EFFECTS OF INCORPORATING HIGH PERCENTAGES OF REGRIND INTO GEOFOAM BLOCKS

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ABSTRACT

A series of laboratory tests were performed on EPS geofoam with varying percentages of recycled content to investigate engineering properties. Unconfined compression, flexure, interface shear, creep and water absorption tests were performed on samples containing 0%, 30%, 50%, and 100% recycled content. The compression strength of samples containing recycled content is less than that of the virgin geofoam. The interface friction increases with recycled content for cut surfaces. Bending and compression tests indicate lower values of elastic modulus for higher recycled content. The percentage of recycled content to produce geofoam blocks can be increased up to 30% without significant influence on properties that were investigated in this study.

KEYWORDS: creep, EPS geofoam, modulus, recycled, regrind, strength, water absorption

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INTRODUCTION

EPS geofoam is relatively expensive compared to traditional lightweight fill materials. For projects that involve large volumes of EPS geofoam, one way to achieve some cost reduction may be to use a larger percentage of recycled content. Waste generated from cutting and trimming EPS blocks in manufacturing plants is usually ground and mixed with expanded beads during the molding process. Geofoam blocks made from pure expanded beads are called virgin geofoam. However manufacturers typically add on average of about 10% regrind to produce regular geofoam blocks.

Bartholomew (1992) investigated the effects of recycled contents of 0%, 20% and 40% on various EPS geofoam properties. Three different types of waste foam named modified scrap, packing scrap and cup scrap were tested and the properties were compared with EPS geofoam with zero percent recycled content. Compression tests were performed using 100 mm high and 50 mm by 50 mm square cross section at a rate of 1% per minute. The results indicated that no correlation can be made between the compressive strength of different percentages of recycled content and density. Samples nominally 305 mm in length with cross-sectional dimensions of 50 mm by 50 mm were tested for flexure strength. The results showed that the flexure strengths of both 20% and 40% scrap samples increase with density. The results also showed that the flexure strength reduces with increasing recycled content. Creep tests were performed over two days on 50 mm cubic samples by applying 150 kPa of pressure. The results show almost the same deformation in 2 weeks of loading for virgin and samples containing 20% and 40% scrap. Lower density samples deformed more and rebounded more than the heavier samples. Duplicate 76 mm cubic specimens of each type of scrap content were tested for water absorption. Samples were immersed in water for durations of 1 to 16 days and weighed. A maximum density increase of 277% was reported for 17.5 kg/m^3 density sample with 20% modified scrap. The study showed EPS blocks for lightweight fill can be produced using up to 40 % scrap content.

A series of laboratory tests were performed on geofoam samples with up to 100% recycled content produced by one manufacturer. The effects of recycled content on compressive strength, flexure strength, modulus, interface friction, creep deformation and water absorption of geofoam samples are examined in this paper.

TESTING PROGRAM

TEST SAMPLES

Tests were carried out using regular and "reclaimed" geofoam. All testes were performed on samples derived from the same source resin. The reclaimed geofoam included samples containing 30%, 50% or 100% recycled content. The virgin, 30% and 50% samples were of 14 kg/m^3 nominal density and the 100% sample was of 11 kg/m^3 nominal density. The data for virgin samples of 11 kg/m^3 density was obtained from Srirajan (2001) for comparison with the 100% recycled content at the same density. However, Srirajan's results are not for geofoam supplied by the same manufacturer as were all other samples.

TESTS

Compression Tests

Compression tests were carried out using 50, 100, 150 and 200 mm cube samples. In each type, up to five repeat samples were tested. Load was applied in displacement-controlled mode at 10% strain per minute. A load transducer at the base plate and a displacement transducer connected to the hydraulic actuator continuously monitored load and displacement, respectively (Photo 1).

Flexure Tests

Flexure tests were performed on 300 mm x 100 mm x 25 mm samples and also 300 mm x 75 mm x 25mm specimens in accordance with ASTM C 203. Five samples of each geometry were tested for each percentage of recycled content. A load transducer and a displacement transducer continuously monitored load and displacement, respectively. A bevelled loading head of 12 mm width and 120 mm length was used. The supports were cylindrical of 18 mm diameter to reduce excessive indentation due to stress concentration at contact points. Samples were placed on supports at 250 mm span as shown in Photo 2. The loading head was lowered to make contact with the sample and load was then applied maintaining a displacement rate of 42 mm/min.

