YOUNG'S MODULUS OF EPS GEOFOAM BY SIMPLE BENDING TEST

D. Negussey[1] and N. Anasthas[2]

ABSTRACT

Young's modulus of EPS geofoam is routinely determined by unconfined compression testing of cubic or in some cases cylindrical samples. Laboratory tests on small specimens provide a greater variation in the results compared to tests on large specimens. Some performance observations suggest that back calculated elastic modulus values are higher than values derived from laboratory tests on small samples. There is a significant sample size influence on elastic parameters and Young's modulus values generally tend to be underestimated. The cause for the underestimation is attributed to be due to end effects. Unconfined compression tests on large samples reasonably estimate the Young's Modulus of EPS blocks (Elragi et al, 2000). This paper summarizes the work done to find an alternate method for determining Young's modulus for EPS geofoam. Simple bending tests were performed on small EPS beams. Test results show the method can be used as an alternative and relatively quick procedure to obtain realistic Young's modulus values. The modulus values obtained by this method fall slightly above corresponding middle third modulus values that were obtained from unconfined compression tests on large cubic blocks. Flexure strengths of EPS geofoam determined in this investigation are in agreement with values in ASTM C 578. Extension and compression tests were also performed on EPS geofoam cylinders. The results show EPS geofoam behaves isotropically in the range of small strains that apply for modulus determination.

KEY WORDS: compression, elastic, EPS geofoam, flexure, isotropy, modulus, strength, tension

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INTRODUCTION

EPS geofoam is used in many geotechnical applications such as embankments, retaining walls, slope stabilizations, bridge abutments and below pavements. In many cases, geofoam blocks are stacked in multi layers. Dead loads induce relatively uniform stress while live loads result in an alternating stress distribution with depth. Young's modulus values are required to estimate the deformation of EPS geofoam layers in response to both live and dead loading conditions. Young's modulus of EPS geofoam is commonly determined by performing unconfined compression tests on 50 mm cube samples according to ASTM D 1621, EN 826 or ISO 844.

Duškov (1997) investigated the compression behavior of EPS15 (EPS of 15 kg/m^3 density) and EPS20 geofoam. Cylindrical samples of 150 mm diameter and 300 mm height were subjected to uniaxial compression. Dry and wet EPS samples were tested at strain rates of 4, 20, 200 and 2000% per minute. The average water absorption among the wet EPS was 1.56% by volume. For tests at low temperatures, EPS samples of 200 mm height and 100 mm diameter were compressed at temperatures ranging between -8.6 and –12.9°C at a strain rate of 7% per minute. The yield stress of EPS was found to increase with strain rate. The influence of strain rate on the modulus, however, seemed to be limited in the strain range from 0 to 1%. Neither water absorption nor treatment by freeze-thaw cycles showed to have significant effects on the compression behavior of EPS geofoam. Young's modulus values of 4.9 MPa and 7.4 MPa were reported for dry samples of EPS15 and EPS20, respectively. A general equation (Equation 1) was derived to express the modulus (E_{EPS} in MPa) in terms of density (ρ in kg/m^3) of EPS. Low temperature conditions that were examined did not impact the mechanical behavior of EPS geofoam.

$$E_{EPS} = 0.1284\ \rho^{1.368} \qquad \textbf{Equation 1}$$

Duškov (1991) had earlier tested 150 mm diameter cylindrical samples of 600 mm height and compared elastic modulus of geofoam derived from laboratory test results to values back calculated from falling weight deflectometer testing. The back calculated modulus values exceeded those derived from the laboratory testing or previously reported results.

Eriksson and Trank (1991) performed a series of unconfined compression tests on EPS samples from large blocks of 15 and 20 kg/m^3 nominal density. Both density variation and stress-strain behavior of EPS were investigated. Bulk density was determined in a total of 387 specimens and compressive strength in 162 specimens. Samples of dimensions 50 mm x 50 mm x 50 mm, 200 mm x 200 mm x 165 mm, and 400 mm x 400 mm x 400 mm were compressed at strain rates of 1, 2, and 10% per minute. For specimens from the same block, a variation in bulk density of approximately 25% was observed. The results on small specimens gave a greater variation compared to tests on large specimens. Use of the current standard (ASTM D 1621, EN 826 or ISO 844), based on specimens of 50 mm cube was therefore questioned. The relation in Equation 2 was derived to estimate the compression modulus of EPS (E_{EPS} in kPa) in terms of density (ρ in kg/m^3). The equation applies to a deformation rate of 1% per minute. However, the specific specimen size from which the equation was derived is not readily evident.

$$E_{EPS} = 9.7\ \rho^2 - 14\ \rho + 1800 \qquad \textbf{Equation 2}$$

Elragi et al (2000) suggested that non-uniform stress distribution and end effects occur in the zone of geofoam immediately adjacent to the rigid loading platens. Unconfined compression tests were performed on 50 mm, 600 mm cube samples and stack of four 600 mm cube blocks. The elastic modulus derived from testing conventional 50 mm cube samples were about half the corresponding value obtained from the middle third segment of 600 mm cube blocks. The modulus obtained for the mid point of the stacked blocks was higher than the corresponding value obtained in 600 mm cube samples.

Srirajan (2001) performed a series of unconfined compression tests on EPS block samples of various sizes. Two series of tests were performed, one in strain-controlled mode and the other in load-controlled mode. The first series of tests were performed at a constant strain rate of 10% per minute. Samples of 50 mm cube and 300 mm cube with density ranging from 12 to 35 kg/m^3 were compressed uniaxially. The results show that the modulus linearly increases with density, and small samples give low modulus values than large samples for a given density. The results from the above work are combined with the results of a similar work done by Elragi (2000) to show the effect of sample size on Young's modulus. The second series of tests were performed under load-controlled mode. The purpose of these tests was to investigate the effect of sample size on creep behavior of EPS geofoam. Samples of 50 mm cube, 100 mm cube, 300 mm cube, and 300 mm x 300 mm x 600 mm block were used for the creep study. Tests were performed by ramping the load to the required stress level at a constant loading rate of 9.5 N/second. The ramp loading portion of the stress-strain curves were used to determine the Young's modulus.

