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Temperature and mold size effects on density gradients and mechanical properties in a polyurethane foam system

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TEMPERATURE & MOLD SIZE EFFECTS ON DENSITY GRADIENTS AND MECHANICAL PROPERTIES IN A POLYURETHANE FOAM SYSTEM

by

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ABSTRACT

Temperature and Mold Size Effects on Density Gradients and Mechanical Properties in a Polyurethane Foam System

by

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Rigid polyurethane foams can be used as a thermal or vibration insulator and energy absorption material. They are often molded directly in place, where a smooth, thin skin forms between the mold and the cellular structure of the foam. Density gradients and the skin are shown to have an effect on the mechanical properties of the foam.

This work will investigate the effects of processing temperature and mold size on the average density, density gradient, compressive modulus, and compressive strength, for a molded free rise, water blown polyurethane foam system. Four processing temperatures are used during foam fabrication: 25°C, 40°C, 65°C, and 85°C. Three aluminum cylinder mold sizes are used with diameters of 29mm, 41mm, and 51mm. The properties are also compared to reference samples with a uniform density of 0.101 g/cc.

Results show that processing temperature and mold size have a significant effect on density, density gradients and some mechanical properties.

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who make me laugh and remind me that there are simple pleasures in the world. Their joy and curiosity are always amazing and inspiring. To see the world through the eyes of a child is like discovering new worlds. I can hardly wait to see them grow.

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CHAPTER 1

INTRODUCTION

1.1 Purpose of Study

Rigid polyurethane foams are used as shock and thermal insulators and energy absorption material for sensitive electronic components. Toluene Di-Isocyanate (TDI) foam is the most common polyurethane foam used in the Department of Energy (DOE) stockpile [1]. TDI has proven to be hazardous to handle during the fabrication process and may degrade over long periods of time. The DOE is investigating new foams, using materials with less health risk, as replacements for TDI [2,3]. Researchers are preparing and comparing a variety of these foams by evaluating chemical and mechanical properties. Replacement foams must demonstrate equivalent mechanical properties such as strength and energy absorption and similar or better aging characteristics to be considered an adequate replacement. One of these candidate replacement foams is ReCrete, a water blown, rigid closed cell polyurethane foam developed by Dr. Leroy Whinnery at Sandia National Laboratory in Livermore CA (SNL) [4].

Density gradients and the skin are shown to have an effect on the mechanical properties of the foam [5]. Without changing the design formulation, other parameters in the fabrication of the foam, such as the temperature of the molds during the foaming process and the size of the molds, are changed to determine the effect on the foam's physical and mechanical properties.

1.2 Objectives of Study

The objective of this study is to investigate the effect of processing temperature and mold size on density, density gradients, and compressive mechanical properties of a polyurethane foam system. If the foam is shown to exhibit density gradients, the change in density may correlate with the changes in the compressive mechanical properties of the foam. By molding the foam in three different sized cylinders, the affect of mold size can be examined. Foam formation is an exothermic reaction that can generate significant heat, especially when made in large quantities. The molds used to make foam can heat up throughout a production day. The effect of mold temperature during the foaming process will also be examined. Reference batches of foam are also evaluated. These batches are prepared in larger molds at room temperature. Test samples are cut from the center of the foam block where the density is uniform. Some questions to be considered are:

- Does a density gradient exist within the foam system in the radial (from center to outside edge) or vertical (from bottom to top) directions?
- How does changing the processing temperature of the foam affect the average density, the density gradients and the compressive mechanical properties (Young's modulus, collapse strength, peak stress, etc.)?
- How does increasing the mold size affect the average density, the density gradients and compressive mechanical properties of the foam?

1.3 Summary of Study Plan

This study will directly address the effect of processing temperature and mold size on the density gradients and compressive mechanical properties for a free rise, water blown

polyurethane foam system molded in aluminum cylinders. Quasi-static compression tests are used to determine the mechanical properties of the foam. An analysis of the average density and density gradients in the radial and vertical directions is also conducted. The properties are compared to reference samples with a uniform density of 0.101 g/cc. Additional studies performed by the UNLV Chemistry Department, which are not discussed in this thesis, will examine the chemical changes and thermal properties of the foam [5,6].

Foam samples are fabricated using four different processing temperatures: 25°C, 40°C, 65°C, and 85°C. Three aluminum cylinder sizes, with diameters of 28.7 mm, 40.6 mm, and 49.5 mm, are used to mold the foam. Each cylinder of foam is cut into four sections for testing. The average density of each sample can be determined by measuring the dimensions of the sample and weighing the sample. The density gradient is found using a coring method. A cork borer is used to remove small cylindrical samples at several radial positions from the foam. Quasi-static compression testing is performed on a mechanical test frame to determine the modulus, collapse strength, and peak yield strength. The testing data is used in creating stress-strain graphs.

1.4 Organization of Thesis

This thesis is divided into six chapters: Introduction, Background, Experimental Procedures, Results, Discussion of Results, and Conclusions and Recommendations. The purpose of the study and the objectives were presented in Chapter 1. A general description of how foam and skin are formed and a discussion of previous work are presented in Chapter 2. Chapter 3 details all of the procedures for the study, including

creating the foam, processing the samples, measuring the density and performing compression testing. The results are presented in a series of graphs in Chapter 4. The results are analyzed and discussed in Chapter 5. Conclusions derived from the results and recommendations for future work are presented in Chapter 6.

CHAPTER 2

BACKGROUND

2.1 Chemistry of Foam

2.1.1 TDI Based Foams vs. MDI Based Foams

Currently the Department of Energy (DOE) uses toluene di-isocyanate (TDI) foams to protect sensitive electronics in weapons. TDI foam (BKC 44402) may be a human carcinogen. Work is being done at SNL to develop a new foam system which does not use the same hazardous constituents as TDI foam. A focus has been placed on methylene di-isocyanate (MDI) foams. One replacement foam (BKC 44320), developed at Sandia National Labs in New Mexico (SNL/NM), combines a polyester polyol component with a quasi-prepolymer, polymeric methylene di-isocyanate (PMDI). It is found that the vapor pressure of PMDI is significantly lower than TDI, making it easier to control the levels of airborne isocyanate. Another replacement (BKC 44307), also based on PMDI, uses a polyether polyol. The constituents of BKC 44307 have a higher functionality, resulting in a higher degree of cross-linking, making the foam stiffer and more brittle than the other foams discussed [2].

One purpose of the foam is to fill areas surrounding electronic components. A foam that does not completely cure (or "gel") before it expands (or "rises") to fill the molded area is desired. The reaction temperature of the formulation, which shows some dependence on pour size, will determine how much the foam can expand beyond its

curing point. For example, smaller pour sizes, like those used in DOE applications, will have a lower reaction temperature and less expansion. An equal time ratio (unity) between curing and expansion is desired to fill small areas. In PMDI foam systems, which have a low cure-to-expansion ratio, catalysts are used to balance the cure and expansion times, giving a ratio close to one [2].

2.1.2 ReCrete Polyurethane Foam

The rigid polyurethane foam system used in this study is ReCrete. ReCrete is an attempt to create a foam system with mechanical properties similar to TDI foam. A modified-MDI (MMDI) is used to delay the reaction time by lowering the functionality of the components. A tertiary amine catalyst (Polycat 17) is used to further control the cure-to-expansion ratio [2]. ReCrete is made of five components (information on the components is in Appendix A):

- Voranol 490: A polyether polyol, made from polypropylene oxide and a sucrose/glycerin base.
- DC193: A silicone glycol copolymer surfactant
- Polycat 17: A tertiary amine catalyst (trimethyl-N-hydroxyethyl propylene diamine).
- Distilled Water: A chemical blowing agent.
- Rubinate 1680: A Di-isocyanate

Similar to TDI, the distilled water is used as a chemical blowing agent. The density of the foam can be adjusted by changing the amount of water in the formulation. Adding more water causes the more rise in the foam and lower density [3].

Figure 2.1 shows the gel formation and gas generation chemical reactions in polyurethane foam making. The water reacts with the di-isocyante (Rubinate) to form an unstable intermediate. The carbonic acid intermediate decomposes, giving off CO_2 gas, causing the foam to expand. An amine is also formed and reacts further with the di-isocyante to form another linkage called a 'urea.' A cross-linked network of urea and urethane linkages form as the carbon dioxide gas tries to escape. Not all the gas molecules escape the foam cellular structure and some unreacted groups remain after formation. This occurs because as the polymer foam forms a network the chains stiffen, preventing the reaction of some groups and trapping some of the CO_2 gas [7,8].

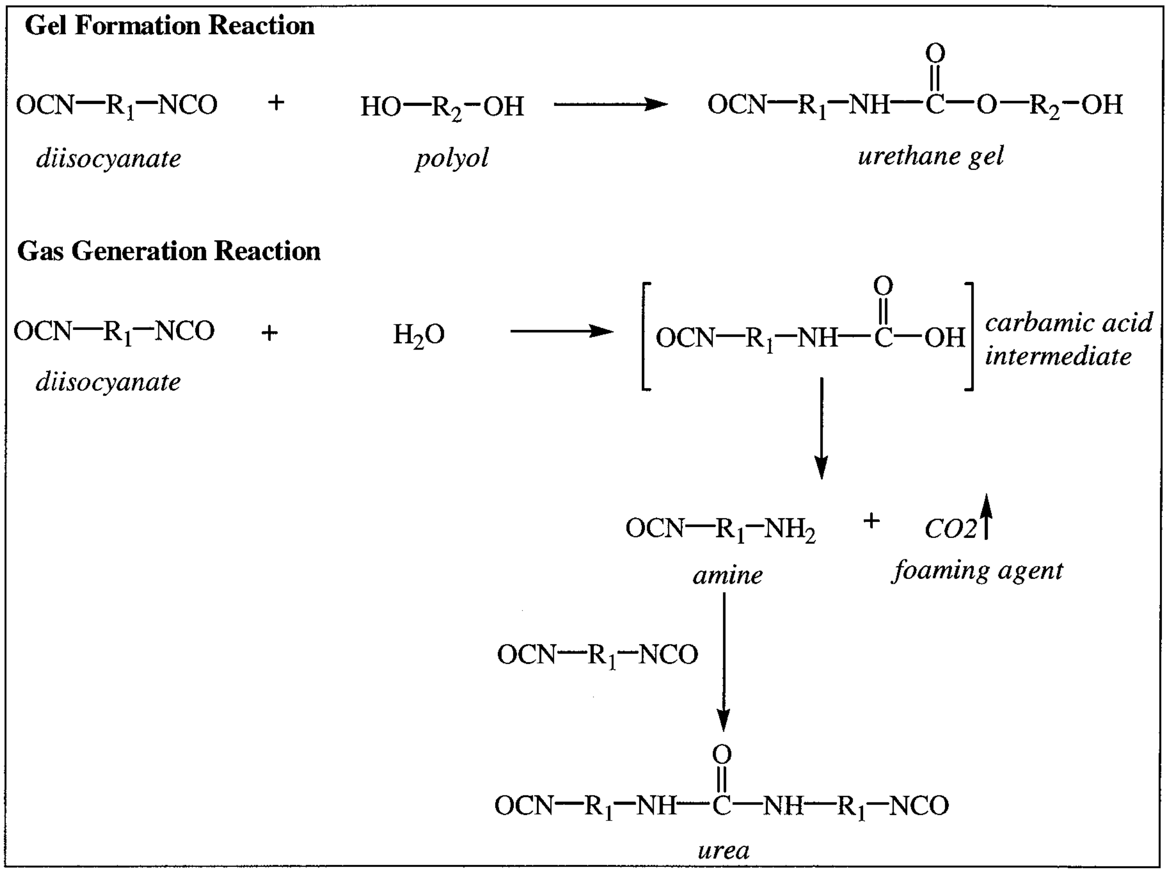


Figure 2.1: General Polyurethane Foam Reactions

Previous studies of ReCrete were performed on foams cut from relatively large batches with uniform density and skins removed [4]. However, foams are often molded directly in place, where a smooth, thin skin forms between the mold and the cellular structure of the foam. Density gradients and the skin are shown to have an effect on the mechanical properties and affect the aging characteristics of the foam. Brachos and Douglas showed that the foam core and the core/skin properties have a significant effect on the energy absorption properties of foam–cored composites [9]. Gupta and Khakhar reported a decrease in density as the mold temperature was increased while foaming packed integral skin polyurethane foams blown with a volatile solvent [10]. More recently, Harbron showed that higher processing temperatures reduced the density gradient in water blown polyurethane foams [11].

Polyurethane skins are high density and surround a lower density foam core. Skins are formed by a polymerization of polyol and isocyanate inside the mold. The heat of the reaction causes vaporization of the blowing agent (water), which then condenses near the cooler mold wall, creating a skin layer during the foaming process [10].

2.2 Compressive Mechanical Properties

Compression testing is used to determine some of the mechanical properties of the foam. A sample is placed between two plates and stress and strain data is collected while the plates compress the sample. Stress is the amount of force applied to the sample in the axial direction divided by the sample's cross-sectional area. Strain is a ratio of the sample's deformation (shortened length) to the sample's original (gage) length. Figure 2.2 shows a typical stress-strain curve.

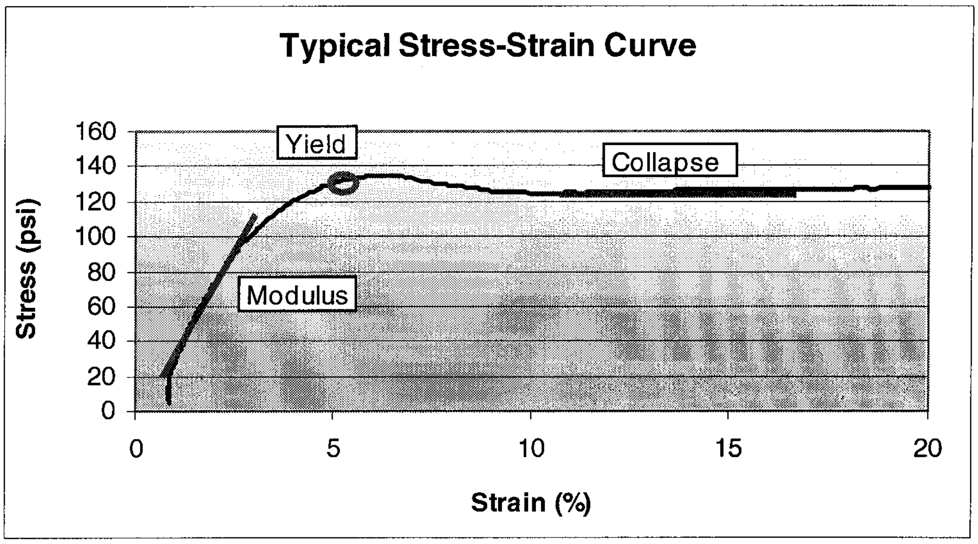


Figure 2.2: Example of Typical Stress-Strain Curve

The curve begins linear and proportional, which is known as the elastic region of the material. The modulus of elasticity is a measure of the stiffness of the material; the higher the modulus the more rigid the material. The modulus of the sample is determined by the slope of the curve in the elastic region. Strain increases more rapidly beyond the limit of elasticity, decreasing the slope. Peak (yield) strength is where the slope decreases to zero. The peak strength of a sample is determined by the point on the curve where the stress has reached a maximum. The material bulges outward, becoming barrel shaped during compression. Collapse strength is defined as the region of the curve where the foam shortens continuously under a constant load and the curve becomes horizontal and perfectly plastic. The collapse strength of the sample is determined by the plateau (flat) region of the curve [12].

There is no target modulus of elasticity, peak yield or collapse strength. The optimal values for the mechanical properties depend on the application of the material. For

example, a large change in stress over a small change in strain will have low energy absorption (determined by the area under the modulus curve). Determining how the processing temperature and size of mold affect the properties of the material is important to its application. If Recrete is to be used in DOE applications, the properties of the foam will need to be predictable.

2.3 Current and Previous Work Done at UNLV

2.3.1 Study of the Effects of Skin

A theoretical study of the effect of skin on polyurethane foams was preformed in summer 2000 by M.C. Nelson. Molded polyurethane foams with a thin skin layer are similar to composite sandwich structures. Assuming a constant skin thickness, the skin volume fraction (area of skin to area of skin and foam) decreases as mold size increases. The rule of mixture equation was used to relate the modulus and stress to the skin thickness to foam thickness ratio [13].

The results for this study were theoretically based on mechanical property data gathered from other applications. It was shown that as the skin volume fraction increases, the modulus of elasticity and tensile strength increase linearly. Increasing the skin thickness increases the skin volume fraction exponentially [14]. This analysis was based on a thick skin model unlike the skins formed in this thesis. A further analysis of how the skin thickness affects the mechanical properties, using actual experimentation, would be beneficial.

2.3.2 Study of the Effects of Mold Size

A study of the effects of mold size on density and density gradients was performed in spring 2001. Three different molds were used: a right aluminum cylinder with an inner diameter on 29mm, a 1-liter plastic pour cup with an increasing diameter between top (95mm) and bottom (76mm), and a 4-liter plastic bucket with an inner diameter of 175mm. Foam was fabricated at room temperature and all the molds yielded four vertical levels for testing. Cores were removed for the samples in a radial pattern to determine the density at different radial positions (radial density gradient). Vertical density gradients were studies by coring 25.4mm samples out of the larger mold at different vertical positions and determining the average density of the samples.

The results showed that both the radial and vertical density gradients were affected by the change in mold size. The density increased from the center of the sample to the outside. The radial density gradient decreased as mold size increased. All of the molds showed an increase in density from the top to the bottom. Increasing the mold size resulted in a decrease in vertical density [15].

This was a generalized study, using widely different mold sizes. The different material of each mold may have had an effect on the results. This thesis changes the parameters of the study to only address uniform right cylinder molds made of aluminum and to also examine the effect of mold size on mechanical properties.

2.3.3 Study of the Effects of Processing Temperature

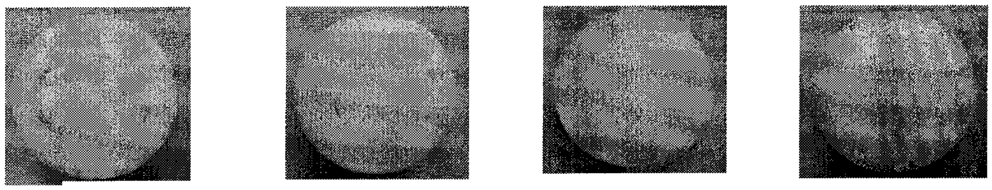
A study of the effects of processing temperature on density, density gradients and mechanical properties was performed in summer 2001. Five different processing temperatures were used: 0°C (ice bath), 25°C (room temperature air), 25°C, 40°C and

90°C (water bath). The foam was fabricated in right aluminum cylinders with a 29mm diameter. Density and density gradients were studied using the same methods as the mold size study. Quasi-static compression testing was used to determine the mechanical properties.

The results showed that temperature had a significant effect on the density gradients and mechanical properties of the molded foam. There was little change in the compressive stress and peak yield, but the modulus of elasticity showed a marked change. Increasing the temperature decreases the density and density gradients. The extreme temperature batches (0°C and 90°C) showed a large scatter in data [16].

This processing temperature study encouraged a closer look at the affects of temperature during the foaming process. The inconsistencies in the extreme processing temperature batches suggest changes in the chemistry of the foam. Controlling the processing temperature during foaming affects the formation of CO_2 gas and urea linkages. The low processing temperature of the ice bath decreased the gas generation and increased the viscosity of the formulation. The even dispersion of gas and the diffusion of mixture reagents were reduced, increasing non-uniformity in the foam samples [7]. Figure 2.3 shows examples of samples take from each processing temperature batch. Large voids can be seen in both the ice bath and the 90°C samples.

This thesis changes the parameters of the study to only address temperatures higher than standard room temperature conditions. Also, processing temperatures lower than 90°C are used in this study because the mechanical analysis and density analysis results have less variation than the results for the 90°C bathes. Future work may indicate changes in the chemistry of the foam on a microscopy level.



0°C 25°C 40°C 90°C

Figure 2.3: Photographs of Foam Samples

2.3.4 Chemistry Analyses

There are three main types of testing being performed by the chemistry department at UNLV: Infrared Spectroscopy (IR) and X-Ray Spectroscopy, Netzsch Simultaneous Thermal Analyzer (STA), and Thermal Mechanical Analysis (TMA). Small circular samples are cored from larger prepared samples. From each foam sample, small circular specimens are cored (two from the center and two from the edge). The samples have an average height of 2.8 mm [7].

The IR and X-Ray methods are used to study changes in chemistry as the polyurethane ages. The goal of this study is to determine spectral features characteristic of aging polymer. The amount of di-isocyanate that reacts relates to the processing temperature, lower temperatures have fewer reactions [17].

The STA system is used to perform differential scanning calorimetry (DSC) and thermal gravimetric analysis (TGA) simultaneously. The experiments use open aluminum crucibles. The temperature ranges from 25°C to 540°C at a rate of 10°C/min. The tests are run in a nitrogen atmosphere with a flow rate of 50 mL/min. An indium standard is used for temperature calibration [7]. The DSC results show a dependence on processing

conditions and aging. The TGA results show no significant change related to processing conditions or sample position [5].

The TMA uses a Netzsch TMA 202 instrument. Silica gel plates are used for height calibration. This test used a constant load with an increasing temperature, while mechanical compression tests increase load. The temperature ranges from 25°C to 250°C with a constant force of 5cN. The tests are run in the same environment and the temperature calibrated using the same method as the STA [7]. The TMA results show that the edges have larger variations than the centers and controlled processing temperatures showed less variation. Two expansion/collapse steps are seen in all the samples tested [5,6].

2.3.5 Future Work at UNLV

Foam morphology is also being studied at UNLV. Microscopy is used to collect data, such as average cell size, cell shape (anisotropy), strut wall thickness, and skin thickness. Some of the methods being considered to study morphology are confocal, optical, and Scanning Electron Microscope (SEM). It is being shown that cell size is more uniform throughout the sample at higher processing temperatures. The SEM can image a section 7 mm x 5.25 mm, and requires thirty-one images to model the cross-section of a 29 mm diameter sample [8].

The aging characteristics of ReCrete will be studied in the future. Aging ovens are being set up to age foam samples in an inert (nitrogen) atmosphere. New, non-destructive (FTIR photoacoustic spectroscopy) will be employed to further study the chemical changes within the foam. New types of replacement foam from SNL will also be investigated in the future [8].

CHAPTER 3

EXPERIMENTAL PROCEDURES

3.1 Fabrication of Foam

Recrete foam is fabricated from five constituents: Voranol 490, DC 193 Surfactant, Polycat 17 Amine Catalyst, distilled water, and Rubinate 1680. Material data sheets and supplier information for these materials are included in Appendix A. The mass of each component is selected to produce foam with a target density of 0.096 g/cc [4].

The Voranol is weighed in a 1-liter plastic container, with a height of 127.0 mm, under a chemical hood, as shown in Figure 3.1. The outside walls of the 1-liter container slope slightly, making the inner diameter 75.9 mm at the base and 95.0 mm at the rim. The next three chemicals are added to the plastic container using an eye dropper. Each chemical is added at a different place in the plastic container to limit early reactions. The chemicals are mixed by hand using a spatula for two minutes before adding the Rubinate. A slow, circular motion is used to minimize air bubbles. The spatula is then scraped clean into the plastic container using a wooden applicator stick to avoid wasting any of the formulation. Finally, the isocyanate (Rubinate) is weighed into the plastic container.

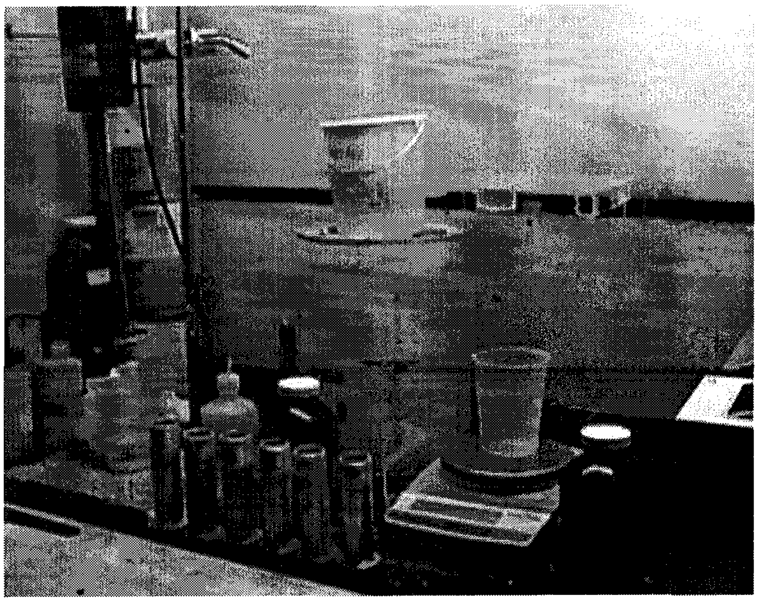


Figure 3.1: 1-Liter Plastic Container in Chemical Hood

Two people are present during the process. The actual material amounts vary during the mixing. The entire procedure is documented as shown in Figure 3.2. Each batch of foam is assigned a number designation. The date, room temperature and humidity, and other initial information are recorded on a data sheet. The data sheet states the target weight of each constituent; the actual measured weight is recorded on the sheet during the fabrication process. The data sheets are used to track any oddities in the foam's composition.

The completed formulation is then mixed for ninety seconds using an overhead mixer. To ensure thorough mixing, a spatula is used to scrape the sides of the plastic container during mixing. The foam is poured into six aluminum cylinder molds. The molds are left open on the top to allow the foam to rise freely. Enough formulation is poured into the molds so that a small bun will form at the top of each cylinder.

DATE: 3-4-02
BATCH NUM: D6
CHEMICALS: Cameron Nelson
ASSISTANTS: Dacia Jackovich
ADDTL INFO: 40°C WB Cyl FR (1.6" tubes)
B150 TEMP: 71.6°F B150 HUMIDITY: 28%
B150 BAROMETRIC PRESSURE: 30.36"

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	140.40	139.8
DC 193 Surfactant	(g)	3.55	3.54
Polycat 17 Amine Catalyst	(g)	0.82	0.85
Distilled Water	(g)	1.63	1.63
Rubinate 1680	(g)	214.18	214.8
Mix Size	(g)	360.58	
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 11:15 AM
TIME FOAM WAS PUT INTO OVEN: 11:45 AM
TIME FOAM WAS TAKEN OUT OF OVEN: 3:50 PM
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure 3.2: Chemical Formulation Documentation Sheet

Since the foam making procedure is performed by hand, some variations between batches made under the same conditions exist. Variations may also exist within the batches, between the tubes. The foam continually expands, lowering viscosity of the formulation and making pouring increasingly difficult. Six tubes are the maximum number that can be poured by hand after the final mixing step. The cylinders are poured in order, one through six. The same cylinder is used for each type of test (i.e. cylinder five is always used for radial density analysis). Figure 3.3 shows the foam in the cylinder molds with a bun top.

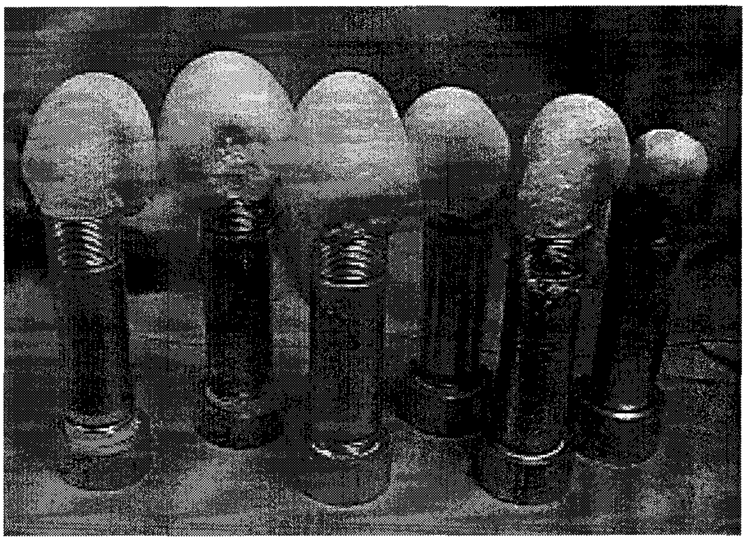


Figure 3.3: Foam after Rising for Thirty Minutes

The foam is allowed to rise in aluminum molds for thirty minutes under four different thermal conditions: 25°C, 40°C, 65°C, and 85°C. A water bath is used to create a controlled thermal environment for the molds. The water bath is set to the desired temperature before the chemicals are prepared. The aluminum cylinders are submerged and allowed to heat to the temperature of the water bath. The tops of the cylinders extend

about 12.5 mm out of the water. Figure 3.4 shows the foam in the water bath during the rising period.

A water bath is chosen to control the temperature of the aluminum cylinders during processing, despite the fact that water is the blowing agent for ReCrete, making the formulation sensitive to changes in the amount of water added. Increasing the amount of water allows more expansion and a lower density. Several precautionary measures are taken to ensure the use of the water bath would not affect the foam. The humidity is taken in the laboratory, both near the lab door and near the water bath (inside the hood), before heating the water bath. The humidity readings are taken again after the water bath is heated to 90°C. An insignificant change (less than 0.2%) is detected after the water bath is heated, indicating no real condensation effects. Temperatures below the boiling point of water are chosen to limit additional moisture in the air. O-rings and Teflon tape are used to prevent water from leaking into the cylinders, and a visual inspection of the tubes is made before the foam is poured. Finally, additional moisture would affect the surface of the foam, but not the overall foam composition because the formulation is already mixed and the reacting.

The water bath temperature of 25°C is chosen because it is approximately the ambient condition. The water bath temperature of 65°C is chosen because it is the same as the post-cure oven temperature. The water bath temperatures of 40°C and 85°C are chosen because they are midway between the ambient and the post-cure temperature and midway between the post-cure temperature and water boiling point respectively. Post-curing is conducted in a recirculating air oven at 66°C for four hours.

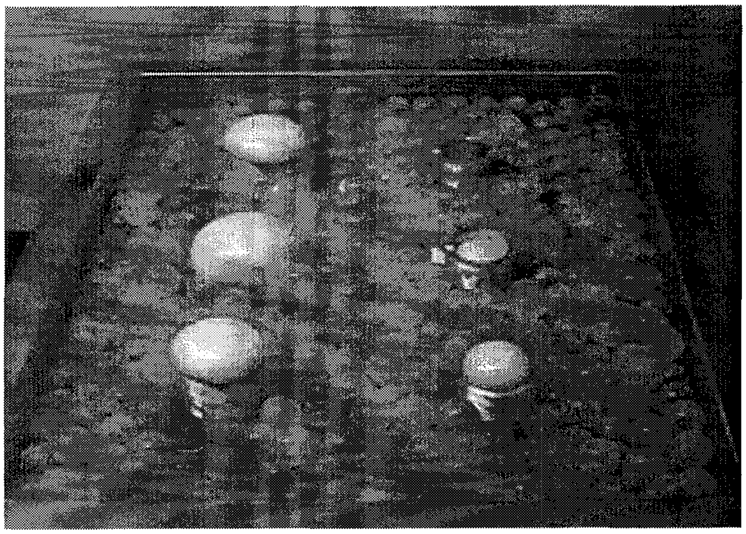


Figure 3.4: Foam Rising in the Water Bath for Thirty Minutes

Two reference batches of foam are fabricated in the same manner and molded in four 4-Liter plastic buckets. The buckets have a diameter of 190.5 mm and a height of 174.6 mm. The foam is processed in air at room temperature. Two buckets are used for density analysis and two buckets are used for mechanical testing. Figure 3.5 shows the 4-Liter plastic bucket and a sample of the molded foam.

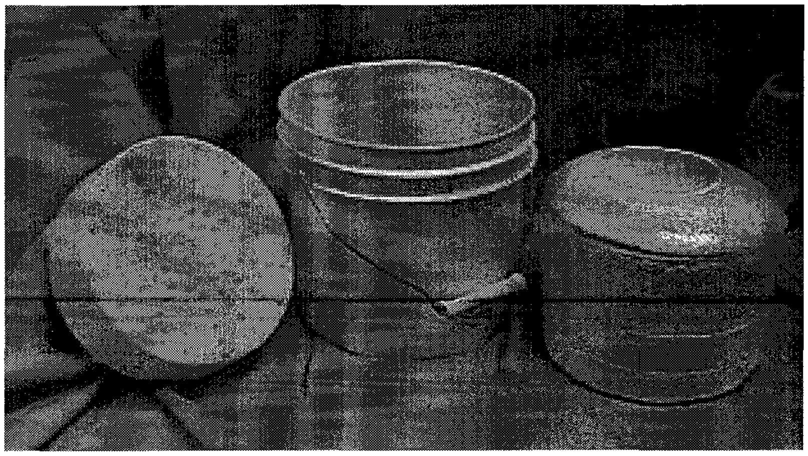


Figure 3.5: 4-Liter Plastic Bucket and Reference Foam

3.2 Aluminum Molds

3.2.1 Fabrication of Molds

Three sets of aluminum right circular cylinders are fabricated as molds, as shown in Figure 3.6. The small molds have a volume of 100.7 mL, an inner diameter of 29 mm and a wall thickness of 4.2 mm. The medium molds have a volume of 201.2 mL, an inner diameter of 41 mm and a wall thickness of 4.9 mm. The large molds have a volume of 311.3 mL, an inner diameter of 51 mm and a wall thickness of 6.5 mm. Aluminum tubing is used as the raw material. The tubing is cut into 152.4 mm sections and cored out with a lathe to the desired thickness. Using the lathe, one end of each section is threaded on the outside to at least a height of 29 mm.