Interface Shear Tests

Interface shear tests were carried out using 406 mm x 150 mm x 25 mm samples. The upper side of each sample was glued to a wooden board (406 mm x 150 mm x 19 mm). The lower portion of the test sample was a large geofoam block. Shear was applied by a DC motor system as shown in Photo 3. A load cell and a displacement transducer were used to record force and displacement, respectively. A normal pressure of 26 kPa was applied using dead weights. The sample was then sheared by displacing the upper block at a rate of 25 mm/min relative to the stationary base. Both dry and wet interfaces were tested. For virgin and 30% recycled content geofoam, both factory skin finish and hot wire cut surfaces were tested.

Creep Tests

Creep tests were performed on 100 mm cubic samples at loads corresponding to 30% and 50% compressive strength. For each sample type, loads were determined from standard 50 mm cube unconfined compression test results. The load was rapidly applied at a rate of 9.5 N/second to the target stress and was maintained for 48 hours.

Creep tests were also performed using 0.3 m x 0.3 m x 0.6 m samples with 30% recycled content at 30% of compressive strength. Displacement transducers were mounted at the upper and lower third positions along the face of the block to monitor incremental displacements.

Water Absorption Test

Water absorption tests were performed using samples of 12.5 mm height with cross sectional dimensions of 76 mm by 76 mm. The samples were weighed and immersed completely in de-ionized water at 70°F according to ASMT C 272. After 24 hours, the samples were withdrawn and surface water was removed. Each sample was weighed periodically for up to seven hours following withdrawal.

RESULTS

Compression Tests

As specified in ASTM D 1621, the straight portion of stress-strain curves were extended back and shifted to the origin to establish corrected stress strain curves as shown in Figure 1. Compressive strength is defined as stress at 5% strain in unconfined compression performed at 10% strain per minute.

The average compressive strength at 5% strain, and average initial modulus for each sample size are shown in Figures 2 and 3, and are also presented in Tables 1 and 2. The average compressive strength for 30% and 50% recycled content are about 5 and 10% less than the compressive strength of virgin geofoam, respectively. Figure 4 shows the general trend of decreasing compressive strength with increasing percentage of recycled content for 14 kg/m^3 nominal density samples. The compression test results indicate no significant change in modulus between 30% and 50% recycled content. The results also show that the modulus of virgin geofoam is about 25% higher than the modulus for 30% recycled content. However, the compressive strength for the 100% recycled content is about half of the compressive strength of virgin geofoam of the same density. The results also indicate that the modulus of 100% recycled geofoam is some 60% less than the modulus of comparable virgin geofoam as shown in Figure 3.

Flexure Tests

A flexure test load-deflection plot for 300 mm x 100 mm x 25 mm virgin geofoam sample is shown in Figure 5. For mid point loading of a simply supported beam sample, the maximum stress (flexure strength) S (MPa) and initial modulus E (MPa) were calculated using the following equations (ASTM C 203).

$$S = \frac{3PL}{2bd^2}$$

Where, P - failure load (N); L – support span (mm); b – width of beam tested (mm); d – depth of beam (mm)

$$E = \frac{(p/D)*L^3}{48ID}$$

Where, I - the moment of inertia (mm^4)
p - load (N)
D - displacement (mm)
p/D - the tangent of the linear portion of the load-deflection curve (N/mm)

The flexure strength and elastic modulus determined using the above equations are shown in Figures 6 to 9 and in Table 3. The flexure strength and elastic modulus values obtained using 75 and 100 mm wide samples are in good agreement. The average flexure strength of the 30% regrind material is about 13% higher than that of virgin geofoam. The average elastic modulus of the 30% regrind material and regular geofoam are about the same.

Anasthas (2001) reported bending test results for geofoam ranging in density from 12 to 20 kg/m^3. These test results are compared with the flexure strength and modulus obtained using recycled material in Figures 6 to 9. The tests performed on both geometries indicate that flexure strength of virgin geofoam is slightly less than the flexure strength determined by Anasthas as shown in Figure 6 and 7. Figure 8 shows that the modulus values determined by Anasthas are in good agreement with the results for virgin samples.

