RESEARCH REPORT

INITIAL MATERIAL CHARACTERIZATION OF STRAW LIGHT CLAY

EXTERNAL RESEARCH PROGRAM

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Initial Material Characterization of Straw Light Clay

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Note: Text is complete despite inconsistencies in paging

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Abstract

Straw light clay (SLC) is a contemporary variant of earth building techniques, which have been a part of advanced civilizations for thousands of years. Africa, the Middle East, Asia, Europe and the Americas all have rich traditions in these techniques. Indeed, all of these regions have structures, which were built 500-1000 years ago with earth, often mixed with straw, frequently in combination with timber structural elements that are standing today. This serves as a testament to the endurance of the materials, as well as traditional knowledge.

This research has been undertaken in an effort to begin to quantify the material properties of (SLC). It is a first step in complementing the experiential and anecdotal evidence, as provided by builders and regional tradition, with empirical laboratory analysis as provided by established testing protocol. It is this bilateral approach that is currently required in North America, as the data generated from the latter, is used by architects, engineers, and code officials to specify, analyze, and uphold code policy. This research is intended to promote deeper investigation within the natural and sustainable building envelope research community.

Executive Summary

Introduction

Straw light clay (SLC) is prepared by coating a straw aggregate with a clay binder. This creates a versatile non-structural and insulative infill material with a very low embodied energy. Applications include exterior walls as well as interior partition walls.

In most applications SLC is formed *in situ*, but several practitioners have also been developing methods of forming blocks. The blocks are then air dried at the manufacturing facility. This allows for a dry assembly on site, which effectively extends the building season in regions that experience significant spring and fall precipitation. The three density classes of SLC most often referred to in North America are; 480-560 kg/m^3, 640- 720 kg/m^3, and 800-880 kg/m^3 (30-35 pcf, 40-45 pcf, and 50-55 pcf respectively).

North America has seen a steady growth of interest over the past several decades in natural building techniques. Many of these techniques and systems are in fact, contemporary adaptations of traditional methods, and SLC is no exception. One of the most definitive characteristics of current building practice is the need to adhere to building codes and standards. These codes are often based upon evidence gathered from laboratory analysis of materials characteristics. Therefore, placing natural building materials in a contemporary context requires testing which demonstrate basic material properties. This research program is an initial materials characterization of straw light clay, and is the first step in establishing these material properties for straw light clay.

Sample and Specimen Preparation

To prepare for testing, large sections of straw light clay elements, were created in three density classes. Specimens for each testing program were then cut from these larger elements. This reduced voids and increased accuracy of the sample dimensions. Thermal specimens were 400 x 250 x 150mm, and all others were 150 x 150 x 150mm. All samples were left to air dry for a minimum of 12 weeks.

Loam is a mixture of sand, clay, silt, and organic matter. To define the properties and characteristics of loam and assess its suitability for use in the testing program, several texture field tests were conducted. In addition an effervescence test was conducted using a solution of 10% HCl (hydrochloric acid). Lastly, a grain size distribution analysis was conducted.

Testing Results: Thermal and Moisture Characteristics.

The table below summarizes the results of the Thermal and Moisture related properties as found through this testing program. Specific densities are given for each sample. All of the tests in this series were performed to ASTM standards with the exception of the moisture storage test. This procedure, however, has been well established in many labs throughout the world.

The thermal conductivity ranged from 0.18 to 0.068 W/mK (0.8 R_{imp} to 2.1 R_{imp} / in),the higher the density, the lower the insulating value. The most common density, and the easiest to achieve in practice, is between 600 and 700 kg/m^3. In this density range, SLC will be compliant with the Ontario Building Code requirements for minimum thermal resistance. The lack of thermal bridging inherent in the typical SLC wall system makes whole wall R-values much closer to the calculated R-value than most conventional products. A calculated R-value, based on the average of data from the thermal testing program, would be RSI = 3.30 (R_{imp} = 19) mm (12 in) thick layer of core material.

Sample	Dimensions (of density sample)	Density (pcf)	Density (Kg/m3)	k (w/mK)	RSI (25.4mm)	R-value (in)	Permeability (ng/Pasm)	Permeance (ng/Pasm2)	Sorption (%mass@75%)	Absorption Coefficient w (kg/m2h0.5)
A3	150x155x150mm (5.875 x 6.125 x 6)	38	601	0.149	0.17	1.0	75.9	747	2.4	1.7
C3	150x150x150mm (6 x 6 x 6)	39	626	0.076	0.33	1.9	59.9	590	2.5	0.9
B3	155x150x150mm (6.125 x 6 x 6)	40	638	0.068	0.37	2.1	51.2	504	2.2	2.0
B4	150x150x150mm (6 x 6 x 6)	40	647	0.090	0.28	1.6	45.9	451	-0.2	3.4
C4	155x150x150mm (6.125 x 6 x 6)	45	717	0.125	0.20	1.2	35.2	346	2.0	3.3
A4	150x150x150mm (6 x 6 x 6)	47	749	0.111	0.23	1.3	44.1	434	2.4	3.6
A5	150x150x150mm (6 x 6 x 6)	59	951	0.180	0.14	0.8	27.4	270	1.9	3.2

Table 1. Results of thermal and moisture related testing programs.

The vapor permeability of SLC is quite high, similar to fiberglass and cellulose insulation, and this allows for fast drying. The water absorption coefficient is also rather high i.e. water is “wicked” quickly into the material. The moisture storage (based on mass) at 75% RH is low compared to wood or straw, however the volumetric storage capacity is relatively high.

Based on these material properties and characteristics, as well as building science theory, certain conclusions about wall systems can be made. Provided moisture storing, and vapor permeable plasters are used on the interior, and exterior, a SLC wall can be expected to perform well as a flow through wall. The high vapor permeability of SLC allows for quick drying. This, in combination with the fact that liquid transport is available as a transport mechanism to redistribute liquid moisture and that SLC has a very large moisture storage capacity, results in a wall system that can be used in a flow through design. This approach seeks to allow for water to flow via vapor diffusion through the wall without significant accumulation in the wall assembly. The flow would be from the interior to the exterior during heating periods, and from the exterior to the interior during cooling periods.

Compression and Bending

The compression and bending tests were conducted at the University of Waterloo, and the results of this testing program are tabulated below.

The compression data in table 3 shows the compressive strength at 5% strain. This represents the load at the maximum reasonable displacement, in service conditions. The compression curves exhibit a fairly wide elastic range, as well as a wide plastic range, indicating a high ductility.

The bending data in table 4 displays the peak moment, modulus of rupture, and the modulus of elasticity. All values are given in Megapascals (Mpa) as well as pounds per square inch (psi).

Sample	**Avg. Density**		**Compressive Strength @ 5% strain**		**Modulus of Elasticity**	
	kg/m^3	**pcf**	**MPa**	**psi**	**MPa**	**psi**
35-1	520	32.5	0.04	6.4	1.19	175
35-2	520	32.5	0.1	14.9	2.65	390
35-3	520	32.5	0.05	8.1	4.83	710
45-1	680	42.5	0.08	11.9	1.36	200
45-2	680	42.5	0.06	9.4	1.26	185
45-3	680	42.5	0.14	20.9	6.29	925
55-1	920	57.5	0.14	20.8	2.55	375
55-2	920	57.5	0.19	28.7	3.91	575

Table 2. Compression results

Terms:
kg/m^3 = kilograms per cubic meter
pcf = pounds per cubic foot.
Mpa = Megapascals
psi = pounds per square inch

section modulus	moment of inertia
$S=bh^2/6$	$I=bh^3/12$
589934	4.50E+07

sample	peak moment	rupture modulus		modulus of elasticity	
	M=PL/2 kNm	f'r=M/S		$E=48dI/PL^3$	
		(MPa)	*psi*	*(MPa)*	*psi*
35-1	0.1	0.17	26	0.002	0.4
35-2	0.26	0.43	64	0.001	0.2
35-3	0.09	0.15	22	0.002	0.3
45-1	0.14	0.23	34	0.001	0.1
45-2	0.21	0.35	51	0.003	0.4
45-3	0.11	0.19	28	0.002	0.2
55-1	0.23	0.39	58	0.007	1.0
55-2	0.34	0.57	84	0.008	1.2

Table 4 Bending Results

Settling

The settling test was a very initial investigation into this characteristic of straw light clay, and effectively establishes a field test for quantifying this characteristic on-site with local materials. Measurements were taken across the top of each sample with a wooden registration gauge.

Prior to air drying, the height of the sample, relative to the height of the top of the form was measured and recorded. A corresponding measurement was taken after the samples had reached air-dried equilibrium moisture content. The difference between these two figures was then multiplied by 100 and divided by the initial height of the block when formed, 300mm (12 in) e.g.

$$(H_b-H_a) * 100 / 300$$

Where:
H_b = height before drying
H_a = height after drying

Density Class Kg/m3	Before Drying	After Drying	Difference	Settlement (%)
560-640	22mm 1"	46mm 2"	24mm 1"	8.0%
720-800	19mm .75"	41mm 2"	22mm 1.25"	7.0%
880-960	19mm .75"	38mm 1.5"	19mm .75"	6.0%

Table 5. Settling results.

Significant settling occurred in all samples (an average of 7%). As density increased shrinkage decreased. A much broader investigation is required to have a sufficient statistical spread for reliable values to be determined. This data does however serve to illustrate this phenomenon.

Fire

The fire testing was conducted on the basis of established field tests.This test simply observed samples exposed to a pressurized propane flame, at the flame tip with an average temperature of approximately 2000°F (1093°C) for a period of four hours and recorded the average depth of penetration. All samples (measuring 150 x 150 x 150mm) could be handled with bare hands after four hours. Even the lowest density exhibited penetration of only 70mm. The high density exhibited much less at 19mm. The results were encouraging for future research based on ASTM standards. It is quite reasonable to expect that such investigation would establish a 4 hr. fire resistance for 150mm straw light clay.

sample	penetration	density class	avg. penetration
A-1	63mm (2.5")	560-640 Kg/m3	70mm (2.75")
A-2	76mm (3")		
A-3	70mm (2.75)		
B-1	51mm (2")	720-800 Kg/m3	51mm (2")
B-2	38.1mm (1.5)		
B-3	63mm (2.5)		
B-4	19mm (.75")	950 Kg/m3	19mm (0.75)

Table 5. Fire testing results

Résumé

Introduction

Le matériau de construction constitué de paille et d’argile légère (PAL) se prépare en enrobant la paille d’un liant d’argile. Le produit obtenu donne un matériau de remplissage isolant, non structural, mais polyvalent, nécessitant très peu d’énergie de production. Il peut entrer dans la fabrication des murs extérieurs comme des cloisons intérieures.

Dans la majorité des cas, la PAL se confectionne sur place, mais plusieurs praticiens ont également mis au point des méthodes consistant à former des blocs que l’on fait sécher à l’air à l’usine de fabrication. Cela permet d’obtenir un matériau sec sur le chantier et ainsi de prolonger la saison de construction dans les régions qui enregistrent de fortes précipitations au printemps et en automne. Voici les trois catégories de masse volumique du produit auxquelles on se réfère le plus en Amérique du Nord : 480-560 kg/m^3 (30-35 lb/pi^3), 640-720 kg/m^3 (40-45 lb/pi^3) et 800-880 kg/m^3 (50-55 lb/pi^3).

L’Amérique du Nord a connu, au cours des dernières décennies, un accroissement d’intérêt constant à l’égard des techniques de construction écologiques. Bon nombre de ces techniques et systèmes de construction sont, en réalité, des adaptations contemporaines de méthodes classiques et la PAL ne fait pas exception à la règle. L’une des caractéristiques absolues des techniques de construction courantes traduit la nécessité de se conformer aux codes du bâtiment et aux normes. Les codes sont bien souvent fondés sur des preuves recueillies à partir d’analyses en laboratoire des caractéristiques de matériaux. Par conséquent, transposer des matériaux de construction écologiques dans un contexte contemporain requiert des essais attestant les propriétés fondamentales des matériaux. Le présent programme de recherche tend à caractériser pour la première fois la paille et l’argile légère, et constitue la première étape visant à établir les propriétés de ce matériau.

Préparation des spécimens

En guise de préparation pour la mise à l’essai, on a constitué de gros éléments de paille et d’argile légère de trois catégories de densité. Des spécimens pour chaque programme d’essai ont ensuite été prélevés de ces éléments. On a pu ainsi réduire les vides et accroître l’exactitude des dimensions des spécimens. Les spécimens thermiques mesuraient 400 x 250 x 150 mm, et tous les autres 150 x 150 x 150 mm. On a fait sécher à l’air les échantillons pendant au moins 12 semaines.

Le limon se compose de sable, d’argile, de silt et de matière organique. Pour définir les propriétés et les caractéristiques du limon et juger de son acceptabilité pour fins d’emploi dans le programme d’essais, plusieurs essais de texture ont été menés à pied d’œuvre. On a également effectué un essai d’effervescence à l’aide d’une solution de 10 % d’acide chlorhydrique (HCl), puis mené une analyse de distribution de la granulométrie.

Résultats d'essais : caractéristiques thermiques et hygrométriques

Le tableau ci-après résume les propriétés thermiques et hygrométriques obtenues dans le cadre du programme d'essais. La densité spécifique de chaque échantillon est indiquée. Tous les essais de cette catégorie ont été effectués conformément aux normes ASTM, à l'exception de l'essai de stockage à l'humidité. Cette marche à suivre est toutefois bien établie dans de nombreux laboratoires du monde entier.

La conductivité thermique varie de 0,18 à 0,068 W/mK (0,8 R à 2,1 R / po), mais plus la densité augmente, plus la valeur d'isolation thermique diminue. La masse volumique la plus courante, et la plus facile à réaliser en pratique, se situe entre 600 et 700 kg/m³. Dans cette gamme de masses volumiques, la PAL est conforme à la résistance thermique minimale requise par le Code du bâtiment de l'Ontario. Le manque de ponts thermiques propre au mur PAL type fait en sorte que les valeurs R de l'ensemble du mur se rapprochent beaucoup plus des valeurs R calculées que la plupart des produits classiques. En effet, la valeur R calculée, fondée sur la moyenne des données obtenues à partir du programme d'essais thermiques, donne au matériau de 12 po d'épaisseur la valeur RSI 3,30 (R 19).

Échantillon	**Dimensions**	**Masse volumique (lb/pi³)**	**Masse volumique (kg/m³)**	**k (W/mK)**	**RSI (25,4 mm)**	**Valeur R (po)**	**Perméabilité (ng/Pa.s.m)**	**Perméance (ng/Pa.s.m²)**	**Sorption (% masse à 75 %)**	**Coefficient d'absorption W (kg/m²h0,5)**
A3	150x155x150 mm (5,875x6,125x6)	38	601	0,149	0,17	1,0	75,9	747	2,4	1,7
C3	150x150x150 mm (6x6x6)	39	626	0,076	0,33	1,9	59,9	590	2,5	0,9
B3	155x150x150 mm (6,125x6x6)	40	638	0,068	0,37	2,1	51,2	504	2,2	2,0
B4	150x150x150 mm (6x6x6)	40	647	0,090	0,28	1,6	45,9	451	-0.2	3,4
C4	155x150x150 mm (6,125x6x6)	45	717	0,125	0,20	1,2	35,2	346	2,0	3,3
A4	150x150x150 mm (6x6x6)	47	749	0,111	0,23	1,3	44,1	434	2,4	3,6
A5	150x150x150 mm) (6x6x6)	59	951	0,180	0,14	0,8	27,4	270	1,9	3,2

Tableau 2 Résultats des programmes d'essais thermiques et hygrothermiques

Le PAL enregistre une perméabilité à la vapeur d'eau assez élevée, à l'exemple de l'isolant en fibre de verre ou cellulosique, et cette propriété lui permet de s'assécher rapidement. Le coefficient d'absorption d'eau est également plutôt élevé, c'est donc dire que l'eau parvient rapidement dans le matériau par capillarité. Le stockage d'humidité (fondé sur la masse) à une HR de 75 % est faible comparativement à celui du bois ou de la paille, mais la capacité de stockage volumétrique demeure plutôt élevée.

D'après ces caractéristiques et propriétés des matériaux, et les principes de la science du bâtiment, on peut tirer certaines conclusions à l'égard des systèmes muraux. À condition de pouvoir stocker l'humidité et d'être revêtu d'enduit perméable à la vapeur d'eau à l'intérieur comme à l'extérieur, le mur PAL devrait donner une bonne tenue en service à titre de mur hautement perméable. La perméabilité élevée à la vapeur d'eau du mur de paille et d'argile légère lui permet de s'assécher rapidement. Cette caractéristique, combinée au fait que le transfert d'eau permet de répartir l'humidité et que le mur PAL a une très importante capacité d'absorption de l'humidité permet d'employer ce type de mur dans un concept de mur hautement perméable. Cette démarche vise à permettre à l'eau de s'écouler par diffusion par le mur sans y favoriser l'accumulation appréciable d'eau. Le mouvement d'eau se ferait de l'intérieur vers l'extérieur au cours de la saison de chauffage et de l'extérieur vers l'intérieur au cours de la période de climatisation.

Compression et flexion

Les essais de compression et de flexion ont été effectués à l'Université de Waterloo; les résultats sont d'ailleurs reproduits ci-dessous.

Les données de compression du tableau 3 indiquent la résistance à la compression selon un allongement de 5 %. Il s'agit de la charge suivant un déplacement raisonnable maximal en service. Les courbes de compression affichent une gamme d'élasticité assez large, de même qu'une importante plage de plasticité, témoignant ainsi d'une forte ductilité.

Les données de flexion du tableau 4 affichent le moment de pointe, le module de rupture et le module d'élasticité. Toutes les valeurs sont exprimées en mégapascals (MPa) de même qu'en livres par pouce carré (lb/po2).

Échantillon	Masse volumique moyenne		Résistance à la compression suivant un allongement de 5 %		Module d'élasticité	
	Kg/m^3	Lb/pi^3	MPa	Lb/po^2	MPa	Lb/po^2
35-1	520	32,5	0,04	6,4	1,19	175
35-2	520	32,5	0,1	14,9	2,65	390
35-3	520	32,5	0,05	8,1	4,83	710
45-1	680	42,5	0,08	11,9	1,36	200
45-2	680	42,5	0,06	9,4	1,26	185
45-3	680	42,5	0,14	20,9	6,29	925
55-1	920	57,5	0,14	20,8	2,55	375
55-2	920	57,5	0,19	28,7	3,91	575

Tableau 3   Résultats des essais de compression

Termes
Kg/m^3 : kilogrammes par mètre cube
Lb/pi^3 : livres par pied cube
MPa : mégapascals
Lb/po^2 : livres par pouce carré

Section Modulus	Moment of inertia
$S=bh^2/6$	$I=bh^3/12$
589934	4.50E+07

Sample	peak moment	rapture modulus		modulus of elasticity	
	M=PL/2 kNm	Fr=M/S		E=48dl/PL³	
		(MPa)	psi	(MPa)	psi
35-1	0,1	0,17	26	0,002	0,4
35-2	0,26	0,43	64	0,001	0,2
35-3	0,09	0,15	22	0,002	0,3
45-1	0,14	0,23	34	0,001	0,1
45-2	0,21	0,35	51	0,003	0,4
45-3	0,11	0,19	28	0,002	0,2
55-1	0,23	0,39	58	0,007	1,0
55-2	0,34	0,57	84	0,008	1,2

Tableau 4 Résultats des essais de flexion

Tassement

L'essai de tassement traduit la toute première étude de cette caractéristique du matériau de paille et d'argile légère et permet d'établir avec efficacité un essai à pied d'œuvre en vue de quantifier cette caractéristique sur place avec des matériaux locaux. Des mesures ont également été prises en partie supérieure de chacun des échantillons à l'aide d'un gabarit en bois.

Avant l'assèchement à l'air, la hauteur de l'échantillon, par rapport au dessus du coffrage a été mesurée et consignée. Une mesure correspondante a été prise après que les échantillons eurent atteint la teneur hygrométrique équilibrée après le séchage à l'air. L'écart entre ces deux chiffres a ensuite été multiplié par 100 et divisé par la hauteur initiale du bloc au moment de sa formation, 300 mm (12 po), par exemple :

$$(H_b - H_a) * 100 / 300$$

Où :
H_b représente la hauteur avant le séchage
H_a représente la hauteur après le séchage

Catégorie de masse volumique kg/m³	Avant le séchage	Après le séchage	Écart	Tassement (%)
560-640	22 mm 1 po	46 mm 2 po	24 mm 1 po	8 %
720-800	19 mm 0,75 po	41 mm 2 mm	22 mm 1,25 po	7 %
880-960	19 mm 0,75 po	38 mm 1,5 po	19 mm 0,75 po	6 %

Tableau 5 Résultats des essais de tassement

Tous les échantillons ont subi un important tassement (en moyenne 7 %). Le retrait diminuait à mesure qu'augmentait la densité. Une étude plus approfondie s'impose de manière à pouvoir obtenir une répartition statistique suffisante pour déterminer des valeurs fiables. Ces données servent toutefois à illustrer ce phénomène.

Résistance au feu

L'essai de résistance au feu a été effectué en fonction des essais établis à pied d'œuvre. Cet essai consistait à simplement observer les échantillons exposés à une flamme propane comprimée, au bout de la flamme avec une température moyenne d'environ 2 000 °F (1 093 °C) pendant quatre heures et à consigner la profondeur de pénétration moyenne. Tous les échantillons (mesurant 150 x 150 x 150 mm) pouvaient être touchés les mains nues après quatre heures. Même l'échantillon de la plus faible densité enregistrait une pénétration de seulement 70 mm. L'échantillon de haute densité en affichait beaucoup moins, soit 19 mm. Les résultats étaient encourageants pour la future recherche concernant les normes ASTM. Il est tout à fait raisonnable de s'attendre à ce que cette étude établisse une résistance au feu de 4 heures pour le matériau de paille et d'argile légère de 150 mm.

Échantillon	Pénétration	Catégorie de masse volumique	Pénétration moyenne
A-1	63 mm (2,5 po)	560-640 kg^3	70 mm (2,75 mm)
A-2	76 mm (3 po)		
A-3	70 mm (2,75 po)		
B-1	51 mm (2 po)	720-800 kg/m^3	51 mm (2 po)
B-2	38,1 mm (1,5 po)		
B-3	63 mm (2,5 po)		
B-4	19 mm (0,75 mm)	950 kg/m^3	19 mm (0,75 mm)

Tableau 6 Résultats des essais de résistance au feu

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Initial Materials Characterization of Straw Light Clay Infill

Joshua Thornton

1. Introduction

1.1 Scope

This research investigates the thermal resistance and moisture related performance characteristics of straw light clay (SLC) in order to assess the viability of this material for Canadian climates, and the need for future research. In addition; fire resistance, shrinkage and swelling, compression and bending, and density were investigated to support the above mentioned objectives.

This research project consists of three major components:

1.) Literature review

2.) Development and reporting of economical, reliable test methods, which are easily reproduced.

3.) Publishing of data based on these tests, which reveal initial performance characteristics of one formulation of SLC

The test program included:

1.) Preparing a loam/clay mixture and producing samples from which test specimens were derived (80 in total).

2.) Preparing specimens from three density classes (45 specimens in total) to be used in the tests

This test program also investigated several material properties:

a.) Thermal conductivity
b.) Vapor permeability
c.) Moisture storage
d.) Capillary absorption
e.) Compression and bending
f.) Fire resistance
g.) Density

The testing methodologies were developed with the assistance of Dr. John Straube of the University of Waterloo. Section one provides an introduction and some technical background. In section two, the reader will find an extensive literature review. Section three details the material composition, and preparation of the samples.. Sections 4-11 contain the test procedures and results. The discussion section of each of these chapters is dedicated to looking at the test results from a practical, applied perspective.This discussion thread is summarized in the appendix section titled: Application to Enclosure Wall Design.

1.2 Straw Light Clay

SLC is comprised generally of a straw aggregate coated with a "clay" slip, which serves as a binder. Square bales of straw should be clear of any cereal grains. This is a result of careful harvesting and can vary. These are then broken apart. In the case of in situ forming, the straw can be used without chopping. For ideal blocks however, the straw should be chopped in lengths no longer than the width of the desired block. The "clay" slip is typically comprised of loam, mixed with water until the majority of particles are suspended in the liquid. Clay serves as the binder for other, larger particles in the loam. Additives are sometimes used to change the characteristics of the loam, depending upon what is available at a specific site. This slip is then mixed with an aggregate (typically straw). Other aggregates may also be used provided that they are porous enough to create airspace while being rigid enough to resist crushing during the mixing and forming process. Wood chips, sawdust, hemp, and bulrushes are but a few examples known to the author to have been utilized with varying degrees of success.

Straw light clay is one of the most versatile earth building techniques in use. One of the most distinguishing characteristics of the material is that wide ranges of density are achievable by adjusting the aggregate to binder ratio.

The three density classes most often referred to in North America are; 480-560 kg/m^3, 640- 720 kg/m^3, and 800-880 kg/m^3 (30-35 pcf, 40-45 pcf, and 50-55 pcf respectively). In Germany, anywhere from 470 kg /m^3 - 1150 kg /m^3 is considered *lichtlehm* (light loam) [Minke 2000]. This is in contrast to adobe, which has a density of about 1600-1700 kg /m^3 (100 –110 pcf)[Moquin 2000] or strawbales, which have a density which varies from below 110 to over 190 kg /m^3 (7-12 pcf). [Straube 2003]

Forming techniques for SLC add to the versatility of the material. With the ability to be formed into thicknesses ranging from 50- 450mm (2 in -18 in), SLC has been used for interior wall and ceiling applications. In addition, it has been used as roof insulation, and sub floor insulation in rammed earth and adobe floor applications. The most common method of utilizing this mixture, however, is as a non-structural, enclosure material.

Most often, SLC is formed *in situ* in North America. The mixture is placed into slipforms and lightly packed and then tamped around the edges of the form. The slipforms can be removed and "leapfrogged" to the next level immediately after filling each lift. This process makes it possible to form entire walls in a day. A typical 300mm (12 in) thick wall is left to dry for up to eight weeks prior toplastering, and finishing [Laporte, Andreson 2000]

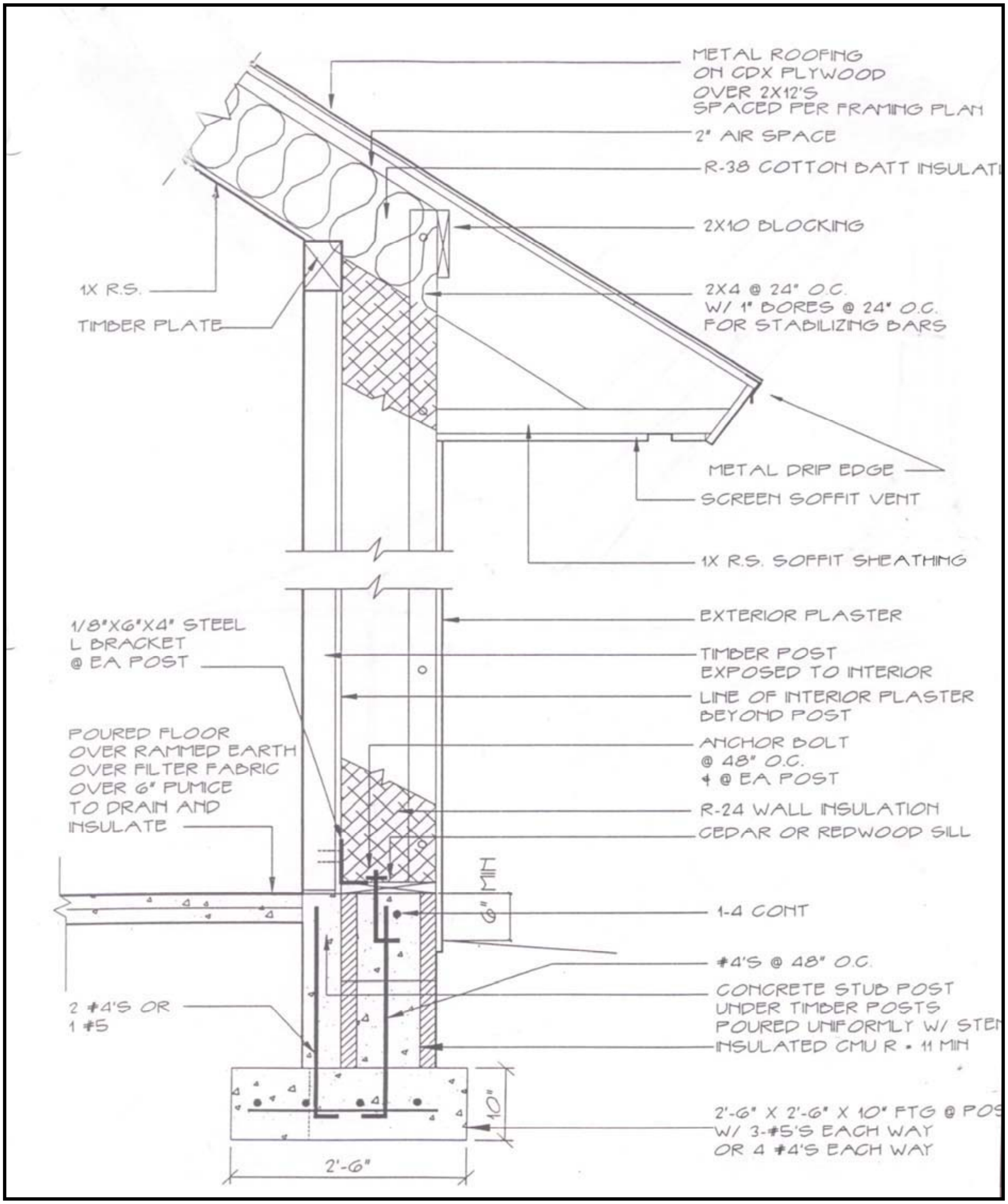

Fig. 1.2-1 Typical wall section

Fig. 1.2-2 View of wall upon removal of first tier of formwork.

Fig. 1.2-3 Completely formed wall

Fig. 1.2-4 Exterior view of walls prior to plastering

Recently, builders in North America have begun to realize advantages to creating SLC blocks. Blocks can be produced, air dried, and stored in a controlled environment. In addition, they can be "laid up" in a wide range of weather conditions. In climates where the building season is limited due to seasonal weather constraints, the building "window" can be significantly increased.

To formulate sound recommendations for further research into SLC as a material, an initial material characterization is needed. The focus of this research is to provide an initial material characterization of the core material of a typical straw light clay wall.

More specifically, this research investigates the thermal resistance and moisture related performance characteristics of SLC in order to assess the viability of this material for Canadian climates, and future research. In addition, fire resistance, shrinkage and swelling, compression and bending, and density were all investigated to support the above mentioned objectives. The material properties given reflect one type of "clay" combined with one type of aggregate.

1.3 Technical Background

The material properties being examined for this research are fundamental to building science. This section is for the benefit of those readers who may not be familiar with some of these terms and definitions. They have been summarized below.

1.3.1 Thermal Conductivity[1]

Thermal conductivity k (or symbol λ) is a fundamental material property that describes the rate of heat flow across a unit area, through a unit thickness for a temperature gradient of one degree. Thermal conductivity often varies with the mean temperature and the magnitude of the temperature differential. Standards normally specify these values so that different materials can be compared.

Units:	SI	W/m·K
	Imperial	Btu· in/ (hr·ft · °F)
	Conversion	0.144 Btu· in / (hr · ft^2 · °F) = 1W / m·K

[1] Reprinted from: Moisture Properties of Plaster and Stucco for Strawbale Buildings, Straube,J , 2000 with permission from the author.

Thermal conductance, C, is a layer property and is therefore relative to the known thickness of a given material. A layer property is a property specific to a given thickness of a given material. A material property is specific for a material, 1 meter thick.

Units: SI $W / m^2 \cdot K$
Imperial $Btu / (hr \cdot ft^2 \cdot °F)$ $Btu / (hr \cdot ft^2 \cdot °F) = 0.176 W / m^2 \cdot K$
Conversion $5.678 Btu / (hr \cdot ft^2 \cdot °F) = 1 W / m^2 \cdot K$ or

Thermal resistance is the reciprocal of conductance.

$$\text{Resistance} = 1/C = \text{thickness} / \text{conductivity} = \ell/k.$$

Units: SI $(m^2 \cdot K) / W$ (RSI)
Imperial $hr \cdot ft^2 \cdot °F / Btu$
Conversion $1 \text{ RSI} = 5.678 R_{imp}$

Hence, R-value is valid for a specific wall thickness, temperature difference, and temperature across the specimen. It is not uncommon for R-values to be reported as R-values per inch, so that users can simply multiply the given value by the thickness of the material to assess the total R-value. It should be emphasized that the heat flux decreases with the inverse of R-value, that is:

$$\text{Heat flux} = 1 / \text{R-value} * \text{Temperature difference}$$

1.3.2 Vapor Permeability

Vapor diffusion is the process by which vapor moves through a permeable material. It is a function of the permeability of a given material, and the relationship of that material to a driving force.

This driving force is typically the result of a difference in vapor pressure on either side of a material. The amount of water vapor present in the air determines the partial pressure exerted across the surface of a material. The partial pressure is relative to the overall barometric pressure of the air, and is determined by temperature and the amount of water vapor in the air from sources such as human occupancy, combustion appliances, construction materials etc. The temperature determines the relative humidity (RH), as warm air holds significantly more moisture than cold air.

The rate at which moisture is transmitted through a material via vapor diffusion is referred to as the permeability of the material. Permeability is a material property and is expressed independently of the thickness of material.

Vapor permeance is a layer property and is therefore relative to the thickness of a given material. The vapor permeance and permeability values can be calculated from the measured, steady state weight loss (or gain).

The unit of permeance is called the "perm," which is defined as one grain of water passing through one square foot in one hour under the action of a vapor pressure differential of one inch of mercury (Imp). The corresponding unit of permeability is the "perm-inch," the permeance of unit thickness.[Beach, Latta 1964]. Vapor pressure (the driving force) is calculated from the actual temperatures and relative humidities imposed.

Permeability and permeance are analogous to thermal conductivity and thermal conductance respectively. As well, Imperial Perms can be converted to metric perms as:

1 perm (Imp) = 57.1 perm (SI)

The permeabilty is calculated by:

Permeability in ng / Pa s m = permeance/average sample thickness in m.

And the permeance is calculated from:

Permeance in ng/ (Pa s m^2) = (weight loss in nanograms) / (duration of time interval in seconds) x (sample area in m^2) x (average vapor pressure difference in Pa).

A psychrometric chart (see fig. 5.3-2) is used to determine the average vapor pressure difference, at a given temperature and relative humidity.

The vapor permeance and sorption isotherm values are key figures when modeling or predicting hygric response. Hygroscopically active materials are known to have significant implications with respect to indoor air quality. [deGraauw, Straube 2001].

1.3.3 Moisture Storage

A sorption isotherm is the graphic representation of the sorptive behavior of a hygroscopic material. It represents the relationship between the water content physically *adsorbed* by a material and the relative humidity of the ambient air at a given temperature.[1]

Adsorption is the process whereby water molecules in a vapor state, are attracted to and bond to the surface of particles within a given material. Water is polar in nature and therefore when water molecules are in contact with the surfaces provided by the porous nature of a building material it "clings" to these surfaces. It may take several weeks or months for a thick, solid material to reach equilibrium with its relative humidity environment. If left long enough under 100% RH conditions, this process continues to the point at which the material adsorbs so much water from the vapor state that water separated from the vapor is incorporated into the pore spaces by absorption and fractures by capillary suction.

The moisture content of a material will fluctuate with changing RH conditions. The higher the RH, the more moisture is adsorbed. If the relative humidity reaches between 80-90%, liquid water will become incorporated into the smallest pores through absorption and the larger pores and cracks via capillary suction.

Capillary saturation occurs when a material has adsorbed all of the vapor it can from the air (e.g. the moisture a material will adsorb when left in 100% RH conditions for long enough). At this point, all of the cracks and pores have been filled with water by capillary suction and/or absorption. When a material is capillary saturated it is no longer able to store moisture. When this moisture content is exceeded a material is said to be over-saturated. Drainage is then required to remove excess moisture.

The sorption isotherm is a representation of the relationship of air relative humidity to the moisture content of a material and is unique to each material.

In order for a material to have a moisture storage capability, it needs to have an internal surface area. Examples of materials which do not have internal surface areas capable of moisture storage would be steel or plastic. Many building materials, however, do have moisture storage capabilities due to their

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[1] International Union of Pure Applied Chemistry; Division of Physical Chemistry**.**
Manual of Symbols and Terminology For Physicochemical Quantities and Units: Appendix IIDefinitions, Terminology and Symbols in Colloid and Surface Chemistry. Everett et al.

internal surface areas. These include materials such as brick, with an internal surface area typically ranging from 1 to 10 m^2/g or cement paste, which ranges from 10 to 100 m^2/g. Wood, straw, or cellulose can have even larger surface areas [Straube 2003]. In addition, surface areas of clay particles themselves tend to be very large, and this is also known to have an effect on adsorption/desorption.

1.3.4 Liquid Uptake

The water absorption coefficient is a measure of a materials ability to transport capillary water. It is determined experimentally by measuring the rate of water absorption when a sample is placed in contact with liquid water. The water absorption coefficient so determined can then be used to estimate the liquid diffusivity, the fundamental measure of liquid water movement within porous bodies [Straube 2000].

In general, water absorption is measured in units of $kg/m^2\ s^{0.5}$, and given the symbol A.

Units: SI: $kg/m^2\ s^{0.5}$ (or $kg/m^2\ h^{0.5}$)
Imperial: ounces/$ft^2\ s^{0.5}$
Conversion 1 $kg/m^2\ s^{0.5}$ = 0.334 ounces/$ft^2\ s^{0.5}$

1.3.5 Shrinkage/Settlement

One challenging characteristic of straw light clay is the vertical settlement, and/or shrinkage that occurs as the mixture reaches its air-dried state. Settlement can be observed at the top of wall assemblies, and occurs vertically. Shrinkage occurs vertically and laterally. The aggregate to clay ratio, as well as the type of clay used, plays a significant role in either occurrence. With straw clay (480-880 kg/m^3), settlement appears to be the main concern. With mixtures containing other aggregates such as wood chips, or other shorter fibers, shrinkage becomes an issue, the rate of which is dependent on the type of loam used. Although these issues are remedied relatively easily, one has to wait for the material to reach its air dried equilibrium, prior to remedial action, which as mentioned in section 1.1 may take up to eight weeks.

In order to predict and quantify this settlement, measurements were taken targeting the three density classes used in the other testing programs, those being 480-560 Kg/m^3, 640- 720 Kg/m^3, and 800-880 kg/m^3 (30-35 pcf, 40-45 pcf, and 50-55 pcf respectively).

1.3.6 Compression and Bending

Although SLC is typically used as a non load-bearing building envelope, these elements will be subjected to lateral wind loading, so bending strength can be an issue. Similarly, bearing capacities are helpful to know when designing openings in the envelope. Compression and bending tests were carried out at the University of Waterloo, on machines capable of subjecting samples to loads at steady increments. The section modulus is an expression of the size of the sample being tested.

Where:

Section Modulus $S = bd^2/6$

where;

b= the width of sample

d= the depth of sample

Stress: A compressive or tensile force acting on a material results in stress. This is the amount of force per unit area, expressed in Mpa.

1 Mpa = 145 psi

Strain: Strain is the deformation per unit of a material under load (expressed in mm. of deformation per mm of material - mm/mm).

The modulus of elasticity is the proportion of load to deformation. This is usually plotted as the ratio of stress to strain. The resulting plot is used to create a slope from which the modulus of elasticity is calculated as:

Modulus of Elasticity E (Mpa) = Stress (Mpa) / Strain mm/mm

The Moment of Inertia (I) $= I = bd^2/12$

1.3.7 Density

Vapor permeance, thermal resistance, capillary suction, and sorption isotherms all vary significantly with density. As such, density is a critical property, and is used to classify different types of SLC. The density of SLC is most affected by the aggregate (straw) to binder (clay) ratio.

The most accurate means of obtaining the density is by saw cutting a cuboid out of a larger block. [Minke 2000]. The advantage being that any voids, or spaces created by bent over straws at the corners of a larger sample are eliminated, greatly improving accuracy.

This sample is then oven dried at 52°C, and then weighed periodically on a balance capable of measuring the weight to an accuracy of 0.1g or better and weighed until the same weight is achieved for three readings. The sample is then left for a period of 24 hrs. to return to equilibrium with ambient room conditions, and weighed again. This method gives both the oven dried, and room dried densities of each sample.

1.3.8 Fire Resistance

Standard methods of fire testing require access to large furnaces, designed specifically for fire testing. A method, which has been used colloquially within the natural building community, involves simply placing a pressure driven flame some distance from the element to be tested and observing the results. Rather than being an attempt to model conditions of a residential fire, this method is used to gain an intuitive sense of the possibilities of the material within an extreme condition.

2. Literature Review

Specific research on straw light clay in North America is in short supply. There have been some recent developments, however, which cumulatively have paved the way for this research. The publishing of the first English translation of the German text, Earth: Construction Handbook, by Gernot Minke, as well as several papers published by Dr. John Straube of the university of Waterloo, have been an invaluable resource for the carrying out of this research.

2.1 Thermal Properties

One of the most frequently sought after material properties by the North American layperson and tradesperson alike is the thermal resistance coefficient of a given material. There have been no known studies carried out in North America which would yield these values for straw light clay. The table on the next page, however compares the thermal properties of various selected materials as published in North America.

