Investigation of the shear behavior of EPS geofoam

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ABSTRACT
Expanded polystyrene (EPS) geofoam has been used in a wide range of geotechnical applications since 1960s. These applications involve the use of geofoam either as a lightweight fill material (e.g. in embankments and bridge approaches) or as a compressible inclusion (e.g. in retaining walls and culverts). In these applications, geofoam is placed directly in contact with other construction materials. Therefore, for successful analysis and design of these composite structures, a detailed knowledge of both compression and shear behavior of the geofoam material as well as the strength of the interface are needed. In the present research, an attempt has been made to determine the shear strength parameters of geofoam monoblocks and the interface strength properties of EPS blocks in contact with other construction materials using direct shear tests (DSTs). Test results showed that both the geofoam density and the applied level of normal stress have significant effects on the shear strength of monoblock as well as the interface properties of EPS geofoam.

RÉSUMÉ
La mousse de polystyrène expansé (EPS) a été utilisée dans une vaste gamme d'applications géotechniques depuis les années 1960. Ces applications impliquent l'utilisation de géomousse soit en tant que matériau de remplissage léger (par exemple dans des remblais et des approches en pont), soit en inclusion compressible (par exemple dans des murs de soutènement et des ponceaux). Dans ces applications, geofoam est placé directement en contact avec d'autres matériaux de construction. Par conséquent, pour une analyse réussie et la conception de ces structures composites, une connaissance détaillée des deux; Comportement de compression et de cisaillement du matériau en géofoam ainsi que la force de l'interface. Dans la présente recherche, nous avons tenté de déterminer les paramètres de résistance au cisaillement des propriétés de la géométrie monobloc et de la résistance de l'interface des blocs EPS en contact avec d'autres matériaux de construction, notamment en effectuant des essais de cisaillement direct. Les résultats des tests ont montré que la densité de la géomousse et la contrainte normale appliquée ont un effet significatif sur les propriétés de monobloc et d'interface de la géomousse EPS.

1 INTRODUCTION

Expanded polystyrene (EPS) geofoam refers to a rigid, air filled closed cell, very lightweight, plastic foam material (Horvath 1992). It is almost 100 times lighter than soil and 10-30 times lighter than other light weight fill materials (Stark et al. 2004). It has become an essential part of the geosynthetic family as suggested by Horvath (Horvath 1991).

The use of EPS geofoam as construction material started around 1960s. Norwegian geotechnical engineers used EPS geofoam in a road project for thermal insulation (Aaboe 2000) and in 1972 geofoam was used as a lightweight fill material to construct embankments on soft soils (Frydenlund 1991). Since then it has been used in many geotechnical engineering applications, most of which involve the use of molded blocks of expanded polystyrene (Horvath 1994). Some of the important application of EPS geofoam as light weight fill material can be found in: slope stabilization, sub base fill material, embankments, earth retaining structures, bridge abutments and bridge approaches, buried pipes and thermal insulation for roads. High compressibility of EPS geofoam also makes it a suitable for use as compressible material in underground applications (Ahmed et al. 2013; Meguid and Hussein 2017; Meguid et al. 2017).

EPS geofoam blocks are usually combined with other construction materials to form a composite section e.g. soil, concrete, wood, PVC, steel, geogrid etc., which is then exposed to static or dynamic loading. Therefore, detailed information of the monoblock and interface shear strength is essentially required for a successful analysis of structures constructed with EPS geofoam and with other interacting materials.

In the past several researchers have investigated the monoblock shear strength and interface shear strength characteristics of geofoam interacting with other construction materials. A brief description from the past studies is presented as follows:

Stark et al. (2004) conducted direct shear test on geofoam samples of varying density and found that geofoam density has a significant effect on material cohesion. Padade and Mandal (2012) also performed shear tests on geofoam samples having density 15 to 30 kg/m^3 and concluded that both cohesion and angle of internal friction are function of geofoam density. Direct shear tests conducted by Özer and Akay (2015) showed that for monoblock, cohesive strength is associated with geofoam density while for a geofoam interface, strength is related to both adhesion and angle of interface friction values. Direct shear tests were also performed on geofoam samples by Abdel Salam and Azzam (2016) both in wet and dry conditions. It was noticed that under same applied normal stress, wet samples showed 30% less strength as compared to dry samples.