Shear Tests

The friction factor or interface friction coefficient is the ratio of the resisting shear to the applied normal stress. The normal stress of 26 kPa over which all tests were performed simulates an approximate field condition. The plot of shear load versus displacement for tests on wire cut interfaces is shown in Figure 10. Each of the shear stress versus displacement plots show peak and residual strengths. The average friction factors for each sample type under wet and dry surface conditions are shown in Figure 11 and Table 4. The results show that friction factor increases with increasing percentage of recycled content for wire cut interfaces for both dry and wet surface conditions. Residual interface friction factors for dry and wet conditions are about the same. There is no discernable difference between friction factors for corresponding skin surfaces in peak and residual as well as dry and wet conditions. The interface shear results obtained for virgin samples in this investigation are in good agreement with values reported by Sheeley and Negussey

(2000). The interface shear strength of geofoam with recycled content is not much different than virgin geofoam under the conditions examined.

Creep Tests

Creep behavior of geofoam containing different recycled content for 30% of compressive strength loading is shown in Figure 12. The total axial strain includes initial and creep deformation and increases with recycled content. Both the low initial strain and creep strain rate for the low density 100% recycled content sample compared to results for the higher density 50% recycled content sample are anomalous. The creep strain rates to 40 hours for the virgin and 30% recycled content samples are about equal. The results also show that the different values of total strain for samples containing recycled content from zero to fifty percent are mainly due to different amounts of initial strain.

Creep behavior of geofoam containing different amounts of recycled content at 50% strength is shown in Figure 13. The total strain state increases with increasing recycled content. That is, samples containing low recycled content deformed less than the samples containing larger recycled content. To reach 50% of compressive strength, 300 and 292 N ramped loads were applied over the specimen containing 30 and 50% recycled content, respectively, based on the actual density of the samples. However, the 50% recycled content experienced a total strain almost double the amount for the 30% recycled content.

Results from creep testing of 0.3 m x 0.3 m x 0.6 m sample with 30% recycled content subjected to 30% compressive strength loading is shown in Figure 14. The results show less immediate strain for this large sample. The total strain determined for the middle third of the block is about 20 percent less than the total strain determined from global measurement. Elragi et al.(2000) also observed less strain in mid sections of large samples. Elragi (2000) concluded that end effects at the geofoam and rigid platen loading interfaces contribute to excessive axial deformation and a higher strain estimate for entire blocks. Extrapolation of the creep data for the large samples with 30% recycled content and 30% loading to 25 years indicate about 2% total strain.

Water Absorption Tests

The average of three mass ratio (wet/dry) determinations from immersion tests are plotted against elapsed time as shown in Figure 15. The results show that mass ratio in percent decreased with elapsed time and diminished in 3 to 6 hours after withdrawal. The maximum mass ratio observed at withdrawal is less than 450%. This means that the maximum wet mass of the geofoam regardless of the recycled percentage was no more than 4.5 times the dry mass. Thus geofoam with recycled content does not absorb detrimental quantities of water on immersion to compromise the desired light weight property.

On immersion the opportunity of water to be absorbed by a body increases with surface to volume ratio. The larger the surface area relative to volume the greater the opportunity for absorption. For the test sample size of 12.5 mm x 76 mm x 76 mm, the surface area to volume ratio is 213 m^{-1} whereas the surface area to volume ratio for a full size geofoam block of 0.6 m x 1.2 m x 4.8 m is of the order of only 5 m^{-1}. Thus the moisture absorption potential of the laboratory samples is about 40 times greater than for full sized blocks. Since the amount of absorption due to immersion is negligible for all small size samples tested, the water absorption by full sized blocks that have or do not have recycled content should be even more negligible.

CONCLUSION

The following conclusions can be made from the studies and observations reported in this paper.

- The compressive strength of EPS geofoam containing 30% recycled content is about 5% less than the compressive strength of virgin geofoam.

- Results from unconfined compression tests indicate that the modulus of EPS geofoam containing 30% recycled content is almost 25% less than the modulus of virgin geofoam. However, the moduli determined from bending tests are significantly higher and show no significant difference between virgin and 30% recycled geofoam.

- Interface friction factors for geofoam containing different percentages of recycled content are comparable to interface strengths of virgin samples.

- EPS geofoam containing regrind deform more than virgin geofoam when subjected to stresses more than 30% compressive strength. Creep deformation of samples containing 30% recycled content is acceptable if loading is limited to 30% compressive strength.

- Water absorption of geofoam containing recycled content as well as virgin geofoam is negligible.