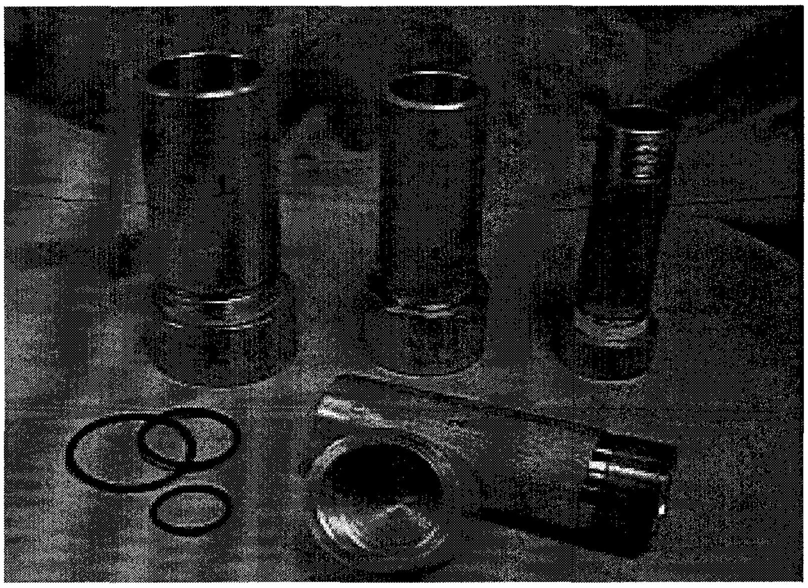


Figure 3.6: Aluminum Molds, Caps and O-Rings

Threaded caps are made from solid aluminum rods. The small mold caps have a diameter of 51mm and a height of 25.6 mm. The medium mold caps have a diameter of

63.6 mm and a height of 42.6 mm. The large mold caps have a diameter 76.4 mm and a height of 40.4 mm. The rods are cut into sections and cored out to a depth of about three-quarters the height. The inside of the caps are threaded on a lathe to mate with the threading on the cylinders.

3.2.2 Preparation of Molds

The aluminum cylinders are prepared with a mold release (PTM&W Industries #PA0801). The material data sheets and supplier information for the mold release are included in Appendix A. The wax-like substance is applied to the inside of the cylinders and the threaded caps. A soft rag is used to buff the inside surface of the cylinders after application of the release agent.

Excess water in the chemical formulation will affect the foam density and consistency, so the cylinders are treated for leaks before they are submerged in the water bath. O-rings are placed in the caps and Teflon tape is wrapped around the threads of the cylinders before the caps are attached. The cylinders are tested for leaks in a bucket of water for thirty minutes prior to being placed in the water bath.

The cylinders are numbered from one to six and placed in the water bath. The cylinders are allowed to heat in the bath in preparation for the foam rising process. The time required to heat the tubes to the water bath temperature is measured with a thermocouple placed inside the tube during a trial run. The inside tube wall temperature is approximately a linear relationship with time, approximately 1.5 °/minute, as shown in Figure 3.7.

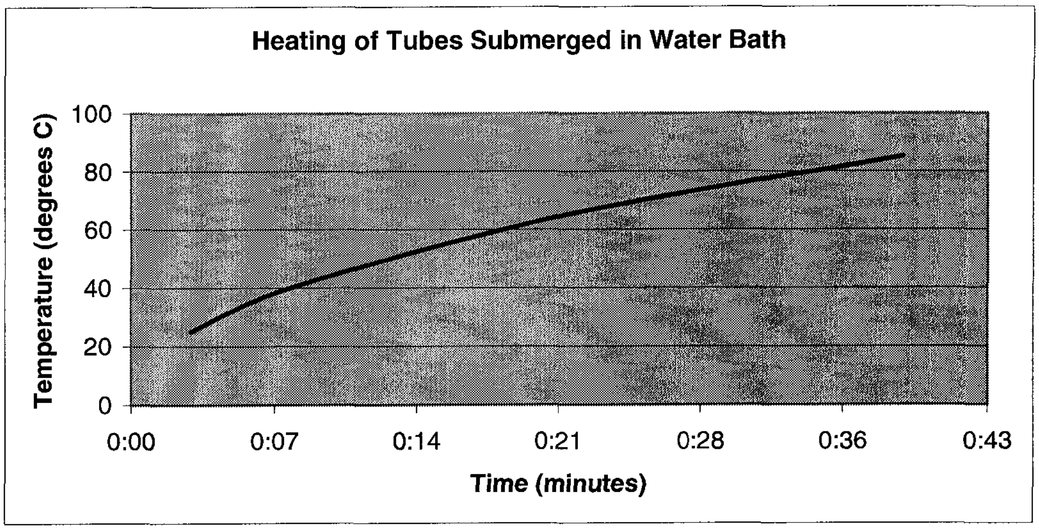


Figure 3.7: Time to Heat Cylinders in Water Bath

3.3 Processing of Foam

3.3.1 Aluminum Cylinder Molds

The foam is extracted from the cylinders after post-curing. The cylinders are allowed to cool for thirty minutes, making the removal easier. The cooled cylinders are easier to handle and the skin does not detach from the foam columns. The threaded caps and o-rings are removed and the foam is gently pushed out of the cylinders from the bottom. Each foam cylinder is numbered, to track the order in which the foam mixture is poured into the aluminum molds. Occasionally the bun tops extend over the tops and sides of the cylinders, making a quick extraction impossible. The bun is removed first, to free the top of the cylinder, by slicing chunks off with a knife. The foam column is then removed as previously described.

Figure 3.8: Cutting a Foam Column into Four Levels with a Band Saw

The bun tops and the bottoms are cut off the foam columns using a band saw. The columns are marked at 31.75 mm intervals and cut horizontally into four sections, as shown in Figure 3.8. Each sample is numbered one to twenty-four, in descending order from top to bottom and cylinder one to six, with four numbers per foam column, as shown in Figure 3.9.

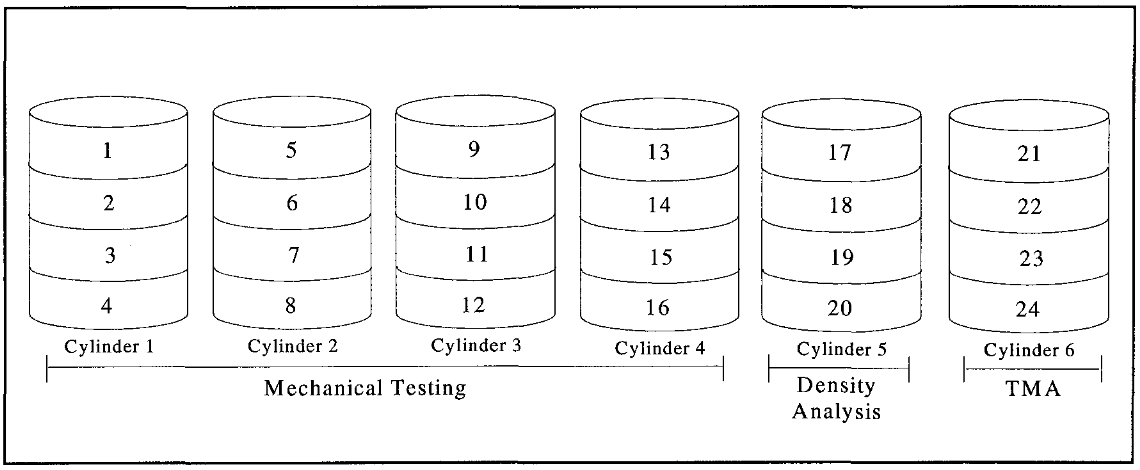


Figure 3.9: Foam Columns Divided into Levels and Numbered

Each sample is sanded on the top and bottom to a height of 25.4 mm to achieve sample consistency, as shown in Figure 3.10 [18]. Samples one through sixteen are used in mechanical testing and samples seventeen through twenty are used for density gradient analysis. Samples twenty-one through twenty-four are given to the Chemistry Department to be used for thermal mechanical analysis (TMA) in another study [5,6].

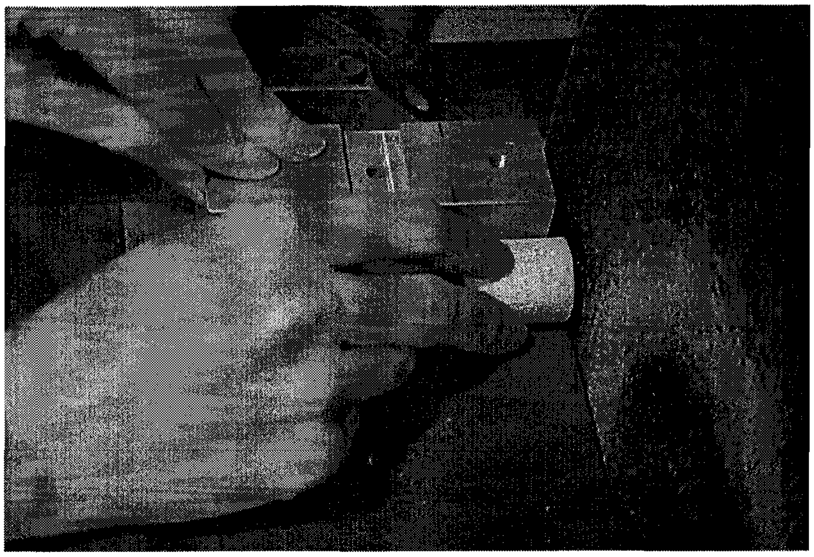


Figure 3.10: Sanding a Foam Sample

3.3.2 Reference Batch

Four equal vertical levels of 31.75 mm each are marked on the reference batch and cut with a band saw. Each level is then cut horizontally into four strips. The strips of foam are clamped in place and a hole saw is used to core samples out of the strips, as shown in Figure 3.11. The core drill has an inner diameter of 28.7 mm and yielded samples with an average diameter of 27.7 mm.

Each level yields twelve samples, as shown in Figure 3.12, for a total of forty-eight samples from the 4-Liter plastic bucket. The samples are numbered one through twelve

for each level. Each level is color coded to track the original position of each sample taken from the mold. Level one is marked with white, level two is marked with yellow, level three is marked with orange, and level four is marked with blue.

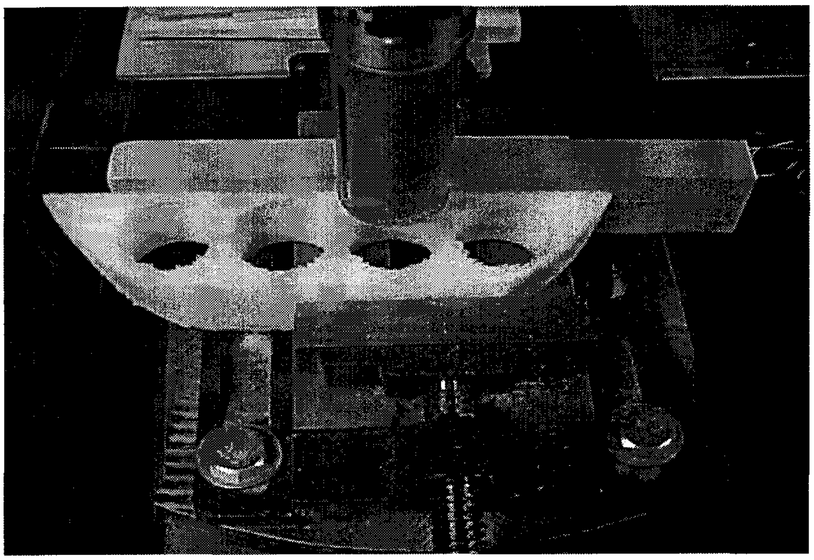


Figure 3.11: Cutting Reference Samples with a Hole Saw

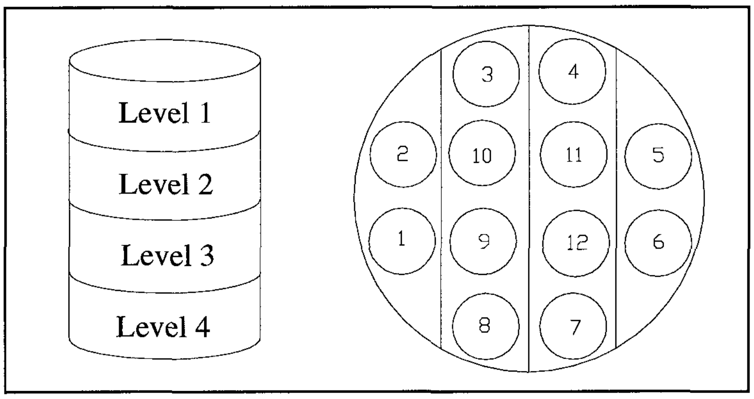


Figure 3.12: Sample Coring Schematic for 4-Liter Plastic Bucket

3.4 Average Density Measurements

Excess foam dust is removed from the samples by tapping them on a countertop to ensure accurate density calculations. All samples are weighed on a precision balance (Mettler Toledo AG204), and the length and diameter measurements are taken using digital calipers. Figure 3.13 shows foam samples being measured and weighed. Four readings are averaged and recorded for all measured dimensions [19].

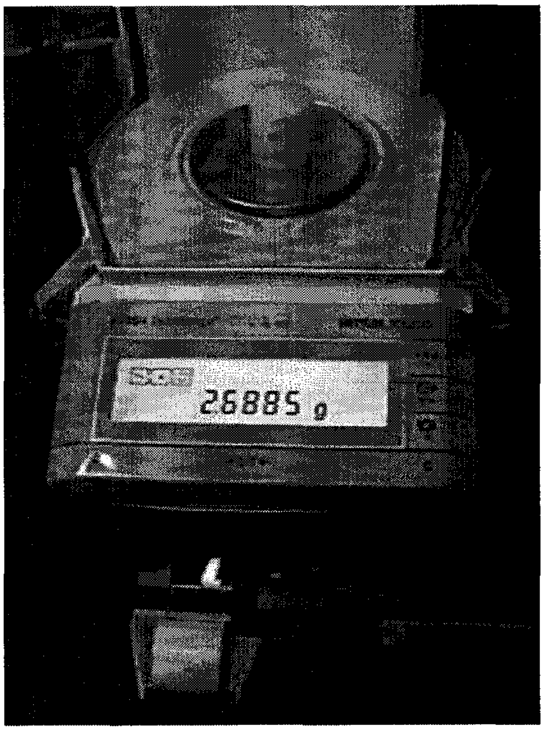


Figure 3.13: Sample Measurement for Density Calculations

The calipers are laid flat on a countertop while measurements are taken. The first measurement is taken for the diameter of the sample, then the sample is rotated ninety degrees and a second measurement is taken. The sample is then turned over and the process repeated for two more measurements. The sample is rotated ninety degrees

between each measurement of the height. The samples are left on the scale an average of one minute to allow the scale time to calibrate.

The volume and weight of each sample is used to calculate the average density. The same process is used to determine the average density of the samples for all the batches, including the samples cut from the reference batch.

3.5 Density Gradients

3.5.1 Vertical Density Gradients

The vertical density for the foam columns is found using the average density of each sample, as determined earlier. The sample density at each level is averaged from all six columns to determine the density for that level. The density at each level can then be compared to determine the vertical density gradient for each size mold.

3.5.2 Radial Density Gradients

A coring method is used to determine the radial density gradients. Samples seventeen through twenty are marked with concentric circles starting at the center and increasing by 3mm increments to the outer edge. A cork borer is used to remove samples from each radial position. The cork borer has an outer diameter of 5.0 mm and yields core samples with a diameter of 3.5 mm. Circles the size of the coring tool are etched onto the sample with a pencil to assist with the placement of the tool.

The borer is held in a position perpendicular to the sample surface, pressed through the foam, and twisted to cut the core out of the sample. The borer must be carefully applied in a perpendicular motion, because the closeness of the core positions can cause overlapping and chipped cores. The application of the borer must be steady and firm or

the core's surface will be ragged. The cores are extracted from the cork borer by gently pushing the core out with a wooden applicator stick. Figure 3.14 shows the cork boring tool, wooden applicator stick, and a cored sample.

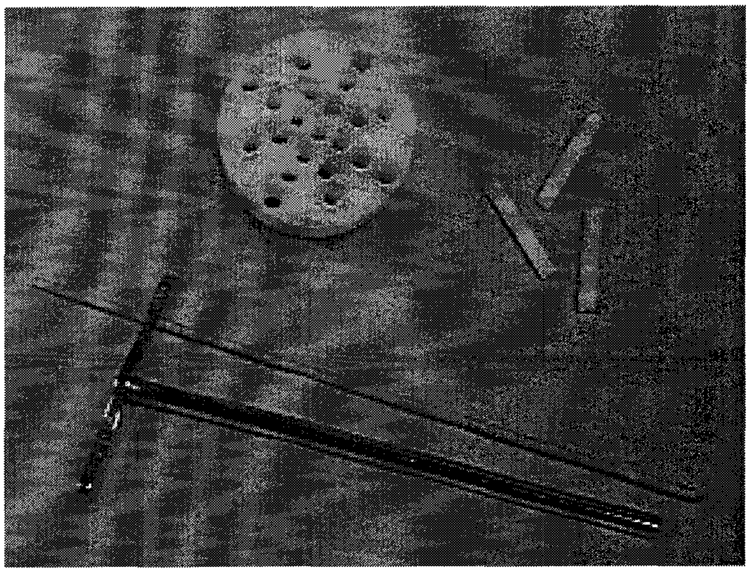


Figure 3.14: Cork Borer, Wooden Applicator Stick, and Cored Sample

Chipped cores are trimmed with a razor blade, removing the chipped end to leave a partial core for measurements. Ragged cores are brushed off, removing excess foam chunks before measuring. Foam samples with larger voids will sometimes yield cores with large chucks missing. These cores are discarded as unusable because the volume measurements would be incorrect. Occasionally the foam will compress in the axial direction, leaving an unusable core. Compressed cores are discarded since the measurements from these would be inaccurate. Figure 3.15 shows examples of foam cores.

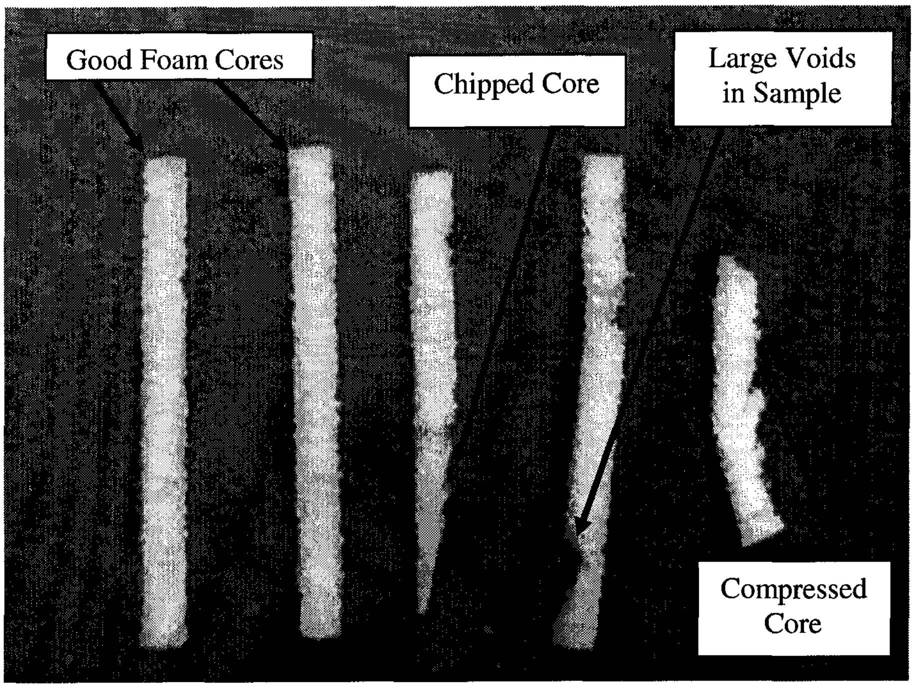


Figure 3.15: Example of Radial Density Gradient Foam Cores

Four cores are taken at each radial position and one at the center. The small molds have four radial positions, for a total of thirteen cores from each small sample. The medium molds have six radial positions, for a total of twenty-one cores from each medium sample. The large molds have eight radial positions, for a total of twenty-nine cores from each large sample. Figure 3.16 shows the coring schematic for all three aluminum molds.

The cores are laid out on a countertop in rows, each row representing the level the core is taken from, to track the extraction position of each core. Excess foam dust is gently rubbed off of the cores before measurements are taken. Each core is weighed on a precision balance and the height and diameter measured using digital calipers to determine the density. The densities of the four cores at each radial position are averaged to determine the density gradient of the foam.

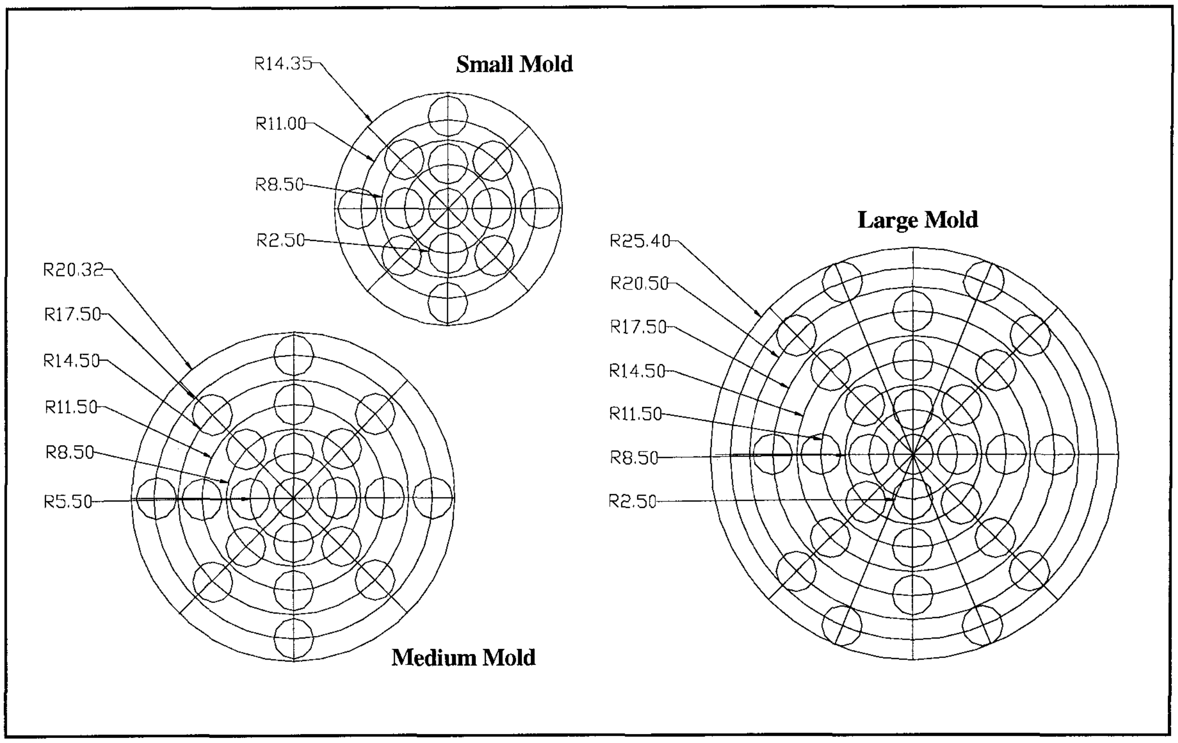


Figure 3.16: Small, Medium, and Large Core Diagrams

The cores are easily deformed, so care is used in the measuring process. The calipers are laid on a countertop and papers are placed under the grips to support the sample while taking measurements. The calipers are gently closed on the core, making sure the core is perpendicular to the grips and is not bent. Four measurements are taken of each dimension and averaged. The same person measures all the cores from each sample to ensure consistency in the amount of pressure applied while measuring.

The cork borer used in this analysis is the smallest available size (3.5 mm inner diameter) that produces a good core. The smallest size was chosen to maximize the number of cores that can be taken from a sample. A maximum of four radial positions can be taken from the small samples using this size cork borer. As the sample size increases, more radial positions can be taken. Also, results closer to the edge can be taken

and a larger percentage of the sample studied as the borer-to-sample diameter ratio decreases.

The radial position of the cores is defined as the length between the center of the sample and the center of the core. The radial positions are normalized to provide a relative position for each horizontal section in relation to the outside radius of the sample. Therefore, the center of the sample is denoted as "0" and the outside edge of the sample is denoted as "1". Using a normalized position, the three mold sizes can be compared. The small cylinders yield a maximum absolute radial position of 11 mm, or a normalized position of 76% of the sample radius. The medium cylinders yield a maximum absolute radial position of 17.5 mm, or 86% of the sample radius. The large cylinders yield a maximum absolute radial position of 22.9 mm, or 90% of the sample radius.

3.5.3 Reference Batch Density Gradients

To determine the radial density gradient for the 4-Liter mold, the foam is cut horizontally into two levels. Each level is marked with concentric circles starting at the center and increasing by 3mm increments to the outer edge. A cork borer is used to remove samples from each radial position. Four cores are taken at each radial position and one at the center. The bucket molds has twenty-eight radial positions, for a total of 109 cores from each level, or 218 cores from the reference batch. The cores from each radial position and both levels are averaged to determine density for each position.

The vertical density for the reference batch is found using the average density of each sample, as determined earlier. The sample density at each level is averaged to determine the density for that level. The vertical density gradient density can then be compared to the vertical density gradient for each size mold.

3.6 Mechanical Testing

3.6.1 Compression Testing

Compression testing is used to determine some of the mechanical properties of the foam. A sample is placed between two plates and stress and strain data is collected while the plates compress the sample. Stress is the amount of force applied to the sample in the axial direction divided by the sample's cross-sectional area. Strain is a ratio of the sample's deformation (shortened length) to the sample's original (gage) length. Figure 3.17 shows a typical stress-strain curve.

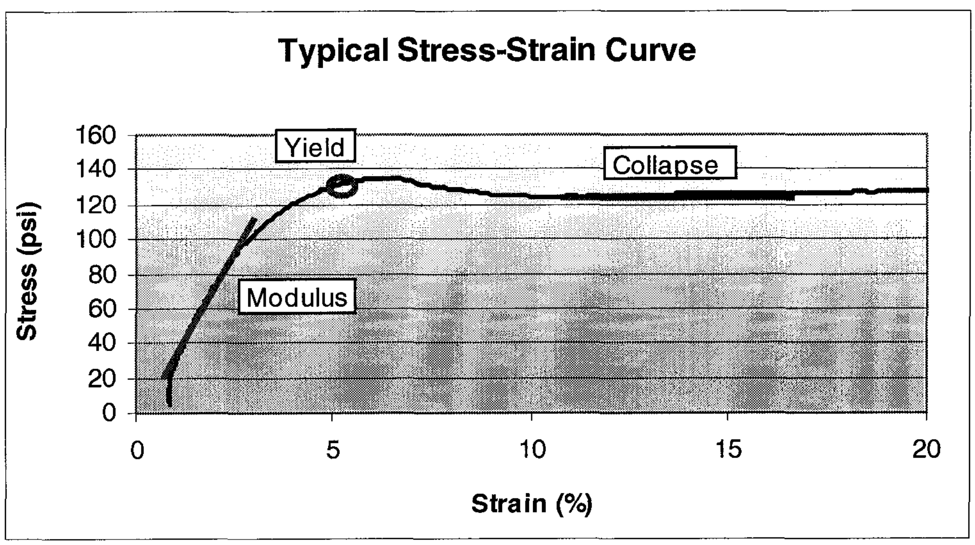


Figure 3.17: Example of Typical Stress-Strain Curve

The curve begins linear and proportional, which is known as the elastic region of the material. The modulus of elasticity is a measure of the stiffness of the material; the higher the modulus the more rigid the material. The modulus of the sample is determined by the slope of the curve in the elastic region. Strain increases more rapidly beyond the limit of

elasticity, decreasing the slope. Peak (yield) strength is where the slope decreases to zero. The peak strength of a sample is determined by the point on the curve where the stress has reached a maximum. The material bulges outward, becoming barrel shaped during compression. Collapse strength is defined as the region of the curve where the foam shortens continuously under a constant load and the curve becomes horizontal and perfectly plastic. The collapse strength of the sample is determined by the plateau (flat) region of the curve [12].

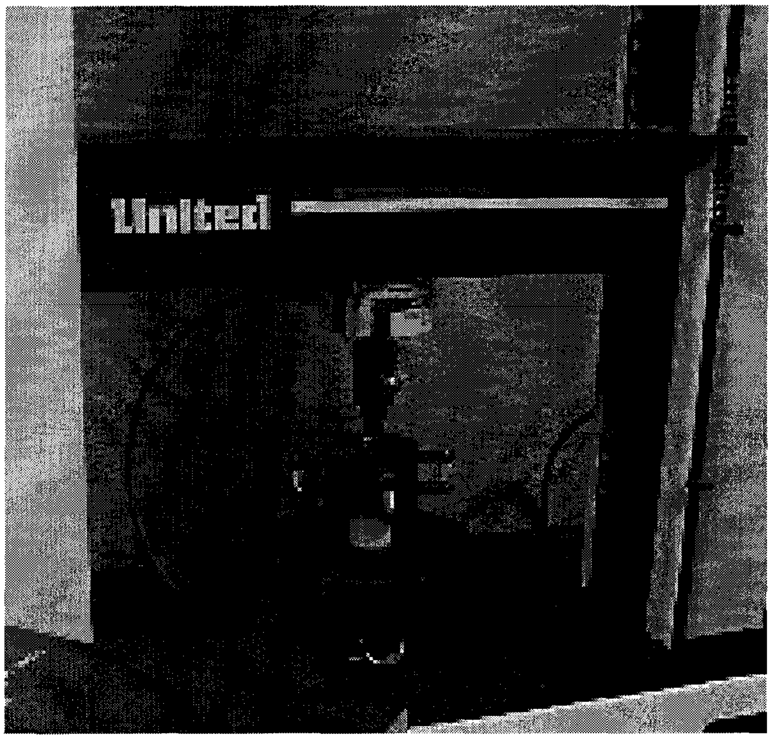


Figure 3.18: Compression Testing Using a United Machine and Laser

Compression tests are performed according to D1621 on the 25.4 mm samples [18]. Modulus, peak strength, and collapse strength are determined from the quasi-static compression tests using a United Testing Model SSTM-1 frame with a 4.4 kN load cell.

Strain is measured with a United Testing Model EXT-62-LOE laser extensometer, as shown in Figure 3.18.

Reflective marker strips are adhered to the samples with an initial gage length of approximately 19 mm. Datum 27 software is used to run the experiments and collect the data. The compression tests are run at a crosshead velocity of 1.27 mm/minute. The samples are compressed to approximately 15% strain.

3.6.2 United Testing Machine and Laser

The United Optical Extensometer is a scanning device that measures the change in distance between reflective marks applied to a sample. The transmitter uses a solid-state laser diode at a wavelength of 630 nanometers. The laser has a scan range of eighty degrees; forty degrees above and forty degrees below the level position. The scan line is produced by light emitted from the transmitter striking a rotating mirror assembly. The reflective strips intercept and return the laser light to the mirror and the receiver. The transmitter and receiver are coaxial. The computer sums the counts from scans to compute the changes in distance between the reflective strips [20].

The receiver uses a two-element collector lens. The optical energy is converted to electrical current by a fast photo diode. The current is converted to a voltage signal by a trans-impedance amplifier. A video amplifier is used to process the voltage signal. The counter board uses two counters. The first counter measures the angle (A) between the index pulse and the top of the first reflective strip. The second counter measures the angle (B) between the top of the first reflective strip and the top of the second strip. The constant horizon angle (C) is the angle between the index pulse and the horizontal

position. Figure 3.19 shows the laser extensometer angle measurement. Figure 3.20 shows the United Machine and laser set-up [20].

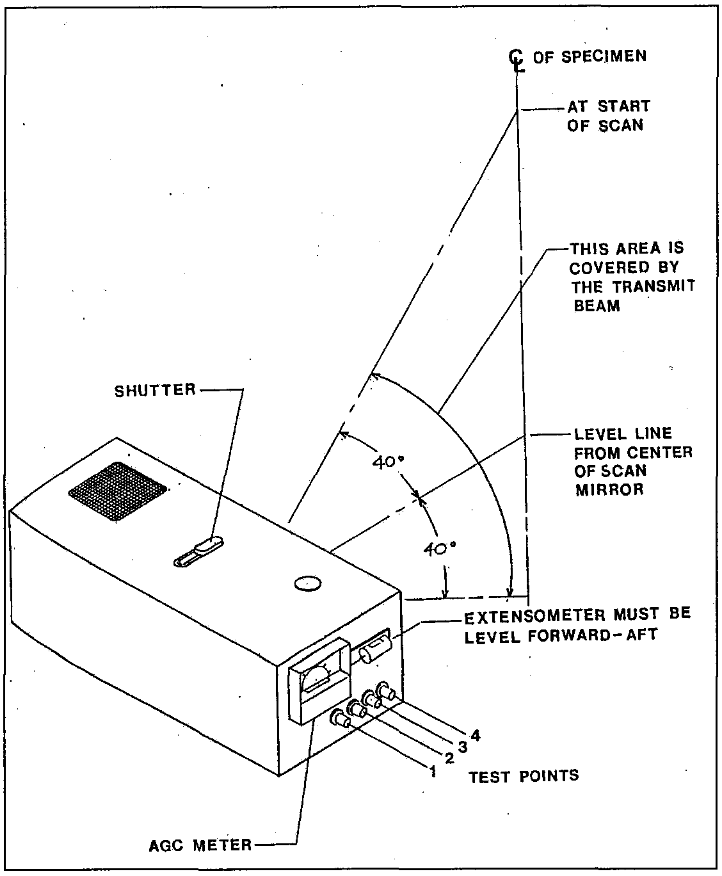


Figure 3.19: Laser Extensometer

The measured angles are determined by count values dependant on: variations in the rotation of the scan mirror, mechanical imbalance, electrical or ambient light noise, variation in test distance during the test, and frequency variations of the time base. The counter will record 1667 counts for each scan of a target one degree apart. The position of the targets is detected by the point where the amplitude of the reflected light is 50% of the peak amplitude. Random errors are generated by stray light disturbing the detection.

The beam width should be 1/8 inch for optimal focus, decreasing errors. Other errors may arise from target movement during the test [20].

