgin and recycled material), 20, 30 and 40 kg/m can be seen in Figures 3 to 8.

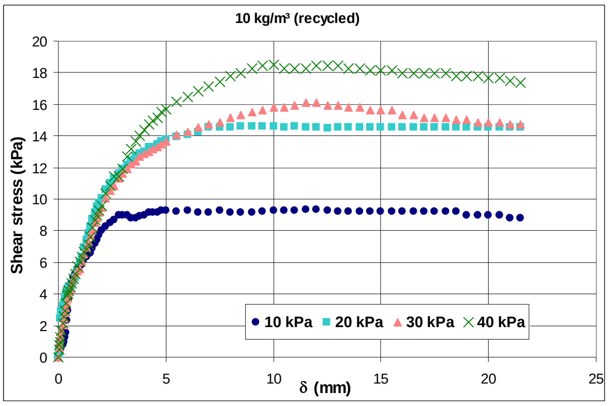

Figure 3. Direct shear in the 10 kg/m³ (recycled) EPS sample

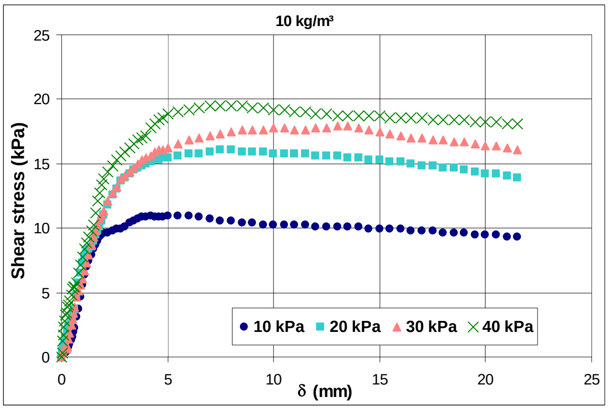

Figure 4. Direct shear in the 10 kg/m³ EPS sample

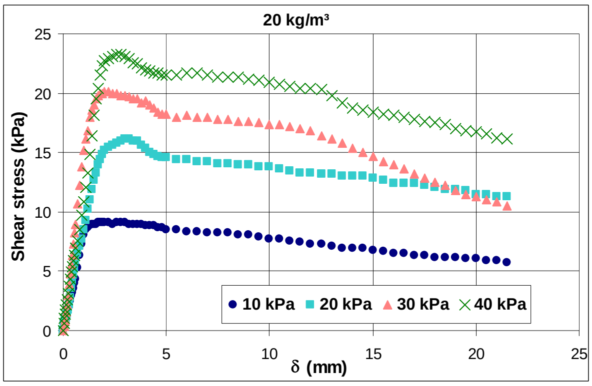

Figure 5. Direct shear in the 20 kg/m³ EPS sample

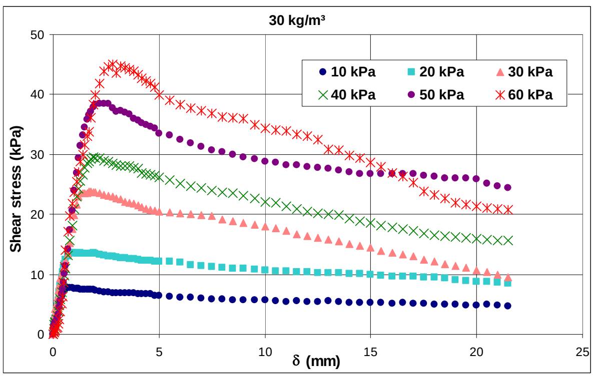

Figure 6. Direct shear in the 30 kg/m³ EPS sample

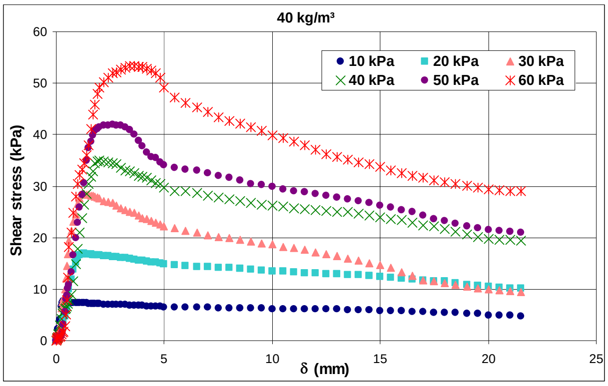

Figure 7. Direct shear in the 40 kg/m³ EPS sample

The EPS behaviour in the shearing is similar to the behaviour of soil samples, as seen in these figures. There is a peak value to the shear stress, similar to over consolidated soils, followed by a reduction of shear stress due to changes in the contact surface area of the blocks for the sample with higher densities (20, 30 and 40 kg/m³) . However, for the samples with a lower density (10 kg/m³ virgin and recycled), the behaviour is similar to normally consolidated soil, without a peak value.