Anasthas (2001) performed a series of triaxial tests on cylindrical EPS geofoam samples at different confining stress levels to investigate the effect of confining stress on compressive strength of EPS geofoam. Tests were performed on samples of 76 mm diameter and 150 mm height with 16 and 26 kg/m^3 nominal density at confining stress levels ranging from 0 to 100 kPa with duration of confinement of 0, 3 and 24 hours. The initial moduli increased with EPS density and reduced with confining stress. For both densities, there was a significant reduction in initial Young's modulus and the post-yield modulus remained relatively unchanged with confining stress. Duration of confinement had increasing significance on initial Young's modulus with confining stress while the post-yield modulus was not affected. The initial Young's moduli decreased with increasing duration of confinement and increasing confining stress. However, the effect of duration of confinement is minimal after 3 hours. In 24 hours, the decrease in initial Young's modulus for confining stress levels above 50% of the unconfined compressive strength was more than 10% of the initial Young's modulus for 0 hour confinement. The following equations were proposed for initial Young's modulus (E_i in MPa) and post-yield modulus (E_p in kPa) of EPS in terms of Density (D in kg/m^3) and confining stress (σ in kPa).

$$E_i = 0.0001\, D\sigma_3 + 0.008\, D^2 + 0.152\, D + 0.015 - 0.041\sigma_3 + 0.00006\, \sigma_3^2 \qquad \textbf{Equation 3}$$

$$E_p = -0.01\, D\sigma_3 - 0.051 D^2 + 9.566\, D + 0.966 + 1.812\, \sigma_3 - 0.005\, \sigma_3^2 \qquad \textbf{Equation 4}$$

Conventional 50 mm cube samples give very low modulus values and most laboratories cannot test large samples. Flexure tests are routinely performed in manufacturing plants for quality control. This paper describes a method for estimating Young's modulus from the bending response of flexure tests.

METHODOLOGY

A series of simple bending tests were performed on relatively small beams of EPS geofoam to determine the Young's modulus. The average load to displacement ratio of the linear portion of the load-deflection curve was substituted in the simple bending formula to determine the Young's modulus. Bending tests were performed with different displacement rates to investigate rate effects. All the samples were loaded up to rupture to obtain the flexure strength. Deflection measurements were taken at the top and the bottom of the beam samples during bending to assess the degree of indentations at the loading points. The simple bending formula is valid only if the material behaves isotropically. The Young's modulus of the material in tension and compression must be comparable within the strain range of the load-deflection values. For a cross section in bending, the upper half is in compression while the lower half is in tension. A series of compression and extension tests were performed on cylindrical samples to study the stress strain behavior of EPS geofoam under compression and tension.

EQUATIONS

Flexure strength, Young's modulus, and rate of deflection for bending

Derivation of equations for the above parameters begins with the bending formula, where σ_{max} is the maximum normal stress in the beam, *M* is the mid span moment, *c* is the distance to the edge from the neutral axis and *I* is the moment of inertia of the cross section of the beam about the bending axis.

$$\sigma_{max} = \frac{Mc}{I} \qquad \textbf{Equation 5}$$

Maximum stress (MPa) at mid span due to load *p* (N) can be expressed as follows:

$$\sigma_{max} = Mc/I = (pL/4)\times(d/2)/(bd^3/12) = 3pL/2bd^2 \qquad \textbf{Equation 6}$$

Where *d* – depth (mm)
b – width (mm)
L – span (mm)

Flexure strength *S* is the maximum stress at the mid span of the beam at failure when p_{max} = P (N)

$$S = 3PL/2bd^2 \qquad \textbf{Equation 7}$$

Deflection *D* at mid span of a simply supported beam with load p at the mid span is given as in Equation 8 and rearranged to give an expression for Young's modulus *E* as in Equation 9.

$$D = pL^3/48EI \qquad \textbf{Equation 8}$$

$$E = (p/D)L^3/48I \qquad \textbf{Equation 9}$$

Substitution of Equation 9 and Equation 6 for *E* and σ in $\sigma = \varepsilon E$ relates the strain ε at the extreme edge at the mid span section to the mid point deflection *D* as in Equation 10. Differentiation of Equation 10 with respect to time gives the expression for the rate of loading head motion *R* as in Equation 11.

$$D = \varepsilon L^2/6d \qquad \textbf{Equation 10}$$

$$R = ZL^2/6d \qquad \textbf{Equation 11}$$

Where, Z is the strain rate.

TEST SPECIMENS

For bending tests EPS beam sample dimensions were selected according to ASTM standard (ASTM C 203). The following are the recommended and minimum dimension ratios for the test specimen cross-section and support span:

Recommended L/d = 10	Require 20 ≥ L/d ≥ 2
Recommended L/b = 2.5	Require L/b ≥ 0.8
Recommended b/d = 4	Require b/d ≥1

Two geometries were selected, each with 25 mm thickness, 250 mm span and 300 mm length. One sample series was of 75 mm in width and the other sample series was of 100 mm. The dimensions of both sample groups are in accordance with the recommendation of ASTM C 203.

For extension and compression tests, cylindrical EPS samples were used. The geofoam cylinders were cut at the factory to a nominal diameter and length of 76 mm and 915 mm, respectively. The long geofoam cylinders were cut to produce samples that have an aspect ratio of two. Densities for all test samples were in the range of 10 to 30 kg/m^3. Samples were cut using a hot wire and the dimensions and the weights were recorded to calculate the actual density of each sample.

