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# Evaluation of the interface strength of expanded polystyrene (EPS) with sandy and clayey soils

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ABSTRACT
Expanded polystyrene (EPS) is widely used in works where there are soils with low support capacity, bridges and/or viaducts and road widening. This is due to its properties such as low specific mass, high strength and low compressibility to high EPS specific masses. Therefore, it is widely used in conjunction with soils. By analyzing the possibilities of rupture, it is observed that the greater probability of failure occurs at the interface between the materials. In this way, it is essential to analyse the direct shear parameters, especially the interface friction, in order to verify external and internal stabilities by the action of horizontal loads. Thus, this work evaluated the shear strength parameters of EPS in different specific masses (18, 28 and 33.5 kg/m³) with sandy and clayey soils interfaces measured at the optimum water content obtained by the compaction test (Standard Proctor). In the laboratory, specific mass tests for characterization and direct shear tests at EPS/Soil interfaces according to ASTM D3080 (shear box of 100x100 mm) were performed. Five normal stresses (11, 22, 33, 44 and 55 kPa) and speed of 0.2 mm/min were applied. Peak shear stresses were evaluated by two ways: peak stress as the changing stress from elastic to plastic (inflection of stress versus displacement curve) and peak as the maximum stress obtained in the test. The main results show an increasing trend of interface friction with the increase of the specific mass of the EPS.

KEYWORDS: Expanded Polystyrene, Shear Strength Interface, Sandy Soil, Clayey Soil, Peak Stress

## 1. INTRODUCTION

Many works have been conducted on EPS/EPS interfaces to evaluate its shear stress proprieties (SHEELEY, 2000; ATMATZIDIS et al., 2001; NEGUSSEY et al., 2001; SHEELEY & NEGUSSEY, 2004). Sheeley (2000) and Atmatzidis et al. (2001) used direct shear tests to determine the frictional behavior of EPS/EPS interfaces. Sheeley & Negussey (2004) have been performed EPS/EPS friction tests in both dry and wet conditions. However, according to Padade & Mandal (2012), analyzing the direct shear properties of EPS on other interfaces are also important, because the results may be different.
The main geofoam aplications involve road constructions on low support capacities soils, road widening, and light bridge/viaduct meeting landfills (AVESANI NETO, 2008; JAFARI, 2010; STARK et al. 2012; BARTLETT et al. 2015). Under these conditions, geofoam may be subject, according to Horvat (2001), to both internal shear and interface shear (relative to the displacement between the EPS and other material). However, according to Padade & Mandal (2012), in cases with horizontal loads, the rupture plane where there is a higher probability of failure is at the interface between the materials. Thus, it is important to evaluate the direct shear parameters (adhesion and friction angle) between the EPS and other materials (specially soils), aiming to verify the stability due to the action of normal loads at EPS plane. Therefore, this work evaluated the shear stress parameters of EPS in different specific masses (18, 28 and 33.5 kg/m³) with clayey and sandy soils interfaces measured at the optimum water content obtained by the compaction test (Standard Proctor).

## 2. MATERIAL AND METHODS

In this work, 100x100 mm EPS samples in three different specific masses (18, 28 and 33.5 kg/m³) and sandy and clayey soils of Bauru region (SP, Brazil) were used.

### 2.1 *Soil characteristics*

The soil particle size analysis, specific mass of solids and compaction (Standard Proctor) tests were performed following, respectively, the ABNT NBR 7181 (2016), ABNT NBR 6508 (1984) and ABNT NBR 7182 (2016) standards.

### 2.2 *Molding of soil*

The soil specimens were molded considering the values of maximum dry specific mass and the optimum water content (Table 2) from the compaction test (Standard Proctor). A maximum difference of 1% of soil moisture was considered in relation to the optimum water content. Furthermore, It was adopted a 95% degree of compaction.

During the direct shear test, a slip occurs between the materials that are placed between the two metallic cells of the test (Figure 1). Therefore, molds (for the execution of soil specimens) have been designed with specific dimensions to ensure that the contact between the EPS and the soil occurs in the region where the materials will slip, as shown in Figure 1, ensuring all the necessary conditions for joint shear to occur.