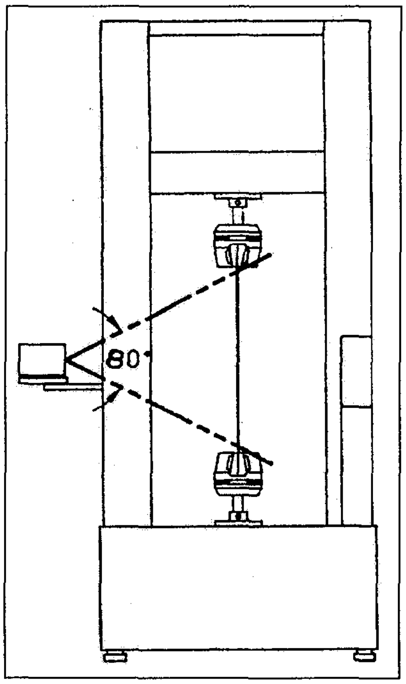


Figure 3.20: United Machine and Laser Set-up

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Average Density

The average density of each batch is determined by weighing and measuring all of the samples in the batch and then finding the average value. The position of the sample in the foam column is not considered during this analysis since only an overall batch density is desired. Each foam batch is represented separately in Figure 4.1. The average density of all the samples in each batch can be found in Appendix B. The density of the reference batch is plotted as a dashed line, with a density of 0.101 g/cc. The first and second standard deviations are indicated by the rectangular boxes and vertical lines, respectively.

4.1.2 Average Density vs. Mold Size

The change in average density as mold size increases is presented in Figure 4.2. Each temperature is represented separately with three data points. Each data point represents the average density at one of three mold sizes: 29mm diameter (small), 41mm diameter (medium), and 51mm diameter (large).

4.1.1 Average Density vs. Processing Temperature

The change in average density as temperature increases is presented in Figure 4.3. Each mold size is represented separately with four data points. Each data point represents the average density at one of four processing temperatures: 25°C, 40°C, 65°C, 85°C.

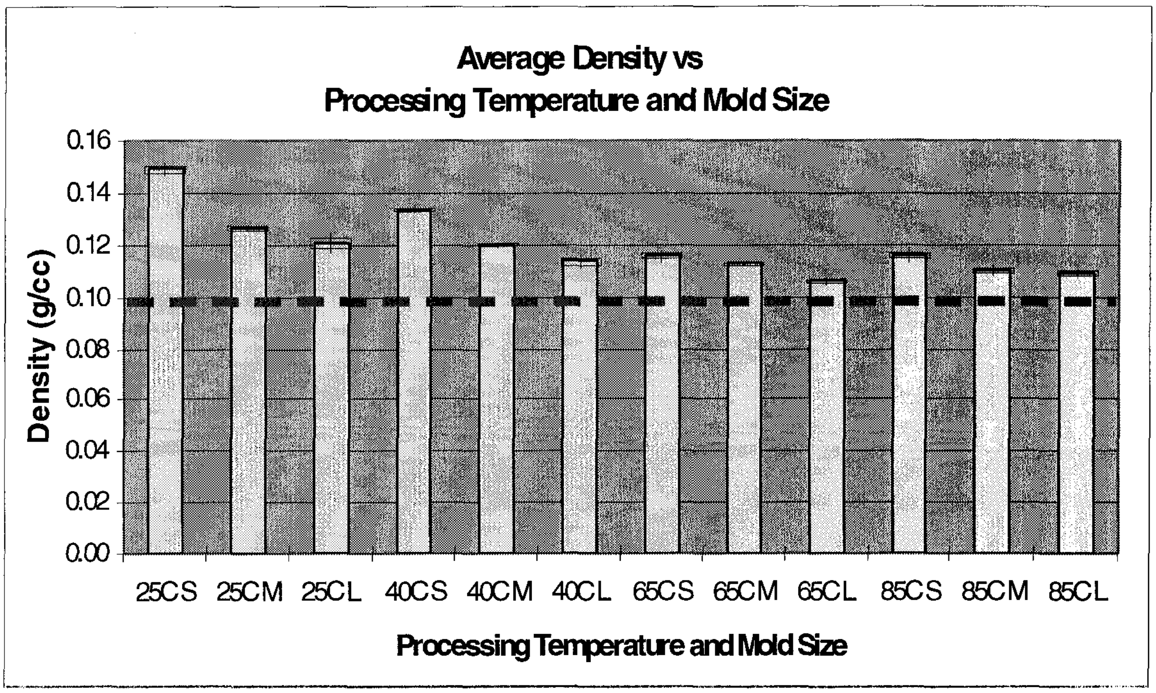


Figure 4.1: Average Density of All Foam Batches

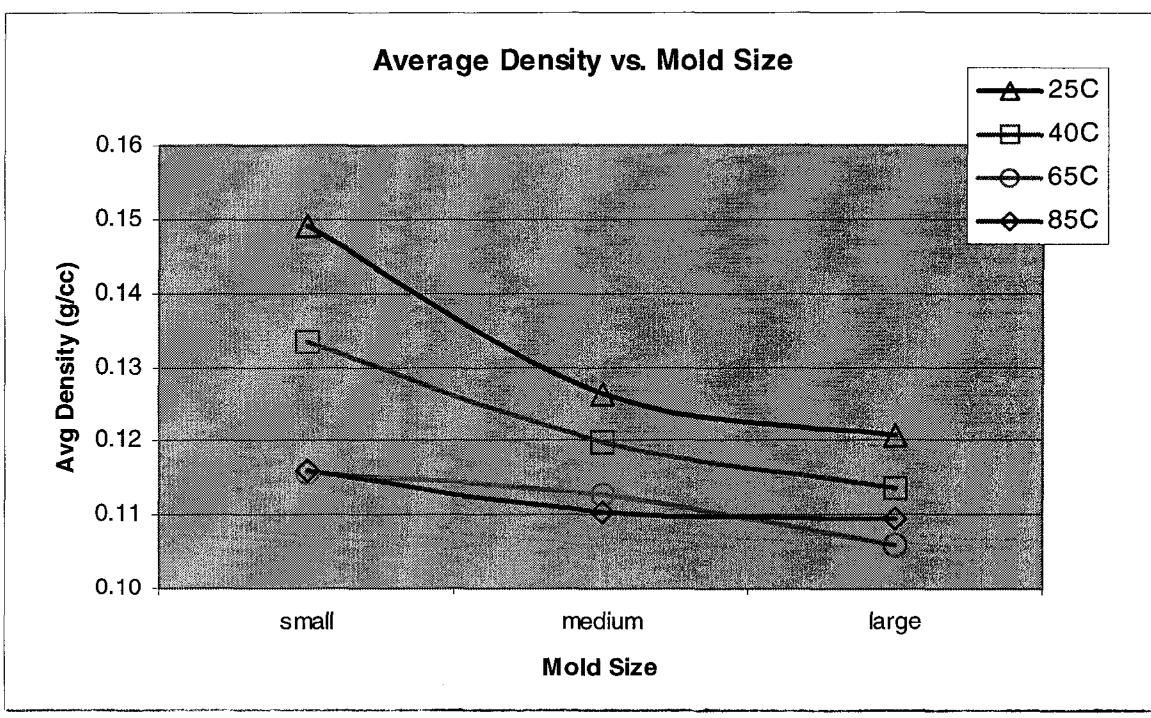


Figure 4.2: Average Density as Mold Size Increases

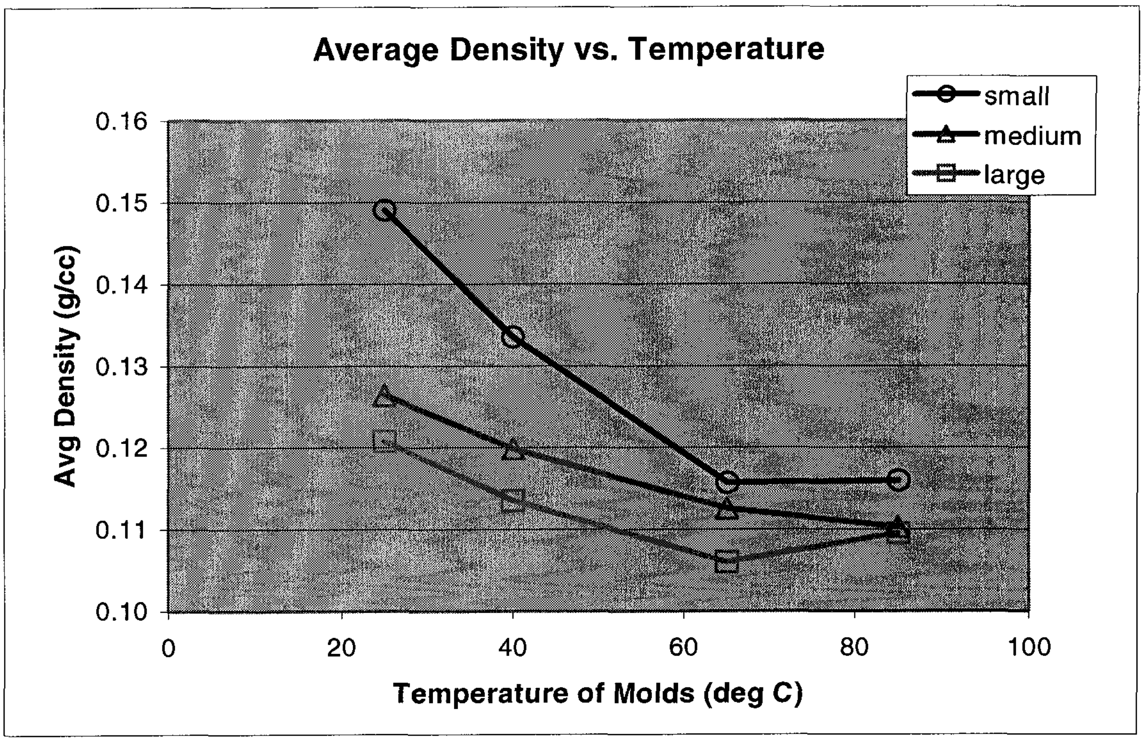


Figure 4.3: Average Density as Temperature Increases

4.2 Radial Density Gradient

The radial density gradient of each batch is determined by weighing and measuring cores taken from samples in each batch. Cores are taken at different radial positions (four each except the center) and averaged at each position. The vertical position of the sample in the foam column is not considered during this analysis. Each foam batch is represented separately in Figure 4.4. The average density of the cores at each radial position for each batch can be found in Appendix C. The radial positions are taken from the center outward. Small molds have four radial positions, medium molds have six radial positions, and large molds have eight radial positions.

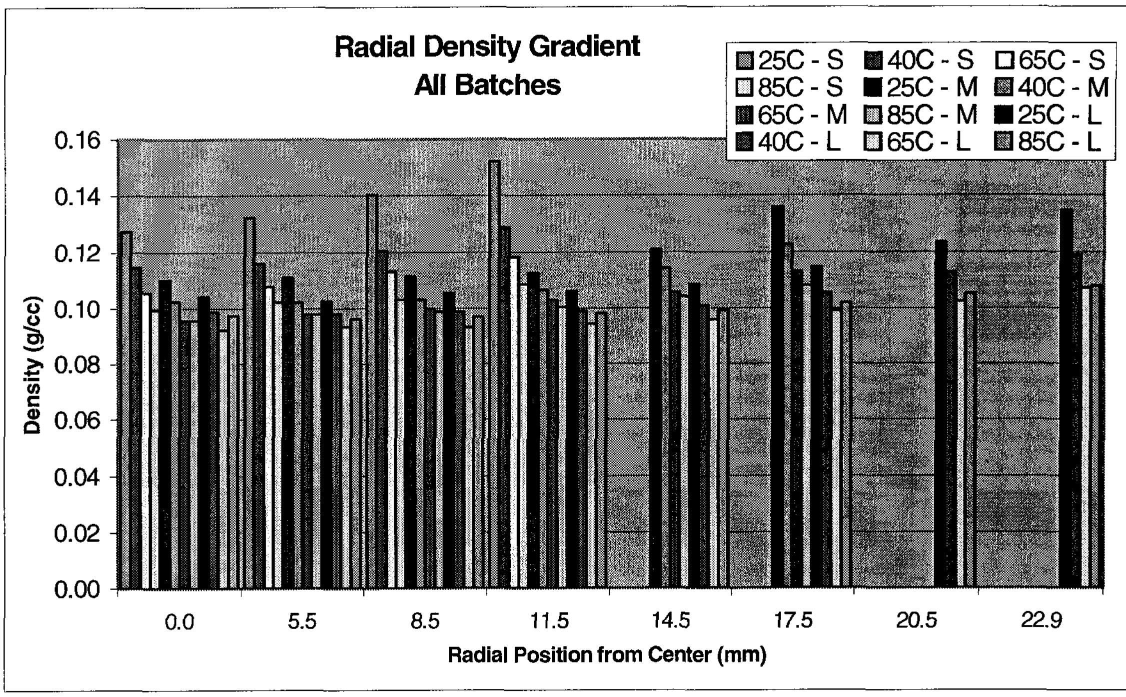


Figure 4.4: Radial Density Gradient for All Batches

The radial densities of all the foam batches, despite sample size, are compared by normalizing the radial positions where the cores are taken, as shown in Figure 4.5. The actual radial positions are converted into ratios of the actual position to the total radius of sample. The center is zero and the outer edge of the sample is one. The reference batch, made at ambient conditions, is plotted as a dashed line.

The overall change in the density in the radial direction can be shown by examining the percent difference. The percent difference is taken between the density at the center and the density at the outer edge with respect to the center of the sample. A positive percent difference indicates an increase in the density from the center to the edge. Figure 4.6 shows the percent difference for each batch, grouped together by mold size.

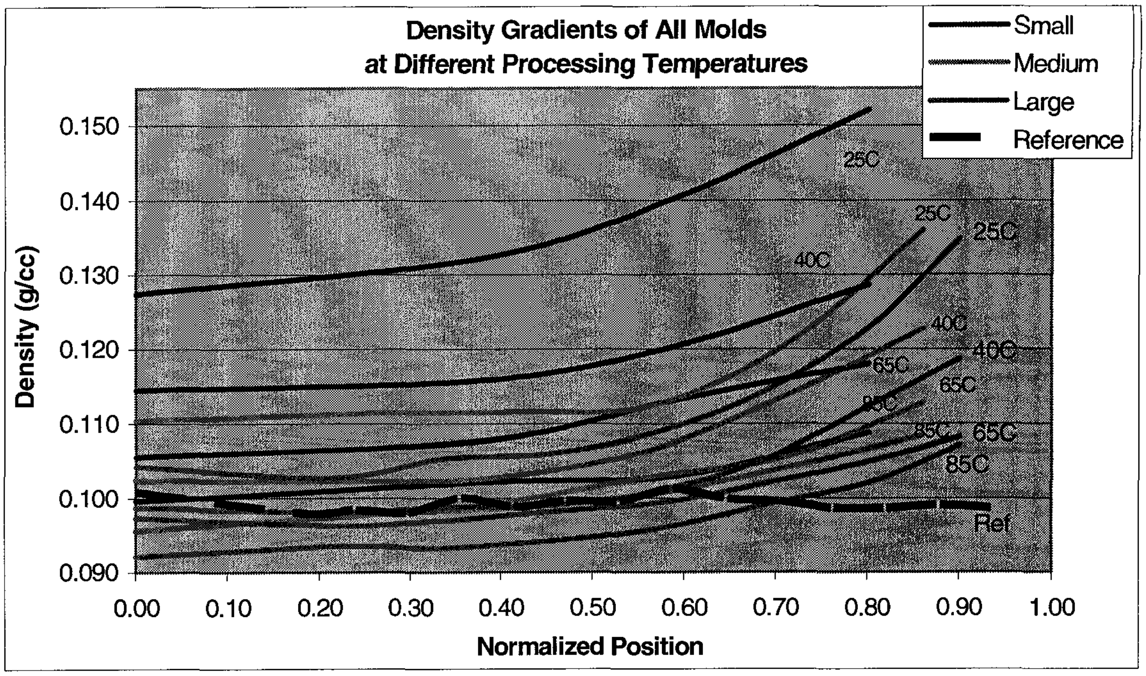


Figure 4.5: Radial Density Gradient at Normalized Radial Positions

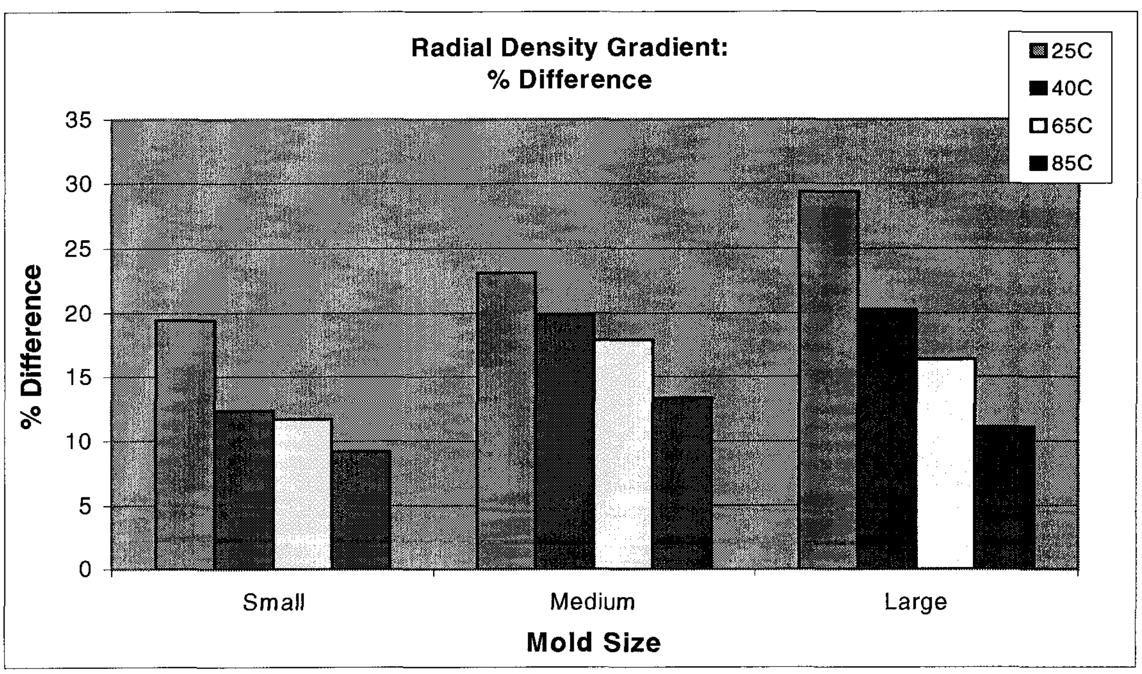


Figure 4.6: Percent Difference of Radial Density Gradient (Center to Edge)

4.2.1 Radial Gradient vs. Mold Size

The diameters of the cork borer and the sample limit how close to the outer edge a core can be taken. The maximum normalized position increases as the mold size increases. The reference batch yields cores at radial positions up to 94% of the sample radius. The small, medium, and large molds yield cores up to 80%, 86%, and 90% respectively. A more direct correlation between the different mold sizes can be seen when comparing the radial density gradient up to approximately 80% of the radius of the sample. Figure 4.7 focuses on the results of each processing temperature individually, showing the effect of increasing the mold size.

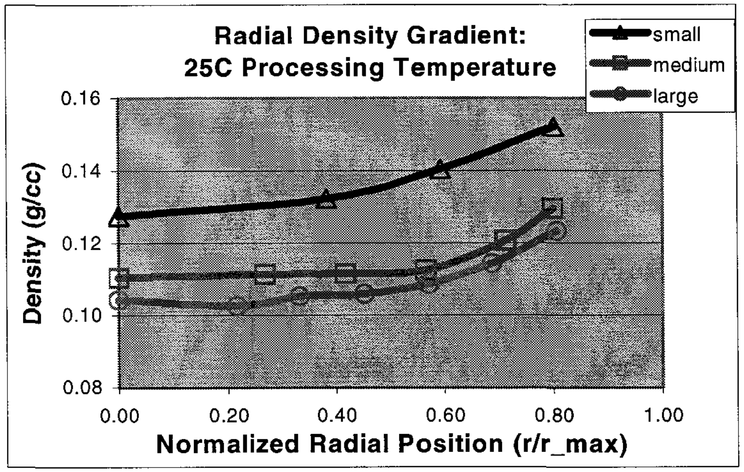


Figure 4.7 (a)

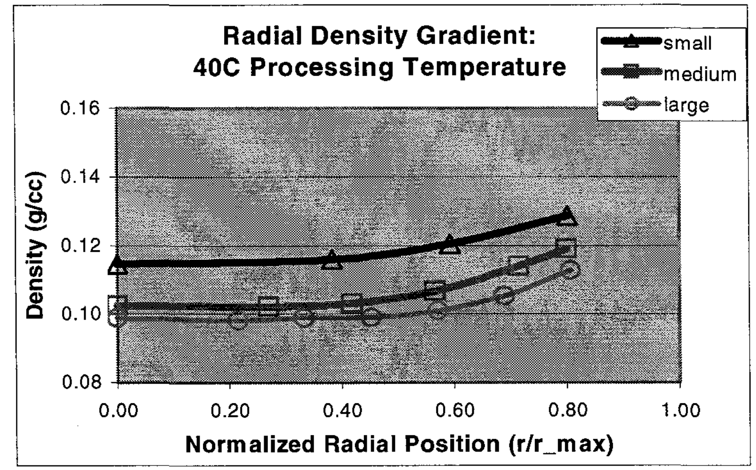


Figure 4.7 (b)

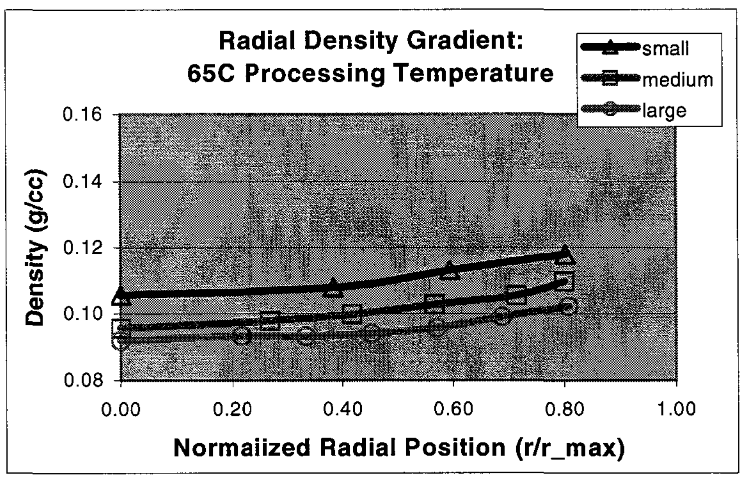


Figure 4.7 (c)

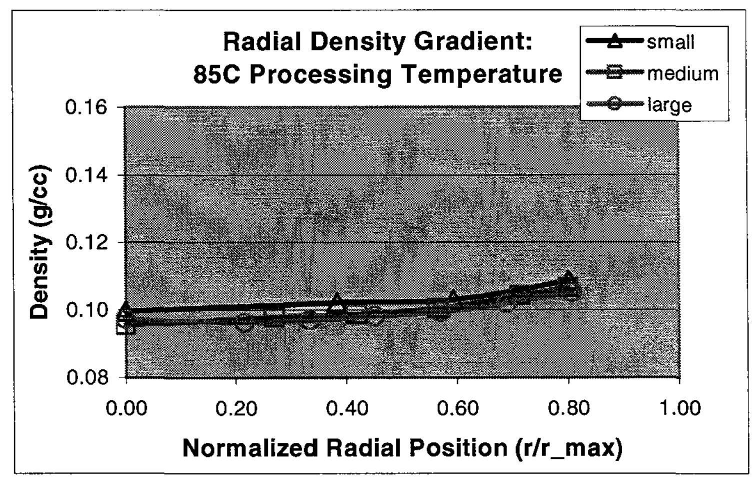


Figure 4.7 (d)

Figure 4.7: Radial Gradient vs. Normalized Position for Each Temperature

The overall change in density in the radial direction can be shown by percent differences. Figure 4.8 shows the percent difference of the density between the center and the outer edge with respect to the center for 80% of the sample diameter.

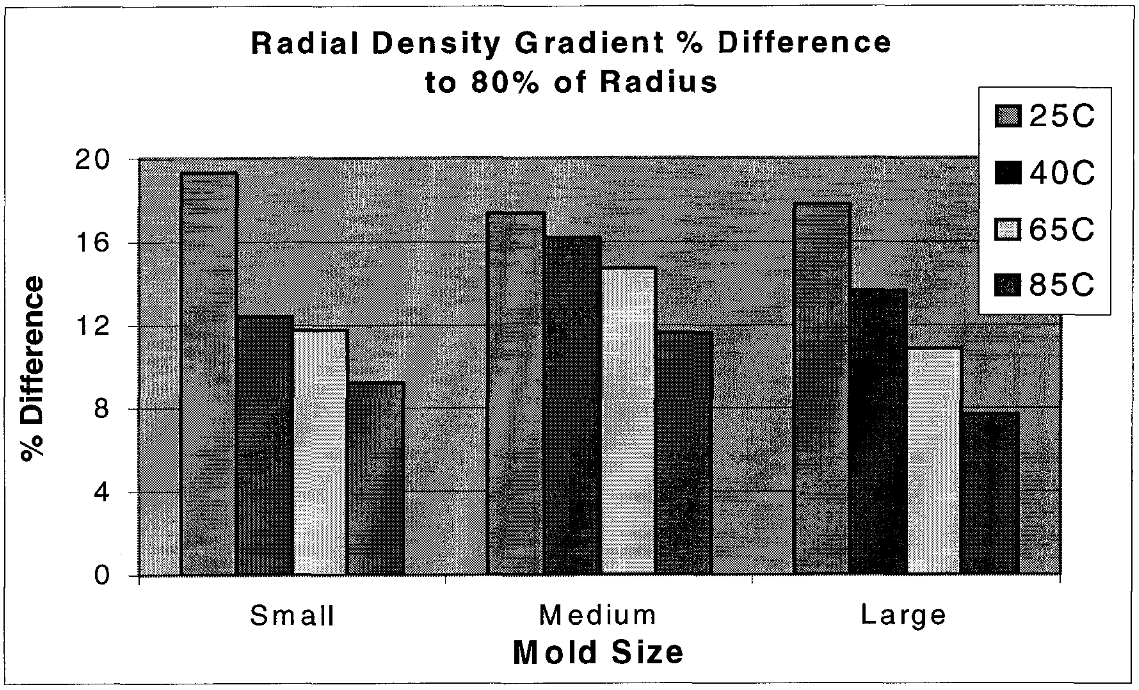


Figure 4.8: Percent Difference in Density between Center and Outer Edge

4.2.2 Radial Gradient vs. Processing Temperature

Each graph in Figure 4.9 represents one mold size, showing the effect of increasing the processing temperature. The number of data points is determined by the sample diameter. The number of radial positions increases as the core diameter to sample diameter ratio decreases. The small molds have four data points, the medium molds have six data points, and the large molds have seven data points for 80% of the sample radius.

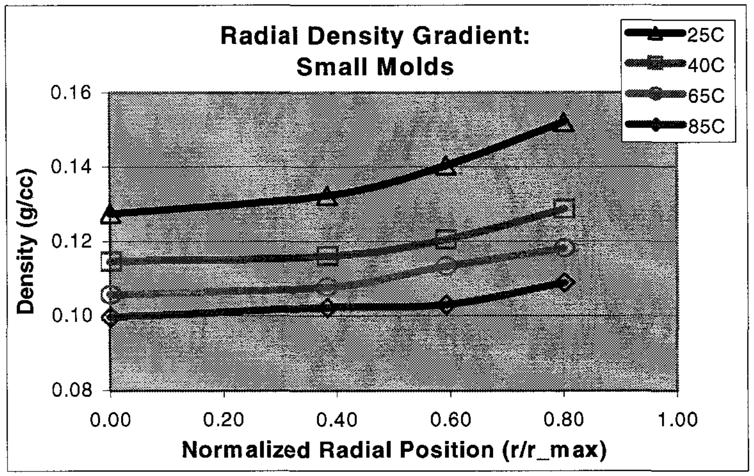


Figure 4.9 (a)

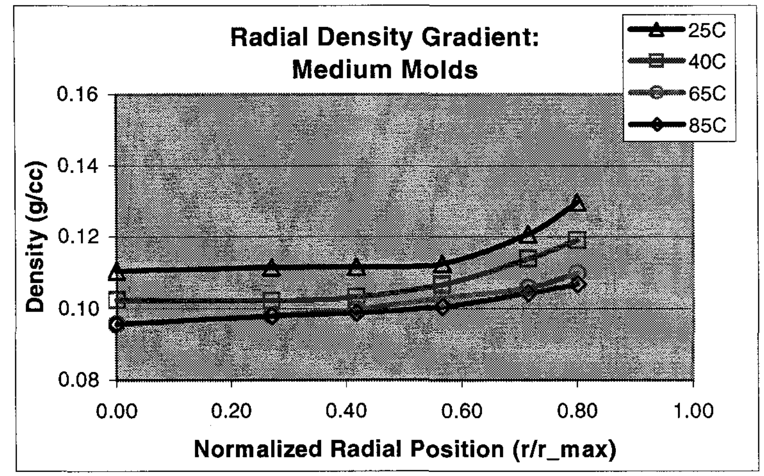


Figure 4.9 (b)

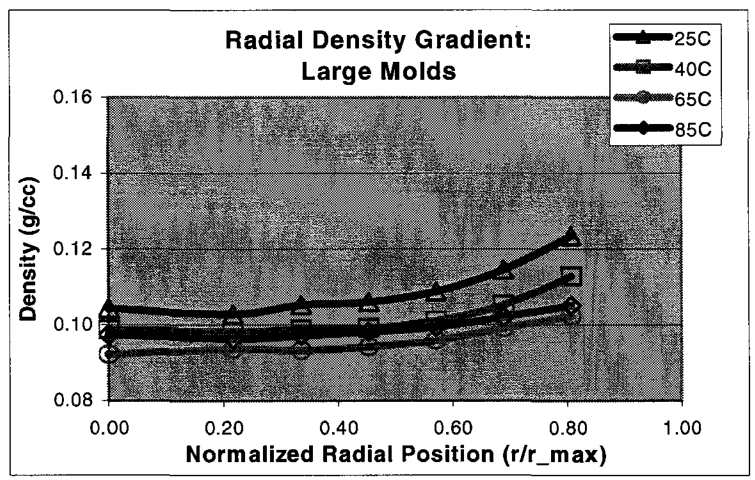


Figure 4.9 (c)

Figure 4.9: Radial Gradient vs. Normalized Position for Each Mold Size

4.3 Vertical Density Gradients

The vertical density of each batch is determined by weighing and measuring the samples in each batch. The columns of foam are divided into four levels; the average density at each level is used to determine the vertical gradient. Each foam batch and each level is represented separately in Figure 4.10. The vertical positions are taken from the top (level 1) to the bottom (level 4).

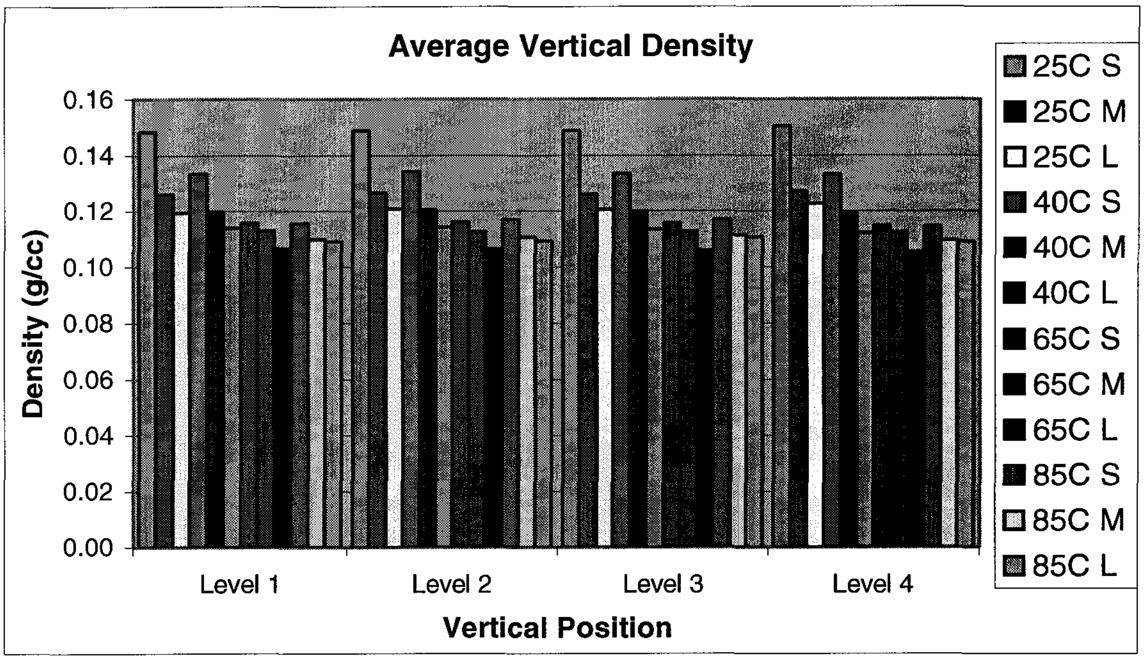


Figure 4.10: Average Density at Each Vertical Level for All Batches

The overall change in the density in the vertical direction can be shown by examining the percent difference of the density. The percent difference is taken between the density at the top (level 1) and the density at the bottom (level 4) with respect to the bottom of the sample. A positive percent difference indicates the average density increases from the top to the bottom, while a negative percent difference indicates a decrease in average

density from top to bottom. Figure 4.11 shows the percent difference for each batch, grouped together by processing temperature.