EXPERIMENTAL SETUP AND PROCEDURE

Compression and Extension Tests

Compression and extension tests were performed on cylindrical samples described under test specimens. Samples were glued to the loading plates using an adhesive. Glue was sprayed evenly on the loading plates. A very thin layer of glue was gently applied to the top and bottom of the cylindrical samples. Some glue products weaken the foam. After several trials, the type of glue that was found to work best is known by the trade name Foam-Lok. Samples were first glued to the bottom loading plate and then the top loading plate was lowered to come in touch and a small seating load of 5 N was applied. Testing was performed after allowing 48 hours for the glue to set and harden. An extensometer was mounted on the mid portion of the sample and compression and extension loading cycles were applied at a strain rate of 10% per minute up to strain levels of 0.5%. Similar tests were also performed up to 1.0% strain both in compression and in tension to check the linearity of the modulus within that strain range. Compression and extension tests were performed to examine the validity of assuming isotropic behavior of EPS geofoam.

Bending Tests

The experimental setup (Figure 1) consists of a loading system and sensors, with a dedicated data acquisition system. The servo-hydraulic loading system operates at either constant load or constant displacement modes. The loading setup (Figure 1) consists of a base, two supports and a loading head. The supports are mounted on the base and the span can be adjusted as required. The bearing edges of the support and the loading head are cylindrical to avoid excessive indentation. The diameter of these bearing edges is 32 mm and in accordance with provision of ASTM C 203. The bearing cylinders are straight and parallel to each other. An LVDT bracket is bolted to the base to register the maximum deflection of the test specimen. In order to minimize indentation on the specimen at the LVDT tip itself, a thumbnail cap of 8 mm diameter was provided in place of the LVDT tip. The loading head displacement is registered separately by the actuator control LVDT.

The support span was set to 250 mm in accordance with ASTM C 203 for all bending tests. Samples were placed centrally on the bottom loading plate. The loading rate was calculated using Equation 11.

For:

L = support span, mm = 250
d = depth of beam, mm = 25 (nominal)
Z = maximum rate of strain at outer surface, mm/mm.min = 0.10.
R = rate of loading head motion, mm/min = 42 mm/min.

Load was applied to the specimen at the specified loading head motion of 42 mm/min and the load, deflection readings were recorded by the data acquisition system. Indentation at the supports would have resulted in a downward translation in the position of the specimen to register more bending. Similar indentation may also occur at the loading head. Thus, the actuator movement of the servo-hydraulic machine may not provide a true measure of the deflection due to bending of the specimen. Further considerations of indentation at loading points and steps for compensation or correction of the load-deflection curve for indentation are presented below. Flexure strength and Young's modulus of EPS were determined from Equations 7 and 9, respectively.

Substituting the following values in Equation 7 gives the flexure strength *S* in MPa:

P = maximum load at rupture on the load-deflection curve, N,
b = width of beam tested, mm = 100 or 75 (nominal)

Substituting the following additional values in Equation 9 gives the Young’s modulus *E* in MPa:

p/D =initial slope of the load-deflection curve, N/mm
I = moment of inertia, mm^4

The value of (p/D) was obtained by fitting a trend line to the initial linear portion of the load-deflection curve (Figure 2). The linear portion below 0.5% strain (2 mm deflection) was considered for fitting the trend line. The value of (p/D), the slope of the trend line, was substituted in Equation 9 to determine Young's modulus.

Indentation Assessment

Assessment of indentation in the beam specimen at the loading head and supports is explained using the diagrams in Figure 3. Total deflection at the top, Δ_{top}, is the movement of the loading rod and was recorded by the actuator or loading head LVDT. Total deflection at the bottom, Δ_{bottom}, was recorded by the LVDT beneath the sample. The top LVDT output represents the actual deflection of the beam (D) plus the indentations at the loading head (δ_1) and the supports (δ_2). Similarly, the bottom LVDT output is equal to the actual deflection of the beam plus the indentation at the supports (δ_2). Therefore the actual deflection in terms of the recorded deflection and indentations can be expressed as follows:

$$D = \Delta_{top} - \delta_1 - \delta_2$$ **Equation 12**

$$D = \Delta_{bottom} - \delta_2$$ **Equation 13**

In Figure 3, (a) shows the top and bottom deflection readings due to indentations alone and (b) shows the deflection readings for an ideal beam without indentations. Total deflections at top and bottom are obtained as in (c) by superposition of (a) and (b). The difference between the top and bottom readings is equal to δ_1. The loading head and supports are of the same diameter. Equilibrium conditions require the reaction at the supports be half of the load. As an approximation, δ_1 was assumed to be equal $2\delta_2$. Accordingly, the following equations are obtained:

$$\delta_1 = \Delta_{top} - \Delta_{bottom}$$ **Equation 14**

$$\delta_1 = 2\delta_2$$ **Equation 15**

Substituting δ_1 and δ_2 in Equations 12 and 13 gives the following equation for actual or corrected mid span deflection (D).

$$D = \frac{3\Delta_{bottom} - \Delta_{top}}{2} \qquad \textbf{Equation 16}$$

RESULTS

Figures 4 through 8 present the results of compression and extension tests. All these tests were performed at a constant strain rate of 10% per minute, which equals the strain rate at the extreme edge of the EPS beams, and strained only up to 0.5% in both compression and in extension. Figure 4 shows the stress-strain curve in compression and extension for a sample of 30.7 kg/m^3 density. Displacement measurements were taken globally and the Young's modulus in compression and tension were 13.9 and 14.4 MPa, respectively. The tensile modus was about 2% higher than the modulus in compression. Figure 5 shows the stress-strain behavior of a sample of 29.8 kg/m^3 density. Local strain measurements registered by the extensometer were used to plot the stress-strain curve. The compression modulus is 16.2 MPa and the tensile modulus is 16.4 MPa. Samples associated with Figures 4 and 5 have about the same densities and the global measurements in Figure 4 give modulus values that are about 15% less than obtained by local measurements (Figure 5). This suggests that end effects due to seating and non uniform contact stresses prevail at the top or bottom zones of the relatively soft samples and immediately adjacent to the rigid loading plates. Elragi et al (2000) also noted such behavior.

