Investigation of Thermal Behaviour and Structural Capacity of Bottom Ash as an Insulation Layer

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INTRODUCTION

•A combination of prolonged low temperatures, shallow water table and frost susceptible subgrade soil can result in frost heave of pavements during the winter. Also, during the thaw season, pore water pressure builds up in the subgrade soil, reducing the subgrade modulus and degrading the structural adequacy of the pavement [1].

•Insulating the pavement foundation is a common strategy in cold regions to prevent frost penetration into the pavement during the winter months.

•Structural capacity of the pavements containing insulation layers requires investigation to ensure a sufficiently strong foundation to carry the traffic.

DESCRIPTION OF TEST ROAD

•Integrated Road Research Facility (IRRF)'s test road is the new access to the Edmonton Waste Management Centre (EWMC), constructed in August 2012.

•The test road includes two test sections with Bottom Ash and Polystyrene Boards as insulation layers placed immediately underneath the granular base layer as well as an adjacent Control Section (Figure 1).

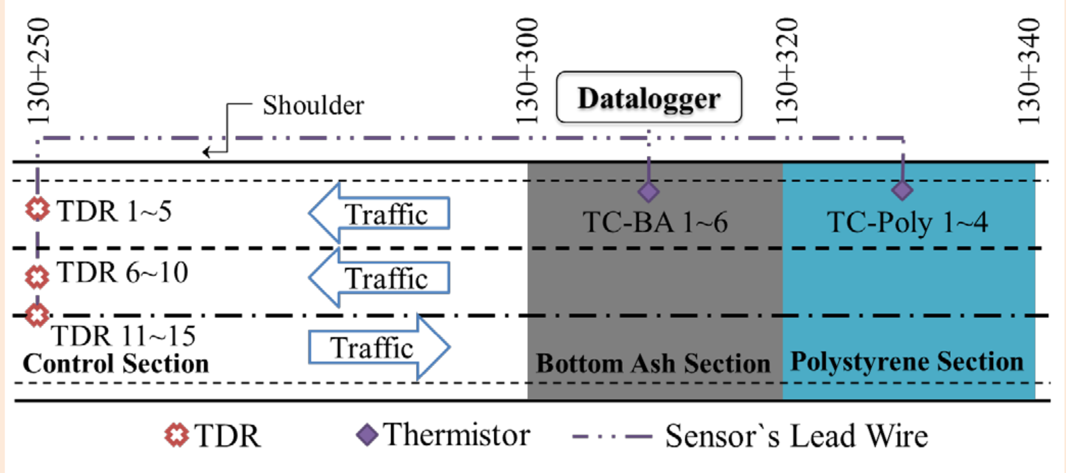

Figure 1- Plan view of the test sections.

Materials and Instrumentation

•Thermal properties of the pavement materials, thermal conductivity (k), heat capacity (c_p) and thermal resistivity (R-value = D/k), where D is the layer thickness is provided in Table 1.

Table 1- Typical Thermal Properties of the Materials.

Material	c_p (kJ/kg.°C)	k (W/m.°C)	D (mm)	R-value (m².°C/W)	Source
Asphalt concrete	0.92	1.21	160	0.13	[2]
Granular base course (GBC)	0.71	0.9	450	0.50	
Subgrade soil	0.71	0.6	1,000	-	
Bottom ash	0.8	0.7	1,000	1.43	[3]
Polystyrene boards	1.25	0.007	100	14.29	[4]

•All three pavement sections were instrumented with thermistors and Time Domain Reflectometers (TDR). As-built depth and location of the instrumentation is presented schematically in Figure 2.