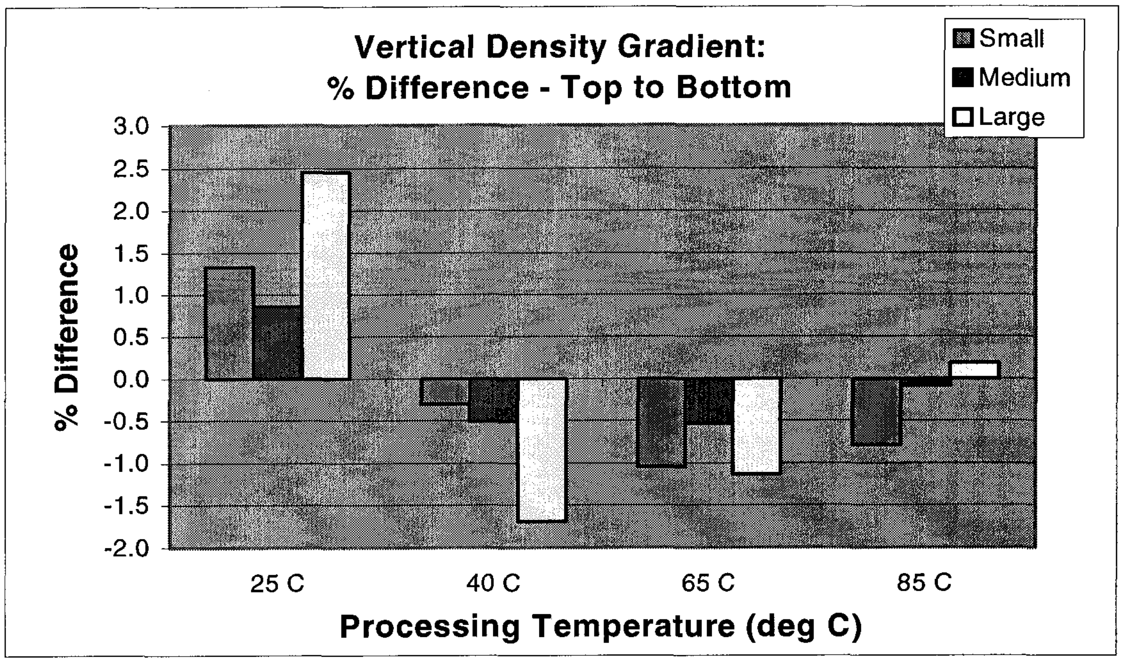


Figure 4.11: Percent Difference of Vertical Density Gradient (Top to Bottom)

4.3.1 Vertical Density Gradient vs. Mold Size

Grouping the foam batches together by a common factor will allow an examination of trends between the batches. Figure 4.12 focuses on the results of each processing temperature individually, showing the effect of increasing the mold size.

A reference batch, made at ambient conditions, is compared to the three mold sizes in Figure 4.13. All the batches represented are made at 25°C for a direct comparison. The vertical density of the reference batch is found by dividing the batch into four levels. The average density of the cored samples from each level is determined. The results for each batch are grouped by vertical level.

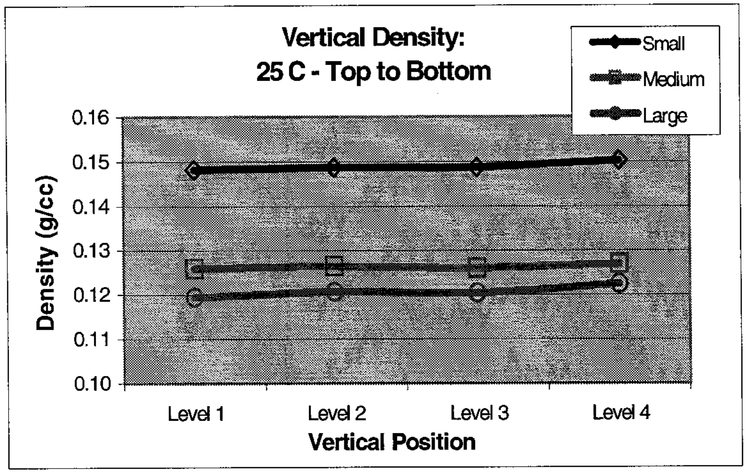


Figure 4.12 (a)

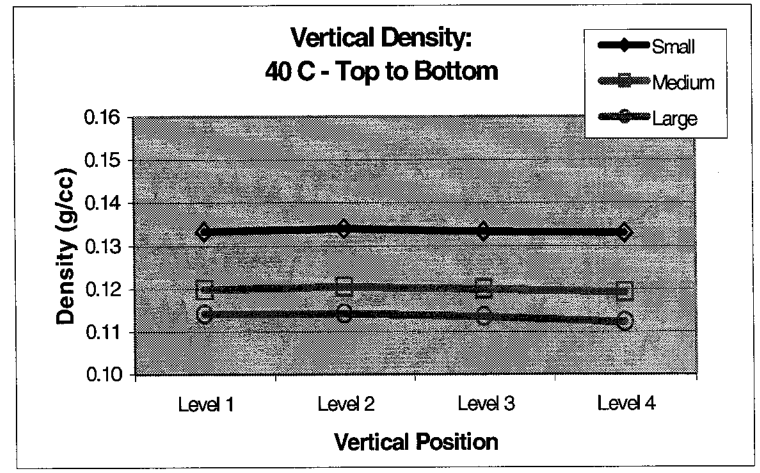


Figure 4.12 (b)

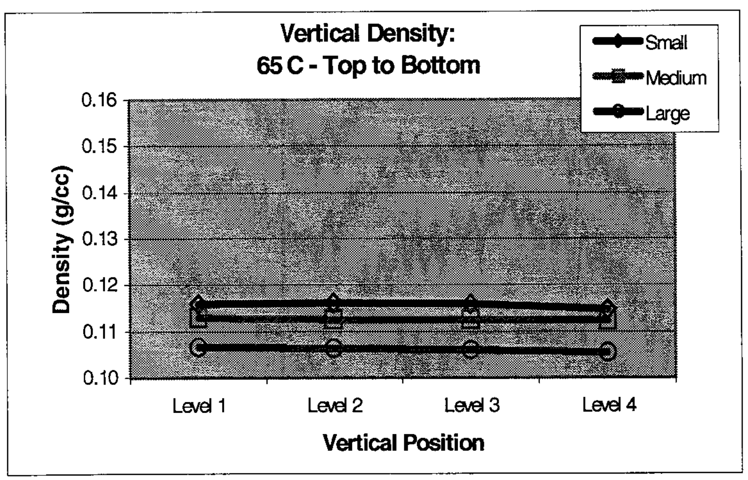


Figure 4.12 (c)

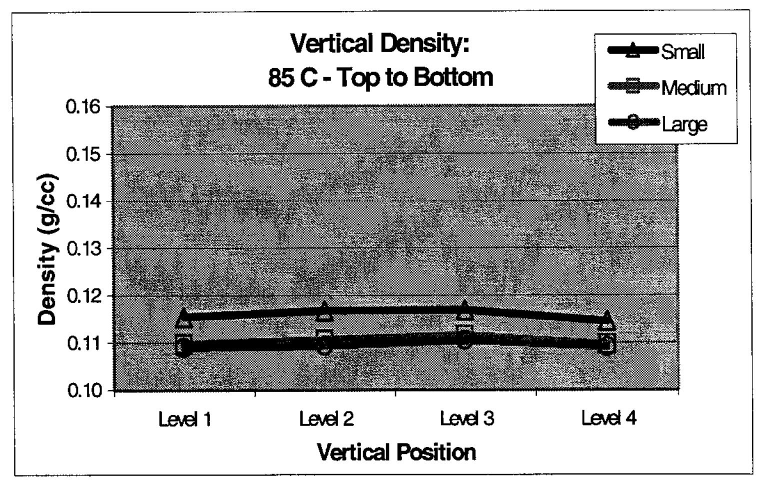


Figure 4.12 (d)

Figure 4.12: Vertical Density Gradient vs. Level for Each Processing Temperature

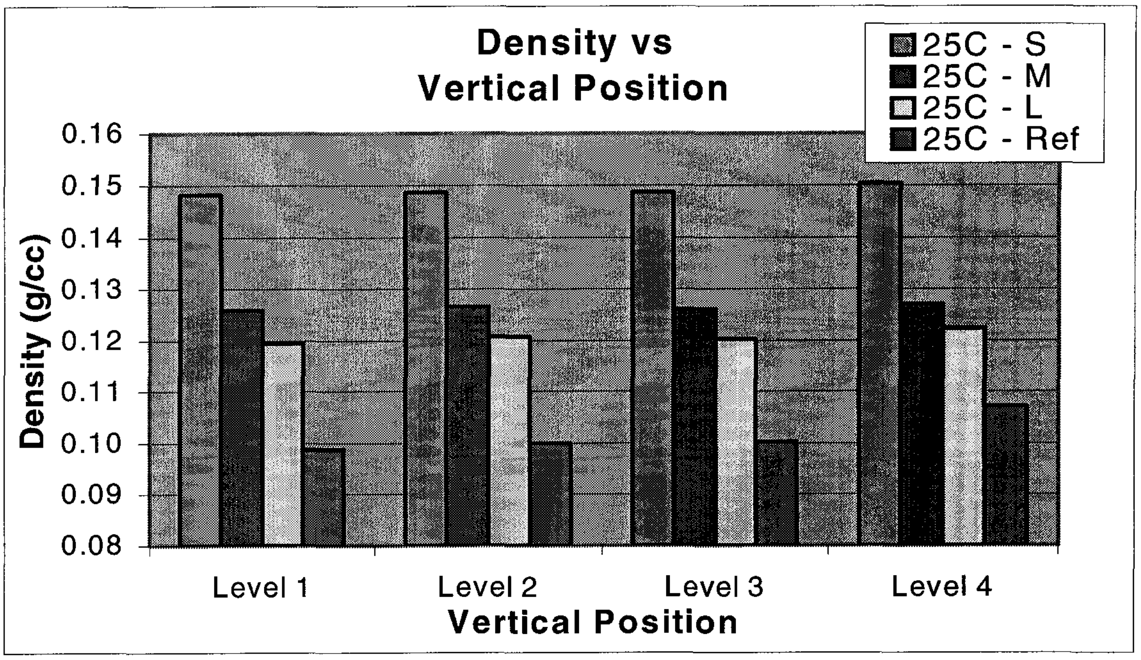


Figure 4.13: Vertical Density Gradient for All Mold Sizes at 25°C

4.3.2 Vertical Gradient vs. Processing Temperature

Figure 4.14 focuses on the results of each mold size individually, showing the effect of increasing the processing temperature. Each line represents a different processing temperature. All of the samples taken at a particular level are averaged for each batch, making each data point an average of six samples.

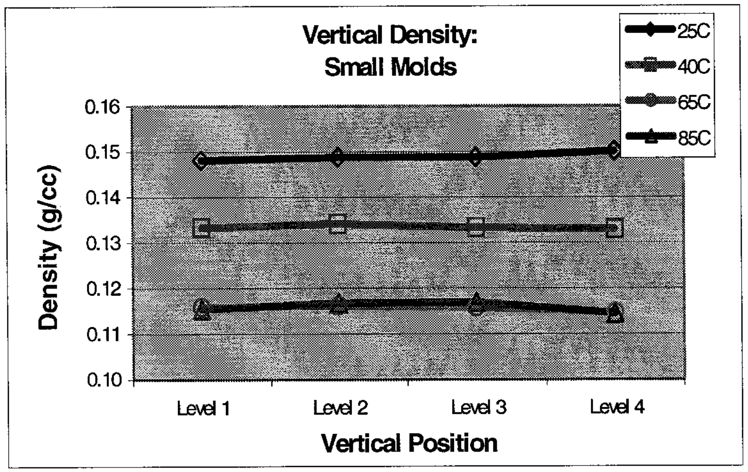


Figure 4.14 (a)

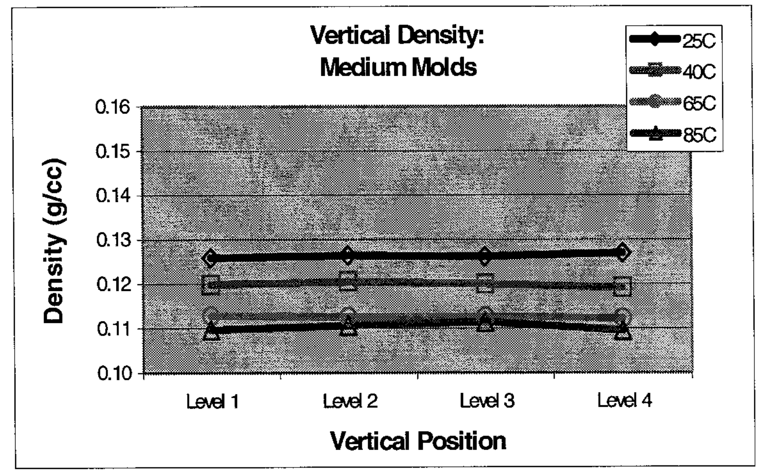


Figure 4.14 (b)

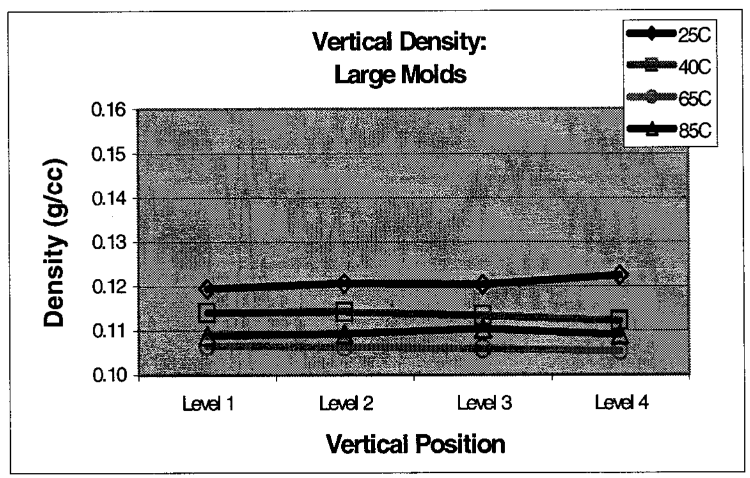


Figure 4.14 (c)

Figure 4.14: Vertical Density Gradient vs. Position for Each Mold Size

4.4 Mechanical Analysis

The mechanical properties of the foam (modulus, peak yield, and collapse strength) are determined by performing quasi-static compression tests on foam samples. The mechanical properties can be read directly from the resulting stress-strain curves. The stress-strain curves for all the samples tested in each foam batch can be found in Appendix D. The boxes and vertical lines in the results represent the first and second standard deviations respectively. The properties of the reference batch reference batch, made at ambient conditions, are plotted as a dashed line.

The modulus of elasticity is a measure of the foam stiffness. A high modulus indicates a high material stiffness. The modulus is the slope of the stress-strain curve in the elastic region. Figure 4.15 shows the modulus results for all the foam batches.

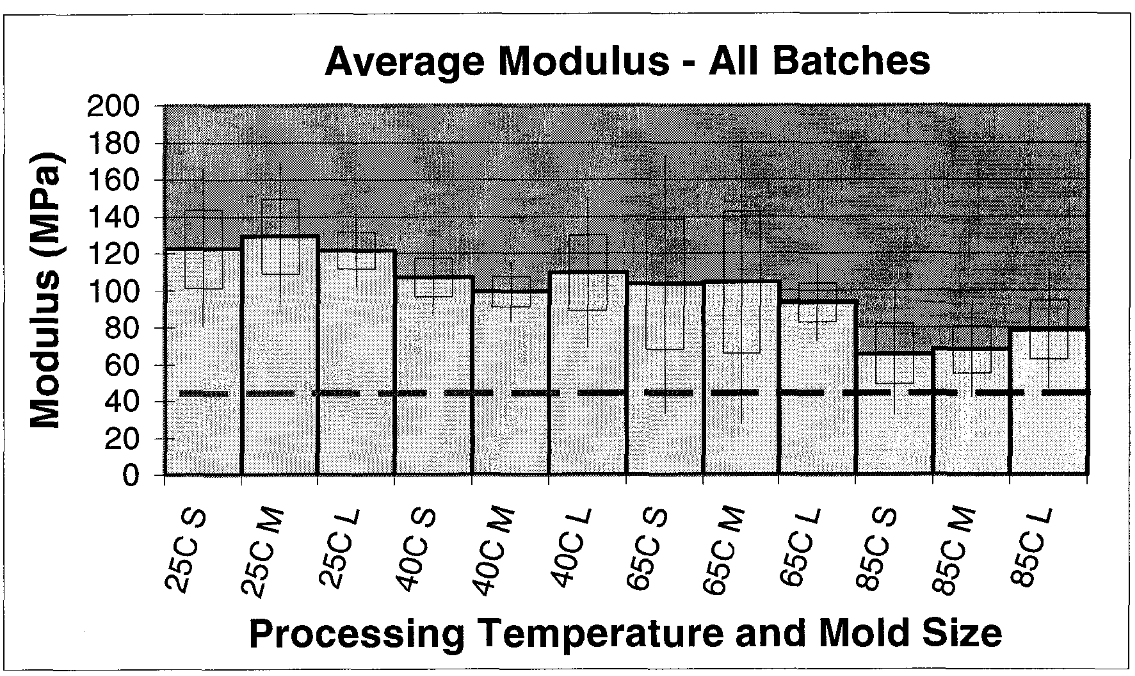


Figure 4.15: Modulus of Elasticity for All Foam Batches

The peak yield is where the slope of the stress-strain curve decreases to zero. The peak strength of a sample is determined by the point on the curve where the stress has reached a maximum. Figure 4.16 shows the peak yield results for all the foam batches.

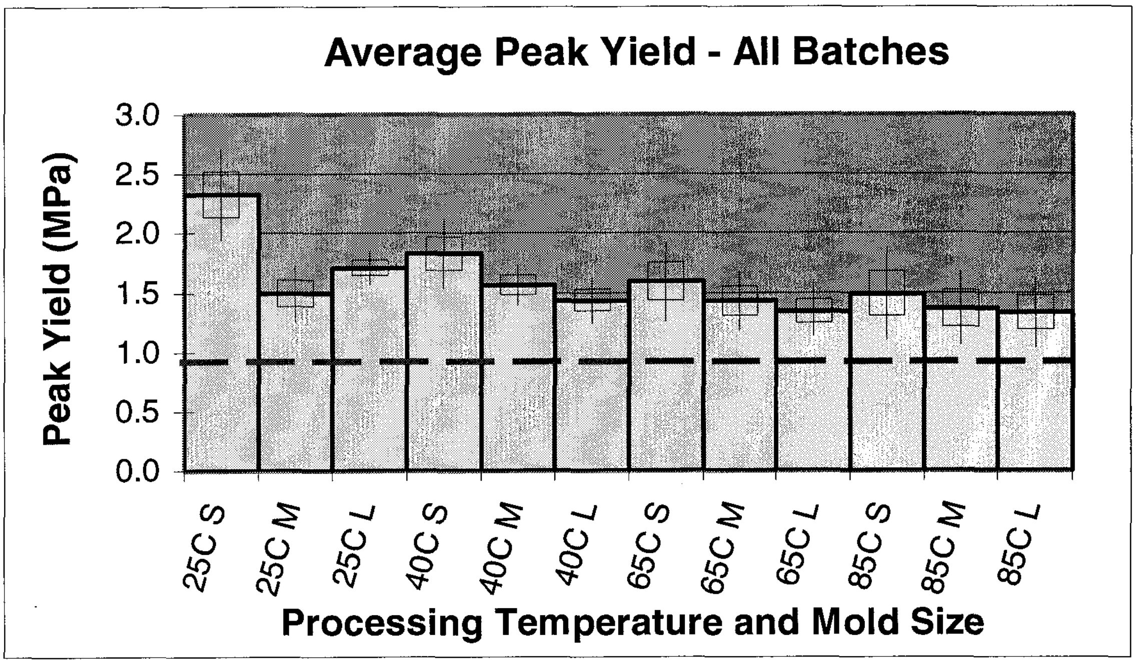


Figure 4.16: Peak Yield for All Foam Batches

The collapse strength is where the curve becomes horizontal and perfectly plastic. The collapse strength of the sample is determined by the plateau region of the curve. Figure 4.17 shows the collapse strength results for all the foam batches.

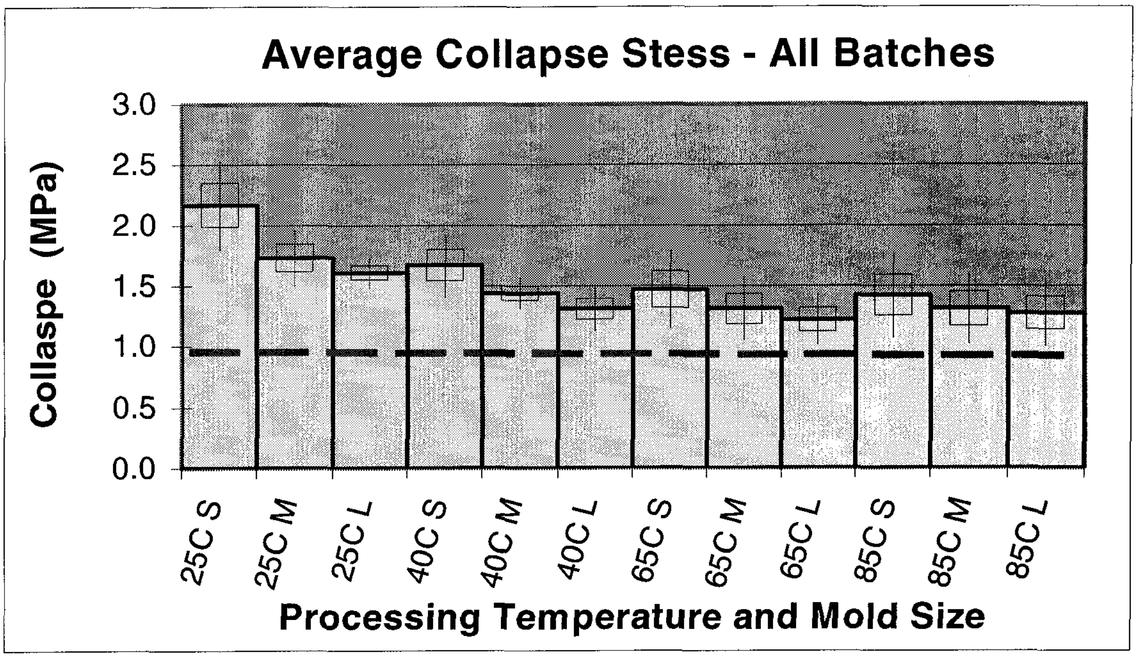


Figure 4.17: Collapse Strength for All Foam Batches

4.4.1 Normalized Mechanical Properties

It has been shown that foam modulus and strength have a predictable dependency on density [21]. Leroy and Whinnery showed that ReCrete foam also follows this general pattern [4]. Large density variations are observed in the foam samples so the experimental modulus and strength for each sample is normalized from the sample average density to the reference foam density of 0.1 g/cc. The normalized modulus and strength are determined as:

$$E_{norm} = E_{\exp}\left(\frac{0.1}{\rho}\right)^{1.7} \qquad \sigma_{norm} = \sigma_{\exp}\left(\frac{0.1}{\rho}\right)^{2.1} \qquad \text{(Eqn 4.1)}$$

where E_{exp} and σ_{exp} are the modulus and strength determined from the raw data, ρ is the sample density and E_{norm} and σ_{norm} are the normalized modulus and strength values [21].

The results are normalized with respect to average density to determine if there are any other factors (besides average density) that may be causing changes in the mechanical properties.

The normalized modulus of elasticity, normalized peak yield, and normalized collapse strength for all foam batches are shown in Figure 4.18, Figure 4.19, and Figure 4.20 respectively. Outliers are removed from the results, using a 95% probability, after the raw data is normalized. Results outside 95% of the average value, assuming a standard bell curve distribution of the data, are eliminated and the values recalculated [22]. Normalization of the raw data significantly decreases the mechanical properties. The boxes and vertical lines represent the first and second deviations respectively. A reference foam batch, made at ambient conditions, is represented as a dashed line.

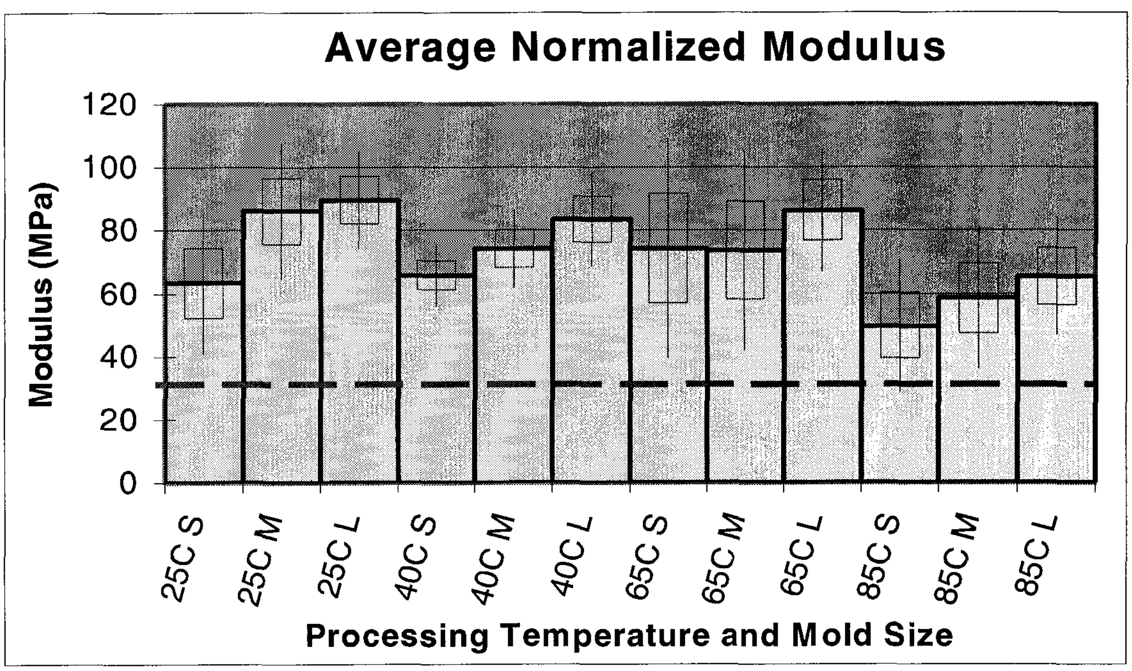


Figure 4.18: Normalized Modulus of Elasticity for All Foam Batches

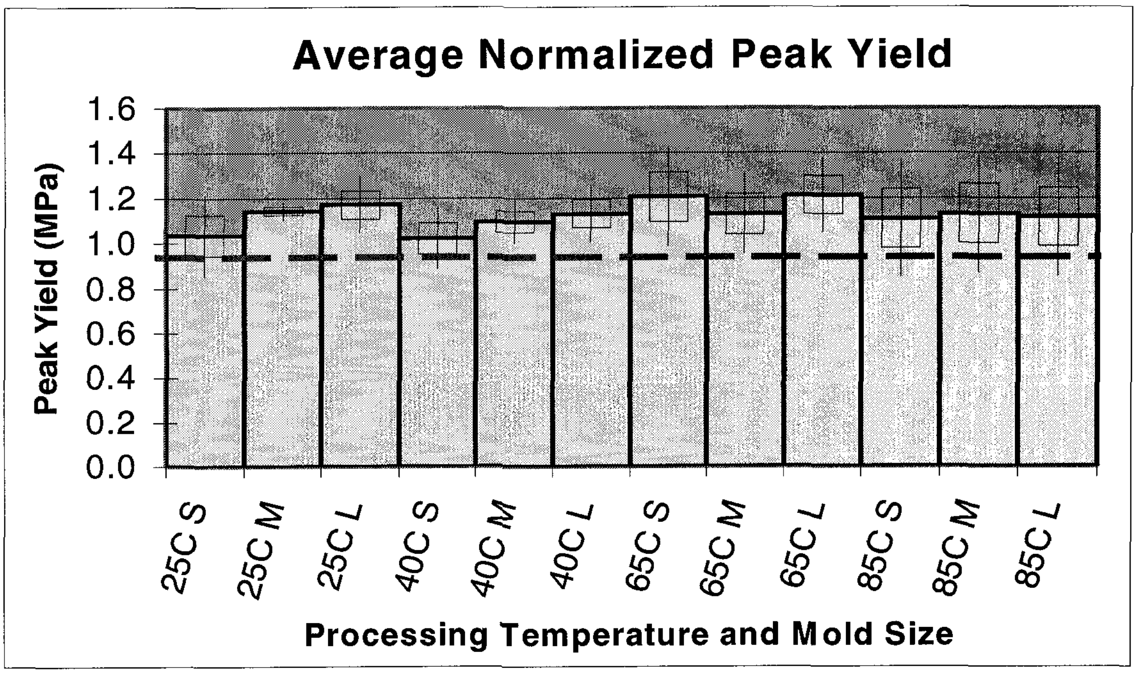


Figure 4.19: Normalized Peak Yield for All Foam Batches

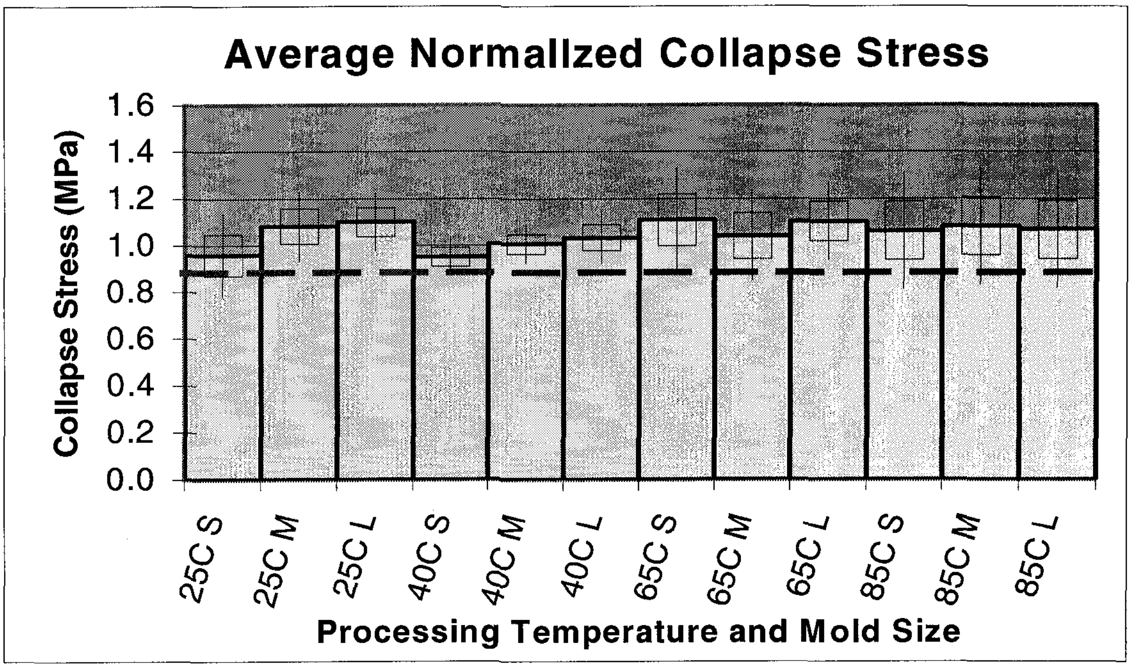


Figure 4.20: Normalized Collapse Strength for All Foam Batches

4.4.2 Normalized Mechanical Properties vs. Mold Size

The following series of graphs (Figure 4.21, Figure 4.22, and Figure 4.23) compare the mechanical properties to the change in mold size. The change in the average modulus of elasticity as mold size increases is presented in Figure 4.21. Each temperature is represented separately with three data points. Each data point represents the average modulus at one of three mold sizes. Figure 4.22 shows the change in the average peak yield as mold size increases. The change in the average collapse strength as mold size increases is presented in Figure 4.23.