Figure 6 shows the stress-strain curve of a similar test on a sample of 17.0 kg/m^3 density. The global strain measurements give a compression modulus of 6.2 MPa and a tension modulus of 6.4 MPa, a difference of about 4%. Figure 7 shows the stress-strain curve for a cyclic compression and tension test performed on a sample of 16.4 kg/m^3 density. The global measurements for this test cycles show a 10% difference between the compression and tension modulus. However, the results of a similar test on a sample of 29.0 kg/m^3 density with local measurements showed a difference of about 4% between the compression and tension modulus (Figure 8).

The results from the compression and extension tests show that the tension modulus is slightly higher than the compression modulus within the initial 0.5% strains in compression and tension. Based on the results obtained by local measurements the difference between compression modulus and tension modulus is less than 3%. The average difference in compression and tension modulus obtained by both local and global measurements is less than 5%. Therefore, it is reasonable to assume that EPS geofoam behaves isotropically within the initial 0.5% strain range. Thus the simple bending formula can be used to calculate Young's modulus from bending tests. The results also show that the global measurements underestimate the modulus values by as much as 15%.

Figure 9 shows the stress-strain curve obtained from cyclic tests of up to 1.0% strain in compression and in tension. The average modulus within the initial 0.5% strain is greater than the average modulus within the next 0.5% strain range. The compression modulus within the initial 0.5% strain is 4.9 MPa and that in the next 0.5% strain range is 3.8 MPa. This shows that the modulus within 1% strain is not linear. The compression modulus within the initial 0.5% strain is greater than that in the following 0.5% strain range and the difference is as much as 20%. Elragi et al (2000), Duškov (1997) and Eriksson and Trank (1991) have observed the same behavior.

Figure 10 shows the effect of sample size on Young's modulus obtained by unconfined compression tests for EPS geofoam of different densities. The data in Figure 10 were used to develop Figure 11 where the trend of sample size effect on modulus is shown to be density dependent. The increase in modulus when comparing 50 to 600 mm cube samples varies from 38% for samples of 12 kg/m^3 density to 112% for samples of 30 kg/m^3 density. This shows that the effect of sample size on Young's modulus is more severe for higher density EPS than for lower density EPS. Figure 12 shows similar sample size effects in load-controlled tests. However, the sample size effects in this case are marked by higher strain rate in the small samples.

Figure 13 compares the results of bending tests on 75 mm samples at deflection rates of 6 and 42 mm/min. The deflection rate according to ASTM standard is 42 mm/min for samples of 25 mm depth. Tests with deflection rate of 6 mm/min give essentially the same results as for 42 mm/min. Deflection rate for live loading such as for vehicle traffic at high speed would be higher. Results by Sivathayalan et al (2001) indicate Young's modulus values for EPS geofoam evaluated by considering wave propagation properties are higher than the results from bending tests.

Figure 14 compares the Young's modulus values obtained by compression tests on 600 mm cube blocks (Elragi, 2000) and bending tests on 75 mm and 100 mm samples. The data points from 75 mm samples are found to be more scattered compared to those from 100 mm samples. The bending test results share a common best-fit line to give an expression for Young's modulus (E in MPa) as a function of density (D in kg/m^3) as in Equation 17. The bending test results are in good agreement with responses representing the middle third segments of compression tests on 600 mm cube samples. For practical purposes, the modulus values appropriate for larger samples can be estimated from results on small 50 mm cube samples as in Equation 18.

$$\mathbf{E = 0.82\ D - 4.9} \qquad \textbf{Equation 17}$$

$$\mathbf{E_{bending} \sim 2.3\ E_{50}} \qquad \textbf{Equation 18}$$

Figure 15 compares the flexure strength values obtained by bending tests on 75 mm and 100 mm samples with the values suggested in ASTM C 578. Both sets of data share a common best-fit line to give an expression for flexure strength (S in kPa) in terms of density (D in kg/m^3) as in Equation 19. Within the density range of 15 to 25 kg/m^3 the bending test results are in good agreement with the flexure strength values suggested in the ASTM C 578. For densities lower and higher than this range the ASTM C 578 results are lower by about 25%.

$$\mathbf{S = 16.9\ D - 86} \qquad \textbf{Equation 19}$$

Figures 16 through 19 give the deflection vs. time curves obtained from the bending tests. The deflection was measured at the mid span of the beam specimen at top and bottom to assess the indentation at the loading head and/or the supports. Typical deflection from top and bottom for lower and higher density samples are shown in Figures 16 through 19. Results show that within the initial 2 mm deflection or 0.5% strain limit the top and the bottom deflection readings are about the same, thus δ_1 is negligible. Therefore δ_2 is also negligible and indentation effects can be ignored in the determination of Young's modulus by bending tests in accordance with ASTM C 203.

CONCLUSION

- Conventional unconfined compression tests on 50 mm cube samples underestimate Young's modulus values for EPS geofoam due to end effects. Larger samples give much higher values for modulus.

- The effect of sample size on Young's modulus is more severe for higher density EPS geofoam than for lower densities. The increase in modulus when comparing 50 to 600 mm cube samples varies from 38% for samples of 12 kg/m^3 density to 112% for samples of 30 kg/m^3 density.

- Bending tests on EPS geofoam provide a simple alternative for the determination of Young's modulus that compare favorably with results from large samples.

- Indentations on the EPS beams during bending were negligible and can be ignored provided the load and support contacts have adequate curvature.

- The Young's modulus of EPS geofoam in the range of small strains in tension and compression are approximately the same and the behavior can be considered isotropic.

- The stress-strain curve of EPS geofoam to 1% strain is not linear. Modulus values evaluated at 0.5% are higher than for 1%.