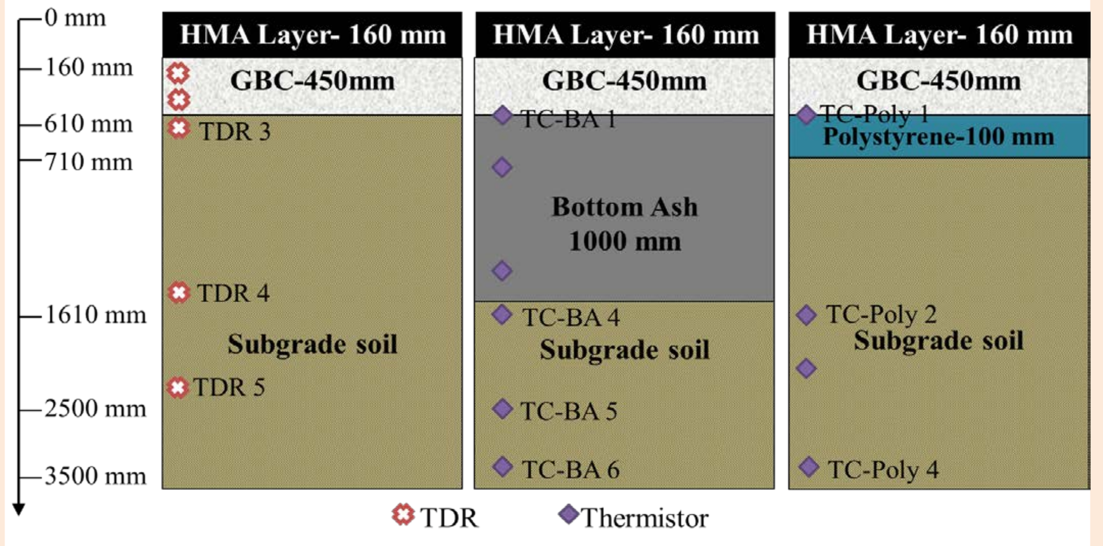

Figure 2- Cross section and as-built depth of thermistors and moisture probes.

ANALYSIS of DATA

Frost Depth

•Max frost depth in Control Section was ~2.0 m (see Figure 3). Frost remained in the subgrade from mid-Nov to mid-Apr.

•Subgrade in Bottom Ash section did not freeze at any depth, and frost depth was limited to 1.4 m, which is within the Bottom Ash layer. Frost started in mid-Dec and was fully thawed by mid-April.

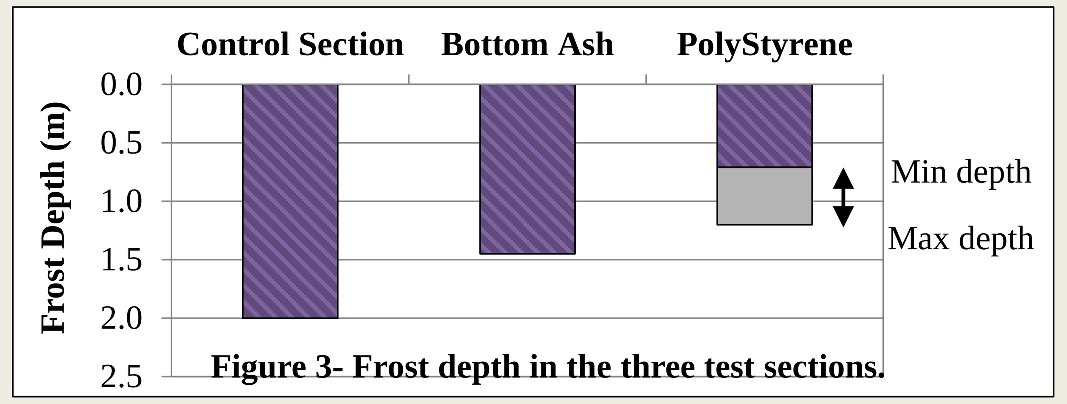

Figure 3- Frost depth in the three test sections.

•Due to lack of thermistors between 0.6 and 1.7m, the exact frost depth can not be established for the Polystyrene section, but is expected to be in the range of 0.6 and 1.2m.

Structural Capacity Evaluation

•Falling-Weight Deflectometer (FWD) tests were conducted at 10-m intervals along the Centre line in different months (see Table 2).

Table 2- Date and Temperature of FWD tests

Symbol	FWD Test No.	Date	Ambient Temp. (°C)
■	1	Aug. 28, 2012	22
▲	2	May 31, 2013	27
✖	3	July 3, 2013	37
✱	4	July 30, 2013	30
	5	Aug. 28, 2013	26

•FWD deflections for a seven-sensor configuration test setup was used in EVERCALC for backcalculation (see Table 3 for inputs).