Description	Density† Lb/ft.³	Conductivity† (*k*) Btu·in / °F · ft² · h	Conductivity λ (w/mK)	Conductance† (*C*) Btu / °F · ft² · h	Resistance† per in. thick (1/*k*) °F · ft² · h / Btu·in	Resistance† For thickness Listed (1/*C*) °F · ft² · h / Btu·in
Expanded polystyrene, extruded (smooth surface) (CFC-12exp)	1.8 – 3.5	0.20	-	-	5.00	-
Mineral fiber : *loose fill* (rock,slag, glass)						
Approx. 6.5 – 8.75 in.	0.6 - 2.0	-	-	-	-	19.0
Approx. 7.5 – 10 in	0.6 – 2.0	-	-	-	-	22.0
Mineral fiber : *blanket & batt* (rock,slag,glass)						
Approx. 5.5-6.5 in	0.4 - 2.0	-	-	.053	-	19.0
Approx. 6-7.5 in	0.4 - 2.0	-	-	.045	-	22.0
Approx. 8.25 – 10 in	0.4 - 2.0	-	-	-	-	30.0
Cellulosic insulation: *loose fill* (milled paper or wood pulp)	2.3 – 3.2	0.27 – 0.32	-	-	3.70 – 3.13	-
Cement fiber slabs (shredded wood w/ Portland cement binder)	25.0 - 27.0	0.50 - .053	-	-	2.0 – 1.89	-
Wood: *Softwoods*						
Hem-Fir, Spruce, Pine, Fir	24.5 - 31.4	0.74 - 0.90	-	-	1.35 - 1.11	-
West coast woods, Cedars	21.7 - 31.4	0.68 - 0.82	-	-	1.48 - 1.11	-
***Straw clay** (Minke)						
500-600 kg/m³	31.2 - 37.4	-	.14-.17	-	-	-
600-700 kg/m³	37.4 - 43.7	-	.17- .21	-	-	-
800-900 kg/m³	49.9 – 56.1	-	.25- .3	-	-	-
‡Durisol (cement bonded wood fibre)	31.2 - 37.4	0.576	.083	-	-	-

† All values are taken from <u>*ASHRAE Handbook, 1993 Fundamentals*</u> (unless otherwise noted)
‡ Durisol values taken from Durisol product literature
* From Earth: Construction Handbook [Minke 2000]

Table 2.1 –1 Thermal properties of selected building materials

In Germany, Gernot Minkes' research has resulted in some k (conductance) values, which are helpful for comparison. In Fig 2.1.1, k values are given for a range of materials (including SLC) of varying densities. For the target densities of this research (480-560 kg/m^3, 640- 720 kg/m^3, and 800-880 kg/m^3) the k-values given range from .18 to .275. This would suggest that we might expect RSI values in the order of RSI .141(R_{imp}/in. .801) to RSI .092 (R_{imp}/in. .524)

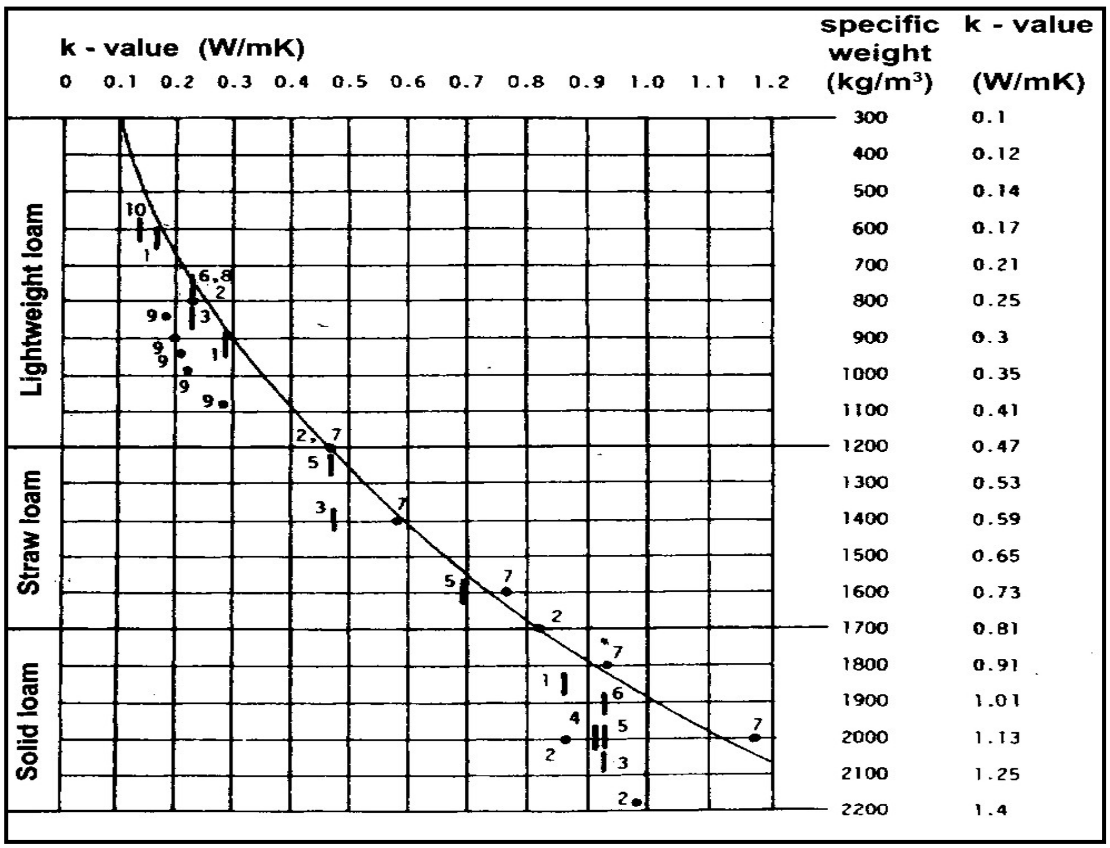


Figure 2.1-1 k-Values as given by Minke[2000] After [Volhard 1983]

2.2 Vapor Permeability

Understanding the vapor permeability of a material allows for an understanding of the drying of SLC. Both the vapor permeability, and moisture storage properties combined with the capillary suction of a given material play significant roles in regulating and moderating the relative humidities in indoor environments. The vapor permeance and permeability values of selected various building materials are given in table 2.2-1, on the following page.

Material	Thickness (in.)†	Permeance Perm.†	Permeability ng/Pa s m	Resistance Rep†	Permeability Perm-in.†	Permeance ng/Pa s m (38 mm)	Resistance/in. Rep/in.†
Air (still)	-	-	-	-	120	-	0.0083
Brick masonry	4	0.8	-	1.3	-	-	-
Plaster on wood lath		11	-	0.091	-	-	-
Gypsum wall board	.375	50	-	0.020	-	-	-
Wood, sugar pine	-	-	-	-	0.4-5.4	-	2.5-0.19
Mineral wool (unprotected)	-	-	-	-	116	-	0.0086
‡Durisol			20.5-26.5			800-1000	
Polyethelene	.010	0.03	-	33	-	-	3100
*Clay soil	-	-	25.7	-	17.6	675	-
*Silty soil	-	-	31.0	-	21.3	816	-
*Sandy soil	-	-	24.8	-	17.0	653	-
*Strawclay (1250 kg/m³)	-	-	41.3	-	28.4	1088	-
*Strawclay (950 kg/m³)	-	-	62.0	-	42.6	1632	-
*Strawclay (750 kg/m³)	-	-	64.1	-	44.1	1688	-
*Strawclay (450 kg/m³)	-	-	82.7	-	56.8	2175	-
*Clay earth plaster	-	-	23.3	-	16.0	612	-
*Silty earth plaster	-	-	19.1	-	13.1	502	-
*Lime plaster	-	-	16.9	-	11.6	445	-
*Lime-casein plaster (10:1)	-	-	14.3	-	9.8	377	-
*Lime-linseed oil-plaster (20:1)	-	-	13.2	-	9.1	347	-
*Cowdung-earth-lime plaster (12/4/3/20)	-	-	23.25	-	16.2	620	-

† All values are taken from *ASHRAE Handbook, 1993 Fundamentals* (unless otherwise noted)
* From Moisture Properties of Plaster and Stucco [Straube 2000] (after Minke)
‡ From Durisol product literature

Table 2.2-1 Vapor permeability, and permeance of common materials.

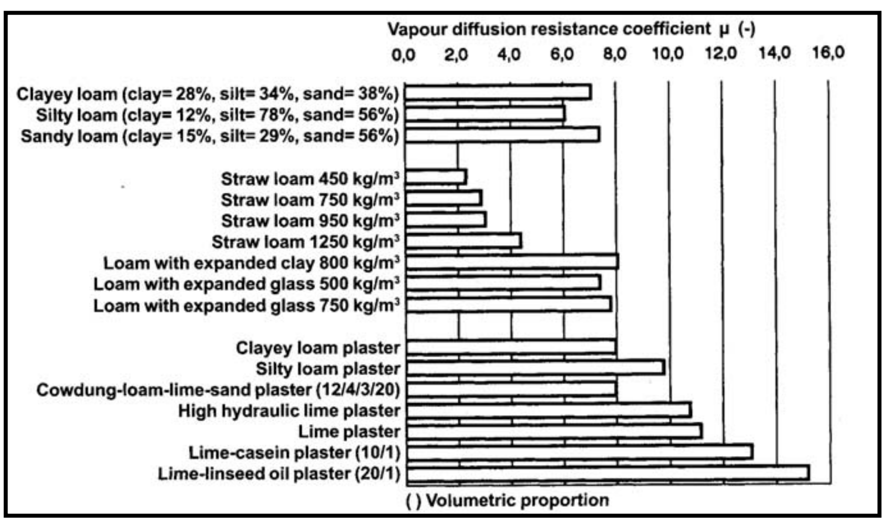


Figure 2.2-1 Vapor diffusion resistance coefficient(μ-) of earthen building materials [Minke 2000]

Minke has studied the vapor diffusion properties of straw clay. The vapor diffusion resistance coefficient μ (-) of various materials including straw light clay (Straw Loam) is shown in Fig. 2.2-1.

In a research paper titled: Indoor Air Quality and Hygroscopically Active Materials [deGraauw, Straube- 2001] Comparisons were given for the water vapor permeance of various building materials.

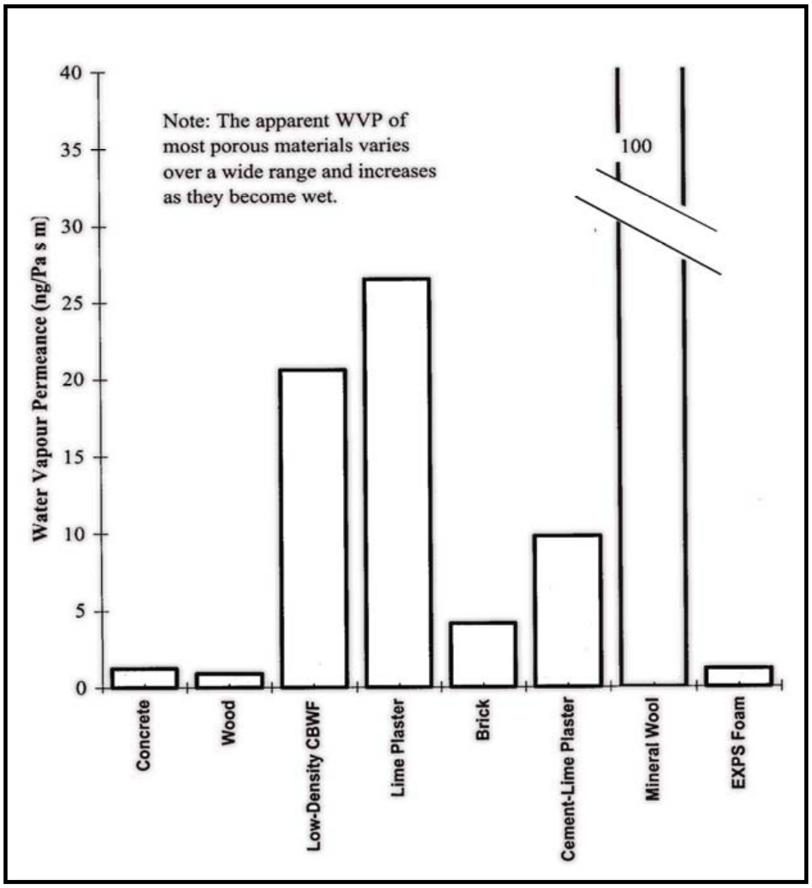


Figure 2.2-2 Vapor permeance of various building materials [deGraauw, Straube 2001]

2.3 Moisture Storage

As discussed in the technical background, it is important to know the moisture storage function of SLC. This allows for the prediction of the durability of SLC upon exposure to adsorption, absorption and desorption. Durability should not be compromised provided the equilibrium moisture content is not exceeded for a significant amount of time

Sorption Isotherms for several common building materials are given below, in fig. 2.3-1. These were also a part of the study of hygroscopic characteristics of cement-bonded wood fiber blocks [deGraauw, Straube 2001].

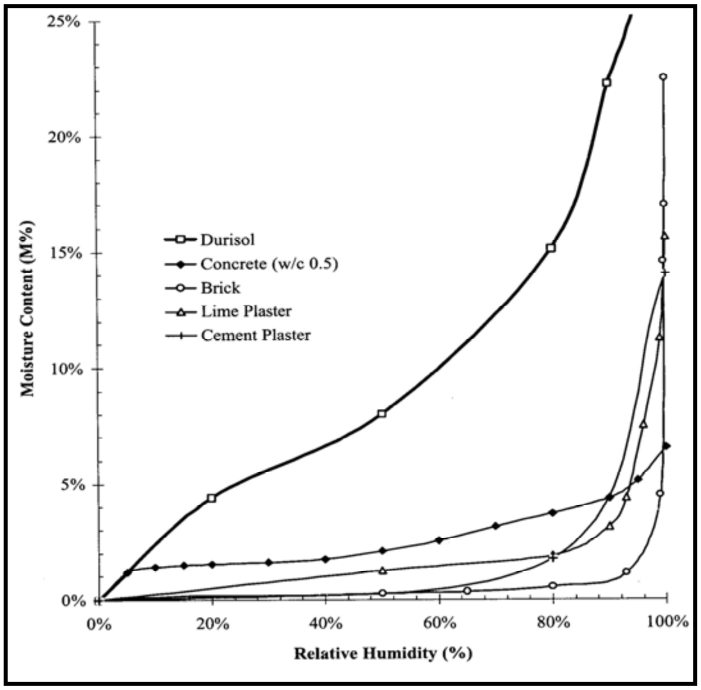


Figure 2.3-1 Sorption isotherm for various building materials.

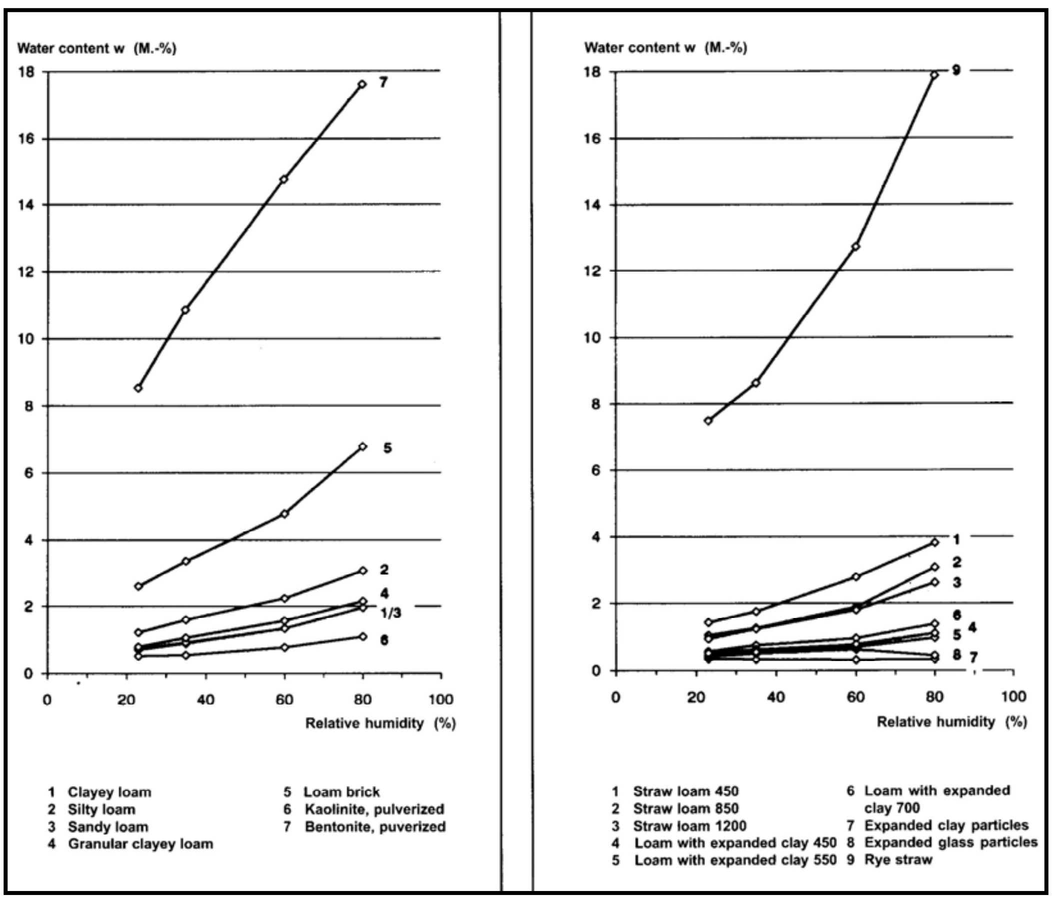


Fig. 2.3-2 Sorption isotherms as given by Minke [2000] for various solid (left) and lightweight loams (right).

2.4 Liquid Uptake

Capillary suction plays an important role in hygroscopic materials within the building envelope. It is this action which determines the rate which liquid water is physically absorbed by a material after contact with liquid water (e.g. after a rain event). This usually occurs at a rate which is proportional to water content, and this liquid transport coefficient is called liquid diffusivity. Because the water content often changes rapidly (rain stops, surface dries) two different liquid diffusivities are used to describe the liquid transport within building assemblies. Determining the water absorption (w) of a material then serves as the first step toward describing these more complex phenomenon.

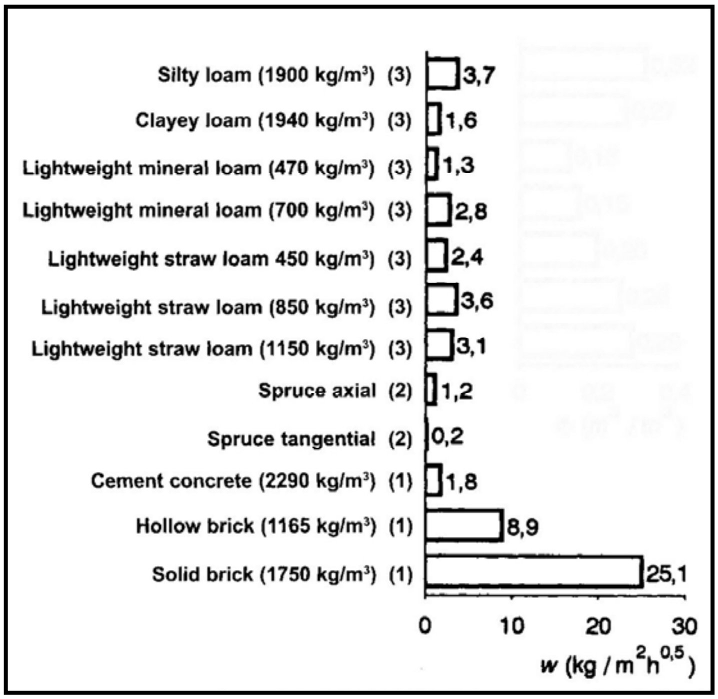


Fig. 2.4-1 Water absorption coefficient "w" of loams compared with common building materials.[Minke 2000]

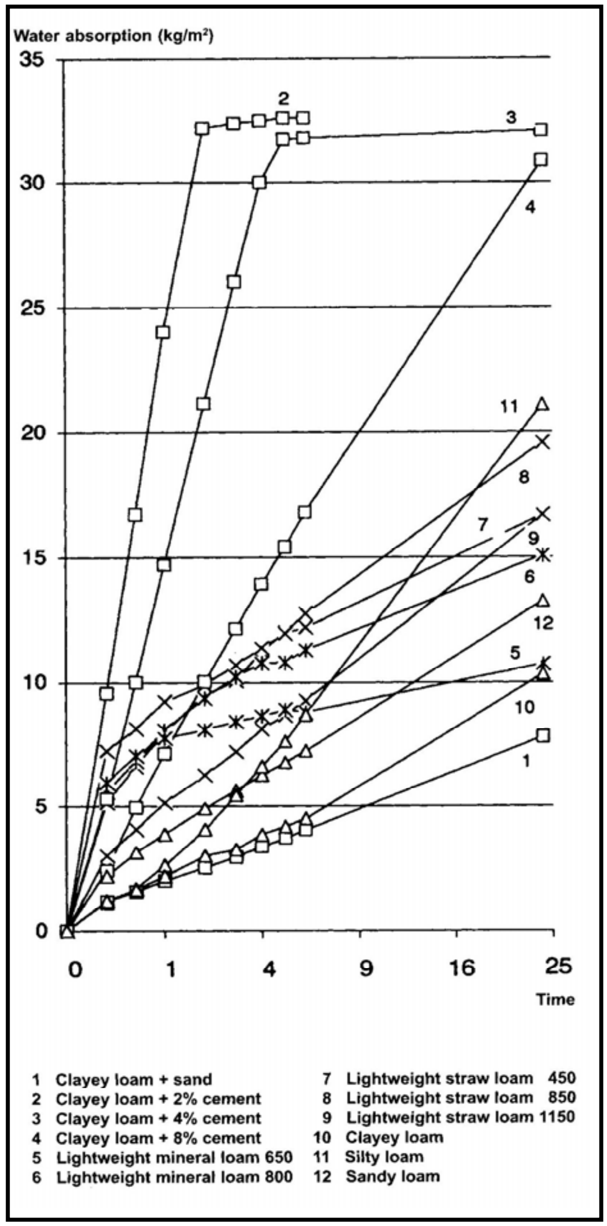


Fig.2.4-2 Water absorption curves of loams [Minke 2000] (Right)

2.5 Shrinkage and Settling

SLC tends to "shrink" as it dries to its air-dried state. This is a generally known phenomenon, which occurs when forming this material *in situ*. Minke[2000] refers to this as a vertical settlement (rather than a shrinkage occurrence) and, this may well be the case as loosely packed straw with no binder would certainly settle. It is then easy to imagine that with the added weight of the binder this settlement would be pronounced.

This author has witnessed some lateral shrinkage in similar materials (light clay with wood-chip aggregates). And this would probably have been due to the type of clay and/or the aggregate being used.

Fig. 2.5-1 Vertical settlement of a straw clay test element [Minke 2000]

2.6 Compression and Bending

The Center for Ecological Building in Tartu (Estonia) has done some compression testing on light clay materials. Their testing program consisted of samples created with various aggregates. Cat-tail chips, wood chips, reed and wood slivers were investigated. This study concluded generally that "Light clay is hard to disintegrate in high compression. Material deforms and bears very heavy weight. "Depending on the components and compression light clay material can also be resilient material" [Suursild 2001]. The researcher found an average of 37.5 kN for 50mm deformation.

Minke discusses several parameters, which have an apparent affect on the compressive strength of earth-based materials.

As a part of the mixing process, it is recommended that "*Mauken*" be accommodated. Mauken is a German expression describing a type of curing wherein the mixture is allowed to stand for a period of 24-48 hrs. under cover of tarps. It is suggested that an electrochemical process occurs during this period in which the clay minerals are forced into a more ordered pattern. This has been anecdotally related within earth building circles in North America as well.

Minke [2000] continues his analysis of compression characteristics by challenging several commonly held perceptions. More significantly, perhaps, is the assertion that optimum grain size distribution is the only way to enhance the compressive strength of a mix. This can be achieved "only by optimizing and varying the proportion of the silt, sand and gravel particles, and without increasing the clay content." This latter observation becomes more relevant when working with elements that have a higher content of earth.

2.7 Density

The only reference to accurately measuring the density of light clay element came again from Minke [2000]. He states that the only way of accurately measuring the density is to saw cut a cuboid out of a larger sample. This has the advantage of eliminating any of the voids created around the edges of the block due to bent over fibers and forming inconsistencies.

2.8 Fire Resistance

A literature review of fire testing methodologies confirmed that generally accepted standards for fire testing, such as ASTM E 119 and E 84, are of a scale and expense which are beyond the scope of this initial characterization. Several tests were conducted however, with propane torches set at a given distance from test specimens for a period of four hours and the results are to be found in section 11. Some small scale fire testing based on the ASTM E 119 standard has been done on straw bales, in New Mexico. This testing program concluded that straw bale would likely meet the requirements for a four hour fire resistance rating. Similar if not better results are expected for straw light clay.

3. Sample and specimen preparation

3.1 Loam

Loam was not available immediately on site but was known to be plentiful in this particular region of Ontario. A source was sought in the commercial sector. After an extensive phone survey of pond excavators, building sites and aggregates retailers, a cheap and plentiful source of loam was located. Aggregate producers consider loam to be an unwanted by-product. The Grey-Bruce region has extensive aggregate resources, and the loam used in this project was relatively cheap and abundant.

In order to assess the suitability of the loam acquired for testing, several field tests were carried out, in combination with laboratory analysis performed at the University of Guelph Soil and Nutrient lab.

3.1.1 Sedimentation Test

A mixture of the subject loam and water were agitated so that all particles were suspended in water at which point it was placed on a flat surface and left to settle. The result is a stratification, which may correspond to the proportions of clay, silt and sand present in the sample.

This is a common field test, which is referred to in a number of handbooks and guides for earth building. While at times there may be a correspondence between the layers of sedimentation, and the actual grain size distribution of a given sample, Minke [2002] challenges this interpretation, when he states: "Several experiments at the *Forschungslabor für Experimentelles Bauen* (FEB), University of Kassel, showed that the error can be as much as 1750%

In the case of this loam sample, the sedimentation test was not very useful, as the layers were very difficult to distinguish (fig. 3.1-1). The only possible delineation could be observed at about 25.4mm, but was so diffuse that an actual correlation could not be determined.

Fig. 3.1-1 Sedimentation test

3.1.2 Texture Field Tests

The Field Manual for Describing Soils in Ontario describes several texture field tests, which can be used to determine with a fair degree of accuracy the textural class of soil available. Similar tests are referred to in German research.The following tests were performed prior to lab analysis.

(A) Feel Test

Graininess Test- The soil sample was rubbed between thumb and fingers and deemed to be somewhat grainy. This indicated that there was a percentage of sand, which was <50%.

(B) Stickiness test

Soil was wetted and compressed between thumb and forefinger and determined to be adhering strongly. This indicates clay content.

(C) Moist Cast Test

Moist soil was compressed by clenching in hand. Difficulty was encountered in attempting to toss the cast, as it was rather sticky. The cast was, however, somewhat durable indicating the presence of an amount of clay.

(D) Ribbon Test

In this test a moist sample was rolled into a long cylindrical shape and then squeezed out between the thumb and forefinger in an attempt to form the longest ribbon possible. Only a very short ribbon was achieved, indicating a high silt content.

(E) Taste Test

A small amount of soil was worked between the front teeth. No distinguishable gritiness was found, indicating very fine or fine particle sizes of sand in small amounts.

(F) Effervescence

A solution of 10% HCl (hydrochloric acid) was placed on a small sample of the test soil. A strong hissing was observed combined with a thick foam forming across the sample. This indicates a CaC03 (calcium carbonate) content of between 25% and 40 % (quite high).

3.1.3 Grain Size Distribution

A sample of the soil was delivered to Laboratory Services at the University of Guelph to confirm these results. The results of this analysis indicated that the soil composition was of loam consistency, with 39.7% sand, 48.1% silt, and 12.2% clay. Further, the presence of calcium carbonate, CaC03 was also confirmed at 28.1%.

As illustrated in Fig. 3.1-2,the loam in our test sample falls just within the loam region of the texture triangle, toward the silty edge of the spectrum.

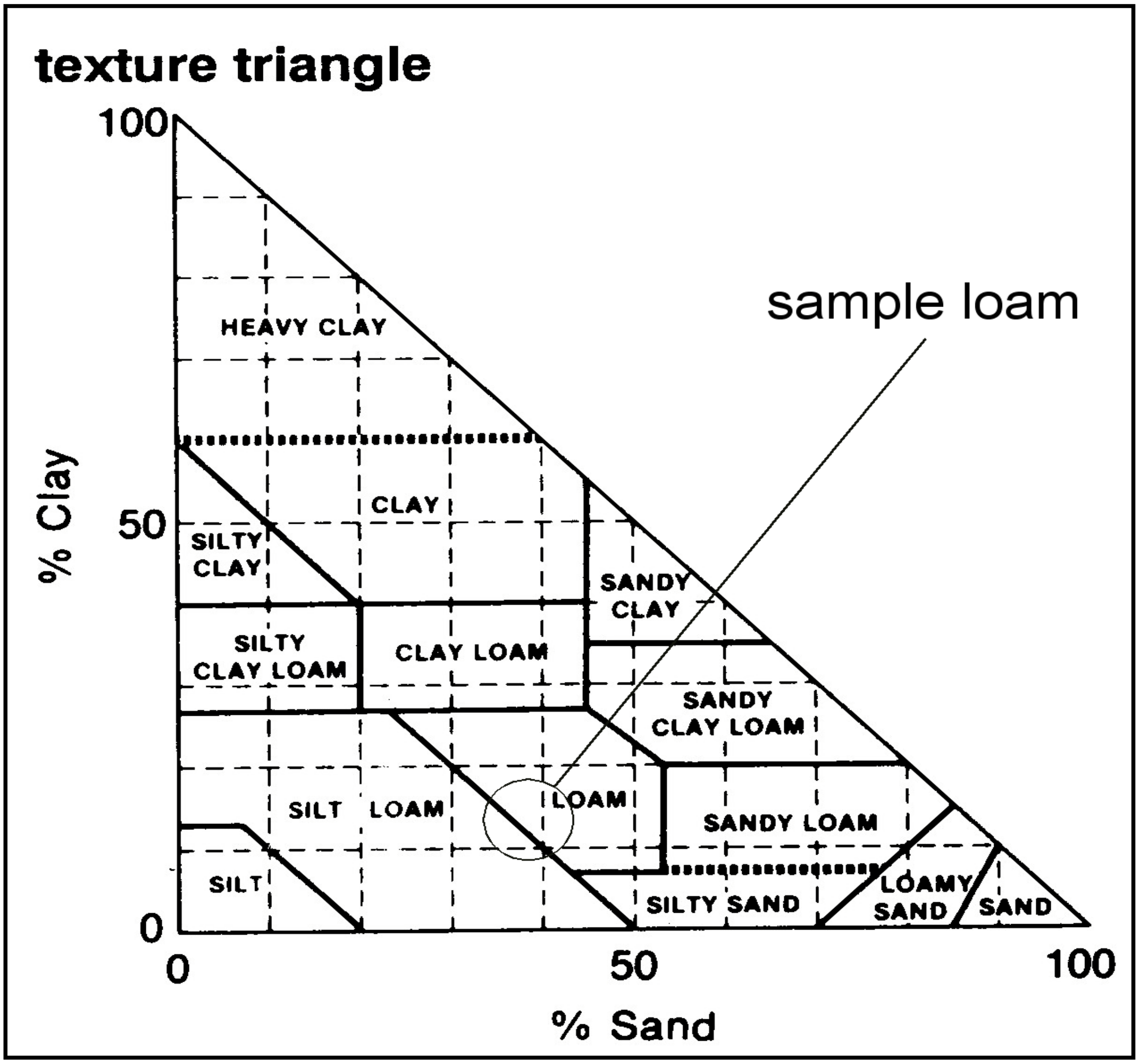


Fig. 3.1-2 Texture triangle.

"In traditional soil mechanics, if the clay content is less than 15% by weight, it is a lean clayey soil.Thus, for instance a rich silty, sandy, lean clayey soil has more than 30% of silt, 15% to 30% sand and less than 15% clay with less than 5% gravel or rock. However in earth construction engineering, this method of naming soils is not so accurate because, for example, a loam with 14% clay which would be called lean clayey, in soil mechanics would be considered a rich clayey soil from the point of view of earth construction." [Minke 2000]

Therefore, in terms of earth construction engineering the subject loam is designated as a rich clayey loam. And "in order to produce these lightweight loams, a rich clayey slurry is used."[Minke 2000]

3.2 Straw

Barley straw was the most locally abundant and available type, so this was the type of straw chosen for the study. Availability of straw can fluctuate with the season so it is important to have some knowledge of the local agricultural cycles to access the best selection of material. It is ideal to select straw that is clear of any cereal grains. This is a result of the combine operator striving for clear straw. Hay and straw with cereal grains are undesirable, as they represent a potential food source for pests. "Since straw is the stems left over after the grain is harvested, it is more likely to be dry and free of seeds and other matter that attracts the pests commonly drawn to hay."[Bainbridge Steen and Steen 1994] This is perhaps not as critical an issue with SLC as all fibres are coated with loam, which acts as a further deterrent.

3.3 Preparation of Straw Light Clay Mix

Slurry

A rich clayey slurry was created in a large trough by mixing the loam with water with the aid of a mixing paddle and a 12 mm (½in) drill. The loam used for the slurry had been excavated two years prior to use and was thus exposed to several freeze/ thaw cycles. "Exposing a clay layer to the action of weathering (freezing- thawing and wetting-drying) a year or more in advance of harvesting will allow it to weather into a fine powder"[Andresen, LaPorte 2000] The loam is then sieved through 6 mm (¼in) hardw are screen thereby removing any gravel and organic material. Using these techniques to work the loam into a powder greatly facilitates the mixing process as the loam is more readily worked into suspension in the slurry. This is considered to be the most ecological method of harvesting the clay. Also added to the slurry was Borax, which acts as a fungicide, and fire retardant [Steen, Steen, Bainbridge]

Mixing

The slurry was then broadcast over the straw aggregate and mixed with pitchforks until this aggregate was uniformly coated. (Figs. 3.3-1 and 3.3-2) Mechanical methods of mixing have also been developed. A large "Tumbler" is useful for mixing substantial quantities. Some contractors expedite the mixing process using the version illustrated (Figs. 3.3-3 and 3.3-4). The air-dry densities targeted were 480-560 kg/m^3. 640- 720 kg/m^3 and 800-880 kg/m^3 (30-35 pcf, 40-45 pcf and 50-55 pcf respectively). The consistency of the mixture tends to dictate its final air-dry density. This can however be misleading, as there are many variables acting together, including (but certainly not limited to); the relative humidity of the drying conditions, the type of clay, the consistency of the slurry etc. It generally takes 6-8 weeks of drying time for 300mm thickness of straw clay to come to equilibrium with the environment. During the first few days of the drying process, a thin, white mold was observed on some of the samples, despite the addition of Borax. This was however an exception and, in any event the fungus died after several days. According to Minke [2000], who writes of similar observations, this mold can in extreme cases give rise to allergies.

Therefore, good ventilation is required during construction to speed the drying process.

Fig. 3.3-1 Clay slurry being broadcast over straw.

Fig.3.3-2 Straw being mixed with slurry

Fig. 3.3-3 Production mixer with hoppers

Fig. 3.3-4 Production mixer: feeding end view

A considerable degree of experience with the *specific* local material is required to know at the time of mixing whether the target density will be reached. Therefore, the middle density range is easiest to achieve in practice. After the slurry had been mixed with straw, the mixture was set aside under tarps for 24 hrs. to cure. This process is referred to in section 2.6

3.4 Forming, formwork and specimen preparation

In order to produce specimens that were uniform in size, blocks were formed from which smaller samples could be taken. These were formed in such a way as to mimic a wall formed *in situ*. "Prepared straw clay is rolled into cigar-shaped bundles appropriate to fit the wall cavity, about the size of a loaf of French bread. The cylinder of straw clay is then placed snugly at the bottom of the cavity, Carefully tuck the cigar into all corners, and along the edges. Begin tamping with your feet, and follow with wooden tampers, evenly compressing the straw clay into every corner and space. Tamping tools can be fashioned from 2x4's and 2x2's."[Laporte 1993]. Upon reaching their air-dried state, smaller cuboid specimens were saw cut from these larger "blocks".

Forming

Once the mixture had cured under tarps (mauken), it was then ready to place within the formwork. The material was packed into the formwork in a method reflective of current practice *in situ*. That is to say that the formwork was designed to produce blocks, however the mixture was placed into the form in such a manner as to produce block- like samples of a slipformed wall. (Figs. 3.4-1and 3.4-2.)

Fig. 3.4-1 Straw clay mix is lightly tamped into forms

Fig. 3.4-2 Straw clay being tamped with 2x4 around edges of form

Formwork

Formwork was designed to produce twenty "blocks" at a time. 75 blocks, targeting three different density classes 480-560 Kg/m^3, 640- 720Kg/m^3, and 800-880 Kg./m^3 (30-35 pcf ,40-45 pcf and 50-55 pcf) were created in total. Of these "blocks", several were chosen to represent a spectrum of each density class. One towards the heavy side, one in the middle and one on the lighter end of a given density class.

After the formwork was filled with the material, it was immediately removed. The sequence was to first remove the dividers, then the end "keys" and finally to remove the walls. By removing the forms in this way a "screeding" effect was achieved, important for maintaining the integrity of the "block". The "blocks" were then placed on palettes and left to dry for several months. (Figs. 3.4.2-1 - 3.4.2-6.).

Fig. 3.4.2-1 Formwork filled

Fig. 3.4.2-2 Block dividers being removed from formwork

Fig. 3.4.2-3 Removal of block width keys

Fig. 3.4.2-4 Screeding effect of form walls.

Fig. 3.4.2-5 Removal of form walls

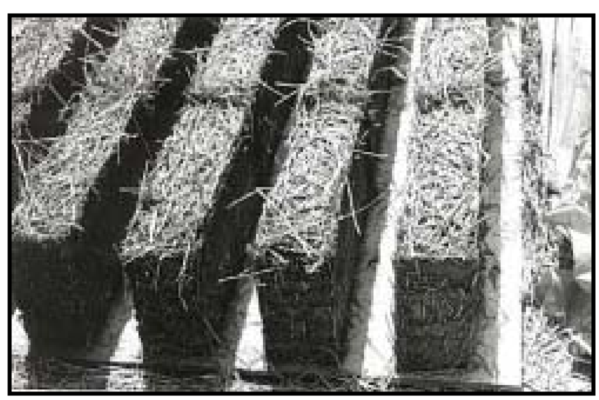


Fig. 3.4.2-6 Finished product drying

Specimen preparation

Upon reaching their air-dried state, the " blocks" were ready to be used to prepare samples for testing. The advantage to using specimens derived from larger samples is that the edges are made square and straight, resulting in a more accurate sample area. A special apparatus was developed for cutting the blocks to sizes suitable for each of the respective testing procedures (Figs.3.4.3-1 through 3.4.3-6)

This consisted of a plywood box with a channel in it (the width of a saw kerf) and a system of "fences" on the top. The "block" is then placed against the fence set at the desired thickness of the sample. A second fence is then clamped into place, thereby placing the sample under a slight compressive load. This second fence is then screwed into place. It was found that using this technique, the larger sample from which the test specimen was being derived was not subjected to an amount of movement which would cause the block to lose it's integrity.

Fig. 3.4.3-1 The specimen cutting box

Fig.3.4.3-2 Cutting with handsaw

Fig. 3.4.3-3 Removal of leftover material

Fig.3.4.3-4 The cut face

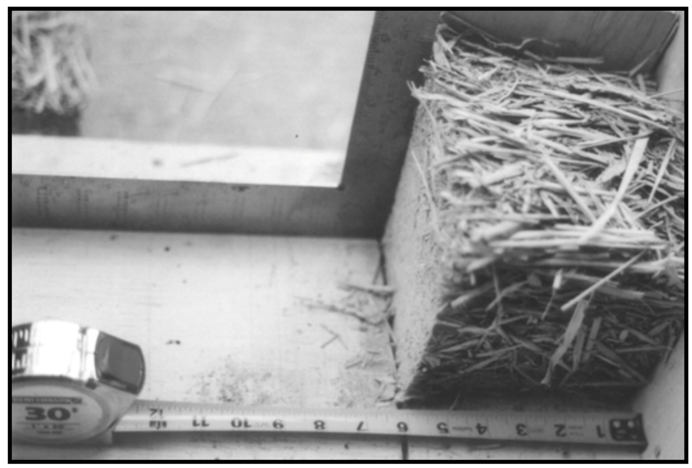


Fig. 3.4.3-5 Sample accuracy illustrated with square and tape

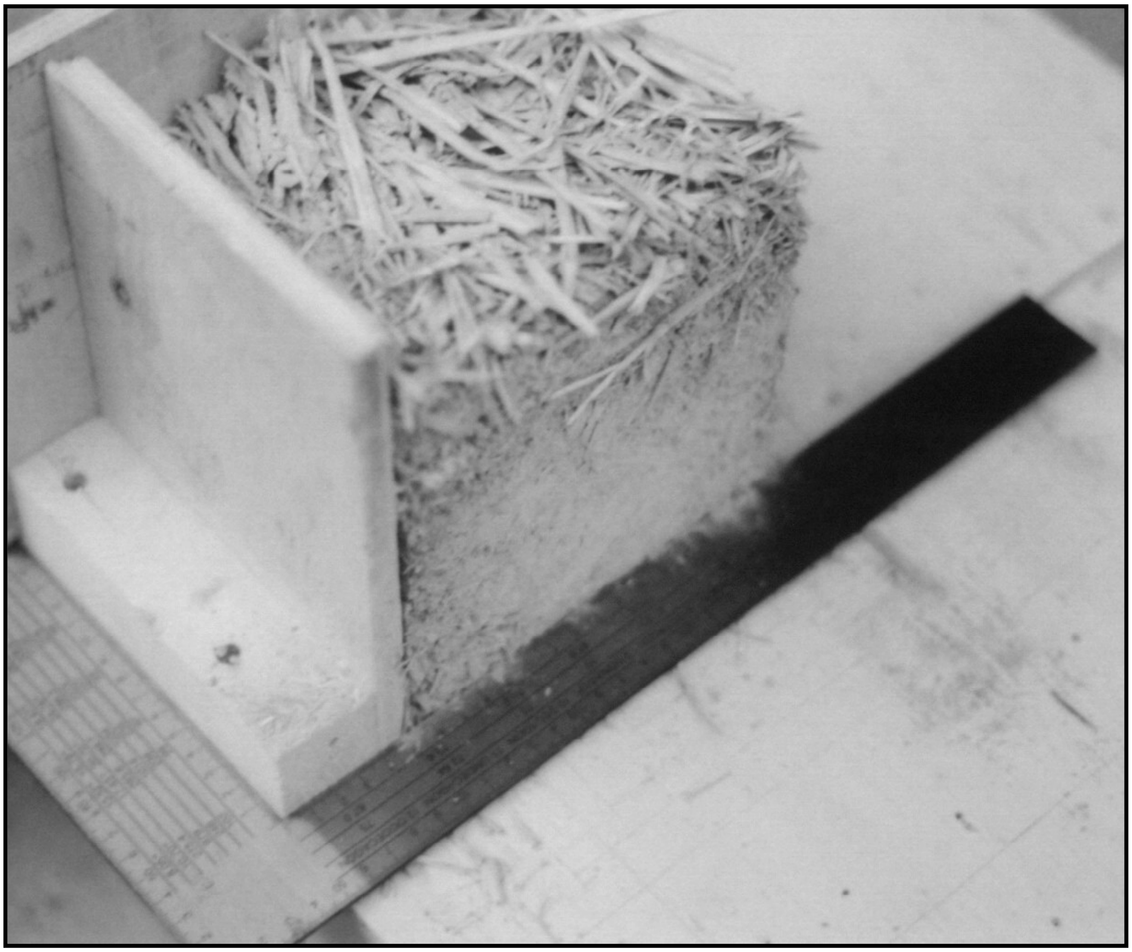


Fig. 3.4.3-6 Sample accuracy with square

4.Thermal Conductivity Testing

4.1 Test protocol

ASTM standards C177 (guarded hot plate) and C-236 (guarded hot box) can be inaccessible for the testing of non-proprietary materials, due to the relatively high cost of these procedures. Therefore, the withdrawn (2002) Standard Test Method for the Thermal Performance of Building Assemblies By Means of a Calibrated Hot Box [ASTM-C-976] is used as a basis for these tests. This test method has the further advantage of being well suited to non-homogenous materials.

4.2 Test equipment and set-up

The primary equipment for this procedure consisted of two parts; a metering chamber and a sample assembly (Figs. 4.2-1 & 4.2-5). The metering chamber was of double-wall 50mm extruded polystyrene rigid insulation board (XPS), with a single wall allowance at the top 152 mm for the combined second wall/sample assembly. All joints were staggered and sealed with aluminum tape. See Figure 4.2-1.

Inside the metering chamber was a heat source consisting of a 15 W light bulb surrounded by a radiation shield. Throughout the testing the electrical flow to the heat source was monitored with an Ideal 730 series 400 amp clamp. A Fenwal Uni-curve Series 10k thermistor (part no. 192-103LET-A01) was wired to take surface readings of the metering side (interior) surface of the sample. All penetrations of the metering chamber walls were sealed with caulk and aluminum tape.