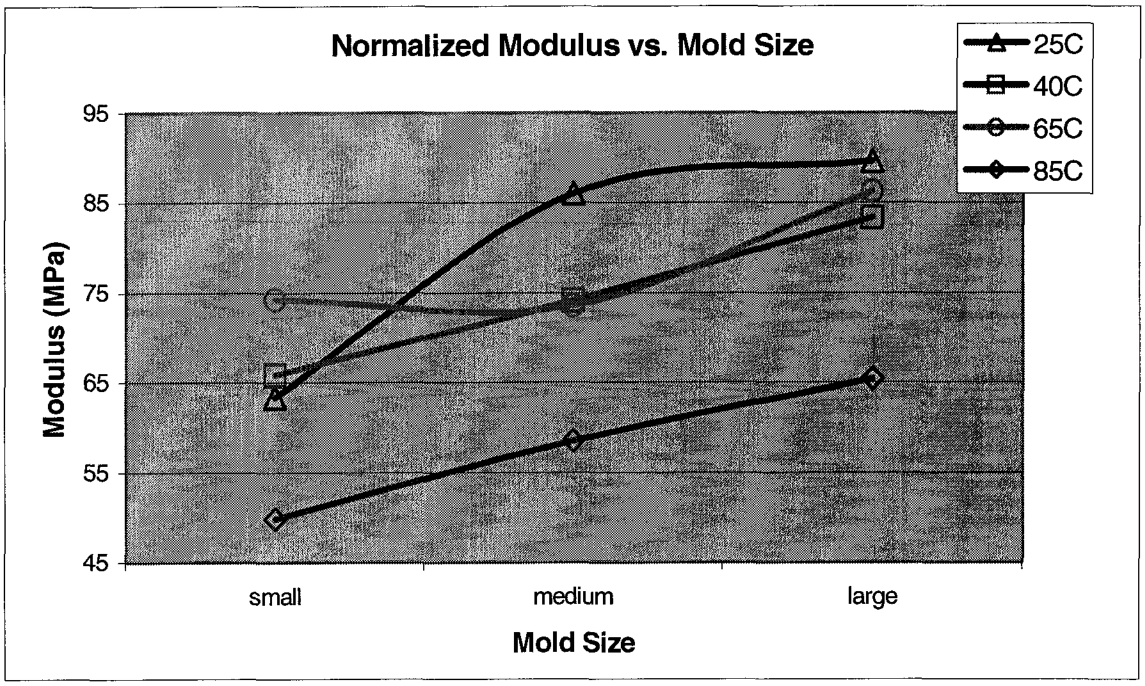


Figure 4.21: Normalized Modulus of Elasticity vs. Mold Size

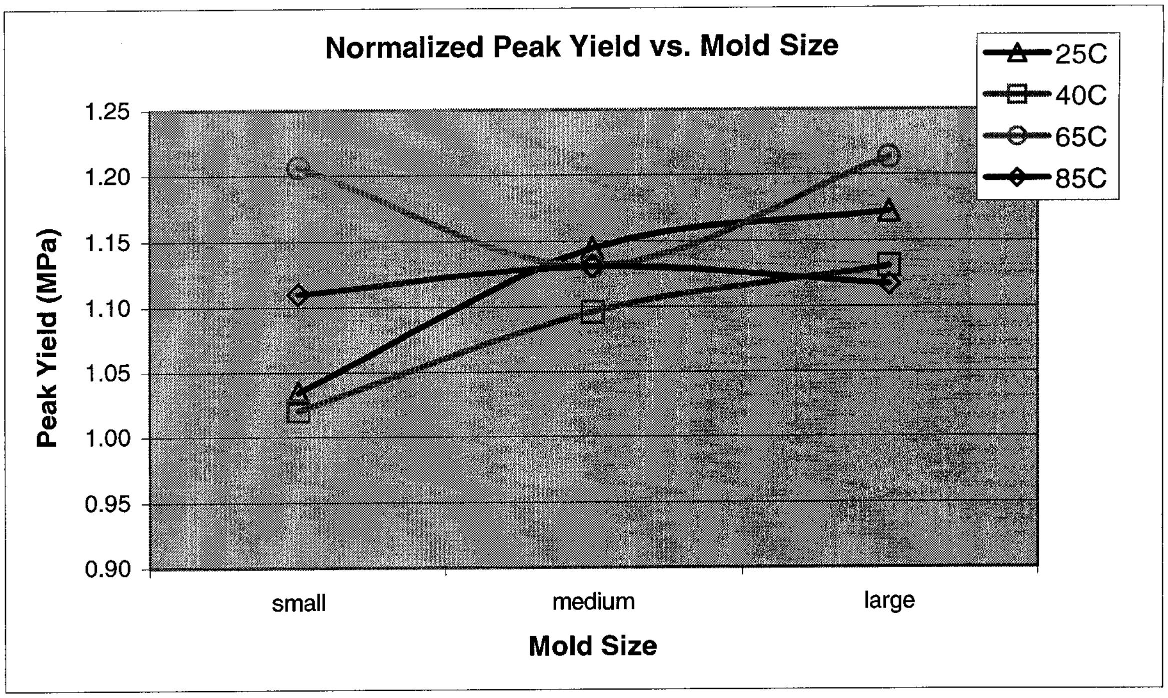


Figure 4.22: Normalized Peak Yield vs. Mold Size

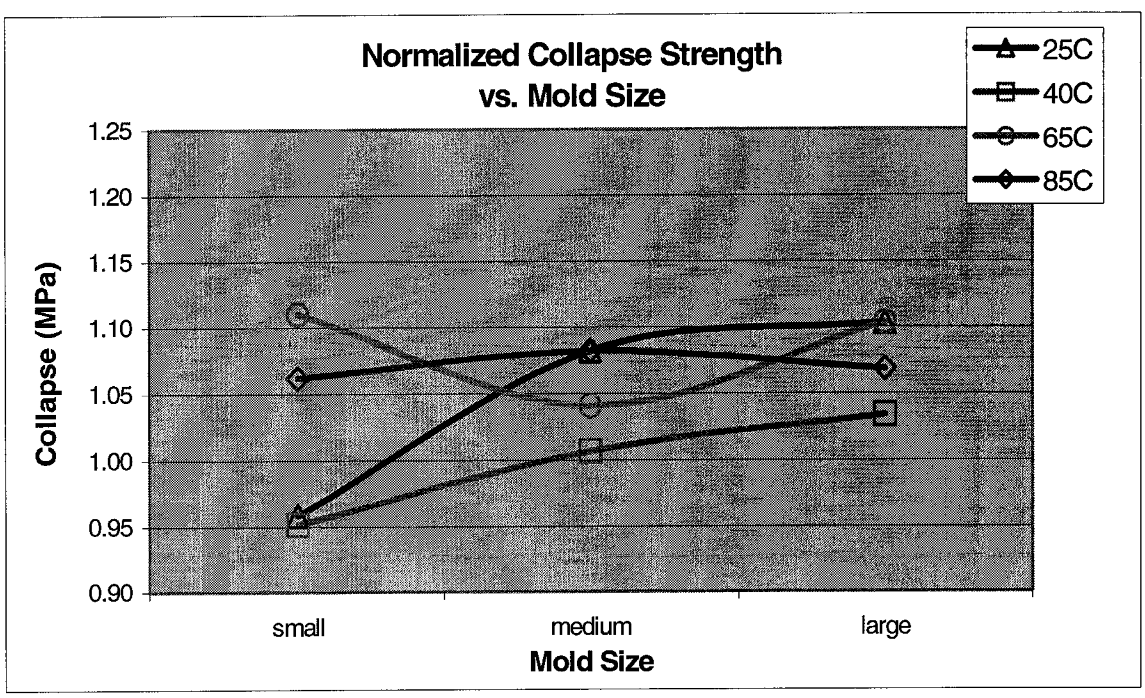


Figure 4.23: Normalized Collapse Strength vs. Mold Size

4.4.3 Normalized Mechanical Properties vs. Processing Temperature

The following series of graphs (Figure 4.24, Figure 4.25, and Figure 4.26) compare the mechanical properties to the change in processing temperature. The change in the average modulus of elasticity as processing temperature increases is presented in Figure 4.24. Each mold size is represented separately with four data points. Each data point represents the average density at one of four processing temperatures. Figure 4.25 shows the change in the average peak yield as processing temperature increases. The change in the average collapse strength as processing temperature increases is presented in Figure 4.26. The peak yield and collapse strength are shown on the same scale for a better comparison.

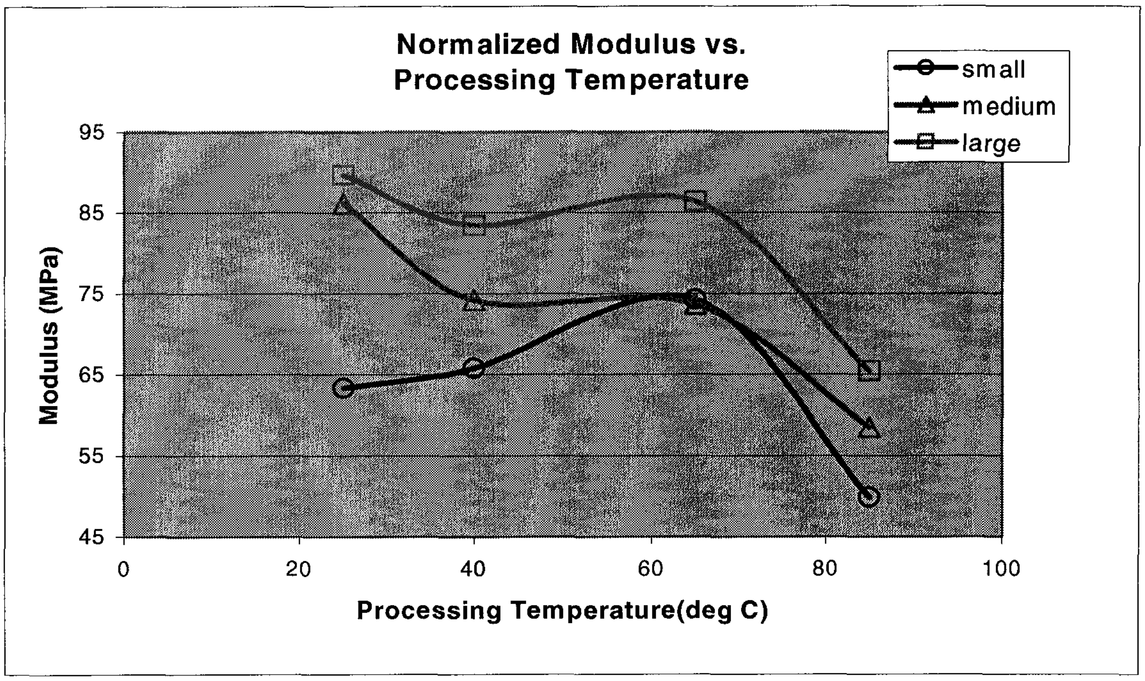


Figure 4.24: Normalized Modulus of Elasticity vs. Processing Temperature

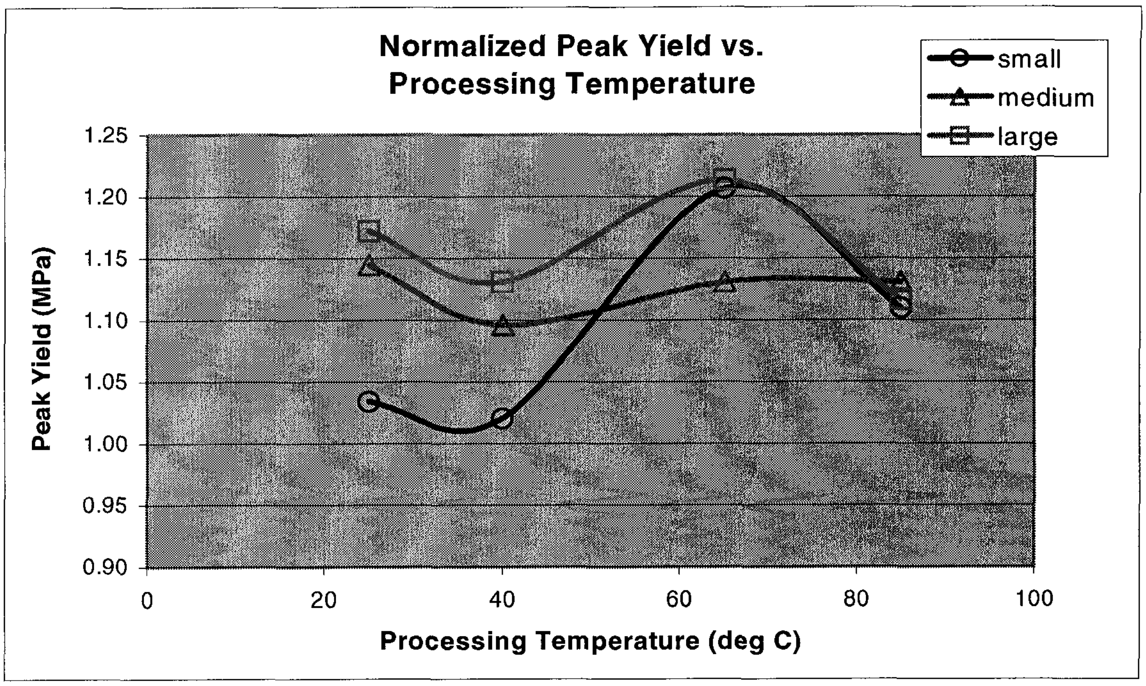


Figure 4.25: Normalized Peak Yield vs. Processing Temperature

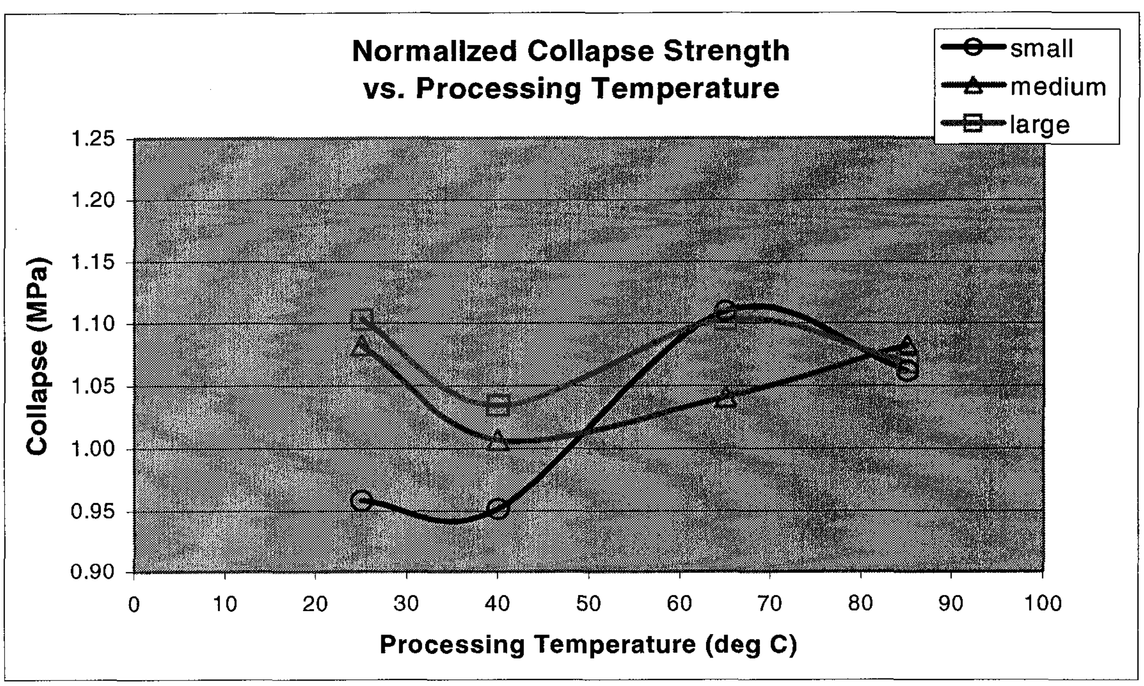


Figure 4.26: Normalized Collapse Strength vs. Processing Temperature

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Average Density

Foam tested by collaborators at Sandia National Laboratories (SNL) is cut from large batches [4]. The foam is made at ambient conditions with a target density of 0.096 g/cc. The reference batch in this study is made under similar conditions in a four liter plastic mold. Samples are cored out of the batch, similar to the skinless samples used at SNL. The average density of the reference batch is 0.101 g/cc (the target density is 0.096 g/cc). A dashed line in Figure 4.1 indicates the average density of the reference batch.

All of the batches made in aluminum tubes have an average density greater than the reference density. The rectangular boxes and vertical lines in all of the results graphs represent the first and second standard deviations respectively. The average density of the samples is fairly uniform, within each tube and among tubes for each batch, resulting in small standard deviations in the data. Both increasing the processing temperature and increasing the mold size reduces the batch average density and brings it brings closer to the reference density. Higher processing temperatures show less variation in the average density between different mold sizes.

5.1.1 Average Density vs. Mold Size

The effect of increasing the mold size on the average density is shown in Figure 4.2. Overall, increasing the mold size decreases the average density. It has been shown that the skin formed by molding the foam has a higher density than the foam [10]. Increasing the mold size decreases the effect of the skin on the entire foam system. Since the skin adds to the density of the sample, the skin to foam area ratio will affect the average density.

The average density values for the processing temperatures of 65°C and 85°C are very close for each mold size. The difference between the average density of the 65°C processing temperature batch and the average density of the 85°C processing temperature batch increases as the mold size increases. These processing temperatures also show the least change in average density between different mold sizes.

5.1.2 Average Density vs. Processing Temperature

The effect of increasing the processing temperature on the average density is shown in Figure 4.3. Increasing the processing temperature decreases the average density. The processing temperatures are controlled by a water bath in this study. Water is the blowing agent for ReCrete, making the density of the foam sensitive to the addition of water [3]. Higher water temperatures can cause condensation, which may add water to the formulation during the rising period of the foam. Additional water will cause more rise in the foam, and a lower density. The maximum temperature for this study (85°C) is chosen to eliminate the effect of condensation on the inside of the molds.

All of the processing temperatures used in this study are below the actual chemical reaction temperature of the foam. All the batches are made in a controlled environment of

a water bath, except the reference batch which is made in ambient air conditions. The processing temperature of 65°C corresponds to the post-cure temperature.

Figure 4.3 shows a decrease in the average density to a processing temperature of 65°C and then a slight increase in the average density to a processing temperature of 85°C. A previous study shows that the average density for foam made at a 90°C processing temperature is less than the average density of foam made at a 65°C processing temperature [7]. The difference between the average density of the 65°C processing temperature and the 85°C processing temperature batches is so small that it can be considered negligible. The average density also varies the least for each mold size between the 65°C and 85°C processing temperatures.

5.2 Radial Density Gradients

An aspect of this study is to determine how the density changes within the molded foam. Cores are removed from the samples at different radial positions, as explained in section 3.5.2. The density of these cores are determined to investigate how the density changes within the sample from center to outer edge, which is called the radial density gradient. Several cores were taken at each radial position to determine an average density at that position. The number of radial positions is limited by the size of the sample. The small molds have four radial positions, the medium molds have six radial positions, and the large molds have eight radial positions.

The density at each radial position for all the foam batches is shown in Figure 4.4. The radial position is measured from the center of the sample to the center of the core. The density at each radial position decreases as temperature and mold size increase. The

density also increases as the radial position increases. Previous studies show that the thin skin on the outer edge of the sample has a higher density than the average foam density, which supports the radial density gradient results.

Figure 4.5 shows the radial density gradient at normalized radial positions. Each radial position is normalized so that different size samples can be directly compared. The density of the reference batch is almost constant from the center to the outer radial position, with a density of 0.101 g/cc. The average density of all the samples is higher than the reference density (Figure 4.1). Figure 4.5 shows that the density of some of the foam batches within 60% of the center of the sample are actually below the reference density. The density throughout the samples for the foam made in the small molds is higher than the foam made in the reference batch. The 25°C processing temperature batches show a dramatic increase in density beyond 50% of the center of the sample. The change in density is negligible within 50% of the center of the sample.

The percent difference of the radial density gradient for all foam batches is shown in Figure 4.6. The percent difference is taken from the center to the edge with respect to the center of the sample. The radial density gradient increases as mold size increases, and decreases as processing temperature increases. Figure 4.6 clearly shows the large change in the density from the center to the edge in the 25°C processing temperature batches.

5.2.1 Radial Density Gradient vs. Mold Size

Figure 4.7, Figure 4.8, and Figure 4.9 only show the radial density gradient up to a maximum of 80% of the total sample radius. Since larger sample sizes provide results closer to the maximum radius of the sample, limiting the normalized radial positions to

80% from the center allows a more direct comparison between batches made with different mold sizes.

The series of graphs in Figure 4.7 show the radial density gradient of each mold size with respect to a normalized radial position. Each processing temperature is shown separately for simplicity. Increasing the mold size causes the radial density gradient to decrease. The change in density between mold sizes decreases as the processing temperatures increases.

Figure 4.7a shows that all of the 25°C processing temperature batches are higher than the reference density. Figure 4.7b shows that for the 40°C processing temperature batches the small and medium mold sizes are higher than the reference density. The large mold size starts below the reference density, and increase to above the reference density beyond 50% of the sample radius. Figure 4.7c shows that for the 65°C processing temperature batches only the small mold size is higher than the reference density. The medium and large mold sizes start below the reference density and increase above the reference density at 50% and 75% of the sample radius, respectively. Figure 4.7d shows that for the 85°C processing temperature batches the small mold size starts at the reference density and increases. The medium and large mold sizes start below the reference density and increase above the reference density at 50% and 65% of the sample radius, respectively.

The percent difference in the density between the center and the outer edge for up to 80% of the radius of the sample is shown in Figure 4.8. The medium size mold batches have a higher percent difference from the center to the outer edge. The largest radial density gradient is in the 25°C processing temperature, small mold size batch, which has

an increase in density from center to outer edge of 19%. The smallest radial density gradient is in the 85°C processing temperature, large mold size batch, which has an increase in density from center to outer edge of 8%. The percent difference from center to outer edge decreases as the processing temperature increases.

5.2.2 Radial Density Gradient vs. Processing Temperature

The series of graphs in Figure 4.9 show the radial density gradient of each processing temperature with respect to a normalized radial position. Each mold size is shown separately for simplicity. Increasing the processing temperature causes the radial density gradient to decrease. The change in density between processing temperatures decreases as the mold size increases.

Figure 4.9a shows that all of the densities of the small mold size batches are higher than the reference density. The 85°C processing temperature starts at the reference and increases. Figure 4.9b shows that for the medium mold size batches the 25°C and 40°C processing temperature batches are higher than the reference density. The 65°C and 85°C processing temperature batches start below the reference density and increase above the reference density at 50% of the sample radius. Figure 4.9c shows that for the large mold size batches only the 25°C processing temperature batch is higher than the reference density. The 40°C, 65°C and 85°C processing temperature batches start below the reference density and increase above the reference density at 50%, 75% and 60% of the sample radius, respectively.

5.3 Vertical Density Gradients

The vertical density gradient is based on the average density of the samples with respect to the vertical position of the sample in the foam column (measured at four different vertical positions). The vertical density gradient is taken top (level 1) to bottom (level 4). There is very little change in the density from top to bottom, making the vertical density gradient minimal.

Figure 4.10 shows the average density at each vertical level for all the foam batches. The average density at each level decreases as mold size and processing temperature increases. The change in density between levels is very small, indicating only a minimal vertical density gradient exists.

The percent difference in the density from top to bottom is shown in Figure 4.11. The percent difference is taken with respect to the bottom of the sample. A positive percent difference indicates the density increases from top to bottom. All of the batches made at 25°C processing temperature show an increase from top to bottom. The largest vertical density gradient, 2.5%, is in the large mold made at a 25°C processing temperature. The 40°C and 65°C processing temperatures show a decrease in density from top to bottom, with the largest percent change being in the large mold size batches.

5.3.1Vertical Density Gradient vs. Mold Size

The series of graphs in Figure 4.12 show the vertical density gradient of each mold size with respect to vertical position. Each processing temperature is shown separately for simplicity. The change in density from top to bottom of the foam column is minimal.

Figure 4.12a shows that there is a small increase in the density from top to bottom for all the mold sizes made at a 25°C processing temperature. The density is relatively

constant for all mold sizes, but increases at the bottom of the sample (level 4). This result may be due to compacting of the foam due to weight (the foam cannot push up as much). Figure 4.12b shows that there is a small decrease in the density from top to bottom for all the mold sizes made at a 40°C processing temperature. The density slightly increases between level 1 and level 2, but decreases between level 2 and level 4 for all mold sizes. Figure 4.12c shows that there is a small decrease in the density from top to bottom for all the mold sizes made at a 65°C processing temperature. The density is relatively constant for level 1 through level 3, but decreases between level 3 and level 4 for all mold sizes. Figure 4.12d shows that there is a negligible change in the density from top to bottom for all the mold sizes made at an 85°C processing temperature. The density slightly increases between level 1 and level 3, but decreases between level 3 and level 4 for all mold sizes.

Figure 4.13 focuses on the change in density with respect to vertical position for all mold sizes made at a 25°C processing temperature. The vertical density gradient of the reference batch is included in the figure for comparison. The density decreases as the mold size increases. The density increases from top to bottom for all the mold sizes. There is very little change in the density between levels, but the vertical density gradient increases as mold size increases. The small mold size has a percent difference, top to bottom, of 1.5%. The large mold size has a percent difference of 2.4%, while the reference batch has a percent difference of 7.7%.

5.3.2 Vertical Density Gradient vs. Processing Temperature

The series of graphs in Figure 4.14 show the vertical density gradient of each processing temperature with respect to vertical position. Each mold size is shown

separately for simplicity. The change in density from top to bottom of the foam column is minimal.

Figure 4.14a shows that there is a small but steady increase in the density from top to bottom for the 25°C processing temperature batch made in a small mold size. The density is relatively constant for the 40°C processing temperature batch made in a small mold size. The 65°C and 85°C processing temperatures show an increase in density from level 1 to level 3, but decrease at the bottom of the sample (level 4).

Figure 4.14b shows that the density is relatively constant for the 25°C processing temperature batch made in a medium mold size from level 1 to level 3, but increases slightly in level 4. The density is relatively constant for the 40°C processing temperature batch made in a medium mold size from level 1 to level 3, but decreases slightly in level 4. The density is relatively constant for the 65°C processing temperature batch made in a medium mold size. The 85°C processing temperature shows an increase in density from level 1 to level 3, but a decrease at the bottom of the sample (level 4).

Figure 4.14c shows that the density is relatively constant for the 25°C processing temperature batch made in a large mold size from level 1 to level 3, but increases in level 4. The 40°C and 65°C processing temperatures show a small but steady decrease in density from top to bottom in the large mold size. The 85°C processing temperature shows an increase in density from level 1 to level 3, but a decrease at the bottom of the sample (level 4).

5.4 Mechanical Analysis

The mechanical properties determined in this study are the modulus of elasticity, the peak yield and the collapse strength of the foam, measured in a quasi-static compression test. Sixteen samples were tested from each batch to determine the average modulus, average peak yield, and average collapse strength for each batch. The rectangular boxes and vertical lines represent the first and second standard deviations respectively. The mechanical properties of the reference batch are plotted as a dashed line. The reference batch samples are cut from a large batch with a hole saw, and they are skinless.

Figure 4.15 shows the average modulus of elasticity for all the foam batches. The average modulus decreases as temperature increases. The largest standard deviations appear in the 65°C processing temperature batches. Large standard deviations indicate a wide range in the raw data, making the average value less secure. The smallest standard deviations appear in the large molds and the 40°C processing temperature batch. All of the foam batches have a modulus higher than the reference batch modulus of 35.7 MPa. The highest modulus' came from the 25°C processing temperature batches, averaging 124.5 MPa.

The average peak yield for all the foam batches is shown in Figure 4.16. Peak yield decreases as processing temperature and mold size increase. The largest standard deviations appear in the 85°C processing temperature batches. Large standard deviations also appear in the small mold batches. All of the foam batches have an average peak yield well above the reference batch peak yield of 0.97 MPa. The highest average peak yield, 2.33 MPa, is for the 25°C processing temperature, small mold foam batch.

Figure 4.17 shows the average collapse strength for all the foam batches. The results were similar to the average peak yield. The average collapse strength decreased as the processing temperature and mold size increase. The largest standard deviations are in the 85°C processing temperature batches. Large standard deviations also appear in the small mold batches. The reference batch has an average collapse strength of 0.88 MPa. All of the foam batches are above the average collapse strength of the reference batch. The highest average collapse strength, 2.17 MPa, is for the 25°C processing temperature foam batch.

5.4.1 Normalization of Mechanical Properties

The mechanical properties are normalized with respect to average density in Figure 4.18 through Figure 4.26. Normalization is performed to determine if the changes in mechanical properties are effected by other factors besides average density. Since the normalization process is based on the target density of the foam, which is equivalent to the average density of the reference batch, the mechanical properties for the reference batch are unchanged. Normalization lowers the average mechanical property values by almost 75%.

Outliers are removed from the data after normalization. Results outside 95% of the average value, assuming a standard bell curve distribution, are removed and a new average value is determined. Removing outliers improves the standard deviations for the batches.

Figure 4.18 shows the average normalized modulus of elasticity for all the foam batches. The average normalized modulus increases as mold size and processing temperature increase. The results for the 85°C processing temperature batches are lower

than all the other foam batches. The largest standard deviations are in the 65°C processing temperature batches. The smallest standard deviations are in the 40°C processing temperature batches. The average normalized modulus for all batches is above the modulus of the reference batch. Comparing the normalized modulus values in Figure 4.18 to the raw average modulus values in Figure 4.15 clearly shows that the modulus increases as mold size increases.

The average normalized peak yield for all the foam batches is shown in Figure 4.19. The largest standard deviations are in the 85°C processing temperature batches. Large standard deviations also appear in the small mold batches. The smallest standard deviations are in the 40°C processing temperature batches. The average normalized peak yield increases as mold size increases for the 25°C and the 40°C processing temperature foam batches. The 85°C processing temperature batches show the least change between mold sizes. All of the foam batches have an average normalized peak yield above the reference peak yield. The highest average normalized peak yield values are in the 65°C processing temperature batches. The raw average peak yield values in Figure 4.16 decrease as mold size increases. Removing the dependency on density by normalizing the peak yield in Figure 4.19 shows that the peak yield increases as mold size increases.

Figure 4.20 shows the average normalized collapse strength for all the foam batches. The results were similar to the average peak yield. The largest standard deviations are in the 85°C processing temperature batches. The smallest deviations are in the 40°C processing temperature batches. The average normalized collapse strength increases as mold size increases for the 25°C and the 40°C processing temperature batches. The 85°C processing temperature batches have the least change in average normalized collapse

strength between mold sizes. All of the foam batches have an average normalized collapse strength above the reference collapse strength. The highest average normalized collapse stress values are in the 65°C processing temperature batches. The raw average collapse strength values in Figure 4.17 decrease as mold size increases. Removing the dependency on density by normalizing the collapse strength in Figure 4.20 shows that the collapse strength increases as mold size increases.

5.4.2 Normalized Mechanical Properties vs. Mold Size

The average normalized mechanical properties as they relate to the change in mold size are shown in Figure 4.21, Figure 4.22, and Figure 4.23. Each processing temperature is plotted separately for the three mold sizes. Each data point represents the average of sixteen tested samples from a single batch. In general the average normalized mechanical properties increase, or shows a negligible change, as mold size increases.

The effect of increasing the mold size on the average normalized modulus of elasticity is shown in Figure 4.21. The average normalized modulus increases as mold size increases. The 40°C and 85°C processing temperature batches both show a relatively steady increase (approximately 30%) between all mold sizes. The 25°C processing temperature batches show a dramatic increase (36%) between the small mold size and the medium mold size, but only a slight increase (4%) between the medium mold size and the large mold size. The 65°C processing temperature batches show a minimal decrease (less than 1%) between the small mold size and the medium mold size, and a large increase (17%) between the medium mold size and the large mold size. The minimal change between the small and medium mold sizes in the 65°C processing temperature batches can be seen as almost no change in the modulus.

The effect of increasing the mold size on the average normalized peak yield is shown in Figure 4.22. The 25°C and 40°C processing temperature batches both clearly show an increase in average normalized peak yield between all mold sizes. The increase is more pronounced (approximately 9%) between the small mold size and the medium mold size, but less than 3% between the medium mold size and the large mold size. The 85°C processing temperature batches show a slight increase (2%) between the small mold size and the medium mold size, and a slight decrease (1%) between the medium mold size and the large mold size. The changes in average normalized peak yield between mold sizes in the 85°C processing temperature batches, compared to the other batches, are small enough to be considered negligible. The 65°C processing temperature batches show a decrease (6%) between the small mold size and the medium mold size, and an increase (7%) between the medium mold size and the large mold size.

The effect of increasing the mold size on the average normalized collapse strength is shown in Figure 4.22. The results for the average normalized collapse strength are similar to the results for the average normalized peak yield. The 25°C and 40°C processing temperature batches both clearly show an increase in average normalized peak yield between all mold sizes. The increase in the 25°C processing temperature batches is more pronounced (13%) between the small mold size and the medium mold size, but minimal (2%) between the medium mold size and the large mold size. The increase in the 40°C processing temperature batches between the small mold size and the medium mold size is approximately 6%. The increase is slightly less between the medium mold size and the large mold size (3%). The 85°C processing temperature batch shows a slight increase (2%) between the small mold size and the medium mold size, and a slight decrease (1%)

between the medium mold size and the large mold size. The changes in average normalized peak yield between mold sizes in the 85°C processing temperature batches, compared to the other batches, are small enough to be considered negligible. The 65°C processing temperature batch shows a decrease (6%) between the small mold size and the medium mold size, and an increase (6%) between the medium mold size and the large mold size.

5.4.3 Normalized Mechanical Properties vs. Processing Temperature

The average normalized mechanical properties as they relate to the change in processing temperature are shown in Figure 4.24, Figure 4.25, and Figure 4.26. Each mold size is plotted separately over the processing temperature. Each data point represents the average of sixteen tested samples from a single batch.

The effect of increasing the processing temperature on the average normalized modulus of elasticity is shown in Figure 4.24. In general the average normalized modulus decreases, or shows a negligible change, as processing temperature increases; with the exception of the 65°C processing temperature batches, which show an increase. The small mold size shows a small increase of 4% between the 25°C and the 40°C processing temperature batches and a further increase of 13% between the 40°C and the 65°C processing temperature batches. The modulus dramatically decreases by 33% between the 65°C and the 85°C processing temperature batches. The medium mold size shows a large decrease of 14% between the 25°C and the 40°C processing temperature batches and a negligible decrease of less than 1% between the 40°C and the 65°C processing temperature batches. The modulus dramatically decreases by 21% between the 65°C and the 85°C processing temperature batches. The large mold size shows a small decrease of

7% between the 25°C and the 40°C processing temperature batches and a small increase of less than 1% between the 40°C and the 65°C processing temperature batches. The modulus dramatically decreases by 24% between the 65°C and the 85°C processing temperature batches. It is interesting to note that the dramatic decrease in modulus between the 65°C and the 85°C processing temperature batches does not correlate to any change in the average density of the batches. Therefore, something besides density must be affecting the mechanical properties of the foam.

The effect of increasing the processing temperature on the average normalized peak yield is shown in Figure 4.25. In general the average normalized peak yield shows a sinusoidal relationship, as processing temperature increases. All the mold sizes show a slight decrease (between 1% and 4%) as the processing temperature increases from 25°C to 40°C. The average normalized peak yield increases as the processing temperature increases from 40°C to 65°C. The increase is dramatic in the small mold size (18%), large in the large mold size (3%), and small in the medium mold size (7%). The average normalized peak yield decreases as the processing temperature increases from 65°C to 85°C for the small mold size and large mold size. The change in both mold sizes is the same (8%). The medium mold size shows no change in the average normalized peak yield as processing temperature increases from 65°C to 85°C.

The effect of increasing the processing temperature on the average normalized collapse strength is shown in Figure 4.26. The results for the average normalized collapse strength are similar to the results for the average normalized peak yield. In general the average normalized collapse strength shows a sinusoidal relationship, as processing temperature increases. All the mold sizes show a decrease as the processing temperature

increases from 25°C to 40°C. The decrease is negligible (less than 1%) for the small mold size. The average normalized peak yield increases as the processing temperature increases from 40°C to 65°C. The increase is dramatic in the small mold size (17%). The average normalized peak yield decreases as the processing temperature increases from 65°C to 85°C for the small mold size and large mold size. The medium mold size shows an increase in the average normalized peak yield as processing temperature increases from 65°C to 85°C.

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

6.1 Average Density

6.1.1 Conclusions

There is no optimal density for the foam. The desired values depend on the application of the material and how the density relates to the mechanical properties of the foam. Determining how the processing temperature and size of mold affects the average density of the material is important to its application. If Recrete is to be used in DOE applications, the density of the foam will need to be predictable.

All of the batches have an average density greater than the reference density of 0.101 g/cc. Both increasing the processing temperature and increasing the mold size brings the batch average density closer to the reference density. The highest average density of 0.15 g/cc is in the 25°C processing temperature, small mold size batch. The lowest average density of 0.106 g/cc is in the 65°C processing temperature, large mold size batch.

Overall, increasing the mold size decreases the average density. The average density of the foam sample takes into account the foam and a thin, dense skin layer on the outer edge of the foam. Increasing the processing temperature decreases the average density. Higher processing temperatures show less variation in the average density between different mold sizes.