A research was conducted by Sheeley and Negussey (2000) on geofoam-geomembrane and geofoam-concrete interfaces showed that smooth geomembrane offer less interface friction in comparison to cast in place concrete interface. A number of direct shear tests were carried out by Chrysikos et al. (2006) and the friction coefficients between geofoam and other materials including, precast and cast-in-place concrete, soils, geomembranes, geotextiles) were found to vary between 0.27 to 1.2. In a similar study, Padade and Mandal (2014) carried out direct shear tests to determine the interface characteristics of geofoam with jute geotextile, fly ash and geogrid. Results showed that increase in geofoam density causes a small increase in adhesion values accompanied with no change in interface friction angle values. A study conducted by AbdelSalam and Azzam (2016) involving direct shear tests performed on geofoam interacting with rough and smooth concrete, concluded that rough concrete offers more interface friction as compared to smooth concrete.

Studies on geofoam-sand interface (AbdelSalam and Azzam 2016; Khan and Meguid 2018; Miki 1996; Xenaki and Athanasopoulos 2001) and on geofoam-geofoam interface (AbdelSalam and Azzam 2016; Barrett and Valsangkar 2009; Kuroda et al. 1996; Padade and Mandal 2014; Sheeley and Negussey 2000; Wagner 1986) have also been reported. In addition, other EPS material properties e.g. Modulus of subgrade reaction (Negussey and Huang 2006), Stress–strain relationships (Hazarika 2006), Resilient modulus (Huang and Negussey 2007) and Compressibility (Leo et al. 2008) have also been investigated by several researchers.

The objective of this study is to determine the monoblock shear strength and shear strength between geofoam and PVC interface. These properties are essentially helpful in designing and analyzing structure constructed with EPS geofoam.

2 EXPERIMENTAL PROGRAM

A detailed laboratory testing program was designed and a series of direct shear tests were conducted to determine the shear strength parameters of monoblock and geofoam-PVC interface.

2.1 MATERIAL PROPERTIES

The materials used in this investigation are EPS geofoam and PVC as shown in Fig.1. Three different samples of geofoam having densities of 15, 22 and 39 kg/m^3 were extracted from large geofoam blocks. PVC (density = 1600 kg/m^3; Tensile strength = 41,368 kPa; water absorption = 0.13%) was cut accurately to be fit into the lower direct shear box.

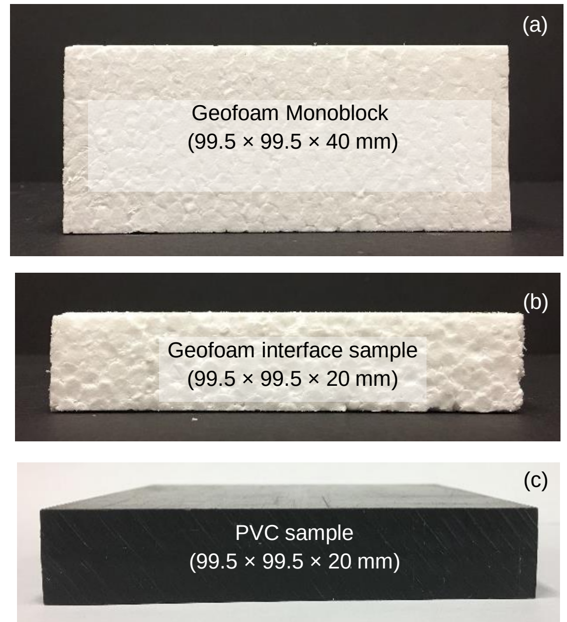

Figure 1: (a) Geofoam monoblock; (b) & (c) geofoam and PVC samples used in the interface tests

2.2 TEST PROCEDURE

Conventional direct shear setup was used to conduct the shear tests as per ASTM D5321-17. A direct shear box of dimensions 100 mm ×100 mm × 50 mm was used. For monoblock geofoam, sample was placed in the shear box and sheared at a constant rate under an applied normal stress range as shown in Fig. 2(a).