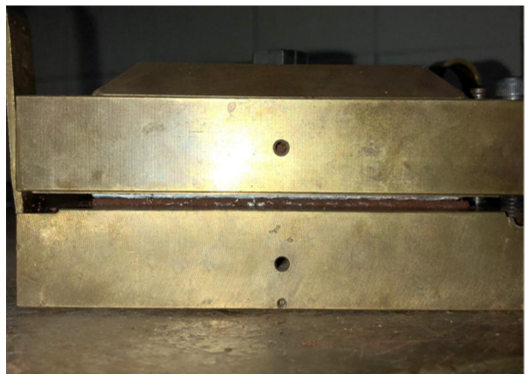


Figure 1. Shear zone: where a slip occurs between the materials (EPS/soil interface).

### 2.3 *Specific Mass Test*

Initially, both samples were measured with the aid of a digital caliper and their respective masses were determined using an analytical balance. Thus, it is possible to calculate the average specific mass of the samples and their standard deviation to compare the results obtained with the nominal values provided by the local supplier (18, 28 and 33.5 kg/m³), in order to verify possible variations of EPS density and determine the EPS shear stress behavior considering its actual specific mass.

### 2.4 *Direct Shear Test*

The direct shear test is standardized by ASTM D 3080-98 (shear box of 100x100 mm). There were considered five normal stresses of 11, 22, 33, 44 and 55 kPa and speed of 0.2 mm/min. The equipment is show in Figure 2.

Figure 2. Equipment used in direct shear tests.

A data acquisition system based on LabVIEW software was used. Peak shear stresses relative to the elastic to plastic behavior change in the shear stress versus displacement curve were evaluated. This consideration has been adopted because is not ideal for EPS to achieve the plastic regime. However, for comparison purposes, the friction angles for the peak situation were also determined considering the shear stress as the maximum occurred in the test. The failure envelopes were plotted for each peak situation and their shear parameters (adhesion and friction angle) were determined. In addition, the percentage variation of the friction angles for the two peak situations was calculated and the $R^2$ factors of the failure envelopes were also determined.

## 3. RESULTS OBTAINED

### 3.1 *Soil characteristics*

Fagundes (2014) and Castilho (2017) made researches involving the same soils used in this work. Their results of soil characterization (soil classification and their properties) are summarized in Tables 1 and 2.

Table1. Particle size of the soils.

| Material | Sandy soil | Clayey soil |
|---|---|---|
| Coarse gravel (%) | 0.0 | 0.0 |
| Medium gravel (%) | 0.0 | 0.0 |
| Fine gravel (%) | 0.0 | 0.0 |
| Coarse sand (%) | 0.3 | 0.0 |
| Medium sand (%) | 41.7 | 1.5 |
| Fine sand (%) | 38.2 | 42.5 |
| Silt (%) | 5.8 | 12.0 |
| Clay (%) | 14.0 | 44.0 |

Table 2. Soils properties.

| Parameters | Sandy soil | Clayey soil |
|---|---|---|
| Optimum water content (%)* | 10.6 | 16.1 |
| Maximum dry specific mass (g/cm³) * | 1.950 | 1.837 |
| Solids specific mass (g/cm³) | 2.649 | 2.688 |
| Void ratio | 0.358 | 0.463 |
| Porosity (%) ** | 26.4 | 31.7 |
| Saturation degree (%) * | 78.4 | 93.4 |

Observations: *Standard Proctor; ** parameters measured in soil compaction

### 3.2 *Specific Mass*

Table 3 summarizes the results of the mean specific masses and their respective standard deviations for each EPS nominal specific mass.

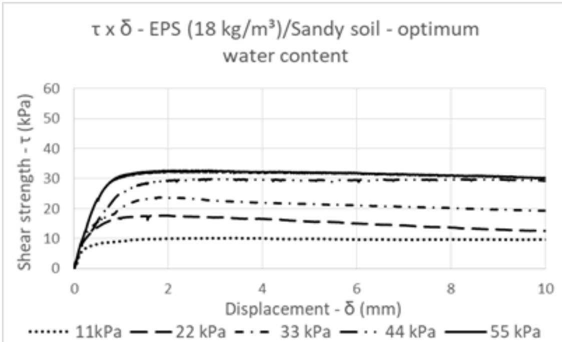
Table 3. Real specific masses.