To create a sample assembly for use in the metering chamber, each sample was surrounded on all four sides by a 50mm (2 in) layer of (XPS) rigid extruded polystyrene insulation board (with a published R_{imp} value of R-10). This layer was adhered to the irregular edges of the sample with low expanding foam, which served the dual role of adhering the sample to the XPS, and filling any small gaps and cracks inherent in the irregularity of the material. This assembly gave full double-wall insulation around the perimeter of the sample, forcing the heat transfer to occur primarily through the sample. The double wall was flush with the room side surface area of the sample.

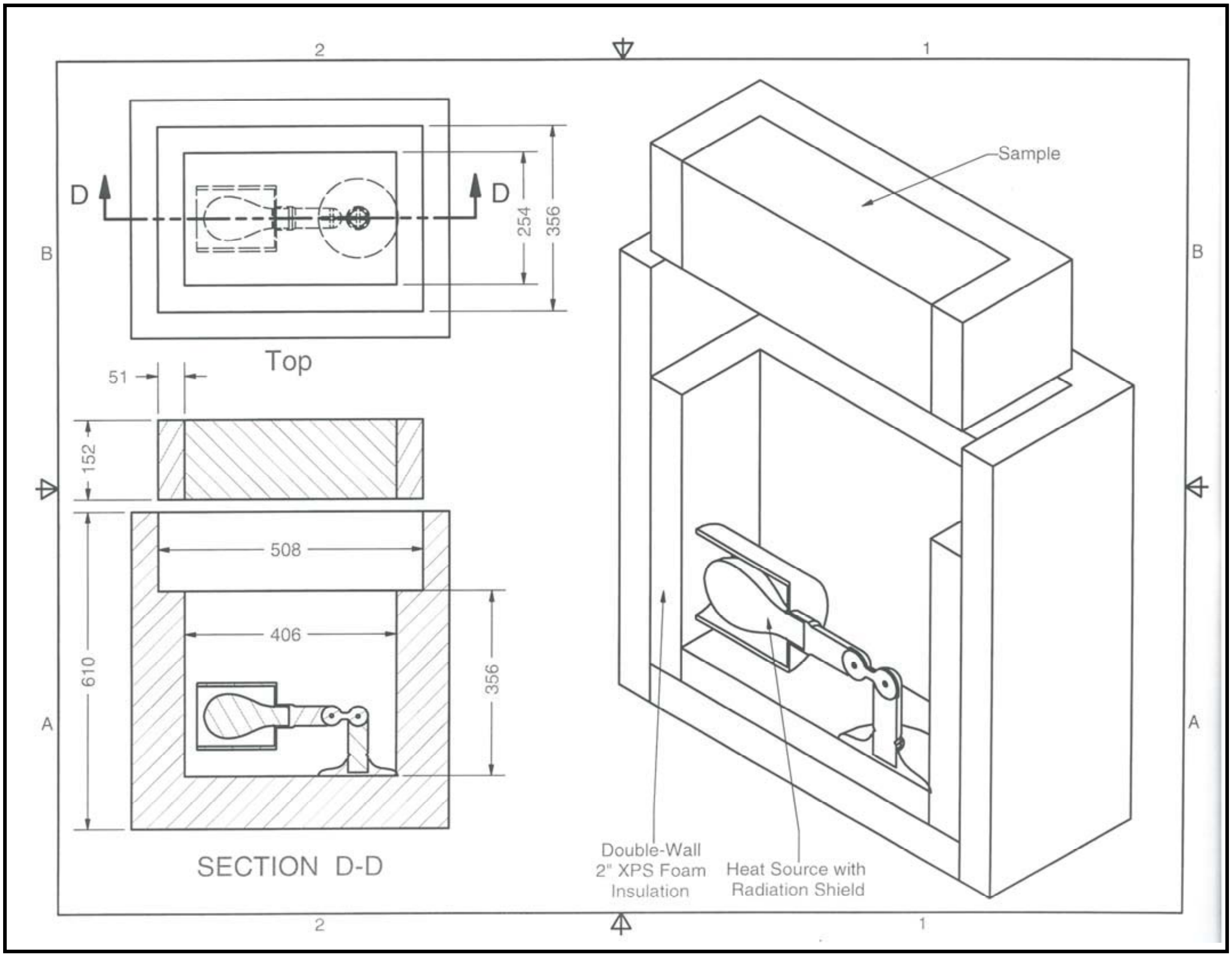


Fig. 4.2-1 Metered chamber schematic.

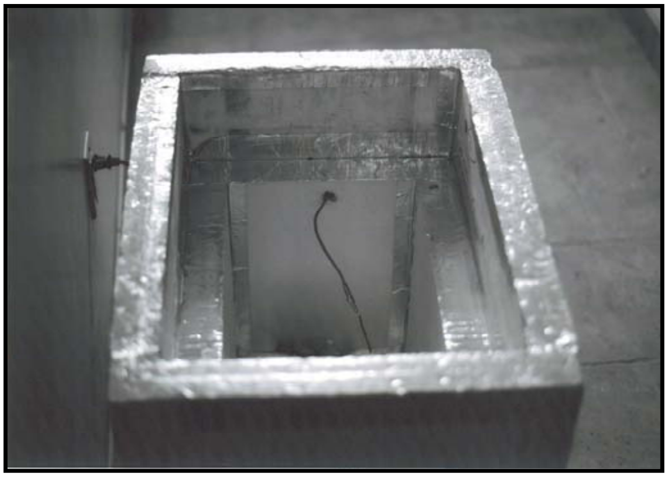


Fig. 4.2-2 View of thermistor with lead into metering chamber.

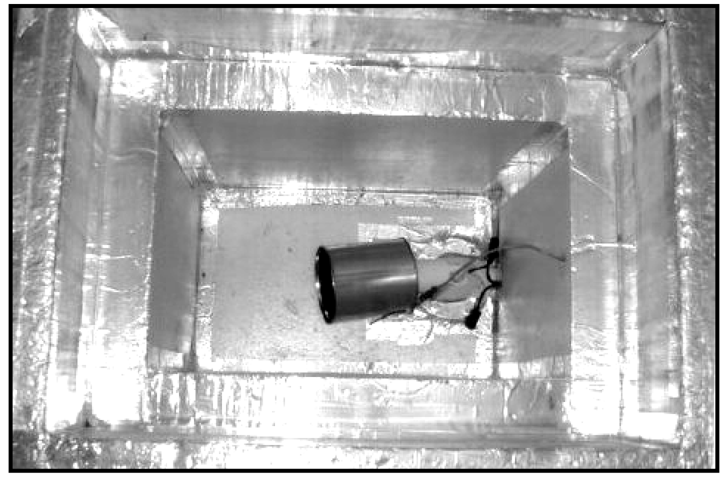


Fig. 4.2-3 Plan view of metering chamber showing heat source with radiation shield.

Fig. 4.2-4 View of test assembly prior to installation.

Fig. 4.2-5 Test assembly installed in metering chamber.

4.3 Procedure

Samples representing each density class were monitored for a period of at least 24 hrs. Readings were taken using a thermistor affixed to the center of the interior surface of the sample (metering chamber side) and one thermistor located similarly on the exterior surface of the sample (room side). These were monitored at regular intervals (generally every two hours) until the readings did not vary by more than ±1%, at which point the specimen was said to have reached equilibrium with the steady state conditions.

The temperature outside the box (the room side condition) was maintained at a steady state of 20 ˚C (±3˚C). Each reading included; time, resistance (ohms) of the interior surface thermistor, resistance (ohms) of the exterior surface thermistor, and room side temp.

The metering chamber was calibrated each time a different sample set was tested,prior to the testing of each sample set. The box was calibrated using a 50mm (2 in) layer of XPS.

4.4 Interpretation

Table 4.4-1 is an example of typical test data (in this case of 50mm XPS). It displays the time, thermistor readings, and climatic chamber (room) temperature on the left. On the right are the values converted from ohms to temp (˚C) using the formula: $T= -0.101(LnR)^3 + 4.346(LnR)^2 - 77.18(LnR) + 446.05$. This formula represents a curve-fit to the manufacturer's published temperature tables, and is accurate to within ± 0.12°C over the range of -20°C to 60°C. The delta T is simply the temperature difference across the sample, and the film is the temperature difference between the room and exterior surface of the sample. Underneath are the average values from the three readings at equilibrium (highlighted).

Nominal R Value: Calibration "A"

Time	Interior (ohms)	Exterior (ohms)	Room Temp.	In	Out	Delta	Film
6:30 AM	**10.65**	**10.49**	**22.2**	23.5	23.9	-0.3	1.7
8:30 AM	**2.27**	**9.59**	**22.2**	62.6	25.9	36.6	3.7
7:12 AM	**2.01**	**9.48**	**22.4**	66.0	26.2	39.8	3.8
12:30 PM	**1.95**	**9.23**	**23.0**	66.9	26.8	40.1	3.8
2:30 AM	**1.92**	**9.04**	**23.5**	67.3	27.3	40.0	3.8
4:30 AM	**1.93**	**9.08**	**23.7**	67.2	27.2	40.0	3.5
	Values chosen		**23.3**	**67.1**	**27**	**40.1**	**3.8**

Table 4.4-1 Example test data from calibration

Calibration: 2" xps rigid insulation

	thick	k	C	R	Delta T	temp	Target Surface	
Temp out						**21.1**		
Ext Film			6.50	0.154	3.664		**3.8**	96.8%
						24.8	**24.9**	99.5%
Test Material	0.0518	0.0290	0.56	1.786	42.539		**42.5**	100.1%
						67.3	**67.4**	99.9%
Int Film			6.50	0.154	3.664			
						71.0		
T box						71.0		
Total				2.094		49.9		
					Heat Flux	**23.831**	**W/m2**	

	Room temp.	InSurf	OutSurf	Delta	Film
Calibration A	23.30	67.10	27.00	40.10	3.80
Calibration B	21.10	69.80	25.00	44.80	3.80
Calibration C	19.00	65.40	22.80	42.60	3.75
Average	**21.1**	**67.4**	**24.9**	**42.5**	**3.8**

Thermal Resistance RSI/25.4 mm 0.8759 Rimp/in 4.97

Table 4.4-2 and 4.4-2a Example calculation table

The tables above were used in the analysis of the test data from the calibration. This served to establish a reasonable layer conductance value for the surface films, for use in the analysis of the other samples. This table also aids in the calculation of heat flow with which to compare the results of the other tests.

Where:

$$\text{Thermal conductivity} = W / m\,K$$

$$\text{Thermal conductance} = W / m^2\,K$$

$$\text{Thermal resistance RSI} = 1 / C = (m^2\,K) / W$$

$$1\ \text{RSI} = 5.68\ R_{imp}$$

For the benefit of readers who may be unfamiliar with the terms and formulae used, a walk-through of the process used in this testing program is provided below.

The first known value is the room side temperature (in this case 21.1˚C). This is the value in the uppermost right corner of Table 4.4-2

We also know the exterior surface temperature is 24.9, and the difference between this value and the exterior air temp is 3.78 hence, our target value for the exterior surface film.

The final target values are 67.4 (the interior surface temperature) and 42.5 (the delta T of 67.4 and 24.9).

After the target values have been established we begin to work towards them starting with our other known values.

The thickness of the material is known (0.0518 Meters) In this case our k-value is known (.0290). Next, the conductance values are established as:

$$C= \frac{W / mK}{m}$$

The thermal conductance of air is known to be from between 1/6 to 1/10 $W/m^2°C$. In this test program the interior temperature inside the box is an unknown. The calibration above therefore, serves to help establish the value used for the layer conductance. The k value, however, *is* known, and the conductance of the material is conductivity (k) over thickness, resulting in .56.

Furthermore, as R is the reciprocal of C, 1 / .56 gives 1.786 as an R_{SI} for the material layer (thickness in meters) and 1 / 6.50 gives an R_{SI} of 0.154 for each surface film.

Finally, to estimate the interior ambient air temperature of the metering chamber, we start back at the beginning. The room side temperature is 21.1.The sum of this, and a surface film of 3.664 gives 24.7 as an exterior surface temp. Close to the target value (99.5%).

When this is taken from our resulting estimated interior surface temperature of 67.3 (99.9% of the target value) to reach our target delta T, we arrive at 42.5. The delta T plus the exterior surface temperature (42.5 + 24.7) =67.3

67.3, together with a surface film of 3.78 gives 71.00 as an interior ambient temperature. Finally, 71.0 – 2 1.1 yields a delta T of 49.8.

$$\text{Heat Flux} = \Delta T / R\ (2.094) = 23.8$$

As described above, these tables can be helpful and fairly straightforward in estimating average k, RSI and R_{imp} values. However, measurements taken of some samples (i.e. A3), were very different than other samples within the same density range, and so the formula;

$$k = \ell / \Delta T_A \cdot C_E \cdot \Delta T_E$$

$$k_{\text{sample}} = \text{Thickness}_{\text{sample}} / \Delta T_{\text{Across Sample}} \cdot C_{\text{Exterior Air Film}} \cdot \Delta T_{\text{Exterior Air Film}}$$

was used to calculate individual conductivity (k) values for each sample. The k-values of each sample were then inserted into the lower portion of the table. In this table, averages of three samples within the same sample set were used to generate target values.

4.5 Results

Despite the simplicity of the test set up, the results were consistent, and compare well with other testing done on this material (Fig 4.6-1). The values generated are shown below in Table 4.5-1, and, as mentioned above, are plotted below in Fig.4.6-1

Sample	Density (kg/m^3)	λ (k) (W/mk)	RSI (25.4mm)	R_{imp} / inch
A3	597	0.149	0.17	1.0
B3	632	0.068	0.37	2.1
C3	622	0.076	0.33	1.9
A4	745	0.111	0.23	1.3
B4	642	0.090	0.28	1.6
C4	715	0.125	0.20	1.2
A5	951	0.180	0.14	0.8

Table 4.5-1 RSI and R_{imp}/inch for each sample.

Sample A3, appears to be an anomaly when compared with other values in its density class, and given that the value for this sample is not consistent with the curve plotted below.

4.6 Discussion

The results of the thermal conductivity testing, are plotted below (Fig. 4.6-1), and generate a curve which nearly matches the curve(s) shown in Minke's text, after Volhard, 1983. The k-values generated by this testing program are more similar to the values given by Minke for light loam, rather than straw loam, and are tabled in Table 4.5-1. Light loam had the lowest of the k-values in Minke's material testing, the lowest being 0.1 W/(mK) at 300 kg / m^3, and ranging to 0.35 at 1000 kg / m^3.

It is possible that a difference in materials explains this difference in results. Further testing is needed to clarify. It is difficult to say precisely what lead to the aberration observed in sample A3. It is interesting to note however, that this sample was an outlier in other tests. This would appear to indicate the sample as being an anomaly rather than a faulty test set-up.

"R 2 per inch" is often heard as a value in North America assigned to straw light clay. This has been loosely translated from other work and has spread word of mouth throughout the natural building community. These tests would seem to support that these R-values are indeed achievable, particularly in the density range of 620- 635 kg./m^3 (40 pcf). To consistently reach target densities however is a matter of the history of experience with particular local materials that a given practitioner might have.

Therefore, a more conservative number might engender the challenges of reaching these target densities and still have a number which is quite acceptable (Material, steady state R-values not being the whole picture of thermal dynamics). The RSI value over 25.4mm is .28 (or R_{imp}/inch of 1.6). This is an average from this testing program which still gives a wall with a thickness of 30mm (12 in) core, steady state R_{imp} value of 19. Lastly, with the systems most widely used at present, thermal bridging is eliminated. Therefore, a whole wall R-value calculation will be closer to the original calculated R-value than more "conventional" products.

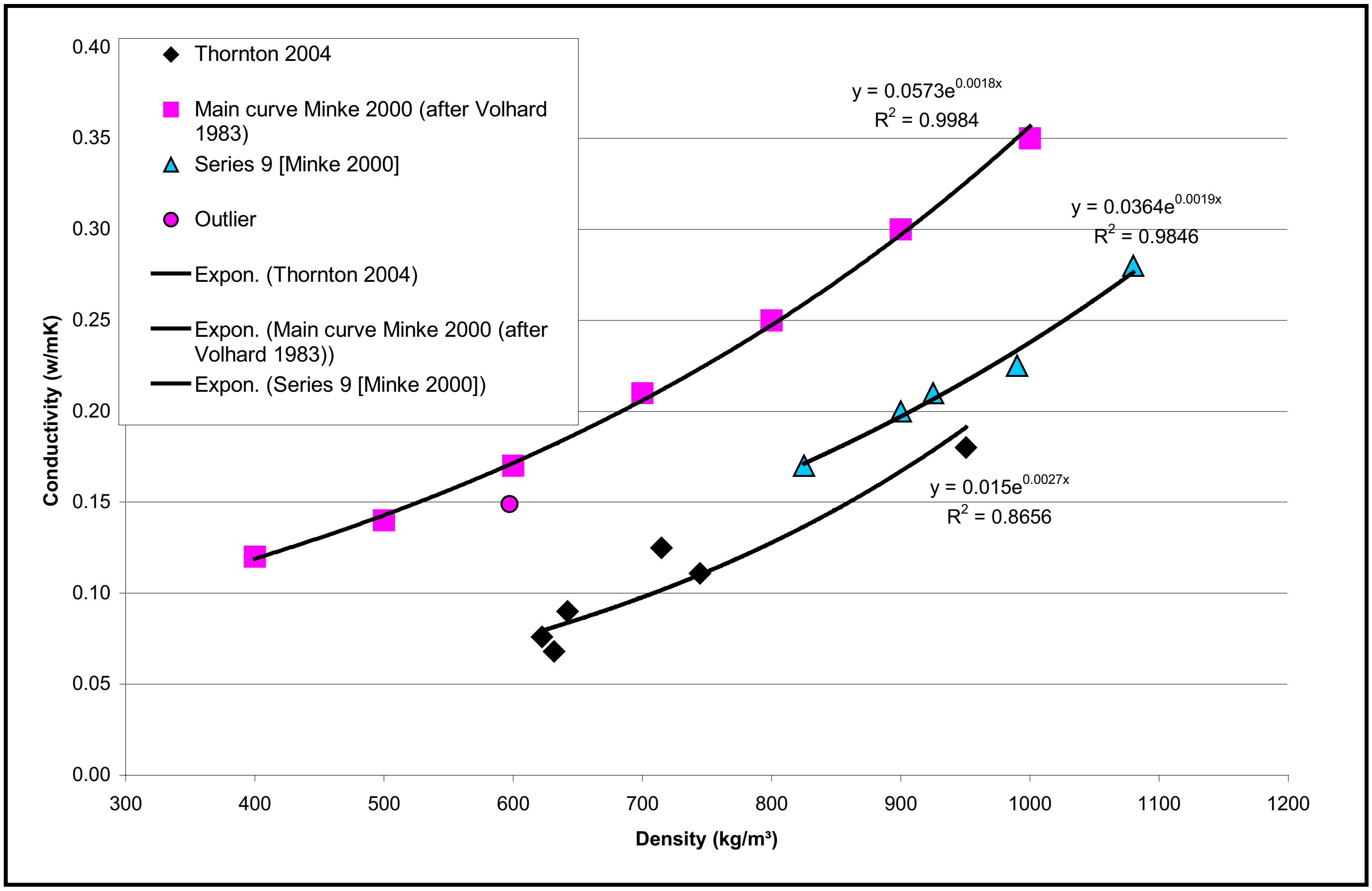


Fig. 4.6-1 Results of testing plotted as compared with others

5. Vapor Permeability Testing

Vapor permeability is the rate at which vapor is able to move through a material. “The vapor flow resistance of a material is the inverse of the ability of the material to permit vapor to flow, i.e. its permeance. The unit of permeance is called the "perm," which is defined as one grain of water passing through one square foot in one hour under the action of a vapor pressure differential of one inch of mercury. The corresponding unit of permeability is the "perm-inch," the permeance of unit thickness.” [Beach, Latta 1964] Imperial U.S perms can be converted to metric perms by multiplying by 57.1.

It is especially important to know the vapor permeability of SLC in order to assess the rates at which wetting and drying occur. This knowledge informs decisions regarding code compliance with respect to vapor barriers within these types of wall assemblies.

5.1 Vapor permeance test protocol

ASTM E96 was used as a basis but some modifications were made. Instead of a wet-cup test (100% /50%) we employed conditions of 75%/100% RH. These conditions more accurately mimic the condition of drying wet material (at 100%RH) to outdoor air in moderately humid conditions (75%) RH.

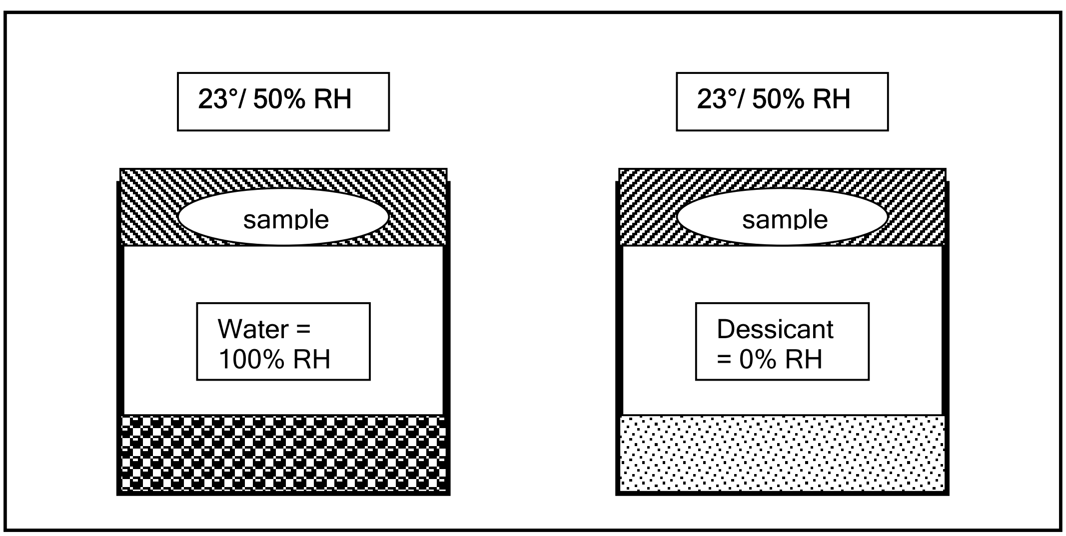


Fig 5.1-1 Typical wet-cup (left) and dry cup (right) testing procedure

5.2 Test equipment and set-up

The samples used were 177 x177 mm (7 in x 7 in) samples which were then immersed in liquid paraffin 12 mm (½ in) on each side, bringing the final area to be tested to 150 x 150 mm (6 in x 6 in). All samples were 100mm (4 in) thick. Samples from each target density were used; 480-560 kg/m³, 640- 720 kg/m³, and 800-880 kg /m³ (30-35 pcf, 40-45 pcf, and 50-55 pcf respectively).

Samples were prepared in order to achieve a vapor tight seal on the sample-container assembly. As the material cannot be sealed with tape, and it was impractical to use an epoxy, another method of achieving a vapor tight seal was developed (Figs. 5.2-1- 5.2-6).

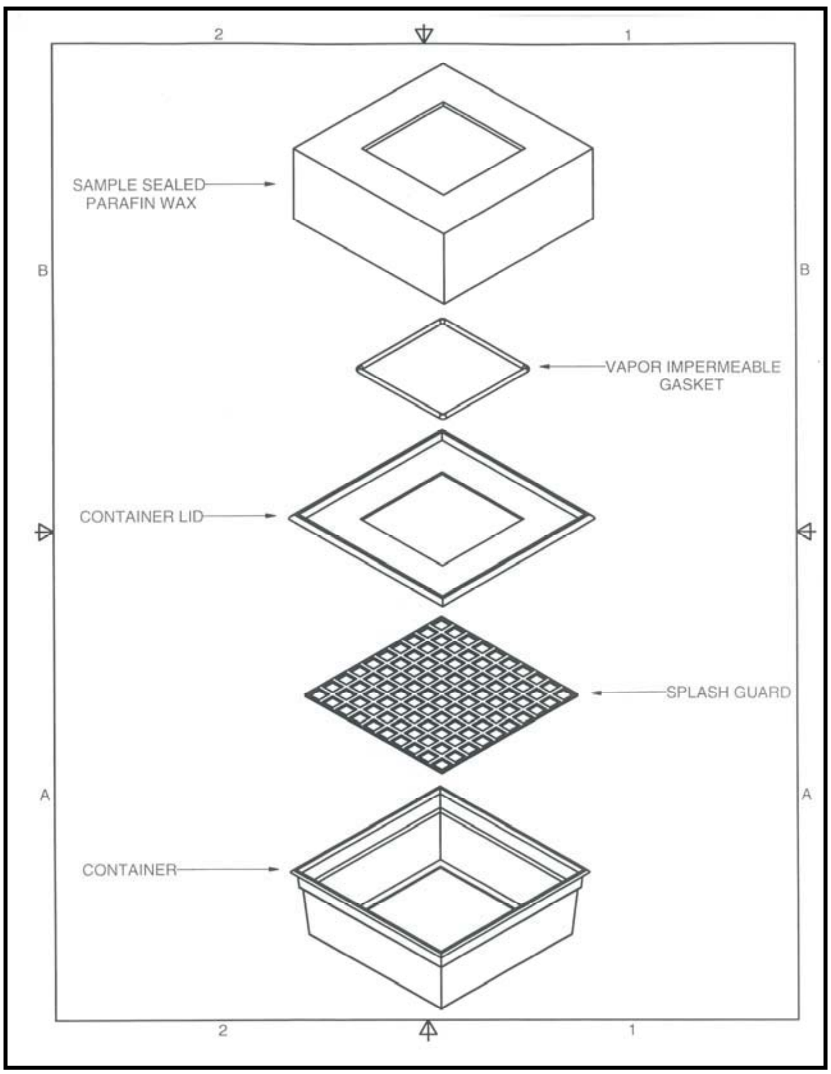


Fig. 5.2-1 Exploded view of sample assembly

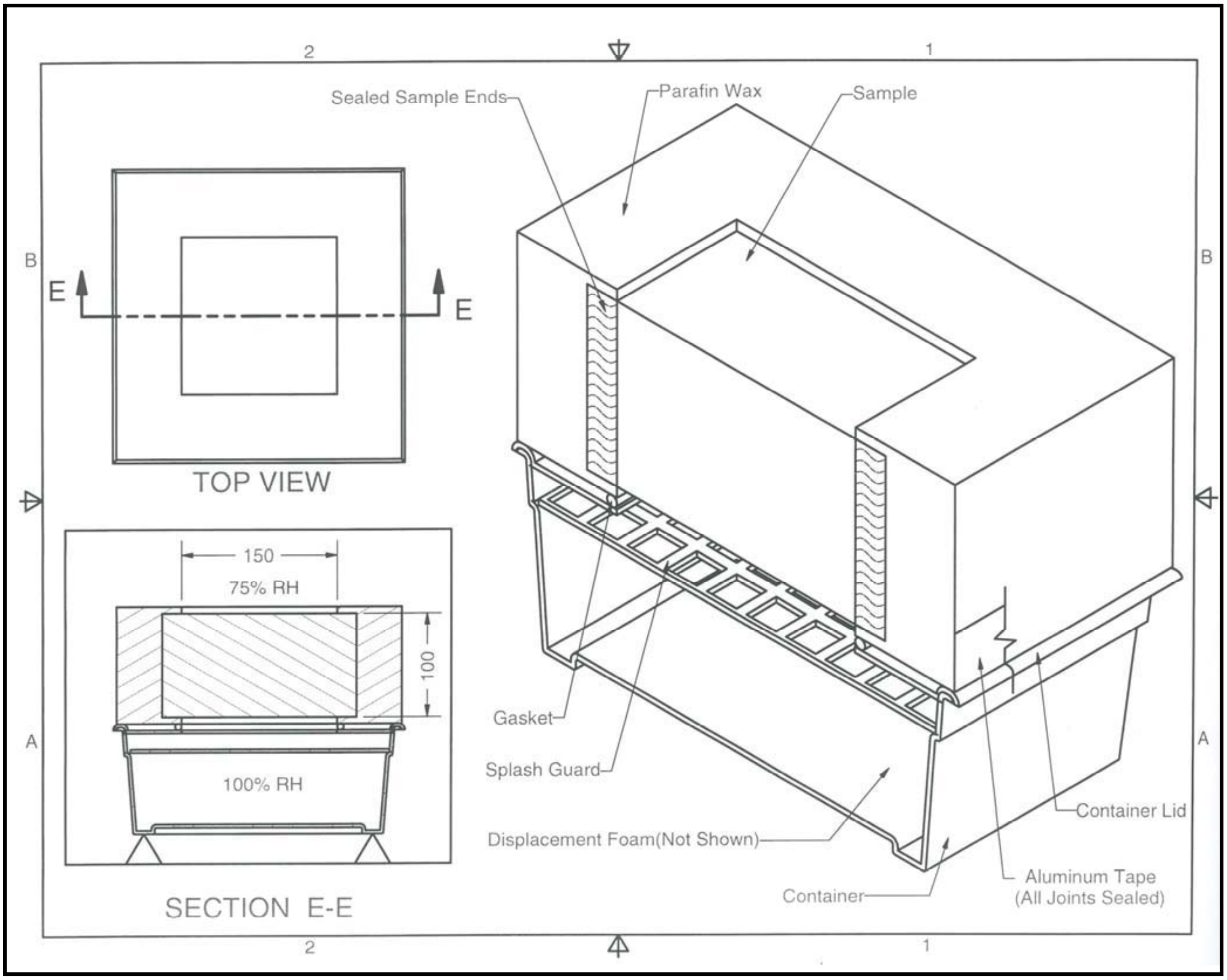


Fig. 5.2-2 Sample assembly (schematic)

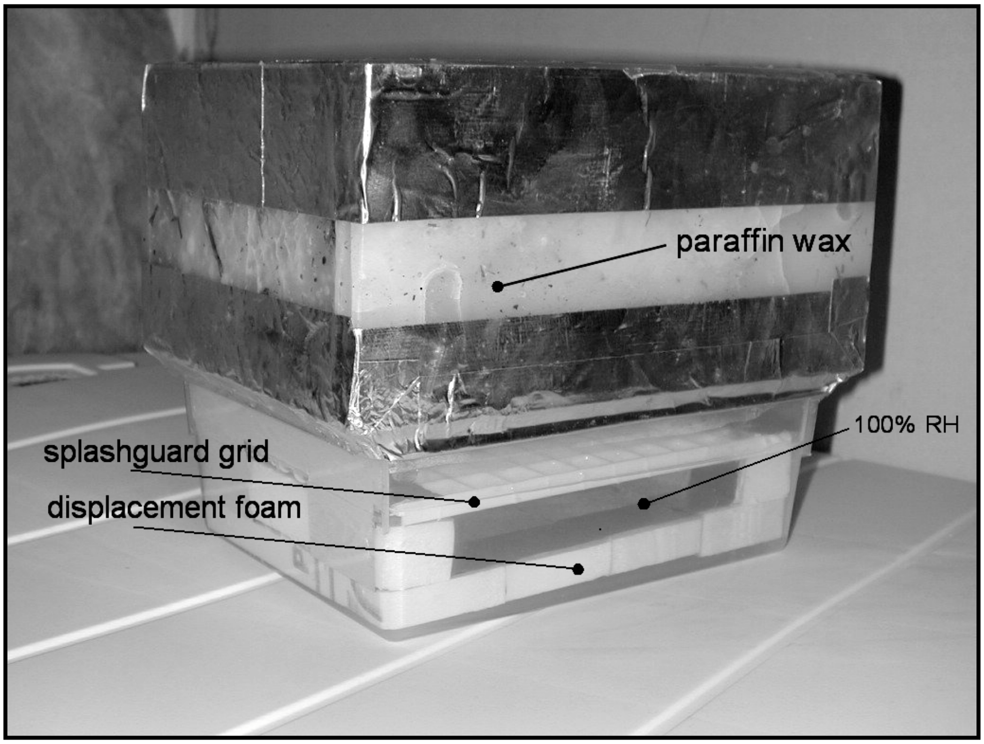


Fig. 5.2-3 Sample assembly (photo)

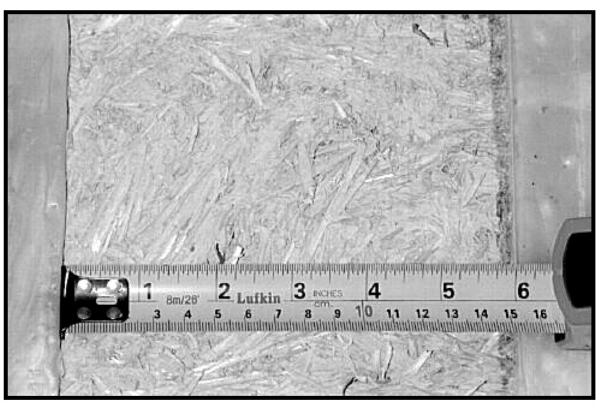


Fig. 5.2-4 Typical sample accuracy

Fig. 5.2-5 Samples within 75% RH container

As special care is required to avoid splashing water onto the sample, a splashguard is added into the assembly, which is made of an open web of plastic. The top of the plastic is placed 25mm (1 in) below the top of the container. Pieces of 2 in extruded polystyrene insulation were also added inside the container to displace some water, thus making the overall sample/container assemblage lighter. Once the sample to be tested was fixed to a lid, and the splashguard and water displacement foam added into the container, the container was then filled to 25mm (1 in) with water (to create a constant 100% RH condition), and the sample then placed and sealed on the container. The area of the sample exposed to the interior was measured and deemed to be accurate to within 1% (Fig. 5.2-4).

A saturated salt solution was placed in a larger vapor impermeable container. Different salts create different RH levels (for example table salt creates a constant 75% RH ±1.5% RH). The sample/container assembly was then placed into a larger, vapor impermeable, plastic container and sealed in an airtight and vapor tight manner. The average temperature reading in the final four weeks of measurements was less than ± 3C. However, the overall temperature variance during the entire eight weeks of testing could be as much as 6 °C .The scale used was a Scientech SG 8000 , capable of measuring up to 8000g with an accuracy of .01g.

5.3 Procedure

The sample/container assemblies were weighed prior to being placed into the container holding the 75%RH solution. The weight of the sample /container assembly was then weighed periodically. At the beginning, the samples were weighed at twenty four-hour increments until it became apparent that several weeks would be required to reach equilibrium.

When the rate of weight change was constant (within 2%) over at least three intervals, equilibrium can be assumed to have taken place, and the permeance of the sample can then be calculated. Figure 5.3-1 shows an example of vapor permeance test data.

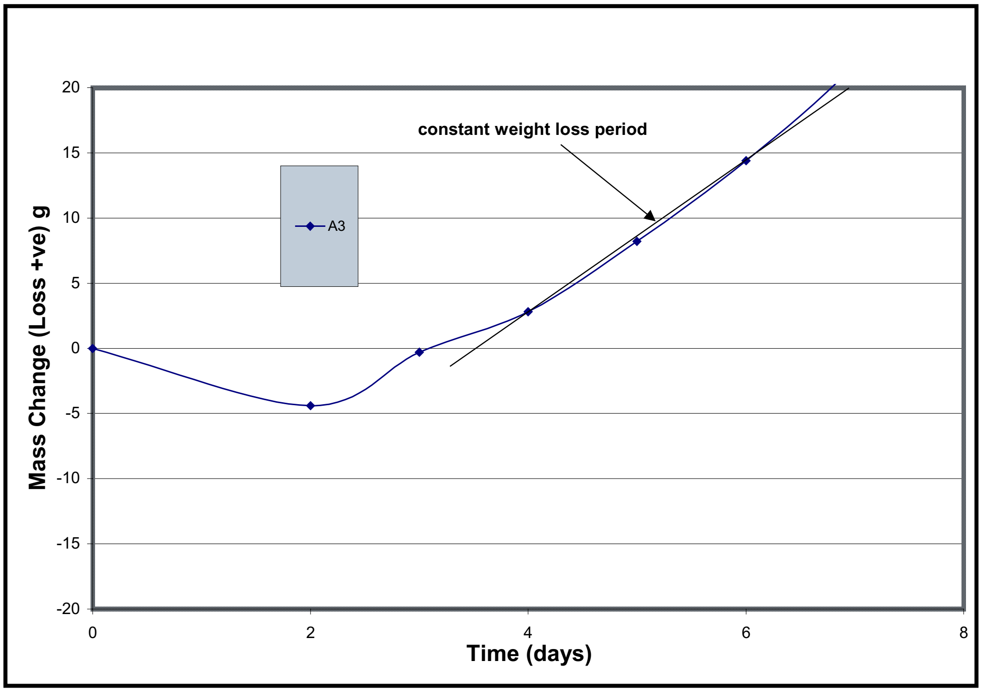


Fig. 5.3-1 Example vapor permeance test data

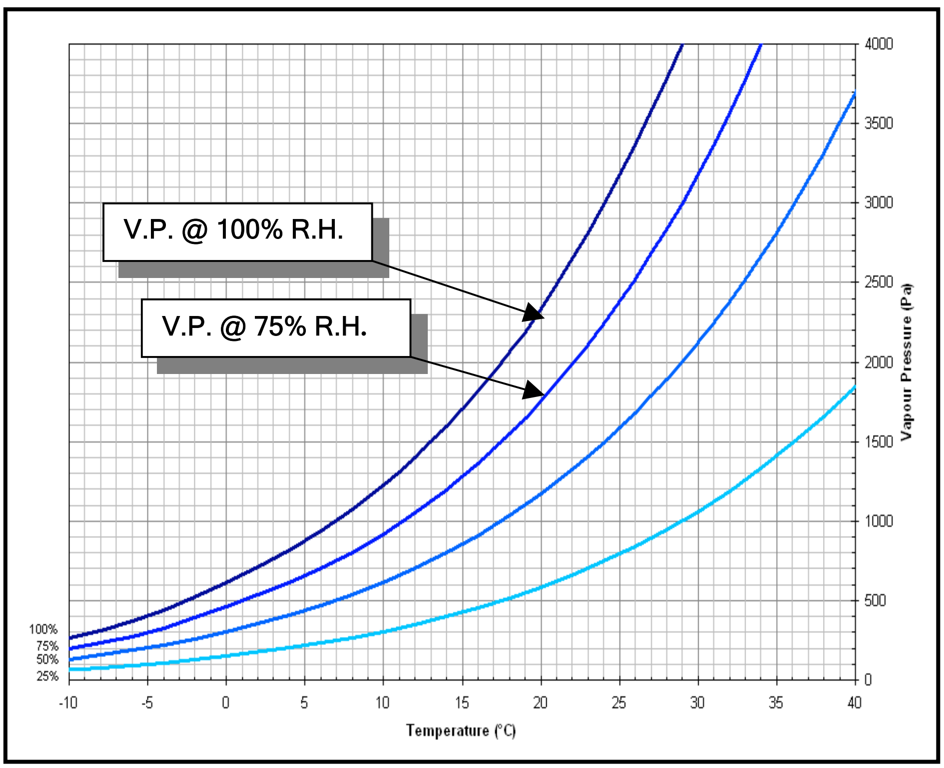


Fig 5.3-2 Psychrometric chart

5.4 Interpretation

The vapor permeance and permeability values can be calculated from the measured, steady state weight loss (or gain). The permeance of the sample is calculated as follows:

Permeance in ng/Pa s m^2 = (weight loss in nanograms*) / (sample area in m^2) x (duration of time interval in seconds) x (average vapor pressure difference in Pa).

The psychrometric chart on the previous page (Fig. 5.3-2) was used to determine the average vapor pressure difference at 20°C.

5.5 Results

The results of the testing program are summarized below and plotted in the appendix.

Sample	Density class	Permeance (ng/Pa m² s)	Permeability (ng/Pa m s)	Permeance for 25.4mm/1in. (ng/Pa s m²)	US Perms
A3	560-640 kg/m³ (35-40pcf)	747	75.9	2988	52.1
B3	560-640 kg/m³	504	51.2	2016	35.3
C3	560-640 kg/m³	590	59.9	2358	41.3
B4	560-640 kg/m³	451	45.9	1807	31.6
A4	720-800 kg/m³ (45-50pcf)	434	44.1	1736	30.4
C4	720-800 kg/m³	346	35.2	1358	23.8
A5	880-960 kg/m³ (55-60pcf)	270	27.4	1078	18.8

Table 5.5-1 Vapor permeance test results

In figure 5.5-1, vapor permeabilty is expressed relative to density, and the results of this testing program are plotted together with Minkes results for comparison.

* 1 nanogram equals one billionth of a gram e.g. $1x10^{-9}$ grams.

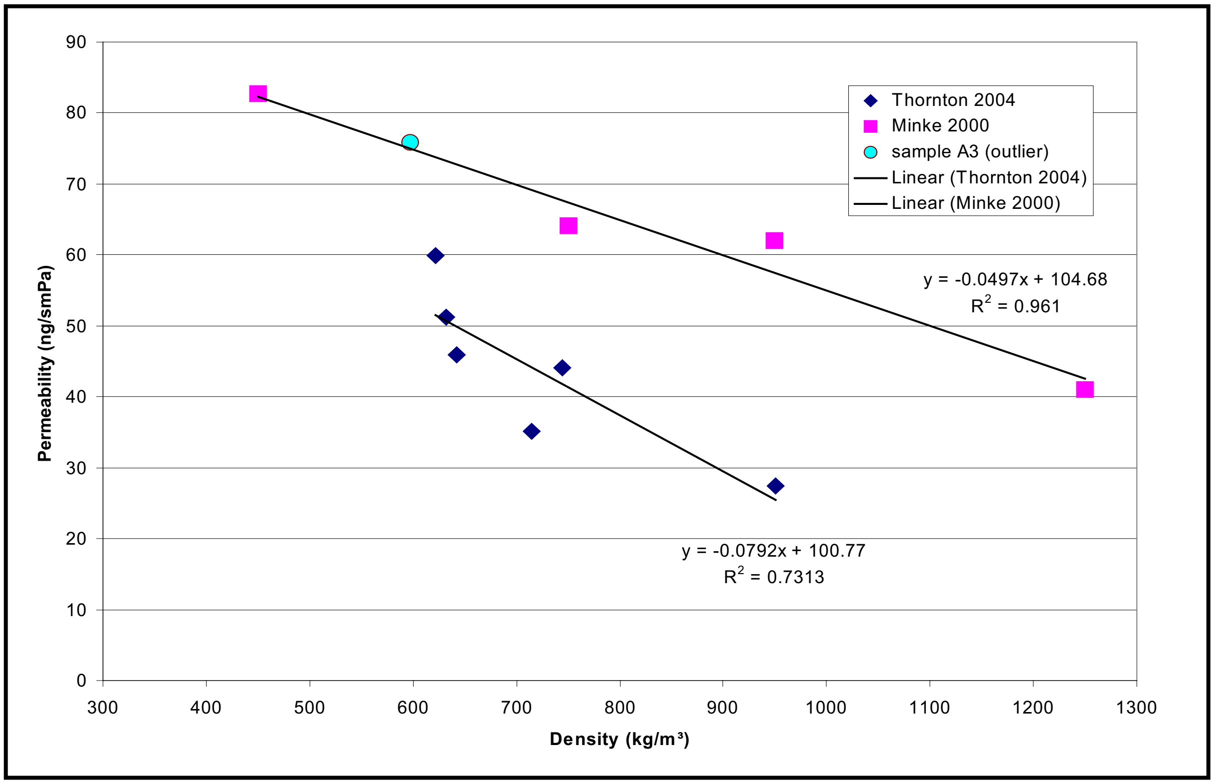


Fig. 5.5-1 Permeability / density

5.6 Discussion

This testing program has produced a number of interesting results. As can be seen in the tabulated data, straw light clay has a high a high permeability, in all density ranges. A correlation between density and permeability can be observed as well, with higher densities exhibiting a lower permeability than the lighter densities. This was expected and the results seem to be consistent with those of Minke's more extensive research and compare well with his data. A possible exception to this would be in the case of sample A3 which exhibited a permeability far above that of the other samples in its density class. This would appear to be an aberration amongst the samples measured for permeance, and interestingly in other testing as well.