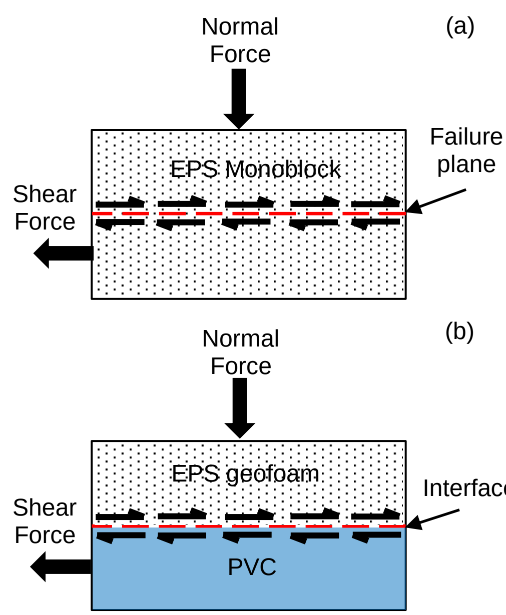

Figure 2: Schematic diagram of (a) Monoblock direct shear test; (b) Interface direct shear test

However, for interface test, geofoam was kept in the upper direct shear box while the PVC sample was positioned in the lower direct shear box as shown in Fig. 2(b). This orientation of samples reduces the chances of tilting that may be faced if the lower sample compresses non-uniformly.

During the test, a horizontal displacement was applied to the lower part of the direct shear box at a rate of 0.9 mm/min while the upper part was fixed. Tests were conducted under 3 different normal stress values of 18, 36 and 54 kPa. Vertical and horizontal displacements were measured with the help of linear variable differential transformers (LVDTs) and the shear force was recorded with the help of a load cell. Tests were stopped when the shear force started to decrease or when the max displacement of direct shear box i.e. 10 mm was reached. According to ASTM D3080-11, peak shear stress could be considered at 10% horizontal strain if no peak is observed.

Cohesion/adhesion and interface friction angles were determined for the investigated materials. Present investigation also includes the effect of density of geofoam and applied normal stress on interface shear strength parameters.

3 RESULTS AND DISCUSSION

A total of 18 direct shear tests were performed: 9 tests for the monoblock and 9 tests for interface. During monoblock shear test, no actual failure was observed except some plastic deformation was observed along the gap between the upper and lower direct shear boxes. However, in interface shear test, the failure plane was found to coincide with the contact surface between geofoam and PVC material as shown in Fig. 2.

3.1 GEOFOAM MONOBLOCK

Relationships between shear stress and horizontal displacement for the case of monoblock geofoam are presented in Fig. 3. Monoblock samples were tested under a normal stress range from 18 to 54 kPa for the three investigated densities. Results showed that for a given geofoam density, under a constant applied normal stress, shear stresses initially increase in a linear fashion with the increase in horizontal displacement. After certain applied horizontal displacement, shear stresses start to change at a very slow rate. It was also observed that for a given horizontal displacement e.g. 2 mm, the average shear stress was found to be 24, 29 and 38 kPa for EPS 15, 22 and 39, respectively.