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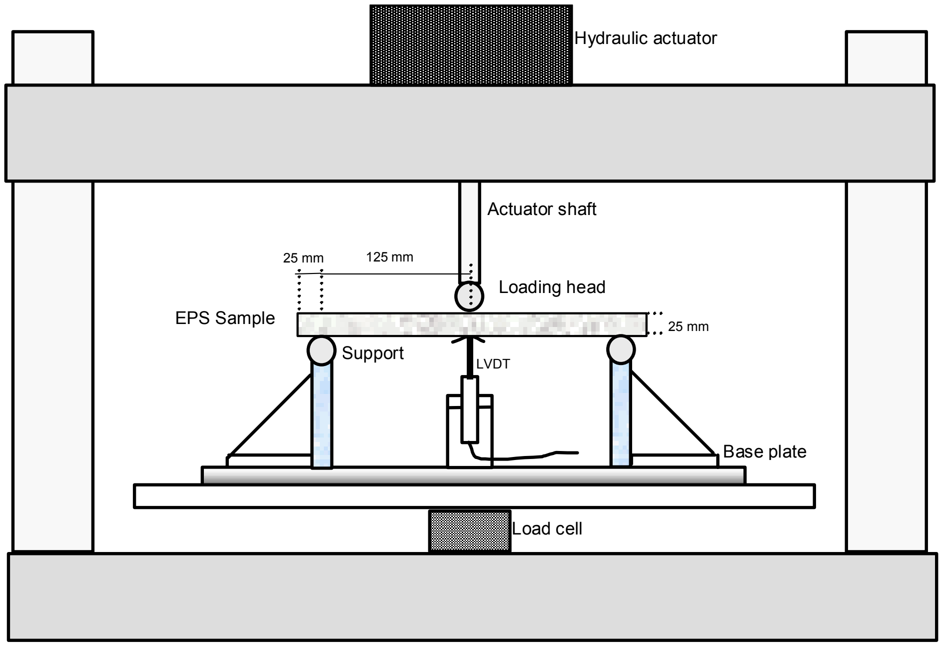

Figure 1. Loading System for Bending Test.

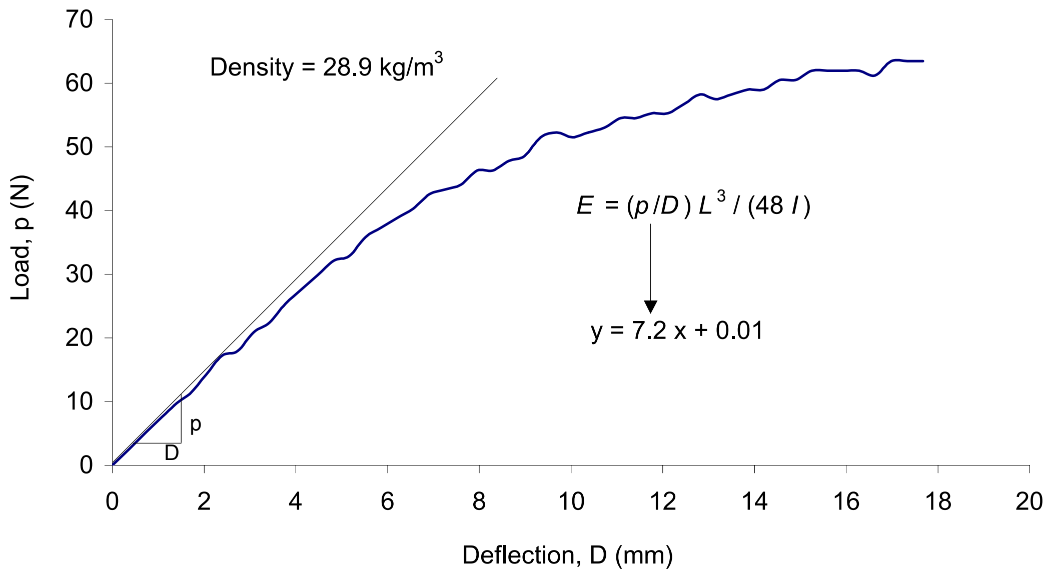

Figure 2 Typical Load-Deflection Curve of a Bending Test

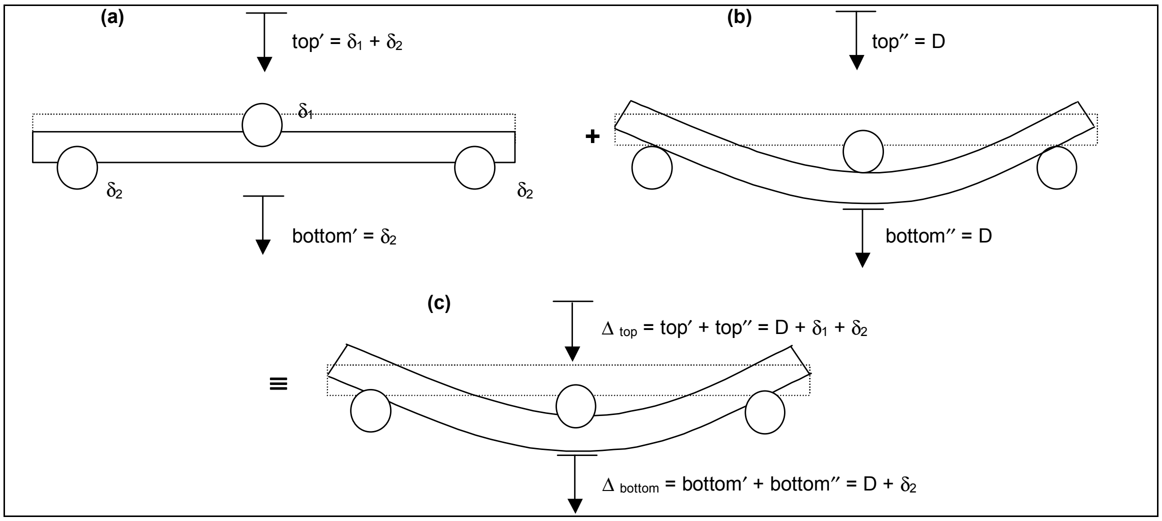

Figure 3. Indentation on EPS Sample in Bending Test.