Straw light clay has the ability to allow for fast drying, given it's high permeability, and provided the wall system is not compromised with a vapor diffusion retarder, which would slow drying of these walls. This material is most frequently used as part of a "flow through" approach to the management of moisture within the building assembly.

6.Moisture Storage

6.1 Test Protocol

There is no established test standard, however, this method has been standardized in laboratories around the world.

6.2 Test equipment and set-up

The space in which these measurements were conducted was maintained at an average temperature of 17.7 C with a variation of less than ±3 C. The temperature was monitored and recorded to verify that these conditions were met.

The samples were dried to a constant weight, and placed inside a metal sample box, which contains any loose material, and leaves the sides and top of the sample completely open to the vapor in the container. This weight was then recorded and the sample then placed in a watertight, air and vapor impermeable container.

6.3 Procedure

This container was filled to within 25mm (1 in) of the bottom of the sample box with a saturated salt solution (or slush). Different salts create different RH levels (for example, table salt, NaC1, creates a constant 75%). For this procedure a solution of 75% RH was used. Great care was taken to ensure that no liquid water was splashed or came in contact with the sample during handling. Other methods of RH generation can be used, provided they can be shown to create RH within ±1%. The container was sealed in an airtight and vapor tight manner at all times other than during sample removal and placement.

The weight of the sample was taken at equally spaced intervals. When the weight over at least two intervals had not changed significantly the final weight was recorded.

6.4 Interpretation

The moisture content of the sample is calculated as final weight divided by dry weight for the 75% RH environment. The relative humidity versus moisture content is plotted, assuming the moisture content at 0%RH is zero

6.5 Results

The moisture content at 75% RH is plotted below (Fig 6.4-1) with Minkes values, for comparison. Figure 6.5-1 shows the mass gain vs. time for the entire test. Note that sample B4 appears to be an anomaly (outlier).

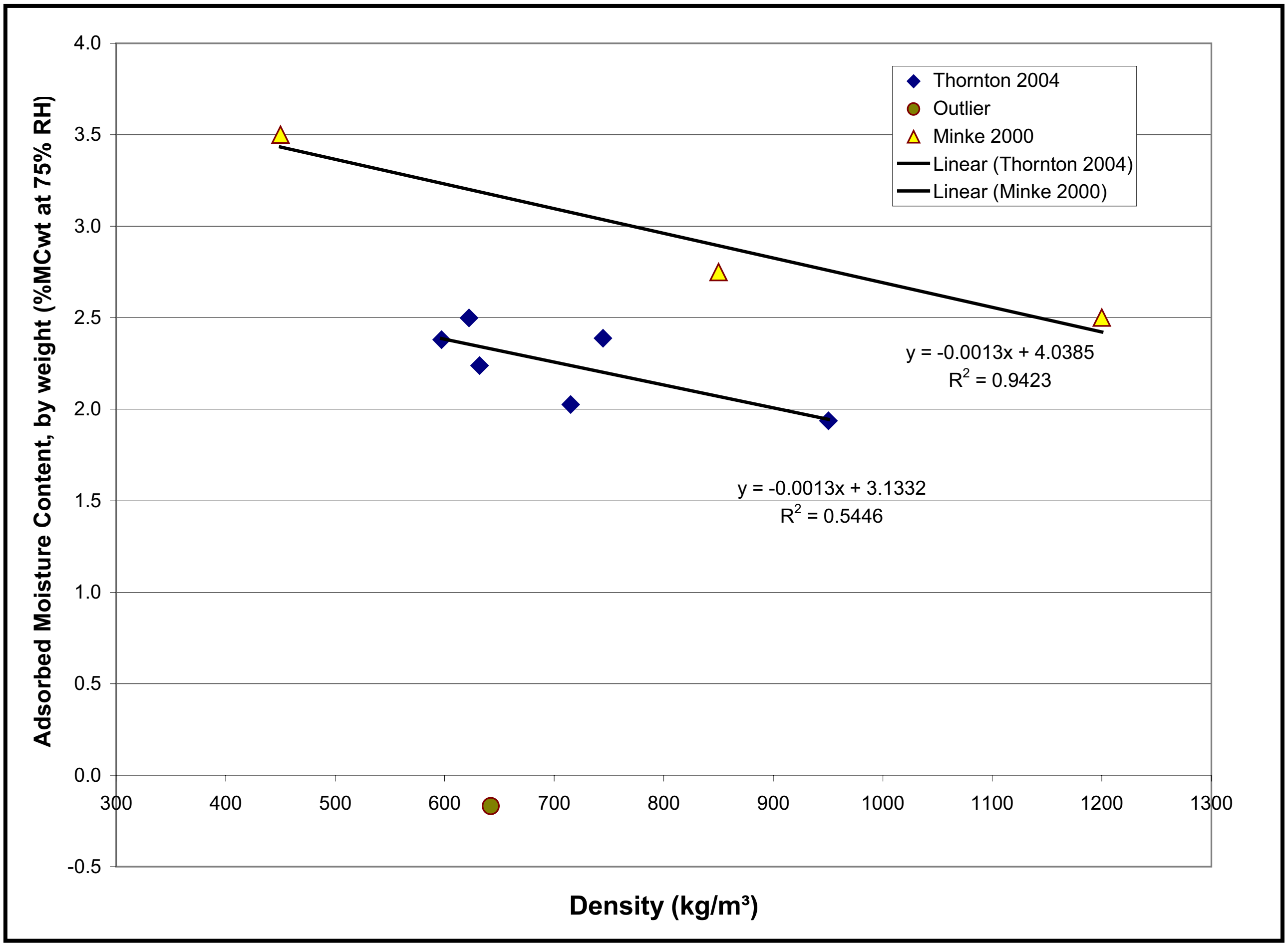


Fig. 6.5-1 Moisture content @ 75% RH.

6.6 Discussion

Although great care was used in the transport and set up of the test samples after oven drying, the only explanation for the outlier is that some contact must have been made between the sample and a source of moisture. The data from this sample does not represent the trend observed amongst the others.

The moisture storage at 75% RH of the SLC tested in this program falls between 1.9% and 2.5%. This lies somewhere between the published values of mortar and stucco. Although Minkes values display a slightly higher moisture content than this testing program, the slopes are very similar. A difference in materials and or mixtures (particularly the type of clay) is the most likely explanation for the difference in values. In either case, the moisture storage (based on mass) of SLC is low relative to unfired loam brick, or loose rye straw. However, the volumetric storage capacity is relatively high. The ability of a material to store a certain amount of moisture at a certain relative humidity (the equilibrium moisture content) does not reflect response to rapid change in humidity levels, which is a time based measurement.

The ability of a material to act as a hygric buffer is important to the stability of the relative humidity within a space. SLC has a very large storage capacity & vapor permeability. SLC is an excellent hygric buffer. This definitely reduces the possibility of short-term condensation, which is beneficial for the durability of building components [Lstiburek 2002] as well as occupant health, according to Minke [2000].

Experiments at the *Forschungslabor für Experimentalles Bauen*, "showed that the first 1.5 cm thick layer of a mud brick wall is able to adsorb about 300g of water per m² of wall surface in 48 hours if the humidity of the ambient air is suddenly raised from 50 % to 80%. However, lime-sandstone and pine wood of the same thickness adsorb only about 100 g/m², plaster 26-76 g/m², and burnt brick only 6-30 g/m² in the same period" [Minke 2000].

A full sorption isotherm curve, with a pressure plate apparatus used to continue the curve through the free saturation region, would facilitate a more detailed analysis of the moisture storage properties of SLC. This would generate data with which a finite element hygrothermal computer simulation could be done, resulting in a curve displaying moisture adsorption over time.

7. Water uptake testing

Samples measuring 150mm x150mm x 150mm (6 x 6 x 6 in) were prepared using the apparatus described in section 3.4.3. Samples from each target density were used;480-560 kg/m³, 640- 720 kg/m³ and 800-880 kg/m³ (30-35 pcf, 40-45 pcf, and 50-55 pcf) respectively.

7.1 Test Protocol

Standard tests include the Euronorm TC 89/WG10 N95 and the German DIN 52617. Soil clay mixtures can disintegrate when exposed to water for long periods of time. To address this possibility, a similar approach to Minke's variation of the German DIN standard 52617, was adopted.

7.2 Test equipment and set-up

The samples were dried to a constant weight over a period of eight weeks. The samples were then oven dried to a constant weight (achieved when the recorded weight was the same for three readings consecutively) and measured with the scale described below in 7.3. After establishing the oven dry density, the samples were allowed to return to room dry density at 55% RH. The weight was recorded again to establish a room dry density. A 150mm x 150mm (6 x 6 in) opening was created in the bottom of a water impermeable container. A liquid water, permeable filter fabric was affixed across the opening. The sample was then placed over the opening inside the container. The bottom of the large container was then filled with room temperature water. The sample was placed face down in contact with a 25mm thick sponge, which was submerged in the water to 1 - 2 mm (1/16 in) above the sponge. Water was added to the container as needed to maintain the contact of the face of the specimen with water for the entire test.

Fig. 7.2-1 Water uptake test set-up

7.3 Procedure

The weight of the sample was measured with a Scientech SG8000 scale, capable of measuring up to 8000g with an accuracy of .01g. Measurement intervals were 1hr, 3hr, 5hr, 12hr, and 24hr. To measure the weight gain the samples were quickly removed, and surface water was removed by wiping with a damp cloth. The sample was then weighed, and returned to the test containers within 2 or 3 minutes

7.4 Interpretation

The total weight gain (measured weight less dry weight) per unit area is plotted versus the square root of time. The resulting plot usually exhibits a straight line, and the water absorption coefficient is defined as the slope of this line in units of kg/(m^2 $hr^{1/2}$) or kg / (m^2 $s^{1/2}$). If the line exhibits an initial slope that is different from the final slope, the initial straight portion is used. If there is no significant change in slope, the total water uptake at 24 hrs. is used to define the water absorption coefficient

7.5 Results

The table below lists the Water absorption coefficients for each of the samples tested. In the chart below, they are plotted against the square root of time.

Sample	Dimensions	Density class	w (kg/m^{2}h0.5)
A3	150x155x150mm (5.875 x 6.125 x6)	560-640 kg/m³ (35-40pcf)	1.70
B3	155x150x150mm (6.125 x 6 x 6)	560-640 kg/m³	1.97
C3	150x150x150mm (6 x 6 x 6)	560-640 kg/m³	0.89
B4	150x150x150mm (6 x 6 x 6)	560-640 kg/m³	3.44
A4	150x150x150mm (6 x 6 x 6)	720-800 kg/m³ (45-50pcf)	3.60
C4	155x150x150mm (6.125 x 6 x 6)	720-800 kg/m³	3.31
A5	150x150x150mm (6 x 6 x 6)	880-960 kg/m³ (55-60pcf)	3.18

Table 7.5-1 Water absorption coefficients of straw light clay

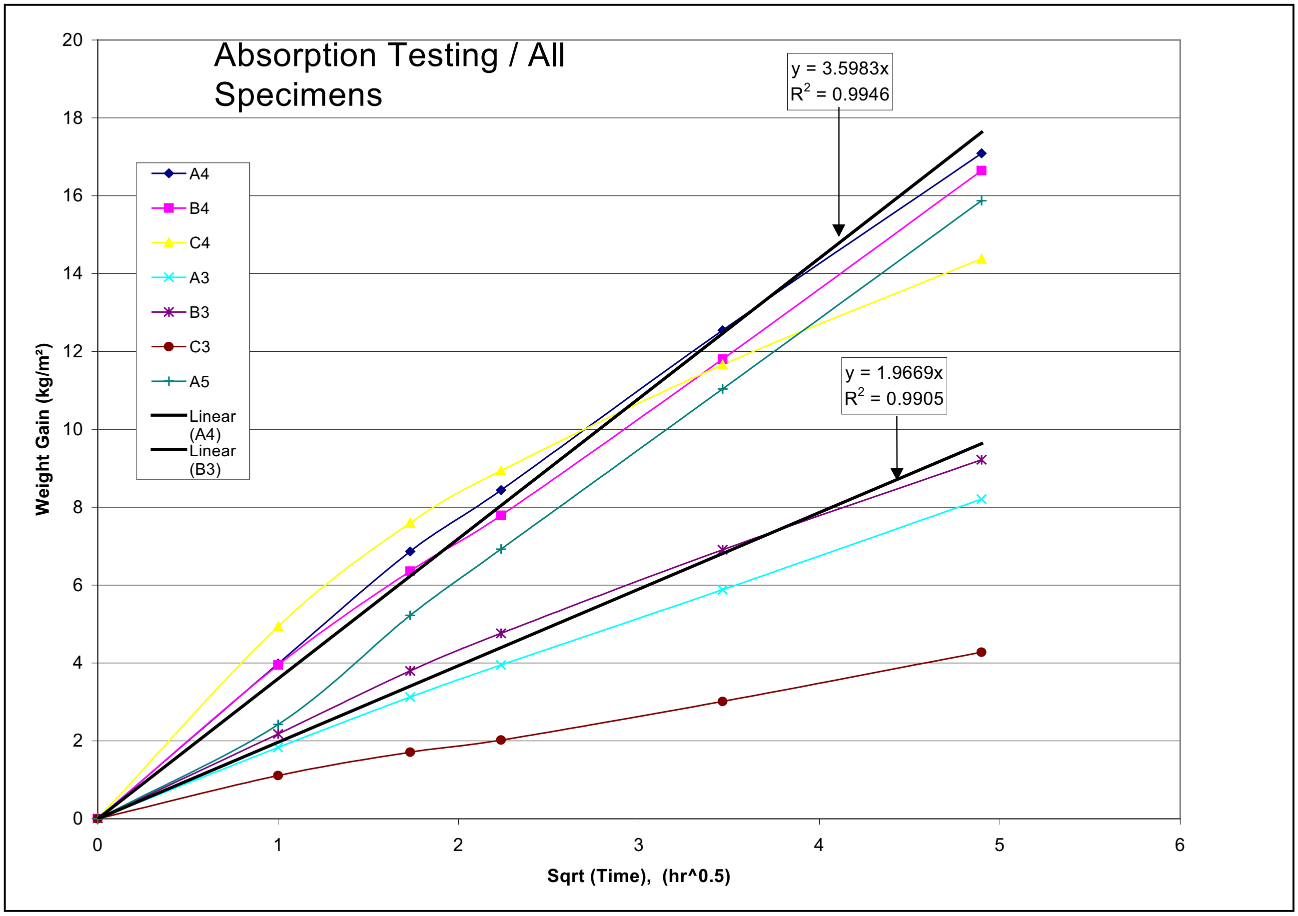


Figure 7.5-1 Absorption testing / all specimens

7.6 Discussion

Figure 7.6-1 plots the water absorption coefficients relative to density. Although the results are scattered, groupings can be observed below, but without a larger statistical spread it is difficult to draw definitive conclusions about the significance of this. Two of the samples in the lower density range exhibited a water absorption coefficient of 1.70, and 1.97 respectively, these values compare well with Minkes. One sample in this range, however, exhibited a coefficient of only .89. This is possibly related to fiber orientation within the sample, as care was taken to ensure that the operative faces of the samples were all of similar composition (i.e. fibers lying flat as opposed to on end.) However, some fibers get crushed and/or bent during forming

The results of this testing program demonstrate that straw light clay has a high capillarity. The liquid transport coefficient is a measure of the bulk transport of water within a material. Although the liquid transport coefficient is generally lower than the coefficient for suction, it will be proportional to the relatively high water absorption coefficient.

This can significantly reduce surface relative humidities when water is moved from surfaces. And when water is moved from within the sample, to the surfaces where it is able to then move via vapor diffusion, to either the exterior or interior climate depending on the conditions in a mixed climate. Measuring the liquid transport coefficient would result in a more detailed picture of moisture redistribution within SLC walls.

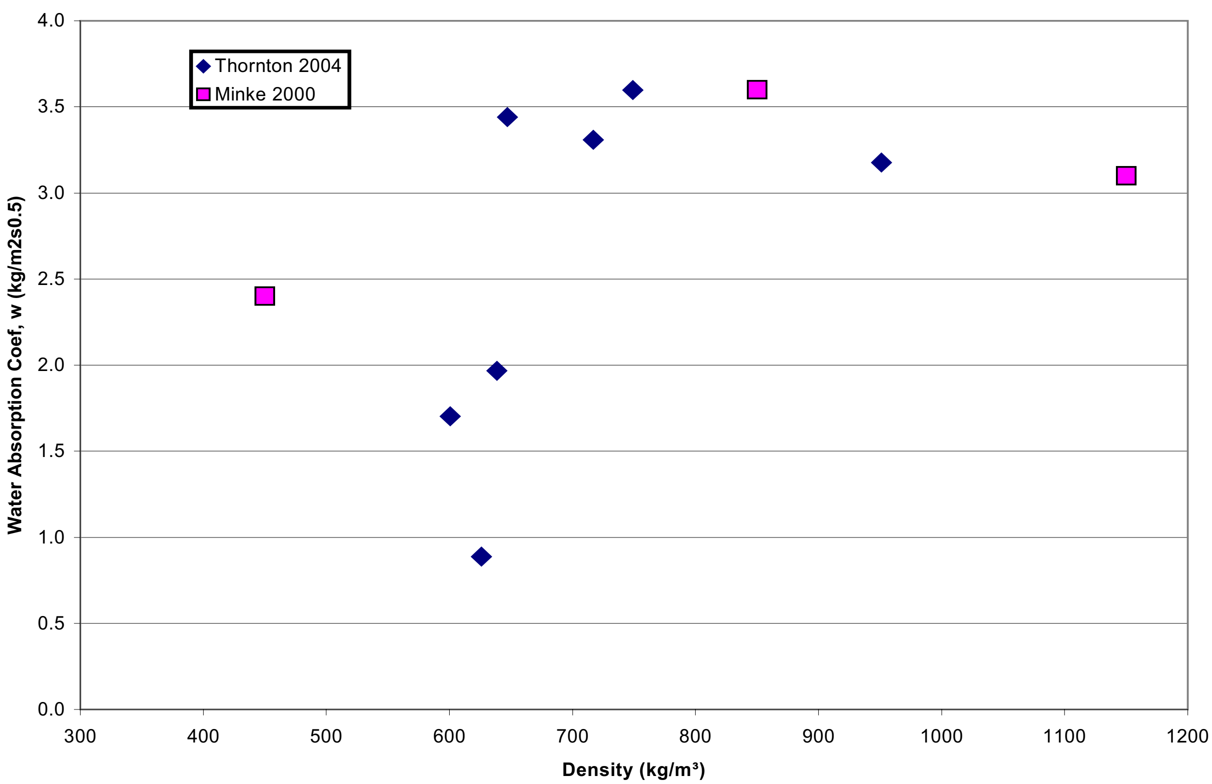


Figure 7.5-2 Water absorption / Density

8. Compression and Bending

Straw Light Clay is primarily used as a non-structural infill material for building envelopes. The establishment of allowable stresses and load limits of SLC facilitates development of design criteria, i.e. calculating strength in wind loading, or sizing lintels over openings. This testing program gives results of both compression and bending testing programs carried out on three different density classes, 480-560 kg/m³, 640- 720 kg/m³ and 800-880 kg/m³(30-35 pcf, 40-45 pcf, and 50-55 pcf respectively).

8.1 Test protocol

This testing program was carried out at the University of Waterloo. The intent was to provide a basic examination of the compressive and tensile properties of SLC. Variations of ASTM standards 495-9 and ASTM 109/109M-02 might form the basis for future investigations into compressive and bending strengths. ASTM D3500 is perhaps a possibility for tension research.

8.2 Test equipment and set-up

The equipment used for both the compression and bending tests, was an MTS 270 Material Testing System.

Fig.8.2-1 The MTS 270 material testing system

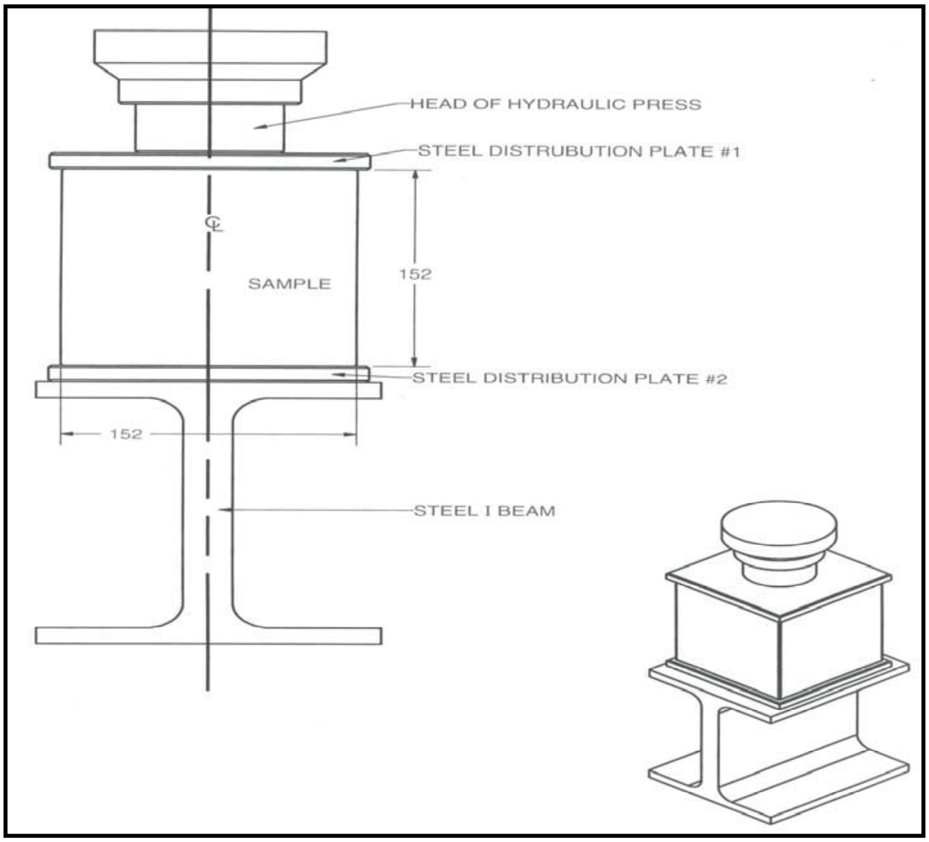


Fig. 8.2-2 Compression schematic

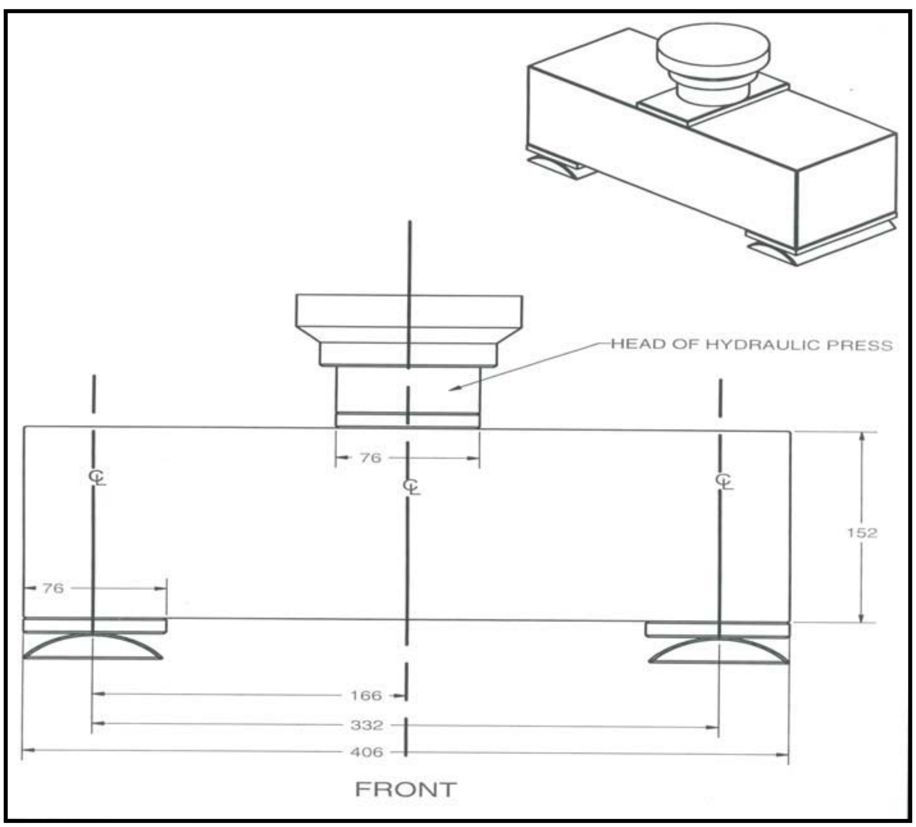


Fig. 8.2-3 Bending schematic

Fig 8.4-1 Typical compression (before)

Fig. 8.4-2 Typical compression (after)

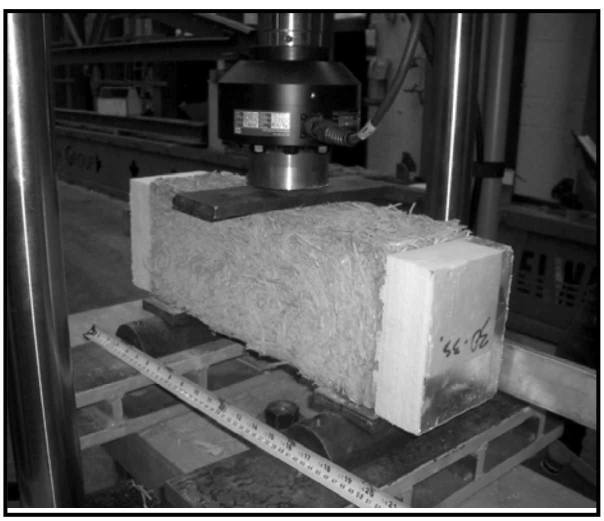


Fig. 8.4-3 Typical bending (before)

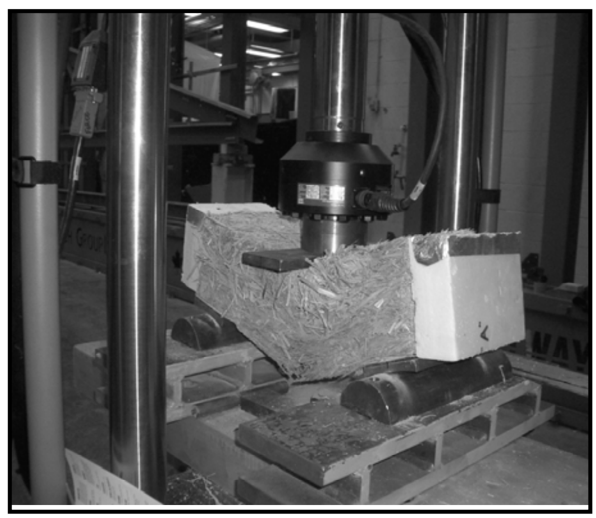


Fig. 8.4-4 Typical bending (after)

8.3 Procedure

Samples (measuring 150 mm x 150 mm x 150 mm), for the compression test were prepared as described in Section 3.4.3, and delivered to the University of Waterloo. The bending samples, (150 mm x 150 mm x 405 mm) were also prepared and delivered in a similar manner. The samples for these tests were grouped into density classes.

The compression samples were set up between two steel plates, which distribute the applied load evenly across the area of the sample. The bending samples were set up across two hemi- cylinders of steel on 75mm wide steel plates bearing at the center point of each. Underneath the head of the hydraulic press (located at mid-span) a 75mm wide steel pate was placed to distribute the load across the width of the sample.

8.4 Interpretation

8.4.1 Compression

The interpretation of the compression curves required a different approach than that used for more homogenous materials. A sometimes-eccentric curve at the beginning of the loading sequence was exhibited. This was likely due to the initial displacement of anomalies around the edges of the material. Pieces of straw fiber, coated with clay protruding from the surface, air spaces etc. could all account for these anomalies. Therefore, the initial portion of the loading curve is ignored, and the stress vs. strain slope is plotted from a point, which is more representative of the elastic region of the curve.

In addition, the compression curves all displayed wide plastic regions, indicating a high ductility. This means that SLC will continue to accept loading long beyond serviceable conditions, and very likely rarely reaches the point of ultimate failure. To address this, we chose a boundary of 5% of the initial strain as a reasonable maximum load. This, again, is in contrast to many homogenous materials (concrete, steel, wood) which often display rapid, or catastrophic failure when safe working loads are exceeded.

$$E = (S_S / S_N) * 100 / 145$$

Where:
E = Modulus of elasticity (Mpa)
S_S = stress
S_N = strain

And:

$$S_S = \text{Axial Force (kN)*1000/Area (of sample)}$$

$$S_N = \text{Axial Displacement (mm) / Thickness (of sample)}$$

Conversion:

1 Mpa = 145 psi

The curves shown below are a sample set from Appendix B (sample 45-3). In Fig. 8.4.1-1, the initial (eccentric) loading, is visible in the upper right hand corner of the curve. In Fig. 8.4.1-2, the curve has been redrawn and the portion, which falls within the elastic region is plotted as stress over strain.

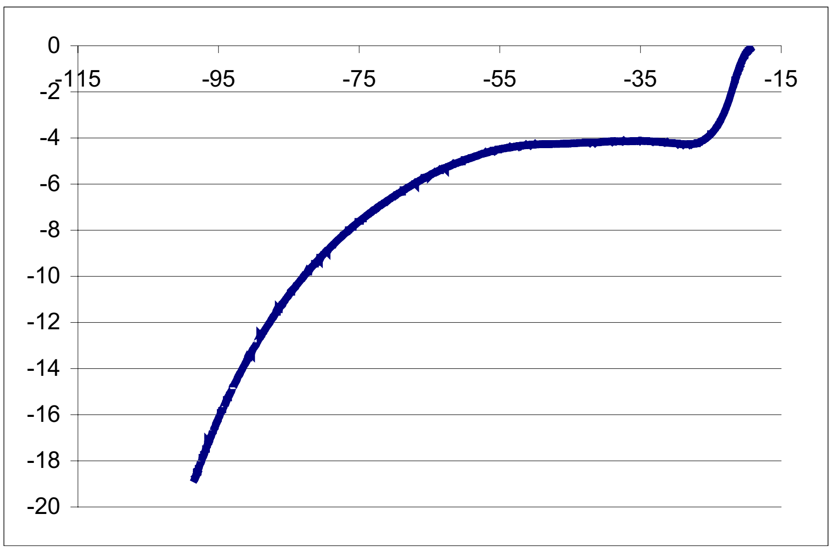


Fig.8.4.1-1 Sample test data (including initial loading)

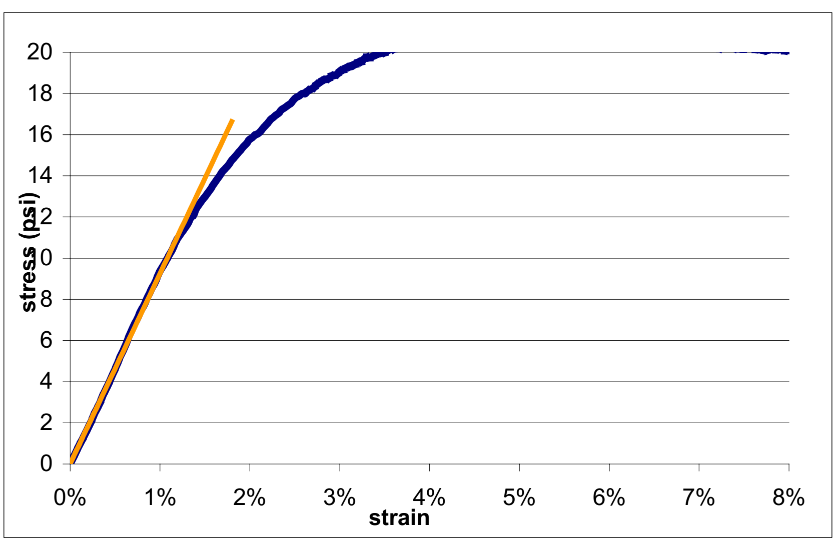


Fig. 8.4.1-2 Sample test data with slope (initial loading removed)

The following chart displays the compressive strength (Mpa) over density. A clear trend can be seen through each density class. Although these results are limited to the scope of this initial testing program, it is expected that more extensive investigations will reveal a similar slope.

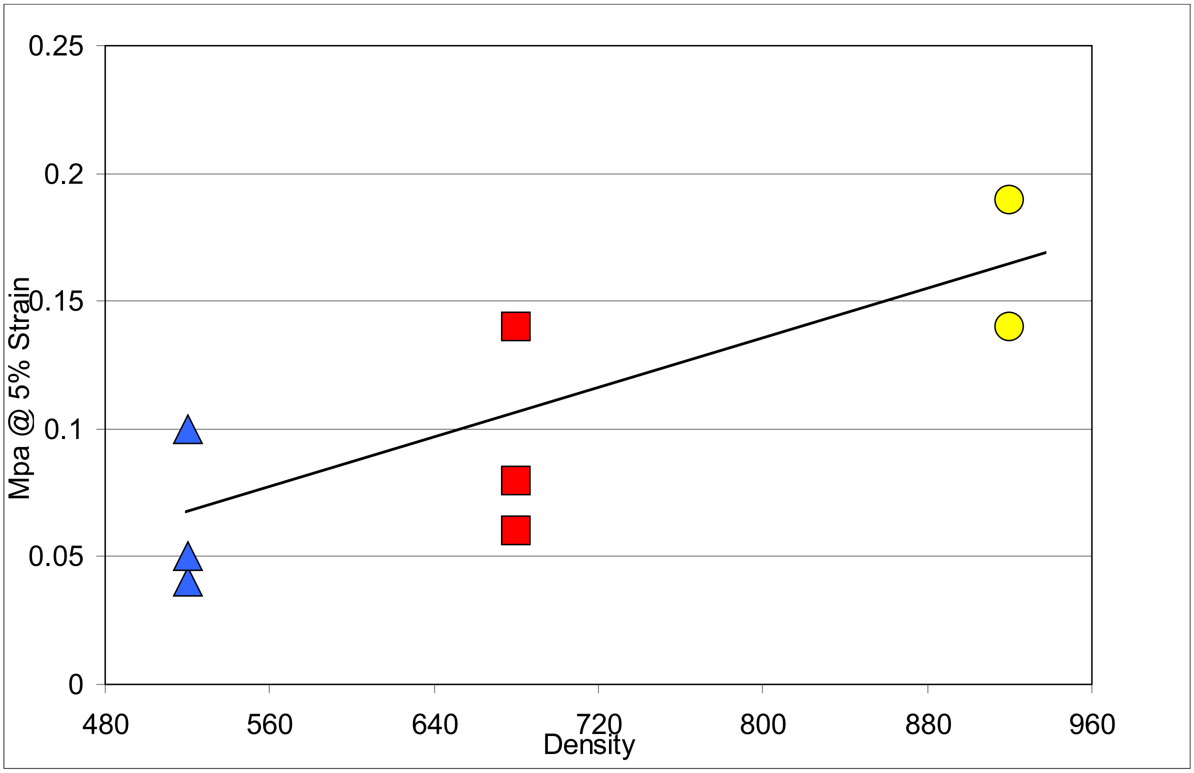


Fig. 8.4.1-3 Compressive strength (at 5% strain) vs. density.

8.4.2 Bending

Interpretation of the bending curves was achieved by plotting a load vs displacement curve based on the data from the testing program (Fig. 8.4.2-1). The peak moment was then selected from the data, and this point plotted on the curve.

The peak moment was then calculated as:

$$PL/2$$

Where:

P= peak load

L = span (330.2mm)

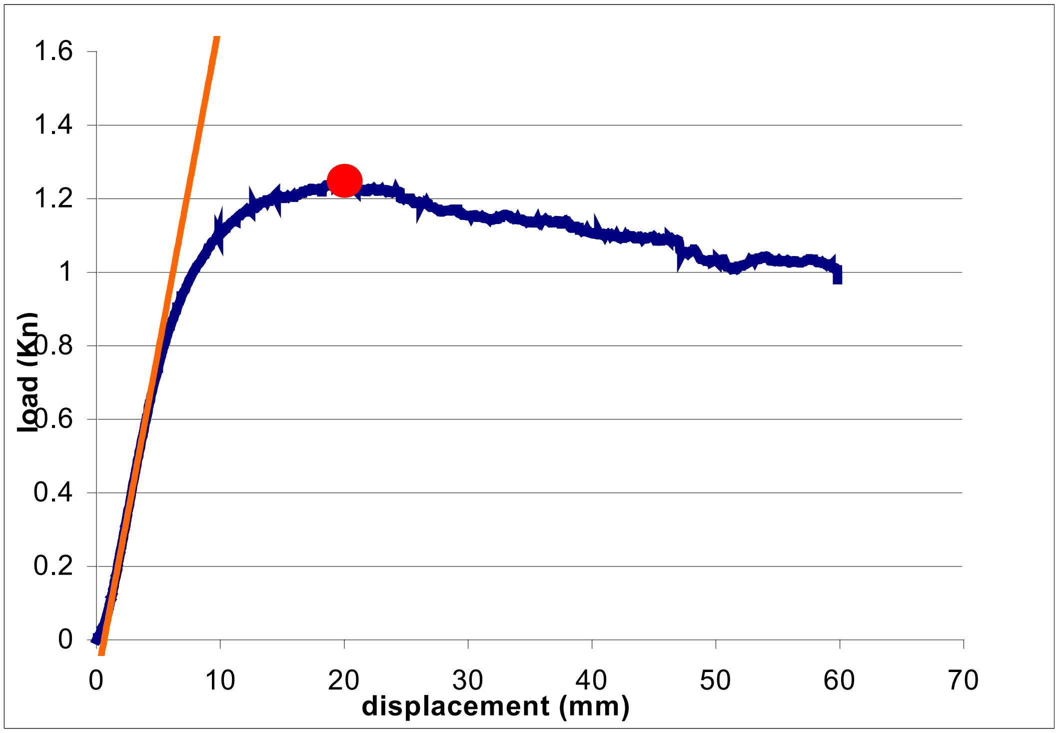


Fig. 8.4.2-1 Load vs. displacement (initial loading removed)

Next the modulus of rupture was calculated as:

$$M/S$$

Where:
M= moment
S = section modulus
The section modulus was calculated as:

$$S= bd^2/6$$

Where:
b= width
d= depth

Finally, the modulus of elasticity was calculated as :

$$E=PL^3/48dI$$

Where:
P= total load (kN)
L= span
D= maximum allowable deflection
I= moment of inertia ($bd^3/12$)

8.5 Results

The results of both, the compression and bending testing programs are tabled below (Figs. 8.5-1 & 8.5-2)

Sample	Avg. Density	Compressive Strength @ 5% strain		Modulus of Elasticity	
	pcf	Mpa	psi	Mpa	psi
35-1	32.5	0.04	6.4	1.19	175
35-2	32.5	0.1	14.9	2.65	390
35-3	32.5	0.05	8.1	4.83	710
45-1	42.5	0.08	11.9	1.36	200
45-2	42.5	0.06	9.4	1.26	185
45-3	42.5	0.14	20.9	6.29	925
55-1	57.5	0.14	20.8	2.55	375
55-2	57.5	0.19	28.7	3.91	575

Table 8.5-1 Compression

section modulus	moment of inertia
S=bh²/6	I=bh³/12
589934	4.50E+07

sample	peak moment	rupture modulus		modulus of elasticity	
	M=PL/2 kNm	f'r=M/S		E=48dI/PL³	
		(MPa)	*psi*	*(MPa)*	*psi*
35-1	0.1	0.17	26	0.002	0.4
35-2	0.26	0.43	64	0.001	0.2
35-3	0.09	0.15	22	0.002	0.3
45-1	0.14	0.23	34	0.001	0.1
45-2	0.21	0.35	51	0.003	0.4
45-3	0.11	0.19	28	0.002	0.2
55-1	0.23	0.39	58	0.007	1.0
55-2	0.34	0.57	84	0.008	1.2

Table 8.5-2 Bending results

8.6 Discussion

In the absence of having any data for straw light clay with which to make a comparative analysis, a wider search revealed some field research done on compressive strengths of plasters for strawbale construction [Donahue, Lerner 2003]. The strengths of SLC seem generally to be lower than those of the plasters tested in the program mentioned above, however as both this testing program, and the one cited are initial studies with limited scope, comparisons may be premature.

The results of this testing program suggest that, combined with these plasters, an SLC wall system has the potential to resist a fair degree of wind loading. More extensive investigation in this area could reveal several options with respect to sub-structural detailing in response to these loading conditions.

In addition, the highly ductile properties observed in this testing program, present interesting possibilities with respect to seismic loading conditions. The stubbornness of this material to reach ultimate failure has the potential to significantly extend the time between early warning signs and occupant evacuation of these structures.

9 Settling

When forming SLC *in situ*, vertical movement occurs. The lack of horizontal movement suggests that this movement is the result of settling rather than shrinkage.

9.1 Test equipment and set-up

Forms were made to accommodate three target densities. The form dimensions were 610 mm x 337 mm x 152 mm. The block dimensions were 610 x 304 x 152 mm. The extra height at the top of the form was used to gauge the final height of the mixture by registering a 19 mm thick wooden registration gauge against a line, which was inscribed at 323 mm. In other words, when the top of the registration gauge was in alignment with the mark at 323 mm, the final height of the mix had been achieved (Fig 9.2-1). This mark was 19 mm below the top edge of the form. This process made it easier to achieve a number representative of the entire top of the sample as it eliminated any irregularities occurring there.

9.2 Procedure

Straw clay mixtures were placed in forms designed to facilitate the measurement of settling. The form dimensions were 600 x 336 x 150 mm. The block dimensions were 600 x 300 x 150 mm. The mixture was placed into the form and tamped as described in section 3.6. An 18 mm thick piece of wood was used to register the final height of the formed mixture. The forms were removed and the blocks were left to dry to equilibrium. Upon reaching their air-dried state, the forms were then replaced around the block and used for measuring the height of the air-dried block.

Fig. 9.2-1 Typical set-up for measuring settling.

9.3 Interpretation

The distance between the top of the form and the top of the samples were measured prior to, and after reaching air-dried equilibrium (Figs. 9.3-1 and 9.3-2). The difference between these two figures was then multiplied by 100 and divided by the initial height of the block when formed, 300 mm (12 in) e.g.

$$(H_b - H_a) * 100 / 300$$

Where:
H_b = Height before drying
H_a = Height after drying

Fig. 9.3-1 Before drying (typical)

Fig.9.3-2 After drying (typical)

9.4 Results

The results of the settling measurements are tabled below in Fig. 9.4-1.

Density Class Kg/m3	Before Drying	After Drying	Difference	Settlement (%)
560-640	22mm 0.88"	46mm 1.81"	24mm 0.94"	8.0%
720-800	19mm .75"	41mm 1.61"	22mm 1.25"	7.0%
880-960	19mm .75"	38mm 1.53"	19mm .75"	6.0%

Table 9.4-1 Vertical settlement of SLC

9.5 Discussion

While an exhaustive testing program is beyond the scope of this research, the results above seem to indicate a trend in which the rate of settlement is related to the density of the material. In the case of straw and clay, the density changes as the aggregate to binder ratio changes. For instance greater settling can be observed in the lighter density class, and this is most likely due to the lesser amount of binder and greater proportion of aggregate, relative to the other samples.