Determining how the density is affected by altering the processing conditions and mold size is important. An exact density was not sought,

6.1.2 Recommendations

Another method of fabricating the foam at higher than ambient air conditions is recommended to eliminate the possibility that condensation affects the average density of the foam. Photo images of the foam cell structure and chemical testing of the foam at different processing temperatures will indicate chemical changes caused by the elevated temperatures.

The effect of processing temperature on skin thickness is not examined in this study. Gupta and Khakhar explained that the skin is formed because the walls of the mold are at a cooler temperature than the center of the formulation where the chemical reactions are taking place [10]. If this theory is valid, then increasing the processing temperature should result in a thinner skin. An accurate procedure for measuring the thickness of the skin, such as photo microscopy, may lead to other conclusions about the average density of the foam.

6.2 Radial Density Gradients

6.2.1 Conclusions

The density increases as the radial position increases, meaning the density increases from center to outer edge, indicating a radial density gradient exists. The radial position only up to 80% of the sample radius is considered when directly comparing the mold sizes. The density was determined up to 80%, 86% and 90% of the sample radius for the small, medium and large mold sizes, respectively. The reference batch shows a very small radial density gradient (less than 4% difference center to outer edge) up to 80% of the radius.

The radial density gradient increases as mold size increase from the small to the medium mold size, and decreases from the medium to the large mold size. The largest radial density gradient is in the medium mold size batches. The change in density between processing temperatures decreases as the mold size increases.

The radial density gradient decreases as processing temperature increases. The largest change in the density from the center to the edge in the 25°C processing temperature batches (9 to 20% difference center to outer edge). The change in density between mold sizes decreases as the processing temperatures increases.

6.2.2 Recommendations

A further radial density analysis is recommended. The small radial density gradient in the reference batch and a previous mold size study [15] indicate that the radial density gradient should decrease as mold size increases. In this study, the medium size mold batches have the largest radial density gradient. Also, the 25°C processing temperature batches show the smallest radial density gradient in the medium size molds. This analysis is based on cores taken from four samples and averaged. An increased number of cores and samples may eliminate any error. A better method for determining the density at different radial positions for the entire sample, perhaps with the use of microscopy, would also provided better results.

6.3 Vertical Density Gradients

6.3.1 Conclusions

Considering only batches made at a 25°C processing temperature, a mold size comparison is performed, including the reference batch. The reference batch has a vertical density gradient of 7.7%. The small, medium, and large mold size batches have a

change in vertical density top to bottom of 1.5%, 0.9%, and 2.4%, respectively. There is very little change in the density between levels, but overall the vertical density gradient increases as mold size increases.

All of the batches made at 25°C processing temperature show an increase in density from top to bottom. Batches made at 40°C, 65°C, and 85°C processing temperatures show a decrease in density from top to bottom. The largest vertical density gradient of 2.4% is in the large mold made at a 25°C processing temperature. The smallest vertical density gradient of 0.09% (bottom to top) is in the medium mold made at an 85°C processing temperature.

6.3.2 Recommendations

There is very little change in the density from top to bottom, making the vertical density gradient minimal. The molds used in this study are 15 cm in height, and four 2.54 cm samples are cut from these columns. This arrangement only allows for four points at which to take the density. Further studies should include cutting several samples from the 15cm high molds, for more data points, and preparing foam in taller molds to determine if vertical density is affected by mold height.

6.4 Average Mechanical Properties

6.4.1 Conclusions

There is no target modulus of elasticity, peak yield or collapse strength. The optimal values for the mechanical properties depend on the application of the material. For example, a large change in stress over a small change in strain will have low energy absorption (determined by the area under the modulus curve). Determining how the processing temperature and size of mold affect the properties of the material is important

to its application. If Recrete is to be used in DOE applications, the properties of the foam will need to be predictable.

All of the batches have an average modulus of elasticity greater than the reference modulus of 35.7 MPa. The average modulus of elasticity decreases as temperature increases. The largest standard deviations appear in the 65°C processing temperature batches. The smallest standard deviations appear in the large molds and the 40°C processing temperature batch. The highest modulus' came from the 25°C processing temperature batches, averaging 124.5 MPa for the three mold sizes. The lowest modulus' came from the 85°C processing temperature batches, averaging 70.7 MPa for the three mold sizes.

All of the batches have an average peak yield greater than the reference peak yield of 0.97 MPa. The average peak yield decreases as processing temperature and mold size increase. The largest standard deviations appear in the 85°C processing temperature batches. Large standard deviations also appear in the small mold size batches. The smallest standard deviations appear in the large mold size batches. The highest average peak yield, 2.33 MPa, is for the 25°C processing temperature, small mold foam batch.

All of the batches have an average collapse strength greater than the reference collapse strength of 0.88 MPa. The results were similar to the average peak yield results. The average collapse strength decreased as the processing temperature and mold size increase. The largest standard deviations are in the 85°C processing temperature batches. Large standard deviations also appear in the small mold batches. The highest average collapse strength, 2.17 MPa, is for the 25°C processing temperature foam batch.

6.5 Normalized Mechanical Properties

6.5.1 Conclusions

Normalization lowers the average mechanical property values by almost 75%. Removing outliers improves the standard deviations for the batches. The average normalized modulus of elasticity increases as mold size increases. The average normalized modulus decreases, or shows a negligible change, as processing temperature increases; with the exception of the 65°C processing temperature batches, which show an increase. The largest standard deviations are in the 65°C processing temperature batches. The smallest standard deviations are in the 40°C processing temperature batches. The results for the 85°C processing temperature batches are lower than all the other foam batches, averaging 57.9 MPa for all three mold sizes.

The average normalized peak yield increases, or shows a negligible change, as mold size increases. The average normalized peak yield shows a sinusoidal relationship, as processing temperature increases. The 25°C and 40°C processing temperature batches both clearly show an increase in average normalized peak yield between all mold sizes. The changes in average normalized peak yield between mold sizes in the 85°C processing temperature batches, compared to the other batches, are small enough to be considered negligible. The largest standard deviations are in the 85°C processing temperature batches. Large standard deviations also appear in the small mold batches. The smallest standard deviations are in the 40°C processing temperature batches. The highest average normalized peak yield values are in the 65°C processing temperature batches, averaging 1.18 MPa for the three mold sizes.

The average normalized collapse strength results are similar to the average peak yield. The average normalized collapse strength increases, or shows a negligible change,

as mold size increases. The average normalized collapse strength shows a sinusoidal relationship, as processing temperature increases. The 25°C and 40°C processing temperature batches both clearly show an increase in average normalized peak yield between all mold sizes. The changes in average normalized peak yield between mold sizes in the 85°C processing temperature batches, compared to the other batches, are small enough to be considered negligible. The largest standard deviations are in the 85°C processing temperature batches. The smallest deviations are in the 40°C processing temperature batches. The 85°C processing temperature batches have the least change in average normalized collapse strength between mold sizes. The highest average normalized collapse stress values are in the 65°C processing temperature batches, averaging 1.08 MPa for the three mold sizes.

6.5.2 Recommendations

Further compression tests are recommended to eliminate any error from this study. The mechanical property conclusions are based on sixteen tested samples for each batch. While sixteen samples are enough for a basic analysis, the high standard deviations would be improved with more data. Additional batches at similar conditions would also confirm repeatability of this experiment.

Another consideration is the age of the chemicals used in fabricating the foam. Aged chemicals may react and bond differently than expected and may affect the mechanical properties of the foam. Foam batches made with fresh chemicals should be mechanically tested, chemically examined and compared to the results of this study to eliminate an effect caused by aging.

A second chemical consideration is the Rubinate 1680 used in the foam formulation. After this study was completed, new information about Rubinate 1680 was discovered.

Rubinate 1680 is pre-treated with a catalyst which causes additional chemical bonds to form during the reaction. These bonds are thermally reversible and therefore sensitive to temperature. Higher processing temperatures can cause a breakdown in the bonds, weakening the material. Figure 6.1 shows the modified gel formation chemical reaction for Rubinate 1680. This affect may account for the decrease in modulus as the processing temperature increases. Additional mechanical tests using foam samples made with a different type of Rubinate, that is not temperature sensitive, are recommended. Also chemical and microscopic studies of the foam processed at different temperatures may indicate how the Rubinate is being affected.

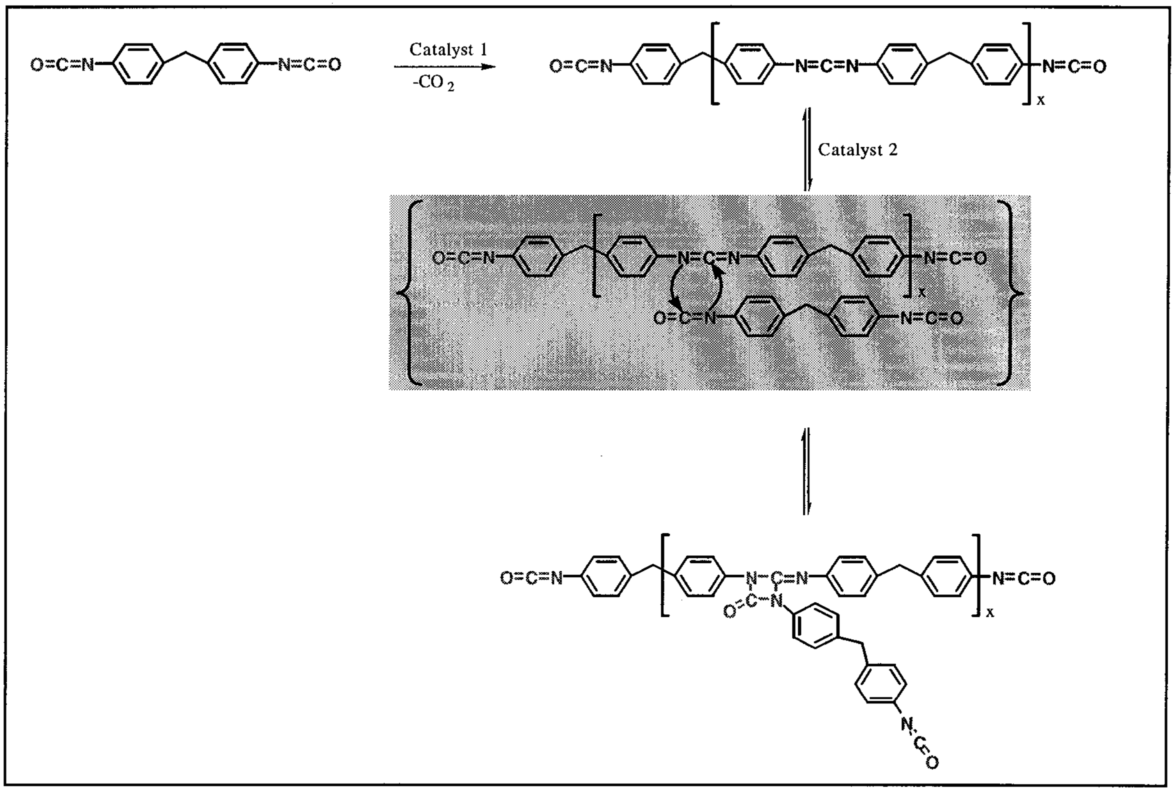


Figure 6.1: Chemical Reaction Using Rubinate 1680

The mechanical properties in this study were determined using quasi-static compression tests. Mechanical properties could also be determined using tension tests. However, previous testing at SNL has shown the foam to be highly brittle with very little yielding before fracture when tested in tension [2]. Tension testing is not the best method of determining mechanical properties for a material that will be primarily used for shock and energy absorption. Impact testing would be a suggested method for collecting information on the dynamic properties of the foam. Another method of compression testing that might be of interest, hydrostatic loading, allows uniform volumetric compression [23].

APPENDIX A

EQUIPMENT & CHEMICALS

The following pages contain a list of the equipment, supplies and chemicals used in this study. The list is alphabetized by product name. The supplier name and product model number are included when available. Other descriptive information is also included for each item on the list. The chemicals used in the foam fabrication are listed with the equipment, but denoted by capital letters.

Arrow Overhead Mixer
VWR
Model# 2000
60Hz/ 115V/AC/ 2A

Axial Loading Machine
United
Model# SSTM-1

Blue M Oven
Model# DC-136-C
Temperature Range: 343°C

Conn Blade
Conn & Co., LLC
Intensive Type (IT)
2" diameter

Cork Borer
Nickel Plated Brass
Beveled on Outside

Craftsman 11-in Band Saw
Sears Hardware
Model# 315.214500
3 wheel/ ⅓ HP
1/16" Blade

Craftsman Drill Press
Sears Hardware
Model# 137.219080
⅓ HP/ 5-Speed
½" Chuck

Delta 12" Disk Sander
Sears Hardware
Model# 31-120
½ HP/ 60Hz/ 120V/ 1725 RPM

DOW CORNING® 193 SURFACTANT
Dow Corning Corporation
Silicone Glycol Copolymer
Average Hydorxyl Number: 75

Kimberly-Clark Kimwipes EXL
VWR
Model# 34256
1 ply/ 38.1 x 43.1 cm

Hole Saw
Abrasive Technology
Custom Order
1.13 x 2.5 x 0.375

Load Cell
United
Model# 1K T/C
4.4 kN

Mettler Toledo (Chemical) Scale
VWR
Model# PB3002-S
Max: 3100g
Min: 0.5g
Readability: d= 0.01g

Mettler Toledo (Density) Scale

VWR
Model# AG204 DeltaRange
Capability: Max 81g/210g
Readability: d= 0.1mg/1mg

Microgrip Ambi Polyshield Latex Gloves
VWR
Powder Free

Mitutoyo Absolute Digimatic Calipers
McMaster-Carr
Model# CD-6"C
Capability: 0-150mm
Resolution: 0.01mm
Accuracy: ±0.02mm
Repeatability: 0.01mm

Mold Release
PTM&W Industries Inc
Model# PA0801-WAX
VOC: 20C-550 gm/lit
Vap Press: 2ml-Hg
65% light petroleum distillate

O-Rings
Hydraulic Seals and Supplies
Item# OR-916/90
Item# 223-70NB
Item# 227-70NB

Optical Extensometer (Laser)
United
Model# EXT-62-LOE
Tolerances: ASTM E83 class B2
Wavelength: 630 nm
Scan Range: 80°

POLYCAT® 17 CATALYST
Air Products and Chemicals Inc.
Tertiary Amine Catalyst (Trimethyl-N-Hydroxyethyl Propylene Diamine)
Average Hydroxyl Number: 400

Precision Water Bath
VWR
Model# 260
Uniformity 37°C ±0.05°C
Sensitivity 37°C ±0.05°C
115 V/ 8.3 Amps

Puritan Wooden Applicators
VWR
Model# REF 807
Length: 15cm

RUBINATE® 1680
Dow Corning
Specific Gravity @ 25°C: 1.07
Viscosity 335.00 CST

Teflon Tape
Hydraulic Seals and Supplies
Item# TFE TAPE-500
½" Wide

Thermo-Hygrometer
VWR
Catalog# 35519-049
Range: 0°C - 50°C
2% - 98% RH

VORANOL® 490 POLYOL
The Dow Plastic Company
Polyether Polyol
Density @ 25°C: 0.11 kg/cm^3
Typical Hydroxyl Number: 490 mg KOH equiv/g of resin
Functionality: 4.3 (calculated)
Average Molecular Weight: 460 g/mole
Viscosity @ 25°C: 5572 cups

Water Bath Balls
VWR
20mm Diameter

APPENDIX B

AVERAGE DENSITY DATA

The following tables summarize the results of the average density study. Table B.1 through Table B.12 show the raw measurements of height, diameter, and mass of each sample in each foam batch. The tables also report the calculation results for the cross-sectional area, volume, and average density of each sample. The average density and standard deviation for each batch is also presented. Table B.13 through Table B.16 show the average density data for each of the four levels of the reference batch. A summery of the average density and standard deviations for each vertical level of each foam batch is presented in Table B.17.

Table B.1: Measurements & Density Calculations for 25°C Small Mold Size Samples

Batch D1: 25C Small Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	2.8616	2.5217	2.4165	6.4313	16.2178	0.14900
RC-2		2.8804	2.5606	2.4936	6.5160	16.6848	0.14945
RC-3		2.8793	2.5377	2.4717	6.5114	16.5242	0.14958
RC-4		2.8793	2.5281	2.5011	6.5114	16.4613	0.15194
RC-5	2	2.8641	2.5260	2.4136	6.4427	16.2744	0.14831
RC-6		2.8689	2.5006	2.4106	6.4644	16.1651	0.14912
RC-7		2.8710	2.5359	2.4460	6.4736	16.4166	0.14900
RC-8		2.8715	2.5448	2.4799	6.4759	16.4800	0.15048
RC-9	3	2.9035	2.5580	2.4896	6.6210	16.9368	0.14699
RC-10		2.9091	2.5370	2.5171	6.6465	16.8620	0.14928
RC-11		2.9093	2.5489	2.5324	6.6477	16.9443	0.14945
RC-12		2.9103	2.5131	2.4829	6.6523	16.7179	0.14852
RC-13	4	2.9027	2.5464	2.5016	6.6176	16.8506	0.14846
RC-14		2.9116	2.5423	2.5072	6.6582	16.9269	0.14812
RC-15		2.9121	2.5560	2.5170	6.6605	17.0242	0.14785
RC-16		2.9147	2.5537	2.5597	6.6721	17.0387	0.15023
RC-17	5	2.8501	2.5425	2.4135	6.3800	16.2214	0.14878
RC-18		2.8532	2.5479	2.4220	6.3936	16.2902	0.14868
RC-19		2.8547	2.5352	2.4208	6.4005	16.2263	0.14919
RC-20		2.8557	2.5591	2.4850	6.4050	16.3908	0.15161
RC-21	6	2.8735	2.5321	2.4266	6.4850	16.4209	0.14777
RC-22		2.8735	2.5273	2.4323	6.4850	16.3897	0.14840
RC-23		2.8773	2.5415	2.4415	6.5023	16.5256	0.14774
RC-24		2.8715	2.5268	2.4474	6.4759	16.3632	0.14957
					Average		0.1491
					Standard Deviation		0.0012
					% Dev		0.78

Table B.2: Measurements & Density Calculations for 40°C Small Mold Size Samples

Batch D2: 40C Small Mold Size							
Sample Number	**Mold #**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
RC-1	1	2.8725	2.5306	2.1926	6.4805	16.3995	0.1337
RC-2		2.8778	2.5606	2.2347	6.5045	16.6554	0.1342
RC-3		2.8781	2.5263	2.1891	6.5057	16.4352	0.1332
RC-4		2.8776	2.5484	2.1946	6.5034	16.5731	0.1324
RC-5	2	2.8710	2.5331	2.1765	6.4736	16.3985	0.1327
RC-6		2.8705	2.5524	2.2100	6.4713	16.5176	0.1338
RC-7		2.8722	2.5464	2.1951	6.4793	16.4986	0.1330
RC-8		2.8712	2.5220	2.1750	6.4747	16.3290	0.1332
RC-9	3	2.9083	2.5547	2.2547	6.6431	16.9712	0.1329
RC-10		2.9103	2.4666	2.1830	6.6523	16.4086	0.1330
RC-11		2.9106	2.5349	2.2456	6.6535	16.8661	0.1331
RC-12		2.9116	2.5083	2.1959	6.6582	16.7003	0.1315
RC-13	4	2.9116	2.5276	2.2523	6.6582	16.8288	0.1338
RC-14		2.9124	2.5540	2.2873	6.6616	17.0136	0.1344
RC-15		2.9134	2.5649	2.2717	6.6663	17.0983	0.1329
RC-16		2.9136	2.5397	2.2458	6.6675	16.9336	0.1326
RC-17	5	2.8550	2.5337	2.1640	6.4016	16.2195	0.1334
RC-18		2.8560	2.5585	2.1997	6.4062	16.3905	0.1342
RC-19		2.8560	2.5372	2.1839	6.4062	16.2538	0.1344
RC-20		2.8575	2.5123	2.1596	6.4130	16.1115	0.1340
RC-21	6	2.8760	2.5438	2.2153	6.4965	16.5259	0.1341
RC-22		2.8750	2.5359	2.2250	6.4919	16.4631	0.1352
RC-23		2.8748	2.5387	2.2073	6.4908	16.4783	0.1340
RC-24		2.8712	2.5347	2.1993	6.4747	16.4113	0.1340
					Average		**0.1335**
					Standard Deviation		**0.0008**
					% Dev		**0.60**

Table B3: Measurements & Density Calculations for 65°C Small Mold Size Samples

Batch D3: 65C Small Mold Size							
Sample Number	**Mold #**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
RC-1	1	2.8560	2.5578	1.8856	6.4062	16.3856	0.1151
RC-2		2.8740	2.5375	1.8841	6.4873	16.4614	0.1145
RC-3		2.8776	2.5387	1.8817	6.5034	16.5104	0.1140
RC-4		2.8781	2.5476	1.8840	6.5057	16.5740	0.1137
RC-5	2	2.8473	2.5403	1.8762	6.3675	16.1751	0.1160
RC-6		2.8677	2.5540	1.9021	6.4587	16.4953	0.1153
RC-7		2.8692	2.5425	1.9029	6.4656	16.4390	0.1158
RC-8		2.8705	2.5588	1.8952	6.4713	16.5587	0.1145
RC-9	3	2.9035	2.5497	1.9450	6.6210	16.8813	0.1152
RC-10		2.9091	2.5489	1.9664	6.6465	16.9413	0.1161
RC-11		2.9103	2.5283	1.9475	6.6523	16.8192	0.1158
RC-12		2.9116	2.5626	1.9416	6.6582	17.0622	0.1138
RC-13	4	2.9009	2.5601	1.9622	6.6095	16.9206	0.1160
RC-14		2.9121	2.5390	1.9717	6.6605	16.9108	0.1166
RC-15		2.9129	2.5514	1.9797	6.6640	17.0026	0.1164
RC-16		2.9154	2.5453	1.9642	6.6756	16.9916	0.1156
RC-17	5	2.8496	2.5491	1.8892	6.3777	16.2577	0.1162
RC-18		2.8539	2.5535	1.9151	6.3971	16.3347	0.1172
RC-19		2.8547	2.5438	1.8972	6.4005	16.2816	0.1165
RC-20		2.8562	2.5522	1.8779	6.4073	16.3527	0.1148
RC-21	6	2.8740	2.5530	1.9388	6.4873	16.5619	0.1171
RC-22		2.8738	2.5352	1.9252	6.4862	16.4436	0.1171
RC-23		2.8735	2.5509	1.9382	6.4850	16.5428	0.1172
RC-24		2.8725	2.5479	1.9174	6.4805	16.5114	0.1161
					Average		**0.1157**
					Standard Deviation		**0.0011**
					% Dev		**0.94**

Table B.4: Measurements & Density Calculations for 85°C Small Mold Size Samples

Batch D4: 85C Small Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	2.8672	2.5339	1.8842	6.4564	16.3599	0.11517
RC-2		2.8738	2.5410	1.9253	6.4862	16.4815	0.11682
RC-3		2.8773	2.5626	1.9466	6.5023	16.6627	0.11682
RC-4		2.8740	2.5550	1.9058	6.4873	16.5751	0.11498
RC-5	2	2.8677	2.5446	1.9188	6.4587	16.4346	0.11675
RC-6		2.8661	2.5484	1.9503	6.4518	16.4417	0.11862
RC-7		2.8684	2.5400	1.9177	6.4621	16.4138	0.11683
RC-8		2.8679	2.5606	1.9169	6.4598	16.5409	0.11589
RC-9	3	2.8903	2.5438	1.9057	6.5609	16.6898	0.11418
RC-10		2.9060	2.5288	1.9251	6.6326	16.7727	0.11478
RC-11		2.9047	2.5453	1.9522	6.6268	16.8675	0.11574
RC-12		2.9058	2.5616	1.9294	6.6315	16.9871	0.11358
RC-13	4	2.9060	2.5573	1.9764	6.6326	16.9614	0.11652
RC-14		2.9055	2.5433	1.9818	6.6303	16.8629	0.11752
RC-15		2.9065	2.5657	2.0064	6.6349	17.0230	0.11786
RC-16		2.9098	2.5575	1.9475	6.6500	17.0076	0.11451
RC-17	5	2.8443	2.5629	1.8735	6.3539	16.2841	0.11505
RC-18		2.8522	2.5641	1.9086	6.3891	16.3825	0.11650
RC-19		2.8550	2.5626	1.9213	6.4016	16.4048	0.11712
RC-20		2.8552	2.5585	1.8711	6.4028	16.3817	0.11422
RC-21	6	2.8697	2.5314	1.8910	6.4679	16.3725	0.11550
RC-22		2.8674	2.5461	1.9172	6.4576	16.4416	0.11661
					Average		0.1160
					Standard Deviation		0.0013
					% Dev		1.16

Table B.5: Measurements & Density Calculations for 25°C Medium Mold Size Samples

Batch D5: 25C Medium Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	4.0993	2.5306	4.1876	13.1981	33.3991	0.1254
RC-2		4.1036	2.5337	4.2308	13.2259	33.5098	0.1263
RC-3		4.1034	2.5260	4.2143	13.2243	33.4049	0.1262
RC-4		4.1031	2.5390	4.2574	13.2226	33.5720	0.1268
RC-5	2	4.0714	2.5542	4.1706	13.0188	33.2529	0.1254
RC-6		4.0731	2.5395	4.1838	13.0301	33.0900	0.1264
RC-7		4.0731	2.5471	4.1823	13.0301	33.1893	0.1260
RC-8		4.0724	2.5133	4.1426	13.0253	32.7368	0.1265
RC-9	3	4.0602	2.5408	4.1358	12.9474	32.8963	0.1257
RC-10		4.0681	2.5624	4.2149	12.9977	33.3046	0.1266
RC-11		4.0701	2.5283	4.1602	13.0107	32.8950	0.1265
RC-12		4.0681	2.5624	4.2370	12.9977	33.3046	0.1272
RC-13	4	4.0541	2.5436	4.1331	12.9086	32.8336	0.1259
RC-14		4.0559	2.5397	4.1519	12.9199	32.8132	0.1265
RC-15		4.0546	2.5649	4.1821	12.9118	33.1173	0.1263
RC-16		4.0559	2.4915	4.0666	12.9199	32.1897	0.1263
RC-17	5	4.0335	2.5382	4.0997	12.7779	32.4331	0.1264
RC-18		4.0348	2.5235	4.1074	12.7859	32.2651	0.1273
RC-19		4.0472	2.5484	4.1269	12.8649	32.7847	0.1259
RC-20		4.0462	2.5268	4.1411	12.8585	32.4906	0.1275
RC-21	6	4.0724	2.5471	4.2086	13.0253	33.1768	0.1269
RC-22		4.0848	2.4971	4.1168	13.1050	32.7242	0.1258
RC-23		4.0846	2.5397	4.1957	13.1034	33.2793	0.1261
RC-24		4.0846	2.5182	4.2111	13.1034	32.9964	0.1276
					Average		**0.1263**
					Standard Deviation		**0.0006**
					% Dev		**0.44**

Table B.6: Measurements & Density Calculations for 40°C Medium Mold Size Samples

Batch D6: 40C Medium Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	4.1044	2.5530	4.0354	13.2308	33.7776	0.1195
RC-2		4.1067	2.5641	4.0921	13.2455	33.9633	0.1205
RC-3		4.1054	2.5664	4.0660	13.2374	33.9726	0.1197
RC-4		4.1046	2.4849	3.9070	13.2324	32.8811	0.1188
RC-5	2	4.0808	2.5524	3.9755	13.0789	33.3833	0.1191
RC-6		4.0744	2.5441	3.9928	13.0383	33.1702	0.1204
RC-7		4.0762	2.5499	3.9896	13.0497	33.2754	0.1199
RC-8		4.0752	2.5331	3.9385	13.0432	33.0402	0.1192
RC-9	3	4.0566	2.5695	3.9822	12.9247	33.2096	0.1199
RC-10		4.0566	2.5489	3.9738	12.9247	32.9437	0.1206
RC-11		4.0635	2.5603	3.9838	12.9685	33.2034	0.1200
RC-12		4.0561	2.5260	3.9049	12.9215	32.6401	0.1196
RC-13	4	4.0422	2.5639	3.9611	12.8326	32.9013	0.1204
RC-14		4.0460	2.4501	3.8005	12.8568	31.5003	0.1206
RC-15		4.0465	2.5649	3.9603	12.8601	32.9847	0.1201
RC-16		4.0452	2.5420	3.9095	12.8520	32.6702	0.1197
RC-17	5	4.0838	2.5535	4.0112	13.0985	33.4465	0.1199
RC-18		4.0856	2.5664	4.0539	13.1099	33.6455	0.1205
RC-19		4.0858	2.5598	4.0445	13.1115	33.5631	0.1205
RC-20		4.0843	2.5436	3.9569	13.1018	33.3250	0.1187
					Average		**0.1199**
					Standard Deviation		**0.0005**
					% Dev		**0.45**

Table B.7: Measurements & Density Calculations for 65°C Medium Mold Size Samples

Batch D7: 65C Medium Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	4.0815	2.5622	3.8078	13.0834	33.5227	0.1136
RC-2		4.0951	2.5346	3.7557	13.1711	33.3835	0.1125
RC-3		4.1002	2.5387	3.7724	13.2038	33.5209	0.1125
RC-4		4.1005	2.5641	3.8167	13.2058	33.8615	0.1127
RC-5	2	4.0583	2.5276	3.6997	12.9353	32.6954	0.1132
RC-6		4.0678	2.5314	3.7158	12.9960	32.8985	0.1129
RC-7		4.0707	2.4895	3.6601	13.0143	32.3994	0.1130
RC-8		4.0704	2.5095	3.6699	13.0123	32.6546	0.1124
RC-9	3	4.0440	2.5368	3.6802	12.8443	32.5838	0.1129
RC-10		4.0491	2.5235	3.6582	12.8766	32.4940	0.1126
RC-11		4.0519	2.5000	3.6266	12.8948	32.2370	0.1125
RC-12		4.0526	2.5079	3.6342	12.8988	32.3494	0.1123
RC-13	4	4.0265	2.5314	3.6130	12.7336	32.2343	0.1121
RC-14		4.0357	2.5362	3.6494	12.7920	32.4428	0.1125
RC-15		4.0396	2.5464	3.6718	12.8161	32.6343	0.1125
RC-16		4.0386	2.5502	3.6663	12.8101	32.6677	0.1122
RC-17	5	4.0786	2.5565	3.7611	13.0651	33.4011	0.1126
RC-18		4.0808	2.5591	3.7683	13.0794	33.4707	0.1126
RC-19		4.0821	2.5673	3.7862	13.0875	33.5996	0.1127
RC-20		4.0818	2.5571	3.7441	13.0855	33.4614	0.1119
					Average		**0.1127**
					Standard Deviation		**0.0003**
					% Dev		**0.31**

Table B.8: Measurements & Density Calculations for 85°C Medium Mold Size Sample

Batch D8: 85C Medium Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	4.0922	2.5517	3.6642	13.1523	33.5606	0.1092
RC-2		4.0970	2.5649	3.7399	13.1834	33.8139	0.1106
RC-3		4.0952	2.5611	3.7608	13.1719	33.7344	0.1115
RC-4		4.0922	2.5682	3.7054	13.1523	33.7777	0.1097
RC-5	2	4.0640	2.5700	3.6736	12.9717	33.3369	0.1102
RC-6		4.0648	2.5522	3.6837	12.9766	33.1187	0.1112
RC-7		4.0653	2.5707	3.7371	12.9798	33.3677	0.1120
RC-8		4.0617	2.5690	3.6609	12.9571	33.2863	0.1100
RC-9	3	4.0470	2.5535	3.6135	12.8633	32.8459	0.1100
RC-10		4.0483	2.5733	3.6930	12.8714	33.1216	0.1115
RC-11		4.0452	2.5537	3.6722	12.8520	32.8204	0.1119
RC-12		4.0444	2.5745	3.6430	12.8472	33.0756	0.1101
RC-13	4	4.0236	2.5601	3.5489	12.7152	32.5517	0.1090
RC-14		4.0523	2.5616	3.6051	12.8972	33.0374	0.1091
RC-15		4.0343	2.5540	3.6205	12.7827	32.6466	0.1109
RC-16		4.0320	2.5560	3.5724	12.7682	32.6356	0.1095
RC-17	5	4.0742	2.5573	3.6651	13.0367	33.3383	0.1099
RC-18		4.0752	2.5524	3.6932	13.0432	33.2919	0.1109
RC-19		4.0754	2.5497	3.6949	13.0448	33.2596	0.1111
RC-20		4.0752	2.5631	3.6270	13.0432	33.4311	0.1085
					Average		**0.1104**
					Standard Deviation		**0.0009**
					% Dev		**0.85**

Table B.9: Measurements & Density Calculations for 25°C Large Mold Size Samples

Batch D9: 25C Large Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	5.0891	2.5499	6.3366	20.3413	51.8685	0.1222
RC-2		5.0952	2.5512	6.4383	20.3901	52.0187	0.1238
RC-3		5.0965	2.5283	6.3841	20.4003	51.5783	0.1238
RC-4		5.0988	2.5530	6.5956	20.4186	52.1276	0.1265
RC-5	2	5.0940	2.5580	6.1928	20.3799	52.1325	0.1188
RC-6		5.0960	2.5649	6.2570	20.3962	52.3140	0.1196
RC-7		5.0935	2.5575	6.2086	20.3759	52.1118	0.1191
RC-8		5.0950	2.5517	6.2845	20.3881	52.0239	0.1208
RC-9	3	5.0980	2.5588	6.2011	20.4125	52.2313	0.1187
RC-10		5.0955	2.5547	6.2165	20.3921	52.0964	0.1193
RC-11		5.0924	2.5433	6.1623	20.3677	51.8013	0.1190
RC-12		5.0947	2.4625	6.0734	20.3860	50.2012	0.1210
RC-13	4	5.1181	2.5557	6.2403	20.5735	52.5806	0.1187
RC-14		5.1229	2.5387	6.2856	20.6123	52.3290	0.1201
RC-15		5.1219	2.5448	6.3028	20.6041	52.4339	0.1202
RC-16		5.1242	2.5359	6.3598	20.6225	52.2973	0.1216
RC-17	5	5.1107	2.5497	6.2220	20.5143	52.3043	0.1190
RC-18		5.1151	2.5243	6.2794	20.5490	51.8708	0.1211
RC-19		5.1151	2.5588	6.3081	20.5490	52.5806	0.1200
RC-20		5.1194	2.5382	6.3970	20.5837	52.2459	0.1224
					Average		0.1207
					Standard Deviation		0.0021
					% Dev		1.75