•One pavement structure was defined for all test sections: 160-mm HMA, 450-mm GBC, subgrade soil (SG) and bedrock.

•Modulus of bedrock remains constant during backcalculation and the depth to the bedrock is calculated internally by EVERCALC.

•Test temperatures in Table 2 were entered as inputs for EVERCALC to correct the HMA modulus for temperature.

Table 3- Layers properties used in EVERCALC.

Layer	Poisson's Ratio	Initial Modulus (Mpa)	Min. Modulus (Mpa)	Max. Modulus (Mpa)
HMA	0.30	2,800 (ASTM D5885)	300	14,000
GBC	0.25	180 (ASTM D5885)	35	3,500
SG	0.35	50 (ASTM D5885)	35	3,500
Bedrock	0.40	345 (default)	-	-

Structural Capacity Analysis Using FWD test

•Backcalculation results for all the tests are provided in Figure 4. Also Table 4 is provided average modulus of HMA, GBC and SG of each test.

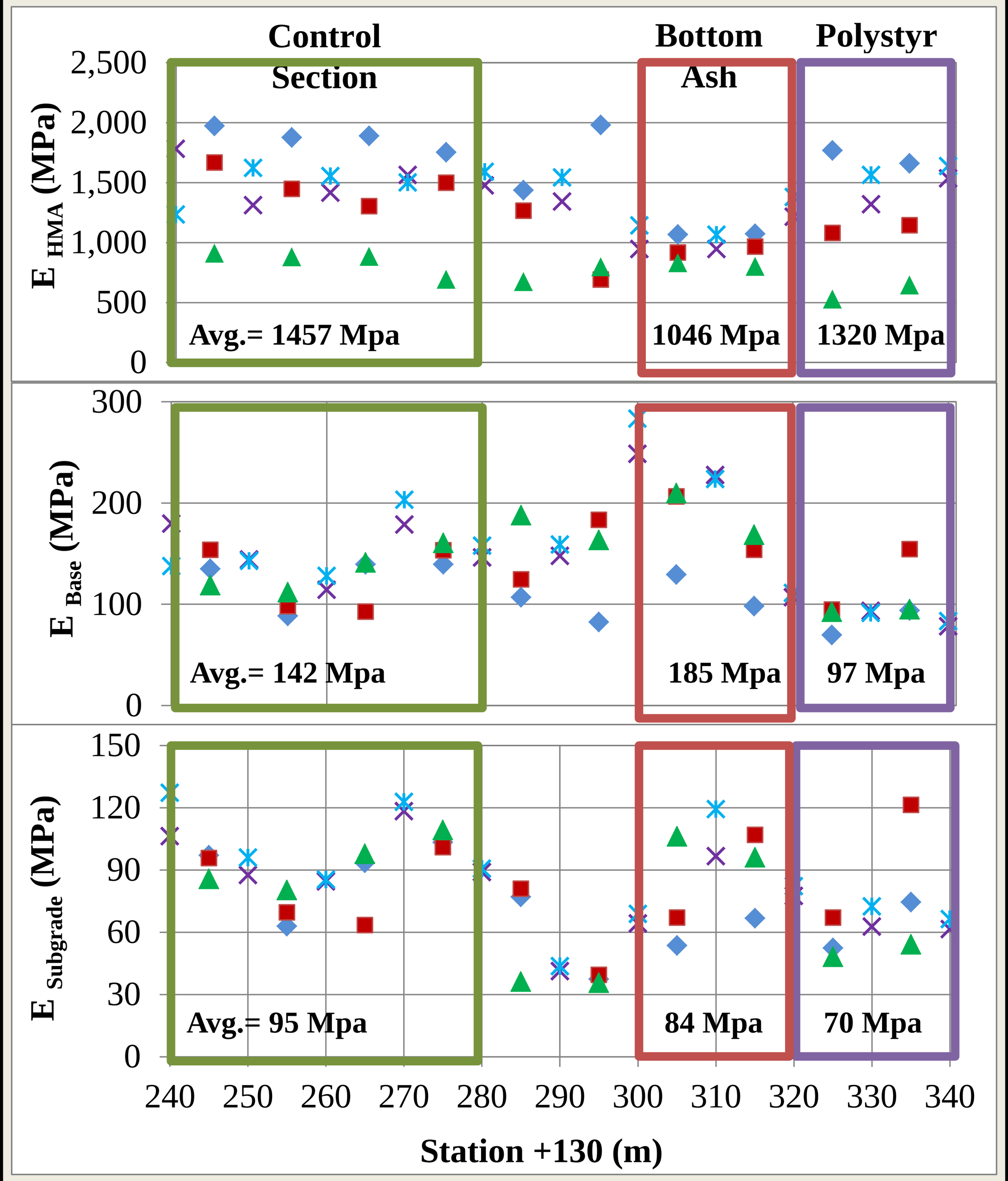

Figure 4- Backcalculated modulus of different layers using EVERCALC

Table 4- Average modulus of Base and Subgrade

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5
Avg. HMA modulus (MPa)	1648	1192	765	1350	1439
Avg. GBC modulus (MPa)	108	142	145	151	157
Avg. SG modulus (MPa)	72	81	75	81	89

•According to Table 4, the highest HMA modulus in Control Section was achieved for Test 1, which was conducted at min test temperature of 22°C. The lowest HMA modulus was obtained for Test 3 conducted at max test temperature of 37°C.

•Average GBC and SG moduli are consistent among all the tests, except for modulus of GBC at the first test.