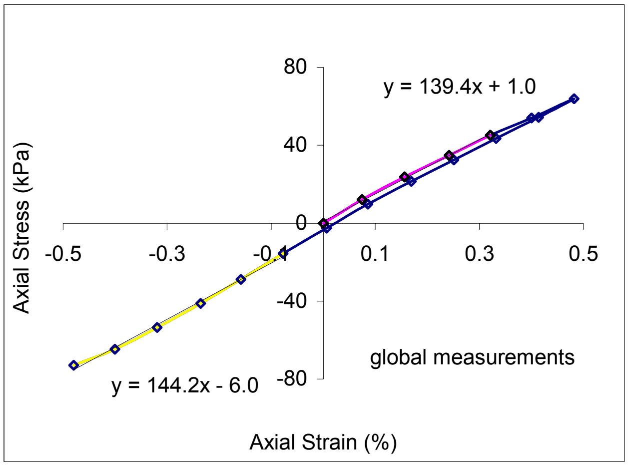

Figure 4. Stress-Strain Curve in Compression and Tension (D=30.7 kg/m³)

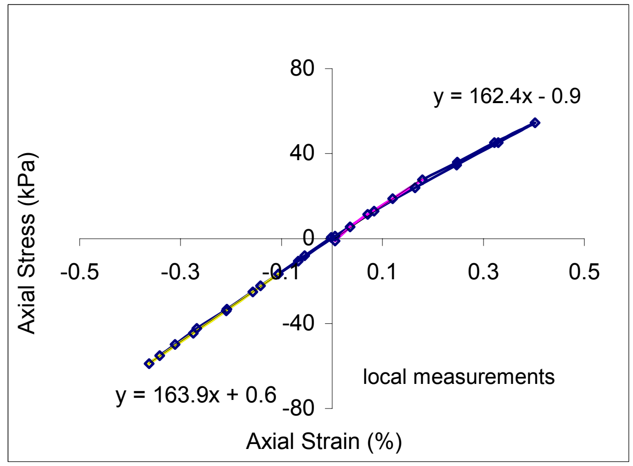

Figure 5. Stress-Strain Curve in Compression and Tension (D=29.8 kg/m³)

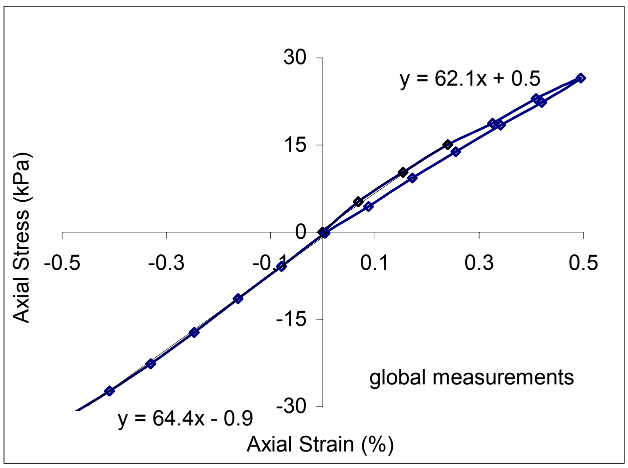

Figure 6. Stress-Strain Curve in Compression and Tension (D=17.0 kg/m³)

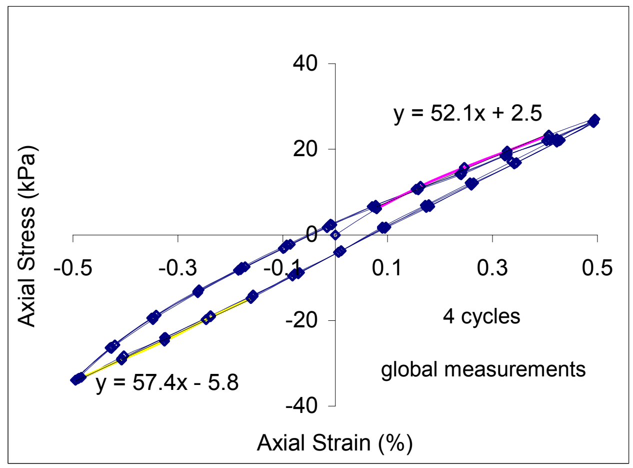

Figure 7. Stress-Strain Curve in Compression and Tension (D=16.4 kg/m³)

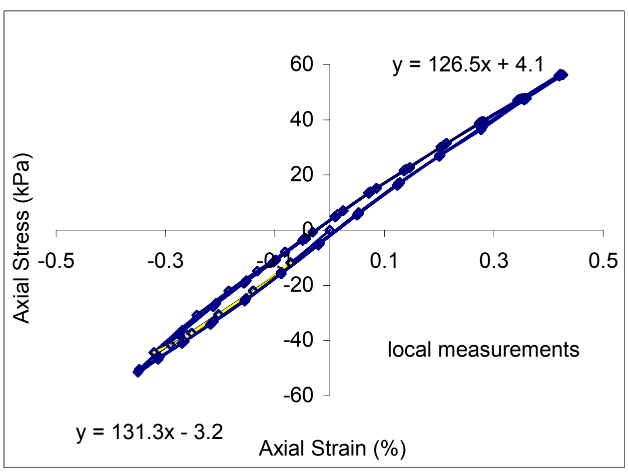

Figure 8. Stress-Strain Curve in Compression and Tension (D=29.0 kg/m³)