Different results, with other aggregates have been observed in the field by the author. For instance wood chips and clay do display lateral as well as vertical shrinkage. This would also seem to support the above supposition that the vertical-only movement observed with straw clay, is a settlement issue as opposed to a shrinkage issue. Furthermore, wood chips and clay require a higher proportion of binder than even the most straw clay mixtures.

The advantage to knowing the settling rates of straw clay is most useful for making blocks insofar as one is able to more accurately predict the final dimensions of the units. In an *in situ* application, the gap, which occurs at the top of wall assemblies as a result of this settling, can be remediated after the wall has dried to equilibrium. The advantage with blocks, among others, is that they can be brought to equilibrium prior to installation and therefore reduce the time required between infilling and plastering.

10. Density

It is important to know the density of materials when interpreting their properties, as density often plays a role in the performance of a given material. The samples weighed here correspond with all moisture and thermal related samples. The fire and compression / bending samples were from another sample set.

10.1 Test protocol

No known testing procedures specific to straw clay, however Minke [2000] recommends cutting a small cube out of a larger sample to accurately determine the density. Future testing could refer to ASTM C-567.

10.2 Test equipment and set-up

A cutting box was constructed so that the samples could be accurately cut (Fig.10.2-1). The samples were cut so that that three sides of the sample were formed when the original block was made, and three sides were cut in the process of creating the sample. This process is described in detail in section three. The formed surface of the original block became the operative surface in the tests.

Fig 10.2-1 The cutting box.

10.3 Procedure

The samples were prepared using the apparatus mentioned above. Once the samples were obtained, they were oven dried at 120°F, and periodically weighed for a period of 24 hrs. Once the samples had reached the same weight for three consecutive readings, the samples were then weighed and allowed to return to equilibrium (room dry) density. A final measurement was done at room dry density.

10.4 Results

Below are the results of the density measurements. In the right hand columns, the weight of the samples has been used to calculate an overall density in pounds per cubic foot, and then converted to be expressed in Kg/m^3, Using the formula:

$$\text{Eq. Density}/216 \cdot 1728 \cdot .002205$$

To calculate pounds per cubic foot, and then multiplying the sum by 16.018 for kg/m^3.

Sample	Dimensions	Oven Dry Density (g)	Equilibrium Density (g)	Equilibrium Density (pcf)	Equilibrium Density (Kg/m3)
A3	150x155x150mm (5.875 x 6.125 x 6)	2110	2130	37.6	602
C3	150x150x150mm (6 x 6 x 6)	2240	2260	39.1	626
B3	155x150x150mm (6.125 x 6 x 6)	2270	2290	39.9	638
B4	150x150x150mm (6 x 6 x 6)	2200	2220	40.4	647
C4	155x150x150mm (6.125 x 6 x 6)	2530	2540	44.8	717
A4	150x150x150mm (6 x 6 x 6)	2640	2650	46.8	749
A5	150x150x150mm (6 x 6 x 6)	3360	3370	59.4	951

Table 10.4-1 Density table.

10.5 Discussion

This research program “targeted” three different density classes for analysis. As stated in the introduction, these density classes were 480-560 kg/m^3, 640- 720 kg/m^3, and 800-880 kg/m^3 (30-35 pcf, 40-45 pcf, and 50-55 pcf respectively). Obtaining the target values can be challenging, even with some experience with the material. A mix which feels, and looks rather heavy at the mixing stage can dry significantly to become a mid-range specimen. Conversely, broadcasting enough clay to adequately coat the straw quickly creates a mixture which, again when dry, yields a material of mid-range densities. In practice, an owner builder, with little or modest experience can easily achieve densities in the range of 600-700 kg./m^3. The heavier densities are also readily achievable, but difficult to predict. The most difficult densities to achieve in practice are the lighter densities in the 480-560 kg/m^3 range. Given the organic nature of the material and processing, the most conservative approach when looking at the material properties of Straw Light Clay would be to use the values generated by the 640-720 kg/m^3 density range for performance calculations.

11. Fire Resistance

11.1 Test protocol

The recommended fire test procedures, such as ASTM E 119, and E 84, are beyond the scope of this paper. Therefore, these tests should serve as a preliminary investigation into the possibilities of the materials potential in a full scale fire-testing program.

11.2 Test equipment and set-up

The test equipment used consisted of four propane cylinders placed approximately 75 mm (3 in) from the face of each sample. The samples were elevated on fireproof platforms and the torches were set up to be perpendicular to the face of the sample. The samples were a nominal 150 x 150 x 150mm for the 560-640 kg/m^3, and the 720-800 kg/m^3 sample sets. Only one specimen was available for the 880-960 kg/m^3 density class. This sample was 150 x 150 x 50mm.

11.3 Procedure

The samples were subjected to the pressurized flame of a propane torch for a period of 4 hours. The samples were then dissected to determine the depth to which the flame was able to penetrate (Figs. 11.3-1, 11.3-2 and 11.3-3).

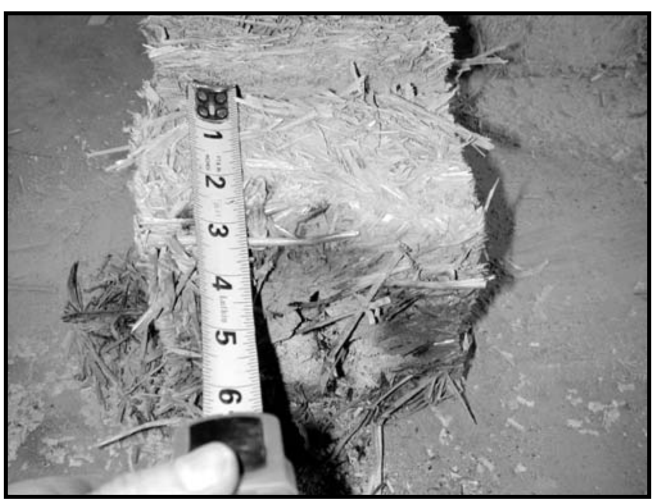


Fig. 11.3-1 Depth of char

Fig. 11.3-2 Charring @ 38mm

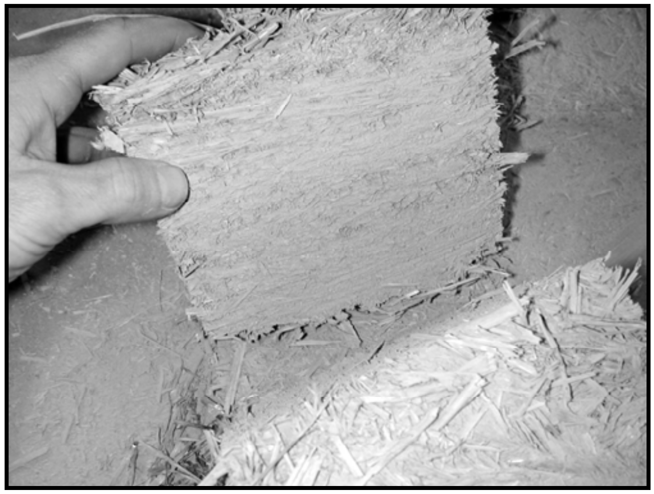


Fig. 11.3-3 No charring @ 76mm

11.4 Interpretation

The BIA Technical Notes 16 [2002], lists several conditions of acceptance for assigning a fire resistance period to both load bearing, and non-loadbearing walls. One of these conditions are that the nine thermocouples on the unexposed face of the sample not have an average temperature increase of more than 250°F (121° C) above their initial temperature. On the exposed side, the standard time-temperature curve (Fig 11.5-1) for ASTM E 119 indicates a temperature of 2000°F (1093°C) at 4 Hrs.
The human touch can safely handle approximately 57°FC (135°F).
All of the samples tested were able to be picked up and handled after being exposed to the propane flame for a period of four hours.

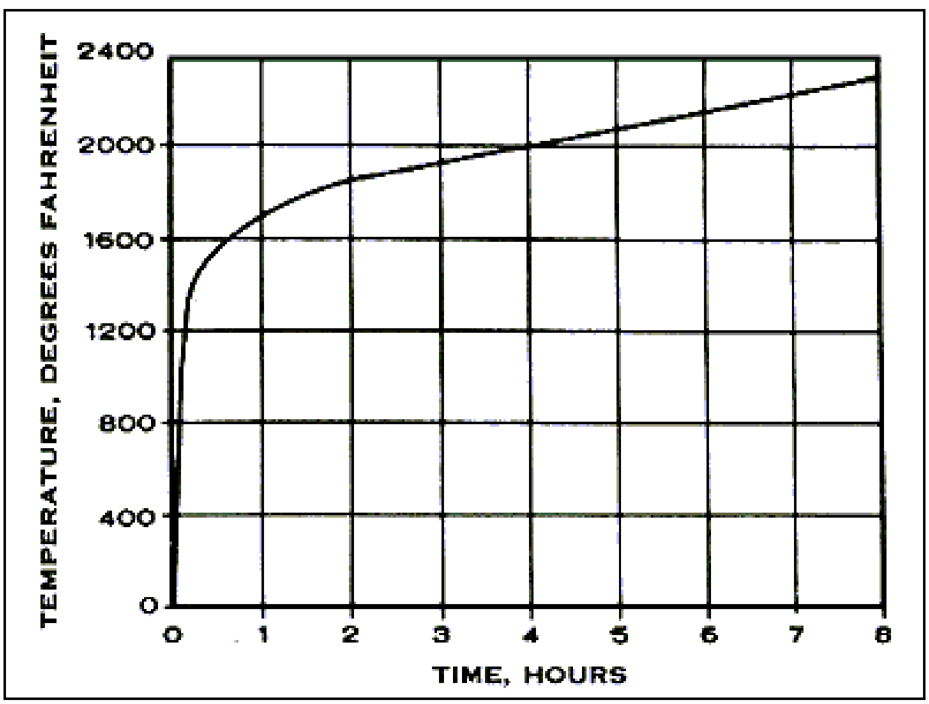


Fig. 11.4-1 Time temperature curve

11.5 Results

Several interesting results can be observed throughout this testing program. The one common feature of all of the samples tested was that the flame burned a hole with an average 25mm dia. in the exposed face. This hole penetrated to varying depths which are tabled below (Fig. 11.6-1). A trend can be seen in the correlation between each density class and the average penetration depth.

sample	penetration	density class	avg. penetration
A-1	63 mm (2.5")	560-640 kg/m3	70mm (2.75")
A-2	76 mm (3")		
A-3	70 mm (2.75)		
B-1	51 mm (2")	720-800 kg/m3	51mm (2")
B-2	38.1 mm (1.5)		
B-3	63 mm (2.5)		
B-4	19 mm (.75")	950 kg/m3	19mm (0.75)

Table 11.5-1 Fire testing results

11.6 Discussion

As can be seen in the table above, different penetration depths were recorded for different samples within the same density class. It was observed throughout the test that the more heavily charred and penetrated pieces were as a result of a variation of material consistency in the locality of the exposed surface contact point with the flame. This charring becomes noticeably visible at 180 min in the series A samples, particularly with sample 2 (centre) and, to a lesser degree sample 3 (right). In the series B samples, this charring becomes visible almost immediately, as the charring can be observed at only 15 minutes. In sample 3 (third from left) a material inconsistency resulted in a fissure.

Smoke was observed travelling this fissure at the 15-minute interval. This was not observed at 30 minutes. This smoke was likely the result of loose strands of straw being burned off. These strands had lost their protective clay coating in transport. The fissure was of the kind formed when a layering of fibres occurs while forming the block. It was further observed that this was the preferred route for the smoke to travel.

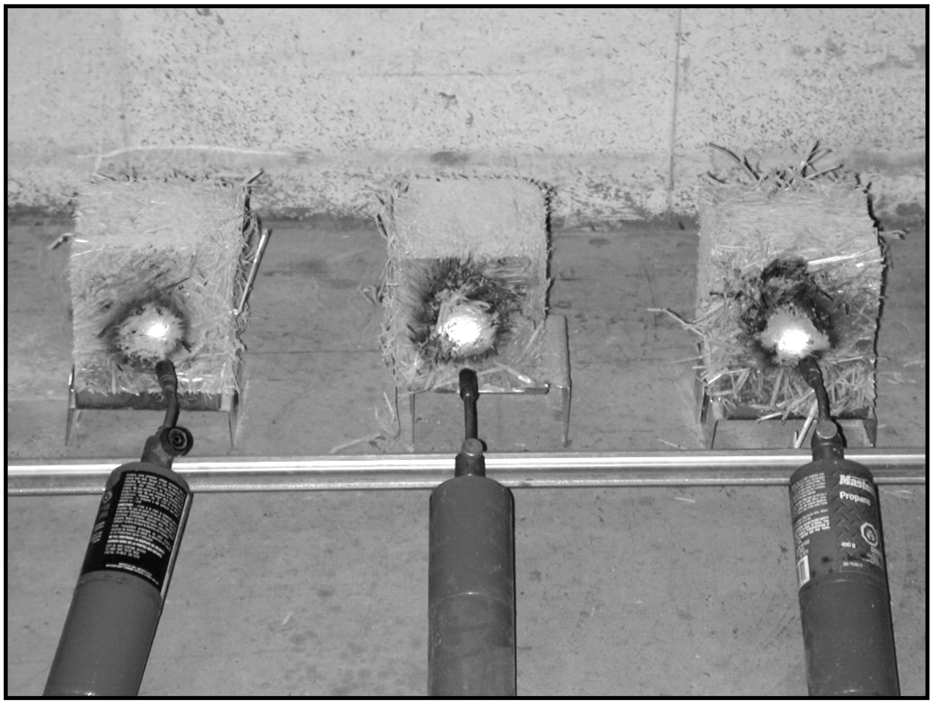
The charring, and attendant material breakdown, happened in two stages. Primarily, the material within the penetration was heated to the point of being red-hot. As the penetration proceeded, the outermost edges (closest to the exposed surface) turned to ash, and sample began to break down (Figs. 11.7-1 &2).

Given the above observations and interpretations, this material would likely meet the conditions for a non-loadbearing fire resistance period of four hours in it's typical 300mm (12 in) thick configuration, and without plaster. As discussed throughout this report, a wall formed *in situ* requires up to eight weeks drying time *prior to* plastering. Therefore, it is advantageous from the point of view of fire safety during construction, that the material be resistive to fire during this time period.

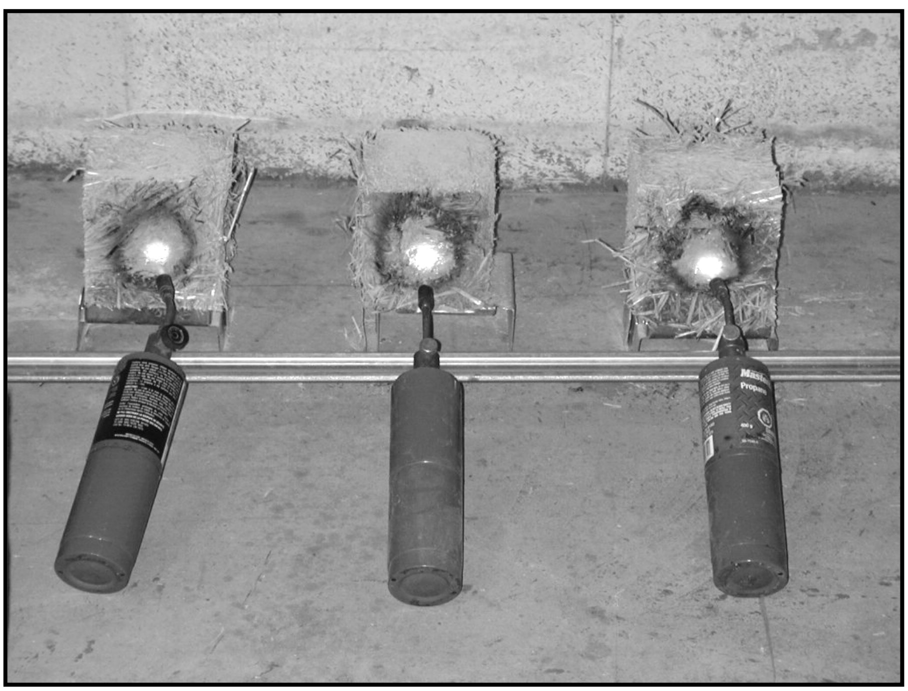
Fig.11.7-1

Fig.11.7-2

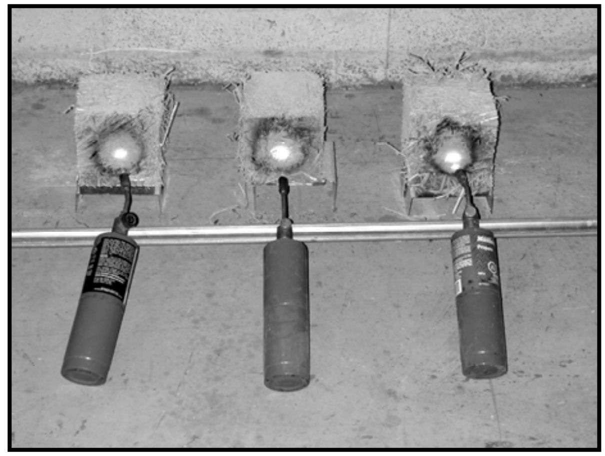
Fire Resistance: Series A 560-640 kg/m³



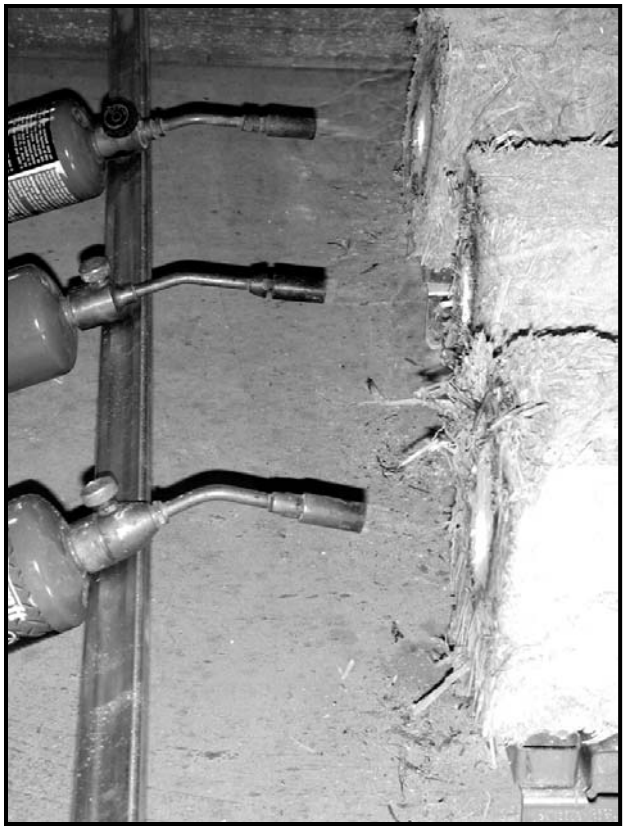
start



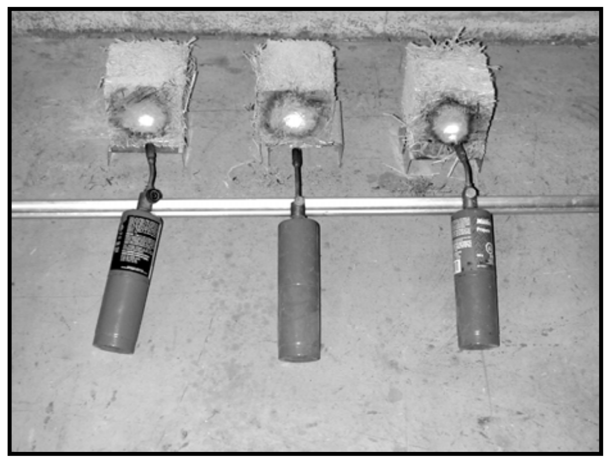
15 mins



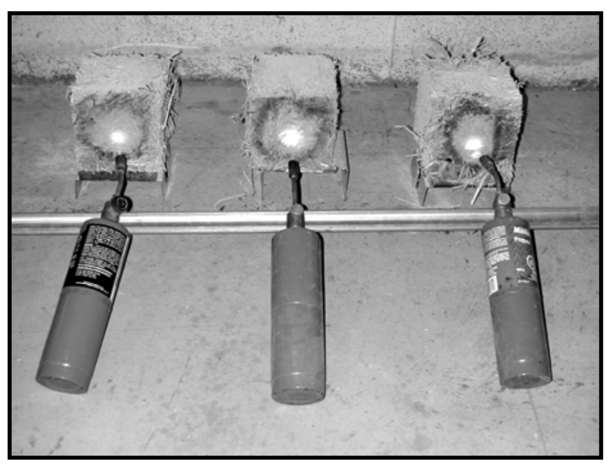
30 mins



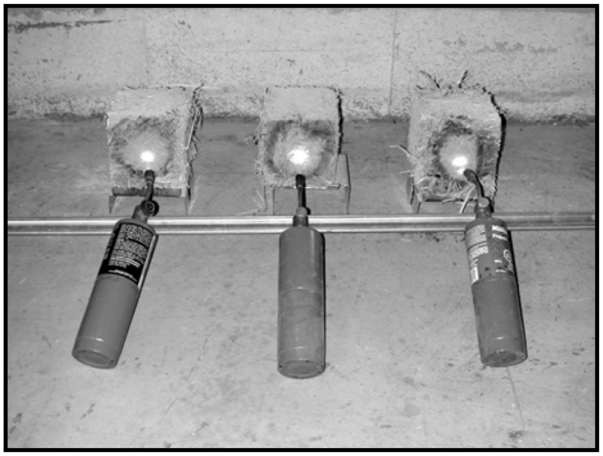
Side view of test set-up



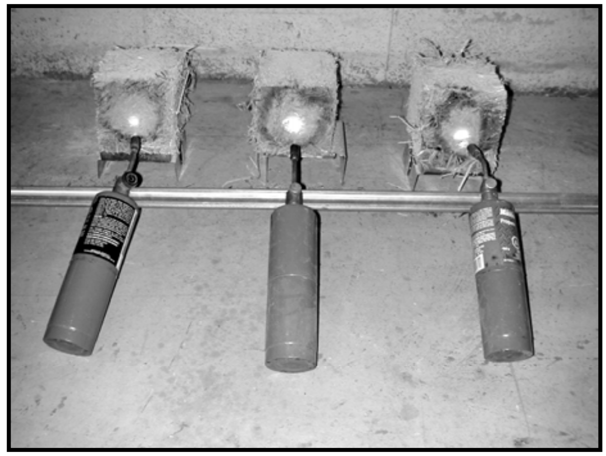
60 mins



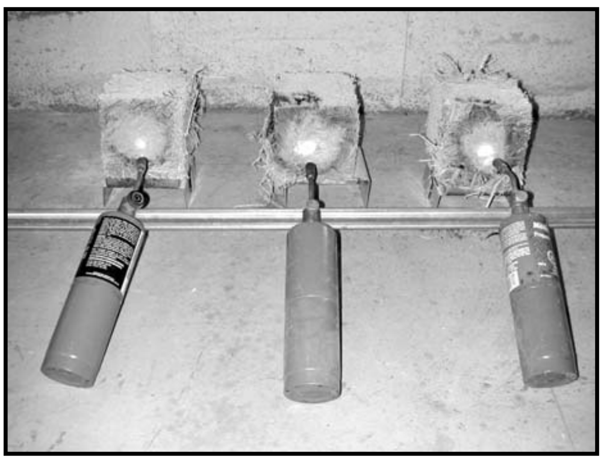
90 mins



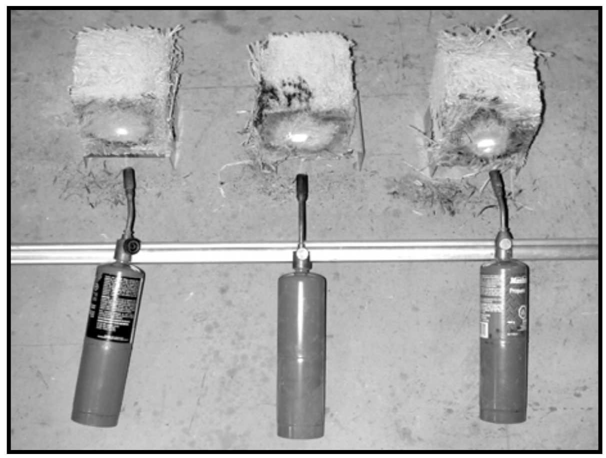
120 mins



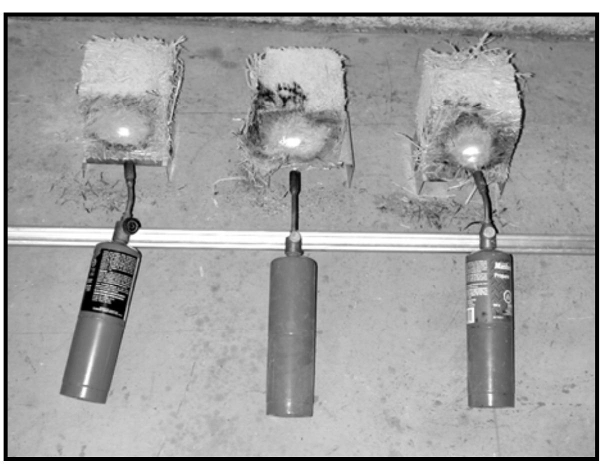
150 mins



180 mins



180 mins view from above

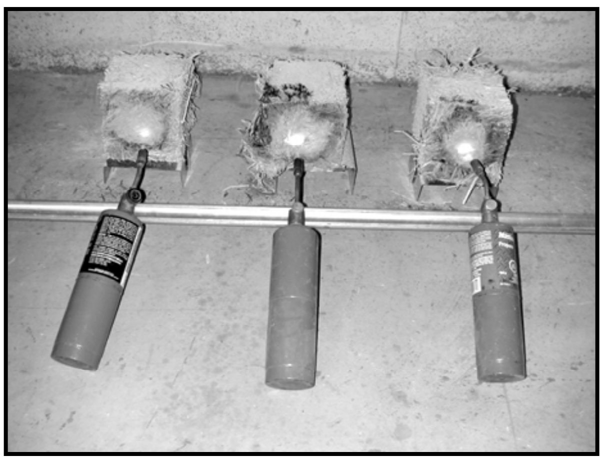


210 mins

Sample 1: charring @ 210 mins

Sample 2: charring @ 210mins

Sample 3: charring @ 210mins



240 mins

Sample1 charring@240mins

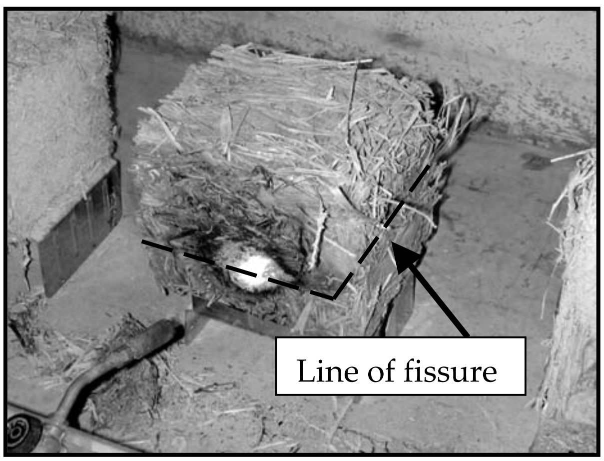
Sample 2 charring@240mins

Sample 3 charring @ 240mins

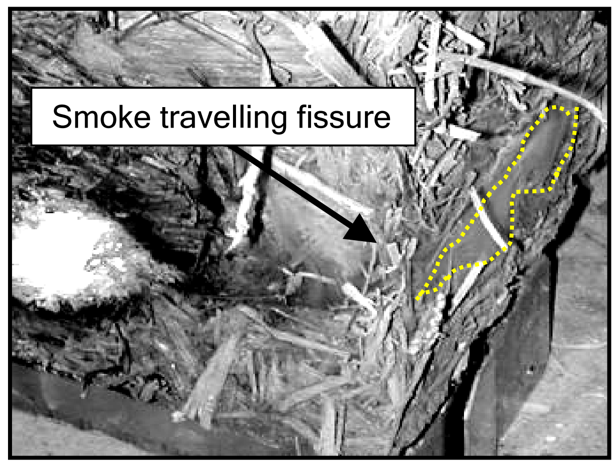
Fire Resistance :
Series B -720-800 Kg./m³ & 950 Kg./m³

start

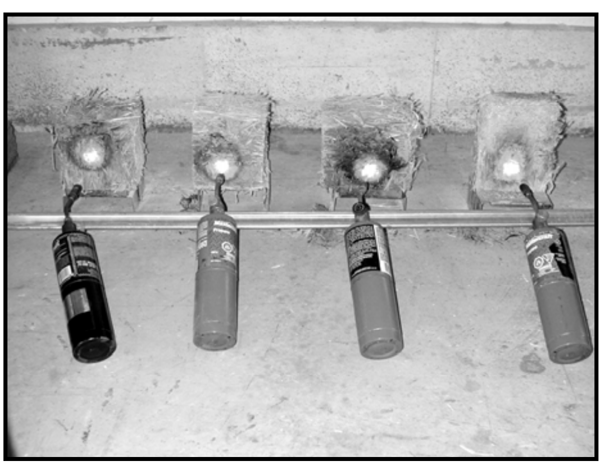
15mins



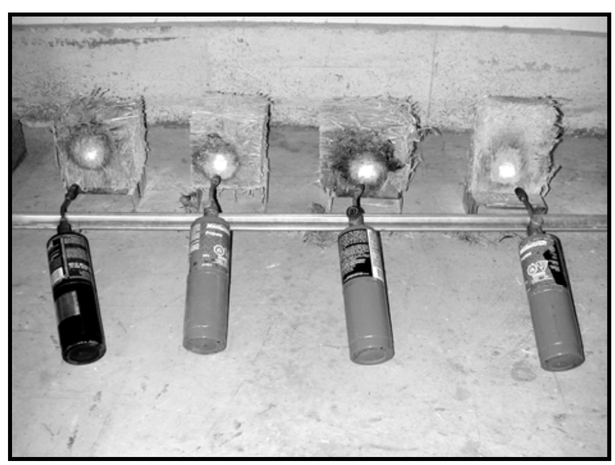
Smoke travelling fissure at 15mins



Detail of smoke travelling fissure



30mins

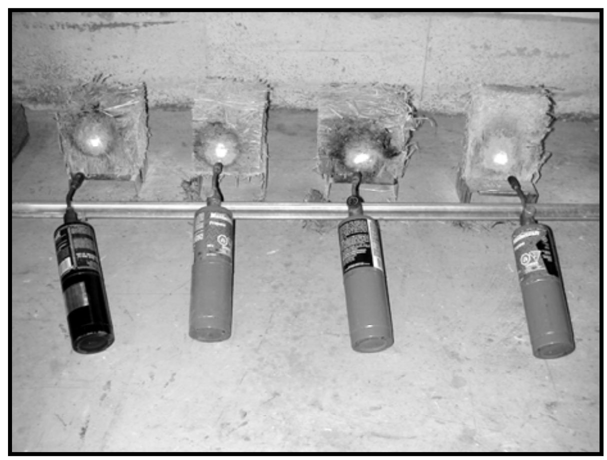


60mins

90mins

150mins

210mins



240mins

Conclusions:

There are several conclusions, which can be drawn based on the test data and literature review.

General

1.) Where data was available for comparison from Minkes text, the testing results from this program were generally in agreement with Minke. That is to say most of the observed slopes and curves essentially matched. The value differences are presumably due to the non-homogenous nature of the material.

2.) Based on this excellent agreement, the data presented here demonstrates the effectiveness of a hybridized field/laboratory approach to the testing of these materials. This economic streamlining is beneficial for non-proprietary materials analysis.

3.) Fire testing based on ASTM standards E 119 and E 84 would very likely meet the conditions of acceptance for a fire resistance period of four hours.

4.) The settlement of straw clay requires remedial work after the settling. This increases the labor input of these walls. One technique to eliminate this has been developed by Robert Laporte, and uses a bamboo matrix throughout the wall. Conversely, preformed blocks can be used which would also eliminate this problem.

5.) The most easily achieved densities were in the range of 640-720 kg/m^3. Lighter and heavier densities are achievable, however, this requires significant experience with the specific local materials in order to consistently reach target densities.

6.) The versatility of straw light clay is advantageous, enabling the material to be used for interior partitions. Moreover, if one were to increase the thickness of the typical 300 mm wall to the 450 mm thickness typical of strawbales, the RSI values would essentially match.

7.) SLC, made on site by an owner-builder, eliminates manufacturing, transportation and waste associated with conventional building products

8.) This building technique builds communities. As it is fairly labor intensive, many hands make the work go quickly. Only a few, inexpensive tools are needed, and little construction experience required. This enables participation by a broad range of people.

Moisture Properties

1.) Straw light clay, in combination with earth or lime-based plasters can play a significant role in balancing interior humidity levels.

2.) Straw light clay has a very high vapor permeability rating (a low vapor diffusion resistance value), allowing this material to release moisture via vapor diffusion rapidly. This allows for fast drying. Plasters that also exhibit a high vapor permeance, e.g. earth, or lime-based plasters, are therefore the most desirable surface finishes for SLC. Earth-based plasters, for example, can have a permeance of over 1200 metric perms (over 20 US perms) which is similar to many housewraps and building papers.

3.) Although SLC has a very large moisture storage capacity, the application of a vapor diffusion retarder may compromise the ability of straw light clay to release moisture quickly enough to maintain moisture levels below the safe moisture storage capacity of SLC

4.) The fact that liquid transport is available as a mechanism to redistribute moisture and that SLC has very high moisture storage capacity results in a material that can be used in a flow-through wall assembly design.

5.) A full sorption isotherm curve, with a pressure plate apparatus used to continue the curve through the free saturation region, would facilitate a more detailed analysis of the moisture storage properties of SLC. The data generated, in turn, could be used in a finite element hygrothermal computer simulation resulting in a curve displaying moisture adsorption over time.

Thermal Properties

1.) The thermal resistance of straw light clay is (R-19 for a 300 mm thick wall). This meets the minimum thermal resistance value prescribed in the Ontario Building Code. Furthermore, due to the lack of thermal bridging in typical SLC wall assemblies, a whole wall R-value calculation will be closer to the calculated R-value than more "conventional" products.

2.) Based upon the literature review, it is likely that the R- value can be increased with the use of other aggregates. Sawdust is the preferred aggregate of many German practitioners.

3.) In regions with large diurnal temperature swings, the thermal mass of SLC is able to store heat during periods of high temperature, and then release this heat during cooler periods.

Structural Properties

1.) Straw light clay is a highly ductile material, and as such has potential to absorb a fair amount of energy in the event of seismic activity.

2.) Reaching target densities is challenging given the variability of materials and workmanship. A fair degree of experience with specific, local materials is required to consistently and predictably reach both lighter and heavier density ranges. The mid- range density class is the most easily obtained.

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Appendices

Appendices

Appendix A: Application to Enclosure Wall Design

Application to Enclosure Wall Design

This section discusses in practical terms the findings of this report. The characteristics, and properties of SLC are a complex interrelationship of functions and mechanisms which work well when used and understood as a system.This holds true with all wall assemblies, and when one part of the system is ignored the whole system is compromised, leading to unnecessary degradation of material performance and durability.

There are several functions, which the design of a wall assembly must accommodate. Often, a system may handle several functions extraordinarily well, but it is rare to have a system that is capable of handling *all* of the following functions at optimum levels. Indeed there is no free lunch. For example, a material that is highly insulative can often be highly flammable. Building practitioners prioritize needs based on health and safety, climate, site, clients' wishes and budget.

Functions of enclosure walls in housing include:

1.) Support
2.) Heat control
3.) Air control
4.) Diffusion control
5.) Rain control
6.) Fire/smoke control
7.) Finish

In most SLC wall assemblies, it is assumed that a timber or other loadbearing structure will provide the support function. It is further assumed for this discussion that a plaster of earth or lime or a mixture of the two will provide the finish. Such plasters are both chemically and physically compatible with SLC [Minke 2000]. These finishes provide serve as air barriers, providing the majority of airflow control. They also assist in fire and rain control.

Airflow is controlled by the plaster skins which act as an air barrier. Attention to proper detailing around window and door openings, and at corners, ensures an effective air barrier is maintained.

Heat flow, is controlled by the insulation values measured in section 4 of this report. However, because the R-value is low relative to most commercial insulation, walls need to be thick (300 mm) in a typical application. SLC is very versatile, in that the wall thickness and the densities can be optimized for specific applications.

The moisture storage capacity at the exterior finish [Straube 2002] and the SLC (see section 6) would provide rain control. Allowing absorbed or penetrant rainwater to dry to the exterior and interior via vapor diffusion is critical to the success of such an assembly. In most cases protection, in the form of overhangs and topography will be needed to reduce the amount of rain deposition. A rain screen wall of board and batten is another option.

For interior wall applications, the heat flow and rain control functions are not of importance, but the excellent fire resistance properties exhibited by testing in chapter 8 will be beneficial.

The high water vapor permeability and storage capacity of SLC (i.e. high vapor diffusivity) means that changes in humidity will be moderated as the material takes on and releases vapor. This is described by some as a breathing wall, although this is a laypersons term. [deGraauw, Straube 2001]. These properties are also useful for the control of vapor diffusion. In cold weather, water vapor will diffuse from the interior to the exterior, provided that no low perm exterior plasters are used. This significantly reduces condensation and its attendant potential for damages such as mold, mildew, and rot. Similarly in warm weather water vapor will diffuse from the exterior to the interior, provided that no vapor diffusion retarders are used.

Appendix B: Recommendations

Recommendations:

Hygroscopic materials such as straw light clay require further study, in order to develop a more complete understanding of the full potential of the material. Several recommendations for further investigation are made below .

General

1.) Fire testing based on ASTM E119 and E 84 in order to obtain a fire resistance period in compliance with National and Provincial building codes.

2.) Material properties of other aggregate/"clay" combinations, such as wood chips, bullrush, hemp, and jerusalem artichoke stalk, should be investigated.

3.) As different clays (Kaolinite, Illite, Bentonite) are known to have different properties, an analysis of specific types of clay would determine their characteristics.

4.) An investigation into the additives and stabilisers referred to in German research.

5.) A structure built and monitored with a data logger to compile a real time actual condition profile of an SLC building envelope for cross referencing with a (WUFI) simulated model.

6.) Research into aspects of blockmaking such as: formwork, block consistency, drying conditions etc., would increase the climatic window of opportunity for building in Northern Climates as well as decreasing the amount of on-site labour.

Moisture Properties

The building envelope research community has made significant advances within the past decade in computational modeling of moisture transport in building materials. These programs are uniquely suited to examine the complex properties of hygroscopic materials, such as SLC.

1.) Investigation into the hygric processes which occur within straw clay building elements .By modeling dynamic moisture loading events with the aid of a computer program (such as WUFI or MATCHBOX) a deeper understanding of the hygric activity within SLC would be greatly facilitated.

2.) A Sorption Isotherm curve determined using controlled climate chambers as well as a pressure plate apparatus to determine the capillary moisture storage function resulting in a more detailed analysis of the sorptive properties of SLC.

3.) Full absorption and desorption curves plotted. This would illustrate the hysterises between the curves and enable a more detailed picture of capillary flow within SLC elements (prelim. To WUFI analysis) .

Thermal Properties

The thermal performance of a typical 300 mm SLC wall, meets the requirements of the Ontario Building Code. Further research into the thermal characteristics of SLC could be oriented towards the following:

1.) Investigating different aggregate/ binder combinations, with an emphasis on optimizing thermal performance.

2.) Thermal testing done on full scale wall assemblies in a guarded hot box. The results of theses tests could be compared to less expensive methods.

3.) Investigating what role (if any) thermal mass has with respect to Northern Climates. Some literature suggests having mass on the warm side of a building envelope during the heating season might reduce heating loads, whereas conventional theory states that without significant diurnal temperature swings the thermal mass benefits are negligible.

Structural

1.) An in depth testing program with many more samples (perhaps incorporating different aggregates) would provide a wider statistical spread with which to simulate and compute various loading events.

2.) Research into additives, which may increase the compressive and/or Bending strengths of SLC.