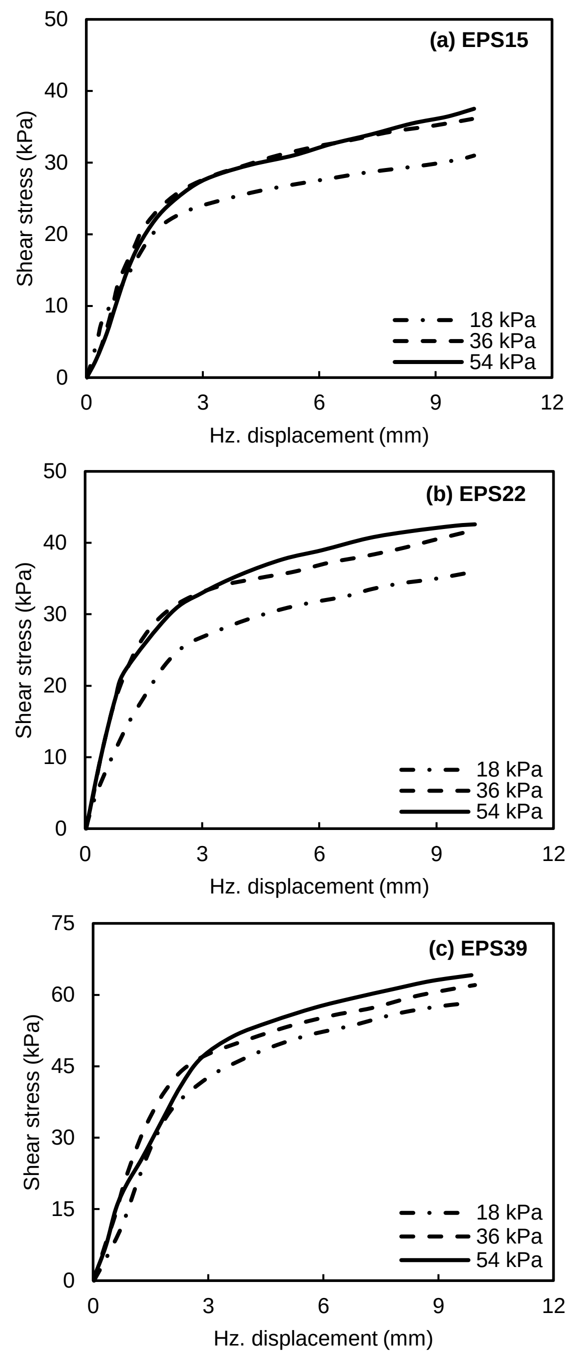

Figure 3. Shear stress vs Hz. displacement relationships for monoblock geofoam having densities that range from 15 to 39 kg/m^3

Fig. 4 shows the maximum shear stress values plotted against normal stress values for the monoblock geofoam to obtain the Mohr-Coulomb failure envelops. Shear properties like cohesion and angle of internal friction were then obtained from the failure envelopes. It was also found that all the failure envelopes were almost parallel to each other with a gentle upward slope. It was also found that under a constant applied normal stress, high density geofoam offered more resistance to shear as compared to low density geofoam. In addition to that for a particular density of geofoam, shear strength is directly associated with the applied normal stress and vice versa. These results were found to be consistent with geofoam density and applied normal stress.

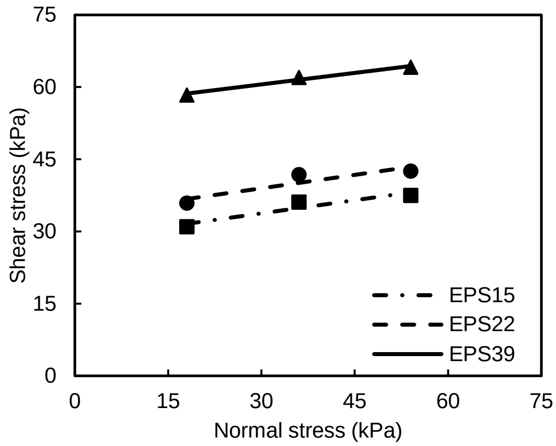

Figure 4. Mohr-Coulomb failure envelopes of monoblock geofoam sample

Fig. 5 shows the changes in cohesion and friction angle for monoblock geofoam having 3 different densities. Cohesion values were found to increase from 28 to 56 kPa and friction angles of monoblock were found to slightly decrease from 10º to 9º with the increase in geofoam density from 15 to 39 kg/m^3.