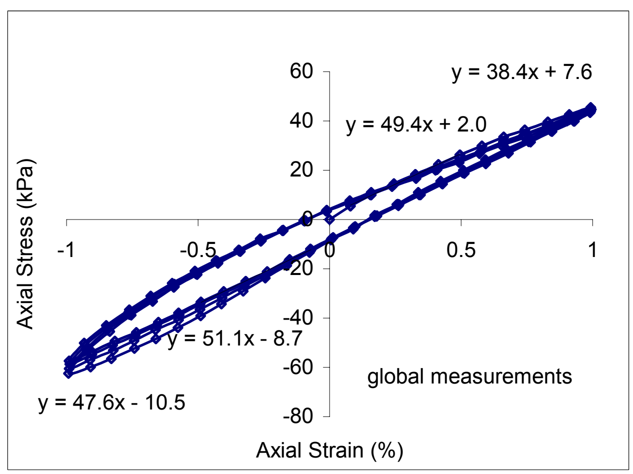

Figure 9. Stress-Strain Curve in Compression and Tension (D=16.4 kg/m³)

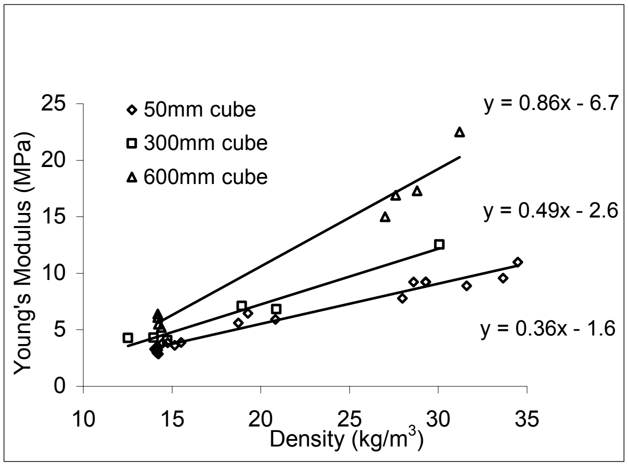

Figure 10.Sample Size Effects on Young's Modulus - Strain Controlled Test (After Elragi 2000 and Srirajan 2001)

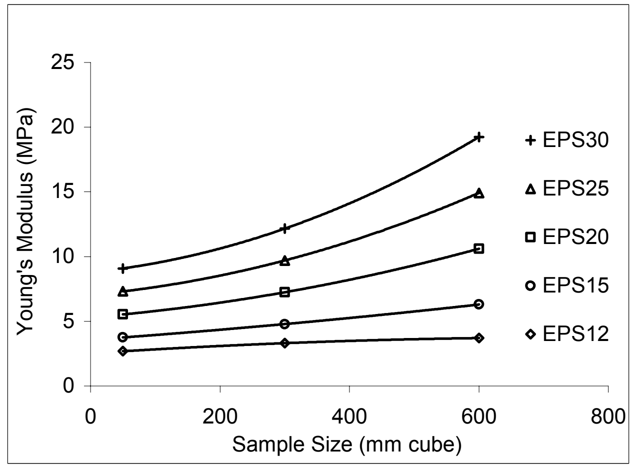

Figure 11. Density Influence on Sample Size Effects

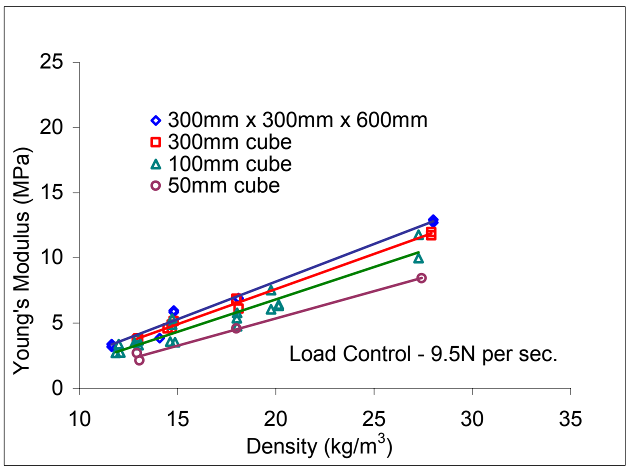

Figure 12. Sample Size Effect on Young's Modulus - Load Controlled Tests

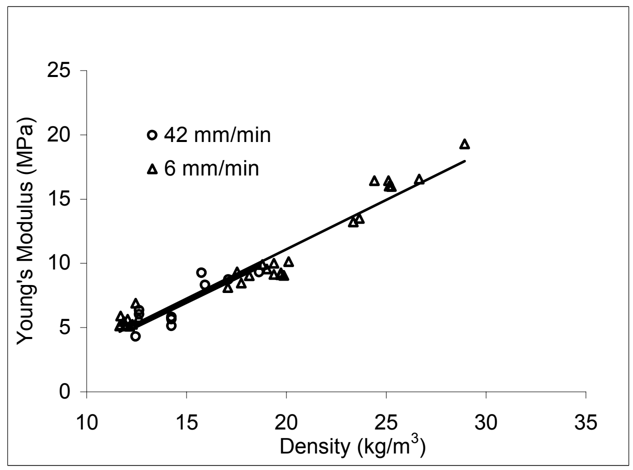

Figure 13. Strain Rate Effect on Young's Modulus

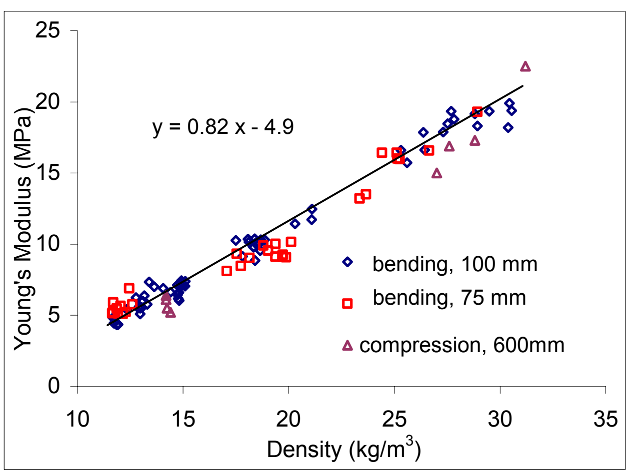

Figure 14. Young's Modulus by Bending Tests and Compression Tests on Large Samples