Appendix C:
Raw Data

C-1 Thermal

Calibration: 2" xps rigid insulation

	thick	k	C	R	Delta T	temp	Target Surface	
Temp out						**21.1**		
Ext Film			6.50	0.154	3.664		**3.78**	96.8%
						24.797	**24.93**	99.5%
Test Material	0.0518	0.0290	0.56	1.786	42.539		**42.50**	100.1%
		0.000				67.336	**67.43**	99.9%
Int Film			6.50	0.154	3.664			
						71.000		
T box						71.000		
Total				2.094		49.867		
					Heat Flow	**23.815**	**W/m2**	

c	w/m2k
r	m2k/w
C Ext Film	6.5

	Room Temp.	InSurf	OutSurf	Delta	Film	
Calibration A	23.30	67.10	27.00	40.10	3.80	0.031
Calibration B	21.10	69.80	25.00	44.80	3.80	0.029
Calibration C	19.00	65.40	22.80	42.60	3.75	0.030
Average	**21.13**	**67.43**	**24.93**	**42.50**	**3.78**	0.030

Thermal Resistance RSI/25.4 mm 0.8759 Rimp/inch 4.973

R- Value calculations; 30-35 pcf 480-560 kg/m³

	thick	k	C	R	Delta T	temp	Target Surface	
Temp out						**20.600**		
Ext Film			6.50	0.154	3.778		**3.77**	100.3%
						24.378	**24.37**	100.0%
Test Material	0.1500	0.0980	0.65	1.531	37.587		**37.63**	99.9%
						61.965	**62.00**	99.9%
Int Film			6.50	0.154	3.778			
						65.743		
T box						65.743		
Total				1.838		45.143		
					Heat Flow	**23.923**	**W/m2**	

	Room temp.	InSurf	OutSurf	Delta	Film	k	RSI	Rimpm/inch	heat flow
Sample A	20.50	63.40	26.20	37.20	5.70	0.149	0.17	1.0	
Sample B	19.10	60.30	21.80	38.50	2.70	0.068	0.37	2.1	
Sample C	22.20	62.30	25.10	37.20	2.90	0.076	0.33	1.87	
Average	**20.60**	**62.00**	**24.37**	**37.63**	**3.77**	**0.098**	**0.29**	**1.6**	

Thermal Resistance RSI/25.4 mm 0.2592 Rimp/inch 1.472 0.29 1.6

C-1 Thermal

R- Value calculations; 40-45 pcf

	thick	k	C	R	Delta T	temp	Target Surface	
Temp out						**20.700**		
Ext Film			6.50	0.154	3.843		**4.00**	96.1%
						24.543	**24.70**	99.4%
Test Material	0.1500	0.1080	0.72	1.389	34.695		**34.40**	100.9%
						59.238	**60.70**	97.6%
Int Film			6.50	0.154	3.843			
						63.081		
T box						63.081		
Total				1.697		42.381		
					Heat Flow	**24.134**	**W/m2**	

	Room Temp.	InSurf	OutSurf	Delta	Film		
Sample A	20.3	59.3	24.3	30.3	4.0	0.111	0.23
Sample B	18.7	61.1	22.3	38.8	3.6	0.090	0.28
Sample C	23.1	61.7	27.5	34.2	4.4	0.125	0.20
Average	**20.70**	**60.70**	**24.70**	**34.40**	**4.00**	0.108	0.24

Thermal Resistance	RSI/25.4 mm	0.2352	Rimp/inch	1.335	1.36

R- Value calculations; 50-55 pcf

	thick	k	C	R	Delta T	temp	Target Surface	
Temp out						**19.900**		
Ext Film			6.50	0.154	5.997		**6.00**	99.9%
						25.897	**25.90**	100.0%
Test Material	0.1500	0.1800	1.20	0.833	32.482		**32.50**	99.9%
						58.378	**58.40**	100.0%
Int Film			6.50	0.154	5.997			
						64.375		
T box						64.375		
Total				1.141		44.475		
					Heat Flow	**26.615**	**W/m2**	

	Room Temp.	InSurf	OutSurf	Delta	Film	
Sample A	19.90	58.40	25.90	32.50	6.00	0.180
Sample B						
Sample C						
Average	**19.9**	**58.4**	**25.9**	**32.5**	**6.00**	0.180

Thermal Resistance	RSI/25.4 mm	0.1411	Rimp/inch	0.801

k= Thickness/deltaT x C layer x deltaT layer
RSI= .0254/k
RSI x 5.678 = Rimp./in.
Heat flow = deltaT/ total R
C = k/thickness and 1/R
R = 1/C

480-560 kg/m³, 640- 720 kg/m³ and 800-880 kg./m³.(30-35 pcf ,40-45 pcf and 50-55 pcf

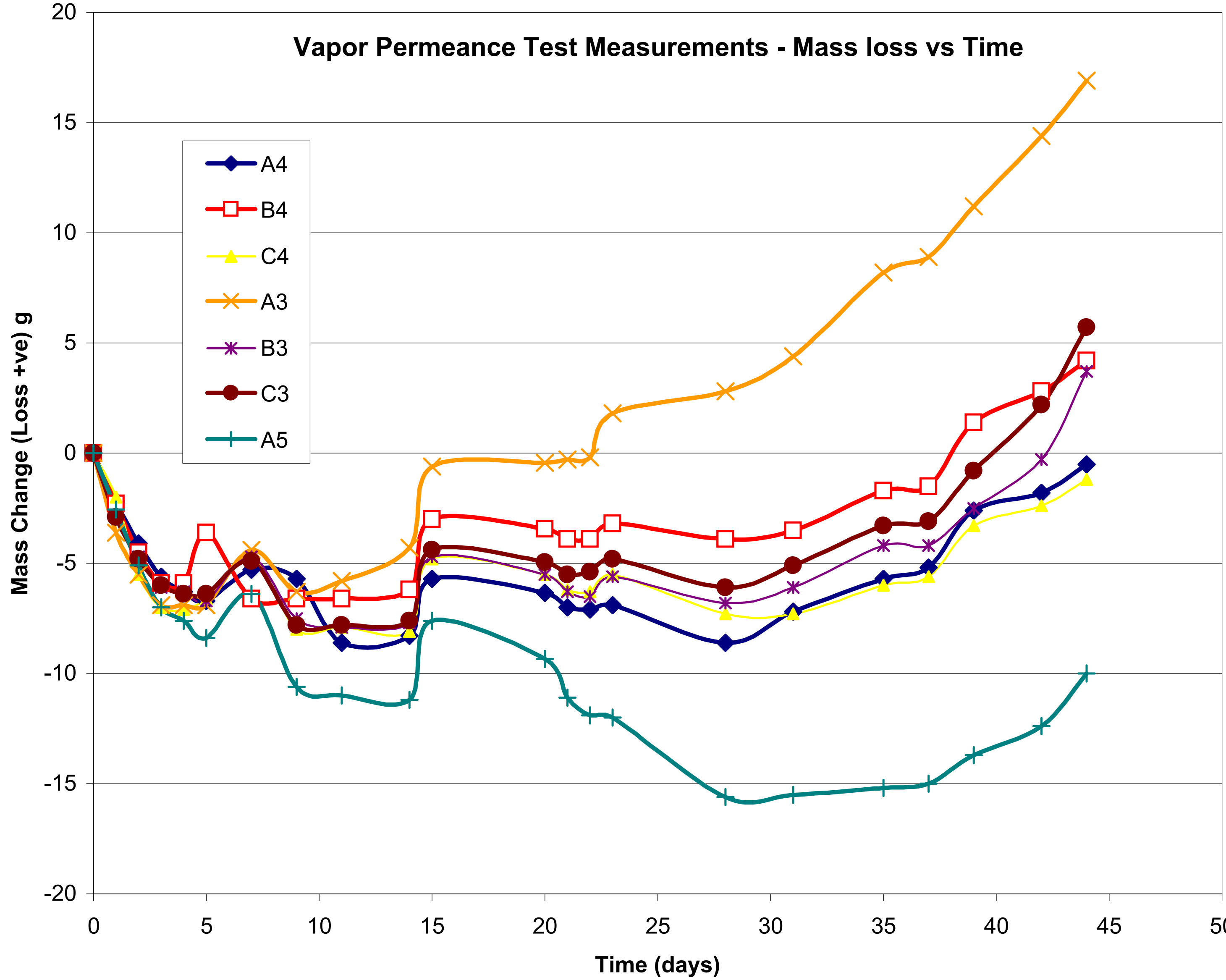
C-2 Vapor Permeability

		VAPOUR PERMEABILITY																
		40-45 lbs./cu.ft.			30-35 lbs/cu.ft.			55-65 lbs./cu.ft.										
Date	Temp.	A	B	C	A	B	C				days	A4	B4	C4	A3	B3	C3	A5
Dec. 15	16.7	5114.3	5319.3	5388.8	5341.2	4599.4	4522.1	6108.8	day0/week1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec. 16	17.0	5116.5	5321.6	5390.8	5344.8	4602.3	4525.0	6111.4			1.0	-2.2	-2.3	-2.0	-3.6	-2.9	-2.9	-2.6
Dec. 17	17.9	5118.4	5323.8	5394.3	5346.7	4604.1	4526.9	6113.9			2.0	-4.1	-4.5	-5.5	-5.5	-4.7	-4.8	-5.1
Dec. 18	15.0	5119.9	5325.2	5395.8	5348.1	4605.5	4528.1	6115.8			3.0	-5.6	-5.9	-7.0	-6.9	-6.1	-6.0	-7.0
Dec. 19	15.4	5120.6	5325.2	5395.9	5348.1	4605.7	4528.5	6116.4			4.0	-6.3	-5.9	-7.1	-6.9	-6.3	-6.4	-7.6
Dec. 20	16.5	5121.0	5322.9	5395.4	5348.1	4606.1	4528.5	6117.2			5.0	-6.7	-3.6	-6.6	-6.9	-6.7	-6.4	-8.4
Dec. 22	18.0	5119.6	5325.9	5393.5	5345.6	4604.1	4527.0	6115.2	day7/ week2		7.0	-5.3	-6.6	-4.7	-4.4	-4.7	-4.9	-6.4
Dec. 24	18.4	5120.0	5325.9	5396.8	5347.5	4606.9	4529.9	6119.4			9.0	-5.7	-6.6	-8.0	-6.3	-7.5	-7.8	-10.6
Dec. 26	16.9	5122.9	5325.9	5396.7	5347.0	4607.3	4529.9	6119.8			11.0	-8.6	-6.6	-7.9	-5.8	-7.9	-7.8	-11.0
Dec. 29	18.8	5122.6	5325.5	5396.9	5345.5	4607.1	4529.7	6120.0			14.0	-8.3	-6.2	-8.1	-4.3	-7.7	-7.6	-11.2
Dec. 30	16.3	5120.0	5322.3	5393.6	5341.8	4604.1	4526.5	6116.4			15.0	-5.7	-3.0	-4.8	-0.6	-4.7	-4.4	-7.6
fudge avei	17.2	5120.7	5322.8	5394.3	5341.7	4604.9	4527.1	6118.2			20.0	-6.3	-3.4	-5.5	-0.5	-5.5	-4.9	-9.3
Jan. 05	18.0	5121.3	5323.2	5395.0	5341.5	4605.7	4527.6	6119.9	day21/week3		21.0	-7.0	-3.9	-6.2	-0.3	-6.3	-5.5	-11.1
Jan. 06	19.6	5121.4	5323.2	5395.1	5341.4	4605.9	4527.5	6120.7			22.0	-7.1	-3.9	-6.3	-0.2	-6.5	-5.4	-11.9
Jan. 07	17.8	5121.2	5322.5	5394.3	5339.4	4605.0	4526.9	6120.8			23.0	-6.9	-3.2	-5.5	1.8	-5.6	-4.8	-12.0
Jan. 12	23.0	5122.9	5323.2	5396.1	5338.4	4606.2	4528.2	6124.4	day28/week4		28.0	-8.6	-3.9	-7.3	2.8	-6.8	-6.1	-15.6
Jan. 15	19.4	5121.5	5322.8	5396.1	5336.8	4605.5	4527.2	6124.3			31.0	-7.2	-3.5	-7.3	4.4	-6.1	-5.1	-15.5
Jan. 19	19.4	5120.0	5321.0	5394.8	5333.0	4603.6	4525.4	6124.0	day35/week5		35.0	-5.7	-1.7	-6.0	8.2	-4.2	-3.3	-15.2
Jan. 21	19.6	5119.5	5320.8	5394.4	5332.3	4603.6	4525.2	6123.8			37.0	-5.2	-1.5	-5.6	8.9	-4.2	-3.1	-15.0
Jan. 23	20.2	5116.9	5317.9	5392.1	5330.0	4601.9	4522.9	6122.5			39.0	-2.6	1.4	-3.3	11.2	-2.5	-0.8	-13.7
Jan. 26	21.0	5116.1	5316.5	5391.2	5326.8	4599.7	4519.9	6121.2	day42/week6		42.0	-1.8	2.8	-2.4	14.4	-0.3	2.2	-12.4
Jan.28	21.0	5114.8	5315.1	5390.0	5324.3	4595.7	4516.4	6118.8			44.0	-0.5	4.2	-1.2	16.9	3.7	5.7	-10.0
Feb.03	21.2	5114.8	5314.0	5389.3	5319.4	4595.7	4516.0	6117.3	day50/week7		50.0	-0.5	5.3	-0.5	21.8	3.7	6.1	-8.5
Feb.05	20.0	5110.0	5309.4	5385.4	5314.9	4592.2	4512.3	6113.2			52.0	4.3	9.9	3.4	26.3	7.2	9.8	-4.4
Feb.09	21.9	5107.6	5306.7	5383.2	5311.4	4589.7	4510.0	6111.0			56.0	6.7	12.6	5.6	29.8	9.7	12.1	-2.2
Feb.11	18.2	5106.5	5305.3	5381.5	5309.1	4588.4	4508.5	6109.5	day58/week8		58.0	7.8	14.0	7.3	32.1	11.0	13.6	-0.7
Feb. 13	19.4	5105.5	5304.3	5380.6	5308.3	4587.5	4508.1	6108.7	day60	slope		0.510	0.530	0.406	0.877	0.591	0.692	0.317

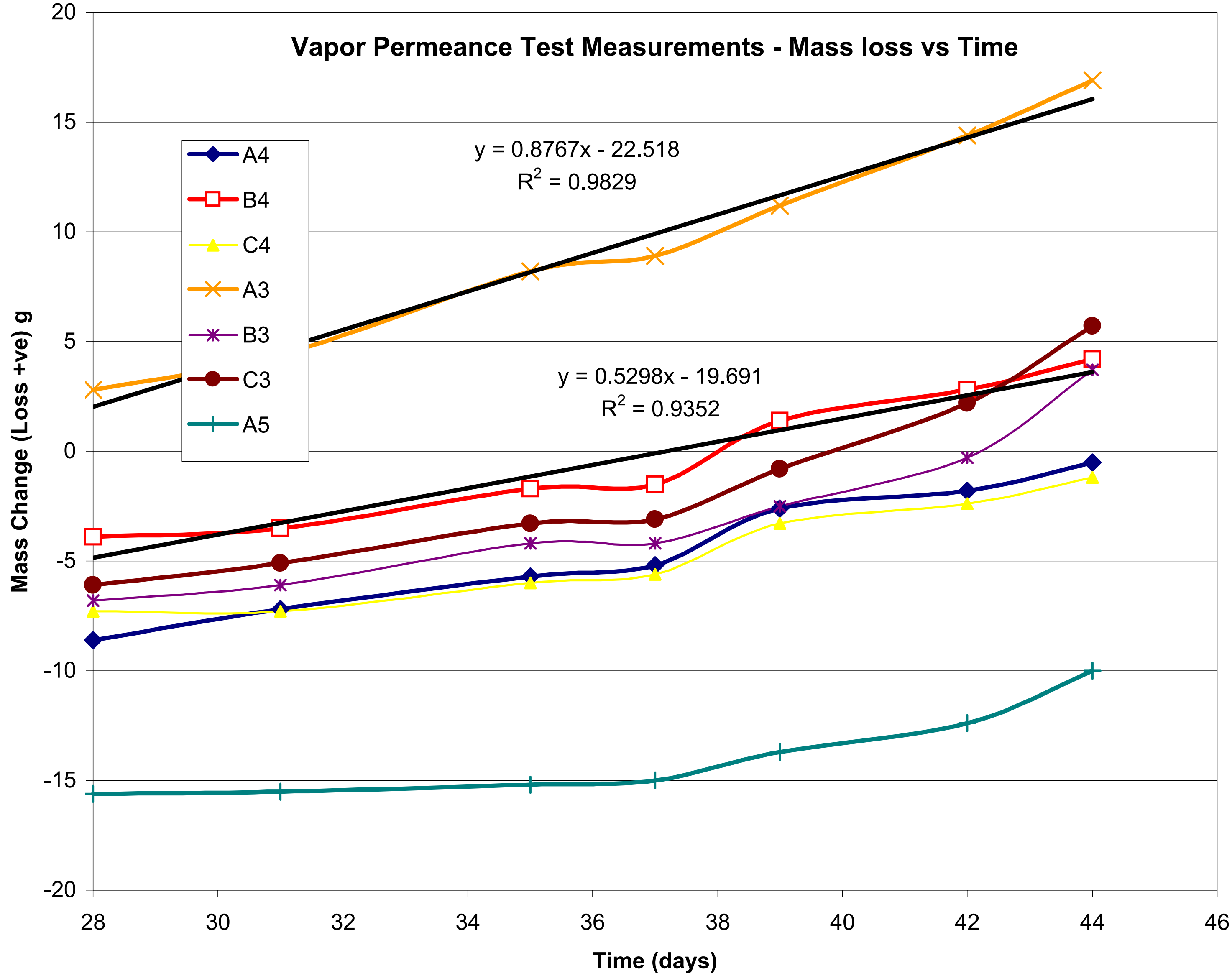
	Water	Box	DeltaP (Pa)
Avg T	20	20	
Avg RH	100	75	
Avg VP	2339	1754	585

	A4	B4	C4	A3	B3	C3	A5
Water VP	2339	2339	2339	2339	2339	2339	2339
Box VP	1754	1754	1754	1754	1754	1754	1754
Delta VP	585	585	585	585	585	585	585
Area (m2)	0.02322	0.02322	0.02322	0.02322	0.02322	0.02322	0.02322
Loss (ng/s)	5898	6132	4702	10147	6841	8014	3668
Perm (ng/sm2Pa)	434	451	346	747	504	590	270
Permeability (ng/smPa)	44.1	45.9	35.2	75.9	51.2	59.9	27.4

C-2 Vapor Permeability



C-2 Vapor Permeability



C-3 Moisture Storage

SORPTION ISOTHERM

Date	Temp.	40-45 lbs./cu.ft. A	40-45 lbs./cu.ft. B	40-45 lbs./cu.ft. C	30-35 lbs/cu.ft. A	30-35 lbs/cu.ft. B	30-35 lbs/cu.ft. C	55-65 lbs./cu.ft
Dec. 17*	17.9	413.3	421.1	425.3	452.3	368.2	423.2	763.7
Dec. 17		401.7	410.2	415.4	441.8	358.5	410.7	748.3
Dec. 17**		393.5	414.2	414.5	441.2	357.4	408.1	748.3
Dec. 18	16.0	398.5	408.4	418.8	446.2	361.4	412.8	753.2
Dec. 19	15.4	400.8	410.6	420.8	448.3	363.4	415.5	756.4
Dec. 20	16.5	401.4	411.7	422.7	449.3	364.1	417.6	759.2
Dec. 22	18.0	402.7	412.2	422.3	451.1	364.5	417.2	761.2
Dec. 24	18.4	402.8	412.9	423.0	451.5	365.0	418.0	762.3
Dec. 26	16.9	403.1	413.4	423.4	451.8	365.4	418.3	762.9
Dec. 29	18.8	403.0	413.4	423.2	451.9	365.5	418.4	763.2
Dec. 30	16.3	402.9	413.5	422.9	451.7	365.4	418.3	762.8
Jan. 05	18.0	404.2	414.4	423.9	453.0	366.0	419.3	764.6
Jan. 06	20.5	405.4	415.3	424.5	454.0	367.2	420.6	
Jan. 08	20.0	405.5	415.5	425.0	454.4	367.2	420.8	

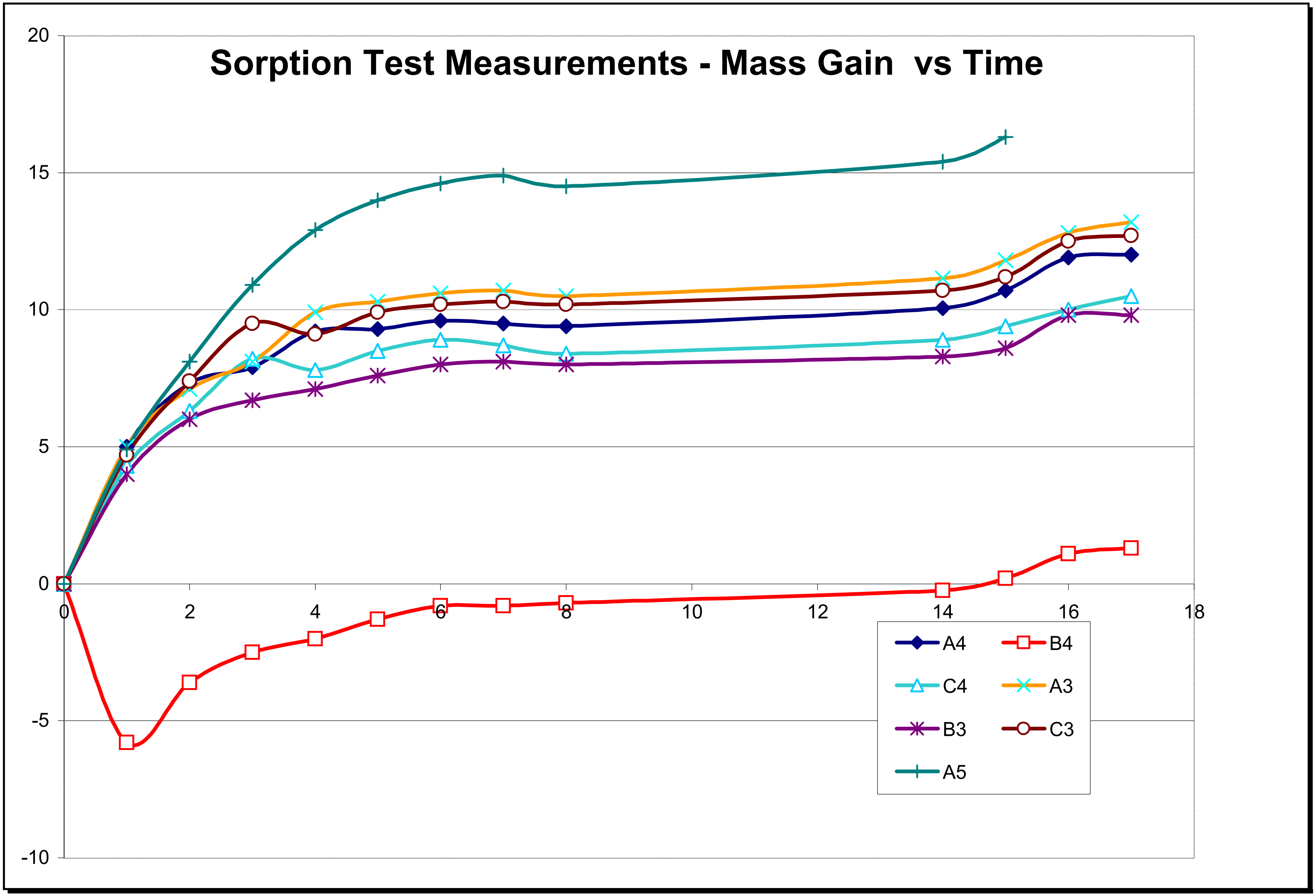
* Room Dry Density

** Final Oven Dry Density

C-3 Moisture Storage

Days	A4	B4	C4	A3	B3	C3	A5	A4	B4	C4	A3	B3	C3	A5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	5.0	-5.8	4.3	5.0	4.0	4.7	4.9	1.3	-1.4	1.0	1.1	1.1	1.2	0.7
2.0	7.3	-3.6	6.3	7.1	6.0	7.4	8.1	1.9	-0.9	1.5	1.6	1.7	1.8	1.1
3.0	7.9	-2.5	8.2	8.1	6.7	9.5	10.9	2.0	-0.6	2.0	1.8	1.9	2.3	1.5
4.0	9.2	-2.0	7.8	9.9	7.1	9.1	12.9	2.3	-0.5	1.9	2.2	2.0	2.2	1.7
5.0	9.3	-1.3	8.5	10.3	7.6	9.9	14.0	2.4	-0.3	2.1	2.3	2.1	2.4	1.9
6.0	9.6	-0.8	8.9	10.6	8.0	10.2	14.6	2.4	-0.2	2.1	2.4	2.2	2.5	2.0
7.0	9.5	-0.8	8.7	10.7	8.1	10.3	14.9	2.4	-0.2	2.1	2.4	2.3	2.5	2.0
8.0	9.4	-0.7	8.4	10.5	8.0	10.2	14.5	2.4	-0.2	2.0	2.4	2.2	2.5	1.9
14.0	10.1	-0.3	8.9	11.2	8.3	10.7	15.4							
15.0	10.7	0.2	9.4	11.8	8.6	11.2	16.3	2.7	0.0	2.3	2.7	2.4	2.7	2.2
16.0	11.9	1.1	10.0	12.8	9.8	12.5		3.0	0.3	2.4	2.9	2.7	3.1	
17.0	12.0	1.3	10.5	13.2	9.8	12.7		3.0	0.3	2.5	3.0	2.7	3.1	
Equlibrium Moisture Content														
Day 8	**2.39%**	**-0.17%**	**2.03%**	**2.38%**	**2.24%**	**2.50%**	**1.94%**							
		outlier												

C-3 Moisture Storage



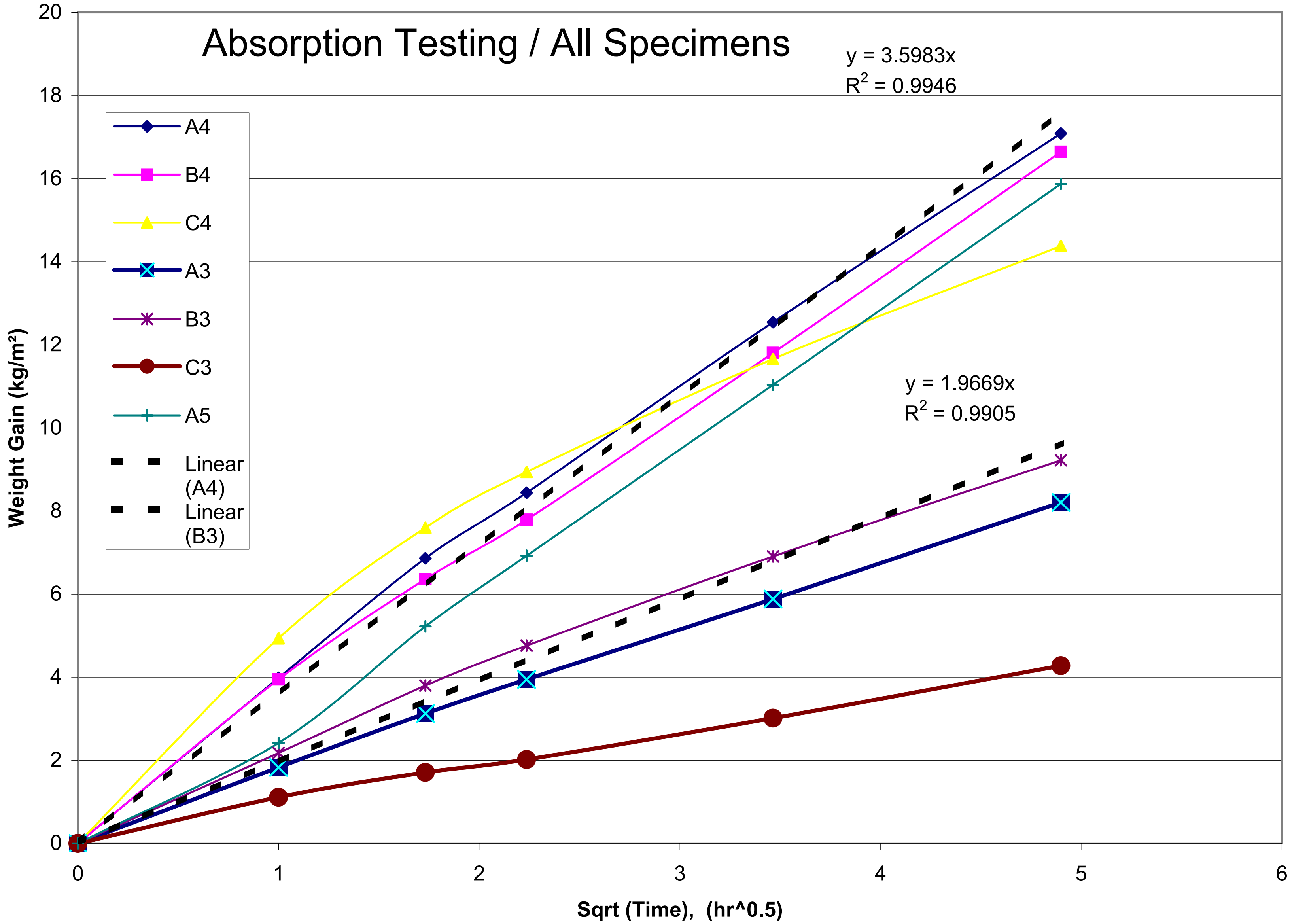
C-4 Capillarity

		CAPILLARITY							
		40-45 lbs./cu.ft.			30-35 lbs/cu.ft.			60-65 lbs./cu.ft.	
Date	**Temp.**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	
Dec. 15	16.7	2706.9	2276.2	2591.6	2198.7	2352.7	2321.6	3408.9	
Dec. 16	17.0	2945.6	2504.8	2963.0	2317.3	2498.1	2739.7	3870.9	
Dec. 17	17.9	3035.1	2597.0	3045.5	2364.2	2555.0	2877.0	4035.9	
Dec. 18	15.0	3082.5	2635.3	3072.1	5348.1	2580.4	2959.9	4118.4	outlier
Dec. 19	15.4	3117.0	2658.2	3082.5	5348.1	2594.7	3016.2	4173.9	
Dec. 20	16.5	3149.4	2676.5	3089.2	5348.1	2605.4	3056.5	4221.2	
Dec. 22	18.0	3183.0	2704.1	3099.2	5345.6	2621.2	3105.5	4298.5	
Dec. 24	18.4	3200.5	2721.5	3113.1	5347.5	2633.0	3130.1	4372.6	
Dec. 26	16.9	3210.8	2733.9	3115.1	5347.0	2638.5	3139.9	4420.7	
Dec. 29	18.8	3213.7	2741.6	3116.1	5345.5	2643.5	3139.5	4460.5	
Dec. 30	16.3	3211.7	2739.8	3113.5	5341.8	2641.4	3130.3	4467.3	
Jan. 05	18.0	3213.0	2745.5	3117.6	5341.5	2640.3	3035.3	4494.4	
Jan. 06	19.6	3198.5	2737.5	3113.3	5341.4	2633.6	3013.0	4498.1	
Jan. 07	17.8	3178.3	2731.9	3111.5	5339.4	2628.1	2981.2	4502.6	
24 Hour		2635.2	2202.3	2530.3	2114.0	2273.0	2236.3	3364.3	***Oven Dry Density**
	Start	2651.1	2215.9	2537.8	2131.1	2290.3	2259.8	3366.1	***Room Dry Density**
	1 Hour	2743.6	2307.6	2652.5	2173.6	2340.9	2285.6	3422.3	
	3 Hour	2810.5	2363.6	2714.2	2203.7	2378.5	2299.5	3487.4	
	5 Hour	2847.1	2396.8	2745.4	2222.8	2400.9	2306.7	3526.9	
	12 Hour	2942.4	2490.0	2808.5	2267.7	2450.7	2329.8	3622.4	
	24 Hour	3047.9	2602.4	2871.7	2321.7	2504.4	2359.1	3734.7	
		45.3	37.8	52.84	36.34	39.08	38.45	57.8	

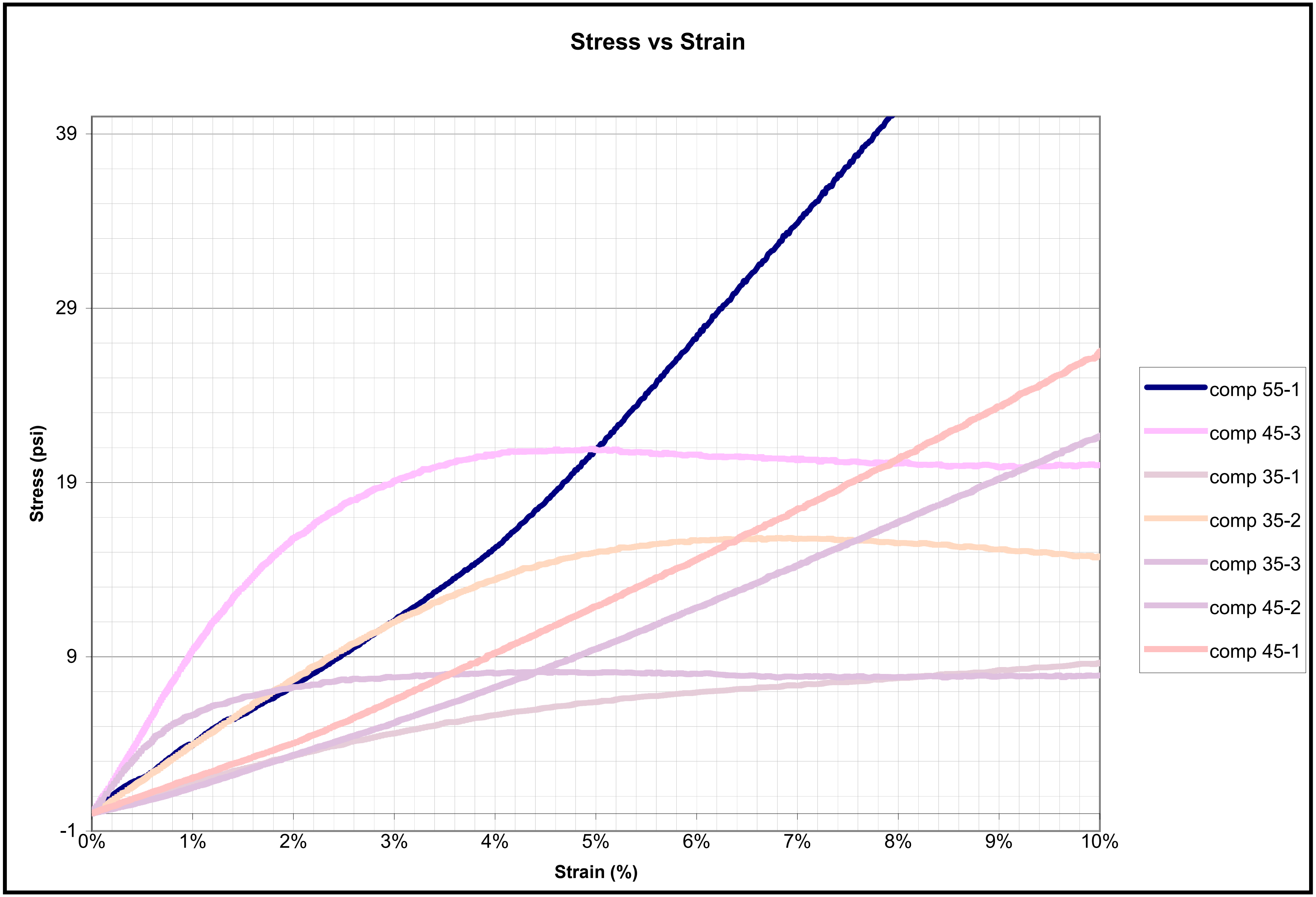
C-4 Capillarity

		Sqrt	A4	B4	C4	A3	B3	C3	A5
	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	1.00	3.98	3.95	4.94	1.83	2.18	1.11	2.42
	3	1.73	6.86	6.36	7.60	3.13	3.80	1.71	5.22
	5	2.24	8.44	7.79	8.94	3.95	4.76	2.02	6.93
	12	3.46	12.55	11.80	11.66	5.88	6.91	3.01	11.04
	24	4.90	17.09	16.65	14.38	8.21	9.22	4.28	15.87
Slope		w (kg/m2h0.5)	3.598	3.441	3.309	1.704	1.967	0.888	3.177
		w (kg/m2s0.5)	0.05997	0.05734	0.05516	0.02840	0.03278	0.01481	0.05295

C-4 Capillarity



C-5 Compression



C-5 Compression (35-1)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

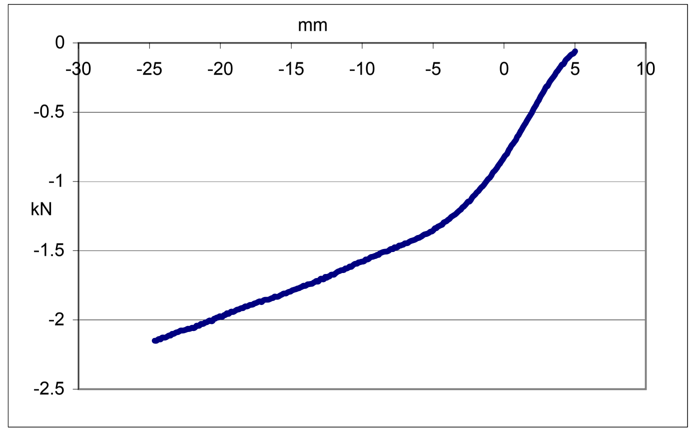
Data Header: Strawclay comp test 35 pcf | Time: 142.7524 Sec | ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

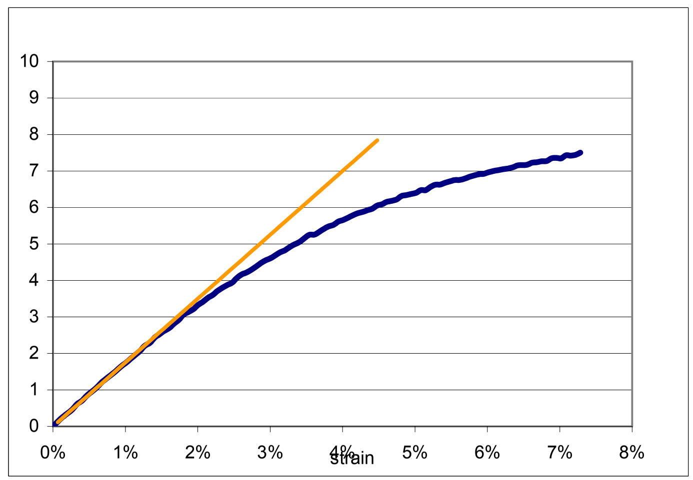
Time	Axial Displ	Axial Force					
Sec	mm	kN	Displacement	Mpa	Strain%	Stress(psi)	Fit Line
0.260254	5.014923	-0.05989					
0.510254	4.914567	-0.07492					
0.760254	4.814798	-0.08115					
1.010254	4.708506	-0.08609					
1.260254	4.609949	-0.09809					
1.510254	4.50769	-0.11022					
1.760254	4.403894	-0.11772					
2.010254	4.302295	-0.13214					
2.260254	4.201864	-0.15284					
2.510254	4.097086	-0.15595					
2.760254	3.996847	-0.16968					
3.010254	3.895723	-0.1834					
3.260254	3.790974	-0.2008					
3.510254	3.691088	-0.21222					
3.760254	3.593111	-0.22984					
4.010254	3.488128	-0.2463					
4.260254	3.384635	-0.2589					
4.510254	3.284846	-0.27281					
4.760254	3.184238	-0.28845					
5.010254	3.081383	-0.31091					
5.260254	2.978205	-0.31497	0.00	0.00	0.00%	0	
5.510254	2.877181	-0.33569	0.10	0.00	0.07%	0.131109	0.116005
5.760254	2.772668	-0.35613	0.21	0.00	0.13%	0.260511	0.236017
6.010254	2.670659	-0.37192	0.31	0.00	0.20%	0.360429	0.353154
6.260254	2.569946	-0.38822	0.41	0.00	0.27%	0.463598	0.468802
6.510254	2.470585	-0.41153	0.51	0.00	0.33%	0.611151	0.582897
6.760254	2.367892	-0.42597	0.61	0.00	0.40%	0.702548	0.700818
7.010254	2.26717	-0.44813	0.71	0.01	0.47%	0.842747	0.816478
7.260254	2.163291	-0.46487	0.81	0.01	0.53%	0.948697	0.935761
7.510254	2.060525	-0.48216	0.92	0.01	0.60%	1.05816	1.053767
7.760254	1.958893	-0.50454	1.02	0.01	0.67%	1.19979	1.17047
8.010254	1.859507	-0.52114	1.12	0.01	0.73%	1.304891	1.284594
8.260254	1.75647	-0.53749	1.22	0.01	0.80%	1.408326	1.402911
8.510254	1.655725	-0.5545	1.32	0.01	0.87%	1.515989	1.518596
8.760254	1.552701	-0.57296	1.43	0.01	0.94%	1.632838	1.636898
9.010254	1.449363	-0.58921	1.53	0.01	1.00%	1.735705	1.75556
9.260254	1.345945	-0.6077	1.63	0.01	1.07%	1.852713	1.874314
9.510254	1.246346	-0.62443	1.73	0.01	1.14%	1.958598	1.988683
9.760254	1.146681	-0.64171	1.83	0.01	1.20%	2.067955	2.103128
10.01025	1.040119	-0.66451	1.94	0.02	1.27%	2.212311	2.225493
10.26025	0.940699	-0.67649	2.04	0.02	1.34%	2.28811	2.339656
10.51025	0.839984	-0.69905	2.14	0.02	1.40%	2.430919	2.455306

Area 23225.76

	x	y
Point 1	0.07	0.13111
Point 2	1.4	2.43
	1.7	points
	1.75	tweak

Compressive Strength, (MPa)	0.04	strength @
(psi)	6.4	
Modulus of Elasticity (MPa)	1.19	
(psi)	175	





C-5 Compression(35-2)

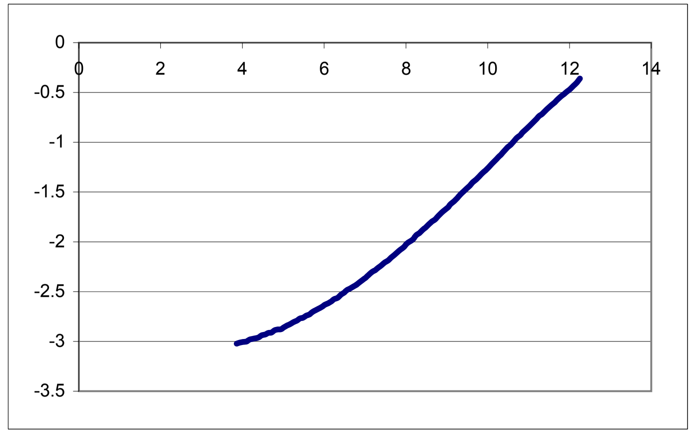
MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

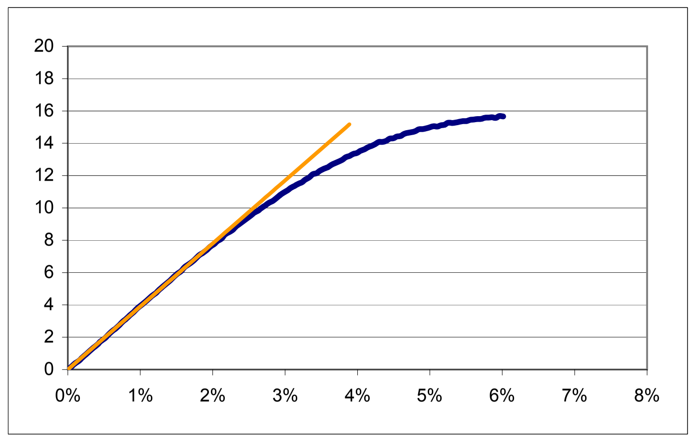
Data Header: Strawclay comp test 35 pcf Time: 162.1038 Sec ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

Time	Axial Displ	Axial Force					
Sec	mm	kN	Displacement	Mpa	Strain%	Stress(psi)	Fit Line
0.259521	12.25706	-0.36044					
0.509521	12.17926	-0.40229					
0.759521	12.10046	-0.43189					
1.009522	12.02636	-0.46256					
1.259522	11.9503	-0.48647					
1.509522	11.87055	-0.51528					
1.759522	11.79483	-0.538					
2.009522	11.71798	-0.56689					
2.259522	11.64219	-0.59935					
2.509522	11.56517	-0.62586					
2.759522	11.48655	-0.65376	0.0	0	0.00%	0	0
3.009522	11.41035	-0.68247	0.1	0.001236	0.05%	0.181712	0.19499
3.259522	11.33192	-0.71492	0.2	0.002633	0.10%	0.387063	0.395702
3.509522	11.25345	-0.73803	0.2	0.003628	0.15%	0.533317	0.596508
3.759522	11.1784	-0.77266	0.3	0.005119	0.20%	0.752488	0.78856
4.009522	11.10151	-0.80299	0.4	0.006425	0.25%	0.944464	0.985326
4.259522	11.02518	-0.83599	0.5	0.007846	0.30%	1.153322	1.180666
4.509522	10.94691	-0.86632	0.5	0.009152	0.35%	1.345338	1.380951
4.759522	10.86882	-0.89575	0.6	0.010419	0.41%	1.531559	1.580795
5.009522	10.79225	-0.9309	0.7	0.011932	0.46%	1.75403	1.776737
5.259522	10.71698	-0.95529	0.8	0.012982	0.50%	1.908425	1.969369
5.509522	10.63863	-0.99152	0.8	0.014542	0.56%	2.137704	2.169877
5.759522	10.56449	-1.02478	0.9	0.015974	0.61%	2.348197	2.359605
6.009522	10.48607	-1.05146	1.0	0.017123	0.66%	2.51712	2.560278
6.259522	10.41	-1.08472	1.1	0.018555	0.71%	2.727594	2.754943
6.509522	10.3283	-1.12319	1.2	0.020212	0.76%	2.971105	2.964023
6.759522	10.25435	-1.15204	1.2	0.021454	0.81%	3.153708	3.15325
7.009522	10.18023	-1.18382	1.3	0.022822	0.86%	3.354821	3.342937
7.259522	10.0997	-1.21664	1.4	0.024235	0.91%	3.562558	3.549023
7.509522	10.02453	-1.25199	1.5	0.025757	0.96%	3.786292	3.741385
7.759522	9.946928	-1.28173	1.5	0.027037	1.01%	3.974503	3.939967
8.009522	9.871273	-1.31019	1.6	0.028263	1.06%	4.154621	4.133573
8.259522	9.792152	-1.34306	1.7	0.029678	1.11%	4.362658	4.336047
8.509522	9.717403	-1.37374	1.8	0.030999	1.16%	4.556865	4.527333
8.759522	9.639424	-1.39976	1.8	0.032119	1.21%	4.721564	4.726886
9.009522	9.561882	-1.43586	1.9	0.033674	1.26%	4.950014	4.925321
9.259522	9.484919	-1.46606	2.0	0.034974	1.31%	5.14114	5.122275
9.509522	9.408746	-1.49504	2.1	0.036222	1.36%	5.324598	5.317205
9.759522	9.332146	-1.52455	2.2	0.037492	1.41%	5.511386	5.513229
10.00952	9.255445	-1.55966	2.2	0.039004	1.46%	5.733568	5.709512
10.25952	9.178682	-1.59251	2.3	0.040418	1.51%	5.941502	5.90595
10.50952	9.099561	-1.61746	2.4	0.041492	1.57%	6.099395	6.108427