| | ρ | | |
|---|---|---|---|
| | 18 | 28 | 33.5 |
| ẋ | 17.04 | 24.52 | 30.13 |
| s | 0.51 | 1.05 | 1.84 |

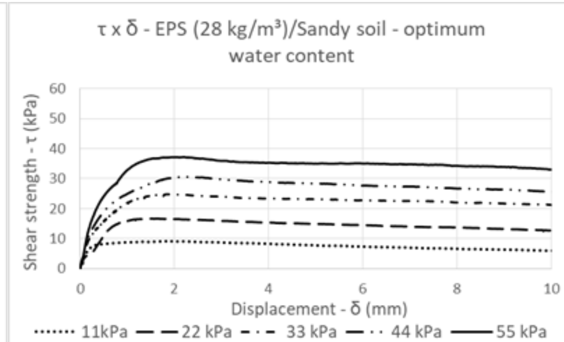
ρ: nominal specific mass (kg/m³); ẋ: mean specific mass (kg/m³); s: standard deviation (kg/m³)

### 3.3 *Shear Stress versus Displacement Curves*

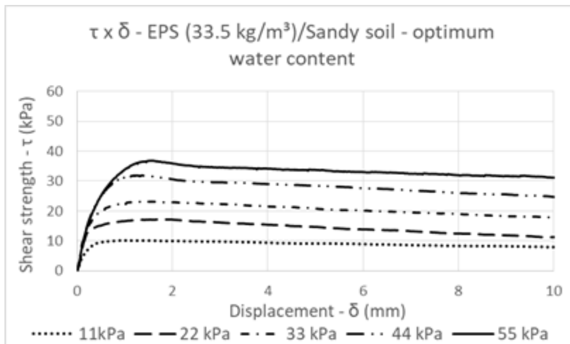
The shear stress versus displacement curves for the sandy and clayey soils are shown, respectively, in Figures 3 and 4.



(a) EPS 18 kg/m³

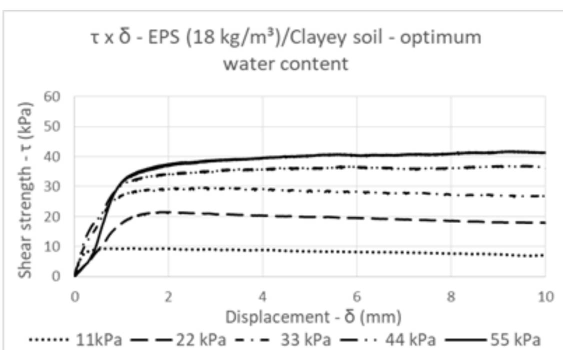


(b) EPS 28 kg/m³

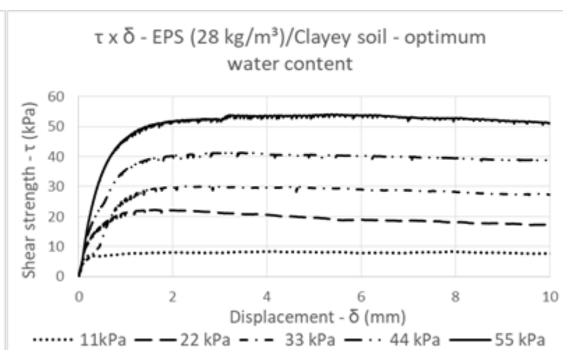


(c) EPS 33.5 kg/m³

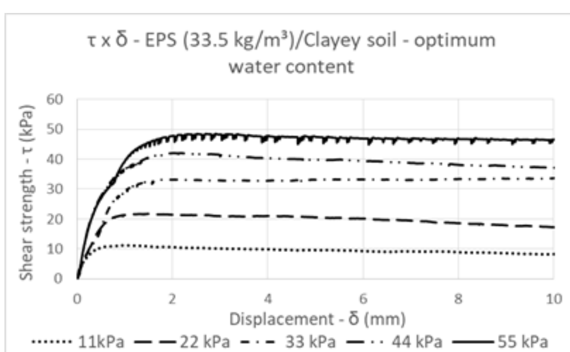
Figure 3. Shear stress versus displacement curves - EPS/Sandy soil (optimum water content).