Table B.10: Measurements & Density Calculations for 40°C Large Mold Size Samples

Batch D10: 40C Large Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	5.0955	2.5504	5.8494	20.3921	52.0084	0.1125
RC-2		5.0973	2.5733	5.9381	20.4064	52.5112	0.1131
RC-3		5.0973	2.5517	5.8796	20.4064	52.0706	0.1129
RC-4		5.0955	2.5573	5.8334	20.3921	52.1482	0.1119
RC-5	2	5.0909	2.5613	5.8977	20.3555	52.1374	0.1131
RC-6		5.0968	2.5669	5.9418	20.4023	52.3711	0.1135
RC-7		5.0968	2.5641	5.9072	20.4023	52.3141	0.1129
RC-8		5.0955	2.5651	5.8580	20.3921	52.3088	0.1120
RC-9	3	5.0930	2.5451	5.9104	20.3718	51.8479	0.1140
RC-10		5.0963	2.5535	5.9644	20.3982	52.0861	0.1145
RC-11		5.0942	2.5563	5.9144	20.3820	52.1015	0.1135
RC-12		5.0924	2.5649	5.8640	20.3677	52.2410	0.1122
RC-13	4	5.1162	2.5556	5.9860	20.5582	52.5375	0.1139
RC-14		5.1225	2.5657	6.0459	20.6092	52.8774	0.1143
RC-15		5.1222	2.5136	5.8869	20.6067	51.7979	0.1137
RC-16		5.1210	2.4882	5.7571	20.5964	51.2490	0.1123
RC-17	5	5.0991	2.5705	6.0288	20.4206	52.4907	0.1149
RC-18		5.0994	2.5498	6.0230	20.4231	52.0758	0.1157
RC-19		5.0984	2.5352	5.9288	20.4155	51.7582	0.1145
RC-20		5.0927	2.5791	5.9151	20.3698	52.5347	0.1126
RC-21	6	5.1048	2.5505	6.0764	20.4664	52.1991	0.1164
RC-22		5.1127	2.5365	5.9830	20.5301	52.0747	0.1149
RC-23		5.1108	2.5575	5.9607	20.5148	52.4658	0.1136
					Average		**0.1136**
					Standard Deviation		**0.0012**
					% Dev		**1.06**

Table B.11: Measurements & Density Calculations for 65°C Large Mold Size Samples

Batch D11: 65C Large Mold Size							
Sample Number	Mold #	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	1	5.0747	2.5484	5.5002	20.2258	51.5430	0.1067
RC-2		5.0752	2.5491	5.4768	20.2298	51.5687	0.1062
RC-3		5.0764	2.5458	5.4554	20.2399	51.5277	0.1059
RC-4		5.0762	2.5522	5.4465	20.2379	51.6510	0.1054
RC-5	2	5.0731	2.5593	5.5485	20.2136	51.7328	0.1073
RC-6		5.0749	2.5568	5.4935	20.2278	51.7177	0.1062
RC-7		5.0731	2.5141	5.3681	20.2136	50.8189	0.1056
RC-8		5.0772	2.5476	5.4098	20.2460	51.5791	0.1049
RC-9	3	5.0775	2.5639	5.5079	20.2480	51.9135	0.1061
RC-10		5.0772	2.5375	5.4454	20.2460	51.3734	0.1060
RC-11		5.0731	2.5512	5.4456	20.2136	51.5685	0.1056
RC-12		5.0759	2.5433	5.4166	20.2359	51.4660	0.1052
RC-13	4	5.1024	2.5179	5.4623	20.4471	51.4837	0.1061
RC-14		5.1029	2.5334	5.4862	20.4511	51.8108	0.1059
RC-15		5.1006	2.5631	5.5374	20.4328	52.3716	0.1057
RC-16		5.1024	2.5497	5.4931	20.4471	52.1329	0.1054
RC-17	5	5.0762	2.5530	5.5257	20.2379	51.6664	0.1069
RC-18		5.0749	2.5441	5.4760	20.2278	51.4608	0.1064
RC-19		5.0724	2.5530	5.4722	20.2075	51.5889	0.1061
RC-20		5.0752	2.5575	5.4738	20.2298	51.7383	0.1058
RC-21	6	5.0891	2.4552	5.3115	20.3413	49.9413	0.1064
RC-22		5.0917	2.4310	5.2894	20.3616	49.4998	0.1069
RC-23		5.0876	2.4912	5.3918	20.3291	50.6446	0.1065
RC-24		5.0899	2.5428	5.4695	20.3474	51.7393	0.1057
					Average		0.1061
					Standard Deviation		0.0006
					% Dev		0.54

Table B.12: Measurements & Density Calculations for 85°C Large Mold Size Samples

Batch D12: 85C Large Mold Size							
Sample Number	**Mold #**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
RC-1	1	5.0752	2.5524	5.6737	20.2298	51.6355	0.1099
RC-2		5.0737	2.5631	5.7076	20.2177	51.8202	0.1101
RC-3		5.0757	2.5169	5.6813	20.2339	50.9263	0.1116
RC-4		5.0790	2.5639	5.6791	20.2602	51.9446	0.1093
RC-5	2	5.0719	2.5441	5.5713	20.2035	51.3990	0.1084
RC-6		5.0744	2.5260	5.5471	20.2237	51.0858	0.1086
RC-7		5.0764	2.5461	5.6873	20.2399	51.5328	0.1104
RC-8		5.0734	2.5588	5.6779	20.2156	51.7277	0.1098
RC-9	3	5.0848	2.5535	5.6171	20.3068	51.8527	0.1083
RC-10		5.0797	2.5479	5.6294	20.2663	51.6359	0.1090
RC-11		5.0795	2.5502	5.6944	20.2642	51.6771	0.1102
RC-12		5.0749	2.5377	5.5835	20.2278	51.3323	0.1088
RC-13	4	5.1024	2.5606	5.7488	20.4471	52.3562	0.1098
RC-14		5.1031	2.5639	5.7892	20.4532	52.4394	0.1104
RC-15		5.1029	2.5588	5.8221	20.4511	52.3303	0.1113
RC-16		5.1018	2.5390	5.6776	20.4430	51.9044	0.1094
RC-17	5	5.0604	2.5540	5.5645	20.1125	51.3668	0.1083
RC-18		5.0820	2.5207	5.5324	20.2845	51.1311	0.1082
RC-19		5.0782	2.4938	5.5218	20.2541	50.5091	0.1093
RC-20		5.0777	2.5598	5.6235	20.2501	51.8364	0.1085
					Average		**0.1097**
					Standard Deviation		**0.0010**
					% Dev		**0.90**

Table B.13: Measurements & Density Calculations for Reference Batch Level 1 Samples

Batch DR2: Reference Level 1						
Sample Number	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	2.7686	2.5466	1.5361	6.0202	15.3310	0.1002
RC-2	2.7681	2.5552	1.5277	6.0180	15.3774	0.0993
RC-3	2.7734	2.5593	1.5438	6.0412	15.4613	0.0998
RC-4	2.7750	2.5644	1.5264	6.0478	15.5090	0.0984
RC-5	2.7722	2.5606	1.5388	6.0357	15.4548	0.0996
RC-6	2.7661	2.5603	1.5396	6.0092	15.3853	0.1001
RC-7	2.7734	2.5298	1.5331	6.0412	15.2833	0.1003
RC-8	2.7785	2.5486	1.5139	6.0633	15.4533	0.0980
RC-9	2.7724	2.5641	1.5054	6.0368	15.4791	0.0973
RC-10	2.7734	2.5575	1.5095	6.0412	15.4505	0.0977
RC-11	2.7760	2.5499	1.4947	6.0523	15.4327	0.0969
RC-12	2.7724	2.5588	1.5103	6.0368	15.4469	0.0978
				Average		0.0988
				Standard Deviation		0.0012
				% Dev		1.26

Table B.14: Measurements & Density Calculations for Reference Batch Level 2 Samples

Batch DR2: Reference Level 2						
Sample Number	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	2.7724	2.5624	1.5675	6.0368	15.4683	0.1013
RC-2	2.7658	2.5651	1.5613	6.0080	15.4115	0.1013
RC-3	2.7803	2.5591	1.5900	6.0711	15.5363	0.1023
RC-4	2.7808	2.5651	1.6037	6.0733	15.5790	0.1029
RC-5	2.7750	2.5166	1.5391	6.0478	15.2202	0.1011
RC-6	2.7709	2.5649	1.5576	6.0301	15.4667	0.1007
RC-7	2.7737	2.5662	1.5469	6.0423	15.5055	0.0998
RC-8	2.7788	2.5639	1.5610	6.0645	15.5485	0.1004
RC-9	2.7739	2.5540	1.4657	6.0434	15.4347	0.0950
RC-10	2.7770	2.5535	1.5228	6.0567	15.4656	0.0985
RC-11	2.7750	2.5598	1.5272	6.0478	15.4813	0.0986
RC-12	2.7686	2.5527	1.4850	6.0202	15.3677	0.0966
				Average		0.0999
				Standard Deviation		0.0023
				% Dev		2.35

Table B.15: Measurements & Density Calculations for Reference Batch Level 3 Samples

Batch DR2: Reference Level 3						
Sample Number	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	2.7854	2.5624	1.6221	6.0933	15.6132	0.1039
RC-2	2.7841	2.5448	1.5985	6.0878	15.4923	0.1032
RC-3	2.7808	2.5550	1.5595	6.0733	15.5173	0.1005
RC-4	2.7772	2.5552	1.5360	6.0578	15.4792	0.0992
RC-5	2.7800	2.5563	1.5729	6.0700	15.5165	0.1014
RC-6	2.7849	2.5593	1.6256	6.0911	15.5890	0.1043
RC-7	2.7757	2.5618	1.5544	6.0512	15.5021	0.1003
RC-8	2.7790	2.5540	1.5215	6.0656	15.4913	0.0982
RC-9	2.7734	2.5306	1.5089	6.0412	15.2879	0.0987
RC-10	2.7798	2.5560	1.5160	6.0689	15.5121	0.0977
RC-11	2.7810	2.5573	1.5160	6.0744	15.5340	0.0976
RC-12	2.7744	2.5420	1.5086	6.0456	15.3682	0.0982
				Average		0.1003
				Standard Deviation		0.0024
				% Dev		2.42

Table B.16: Measurements & Density Calculations for Reference Batch Level 4 Samples

Batch DR2: Reference Level 4						
Sample Number	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
RC-1	2.7737	2.5486	1.6395	6.0423	15.3996	0.1065
RC-2	2.7788	2.5560	1.6963	6.0645	15.5008	0.1094
RC-3	2.7777	2.5591	1.6595	6.0600	15.5079	0.1070
RC-4	2.7719	2.5550	1.6552	6.0346	15.4182	0.1074
RC-5	2.7795	2.5550	1.7034	6.0678	15.5031	0.1099
RC-6	2.7803	2.4994	1.6603	6.0711	15.1739	0.1094
RC-7	2.7747	2.5591	1.6462	6.0467	15.4739	0.1064
RC-8	2.7823	2.5568	1.6350	6.0800	15.5451	0.1052
RC-9	2.7770	2.5618	1.6385	6.0567	15.5163	0.1056
RC-10	2.7788	2.4950	1.5959	6.0645	15.1311	0.1055
RC-11	2.7724	2.5377	1.6367	6.0368	15.3196	0.1068
RC-12	2.7783	2.5649	1.6455	6.0622	15.5490	0.1058
				Average		0.1071
				Standard Deviation		0.0016
				% Dev		1.54

Table B.17: Average Density at Each Vertical Level for All Foam Batches

		Small Mold		Medium Mold		Large Mold	
	Level #	Average Density (g/cc)	Std Dev (g/cc)	Average Density (g/cc)	Std Dev (g/cc)	Average Density (g/cc)	Std Dev (g/cc)
25C	1	0.1482	0.0007	0.1259	0.0006	0.1195	0.0015
	2	0.1488	0.0005	0.1265	0.0005	0.1208	0.0018
	3	0.1488	0.0008	0.1261	0.0002	0.1204	0.0020
	4	0.1504	0.0013	0.1270	0.0005	0.1225	0.0024
40C	1	0.1334	0.0005	0.1198	0.0005	0.1141	0.0014
	2	0.1341	0.0007	0.1205	0.0001	0.1143	0.0009
	3	0.1334	0.0006	0.1200	0.0003	0.1135	0.0006
	4	0.133	0.0010	0.1192	0.0004	0.1122	0.0003
65C	1	0.1159	0.0007	0.1129	0.0006	0.1066	0.0005
	2	0.1161	0.0011	0.1126	0.0002	0.1063	0.0003
	3	0.1159	0.0011	0.1126	0.0002	0.1059	0.0003
	4	0.1147	0.0010	0.1123	0.0003	0.1054	0.0003
85C	1	0.1155	0.0010	0.1097	0.0005	0.1089	0.0008
	2	0.1168	0.0013	0.1107	0.0009	0.1093	0.0010
	3	0.1169	0.0008	0.1115	0.0005	0.1105	0.0009
	4	0.1146	0.0009	0.1096	0.0006	0.1091	0.0005

APPENDIX C

RADIAL DENSITY DATA

The following tables summarize the results of the radial density study. Table C.1 shows the average radial density for all foam batches. The data from each batch is averaged to produce one density gradient and percent difference (center to outer edge) for each batch. Table C.2 through Table C.4 show the average radial density and percent deviations (center to outer edge) for each sample within each batch. The data in the tables are grouped together by mold size. Table C.5 through Table C.17 show the average radial density and the percent difference (center to outer edge) at each radial position for each sample within a batch. The radial position (a percentage) is the normalized position from center to outer edge. The Reference batch, shown in Table C.17, is the average of all the cores for each radial position and two vertical levels. The measurements and calculations for each core within each sample of the individual batches are shown in Table C.18 through Table C.67. Each table shows the results for on sample (out of four) in a batch.

Table C.1: Summary of Average Radial Density Data for All Foam Batches

		25 C			40 C			65 C			85 C		
	Radial Ring #	**Average Density (g/cc)**	**Std Dev (g/cc)**	**% Dev**	**Average Density (g/cc)**	**Std Dev (g/cc)**	**% Dev**	**Average Density (g/cc)**	**Std Dev (g/cc)**	**% Dev**	**Average Density (g/cc)**	**Std Dev (g/cc)**	**% Dev**
Small Mold	**1**	0.1274	0.0074		0.1145	0.0034		0.1056	0.0022		0.0996	0.0033	
	2	0.1323	0.0086		0.1159	0.0021		0.1078	0.0020		0.1021	0.0031	
	3	0.1404	0.0080		0.1204	0.0052		0.1132	0.0015		0.1030	0.0016	
	4	0.1521	0.0022	**19.45**	0.1287	0.0005	**12.40**	0.1180	0.0004	**11.77**	0.1088	0.0018	**9.24**
Medium Molds	**1**	0.110	0.013		0.102	0.002		0.096	0.001		0.096	0.002	
	2	0.111	0.009		0.102	0.003		0.098	0.001		0.098	0.002	
	3	0.112	0.007		0.103	0.003		0.100	0.001		0.099	0.001	
	4	0.112	0.006		0.107	0.003		0.103	0.002		0.101	0.002	
	5	0.121	0.008		0.114	0.003		0.106	0.002		0.104	0.001	
	6	0.136	0.003	**23.12**	0.123	0.004	**19.83**	0.113	0.001	**17.87**	0.108	0.001	**13.39**
Large Molds	**1**	0.1043	0.0059		0.0988	0.0028		0.0921	0.0007		0.0974	0.0034	
	2	0.1027	0.0052		0.0981	0.0022		0.0935	0.0003		0.0963	0.0040	
	3	0.1053	0.0052		0.0988	0.0025		0.0932	0.0017		0.0970	0.0026	
	4	0.1060	0.0059		0.0990	0.0021		0.0942	0.0018		0.0982	0.0022	
	5	0.1088	0.0062		0.1010	0.0024		0.0959	0.0018		0.0994	0.0019	
	6	0.1144	0.0057		0.1053	0.0021		0.0991	0.0023		0.1020	0.0029	
	7	0.1234	0.0040		0.1127	0.0020		0.1023	0.0019		0.1051	0.0013	
	8	0.1349	0.0025	**29.35**	0.1188	0.0019	**20.25**	0.1072	0.0011	**16.36**	0.1082	0.0033	**11.12**

Table C.2: Summery of Average Radial Density Data for all Small Mold Sizes

Batch	Sample #	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cc)	% Dev
25C Small	RC-17	2.8501	2.5425	2.4135	6.3800	16.2214	0.1488	**26.85**
	RC-18	2.8532	2.5479	2.4220	6.3936	16.2902	0.1487	**24.94**
	RC-19	2.8547	2.5352	2.4208	6.4005	16.2263	0.1492	**19.10**
	RC-20	2.8557	2.5591	2.4850	6.4050	16.3908	0.1516	**8.36**
40C Small	RC-17	2.8550	2.5337	2.164	6.4016	16.2195	0.1334	**14.55**
	RC-18	2.8560	2.5585	2.1997	6.4062	16.3905	0.1342	**13.01**
	RC-19	2.8560	2.5372	2.1839	6.4062	16.2538	0.1344	**14.25**
	RC-20	2.8575	2.5123	2.1596	6.4130	16.1115	0.1340	**8.12**
65C Small	RC-17	2.8496	2.5491	1.8892	6.3777	16.2577	0.1162	**11.75**
	RC-18	2.8539	2.5535	1.9151	6.3971	16.3347	0.1172	**14.69**
	RC-19	2.8547	2.5438	1.8972	6.4005	16.2816	0.1165	**10.65**
	RC-20	2.8562	2.5522	1.8779	6.4073	16.3527	0.1148	**10.06**
85C Small	RC-17	2.8443	2.5629	1.8735	6.3539	16.2841	0.1151	**6.93**
	RC-18	2.8522	2.5641	1.9086	6.3891	16.3825	0.1165	**6.65**
	RC-19	2.8550	2.5626	1.9213	6.4016	16.4048	0.1171	**11.56**
	RC-20	2.8552	2.5585	1.8711	6.4028	16.3817	0.1142	**12.05**

Table C.3: Summery of Average Radial Density Data for all Medium Mold Sizes

Batch	Sample #	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cc)	% Dev
25C Medium	RC-17	4.0335	2.5382	4.0997	12.7779	32.4331	0.1264	**31.72**
	RC-18	4.0348	2.5235	4.1074	12.7859	32.2651	0.1273	**29.94**
	RC-19	4.0472	2.5484	4.1269	12.8649	32.7847	0.1259	**29.21**
	RC-20	4.0462	2.5268	4.1411	12.8585	32.4906	0.1275	**6.16**
40C Medium	RC-17	4.0838	2.5535	4.0112	13.0985	33.4465	0.1199	**17.38**
	RC-18	4.0856	2.5664	4.0539	13.1099	33.6455	0.1205	**21.09**
	RC-19	4.0858	2.5598	4.0445	13.1115	33.5631	0.1205	**23.55**
	RC-20	4.0843	2.5436	3.9569	13.1018	33.3250	0.1187	**17.44**
65C Medium	RC-17	4.0786	2.5565	3.7611	13.0651	33.4011	0.1126	**14.66**
	RC-18	4.0808	2.5591	3.7683	13.0794	33.4707	0.1126	**20.44**
	RC-19	4.0821	2.5673	3.7862	13.0875	33.5996	0.1127	**19.07**
	RC-20	4.0818	2.5571	3.7441	13.0855	33.4614	0.1119	**17.38**
85C Medium	RC-17	4.0742	2.5573	3.6651	13.0367	33.3383	0.1099	**10.95**
	RC-18	4.0752	2.5524	3.6932	13.0432	33.2919	0.1109	**13.10**
	RC-19	4.0754	2.5497	3.6949	13.0448	33.2596	0.1111	**16.93**
	RC-20	4.0752	2.5631	3.627	13.0432	33.4311	0.1085	**12.69**

Table C.4: Summery of Average Radial Density Data for all Large Mold Sizes

Batch	Sample #	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cc)	% Dev
25C Large	RC-17	5.1107	2.5497	6.2220	20.5143	52.3043	0.1190	**34.98**
	RC-18	5.1151	2.5243	6.2794	20.5490	51.8708	0.1211	**29.82**
	RC-19	5.1151	2.5588	6.3081	20.5490	52.5806	0.1200	**32.92**
	RC-20	5.1194	2.5382	6.3970	20.5837	52.2459	0.1224	**20.66**
40C Large	RC-17	5.0991	2.5705	6.0288	20.4206	52.4907	0.1149	**19.42**
	RC-18	5.0994	2.5498	6.0230	20.4231	52.0758	0.1157	**18.60**
	RC-19	5.0984	2.5352	5.9288	20.4155	51.7582	0.1145	**24.90**
	RC-20	5.0927	2.5791	5.9151	20.3698	52.5347	0.1126	**18.24**
65C Large	RC-17	5.0762	2.5530	5.5257	20.2379	51.6664	0.1069	**17.24**
	RC-18	5.0749	2.5441	5.4760	20.2278	51.4608	0.1064	**15.09**
	RC-19	5.0724	2.5530	5.4722	20.2075	51.5889	0.1061	**17.57**
	RC-20	5.0752	2.5575	5.4738	20.2298	51.7383	0.1058	**15.70**
85C Large	RC-17	5.0604	2.5540	5.5645	20.1125	51.3668	0.1083	**11.33**
	RC-18	5.0820	2.5207	5.5324	20.2845	51.1311	0.1082	**9.75**
	RC-19	5.0782	2.4938	5.5218	20.2541	50.5091	0.1093	**11.39**
	RC-20	5.0777	2.5598	5.6235	20.2501	51.8364	0.1085	**12.13**

Table C.5: Average Radial Density Measurements for Each Sample in Batch D1

Batch D1: 25C Small Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.1208	0.0000	0.00	0.1208	0.1208	0.1208	0.1208
	0.38	0.1253	0.0022	1.76	0.1275	0.1297	0.1230	0.1208
	0.59	0.1313	0.0010	0.75	0.1323	0.1333	0.1303	0.1294
	0.77	0.1532	0.0056	3.64	0.1588	0.1644	0.1477	0.1421
18	0	0.1236	0.0000	0.00	0.1236	0.1236	0.1236	0.1236
	0.38	0.1274	0.0014	1.11	0.1288	0.1302	0.1259	0.1245
	0.59	0.1367	0.0039	2.88	0.1406	0.1445	0.1327	0.1288
	0.77	0.1545	0.0053	3.45	0.1598	0.1651	0.1491	0.1438
19	0	0.1272	0.0000	0.00	0.1272	0.1272	0.1272	0.1272
	0.38	0.1320	0.0007	0.54	0.1327	0.1334	0.1312	0.1305
	0.59	0.1438	0.0018	1.23	0.1456	0.1474	0.1421	0.1403
	0.77	0.1515	0.0028	1.84	0.1543	0.1571	0.1487	0.1459
20	0	0.1378	0.0000	0.00	0.1378	0.1378	0.1378	0.1378
	0.38	0.1444	0.0021	1.46	0.1465	0.1487	0.1423	0.1402
	0.59	0.1496	0.0012	0.80	0.1508	0.1520	0.1484	0.1472
	0.77	0.1493	0.0019	1.25	0.1512	0.1531	0.1475	0.1456

Table C.6: Average Radial Density Measurements for Each Sample in Batch D2

Batch D2: 40C Small Mold Size								
Sample #	**Radial Pos**	**Avg Density (g/cc)**	**Std Dev (g/cc)**	**Dev %**	**(+) 1st Dev (g/cc)**	**(+) 2nd Dev (g/cc)**	**(-) 1st Dev (g/cc)**	**(-) 2nd Dev (g/cc)**
17	0	0.1122	0.0000	0.00	0.1122	0.1122	0.1122	0.1122
	0.38	0.1141	0.0020	1.76	0.1161	0.1181	0.1121	0.1101
	0.59	0.1132	0.0051	4.51	0.1183	0.1235	0.1081	0.1030
	0.77	0.1285	0.0038	2.99	0.1324	0.1362	0.1247	0.1208
18	0	0.1134	0.0000	0.00	0.1134	0.1134	0.1134	0.1134
	0.38	0.1152	0.0020	1.74	0.1172	0.1192	0.1132	0.1112
	0.59	0.1210	0.0019	1.57	0.1229	0.1248	0.1191	0.1172
	0.77	0.1281	0.0049	3.84	0.1330	0.1379	0.1232	0.1183
19	0	0.1128	0.0000	0.00	0.1128	0.1128	0.1128	0.1128
	0.38	0.1152	0.0028	2.39	0.1180	0.1207	0.1125	0.1097
	0.59	0.1218	0.0017	1.40	0.1235	0.1252	0.1201	0.1183
	0.77	0.1289	0.0040	3.11	0.1329	0.1369	0.1249	0.1209
20	0	0.1196	0.0000	0.00	0.1196	0.1196	0.1196	0.1196
	0.38	0.1189	0.0021	1.76	0.1210	0.1231	0.1168	0.1148
	0.59	0.1256	0.0019	1.50	0.1275	0.1294	0.1237	0.1218
	0.77	0.1293	0.0022	1.73	0.1316	0.1338	0.1271	0.1248

Table C.7: Average Radial Density Measurements for Each Sample in Batch D3

Batch D3: 65C Small Mold Size								
Sample #	**Radial Pos**	**Avg Density (g/cc)**	**Std Dev (g/cc)**	**Dev %**	**(+) 1st Dev (g/cc)**	**(+) 2nd Dev (g/cc)**	**(-) 1st Dev (g/cc)**	**(-) 2nd Dev (g/cc)**
17	0	0.1058	0.0000	0.00	0.1058	0.1058	0.1058	0.1058
	0.38	0.1070	0.0029	2.75	0.1100	0.1129	0.1041	0.1012
	0.59	0.1153	0.0061	5.29	0.1214	0.1275	0.1092	0.1031
	0.77	0.1183	0.0015	1.24	0.1197	0.1212	0.1168	0.1154
18	0	0.1024	0.0000	0.00	0.1024	0.1024	0.1024	0.1024
	0.38	0.1057	0.0014	1.30	0.1070	0.1084	0.1043	0.1029
	0.59	0.1120	0.0040	3.60	0.1160	0.1201	0.1080	0.1039
	0.77	0.1174	0.0049	4.14	0.1223	0.1272	0.1126	0.1077
19	0	0.1067	0.0000	0.00	0.1067	0.1067	0.1067	0.1067
	0.38	0.1079	0.0019	1.79	0.1099	0.1118	0.1060	0.1041
	0.59	0.1123	0.0022	1.93	0.1145	0.1166	0.1101	0.1079
	0.77	0.1181	0.0013	1.09	0.1194	0.1207	0.1168	0.1155
20	0	0.1074	0.0000	0.00	0.1074	0.1074	0.1074	0.1074
	0.38	0.1105	0.0027	2.43	0.1131	0.1158	0.1078	0.1051
	0.59	0.1131	0.0013	1.19	0.1145	0.1158	0.1118	0.1104
	0.77	0.1182	0.0039	3.30	0.1221	0.1260	0.1143	0.1104

Table C.8: Average Radial Density Measurements for Each Sample in Batch D4

Batch D4: 85C Small Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.1024	0.0000	0.00	0.1024	0.1024	0.1024	0.1024
	0.38	0.0989	0.0026	2.61	0.1015	0.1041	0.0964	0.0938
	0.59	0.1014	0.0009	0.87	0.1023	0.1032	0.1005	0.0996
	0.77	0.1094	0.0025	2.27	0.1119	0.1144	0.1070	0.1045
18	0	0.1015	0.0000	0.00	0.1015	0.1015	0.1015	0.1015
	0.38	0.1043	0.0012	1.14	0.1054	0.1066	0.1031	0.1019
	0.59	0.1038	0.0024	2.32	0.1062	0.1086	0.1014	0.0990
	0.77	0.1083	0.0026	2.43	0.1109	0.1135	0.1056	0.1030
19	0	0.0994	0.0000	0.00	0.0994	0.0994	0.0994	0.0994
	0.38	0.1053	0.0010	0.99	0.1063	0.1073	0.1042	0.1032
	0.59	0.1048	0.0033	3.13	0.1081	0.1114	0.1015	0.0982
	0.77	0.1109	0.0037	3.30	0.1145	0.1182	0.1072	0.1035
20	0	0.0951	0.0000	0.00	0.0951	0.0951	0.0951	0.0951
	0.38	0.1000	0.0010	1.01	0.1010	0.1020	0.0990	0.0980
	0.59	0.1021	0.0014	1.33	0.1034	0.1048	0.1007	0.0994
	0.77	0.1066	0.0012	1.17	0.1078	0.1091	0.1053	0.1041

Table C9: Average Radial Density Measurements for Each Sample in Batch D5

Batch D5: 25C Medium Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.1005	0.0000	0.00	0.1005	0.1005	0.1005	0.1005
	0.27	0.1048	0.0025	2.35	0.1072	0.1097	0.1023	0.0998
	0.42	0.1038	0.0006	0.62	0.1044	0.1050	0.1031	0.1025
	0.57	0.1058	0.0028	2.64	0.1086	0.1114	0.1030	0.1002
	0.71	0.1120	0.0033	2.99	0.1153	0.1186	0.1086	0.1053
	0.86	0.1323	0.0059	4.49	0.1383	0.1442	0.1264	0.1204
18	0	0.1037	0.0000	0.00	0.1037	0.1037	0.1037	0.1037
	0.27	0.1069	0.0007	0.69	0.1076	0.1084	0.1061	0.1054
	0.42	0.1111	0.0056	5.03	0.1167	0.1223	0.1055	0.0999
	0.57	0.1115	0.0018	1.62	0.1133	0.1151	0.1097	0.1079
	0.71	0.1153	0.0019	1.68	0.1172	0.1191	0.1133	0.1114
	0.86	0.1347	0.0087	6.43	0.1434	0.1521	0.1261	0.1174
19	0	0.1078	0.0000	0.00	0.1078	0.1078	0.1078	0.1078
	0.27	0.1093	0.0016	1.44	0.1109	0.1125	0.1078	0.1062
	0.42	0.1101	0.0008	0.71	0.1109	0.1117	0.1093	0.1085
	0.57	0.1118	0.0027	2.43	0.1145	0.1172	0.1090	0.1063
	0.71	0.1258	0.0021	1.70	0.1279	0.1300	0.1236	0.1215
	0.86	0.1392	0.0020	1.47	0.1413	0.1433	0.1372	0.1352
20	0	0.1296	0.0000	0.00	0.1296	0.1296	0.1296	0.1296
	0.27	0.1245	0.0020	1.58	0.1265	0.1285	0.1226	0.1206
	0.42	0.1214	0.0034	2.80	0.1248	0.1282	0.1180	0.1146
	0.57	0.1207	0.0027	2.27	0.1234	0.1262	0.1179	0.1152
	0.71	0.1298	0.0028	2.13	0.1326	0.1353	0.1270	0.1243
	0.86	0.1375	0.0019	1.41	0.1395	0.1414	0.1356	0.1337

Table C.10: Average Radial Density Measurements for Each Sample in Batch D6

Batch D6: 40C Medium Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.1009	0.0000	0.00	0.1009	0.1009	0.1009	0.1009
	0.27	0.0987	0.0021	2.11	0.1008	0.1029	0.0967	0.0946
	0.42	0.1004	0.0018	1.79	0.1022	0.1040	0.0986	0.0968
	0.57	0.1056	0.0022	2.13	0.1079	0.1101	0.1034	0.1011
	0.71	0.1097	0.0029	2.61	0.1126	0.1154	0.1068	0.1040
	0.86	0.1184	0.0037	3.09	0.1221	0.1258	0.1148	0.1111
18	0	0.1011	0.0000	0.00	0.1011	0.1011	0.1011	0.1011
	0.27	0.1026	0.0014	1.39	0.1040	0.1054	0.1011	0.0997
	0.42	0.1041	0.0012	1.15	0.1053	0.1065	0.1029	0.1017
	0.57	0.1044	0.0017	1.62	0.1061	0.1078	0.1027	0.1010
	0.71	0.1130	0.0015	1.34	0.1145	0.1160	0.1114	0.1099
	0.86	0.1224	0.0041	3.31	0.1265	0.1305	0.1184	0.1143
19	0	0.1035	0.0000	0.00	0.1035	0.1035	0.1035	0.1035
	0.27	0.1049	0.0013	1.22	0.1062	0.1075	0.1037	0.1024
	0.42	0.1073	0.0023	2.11	0.1096	0.1119	0.1051	0.1028
	0.57	0.1105	0.0015	1.34	0.1120	0.1135	0.1090	0.1075
	0.71	0.1177	0.0006	0.47	0.1183	0.1188	0.1172	0.1166
	0.86	0.1278	0.0028	2.17	0.1306	0.1334	0.1251	0.1223
20	0	0.1040	0.0000	0.00	0.1040	0.1040	0.1040	0.1040
	0.27	0.1027	0.0011	1.03	0.1038	0.1048	0.1017	0.1006
	0.42	0.1005	0.0105	10.46	0.1110	0.1215	0.0900	0.0795
	0.57	0.1057	0.0027	2.60	0.1085	0.1112	0.1030	0.1002
	0.71	0.1152	0.0018	1.56	0.1170	0.1188	0.1134	0.1116
	0.86	0.1221	0.0028	2.31	0.1249	0.1277	0.1193	0.1164