- EPS geofoam blocks can be molded with recycled contents higher than currently acceptable levels without significant effect on properties that were investigated here in. Increasing the percentage of recycled content up to 30% may help make geofoam more cost competitive and environmentally attractive.

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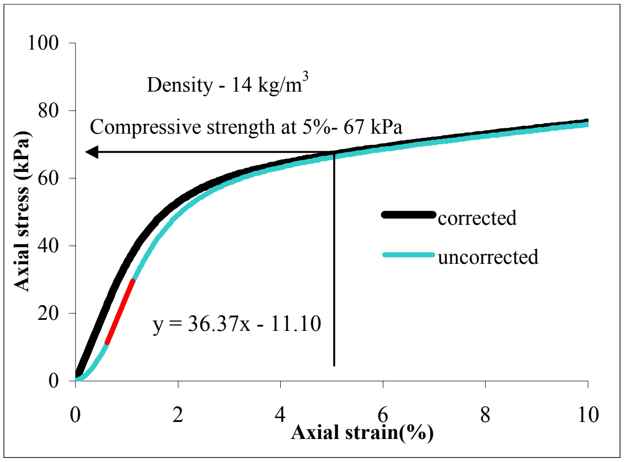

Figure 1. Axial stress vs axial strain of 100mm sample of regular geofoam tested at 10% strain per minute

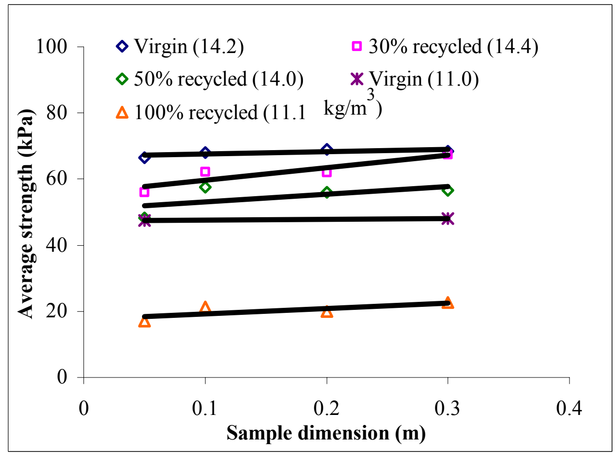

Figure 2. Average compressive strength at 5% strain for different specimen sizes (same aspect ratio)

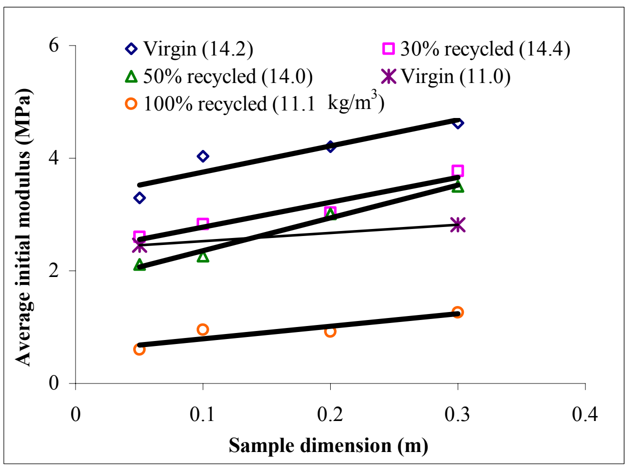

Figure 3. Average modulus for different specimen sizes

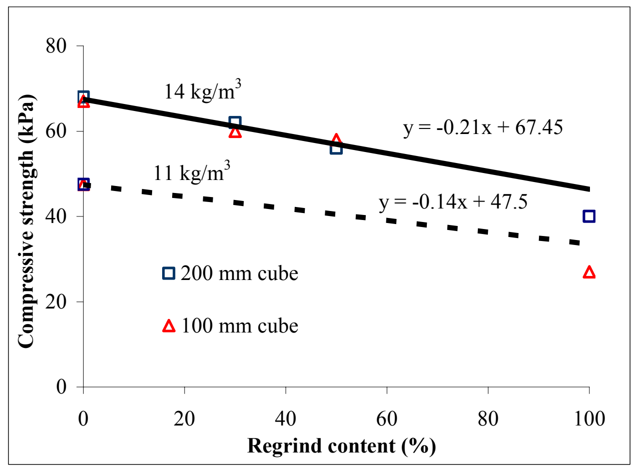

Figure 4. Compressive strength at 5% strain for different recycled content geofoam