Area 23225.76

	x	y		
Point 1	0.05	0.18171	Compressive Strength, (MPa)	0.10
Point 2	1.06	4.15462	(psi)	14.9
	3.9	points	Modulus of Elasticity (MPa)	2.65
	3.90	guess	(psi)	390



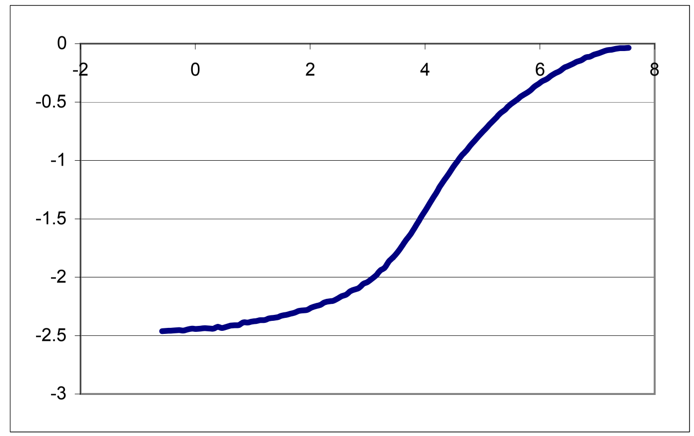


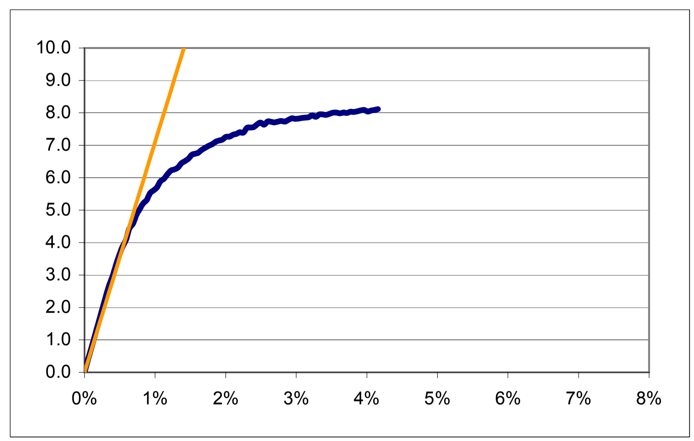
C-5 Compression (35-3)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header:		Strawclay comp test 35 pcf	Time:	127.8638 Sec		########
Data Acqu	Timed					
Station Na	Basic1.cfg					
Test File N	Thornton-March2004.tst					
Time	Axial Displ	Axial Force				
Sec	mm	kN	Displacement	Mpa	Strain%	Stress(psi) Fit Line
0.259521	7.545902	-0.03563				
0.509521	7.472271	-0.03817				
0.759521	7.39637	-0.03812				
1.009522	7.319169	-0.04325				
1.259522	7.247485	-0.0528				
1.509522	7.17227	-0.05656				
1.759522	7.096591	-0.06813				
2.009522	7.024052	-0.08165				
2.259522	6.948322	-0.09342				
2.509522	6.873406	-0.111				
2.759522	6.799685	-0.118				
3.009522	6.725623	-0.14191				
3.259522	6.650311	-0.15413				
3.509522	6.574759	-0.1722				
3.759522	6.501435	-0.18944				
4.009522	6.425036	-0.20635				
4.259522	6.350761	-0.23271				
4.509522	6.275694	-0.25147				
4.759522	6.202156	-0.27346				
5.009522	6.127697	-0.2999				
5.259522	6.053467	-0.31759				
5.509522	5.979366	-0.3442				
5.759522	5.904614	-0.36717				
6.009522	5.831303	-0.40133				
6.259522	5.754339	-0.42626				
6.509522	5.68009	-0.44811				
6.759522	5.606479	-0.47874				
7.009522	5.534614	-0.50322				
7.259522	5.458623	-0.53314				
7.509522	5.384657	-0.56899				
7.759522	5.307424	-0.59874				
8.009522	5.2333	-0.63743				
8.259522	5.157716	-0.67467				
8.509522	5.086516	-0.71173				
8.759522	5.011322	-0.74973				
9.009522	4.93556	-0.7898				
9.259522	4.864479	-0.83135				
9.509522	4.786953	-0.87439				
9.759522	4.713885	-0.91961				
10.00952	4.638913	-0.95698				
10.25952	4.562454	-1.00809				
10.50952	4.487571	-1.05815				

Area	23225.76			
	x	y		
Point 1	0.048995	0.403135	Compressive Strength, (MPa)	0.05
Point 2	1.175015	6.110019	(psi)	8.1
	5.1	from points	Modulus of Elasticity (MPa)	4.83
	7.10	guess	(psi)	710



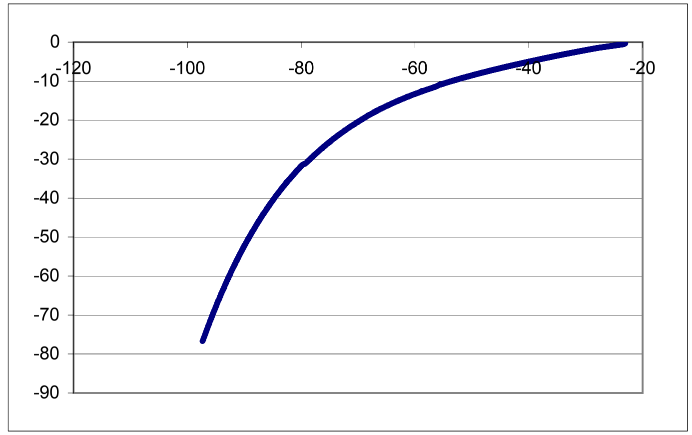


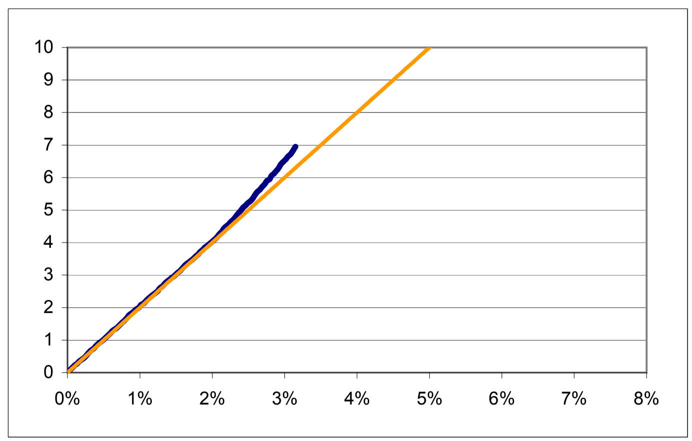
C-5 Compression (45-1)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header:		Strawclay test 45 pcf		Time:	335.8572 Sec		########
Data Acqu Timed							
Station Na Basic1.cfg							
Test File N Thornton-March2004.tst							
Time	Axial Displ	Axial Force					
Sec	mm	kN	Displacement	Mpa	Strain%	Stress(psi)	Fit Line
0.26001	-23.0235	-0.27751					
0.51001	-23.0757	-0.3232					
0.76001	-23.124	-0.37469					
1.01001	-23.176	-0.41474					
1.26001	-23.2261	-0.4502					
1.51001	-23.275	-0.47484					
1.76001	-23.3249	-0.49321					
2.01001	-23.375	-0.51327					
2.26001	-23.4236	-0.52707					
2.51001	-23.4764	-0.53977					
2.76001	-23.524	-0.55424					
3.01001	-23.5759	-0.56706					
3.26001	-23.6263	-0.57993					
3.51001	-23.6754	-0.59163					
3.76001	-23.725	-0.60392					
4.01001	-23.7754	-0.61486					
4.26001	-23.8268	-0.62384					
4.51001	-23.8743	-0.63796					
4.76001	-23.924	-0.65005					
5.01001	-23.975	-0.66449					
5.26001	-24.025	-0.67698					
5.51001	-24.0759	-0.68541					
5.76001	-24.1264	-0.69616					
6.01001	-24.1756	-0.70799					
6.26001	-24.2261	-0.71968					
6.51001	-24.2729	-0.73042					
6.76001	-24.3245	-0.74156					
7.01001	-24.3746	-0.75511					
7.26001	-24.4251	-0.76509					
7.51001	-24.4749	-0.77707					
7.76001	-24.5248	-0.78731					
8.01001	-24.5753	-0.79841					
8.26001	-24.6248	-0.80975					
8.51001	-24.675	-0.81892	0.00	0	0.00%	0	0
8.76001	-24.7245	-0.83136	0.05	0.000536	0.03%	0.078741	0.064997
9.01001	-24.7723	-0.84234	0.10	0.001008	0.06%	0.148231	0.12768
9.26001	-24.8256	-0.85439	0.15	0.001527	0.10%	0.224503	0.197596
9.51001	-24.8745	-0.86176	0.20	0.001845	0.13%	0.271166	0.261812
9.76001	-24.9242	-0.87406	0.25	0.002374	0.16%	0.349001	0.327038
10.01001	-24.9777	-0.88269	0.30	0.002746	0.20%	0.403629	0.397202
10.26001	-25.0248	-0.89008	0.35	0.003064	0.23%	0.450369	0.459104
10.51001	-25.073	-0.90199	0.40	0.003577	0.26%	0.525775	0.522371

Area	23225.76			
	x	y		
Point 1	0.032499	0.078741	Compressive Strength, (MPa)	0.08
Point 2	2.098843	4.261642	(psi)	11.9
	2.0	points	Modulus of Elasticity (MPa)	1.36
	2.00	guess	(psi)	200





C-5 Compression

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header: Strawclay test 45 pcf   Time: 467.1558 Sec   ########

Data Acqu Timed

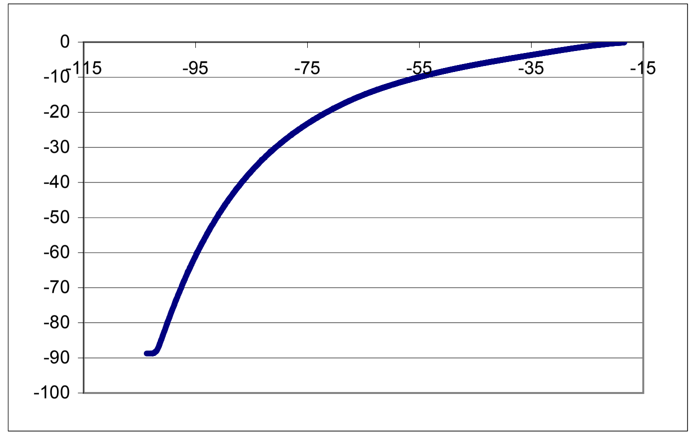
Station Na Basic1.cfg

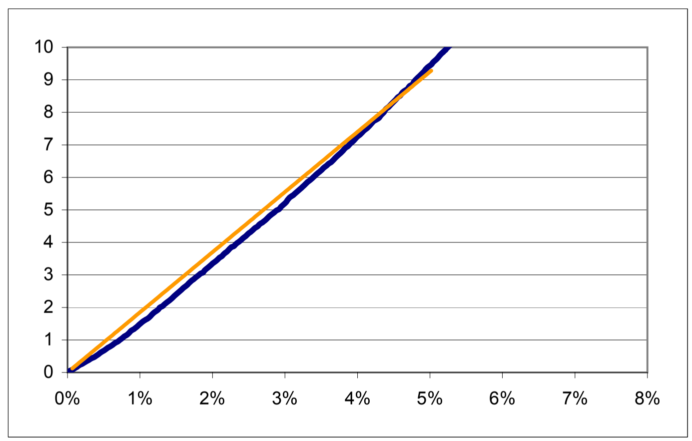
Test File N Thornton-March2004.tst

Time	Axial Displ	Axial Force					
Sec	mm	kN	Displacement	Mpa	Strain%	Stress(psi)	Fit Line
0.260498	-18.3842	-0.09042					
0.510498	-18.4331	-0.10318					
0.760498	-18.4844	-0.10998					
1.010498	-18.5335	-0.11666					
1.260498	-18.5842	-0.12238					
1.510498	-18.6339	-0.12882					
1.760498	-18.6846	-0.13427					
2.010498	-18.734	-0.14024					
2.260498	-18.7849	-0.14541					
2.510498	-18.8352	-0.15044					
2.760498	-18.8846	-0.15583					
3.010498	-18.9329	-0.15997					
3.260498	-18.9848	-0.16554					
3.510498	-19.0339	-0.16997					
3.760498	-19.0848	-0.1736					
4.010498	-19.1351	-0.18085					
4.260498	-19.1821	-0.18693					
4.510498	-19.2333	-0.19192					
4.760498	-19.2839	-0.19581					
5.010498	-19.3336	-0.20121					
5.260498	-19.3837	-0.20821					
5.510498	-19.4347	-0.21354					
5.760498	-19.4853	-0.21822					
6.010498	-19.5336	-0.2273					
6.260498	-19.5833	-0.23129					
6.510498	-19.6333	-0.23985					
6.760498	-19.684	-0.24469					
7.010498	-19.7351	-0.25113					
7.260498	-19.7854	-0.25533	0.00	0	0.00%	0	0
7.510498	-19.8348	-0.26319	0.05	0.000338	0.03%	0.049736	
7.760498	-19.8857	-0.26868	0.10	0.000575	0.07%	0.084496	0.121685
8.010498	-19.9339	-0.27556	0.15	0.000871	0.10%	0.12803	0.180207
8.260498	-19.9837	-0.28193	0.20	0.001145	0.13%	0.168342	0.240618
8.510498	-20.0349	-0.29027	0.25	0.001504	0.16%	0.221115	0.30282
8.760498	-20.085	-0.29561	0.30	0.001734	0.20%	0.254933	0.363634
9.010498	-20.134	-0.30281	0.35	0.002044	0.23%	0.300496	0.423128
9.260498	-20.1857	-0.30976	0.40	0.002343	0.26%	0.344462	0.485897
9.510498	-20.2351	-0.31632	0.45	0.002626	0.30%	0.385963	0.545913
9.760498	-20.2829	-0.32311	0.50	0.002918	0.33%	0.428942	0.603845
10.0105	-20.3357	-0.32873	0.55	0.00316	0.36%	0.464542	0.667999
10.2605	-20.3837	-0.33545	0.60	0.003449	0.39%	0.507047	0.726293
10.5105	-20.4331	-0.3434	0.65	0.003792	0.42%	0.557372	0.786233

Area 23225.76

	x	y		
Point 1	0.07	0.095	Compressive Strength, (MPa)	0.06
Point 2	2.6081	3.826807	(psi)	9.4
Slope	1.5	points	Modulus of Elasticity (MPa)	1.26
	1.85	guess	(psi)	185





C-5 Compression (45-3)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

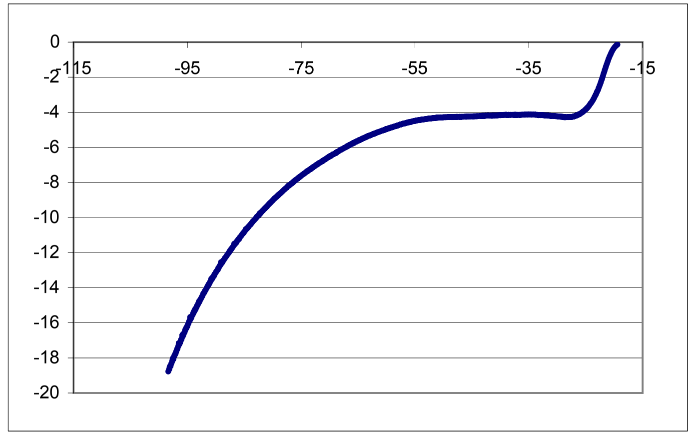
Data Header: Strawclay test 45 pcf   Time: 395.6826 Sec   ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

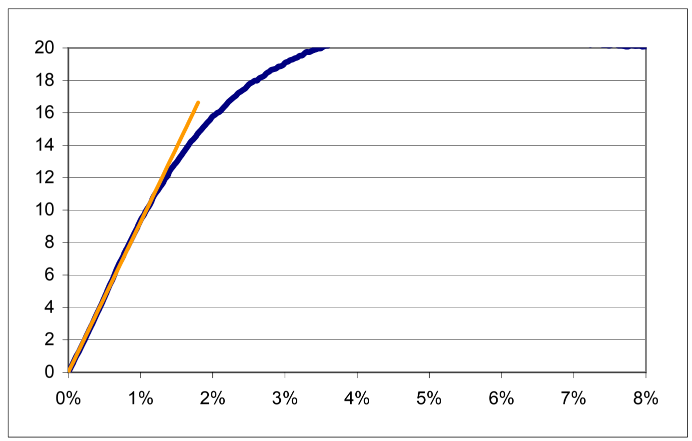
Time	Axial Displ	Axial Force					
Sec	mm	kN	Displ	Mpa	strain%	stress(psi)	Fit Line
0.259766	-19.4073	-0.13501					
0.509766	-19.4594	-0.14613					
0.759766	-19.5083	-0.15719					
1.009766	-19.5571	-0.16784					
1.259766	-19.6091	-0.1792					
1.509766	-19.6575	-0.19722					
1.759766	-19.7084	-0.20799					
2.009766	-19.7569	-0.22934					
2.259766	-19.8057	-0.24636					
2.509766	-19.8548	-0.2631					
2.759766	-19.9069	-0.28278					
3.009766	-19.9564	-0.30061					
3.259766	-20.0058	-0.32229					
3.509766	-20.0555	-0.34539					
3.759766	-20.1058	-0.3697					
4.009766	-20.1562	-0.39321					
4.259766	-20.2048	-0.42025					
4.509766	-20.2555	-0.44701					
4.759766	-20.3042	-0.47717					
5.009766	-20.3556	-0.50775					
5.259766	-20.4046	-0.53604					
5.509766	-20.4538	-0.56843					
5.759766	-20.5031	-0.60201					
6.009766	-20.552	-0.6372					
6.259766	-20.6023	-0.67778					
6.509766	-20.6526	-0.71277					
6.759766	-20.7035	-0.74875					
7.009766	-20.7529	-0.78306					
7.259766	-20.804	-0.82392					
7.509766	-20.853	-0.85906					
7.759766	-20.9031	-0.89597					
8.009766	-20.9547	-0.93969					
8.259766	-21.0017	-0.97849	0.0	0	0.00%	0	0
8.509766	-21.0498	-1.02119	0.0	0.001839	0.03%	0.270275	0.291697
8.759766	-21.1019	-1.06864	0.1	0.003882	0.07%	0.570606	0.607914
9.009766	-21.1504	-1.11768	0.1	0.005993	0.10%	0.881007	0.902403
9.259766	-21.2017	-1.15961	0.2	0.007799	0.13%	1.146393	1.213923
9.509766	-21.2511	-1.20413	0.2	0.009715	0.16%	1.428126	1.513668
9.759766	-21.3	-1.24996	0.3	0.011689	0.20%	1.718224	1.810105
10.00977	-21.3492	-1.29566	0.3	0.013656	0.23%	2.007455	2.108879
10.25977	-21.4004	-1.34743	0.4	0.015885	0.26%	2.335098	2.419725
10.50977	-21.4498	-1.3973	0.4	0.018032	0.29%	2.65076	2.719482

Area 23225.76

		x	y
0.1	Point 1	0.52	1.805
0.2	Point 2	2.06	14.8
		8.4	points
		9.25	guess

Compressive Strength, (MPa)	0.14
(psi)	20.9
Modulus of Elasticity (MPa)	6.29
(psi)	925





C-5 Compression(55-1)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

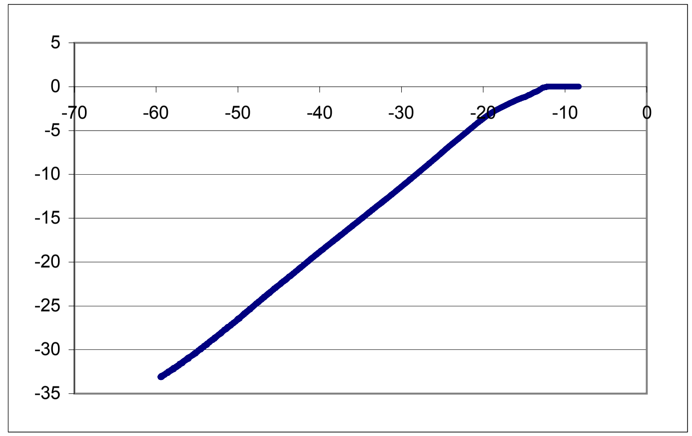
Data Header: Strawclay test 55 pcf   Time: 512.0154 Sec ########

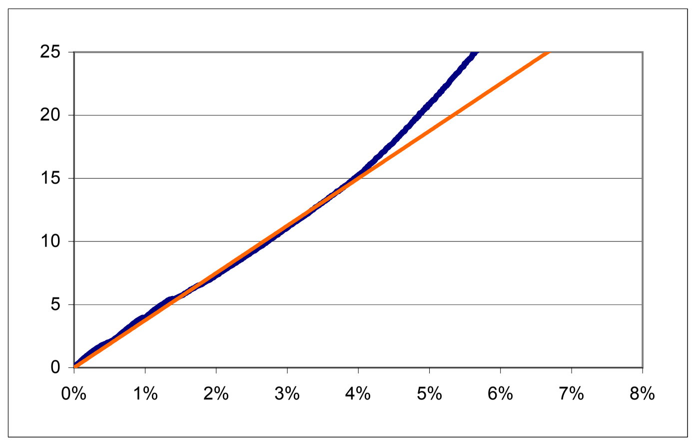
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst   Area 25161.24

Time	Axial Displ	Axial Force				
Sec	mm	kN	Displ	Mpa	strain%	stress(psi) Fit Line
0.260742	-8.31752	0.012198				
0.510742	-8.34409	0.012129		see		line 196
0.760742	-8.36779	0.012049				
1.010742	-8.39113	0.013206				
1.260742	-8.4174	0.011413				
1.510742	-8.44322	0.011403				
1.760742	-8.46675	0.012058				
2.010742	-8.49291	0.011798				
2.260742	-8.518	0.011142				
2.510742	-8.54315	0.011064				
2.760742	-8.56769	0.012433				
3.010742	-8.5912	0.010844				
3.260742	-8.62008	0.011033				
3.510742	-8.64278	0.010944				
3.760742	-8.66647	0.010573				
4.010742	-8.6926	0.011494				
4.260742	-8.71794	0.01088				
4.510742	-8.74221	0.010968				
4.760742	-8.7703	0.012147				
5.010742	-8.79396	0.012746				
5.260742	-8.81759	0.010771				
5.510742	-8.84444	0.011224				
5.760742	-8.86573	0.012556				
6.010742	-8.89426	0.012745				
6.260742	-8.9184	0.012948				
6.510742	-8.94302	0.01133				
6.760742	-8.96721	0.012424				
7.010742	-8.99013	0.012739				
7.260742	-9.01742	0.010626				
7.510742	-9.04286	0.011791				
7.760742	-9.06697	0.011925				
8.010742	-9.09223	0.01027				
8.260742	-9.11783	0.012938				
8.510742	-9.14259	0.011051				
8.760742	-9.16694	0.011375				
9.010742	-9.1922	0.012692				
9.260742	-9.21564	0.012317				
9.510742	-9.24205	0.010519				
9.760742	-9.2666	0.012402				
10.01074	-9.2921	0.012948				
10.26074	-9.31731	0.011408				
10.51074	-9.34409	0.011712				

		x	y
0.1	Point 1	0.031859	0.26386
0.2	Point 2	4.18	17.7
	Slope	4.2	points
		3.75	guess

Compressive Strength, (MPa)	0.14
(psi)	20.8
Modulus of Elasticity (MPa)	2.55
(psi)	375





C-5 Compression(55-2)

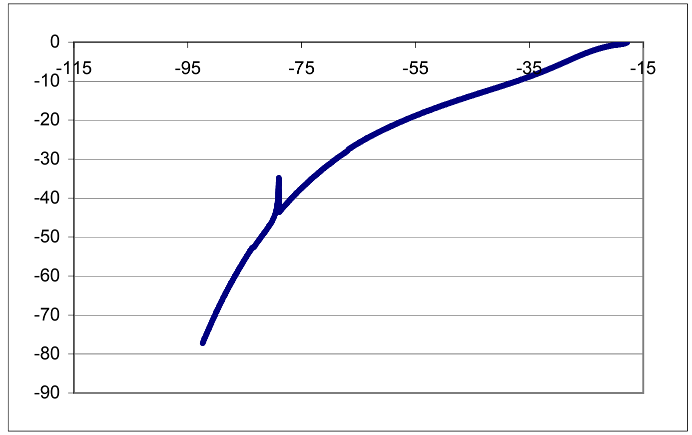
MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

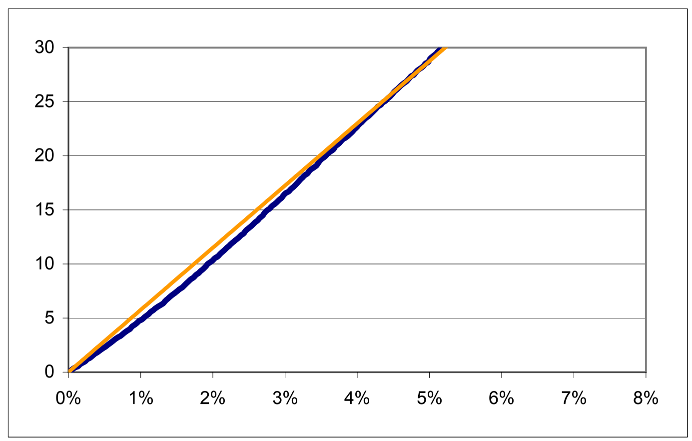
Data Header: Strawclay test 55 pcf   Time: 404.9446 Sec   ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

Time	Axial Displ	Axial Force				
Sec	mm	kN	Displ	Mpa	strain%	stress(psi) Fit Line
0.260742	-17.8005	-0.10083			see	line 114
0.510742	-17.8518	-0.12169				
0.760742	-17.9003	-0.14255				
1.010742	-17.9502	-0.1662				
1.260742	-18.0012	-0.18766				
1.510742	-18.0501	-0.21363				
1.760742	-18.1013	-0.24002				
2.010742	-18.1528	-0.26314				
2.260742	-18.1999	-0.29501				
2.510742	-18.2501	-0.3252				
2.760742	-18.2994	-0.35336				
3.010742	-18.3485	-0.38208				
3.260742	-18.3993	-0.403				
3.510742	-18.4504	-0.41999				
3.760742	-18.4986	-0.43498				
4.010742	-18.5509	-0.44872				
4.260742	-18.5997	-0.46283				
4.510742	-18.6502	-0.47373				
4.760742	-18.6991	-0.48636				
5.010742	-18.7502	-0.49676				
5.260742	-18.801	-0.50621				
5.510742	-18.8495	-0.51892				
5.760742	-18.8993	-0.52857				
6.010742	-18.9495	-0.53973				
6.260742	-18.9995	-0.54977				
6.510742	-19.0496	-0.56193				
6.760742	-19.1008	-0.57564				
7.010742	-19.1477	-0.58639				
7.260742	-19.2009	-0.59796				
7.510742	-19.2486	-0.60959				
7.760742	-19.3007	-0.62112				
8.010742	-19.3477	-0.63065				
8.260742	-19.3986	-0.64236				
8.510742	-19.4498	-0.65808				
8.760742	-19.4999	-0.66811				
9.010742	-19.5471	-0.6855				
9.260742	-19.5976	-0.69393				
9.510742	-19.6484	-0.7071				
9.760742	-19.6982	-0.71713				
10.01074	-19.7492	-0.72654				
10.26074	-19.7998	-0.7369				
10.51074	-19.8489	-0.74291				

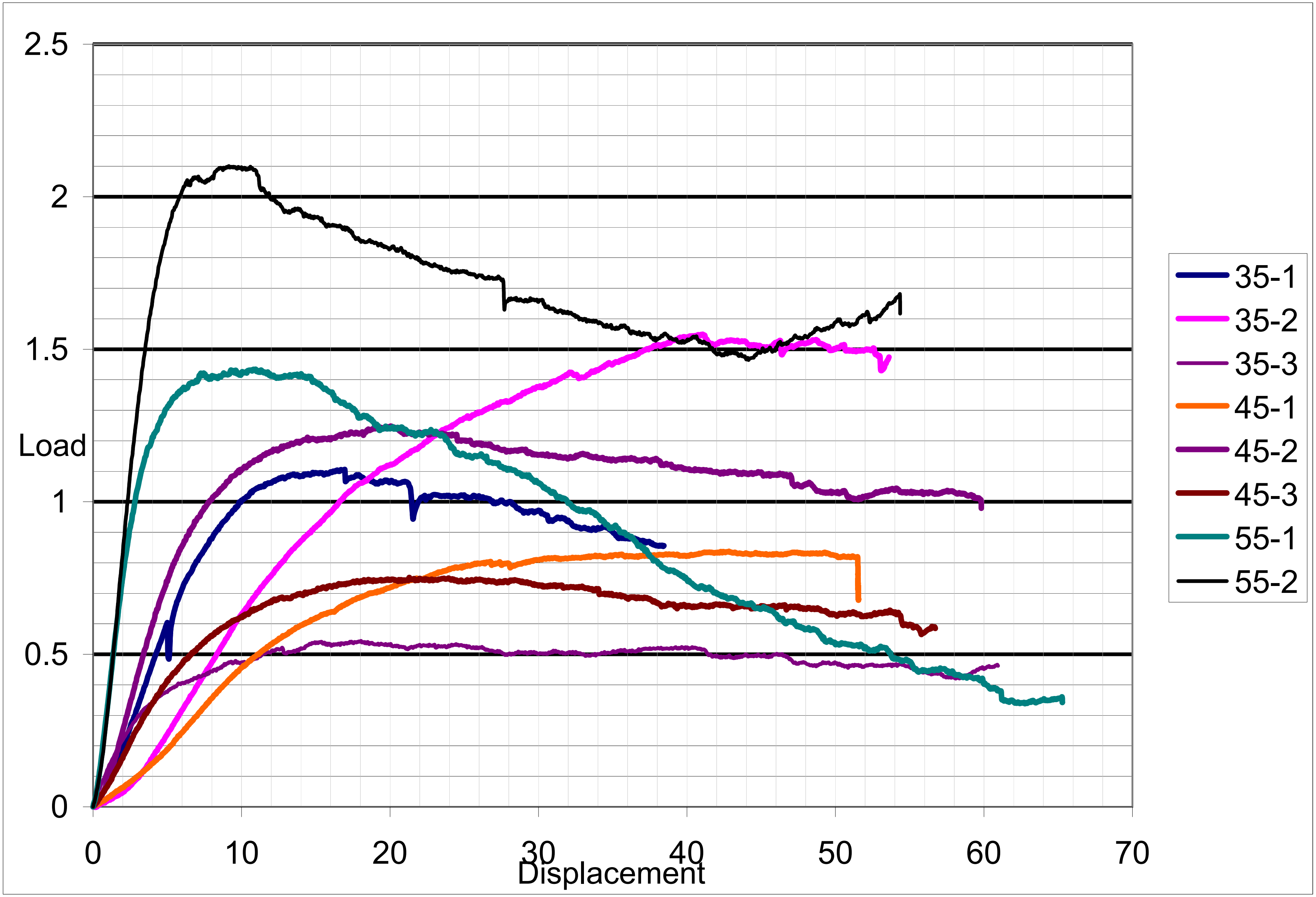
Area 23225.76

	x	y		
Point 1	0.07	0.095	Compressive Strength, (MPa)	0.19
Point 2	2.6081	3.826807	(psi)	28.7
	1.5	points	Modulus of Elasticity (MPa)	3.91
	5.75	guess	(psi)	575





C-6 Bending



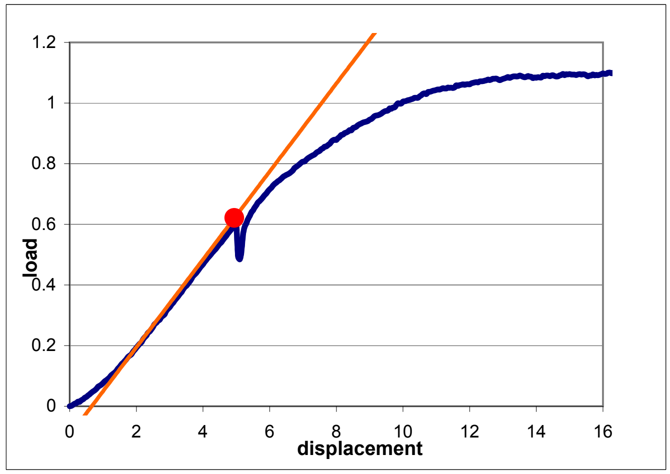
2.5
2
1.5
Load
1
0.5
0
0
10
20
30
40
50
60
70
Displacement
35-1
35-2
35-3
45-1
45-2
45-3
55-1
55-2

C-6 Bending(35-1)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header:		Strawclay bending	Time:	192.676 Sec	########		section modulus	moment of inertia		
Data Acqu	Timed									
Station Na	Basic1.cfg		width, b	height, h	span, L	area, A	S=bh²/6	I=bh³/12		
Test File N	Thornton-March2004.tst		(mm)	(mm)	(mm)	(mm²)	(mm³)	(mm⁴)		
			152.4	152.4	330.2	7669146	589934	4.50E+07		

	x	y		
peak	4.94	0.621	peak moment M=PL/2 (kNm)	0.10
start	1.901	0.1799	rupture modulus, f'r=M/S (MPa)	0.17
slope	0.145		(psi)	26
			modulus of elasticity, E=48dI/PL³ (MPa)	0.002
			(psi)	0.4



Time	Axial Displ	Axial Force			
Sec	mm	kN	Displ	Load (kN)	Fit Line
0.26001	-33.1667	-0.09126	0	0	-0.09575
0.51001	-33.2149	-0.09237	0.048123	0.001113	-0.08877
0.76001	-33.2667	-0.09576	0.099965	0.004508	-0.08125
1.01001	-33.3164	-0.09955	0.149613	0.00829	-0.07405
1.26001	-33.3649	-0.10132	0.198185	0.010066	-0.06701
1.51001	-33.4146	-0.10642	0.247883	0.015164	-0.0598
1.76001	-33.4659	-0.10573	0.299202	0.01447	-0.05236
2.01001	-33.5144	-0.11054	0.347702	0.019288	-0.04533
2.26001	-33.5647	-0.11392	0.397988	0.022668	-0.03804
2.51001	-33.6159	-0.119	0.449192	0.027741	-0.03061
2.76001	-33.667	-0.12176	0.500267	0.030506	-0.02321
3.01001	-33.7162	-0.12636	0.549469	0.035103	-0.01607
3.26001	-33.7669	-0.13073	0.600129	0.039472	-0.00873
3.51001	-33.8148	-0.13567	0.648056	0.044414	-0.00178
3.76001	-33.8647	-0.13982	0.697937	0.04856	0.005456
4.01001	-33.9147	-0.14364	0.747979	0.052389	0.012712
4.26001	-33.9662	-0.14881	0.799477	0.057551	0.020179
4.51001	-34.0153	-0.1556	0.848538	0.064343	0.027293
4.76001	-34.0657	-0.15859	0.898922	0.067335	0.034599
5.01001	-34.1146	-0.1619	0.947876	0.07064	0.041697
5.26001	-34.1633	-0.16717	0.996525	0.07591	0.048751
5.51001	-34.2152	-0.17292	1.048462	0.081669	0.056282
5.76001	-34.2629	-0.17671	1.096207	0.085451	0.063205
6.01001	-34.3154	-0.1813	1.148655	0.090042	0.07081
6.26001	-34.366	-0.18677	1.199223	0.095517	0.078142
6.51001	-34.4161	-0.1936	1.249314	0.102343	0.085406
6.76001	-34.4634	-0.19781	1.296681	0.10655	0.092274
7.01001	-34.5164	-0.2023	1.349652	0.111045	0.099955
7.26001	-34.5647	-0.20725	1.397938	0.115996	0.106956
7.51001	-34.6141	-0.2157	1.447396	0.124444	0.114127
7.76001	-34.6661	-0.22115	1.499379	0.129891	0.121665
8.01001	-34.7148	-0.22826	1.548088	0.137	0.128728
8.26001	-34.7655	-0.23427	1.59874	0.143017	0.136072
8.51001	-34.8169	-0.24069	1.650132	0.149434	0.143524
8.76001	-34.8669	-0.24643	1.7002	0.155173	0.150784
9.01001	-34.9152	-0.25405	1.748501	0.162794	0.157788
9.26001	-34.9645	-0.25811	1.797757	0.166859	0.16493
9.51001	-35.0181	-0.26287	1.851342	0.171614	0.1727
9.76001	-35.0678	-0.27119	1.901085	0.179933	0.179912
10.01001	-35.1177	-0.2771	1.950955	0.185842	0.187143
10.26001	-35.1657	-0.28361	1.998951	0.192357	0.194103
10.51001	-35.2156	-0.29085	2.048863	0.199595	0.20134
10.76001	-35.2655	-0.29724	2.098786	0.205984	0.208579
11.01001	-35.3152	-0.30184	2.148426	0.210581	0.215777
11.26001	-35.3647	-0.31119	2.197934	0.219933	0.222955
11.51001	-35.4156	-0.31799	2.248898	0.226733	0.230345
11.76001	-35.4675	-0.32403	2.300805	0.232772	0.237872
12.01001	-35.5154	-0.33287	2.348626	0.241611	0.244806
12.26001	-35.5666	-0.33771	2.39988	0.246458	0.252238
12.51001	-35.6152	-0.34455	2.448464	0.253295	0.259282
12.76001	-35.6648	-0.3518	2.498066	0.260543	0.266475
13.01001	-35.7127	-0.36123	2.545941	0.269976	0.273416
13.26001	-35.7653	-0.36597	2.598603	0.27471	0.281052
13.51001	-35.8184	-0.37294	2.651642	0.281684	0.288743
13.76001	-35.8661	-0.37629	2.699391	0.285032	0.295667
14.01001	-35.9153	-0.38519	2.748551	0.293931	0.302795
14.26001	-35.9644	-0.38997	2.797669	0.298715	0.309917
14.51001	-36.0155	-0.3939	2.848732	0.302646	0.317321
14.76001	-36.0657	-0.40554	2.898961	0.314285	0.324604
15.01001	-36.1149	-0.41219	2.94817	0.320938	0.33174
15.26001	-36.1663	-0.41792	2.999573	0.326663	0.339193
15.51001	-36.2164	-0.42582	3.049653	0.334568	0.346455

C-6 Bending(35-2)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header: Strawclay bending Time: 268.3491 Sec ########

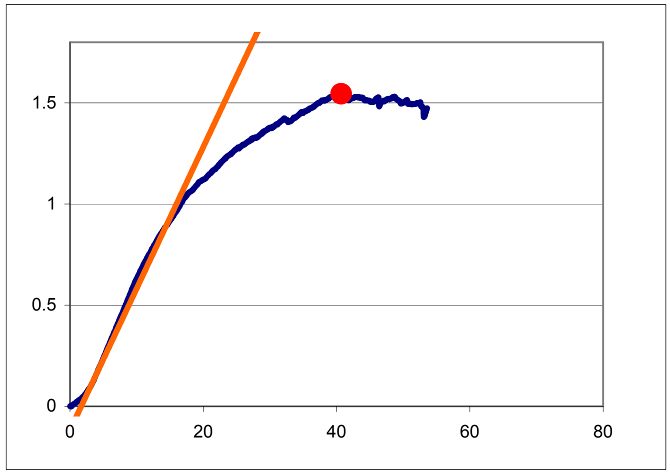
Data Acqu Timed

Station Na Basic1.cfg

Test File N Thornton-March2004.tst

width, b (mm)	height, h (mm)	span, L (mm)	area, A (mm²)	section modulus S=bh²/6 (mm³)	moment of inertia I=bh³/12 (mm⁴)
152.4	152.4	330.2	7669146	589934	44952994

	x	y		
peak	40.7	1.545	peak moment M=PL/2 (kNm)	0.26
start	4.4	0.19	rupture modulus, f'r=M/S (MPa)	0.43
slope	0.07		(psi)	64
			modulus of elasticity, E=48dI/PL³ (MPa)	0.001
			(psi)	0.2