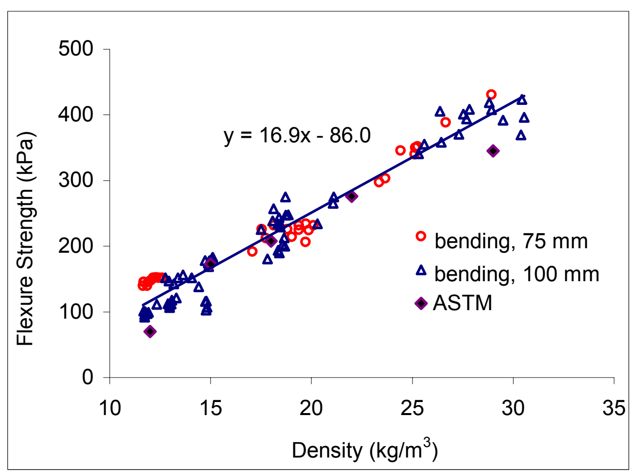

Figure 15. Flexure Strength by Bending Tests

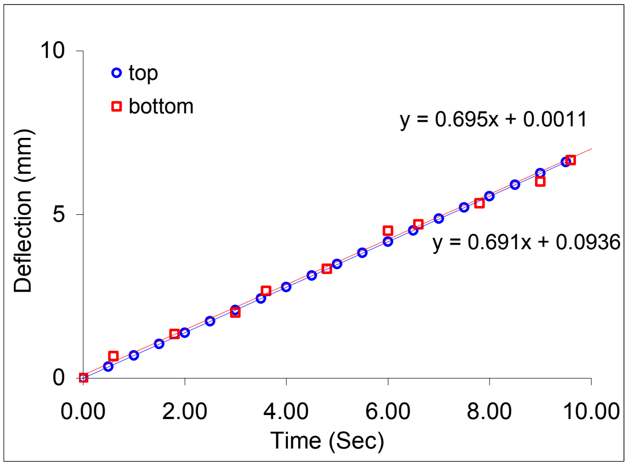

Figure 16. Top and Bottom Deflection During Bending (18.4 kg/m^3 Density, 100 mm sample)

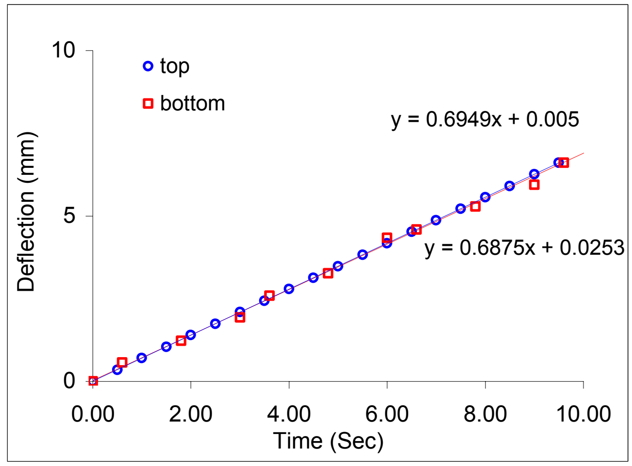

Figure 17. Top and Bottom Deflection During Bending (19.6 kg/m^3 Density, 75 mm sample)

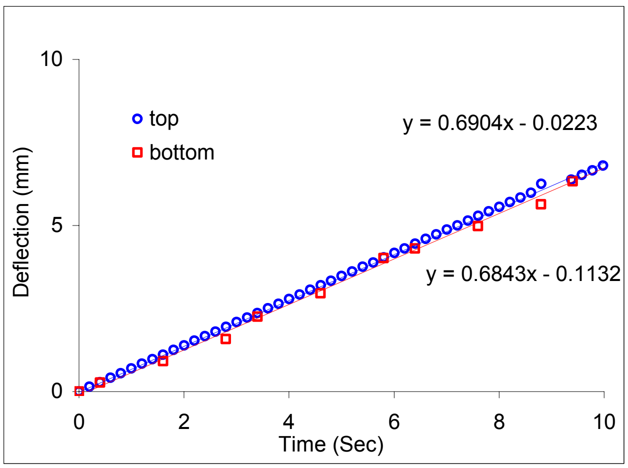

Figure 18. Top and Bottom Deflection During Bending (27.2 kg/m^3 Density, 100 mm sample)

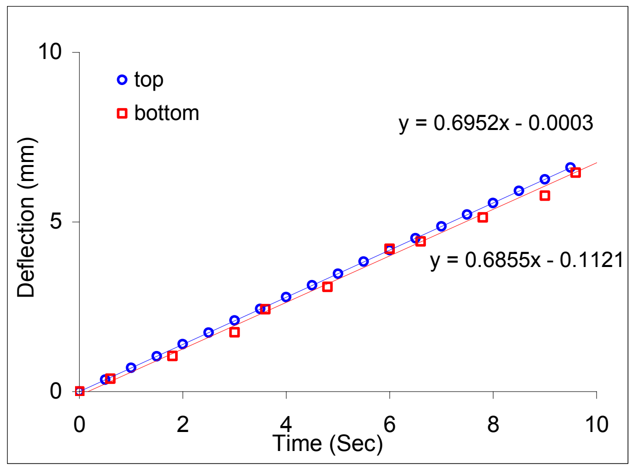

Figure 19. Top and Bottom Deflection During Bending (25.4kg/m^3 Density, 75 mm sample)