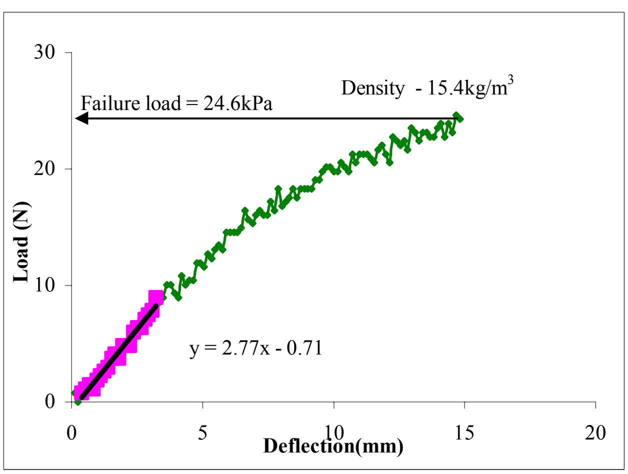

Figure 5. Load-deflection curve for 300 mm x 100 mm x 25 mm virgin geofoam sample

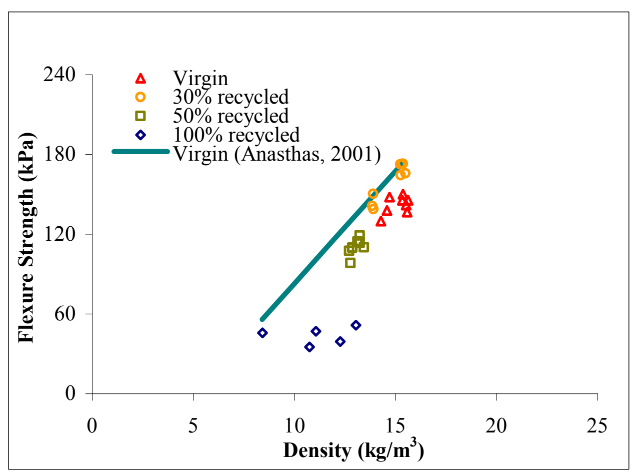

Figure 6. Flexure strength and density of 300 mm x 100 mm x 25 mm geofoam samples