•Using Bottom Ash and Polystyrene decreased HMA modulus by 28 and 9%; and the SG modulus by 12 and 26%, respectively. On the other hand, using the Bottom Ash has increased the GBC modulus by 30%, while using the Polystyrene decreased the GBC modulus by 32%.

MEPDG-Performance Evaluation

•MEPDG Version 1.1 was used a to predict the long-term performance of the three sections.

•Average modulus of all five tests for each section (Figure 3) was used to define the GBC and SG layers in the MEPDG.

•Table 4 shows the general information and performance criteria used in the MEPDG design.

Table 4- General information used in MEPDG.

General Information			
Design Life	20 years	Reliability	90%
Permanent Deformation (Rutting)	1.9 cm	AC Bottom Up Cracking (Alligator Cracking)	25%

•Tables 6 and 7 show the traffic and HMA properties used in the MEPDG. Gradation of GBC and SG are provided in Figure 5. Poisson Ratio of GBC and SG were defined as 0.35.

Table 6- Traffic information used in MEPDG

Traffic			
AADTT	2,000	Operational Speed	40 km/h
Number of Lane	2	Traffic Growth	3%
Directional Distribution	50%	Lane Distribution	100%

Table 7- Material properties used in MEPDG- HMA

Asphalt Mixture Properties			
Cumulative Retain 3/4 inch sieve	0%	Cumulative Retain #4 sieve	36%
Cumulative Retain 3/8 inch sieve	19%	Passing #200 sieve	8.6%
Effective binder content	11.6%	Air void	7%
Total Unit Weight (KN.m³)	23.6	Asphalt Type	PG 46-34