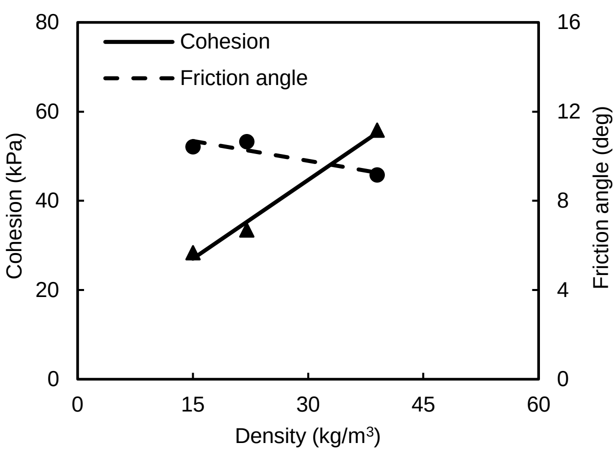

Figure 5. Monoblock cohesion and friction angle as a function of the geofoam density

The relationship between the maximum vertical displacement and normal stresses is shown in Fig. 6. It can be seen that low-density geofoam (EPS15) experiences more compression as compared to high density geofoam (EPS39). In addition, it can also be seen that for a particular geofoam density, the magnitude of vertical compression increased as the applied normal stress increased from 18 kPa to 54 kPa which also validates the dependence of vertical compression of geofoam on applied normal stress.

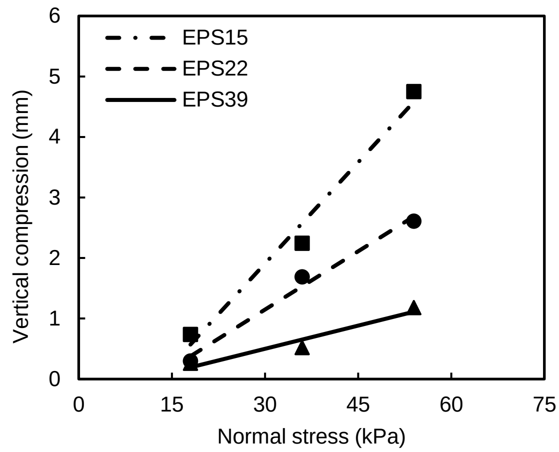

Figure 6. Vertical compression vs Normal stress for monoblock geofoam

Fig. 7 shows the relationship between shear factor and normal stress for different geofoam materials. Shear factor is a dimensionless number which is defined as "the ratio of shear stress at failure to the applied normal stress". Shear factor values greater than 1 indicate that shear forces are dominant during the shear while shear factors having values less than 1 show that normal forces are dominant during shearing of the monoblock geofoam
For a particular geofoam material e.g. EPS39 shear factor were found to decraese in a non-linear fashion from 3.2 to 1.2 as the normal stress values were changed from 18 to 54 kPa. However, for a constant value of normal stress e.g. 36 kPa, shear factor were observed to incraese from 1.0 to 1.7 as the density of geofoam was increased from 15 to 39 kg/m^3.

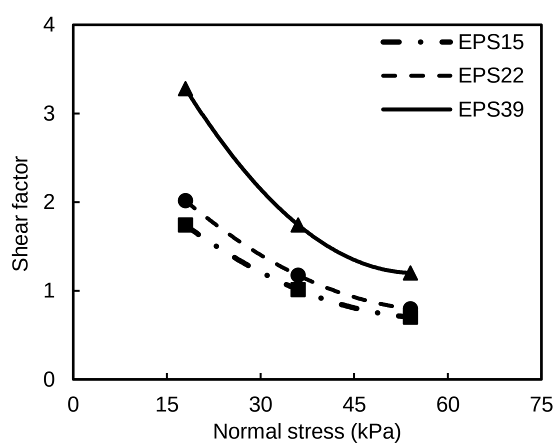

Figure 7. Shear factors for EPS15; EPS22 and EPS39 monoblocks

3.1 GEOFOAM-PVC INTERFACE

Fig. 8 shows the variation of shear stress with the increase of horizontal displacement for EPS-PVC interface. For all the three geofoam densities, shear stress initially increases linearly and then either becomes constant or starts to change at a slow rate until the maximum horizontal displacement of 10 mm is reached.