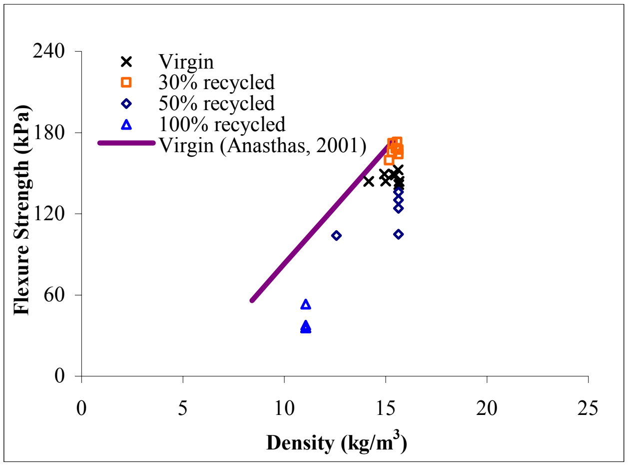

Figure 7. Flexure strength and density of 300 mm x 75 mm x 25 mm geofoam samples

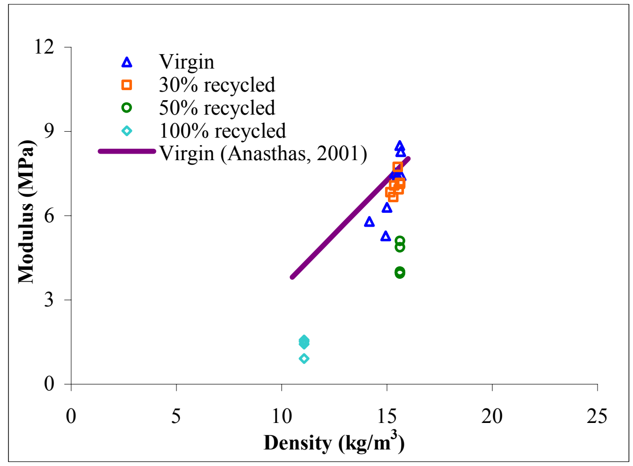

Figure 8. Elastic modulus and density of 300 mm x 75 mm x 25 mm geofoam samples

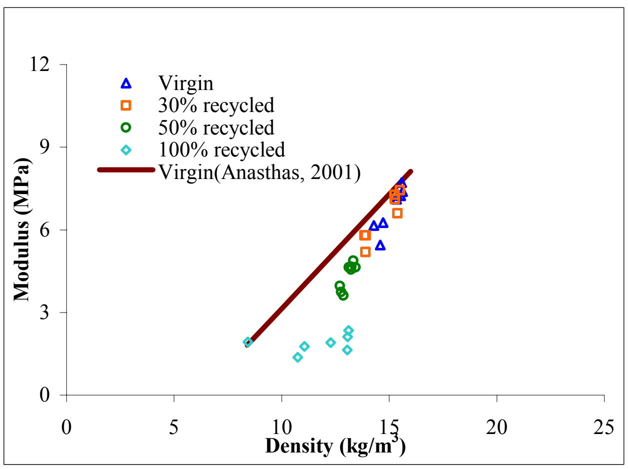

Figure 9. Elastic modulus and density of 300 mm x 100 mm x 25 mm geofoam samples

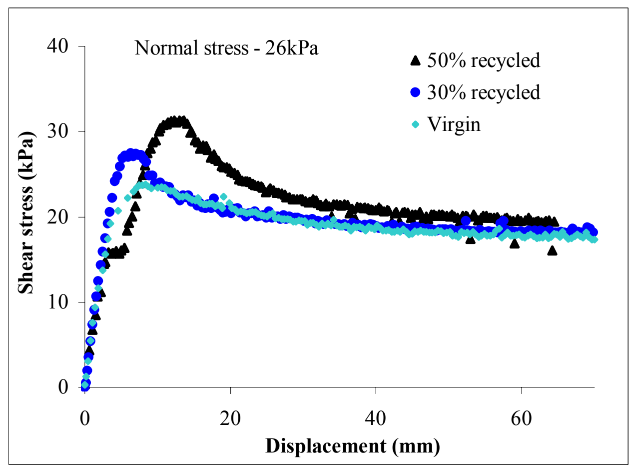

Figure 10. Interface shear stress vs. displacement for different recycled content

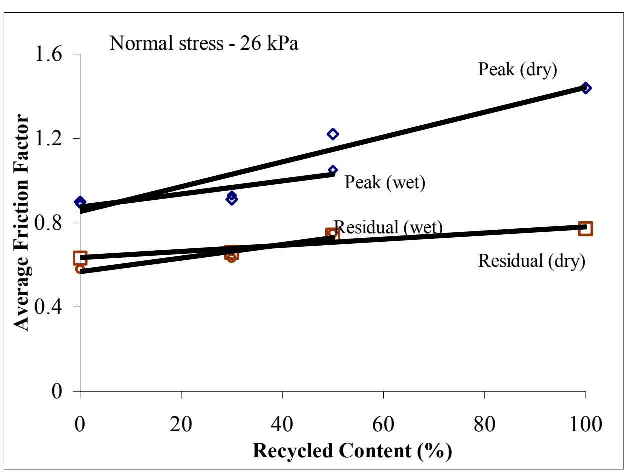

Figure 11. Average friction factors for virgin and recycled geofoam

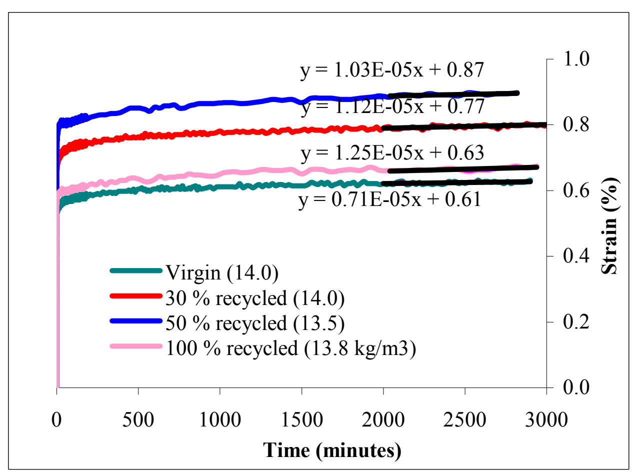

Figure 12. Creep behavior of geofoam containing different recycled content (density) at 30% strength for 100 mm cube samples