With the tests data, two failure envelopes were drawn for each material: one with the peak friction angle, which was given at the peak shear stress defined as the maximum shear stress, and another with the residual friction angle, with a value of the shear stress corresponding to a displacement of 15 mm. Figures 8 and 9 show the failure envelopes for the average peak and the residual friction angles for each sample, respectively.

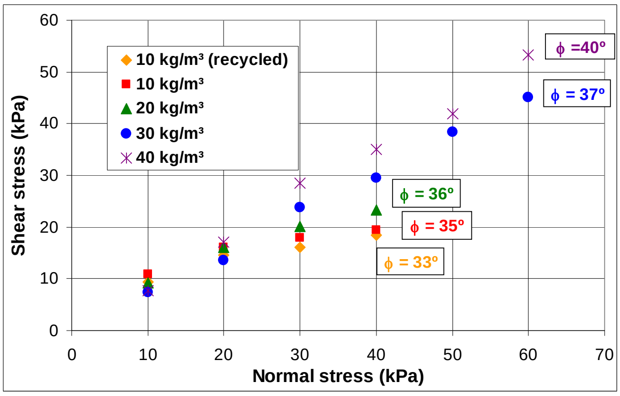

Figure 7. Failure envelopes of EPS samples for the peak condition

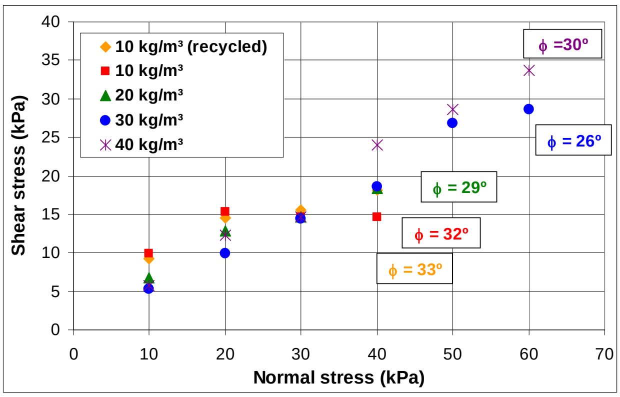

Figure 8. Failure envelopes of EPS samples for the residual condition

The angles of friction obtained for all samples are relatively high, both for the state of peak stress and the residual stress, with values around 40 ° at the peak stress and 33 ° at the residual stress. Comparing the values of friction angles of the samples in each case, we can note a visible increase of its value with the increase of the density for the peak condition. In contrast, for the residual value there is a reduction in the friction angle with increasing density of the samples.

To facilitate viewing of failure envelopes obtained from Figures 8 and 9, the same analyse were made using a linear approximation between the values obtained in the tests, in each sample. Figures 10 and 11 show these results.

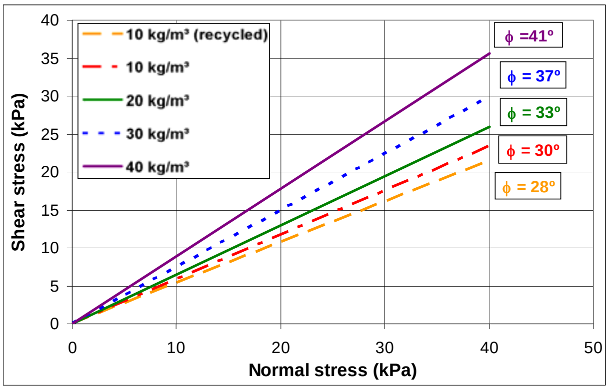

Figure 10. Failure envelopes of EPS samples for the peak condition with a linear approximation analyse

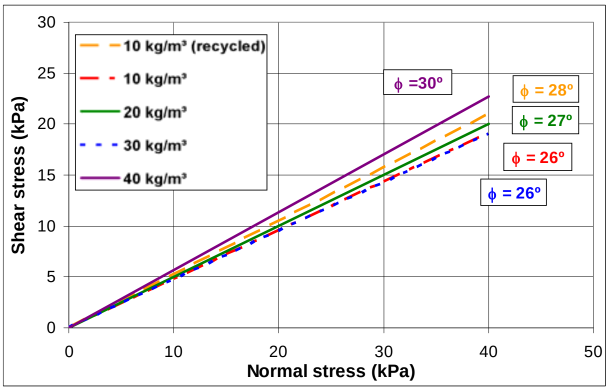

Figure 119. Failure envelopes of EPS samples for the residual condition with a linear approximation analyse

From these figures it can be seen that the values of the friction angles obtained by a linear approximation differ from those previously determined. This difference is the result of the variation in procedures between the linear approximation and simple arithmetic average. This difference in the result is more significant for lower values of specific mass. In this analyse, we can see clearly an increase of the friction angle with an increase of density.