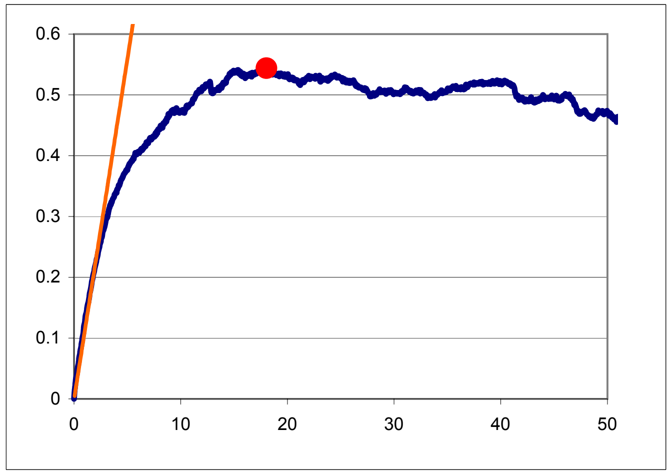


Time	Axial Displ	Axial Force			
Sec	mm	kN	Displ	Load (kN)	Fit Line
0.260254	-65.3303	-0.07338	0	0	-0.118
0.510254	-65.3814	-0.07298	0.051163	-0.00041	-0.11442
0.760254	-65.4317	-0.07582	0.101486	0.002438	-0.1109
1.010254	-65.4801	-0.07189	0.149887	-0.00149	-0.10751
1.260254	-65.5321	-0.07366	0.201859	0.000278	-0.10387
1.510254	-65.5799	-0.07286	0.249665	-0.00053	-0.10052
1.760254	-65.6324	-0.0777	0.302109	0.004313	-0.09685
2.010254	-65.6816	-0.07712	0.351296	0.003734	-0.09341
2.260254	-65.7296	-0.08101	0.399384	0.007623	-0.09004
2.510254	-65.7805	-0.08219	0.450249	0.008808	-0.08648
2.760254	-65.8283	-0.08172	0.498024	0.008335	-0.08314
3.010254	-65.8806	-0.08312	0.550301	0.009733	-0.07948
3.260254	-65.9305	-0.08524	0.600273	0.011858	-0.07598
3.510254	-65.9798	-0.08715	0.649521	0.013763	-0.07253
3.760254	-66.0294	-0.08603	0.69912	0.012644	-0.06906
4.010254	-66.0793	-0.08771	0.749024	0.014328	-0.06557
4.260254	-66.1312	-0.08632	0.800957	0.012938	-0.06193
4.510254	-66.1796	-0.09072	0.849304	0.017335	-0.05855
4.760254	-66.2279	-0.09134	0.897682	0.017957	-0.05516
5.010254	-66.2803	-0.09203	0.950035	0.018646	-0.0515
5.260254	-66.3297	-0.09621	0.999398	0.022824	-0.04804
5.510254	-66.3804	-0.09657	1.050095	0.02319	-0.04449
5.760254	-66.4305	-0.09613	1.100228	0.022749	-0.04098
6.010254	-66.4795	-0.0959	1.149201	0.022517	-0.03756
6.260254	-66.5318	-0.10066	1.201493	0.027272	-0.0339
6.510254	-66.5802	-0.10089	1.249977	0.027506	-0.0305
6.760254	-66.6303	-0.09991	1.300026	0.026525	-0.027
7.010254	-66.6785	-0.10405	1.348259	0.030663	-0.02362
7.260254	-66.7292	-0.10493	1.398987	0.031551	-0.02007
7.510254	-66.78	-0.1055	1.449768	0.032118	-0.01652
7.760254	-66.8301	-0.10716	1.49984	0.033777	-0.01301
8.010254	-66.88	-0.10843	1.549698	0.035049	-0.00952
8.260254	-66.9307	-0.1086	1.600441	0.035219	-0.00597
8.510254	-66.9813	-0.11071	1.651039	0.037322	-0.00243
8.760254	-67.0298	-0.11097	1.699585	0.037588	0.000971
9.010254	-67.0799	-0.11276	1.749604	0.039377	0.004472
9.260254	-67.1299	-0.1172	1.79966	0.043816	0.007976
9.510254	-67.1797	-0.1156	1.849449	0.042221	0.011461
9.760254	-67.2292	-0.11846	1.898979	0.045074	0.014929
10.01025	-67.2797	-0.11818	1.949433	0.044799	0.01846
10.26025	-67.3295	-0.1223	1.999245	0.048912	0.021947
10.51025	-67.3803	-0.12232	2.050064	0.048938	0.025504
10.76025	-67.4298	-0.1229	2.099564	0.049518	0.028969
11.01025	-67.48	-0.12681	2.149735	0.053422	0.032481
11.26025	-67.5318	-0.13062	2.201515	0.057239	0.036106
11.51025	-67.5802	-0.13089	2.249939	0.057507	0.039496
11.76025	-67.6288	-0.13401	2.298531	0.060627	0.042897
12.01025	-67.6818	-0.13451	2.351563	0.061131	0.046609
12.26025	-67.73	-0.13647	2.399788	0.063091	0.049985
12.51025	-67.7795	-0.14107	2.449288	0.06769	0.05345
12.76025	-67.8294	-0.14131	2.499146	0.067924	0.05694
13.01025	-67.8798	-0.14439	2.549507	0.07101	0.060465
13.26025	-67.9305	-0.14643	2.60022	0.073042	0.064015
13.51025	-67.9818	-0.15031	2.651535	0.076924	0.067607
13.76025	-68.0307	-0.15318	2.700424	0.079796	0.07103
14.01025	-68.0808	-0.15531	2.750565	0.081927	0.07454
14.26025	-68.1303	-0.15838	2.800019	0.084995	0.078001
14.51025	-68.1806	-0.15992	2.850312	0.086536	0.081522
14.76025	-68.2294	-0.16372	2.899132	0.090341	0.084939
15.01025	-68.2802	-0.16459	2.949921	0.091206	0.088494
15.26025	-68.33	-0.16698	2.99971	0.0936	0.09198
15.51025	-68.3805	-0.16858	3.050263	0.095199	0.095518

C-6 Bending(35-3)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

													section	moment of
Data Header:			Strawclay bend test 35 pcf		Time:		305.2249 Sec		########				modulus	inertia
Data Acqu	Timed													
Station Na	Basic1.cfg						width, b		height, h	span, L		area, A	S=bh²/6	I=bh³/12
Test File N	Thornton-March2004.tst						(mm)		(mm)	(mm)		(mm²)	(mm³)	(mm⁴)
Time	Axial Displ	Axial Force					152.4		152.4	330.2		7669146	589934	44952994
Sec	mm	kN	Displ	Load (kN)	Fit Line			x		y				
0.258789	-20.057	-0.11162	0	0			peak	18.047		0.544	peak moment M=PL/2 (kNm)			0.09
0.508789	-20.1104	-0.12605	0.053375	0.014434	0.004783		start	0.1		0.01	rupture modulus, f'r=M/S (MPa)			0.15
0.758789	-20.158	-0.13224	0.100979	0.020624	0.01011		slope	0.1119					(psi)	22
1.008789	-20.2084	-0.14	0.151428	0.028384	0.015755						modulus of elasticity, E=48dI/PL³ (MPa)			0.002
1.258789	-20.2585	-0.14625	0.201483	0.034629	0.021356								(psi)	0.3
1.508789	-20.3074	-0.15069	0.250361	0.039072	0.026825									
1.758789	-20.3584	-0.15627	0.301382	0.044647	0.032535									
2.008789	-20.4082	-0.1635	0.351194	0.05188	0.038109									
2.258789	-20.4592	-0.16809	0.402161	0.056472	0.043812									
2.508789	-20.508	-0.17355	0.451038	0.061932	0.049281									
2.758789	-20.5575	-0.18072	0.500519	0.069105	0.054818									
3.008789	-20.6084	-0.18546	0.551424	0.07384	0.060514									
3.258789	-20.6582	-0.1917	0.601166	0.080079	0.06608									
3.508789	-20.7108	-0.19626	0.653757	0.084637	0.071965									
3.758789	-20.7607	-0.20258	0.703665	0.090959	0.07755									
4.008789	-20.8085	-0.20642	0.751454	0.094799	0.082898									
4.258789	-20.856	-0.21256	0.79895	0.100945	0.088213									
4.508789	-20.9072	-0.21768	0.850229	0.10606	0.093951									
4.758789	-20.9571	-0.2251	0.900053	0.113481	0.099526									
5.008789	-21.0056	-0.23256	0.948559	0.120939	0.104954									
5.258789	-21.0577	-0.23674	1.000698	0.125116	0.110788									
5.508789	-21.1075	-0.24355	1.050461	0.131926	0.116357									
5.758789	-21.1568	-0.2496	1.09984	0.137979	0.121882									
6.008789	-21.2088	-0.25281	1.151817	0.141194	0.127698									
6.258789	-21.2594	-0.25721	1.202368	0.145592	0.133355									
6.508789	-21.3078	-0.26336	1.250771	0.151742	0.138771									
6.758789	-21.3582	-0.26822	1.30119	0.156596	0.144413									
7.008789	-21.406	-0.27081	1.349045	0.159191	0.149768									
7.258789	-21.4593	-0.27684	1.402269	0.165218	0.155724									
7.508789	-21.5076	-0.28287	1.450594	0.171252	0.161131									
7.758789	-21.5576	-0.28705	1.50061	0.175431	0.166728									
8.008789	-21.6085	-0.29052	1.551542	0.178902	0.172428									
8.258789	-21.659	-0.29617	1.602045	0.184547	0.178079									
8.508789	-21.7073	-0.30133	1.650293	0.189714	0.183478									
8.758789	-21.7573	-0.30647	1.700323	0.194852	0.189076									
9.008789	-21.8099	-0.31049	1.752901	0.198865	0.19496									
9.258789	-21.8556	-0.31561	1.798645	0.203989	0.200078									
9.508789	-21.91	-0.31943	1.852982	0.207809	0.206159									
9.758789	-21.9569	-0.32323	1.899876	0.211607	0.211406									
10.00879	-22.0072	-0.32775	1.950234	0.216129	0.217041									
10.25879	-22.0589	-0.33093	2.001873	0.219311	0.22282									
10.50879	-22.1064	-0.33503	2.049378	0.223411	0.228135									
10.75879	-22.1581	-0.3392	2.101057	0.227581	0.233918									
11.00879	-22.2064	-0.34267	2.149357	0.231053	0.239323									
11.25879	-22.2559	-0.3468	2.198851	0.235181	0.244861									
11.50879	-22.3051	-0.3518	2.248079	0.240177	0.25037									
11.75879	-22.3585	-0.35554	2.3015	0.24392	0.256348									
12.00879	-22.4101	-0.35957	2.353142	0.247954	0.262127									
12.25879	-22.4592	-0.3633	2.402151	0.251677	0.267611									
12.50879	-22.5089	-0.36732	2.451912	0.255697	0.273179									
12.75879	-22.5594	-0.36967	2.502371	0.258049	0.278825									
13.00879	-22.6089	-0.37493	2.551886	0.263308	0.284366									
13.25879	-22.6596	-0.3774	2.602564	0.265776	0.290037									
13.50879	-22.7111	-0.38215	2.654072	0.270532	0.295801									
13.75879	-22.7631	-0.38655	2.706148	0.274925	0.301628									
14.00879	-22.8121	-0.38898	2.755112	0.277358	0.307107									
14.25879	-22.861	-0.39172	2.80399	0.280098	0.312576									
14.50879	-22.9106	-0.3941	2.853605	0.282479	0.318128									
14.75879	-22.959	-0.39838	2.90201	0.286762	0.323545									
15.00879	-23.0098	-0.40268	2.952799	0.29106	0.329228									
15.25879	-23.0614	-0.40646	3.004439	0.294838	0.335007									
15.50879	-23.1089	-0.41146	3.051918	0.299841	0.34032									



C-6 Bending(45-1)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header: Strawclay test 45 pcf | Time: 351.2544 Sec | ########

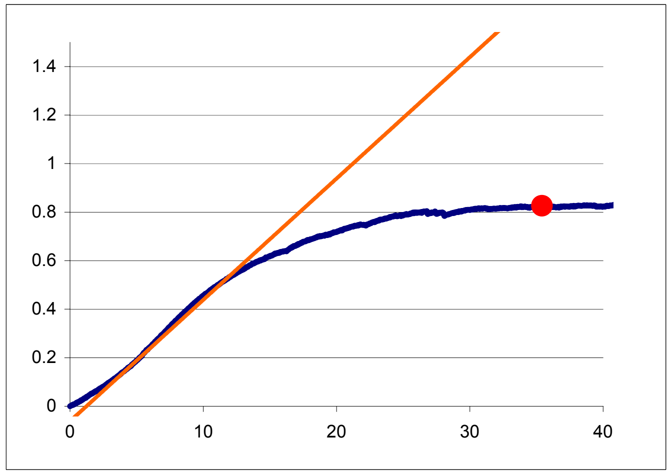
Data Acqu Timed

Station Na Basic1.cfg

Test File N Thornton-March2004.tst

width, b	height, h	span, L	area, A	section modulus S=bh²/6	moment of inertia I=bh³/12
(mm)	(mm)	(mm)	(mm²)	(mm³)	(mm⁴)
152.4	152.4	330.2	7669146	589934	44952994

	x	y		
peak	35.418	0.8259	peak moment M=PL/2 (kNm)	0.14
start	4.03	0.14	rupture modulus, f'r=M/S (MPa)	0.23
slope	0.05		(psi)	34
			modulus of elasticity, E=48dI/PL³ (MPa)	0.001
			(psi)	0.1

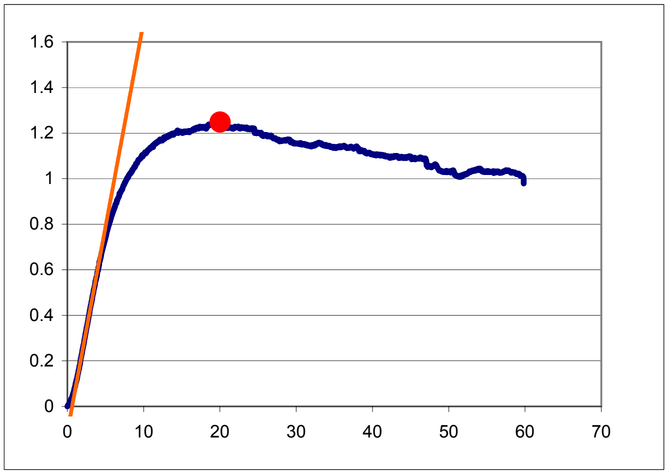


Time Sec	Axial Displ mm	Axial Force kN	Displ	Load (kN)	Fit Line
0.262695	-82.942	-0.00663	0	0	-0.0615
0.512695	-82.9758	-0.00781	0.033722	0.001186	-0.05981
0.762695	-83.024	-0.00911	0.082001	0.002481	-0.0574
1.012695	-83.0777	-0.0104	0.135659	0.003771	-0.05472
1.262695	-83.1267	-0.01249	0.184708	0.005866	-0.05226
1.512695	-83.1757	-0.01195	0.233651	0.005326	-0.04982
1.762695	-83.2279	-0.01553	0.285882	0.0089	-0.04721
2.012695	-83.2782	-0.01487	0.336121	0.00824	-0.04469
2.262695	-83.3254	-0.01616	0.383362	0.009532	-0.04233
2.512695	-83.3751	-0.01728	0.433014	0.010656	-0.03985
2.762695	-83.4253	-0.02119	0.483284	0.01456	-0.03734
3.012695	-83.4762	-0.02134	0.534165	0.014708	-0.03479
3.262695	-83.5255	-0.02377	0.583497	0.017137	-0.03233
3.512695	-83.577	-0.02405	0.634964	0.017418	-0.02975
3.762695	-83.6256	-0.02571	0.683609	0.019086	-0.02732
4.012695	-83.6765	-0.02743	0.734452	0.020799	-0.02478
4.262695	-83.7254	-0.02787	0.783394	0.021241	-0.02233
4.512695	-83.7726	-0.0319	0.830552	0.025273	-0.01997
4.762695	-83.827	-0.03235	0.884957	0.025718	-0.01725
5.012695	-83.8755	-0.03323	0.93351	0.026606	-0.01482
5.262695	-83.9254	-0.03589	0.983391	0.029259	-0.01233
5.512695	-83.976	-0.03828	1.033982	0.031648	-0.0098
5.762695	-84.0244	-0.03908	1.08236	0.032447	-0.00738
6.012695	-84.0745	-0.04067	1.132439	0.034044	-0.00488
6.262695	-84.1248	-0.04113	1.182801	0.0345	-0.00236
6.512695	-84.1743	-0.04547	1.232277	0.038841	0.000114
6.762695	-84.2266	-0.04644	1.2846	0.039811	0.00273
7.012695	-84.276	-0.04749	1.333992	0.040857	0.0052
7.262695	-84.3253	-0.04963	1.383309	0.043001	0.007665
7.512695	-84.3755	-0.0518	1.433465	0.045171	0.010173
7.762695	-84.4261	-0.05392	1.48404	0.047287	0.012702
8.012695	-84.474	-0.05547	1.53193	0.048841	0.015097
8.262695	-84.5234	-0.05846	1.58133	0.051833	0.017567
8.512695	-84.577	-0.05842	1.634957	0.051789	0.020248
8.762695	-84.6259	-0.0596	1.683884	0.052976	0.022694
9.012695	-84.675	-0.062	1.732941	0.055367	0.025147
9.262695	-84.7248	-0.06332	1.782776	0.056688	0.027639
9.512695	-84.7748	-0.06587	1.832787	0.05924	0.030139
9.762695	-84.8255	-0.06641	1.8835	0.059786	0.032675
10.0127	-84.8746	-0.06903	1.932564	0.062405	0.035128
10.2627	-84.9263	-0.06875	1.984231	0.062124	0.037712
10.5127	-84.9739	-0.07136	2.031815	0.064734	0.040091
10.7627	-85.0244	-0.07113	2.08239	0.064499	0.04262
11.0127	-85.075	-0.07593	2.13295	0.069303	0.045148
11.2627	-85.1263	-0.07652	2.184289	0.069895	0.047714
11.5127	-85.1769	-0.08007	2.23491	0.073439	0.050246
11.7627	-85.2259	-0.08131	2.283837	0.074684	0.052692
12.0127	-85.2751	-0.08117	2.333062	0.074539	0.055153
12.2627	-85.3235	-0.08372	2.381455	0.077094	0.057573
12.5127	-85.3746	-0.08626	2.432587	0.079633	0.060129
12.7627	-85.4238	-0.08729	2.481766	0.080658	0.062588
13.0127	-85.4757	-0.08934	2.5337	0.082714	0.065185
13.2627	-85.5252	-0.09037	2.583184	0.08374	0.067659
13.5127	-85.5778	-0.09284	2.635773	0.086217	0.070289
13.7627	-85.6251	-0.09535	2.683083	0.088724	0.072654
14.0127	-85.6733	-0.09636	2.731247	0.089728	0.075062
14.2627	-85.7236	-0.09898	2.781586	0.09235	0.077579
14.5127	-85.7761	-0.10148	2.834084	0.094855	0.080204
14.7627	-85.8245	-0.10339	2.882508	0.096757	0.082625
15.0127	-85.8738	-0.10439	2.931801	0.097759	0.08509
15.2627	-85.9236	-0.10613	2.981537	0.099498	0.087577
15.5127	-85.9751	-0.10876	3.033089	0.102129	0.090154

C-6 Bending (45-2)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header:			Strawclay bend test 45 pcf			Time:	300.2476 Sec		########		section modulus	moment of inertia		
Data Acqu Timed							width, b	height, h	span, L	area, A	S=bh²/6	I=bh³/12		
Station Na Basic1.cfg							(mm)	(mm)	(mm)	(mm²)	(mm³)	(mm⁴)		
Test File N Thornton-March2004.tst							152.4	152.4	330.2	7669146	589934	44952994		
Time	Axial Displ	Axial Force						x	y					
Sec	mm	kN	Displ	Load (kN)	Fit Line		peak	20.0423	1.248	peak moment M=PL/2 (kNm)			0.21	
0.481934	-12.4598	-0.02591	0	0	-0.112		start	1.65	0.185	rupture modulus, f'r=M/S (MPa)			0.35	
0.731934	-12.5112	-0.02837	0.051394	0.002458	-0.10275		slope	0.18				(psi)	51	
0.981934	-12.5619	-0.03216	0.102039	0.006253	-0.09363				modulus of elasticity, E=48dI/PL³ (MPa)				0.003	
1.231934	-12.6098	-0.03255	0.149956	0.00664	-0.08501							(psi)	0.4	
1.481934	-12.6605	-0.03725	0.200709	0.01134	-0.07587									
1.731934	-12.7103	-0.03898	0.250491	0.013075	-0.06691									
1.981934	-12.7588	-0.04165	0.299015	0.015747	-0.05818									
2.231934	-12.81	-0.04777	0.350155	0.021863	-0.04897									
2.481934	-12.859	-0.05183	0.39921	0.025927	-0.04014									
2.731934	-12.9128	-0.05601	0.453012	0.030102	-0.03046									
2.981934	-12.9609	-0.06051	0.501095	0.034599	-0.0218									
3.231934	-13.0099	-0.0619	0.550026	0.035991	-0.013									
3.481934	-13.0603	-0.06543	0.600487	0.039525	-0.00391									
3.731934	-13.1106	-0.07031	0.650774	0.044406	0.005139									
3.981934	-13.1611	-0.07587	0.701254	0.049962	0.014226									
4.231934	-13.2099	-0.08223	0.750033	0.056322	0.023006									
4.481934	-13.2613	-0.08667	0.801453	0.060758	0.032262									
4.731934	-13.3106	-0.09296	0.850757	0.067052	0.041136									
4.981934	-13.3613	-0.10148	0.901431	0.075577	0.050258									
5.231934	-13.4106	-0.1065	0.950786	0.080591	0.059141									
5.481934	-13.4618	-0.11203	1.002015	0.08612	0.068363									
5.731934	-13.5094	-0.11943	1.049584	0.093523	0.076925									
5.981934	-13.5593	-0.12822	1.0995	0.102317	0.08591									
6.231934	-13.6092	-0.13318	1.149338	0.107273	0.094881									
6.481934	-13.6624	-0.14237	1.202584	0.116461	0.104465									
6.731934	-13.7093	-0.14663	1.249463	0.12072	0.112903									
6.981934	-13.7601	-0.15585	1.300284	0.129945	0.122051									
7.231934	-13.8121	-0.16387	1.352295	0.137963	0.131413									
7.481934	-13.8613	-0.17032	1.401438	0.14441	0.140259									
7.731934	-13.9115	-0.18034	1.451632	0.154428	0.149294									
7.981934	-13.9613	-0.18814	1.501488	0.162229	0.158268									
8.231934	-14.0101	-0.19451	1.550252	0.168605	0.167045									
8.481934	-14.0597	-0.20503	1.599865	0.179125	0.175976									
8.731934	-14.1106	-0.21137	1.650727	0.185458	0.185131									
8.981934	-14.158	-0.22227	1.698167	0.196363	0.19367									
9.231934	-14.2105	-0.2328	1.750619	0.206896	0.203111									
9.481934	-14.2621	-0.24157	1.802262	0.21566	0.212407									
9.731934	-14.3088	-0.25013	1.849008	0.224219	0.220821									
9.981934	-14.3603	-0.25761	1.900449	0.231699	0.230081									
10.23193	-14.4087	-0.26749	1.948884	0.241578	0.238799									
10.48193	-14.4589	-0.27656	1.999027	0.250657	0.247825									
10.73193	-14.5102	-0.28463	2.050396	0.25872	0.257071									
10.98193	-14.5598	-0.29355	2.099922	0.267642	0.265986									
11.23193	-14.6107	-0.30113	2.150901	0.27522	0.275162									
11.48193	-14.6588	-0.31226	2.199002	0.286354	0.28382									
11.73193	-14.7086	-0.32103	2.248792	0.295123	0.292783									
11.98193	-14.7625	-0.32978	2.302681	0.303868	0.302483									
12.23193	-14.8114	-0.33998	2.351582	0.314073	0.311285									
12.48193	-14.8586	-0.34698	2.398755	0.321073	0.319776									
12.73193	-14.9082	-0.35723	2.448358	0.331322	0.328704									
12.98193	-14.9612	-0.36722	2.501382	0.34131	0.338249									
13.23193	-15.0088	-0.37658	2.549012	0.350671	0.346822									
13.48193	-15.0602	-0.38236	2.600381	0.356456	0.356069									
13.73193	-15.1105	-0.39103	2.650637	0.365124	0.365115									
13.98193	-15.1588	-0.40069	2.699002	0.374783	0.37382									
14.23193	-15.209	-0.41035	2.749141	0.384441	0.382845									
14.48193	-15.2588	-0.41846	2.798988	0.39255	0.391818									
14.73193	-15.3076	-0.42994	2.847765	0.404034	0.400598									
14.98193	-15.3583	-0.43697	2.898451	0.411058	0.409721									
15.23193	-15.4075	-0.45009	2.947639	0.424185	0.418575									
15.48193	-15.4604	-0.45771	3.000598	0.431801	0.428108									
15.73193	-15.5093	-0.46581	3.049513	0.439903	0.436912									



C-6 Bending(45-3)

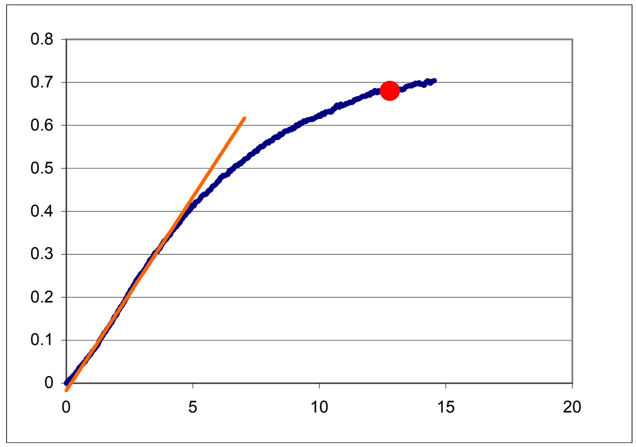
MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header: Strawclay bend test 45 pcf Time: 284.1697 Sec ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

width, b (mm)	height, h (mm)	span, L (mm)	area, A (mm^2)	section modulus $S=bh^2/6$ (mm^3)	moment of inertia $I=bh^3/12$ (mm^4)
152.4	152.4	330.2	7669146	589934	44952994

	x	y
peak	12.79	0.68
start	1.3	0.1
slope	0.09	

peak moment M=PL/2 (kNm)	0.11
rupture modulus, f'r=M/S (MPa)	0.19
(psi)	28
modulus of elasticity, $E=48dI/PL^3$ (MPa)	0.002
(psi)	0.2



Time	Axial Displ	Axial Force			
Sec	mm	kN	Displ	Load (kN)	Fit Line
0.259277	-13.2079	-0.01801	0	0	-0.017
0.509277	-13.2588	-0.02179	0.050829	0.003776	-0.01243
0.759277	-13.3077	-0.02563	0.0998	0.007618	-0.00802
1.009277	-13.3559	-0.02819	0.148	0.010181	-0.00368
1.259277	-13.4077	-0.02991	0.199793	0.011898	0.000981
1.509277	-13.4552	-0.03355	0.247313	0.015542	0.005258
1.759277	-13.5093	-0.03673	0.301409	0.018717	0.010127
2.009277	-13.5568	-0.0399	0.348873	0.021884	0.014399
2.259277	-13.6059	-0.04454	0.398008	0.026526	0.018821
2.509277	-13.6564	-0.04632	0.448468	0.02831	0.023362
2.759277	-13.7056	-0.05371	0.497707	0.035694	0.027794
3.009277	-13.7574	-0.05507	0.549463	0.037056	0.032452
3.259277	-13.8063	-0.06023	0.59836	0.042218	0.036852
3.509277	-13.8541	-0.06181	0.646159	0.043793	0.041154
3.759277	-13.9086	-0.06686	0.700638	0.048852	0.046057
4.009277	-13.9566	-0.06805	0.748648	0.05004	0.050378
4.259277	-14.0058	-0.07453	0.797859	0.056515	0.054807
4.509277	-14.0544	-0.07731	0.846436	0.059295	0.059179
4.759277	-14.1078	-0.08151	0.899853	0.063502	0.063987
5.009277	-14.1542	-0.08423	0.946247	0.066222	0.068162
5.259277	-14.2046	-0.0884	0.996702	0.07039	0.072703
5.509277	-14.2553	-0.09342	1.047371	0.075412	0.077263
5.759277	-14.3073	-0.09646	1.099325	0.078451	0.081939
6.009277	-14.3554	-0.10018	1.147451	0.082169	0.086271
6.259277	-14.4034	-0.10415	1.195454	0.086139	0.090591
6.509277	-14.4552	-0.10759	1.247311	0.089577	0.095258
6.759277	-14.505	-0.11571	1.297025	0.097696	0.099732
7.009277	-14.5559	-0.12074	1.347984	0.102729	0.104319
7.259277	-14.6048	-0.12511	1.396921	0.107099	0.108723
7.509277	-14.6593	-0.1295	1.451383	0.111491	0.113624
7.759277	-14.7048	-0.13502	1.496828	0.117008	0.117715
8.009277	-14.7574	-0.13754	1.54952	0.119528	0.122457
8.259277	-14.8044	-0.1428	1.596519	0.124785	0.126687
8.509277	-14.8563	-0.14684	1.648393	0.128829	0.131355
8.759277	-14.9042	-0.15075	1.696282	0.132737	0.135665
9.009277	-14.9554	-0.15573	1.747514	0.13772	0.140276
9.259277	-15.0048	-0.15993	1.796876	0.141919	0.144719
9.509277	-15.0549	-0.16528	1.846996	0.147273	0.14923
9.759277	-15.1048	-0.17243	1.896901	0.154413	0.153721
10.00928	-15.1541	-0.1745	1.94613	0.156493	0.158152
10.25928	-15.2038	-0.17756	1.995846	0.159545	0.162626
10.50928	-15.2555	-0.18658	2.047586	0.168564	0.167283
10.75928	-15.3062	-0.18951	2.098307	0.171495	0.171848
11.00928	-15.3538	-0.1958	2.145859	0.17779	0.176127
11.25928	-15.402	-0.19806	2.194118	0.180043	0.180471
11.50928	-15.4534	-0.2038	2.245455	0.185789	0.185091
11.75928	-15.5061	-0.20801	2.298182	0.189999	0.189836
12.00928	-15.5577	-0.2144	2.349725	0.196385	0.194475
12.25928	-15.6047	-0.21851	2.396768	0.2005	0.198709
12.50928	-15.6565	-0.22612	2.448622	0.208108	0.203376
12.75928	-15.7044	-0.22826	2.496425	0.21025	0.207678
13.00928	-15.755	-0.23578	2.547048	0.217765	0.212234
13.25928	-15.8035	-0.23779	2.595529	0.219783	0.216598
13.50928	-15.854	-0.245	2.646044	0.226983	0.221144
13.75928	-15.905	-0.24867	2.697067	0.230656	0.225736
14.00928	-15.9546	-0.25596	2.746638	0.237945	0.230197
14.25928	-16.0066	-0.26005	2.79865	0.242039	0.234879
14.50928	-16.0535	-0.26388	2.845561	0.245867	0.2391
14.75928	-16.1028	-0.26738	2.894843	0.249369	0.243536
15.00928	-16.1557	-0.27315	2.947818	0.255141	0.248304
15.25928	-16.2052	-0.27486	2.997313	0.256847	0.252758
15.50928	-16.2556	-0.27901	3.047671	0.260993	0.25729
15.75928	-16.3033	-0.28285	3.09537	0.264836	0.261583
16.00928	-16.3551	-0.28714	3.14717	0.269124	0.266245
16.25928	-16.4043	-0.29337	3.196418	0.275361	0.270678
16.50928	-16.4542	-0.29587	3.246272	0.277855	0.275164
16.75928	-16.5038	-0.30422	3.295892	0.286207	0.27963

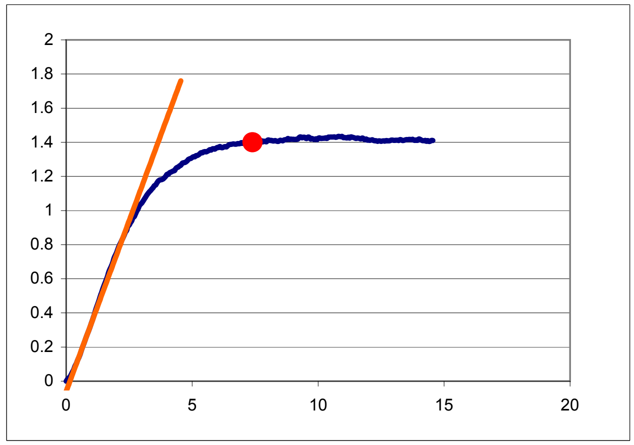
C-6 Bending(55-1)

MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header: Strawclay bend test 55 pcf Time: 327.5855 Sec ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

width, b (mm)	height, h (mm)	span, L (mm)	area, A (mm²)	section modulus S=bh²/6 (mm³)	moment of inertia I=bh³/12 (mm^4)
152.4	152.4	330.2	7669146	589934	44952994

	x	y		
peak	7.4	1.4	peak moment M=PL/2 (kNm)	0.23
start	0.45	0.12	rupture modulus, f'r=M/S (MPa)	0.39
slope	0.4		(psi)	58
			modulus of elasticity, E=48dI/PL³ (MPa)	0.007
			(psi)	1.0



Time	Axial Displ	Axial Force			
Sec	mm	kN	Displ	Load (kN)	Fit Line
0.259033	-9.91017	-0.03558	0	0	-0.06
0.509033	-9.96099	-0.04706	0.050816	0.011484	-0.03967
0.759033	-10.0103	-0.05439	0.100089	0.018814	-0.01996
1.009033	-10.0626	-0.06229	0.152438	0.02671	0.000975
1.259033	-10.1121	-0.07566	0.201893	0.040079	0.020757
1.509033	-10.1597	-0.08947	0.249487	0.053894	0.039795
1.759033	-10.211	-0.1035	0.300855	0.067919	0.060342
2.009033	-10.2619	-0.12326	0.351687	0.087677	0.080675
2.259033	-10.3082	-0.13786	0.397997	0.102281	0.099199
2.509033	-10.3623	-0.15736	0.452083	0.121778	0.120833
2.759033	-10.4115	-0.17324	0.501352	0.137664	0.140541
3.009033	-10.4609	-0.19193	0.550691	0.156348	0.160276
3.259033	-10.5102	-0.21262	0.60002	0.17704	0.180008
3.509033	-10.5603	-0.23502	0.650149	0.199439	0.200059
3.759033	-10.61	-0.25414	0.69978	0.218565	0.219912
4.009033	-10.661	-0.27504	0.750814	0.23946	0.240325
4.259033	-10.7111	-0.29611	0.800926	0.260535	0.26037
4.509033	-10.76	-0.31635	0.849838	0.280769	0.279935
4.759033	-10.8111	-0.33486	0.900907	0.299284	0.300363
5.009033	-10.8612	-0.35552	0.951029	0.319941	0.320411
5.259033	-10.9122	-0.37805	1.002018	0.342476	0.340807
5.509033	-10.9634	-0.39878	1.053239	0.363196	0.361295
5.759033	-11.0115	-0.41835	1.101313	0.382774	0.380525
6.009033	-11.0612	-0.44352	1.151021	0.407941	0.400408
6.259033	-11.1084	-0.46644	1.198179	0.430857	0.419271
6.509033	-11.161	-0.48707	1.250833	0.451491	0.440333
6.759033	-11.213	-0.50931	1.302831	0.473734	0.461132
7.009033	-11.2613	-0.53321	1.351152	0.497628	0.480461
7.259033	-11.311	-0.55085	1.400866	0.515269	0.500346
7.509033	-11.3604	-0.57493	1.450238	0.539354	0.520095
7.759033	-11.4115	-0.5949	1.501279	0.559322	0.540511
8.009033	-11.4619	-0.61416	1.551702	0.578577	0.560681
8.259033	-11.5092	-0.63354	1.598993	0.597957	0.579597
8.509033	-11.5619	-0.6557	1.651754	0.620121	0.600701
8.759033	-11.6092	-0.67824	1.69905	0.642663	0.61962
9.009033	-11.6606	-0.69571	1.75044	0.660132	0.640176
9.259033	-11.7125	-0.71448	1.80231	0.678901	0.660924
9.509033	-11.7609	-0.73143	1.85073	0.695849	0.680292
9.759033	-11.8121	-0.75628	1.901897	0.720704	0.700759
10.00903	-11.8625	-0.77389	1.952297	0.73831	0.720919
10.25903	-11.9096	-0.7899	1.999421	0.754325	0.739768
10.50903	-11.9607	-0.8104	2.050542	0.774826	0.760217
10.75903	-12.0103	-0.82588	2.100145	0.7903	0.780058
11.00903	-12.0617	-0.8447	2.151517	0.809126	0.800607
11.25903	-12.1118	-0.85885	2.201617	0.823271	0.820647
11.50903	-12.1599	-0.87358	2.249697	0.838	0.839879
11.75903	-12.2121	-0.89117	2.301888	0.855595	0.860755
12.00903	-12.2621	-0.90851	2.351949	0.872927	0.880779
12.25903	-12.3108	-0.92024	2.400618	0.884666	0.900247
12.50903	-12.3601	-0.94105	2.449913	0.905473	0.919965
12.75903	-12.4129	-0.95109	2.502711	0.915507	0.941084
13.00903	-12.4597	-0.96362	2.549506	0.92804	0.959802
13.25903	-12.51	-0.97447	2.599854	0.938888	0.979941
13.50903	-12.5612	-0.99387	2.65106	0.958294	1.000424
13.75903	-12.6109	-0.99981	2.700738	0.964233	1.020295
14.00903	-12.6595	-1.01506	2.749373	0.979484	1.039749
14.25903	-12.7101	-1.03241	2.799888	0.996834	1.059955
14.50903	-12.7593	-1.04262	2.849098	1.007045	1.079639
14.75903	-12.8096	-1.06095	2.899395	1.025374	1.099758
15.00903	-12.8632	-1.07281	2.953061	1.037228	1.121224
15.25903	-12.9137	-1.08039	3.003548	1.04481	1.141419
15.50903	-12.9618	-1.0904	3.05162	1.054824	1.160648
15.75903	-13.0108	-1.1023	3.100643	1.066717	1.180257
16.00903	-13.0627	-1.11353	3.152485	1.077949	1.200994
16.25903	-13.1091	-1.12544	3.198901	1.089863	1.21956
16.50903	-13.1601	-1.13505	3.249935	1.099469	1.239974
16.75903	-13.2094	-1.14454	3.299264	1.108961	1.259705

C-6 Bending(55-2)

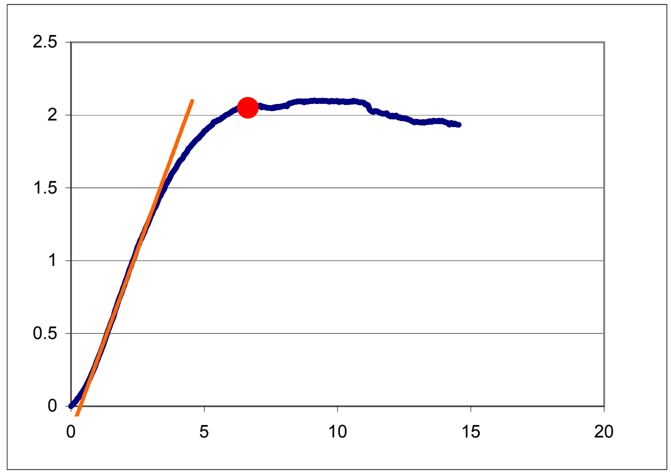
MTS793|BTW|ENU|1|2|.|/|:|1|0|0|A

Data Header: Strawclay bend test 55 pcf Time: 272.6787 Sec ########
Data Acqu Timed
Station Na Basic1.cfg
Test File N Thornton-March2004.tst

	width, b (mm)	height, h (mm)	span, L (mm)	area, A (mm^2)	section modulus $S=bh^2/6$ (mm^3)	moment of inertia $I=bh^3/12$ (mm^4)
	152.4	152.4	330.2	7669146	589934	44952994

	x	y
peak	6.64	2.05
start	0.95	0.3
slope	0.5	

peak moment M=PL/2 (kNm)	0.34
rupture modulus, f'r=M/S (MPa)	0.57
(psi)	84
modulus of elasticity, $E=PL^3/48yI$(MPa)	0.008
(psi)	1.2



Time	Axial Displ	Axial Force			
Sec	mm	kN	Displ	Load (kN)	Fit Line
0.258789	-5.94801	-0.01774	0	0	-0.175
0.508789	-5.99917	-0.02886	0.051152	0.011119	-0.14942
0.758789	-6.04648	-0.03483	0.098465	0.017094	-0.12577
1.008789	-6.09766	-0.04584	0.149643	0.028099	-0.10018
1.258789	-6.14698	-0.05655	0.198966	0.038809	-0.07552
1.508789	-6.19894	-0.0725	0.250931	0.054757	-0.04953
1.758789	-6.24893	-0.08042	0.30092	0.062686	-0.02454
2.008789	-6.29823	-0.09518	0.35022	0.077436	0.00011
2.258789	-6.35	-0.1085	0.401983	0.090764	0.025991
2.508789	-6.39773	-0.12227	0.449713	0.104531	0.049857
2.758789	-6.44825	-0.13647	0.500234	0.118726	0.075117
3.008789	-6.5001	-0.15273	0.552085	0.134993	0.101043
3.258789	-6.54784	-0.17026	0.599823	0.152518	0.124912
3.508789	-6.5976	-0.1876	0.649589	0.169856	0.149795
3.758789	-6.65003	-0.2072	0.702016	0.18946	0.176008
4.008789	-6.69753	-0.22874	0.749521	0.211	0.19976
4.258789	-6.74934	-0.24998	0.801328	0.232241	0.225664
4.508789	-6.79754	-0.27023	0.849523	0.252495	0.249762
4.758789	-6.84565	-0.29009	0.897637	0.272353	0.273819
5.008789	-6.89556	-0.31727	0.947551	0.299536	0.298776
5.258789	-6.94858	-0.34133	1.000567	0.32359	0.325284
5.508789	-6.99801	-0.36473	1.05	0.346991	0.35
5.758789	-7.04755	-0.3845	1.099532	0.366765	0.374766
6.008789	-7.09635	-0.40899	1.148338	0.391247	0.399169
6.258789	-7.14783	-0.4328	1.199818	0.41506	0.424909
6.508789	-7.1967	-0.4594	1.248683	0.441664	0.449342
6.758789	-7.24539	-0.48738	1.297381	0.46964	0.47369
7.008789	-7.29548	-0.51176	1.347466	0.494023	0.498733
7.258789	-7.34723	-0.54056	1.399218	0.522817	0.524609
7.508789	-7.39663	-0.56252	1.448612	0.544786	0.549306
7.758789	-7.45013	-0.59133	1.502118	0.573586	0.576059
8.008789	-7.4964	-0.61279	1.548387	0.595048	0.599194
8.258789	-7.54917	-0.63627	1.601158	0.618532	0.625579
8.508789	-7.59873	-0.67302	1.65072	0.65528	0.65036
8.758789	-7.64673	-0.69557	1.698718	0.677826	0.674359
9.008789	-7.69674	-0.72421	1.748729	0.706468	0.699364
9.258789	-7.74723	-0.75242	1.799214	0.734678	0.724607
9.508789	-7.79687	-0.77589	1.848861	0.758153	0.74943
9.758789	-7.8485	-0.79951	1.900487	0.78177	0.775244
10.00879	-7.89819	-0.82889	1.950175	0.811153	0.800087
10.25879	-7.94736	-0.84883	1.999344	0.831092	0.824672
10.50879	-7.99801	-0.88093	2.049999	0.863189	0.849999
10.75879	-8.04592	-0.90276	2.097903	0.885019	0.873952
11.00879	-8.09768	-0.9307	2.149664	0.912963	0.899832
11.25879	-8.14604	-0.95859	2.198027	0.940851	0.924013
11.50879	-8.19926	-0.97999	2.251242	0.962252	0.950621
11.75879	-8.24732	-1.00742	2.299305	0.989676	0.974653
12.00879	-8.29803	-1.02975	2.35002	1.012016	1.00001
12.25879	-8.34672	-1.05375	2.398706	1.036015	1.024353
12.50879	-8.39765	-1.08234	2.449636	1.064605	1.049818
12.75879	-8.446	-1.11076	2.497988	1.093021	1.073994
13.00879	-8.49717	-1.13167	2.549157	1.113929	1.099579
13.25879	-8.54679	-1.15731	2.598776	1.139571	1.124388
13.50879	-8.59474	-1.17087	2.646722	1.153133	1.148361
13.75879	-8.64873	-1.19666	2.700719	1.17892	1.175359
14.00879	-8.69639	-1.21268	2.748377	1.19494	1.199188
14.25879	-8.74766	-1.23899	2.799648	1.221249	1.224824
14.50879	-8.79662	-1.25869	2.848607	1.240952	1.249304
14.75879	-8.84621	-1.27855	2.898201	1.260815	1.274101
15.00879	-8.89405	-1.30019	2.946038	1.282451	1.298019
15.25879	-8.9458	-1.3243	2.997788	1.306564	1.323894
15.50879	-8.99477	-1.34325	3.046752	1.325513	1.348376

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