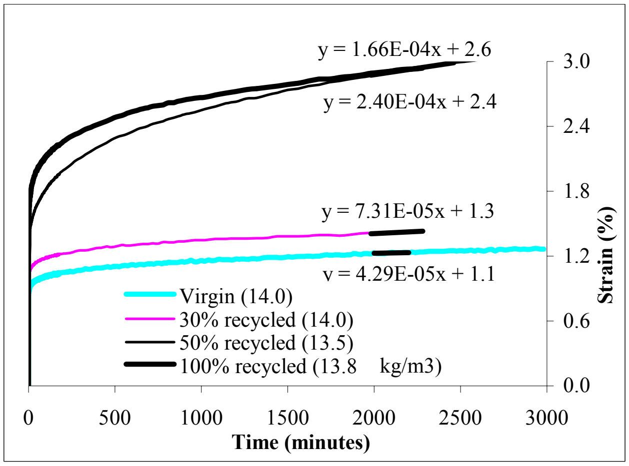

Figure 13. Creep behavior of geofoam containing different recycled content (density) at 50% strength for 100 mm cube samples

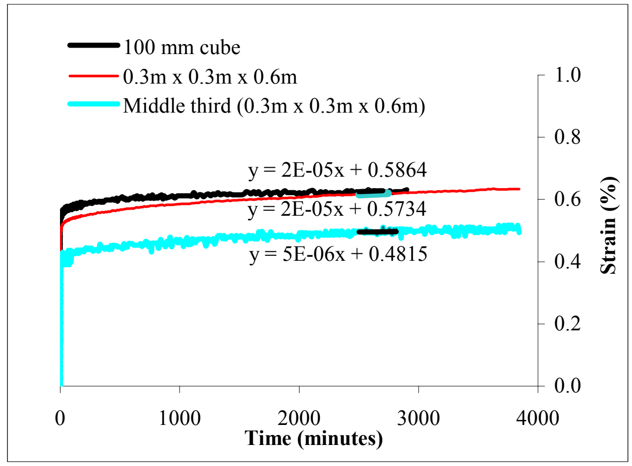

Figure 14. Creep behavior of 0.3m x 0.3m x 0.6m geofoam containing 30% recycled content at 30% compressive strength

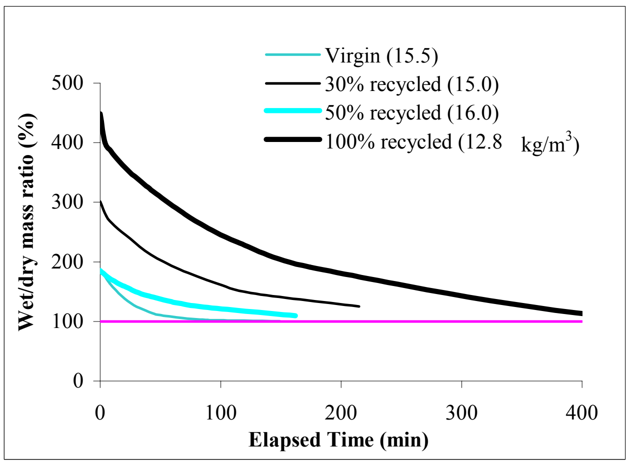

Figure 15. Water absorption test results

Sample size (mm)	Virgin	30%	50%	100%
50	67(4)	60(5)	50(3)	17(4)
100	67(3)	62(5)	58(2)	21(4)
200	69(2)	62(2)	56(2)	20(2)
300	69(1)	62(2)*	57(1)	23(2)

* 30% Regrind sample is 200mm cube

Table 1. Average compressive strength at 5% strain (# samples) for different cube sample sizes, except as noted

Sample size (mm)	Virgin	30%	50%	100%
50	3.3(4)	2.9(5)	2.2(3)	0.6(4)
100	3.9(3)	2.8(5)	2.3(2)	1.0(4)
200	4.2(2)	3.0(2)	3.0(2)	0.9(2)
300	4.6(1)	3.0(2)*	3.5(1)	1.3(2)

* 30% Regrind sample is 200mm cube

Table 2. Average initial modulus(# samples) for different cube sample sizes, except as noted