Comparing the results obtained between the friction angles, we can note a considerable reduction of it for samples with higher density. Table 3 shows this reduction of friction angle.

Table 3. Comparison between peak and residual friction angles

Nominal density (kg/m³)	Peak friction angle	Residual friction angle	Reduction (%)
10 (recycled)	33	33	0.0
10	35	32	8.6
20	36	29	19.4
30	37	26	29.7
40	40	30	25.0

From this table, we can observe a bigger reduction of the sample with a density of 30 kg/m³, the low reduction of the sample with a density of 10 kg/m³ of virgin material and the conservation of the value of friction angle in the sample containing recycled material. The explanation is due to the contact surface of the material containing recycled EPS (and the sample of 10 kg/m³ virgin), which keeps the roughness of the surface further, preventing the formation of a region of lower efficiency of friction between the contacts of the blocks, and keeping the value of the shear stress for larger displacements.

Analysing the results we can observe that there is a proportionality between the friction angle obtained and the density of the material. For higher values of density, there is an increase in the angle of friction peak, and reduction in the residual. Thus it was possible to determine a relationship between the average of friction angle (both peak and residual) of each sample and the average of density. These relationships provided a linear correlation between these two variables. Figures 12 and 13 display the curves obtained for the situation of peak and residual respectively, and the equation of better adjustment.

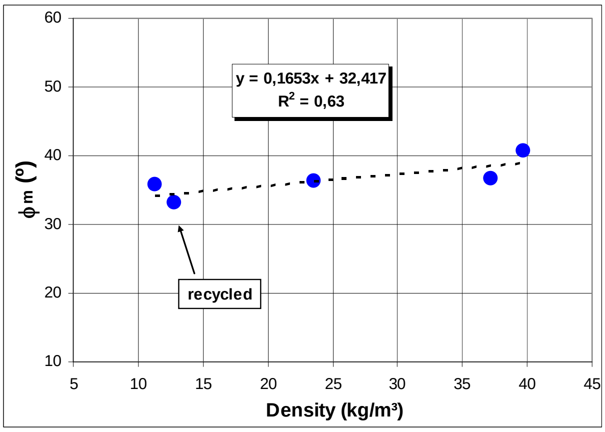

Figure 1210. Relationship between peak friction angle and density

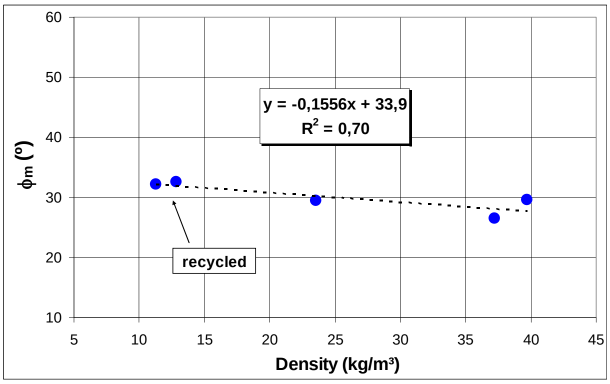

Figure 13. Relationship between residual friction angle and density

From these figures, we can notice the proportionality between the friction angle and density. The recycled material, despite of consisting a higher density, has poor mechanical characteristics compared with the virgin material

CONCLUSION

Direct shear tests of EPS block joint tests were made with samples consisting densities of 10 (virgin and recycled), 20, 30 and 40 kg/m³, with the aim of relating the materials and tests to geotechnical applications.

The main conclusions of this paper are:

- The direct shear test of the joint showed that the behaviour of high density EPS is similar to that of over consolidated soil samples with a peak value of friction angle between 35° and 40 °. For the lower density EPS blocks, the behaviour is similar to that of normally consolidated soils, with a residual friction angle between 33° and 35 °;
- It was observed that the shear resistance (and consequently the friction angle and the failures envelopes) is directly proportional to the density;
- The reduction of the friction angle values from the peak to residual condition is high in EPS samples, showing decreases of up to 30 %. This reduction was more significant for higher density.

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