(a) EPS 18 kg/m³



(b) EPS 28 kg/m³

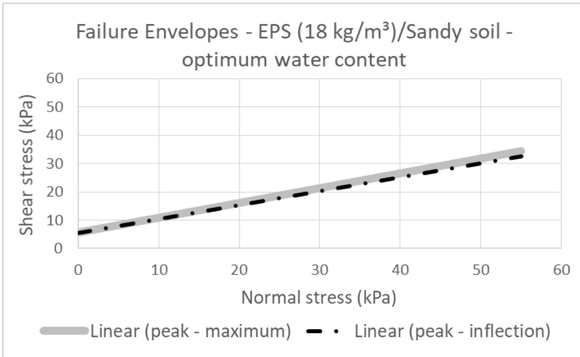


(c) EPS 33.5 kg/m³

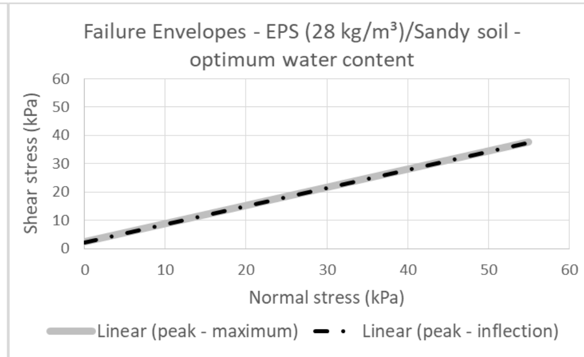
Figure 4. Shear stress versus displacement curves - EPS/Clayey soil (optimum water content).

### 3.4 *Failure Envelopes*

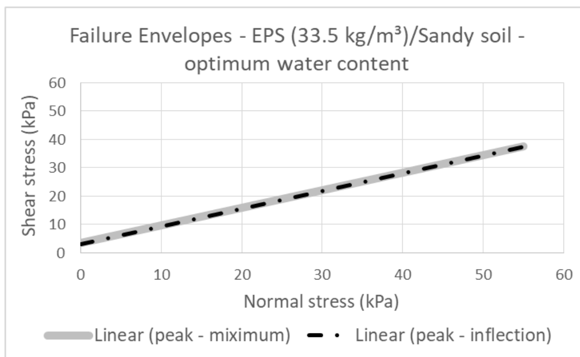
Figures 5 and 7 show de failure envelopes for each soil considering each EPS specific mass. In addition, Figures 6 and 8 show the failure envelopes for each peak situation of each soil, aiming to verify the influence of EPS specific mass on the interface resistance.




(a) EPS 18 kg/m³

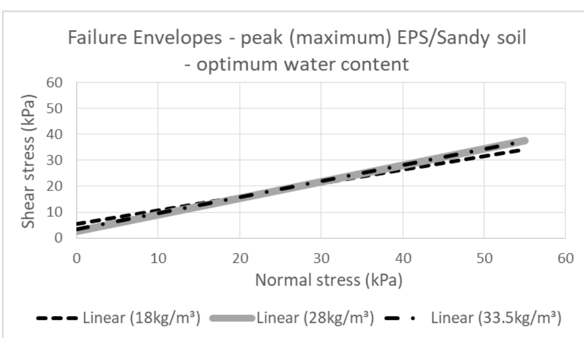



(b) EPS 28 kg/m³

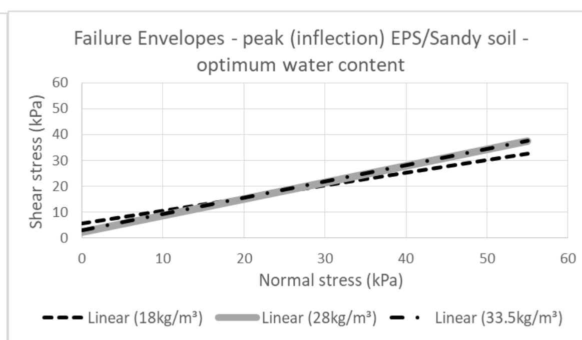



(c) EPS 33.5 kg/m³

Figure 5. Failure envelopes - EPS/Sand soil (optimum water content).