Recycled Content (%)	Average Density (kg/m^3)	Average Strength (kPa)	Average Modulus (MPa)
0	15.2 (15.1)	147 (142)	7.1 (6.8)
30	15.5 (14.7)	167 (158)	7.1 (6.5)
50	15.6 (13.1)	118 (115)	4.5 (4.3)
100	11.1 (11.7)	36 (48)	1.4 (1.9)

Table 3. Flexure strength and modulus for 75mm x 305mm x 25mm (100mm x 305mm x 25mm) samples

Recycled content (%)	Cut Interface		Skin Interface	
	Peak	Residual	Peak	Residual
0	0.90 (0.89)	0.63 (0.58)	0.76 (0.59)	0.76 (0.61)
30	0.91 (0.93)	0.66 (0.63)	0.75 (0.81)	0.67 (0.70)
50	1.22 (1.05)	0.74 (0.75)		
100	1.40	0.77		

Table 4. Peak and residual friction factors for dry (wet) conditions all determined at 26 kPa normal stress

Photo 1. Compression of a 100 mm cube specimen

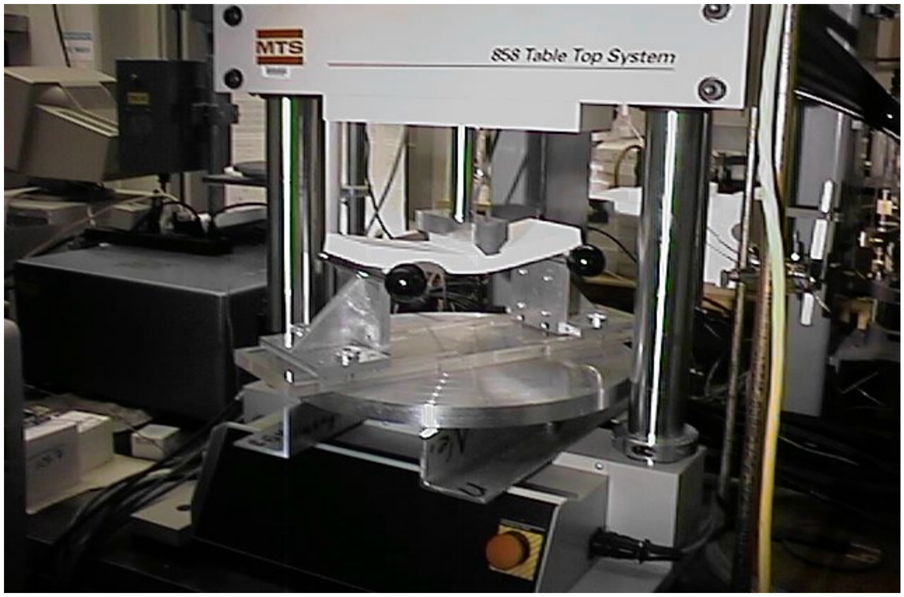

Photo 2. Bending test on geofoam

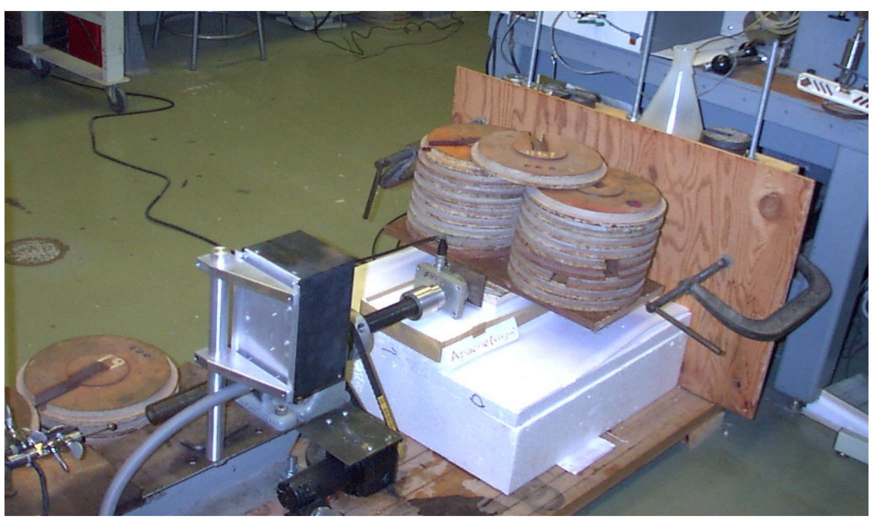

Photo 3. Geofoam interface shear testing at 26 kPa normal stress