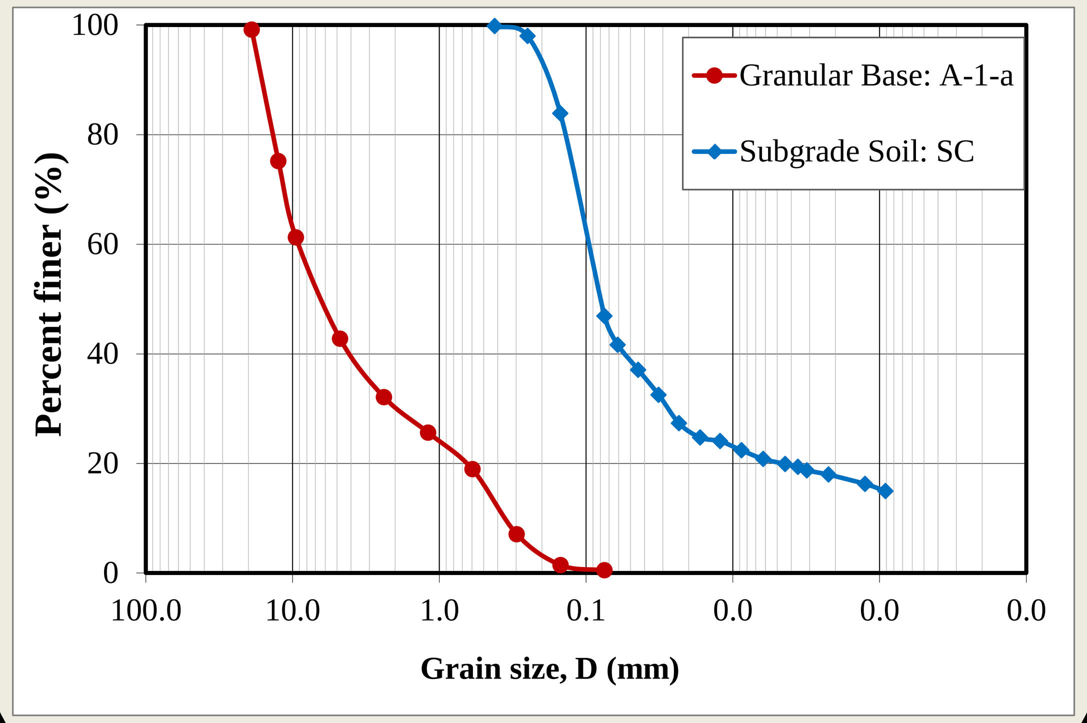

Figure 5- Grain size distribution of the GBC and SG.

•Figures 6 and 7 show the MEPDG-predicted alligator cracking and total pavement rutting.