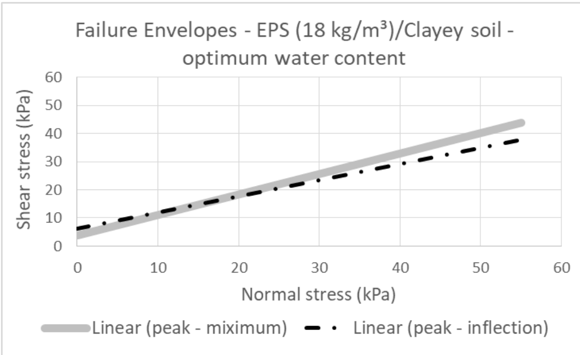



(a) Peak - maximum

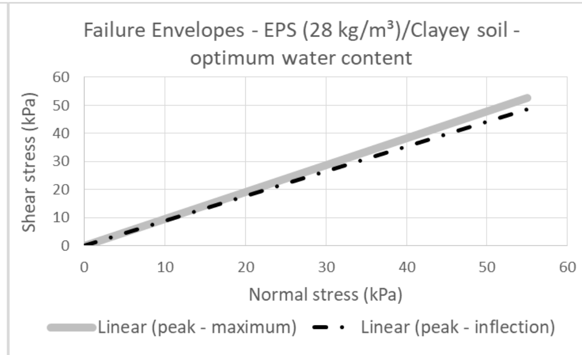



(b) Peak - inflection

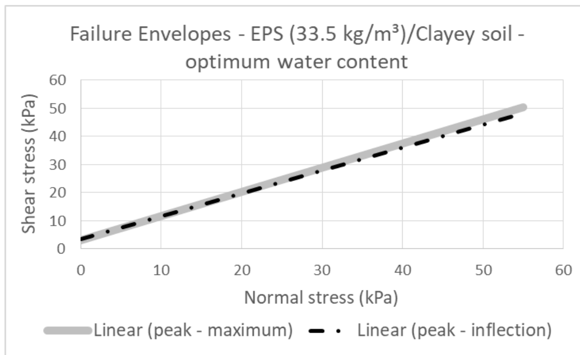
Figure 6. Failure envelopes - EPS/Sand soil (optimum water content) - verification of the EPS specific mass influence.




(a) EPS 18 kg/m³

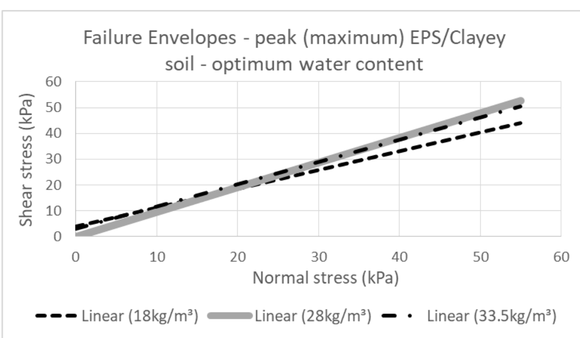



(b) EPS 28 kg/m³

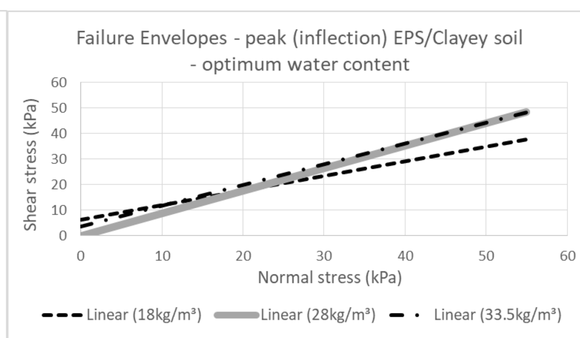



(c) EPS 33.5 kg/m³

Figure 7. Failure envelopes - EPS/Clayey soil (optimum water content).




(a) Peak - maximum




(b) Peak - inflection

Figure 8. Failure envelopes - EPS/Clayey soil (optimum water content) - verification of the EPS specific mass influence.

## 3.5 *Direct Shear Parameters*

Tables 3 and 4 summarize the parameters obtained from the shear tests (adhesion and friction angle) for each interface.

When the friction angle considering peak stress as the maximum shear stress is greater than that which considers the stress at the inflection point of shear stress versus displacement curve, the percentage difference between these friction angles is positive.

This comparison was performed in order to verify the divergence between the two ways adopted to determinate the interface friction.