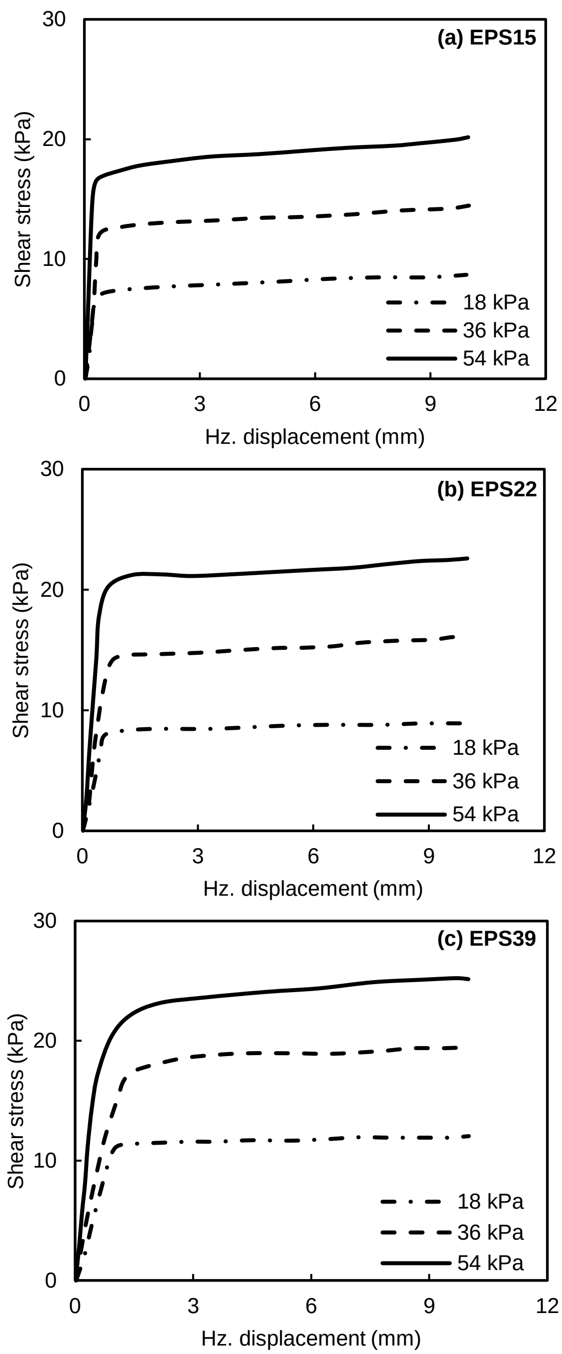

Figure 8. Shear stress vs Hz. displacemnt for geofoam-PVC interface with densities that range from 15 to 39 kg/m^3

Also, no peak or residual behavior were observed for the EPS-PVC interface. For a given horizontal displacement of 2 mm, the average shear stress was found to be 11, 14 and 18 kPa for EPS 15, 22 and 39, respectively.

Maximum shear stress vs. applied normal stress relationship is presented in Fig. 9. Linear Mohr-Coulomb failure envelopes were assumed for all EPS-PVC interfaces. Adhesion and angle of interface friction values were obtained by measuring the y-intercepts and the slope of envelopes. It was found that the higher the EPS density, the higher the measured interface strength in the test.