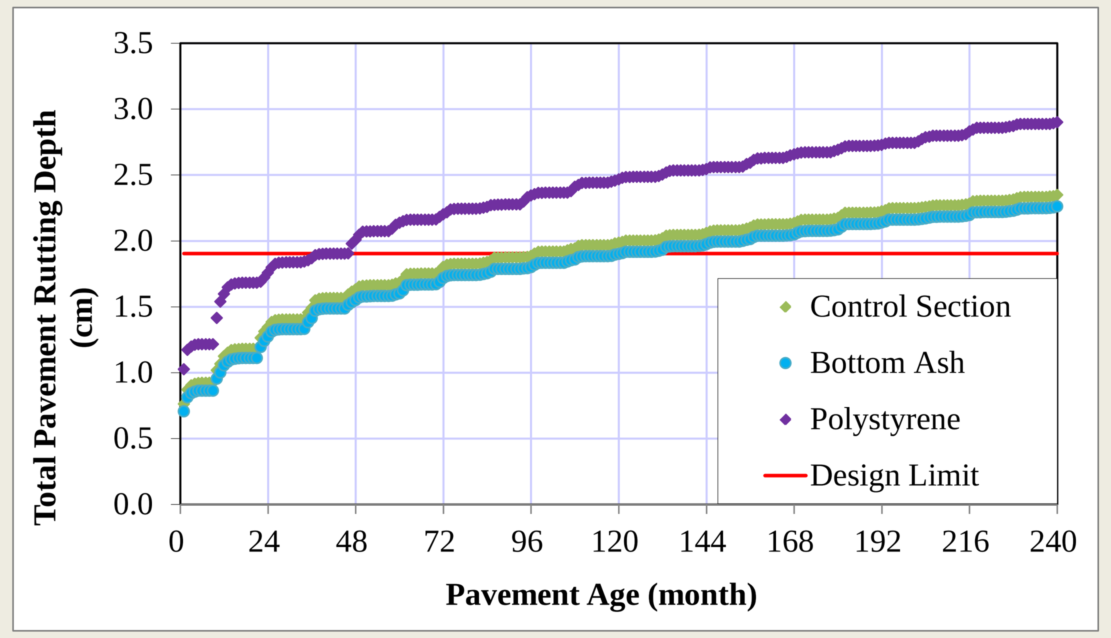

Figure 6- MEPDG-predicted total pavement rutting

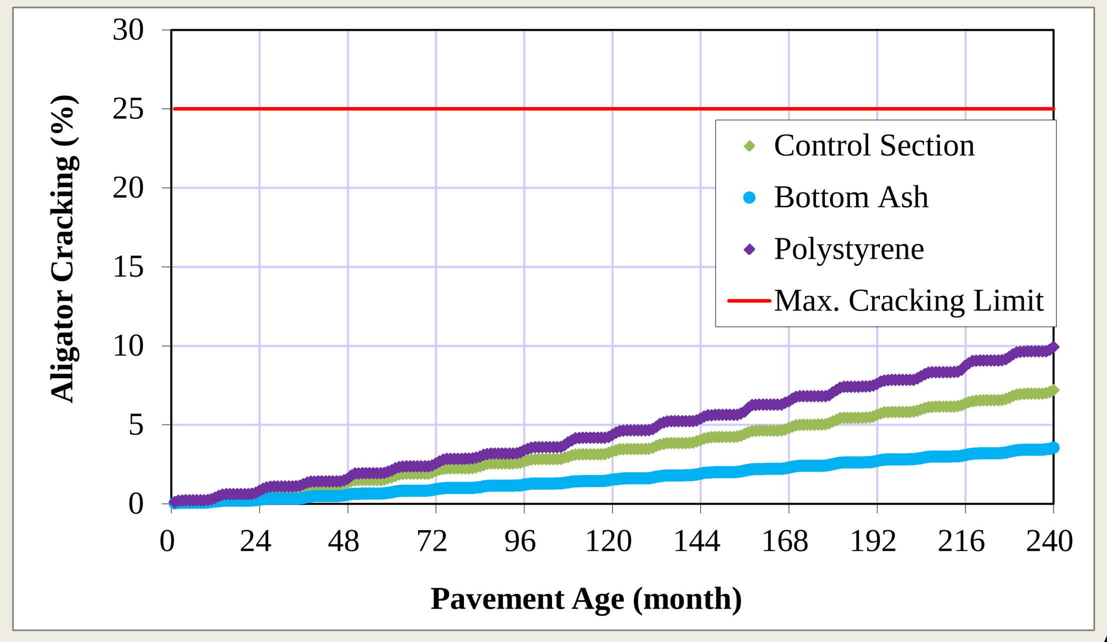

Figure 7- MEPDG-predicted total pavement alligator cracking.

CONCLUSIONS

•Higher R-value of Polystyrene resulted in a decrease in frost depth by at least 40% in comparison to the Control Section, While the Bottom Ash displayed a 28% reduction in frost depth.

•Average GBC and subgrade moduli remain approximately similar in one year of test.

•Using Bottom Ash and Polystyrene decreased HMA modulus by 28 and 9%; and the subgrade modulus by 12 and 26%, respectively.

•Using Bottom Ash increased the GBC modulus by 30%, while Polystyrene decreased the GBC modulus of by 32%.

•Predicted rutting was consistent for Bottom Ash and Control Section (2.3 cm after 20 years), while the Polystyrene Section experienced higher rutting (2.9 cm).

•Bottom Ash Section outperformed both Control and Polystyrene Section by showing the alligator cracking as low as 3.6%.

ACKNOWLEDGEMENTS

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References

[1]Doré, H. K., and G., Zubeck Cold Regions Pavement Engineering. New York: McGraw-Hill Professional, 2009
[2]Tompson, M.R., et al. Characterizing Temperature Effects for Pavement Analysis and Design. TRR, No. 1121, Washington, D.C., 1988, pp. 14–22.
[3] Klein, R., N. Nestle, R. Niessner, and T. Baumann. Numerical Modeling of the Generation and Transport of Heat in a Bottom Ash Monofill. Journal of Hazardous Materials, Vol. 100, No. 1–3, Jun. 2003
[4] Dow Building Solutions. http://dow-styrofoam.custhelp. com/app/answers/detail/a_id/721. Accessed Jul. 1, 2013.