Table 3. Direct shear parameters for EPS/Sandy soil interface – optimum water content

| ρ | 18 | | 28 | | 33.5 | |
|---|---|---|---|---|---|---|
| τ | $\tau_{pm}$ | $\tau_{pi}$ | $\tau_{pm}$ | $\tau_{pi}$ | $\tau_{pm}$ | $\tau_{pi}$ |
| a | 5.6 | 5.5 | 2.6 | 2.2 | 3.4 | 3.0 |
| ϕ | 27.6 | 26.2 | 32.5 | 32.7 | 31.8 | 32.1 |
| $R^2$ | 0.98 | 0.96 | 1.00 | 0.99 | 1.00 | 1.00 |
| | DIFFERENCE (%) OF FRICTION ANGLE BETWEEN THE PEAK CASES | | | | | |
| | 5.1 | | -0.6 | | -0.9 | |

ρ: nominal specific mass (kg/m³); a: adhesion (kPa); ϕ: friction angle (º); τ: shear stress; $\tau_{pm}$: peak stress – maximum; $\tau_{pi}$: peak stress – inflection

Table 4. Direct shear parameters for EPS/Clayey soil interface – optimum water content

| ρ | 18 | | 28 | | 33.5 | |
|---|---|---|---|---|---|---|
| τ | $\tau_{pm}$ | $\tau_{pi}$ | $\tau_{pm}$ | $\tau_{pi}$ | $\tau_{pm}$ | $\tau_{pi}$ |
| a | 3.7 | 6.3 | 0.0 | 0.0 | 2.9 | 3.6 |
| ϕ | 36.2 | 29.7 | 43.8 | 41.4 | 40.8 | 39.0 |
| $R^2$ | 0.97 | 0.92 | 0.99 | 0.99 | 0.99 | 0.98 |
| | DIFFERENCE (%) OF FRICTION ANGLE BETWEEN THE PEAK CASES | | | | | |
| | 18.0 | | 5.5 | | 4.4 | |

ρ: nominal specific mass (kg/m³); a: adhesion (kPa); ϕ: friction angle (º); τ: shear stress; $\tau_{pm}$: peak stress – maximum; $\tau_{pi}$: peak stress – inflection

## 4. DISCUSSION

The main topics to be analyzed are:

- According to ABNT (in references), the soils were classified as fine-grained lateritic soils (medium to fine sand slightly clayey and sandy clay);

- The real specific masses of the EPS specimens are similar to the nominal values provided by the local supplier;

- Regarding the analyzed EPS samples, the greater the specific mass, the greater its surface resistance is. Since friction is a force that resists the relative movement of solid surfaces, there is a tendency of interface friction increase when specific mass increases. As shown in Tables 3 and 4, the friction angle values at the 18 kg/m³ EPS interface are the smallest. However, since the two highest densities are very similar, the values of friction angles are very close;

- Moreover, it is found that the values obtained for both sandy and clayey soils are relatively elevated. The lowest value observed was 26,2º considering the sandy soil and the 18 kg/m³ EPS. The values obtained for the clayey soil were extremely high considering the highest densities (28 and 33.5 kg/m³). These values corroborate the current literature and show that the EPS presents a good behavior when in contact with these two types of local soils;

- The most recommended way to determinate the peak stress is the one which considers the peak as elastic to plastic change behavior (inflection of the shear stress versus displacement curve), since EPS will not be fully plasticized. However, the determination of this tension is visual and may be inaccurate. For this reason, the peak stress as the maximum value was used to determine the shear parameters too (it is expected that the values obtained by this manner are very similar since the normal stresses acting are low , as shown in Tables 3 and 4).

## 5. CONCLUSIONS

From the results obtained, the main conclusions can be listed:

- Trend of interface friction increases with the increase of EPS specific mass;
- The friction angles obtained considering the peak stress as the inflection stress of shear stress versus displacement curve (elastic-plastic limit) are similar to the friction angles obtained considering peak stress as the maximum obtained at direct shear test;
- The interface friction values were relatively high, showing values above 40º for EPS/Clayey soil interface (considering the highest EPS specific mass).

ACKNOWLEDGEMENTS

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ANSWER TO QUESTIONS

The soil classifications are based on ABNT Standards. Probably, this is the reason why they are weird to the reviewer.
Horvath (2001) was mentioned in the references and in the body of text as well