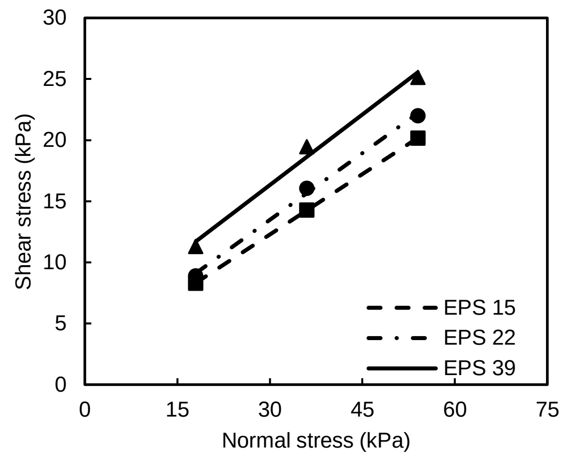

Figure 9. Mohr-Coulomb failure envelopes of geofoam-PVC interface

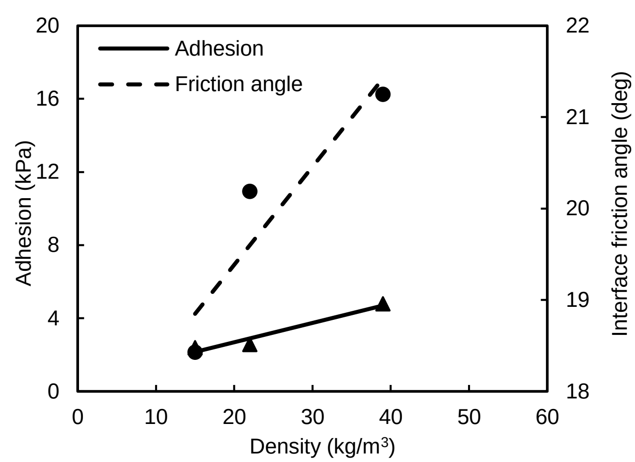

Figure 10. Adhesion and interface friction angle as function of the geofoam density for geofoam-PVC interface

Fig. 10 shows the measured changes in adhesion and interface friction angle with the density of EPS geofoam for EPS-PVC interface. It was found that when the geofoam density increased from 15 to 39 kg/m^3, the adhesion values increased from 2 to 5 kPa and interface friction angle increased from 18° to 21° respectively.

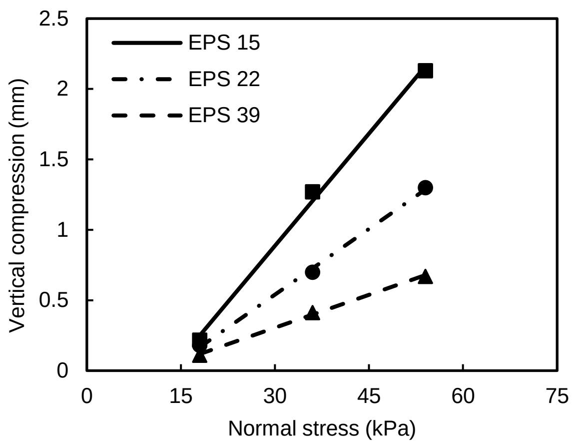

Fig 11. Vertical compression vs Normal stress for geofoam-PVC interface

Changes in the maximum vertical compression vs normal stress for EPS-PVC interface is shown in Fig.11. It can be clearly seen from the graph that vertical compression of geofoam increases with the increase in normal stress and decreases with the increase in geofoam density. These results are consistent with the fact that lighter geofoam experiences more compression under all applied normal stress values.

4 CONCLUSIONS

In the present study, direct shear tests were carried out to investigate the shear behavior of monoblock geofoam and interface shear behavior of geofoam with PVC material. Tests were conducted on three different geofoam densities for two different cases. The following conclusions have been drawn from the present study.

a) For all conducted experiments, density and normal stress were found to have an effect on the shear and interface strength properties of EPS geofoam.
b) Monoblock geofoam showed an increase in cohesion and decrease in friction angles as the density of geofoam increased from 15 to 39 kg/m^3.
c) Geofoam-PVC interface showed an increase in both adhesion and interface friction angle when the density of geofoam increased from 15 to 39 kg/m^3.
d) Shear factors were found to increase with the increase in geofoam density under constant applied normal stress. On contrary, for a constant density geofoam a decreasing trend was observed in shear factors values as the normal stress was incraesed from 18 to 54 kPa.
e) Vertical compression of EPS geofoam followed similar trends for all investigated geofoam densities. The present research reveals that vertical compression of geofoam is directly related to applied normal stress and inversely related to geofoam density.

5 ACKNOWLEDGEMENTS

The present study is jointly funded by McGill University, Canada and University of Engineering and Technology, Lahore, Pakistan. The assistance of Mr. John Bartczak in setting up the experimental setup and in-kind support from Plasti-Fab Inc. are highly appreciated.

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