Table C.11: Average Radial Density Measurements for Each Sample in Batch D7

Batch D7: 65C Medium Mold Size								
Sample #	**Radial Pos**	**Avg Density (g/cc)**	**Std Dev (g/cc)**	**Dev %**	**(+) 1st Dev (g/cc)**	**(+) 2nd Dev (g/cc)**	**(-) 1st Dev (g/cc)**	**(-) 2nd Dev (g/cc)**
17	0	0.0972	0.0000	0.00	0.0972	0.0972	0.0972	0.0972
	0.27	0.0986	0.0016	1.59	0.1002	0.1017	0.0970	0.0955
	0.42	0.0995	0.0017	1.75	0.1012	0.1030	0.0977	0.0960
	0.57	0.1034	0.0010	0.97	0.1044	0.1054	0.1024	0.1014
	0.71	0.1041	0.0018	1.73	0.1059	0.1077	0.1023	0.1005
	0.86	0.1115	0.0022	1.98	0.1137	0.1159	0.1093	0.1071
18	0	0.0944	0.0000	0.00	0.0944	0.0944	0.0944	0.0944
	0.27	0.0962	0.0022	2.31	0.0984	0.1006	0.0940	0.0917
	0.42	0.0987	0.0008	0.85	0.0996	0.1004	0.0979	0.0971
	0.57	0.1013	0.0010	0.98	0.1023	0.1033	0.1003	0.0993
	0.71	0.1073	0.0028	2.63	0.1102	0.1130	0.1045	0.1017
	0.86	0.1137	0.0031	2.72	0.1168	0.1199	0.1106	0.1075
19	0	0.0949	0.0000	0.00	0.0949	0.0949	0.0949	0.0949
	0.27	0.0988	0.0003	0.34	0.0991	0.0994	0.0984	0.0981
	0.42	0.1005	0.0016	1.62	0.1021	0.1038	0.0989	0.0973
	0.57	0.1020	0.0013	1.23	0.1033	0.1045	0.1008	0.0995
	0.71	0.1046	0.0007	0.63	0.1052	0.1059	0.1039	0.1033
	0.86	0.1130	0.0014	1.23	0.1144	0.1158	0.1117	0.1103
20	0	0.0962	0.0000	0.00	0.0962	0.0962	0.0962	0.0962
	0.27	0.0984	0.0011	1.12	0.0995	0.1006	0.0973	0.0962
	0.42	0.1005	0.0019	1.91	0.1024	0.1043	0.0986	0.0966
	0.57	0.1050	0.0015	1.41	0.1065	0.1080	0.1035	0.1021
	0.71	0.1067	0.0017	1.57	0.1084	0.1101	0.1051	0.1034
	0.86	0.1129	0.0014	1.22	0.1143	0.1157	0.1115	0.1102

Table C.12: Average Radial Density Measurements for Each Sample in Batch D8

Batch D8: 85C Medium Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.0981	0.0000	0.00	0.0981	0.0981	0.0981	0.0981
	0.27	0.0986	0.0037	3.78	0.1024	0.1061	0.0949	0.0912
	0.42	0.0987	0.0017	1.67	0.1004	0.1021	0.0971	0.0954
	0.57	0.0997	0.0020	1.96	0.1016	0.1036	0.0977	0.0958
	0.71	0.1036	0.0031	3.02	0.1068	0.1099	0.1005	0.0974
	0.86	0.1088	0.0021	1.94	0.1109	0.1130	0.1067	0.1046
18	0	0.0957	0.0000	0.00	0.0957	0.0957	0.0957	0.0957
	0.27	0.0983	0.0022	2.25	0.1005	0.1027	0.0961	0.0938
	0.42	0.0987	0.0012	1.21	0.0999	0.1011	0.0975	0.0963
	0.57	0.1037	0.0025	2.43	0.1062	0.1087	0.1011	0.0986
	0.71	0.1054	0.0035	3.36	0.1090	0.1125	0.1019	0.0983
	0.86	0.1083	0.0029	2.71	0.1112	0.1141	0.1053	0.1024
19	0	0.0933	0.0000	0.00	0.0933	0.0933	0.0933	0.0933
	0.27	0.0997	0.0007	0.75	0.1005	0.1012	0.0990	0.0982
	0.42	0.1003	0.0011	1.09	0.1014	0.1025	0.0992	0.0981
	0.57	0.0996	0.0021	2.08	0.1016	0.1037	0.0975	0.0954
	0.71	0.1032	0.0029	2.81	0.1061	0.1090	0.1003	0.0974
	0.86	0.1091	0.0018	1.62	0.1108	0.1126	0.1073	0.1055
20	0	0.0953	0.0000	0.00	0.0953	0.0953	0.0953	0.0953
	0.27	0.0950	0.0006	0.64	0.0956	0.0962	0.0944	0.0938
	0.42	0.0972	0.0008	0.80	0.0980	0.0988	0.0964	0.0956
	0.57	0.0990	0.0016	1.58	0.1006	0.1022	0.0975	0.0959
	0.71	0.1044	0.0018	1.73	0.1062	0.1081	0.1026	0.1008
	0.86	0.1074	0.0008	0.77	0.1082	0.1090	0.1065	0.1057

Table C.13: Average Radial Density Measurements for Each Sample in Batch D9

Batch D9: 25C Large Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.1014	0.0000	0.00	0.1014	0.1014	0.1014	0.1014
	0.22	0.0999	0.0014	1.40	0.1013	0.1027	0.0985	0.0971
	0.33	0.1039	0.0015	1.45	0.1054	0.1069	0.1024	0.1009
	0.45	0.1033	0.0008	0.75	0.1040	0.1048	0.1025	0.1017
	0.57	0.1067	0.0024	2.28	0.1092	0.1116	0.1043	0.1019
	0.69	0.1111	0.0027	2.42	0.1137	0.1164	0.1084	0.1057
	0.81	0.1256	0.0034	2.72	0.1290	0.1324	0.1222	0.1188
	0.90	0.1369	0.0040	2.94	0.1409	0.1450	0.1329	0.1288
18	0	0.1046	0.0000	0.00	0.1046	0.1046	0.1046	0.1046
	0.22	0.1016	0.0017	1.71	0.1033	0.1051	0.0999	0.0981
	0.33	0.1024	0.0013	1.31	0.1038	0.1051	0.1011	0.0997
	0.45	0.1033	0.0008	0.82	0.1041	0.1050	0.1025	0.1016
	0.57	0.1074	0.0008	0.73	0.1082	0.1089	0.1066	0.1058
	0.69	0.1146	0.0028	2.42	0.1174	0.1202	0.1118	0.1091
	0.81	0.1238	0.0028	2.28	0.1267	0.1295	0.1210	0.1182
	0.90	0.1358	0.0034	2.47	0.1392	0.1425	0.1325	0.1291
19	0	0.0987	0.0000	0.00	0.0987	0.0987	0.0987	0.0987
	0.22	0.0991	0.0011	1.15	0.1002	0.1013	0.0979	0.0968
	0.33	0.1019	0.0013	1.24	0.1032	0.1045	0.1007	0.0994
	0.45	0.1024	0.0009	0.92	0.1033	0.1043	0.1015	0.1005
	0.57	0.1035	0.0006	0.60	0.1041	0.1047	0.1029	0.1022
	0.69	0.1096	0.0007	0.65	0.1104	0.1111	0.1089	0.1082
	0.81	0.1176	0.0013	1.12	0.1189	0.1203	0.1163	0.1150
	0.90	0.1312	0.0032	2.45	0.1344	0.1377	0.1280	0.1248
20	0	0.1123	0.0000	0.00	0.1123	0.1123	0.1123	0.1123
	0.22	0.1103	0.0023	2.04	0.1126	0.1148	0.1080	0.1058
	0.33	0.1129	0.0018	1.59	0.1147	0.1165	0.1111	0.1093
	0.45	0.1148	0.0009	0.80	0.1158	0.1167	0.1139	0.1130
	0.57	0.1177	0.0019	1.61	0.1196	0.1215	0.1158	0.1139
	0.69	0.1224	0.0011	0.89	0.1235	0.1246	0.1213	0.1202
	0.81	0.1266	0.0009	0.70	0.1274	0.1283	0.1257	0.1248
	0.90	0.1355	0.0032	2.35	0.1387	0.1419	0.1323	0.1292

Table C.14: Average Radial Density Measurements for Each Sample in Batch D10

Batch D10: 40C Large Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.0972	0.0000	0.00	0.0972	0.0972	0.0972	0.0972
	0.22	0.0987	0.0008	0.79	0.0995	0.1003	0.0979	0.0971
	0.33	0.0982	0.0004	0.42	0.0986	0.0990	0.0978	0.0974
	0.45	0.0996	0.0007	0.71	0.1003	0.1010	0.0989	0.0981
	0.57	0.1000	0.0017	1.74	0.1018	0.1035	0.0983	0.0966
	0.69	0.1044	0.0015	1.48	0.1060	0.1075	0.1029	0.1013
	0.81	0.1132	0.0025	2.22	0.1157	0.1182	0.1107	0.1082
	0.90	0.1161	0.0013	1.09	0.1173	0.1186	0.1148	0.1136
18	0	0.1004	0.0000	0.00	0.1004	0.1004	0.1004	0.1004
	0.22	0.0995	0.0006	0.64	0.1001	0.1008	0.0989	0.0982
	0.33	0.0996	0.0003	0.34	0.0999	0.1003	0.0993	0.0989
	0.45	0.0981	0.0020	2.08	0.1001	0.1022	0.0960	0.0940
	0.57	0.1014	0.0006	0.57	0.1020	0.1025	0.1008	0.1002
	0.69	0.1046	0.0019	1.84	0.1065	0.1084	0.1026	0.1007
	0.81	0.1113	0.0033	2.97	0.1147	0.1180	0.1080	0.1047
	0.90	0.1191	0.0028	2.33	0.1219	0.1246	0.1163	0.1135
19	0	0.0956	0.0000	0.00	0.0956	0.0956	0.0956	0.0956
	0.22	0.0948	0.0016	1.70	0.0964	0.0981	0.0932	0.0916
	0.33	0.0956	0.0005	0.48	0.0961	0.0965	0.0952	0.0947
	0.45	0.0968	0.0017	1.71	0.0984	0.1001	0.0951	0.0935
	0.57	0.0984	0.0016	1.60	0.1000	0.1015	0.0968	0.0952
	0.69	0.1038	0.0013	1.26	0.1051	0.1064	0.1025	0.1012
	0.81	0.1110	0.0027	2.40	0.1136	0.1163	0.1083	0.1057
	0.90	0.1194	0.0020	1.71	0.1214	0.1234	0.1173	0.1153
20	0	0.1018	0.0000	0.00	0.1018	0.1018	0.1018	0.1018
	0.22	0.0993	0.0014	1.41	0.1007	0.1021	0.0979	0.0965
	0.33	0.1016	0.0008	0.77	0.1024	0.1032	0.1008	0.1001
	0.45	0.1016	0.0019	1.85	0.1035	0.1053	0.0997	0.0978
	0.57	0.1040	0.0007	0.70	0.1048	0.1055	0.1033	0.1026
	0.69	0.1084	0.0008	0.78	0.1093	0.1101	0.1076	0.1068
	0.81	0.1153	0.0015	1.28	0.1168	0.1182	0.1138	0.1123
	0.90	0.1204	0.0020	1.62	0.1224	0.1243	0.1185	0.1165

Table C.15: Average Radial Density Measurements for Each Sample in Batch D11

Batch D11: 65C Large Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.0914	0.0000	0.00	0.0914	0.0914	0.0914	0.0914
	0.22	0.0933	0.0006	0.67	0.0940	0.0946	0.0927	0.0921
	0.33	0.0933	0.0014	1.54	0.0947	0.0961	0.0918	0.0904
	0.45	0.0955	0.0004	0.42	0.0959	0.0963	0.0951	0.0947
	0.57	0.0969	0.0020	2.05	0.0989	0.1009	0.0949	0.0929
	0.69	0.0986	0.0011	1.13	0.0998	0.1009	0.0975	0.0964
	0.81	0.0997	0.0030	3.01	0.1027	0.1057	0.0967	0.0937
	0.90	0.1071	0.0026	2.40	0.1097	0.1123	0.1046	0.1020
18	0	0.0928	0.0000	0.00	0.0928	0.0928	0.0928	0.0928
	0.22	0.0932	0.0015	1.57	0.0947	0.0962	0.0918	0.0903
	0.33	0.0910	0.0006	0.69	0.0916	0.0923	0.0904	0.0897
	0.45	0.0917	0.0010	1.12	0.0928	0.0938	0.0907	0.0897
	0.57	0.0934	0.0023	2.47	0.0957	0.0980	0.0911	0.0887
	0.69	0.0962	0.0013	1.40	0.0975	0.0989	0.0948	0.0935
	0.81	0.1025	0.0024	2.31	0.1048	0.1072	0.1001	0.0977
	0.90	0.1068	0.0021	1.99	0.1090	0.1111	0.1047	0.1026
19	0	0.0926	0.0000	0.00	0.0926	0.0926	0.0926	0.0926
	0.22	0.0934	0.0019	2.07	0.0954	0.0973	0.0915	0.0896
	0.33	0.0934	0.0013	1.43	0.0948	0.0961	0.0921	0.0908
	0.45	0.0940	0.0018	1.91	0.0958	0.0976	0.0922	0.0904
	0.57	0.0975	0.0013	1.33	0.0988	0.1001	0.0963	0.0950
	0.69	0.1003	0.0019	1.90	0.1022	0.1041	0.0984	0.0965
	0.81	0.1040	0.0020	1.97	0.1061	0.1081	0.1020	0.0999
	0.90	0.1088	0.0014	1.28	0.1102	0.1116	0.1074	0.1060
20	0	0.0917	0.0000	0.00	0.0917	0.0917	0.0917	0.0917
	0.22	0.0939	0.0014	1.49	0.0952	0.0966	0.0925	0.0911
	0.33	0.0951	0.0011	1.19	0.0962	0.0974	0.0940	0.0929
	0.45	0.0957	0.0022	2.30	0.0979	0.1001	0.0935	0.0913
	0.57	0.0957	0.0025	2.61	0.0982	0.1007	0.0932	0.0907
	0.69	0.1014	0.0026	2.56	0.1040	0.1066	0.0988	0.0962
	0.81	0.1031	0.0017	1.66	0.1048	0.1065	0.1014	0.0997
	0.90	0.1061	0.0026	2.43	0.1087	0.1113	0.1036	0.1010

Table C.16: Average Radial Density Measurements for Each Sample in Batch D12

Batch D12: 85C Large Mold Size								
Sample #	Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
17	0	0.1005	0.0000	0.00	0.1005	0.1005	0.1005	0.1005
	0.22	0.1006	0.0015	1.50	0.1021	0.1036	0.0991	0.0976
	0.33	0.0979	0.0014	1.48	0.0993	0.1008	0.0964	0.0950
	0.45	0.0984	0.0010	0.99	0.0994	0.1004	0.0974	0.0965
	0.57	0.1008	0.0010	0.97	0.1018	0.1028	0.0998	0.0989
	0.69	0.1050	0.0021	2.02	0.1072	0.1093	0.1029	0.1008
	0.81	0.1068	0.0015	1.41	0.1084	0.1099	0.1053	0.1038
	0.90	0.1119	0.0032	2.90	0.1152	0.1184	0.1087	0.1054
18	0	0.0996	0.0000	0.00	0.0996	0.0996	0.0996	0.0996
	0.22	0.0984	0.0012	1.18	0.0996	0.1008	0.0973	0.0961
	0.33	0.0999	0.0016	1.57	0.1015	0.1031	0.0984	0.0968
	0.45	0.1010	0.0007	0.73	0.1017	0.1024	0.1002	0.0995
	0.57	0.1012	0.0013	1.30	0.1025	0.1038	0.0998	0.0985
	0.69	0.1035	0.0015	1.46	0.1050	0.1065	0.1020	0.1004
	0.81	0.1051	0.0027	2.61	0.1079	0.1106	0.1024	0.0996
	0.90	0.1093	0.0021	1.96	0.1114	0.1136	0.1071	0.1050
19	0	0.0964	0.0000	0.00	0.0964	0.0964	0.0964	0.0964
	0.22	0.0943	0.0028	3.00	0.0971	0.0999	0.0914	0.0886
	0.33	0.0964	0.0013	1.31	0.0976	0.0989	0.0951	0.0939
	0.45	0.0975	0.0024	2.42	0.0999	0.1022	0.0952	0.0928
	0.57	0.0980	0.0012	1.25	0.0992	0.1004	0.0967	0.0955
	0.69	0.0985	0.0024	2.47	0.1010	0.1034	0.0961	0.0937
	0.81	0.1048	0.0010	0.99	0.1058	0.1069	0.1038	0.1027
	0.90	0.1074	0.0016	1.45	0.1089	0.1105	0.1058	0.1043
20	0	0.0929	0.0000	0.00	0.0929	0.0929	0.0929	0.0929
	0.22	0.0918	0.0008	0.87	0.0926	0.0934	0.0910	0.0902
	0.33	0.0938	0.0015	1.62	0.0954	0.0969	0.0923	0.0908
	0.45	0.0957	0.0008	0.81	0.0964	0.0972	0.0949	0.0941
	0.57	0.0974	0.0009	0.93	0.0983	0.0992	0.0965	0.0956
	0.69	0.1009	0.0017	1.71	0.1027	0.1044	0.0992	0.0975
	0.81	0.1037	0.0015	1.47	0.1052	0.1067	0.1022	0.1006
	0.90	0.1041	0.0019	1.78	0.1060	0.1078	0.1023	0.1004

Table C.17: Average Radial Density Measurements for Each Sample in Batch DR1

Batch DR1: Reference Batch (Average of Two Levels)							
Radial Pos	Avg Density (g/cc)	Std Dev (g/cc)	Dev %	(+) 1st Dev (g/cc)	(+) 2nd Dev (g/cc)	(-) 1st Dev (g/cc)	(-) 2nd Dev (g/cc)
0	0.0977	0	0	0.0977	0.0977	0.0977	0.0977
0.058	0.0969	0.0032	3.2821	0.1000	0.1032	0.0937	0.0905
0.089	0.0960	0.0034	3.4895	0.0994	0.1027	0.0927	0.0893
0.121	0.0971	0.0011	1.1762	0.0982	0.0994	0.0960	0.0948
0.152	0.0977	0.0021	2.1362	0.0997	0.1018	0.0956	0.0935
0.184	0.0967	0.0022	2.2988	0.0989	0.1012	0.0945	0.0923
0.215	0.0977	0.0017	1.7367	0.0994	0.1011	0.0960	0.0943
0.247	0.0981	0.0024	2.4538	0.1005	0.1029	0.0957	0.0933
0.278	0.0989	0.0024	2.4141	0.1012	0.1036	0.0965	0.0941
0.310	0.0974	0.0016	1.6452	0.0990	0.1006	0.0958	0.0942
0.341	0.0976	0.0015	1.4946	0.0991	0.1005	0.0961	0.0947
0.373	0.0968	0.0013	1.3655	0.0981	0.0994	0.0954	0.0941
0.436	0.0972	0.0009	0.9575	0.0982	0.0991	0.0963	0.0954
0.467	0.0973	0.0015	1.5370	0.0988	0.1003	0.0958	0.0943
0.499	0.0967	0.0022	2.2461	0.0989	0.1011	0.0945	0.0924
0.530	0.0963	0.0011	1.1201	0.0974	0.0985	0.0953	0.0942
0.562	0.0971	0.0038	3.9017	0.1009	0.1047	0.0933	0.0896
0.593	0.0982	0.0020	2.0016	0.1001	0.1021	0.0962	0.0943
0.625	0.0984	0.0037	3.7774	0.1021	0.1058	0.0947	0.0910
0.656	0.0968	0.0019	1.9209	0.0986	0.1005	0.0949	0.0931
0.688	0.0952	0.0021	2.2276	0.0973	0.0994	0.0931	0.0909
0.719	0.0974	0.0022	2.3021	0.0997	0.1019	0.0952	0.0929
0.751	0.0987	0.0016	1.6515	0.1004	0.1020	0.0971	0.0955
0.782	0.0973	0.0014	1.4836	0.0987	0.1001	0.0958	0.0944
0.814	0.0993	0.0021	2.1420	0.1015	0.1036	0.0972	0.0951
0.845	0.1013	0.0022	2.2203	0.1035	0.1058	0.0990	0.0968
0.877	0.1066	0.0044	4.1295	0.1110	0.1154	0.1022	0.0978
0.908	0.1069	0.0064	5.9892	0.1133	0.1197	0.1005	0.0941

Table C.18: Radial Density Measurements for Each Core Taken from Sample 17 (D1)

Batch D1: 25C Small Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Voiume (cm^3)**	**Density (g/cm^3)**
1	0	0.3757	2.5321	0.0339	0.1108	0.2807	0.1208
2	0.38	0.3724	2.5321	0.0346	0.1089	0.2757	0.1255
3	0.38	0.3711	2.5302	0.0351	0.1082	0.2737	0.1283
4	0.38	0.3724	2.5317	0.0340	0.1089	0.2757	0.1233
5	0.38	0.3729	2.5343	0.0343	0.1092	0.2767	0.1239
6	0.59	0.3719	2.5292	0.0363	0.1086	0.2747	0.1322
7	0.59	0.3724	2.5340	0.0363	0.1089	0.2759	0.1315
8	0.59	0.3721	2.5343	0.0358	0.1088	0.2756	0.1299
9	0.59	0.3724	2.5317	0.0363	0.1089	0.2757	0.1317
10	0.77	0.3716	2.5340	0.0427	0.1085	0.2748	0.1554
11	0.77	0.3731	2.5324	0.0439	0.1093	0.2769	0.1585
12	0.77	0.3736	2.5308	0.0426	0.1096	0.2775	0.1535
13	0.77	0.3729	2.2035	0.0350	0.1092	0.2406	0.1455
					Average:		**0.1354**
					Std Dev:		**0.0131**
					% Dev:		**9.71**

Table C.19: Radial Density Measurements for Each Core Taken from Sample 18 (D1)

Batch D1: 25C Small Mold Size Sample #18							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3708	2.5464	0.0340	0.1080	0.2750	0.1236
2	0.38	0.3716	2.5349	0.0352	0.1085	0.2749	0.1280
3	0.38	0.3677	2.5403	0.0347	0.1062	0.2697	0.1287
4	0.38	0.3693	2.5378	0.0346	0.1071	0.2718	0.1273
5	0.38	0.3708	2.5397	0.0344	0.1080	0.2743	0.1254
6	0.59	0.3724	2.3997	0.0352	0.1089	0.2614	0.1347
7	0.59	0.3721	2.5422	0.0376	0.1088	0.2765	0.1360
8	0.59	0.3702	2.5375	0.0365	0.1076	0.2731	0.1336
9	0.59	0.3658	1.6710	0.0250	0.1051	0.1756	0.1424
10	0.77	0.3759	2.5537	0.0447	0.1110	0.2834	0.1577
11	0.77	0.3737	2.5394	0.0418	0.1097	0.2785	0.1501
12	0.77	0.3759	2.5384	0.0422	0.1110	0.2817	0.1498
13	0.77	0.3731	2.5575	0.0448	0.1093	0.2796	0.1603
					Average:		**0.1383**
					Std Dev:		**0.0125**
					% Dev:		**9.07**

Table C.20: Radial Density Measurements for Each Core Taken from Sample 19 (D1)

Batch D1: 25C Small Mold Size Sample #19							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3689	2.5298	0.0344	0.1069	0.2704	0.1272
2	0.38	0.3737	2.5371	0.0367	0.1097	0.2783	0.1319
3	0.38	0.3737	2.5292	0.0366	0.1097	0.2774	0.1319
4	0.38	0.3731	2.5184	0.0361	0.1093	0.2753	0.1311
5	0.38	0.3708	2.5295	0.0363	0.1080	0.2732	0.1329
6	0.59	0.3766	2.5292	0.0412	0.1114	0.2817	0.1463
7	0.59	0.3712	2.5359	0.039	0.1082	0.2744	0.1421
8	0.59	0.3740	2.5375	0.0401	0.1099	0.2788	0.1438
9	0.59	0.3731	2.5260	0.0395	0.1093	0.2761	0.1431
10	0.77	0.3696	1.7040	0.0271	0.1073	0.1828	0.1483
11	0.77	0.3734	2.5305	0.0428	0.1095	0.2771	0.1545
12	0.77	0.3677	1.6373	0.0266	0.1062	0.1738	0.1530
13	0.77	0.3731	2.5337	0.0416	0.1093	0.2769	0.1502
					Average:		**0.141253**
					Std Dev:		**0.009234**
					% Dev:		**6.54**

Table C.21: Radial Density Measurements for Each Core Taken from Sample 20 (D1)

Batch D1: 25C Small Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3747	2.5470	0.0387	0.1102	0.2808	0.1378
2	0.38	0.3727	2.5492	0.0409	0.1091	0.2782	0.1470
3	0.38	0.3737	2.5505	0.0402	0.1097	0.2797	0.1437
4	0.38	0.3731	2.5435	0.0403	0.1093	0.2780	0.1450
5	0.38	0.3737	2.5552	0.0398	0.1097	0.2803	0.1420
6	0.59	0.3778	2.5530	0.0423	0.1121	0.2862	0.1478
7	0.59	0.3731	1.6018	0.0263	0.1093	0.1751	0.1502
8	0.59	0.3731	2.5502	0.0419	0.1093	0.2788	0.1503
9	0.59	0.3740	2.5552	0.0421	0.1099	0.2807	0.1500
10	0.77	0.3693	2.1692	0.0343	0.1071	0.2323	0.1477
11	0.77	0.3705	1.4586	0.0233	0.1078	0.1573	0.1482
12	0.77	0.3712	2.5549	0.0414	0.1082	0.2764	0.1498
13	0.77	0.3747	2.5575	0.0428	0.1102	0.2819	0.1518
					Average:		**0.147014**
					Std Dev:		**0.00395**
					% Dev:		**2.69**

Table C.22: Radial Density Measurements for Each Core Taken from Sample 17 (D2)

Batch D2: 40C Small Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3846	2.5250	0.0329	0.1161	0.2933	0.1122
2	0.38	0.3792	2.5222	0.0317	0.1129	0.2849	0.1113
3	0.38	0.3769	2.5217	0.0326	0.1116	0.2814	0.1159
4	0.38	0.3805	2.5105	0.0326	0.1137	0.2855	0.1142
5	0.38	0.3800	2.5128	0.0328	0.1134	0.2850	0.1151
6	0.59	0.3774	2.5016	0.0305	0.1119	0.2799	0.1090
7	0.59	0.3772	2.5077	0.0326	0.1117	0.2802	0.1163
8	0.59	0.3774	2.5042	0.0305	0.1119	0.2802	0.1089
9	0.59	0.3795	2.5154	0.0338	0.1131	0.2845	0.1188
10	0.77	0.3767	2.5288	0.0370	0.1114	0.2818	0.1313
11	0.77	0.3772	2.5156	0.0372	0.1117	0.2811	0.1323
12	0.77	0.3754	2.5042	0.0347	0.1107	0.2772	0.1252
13	0.77	0.3749	2.5179	0.0348	0.1104	0.2780	0.1252
					Average:		**0.1181**
					Std Dev:		**0.0080**
					% Dev:		**6.74**

Table C.23: Radial Density Measurements for Each Core Taken from Sample 18 (D2)

Batch D2: 40C Small Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3823	2.5364	0.0330	0.1148	0.2911	0.1134
2	0.38	0.3785	2.5436	0.0323	0.1125	0.2861	0.1129
3	0.38	0.3774	2.5331	0.0332	0.1119	0.2834	0.1171
4	0.38	0.3785	2.5375	0.0333	0.1125	0.2854	0.1167
5	0.38	0.3774	2.5331	0.0324	0.1119	0.2834	0.1143
6	0.59	0.3747	2.5408	0.0331	0.1102	0.2801	0.1182
7	0.59	0.3741	2.5352	0.0339	0.1099	0.2787	0.1216
8	0.59	0.3744	2.5306	0.0339	0.1101	0.2786	0.1217
9	0.59	0.3741	2.5337	0.0341	0.1099	0.2786	0.1224
10	0.77	0.3759	2.5390	0.0360	0.1110	0.2818	0.1278
11	0.77	0.3749	2.5420	0.0346	0.1104	0.2806	0.1233
12	0.77	0.3785	2.5364	0.0385	0.1125	0.2853	0.1349
13	0.77	0.3759	2.5436	0.0357	0.1110	0.2823	0.1265
					Average:		**0.1208**
					Std Dev:		**0.0064**
					% Dev:		**5.28**

Table C.24: Radial Density Measurements for Each Core Taken from Sample 19 (D2)

Batch D2: 40C Small Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3797	2.5207	0.0322	0.1133	0.2855	0.1128
2	0.38	0.3772	2.5123	0.0326	0.1117	0.2807	0.1161
3	0.38	0.3759	2.5118	0.0326	0.1110	0.2788	0.1169
4	0.38	0.3769	2.5116	0.0327	0.1116	0.2803	0.1167
5	0.38	0.3747	2.5146	0.0308	0.1102	0.2772	0.1111
6	0.59	0.3749	2.5171	0.0335	0.1104	0.2779	0.1206
7	0.59	0.3754	2.5149	0.0346	0.1107	0.2784	0.1243
8	0.59	0.3780	2.5164	0.0342	0.1122	0.2823	0.1211
9	0.59	0.3744	2.5212	0.0336	0.1101	0.2776	0.1211
10	0.77	0.3762	2.5255	0.0359	0.1111	0.2807	0.1279
11	0.77	0.3747	2.5263	0.0363	0.1102	0.2785	0.1303
12	0.77	0.3736	2.5237	0.0369	0.1096	0.2767	0.1334
13	0.77	0.3708	1.3602	0.0182	0.1080	0.1469	0.1239
					Average:		**0.1212**
					Std Dev:		**0.0066**
					% Dev:		**5.48**

Table C.25: Radial Density Measurements for Each Core Taken from Sample 20 (D2)

Batch D2: 40C Small Mold Size Sample #20							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3767	2.5133	0.0335	0.1114	0.2801	0.1196
2	0.38	0.3719	2.5039	0.0328	0.1086	0.2719	0.1206
3	0.38	0.3747	2.5044	0.0324	0.1102	0.2761	0.1174
4	0.38	0.3744	2.5098	0.0334	0.1101	0.2763	0.1209
5	0.38	0.3731	2.5108	0.0321	0.1093	0.2745	0.1169
6	0.59	0.3744	2.5044	0.0344	0.1101	0.2757	0.1248
7	0.59	0.3754	2.5121	0.0343	0.1107	0.2781	0.1234
8	0.59	0.3729	2.5141	0.0349	0.1092	0.2745	0.1271
9	0.59	0.3734	2.5131	0.0350	0.1095	0.2752	0.1272
10	0.77	0.3716	2.5110	0.0346	0.1085	0.2723	0.1271
11	0.77	0.3716	2.5182	0.0357	0.1085	0.2731	0.1307
12	0.77	0.3734	2.5085	0.0351	0.1095	0.2747	0.1278
13	0.77	0.3696	2.5199	0.0356	0.1073	0.2703	0.1317
					Average:		0.1242
					Std Dev:		0.0049
					% Dev:		**3.91**

Table C.26: Radial Density Measurements for Each Core Taken from Sample 17 (D3)

Batch D3: 65C Small Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Voiume (cm^3)**	**Density (g/cm^3)**
1	0	0.3677	2.5362	0.0285	0.1062	0.2693	0.1058
2	0.38	0.3696	2.5365	0.0299	0.1073	0.2721	0.1099
3	0.38	0.3708	2.5359	0.0285	0.1080	0.2739	0.1041
4	0.38	0.3689	2.5349	0.0296	0.1069	0.2710	0.1092
5	0.38	0.3718	2.5349	0.0289	0.1086	0.2752	0.1050
6	0.59	0.3702	2.5340	0.0296	0.1076	0.2728	0.1085
7	0.59	0.3708	2.5321	0.0317	0.1080	0.2735	0.1159
8	0.59	0.3693	2.5337	0.0308	0.1071	0.2713	0.1135
9	0.59	0.3712	2.5362	0.0338	0.1082	0.2744	0.1232
10	0.77	0.3699	1.6088	0.0204	0.1075	0.1729	0.1180
11	0.77	0.3699	2.5359	0.0327	0.1075	0.2725	0.1200
12	0.77	0.3664	2.5406	0.0312	0.1054	0.2679	0.1165
13	0.77	0.3718	2.5387	0.0327	0.1086	0.2756	0.1186
					Average:		**0.1129**
					Std Dev:		**0.0063**
					% Dev:		**5.54**

Table C.27: Radial Density Measurements for Each Core Taken from Sample 18 (D3)

Batch D3: 65C Small Mold Size Sample #18							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3680	2.5346	0.0276	0.1064	0.2696	0.1024
2	0.38	0.3712	2.5381	0.0292	0.1082	0.2746	0.1063
3	0.38	0.3683	2.5384	0.0287	0.1065	0.2704	0.1061
4	0.38	0.3702	2.5371	0.0283	0.1076	0.2731	0.1036
5	0.38	0.3705	2.5410	0.0292	0.1078	0.2740	0.1066
6	0.59	0.3712	2.5422	0.0321	0.1082	0.2751	0.1167
7	0.59	0.3705	2.5393	0.0309	0.1078	0.2738	0.1129
8	0.59	0.3696	2.5425	0.0304	0.1073	0.2727	0.1115
9	0.59	0.3699	2.5413	0.0292	0.1075	0.2731	0.1069
10	0.77	0.3727	2.5381	0.0308	0.1091	0.2770	0.1112
11	0.77	0.3712	1.5596	0.0206	0.1082	0.1687	0.1221
12	0.77	0.3724	2.5549	0.0323	0.1089	0.2783	0.1161
13	0.77	0.3718	2.5483	0.0333	0.1086	0.2767	0.1204
					Average:		**0.1110**
					Std Dev:		**0.0063**
					% Dev:		**5.71**

Table C.28: Radial Density Measurements for Each Core Taken from Sample 19 (D3)

Batch D3: 65C Small Mold Size Sample #19							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3721	2.5244	0.0293	0.1088	0.2745	0.1067
2	0.38	0.3696	2.5251	0.0285	0.1073	0.2709	0.1052
3	0.38	0.3696	2.5257	0.0296	0.1073	0.2709	0.1093
4	0.38	0.3734	2.5317	0.0299	0.1095	0.2772	0.1079
5	0.38	0.3667	2.5276	0.0292	0.1056	0.2670	0.1094
6	0.59	0.3699	2.5337	0.0309	0.1075	0.2723	0.1135
7	0.59	0.3702	2.5384	0.0313	0.1076	0.2732	0.1146
8	0.59	0.3708	2.5235	0.0299	0.1080	0.2726	0.1097
9	0.59	0.3699	2.5314	0.0303	0.1075	0.2720	0.1114
10	0.77	0.3724	2.5381	0.0328	0.1089	0.2765	0.1186
11	0.77	0.3715	2.5327	0.0323	0.1084	0.2745	0.1177
12	0.77	0.3715	2.5260	0.0319	0.1084	0.2738	0.1165
13	0.77	0.3718	2.5352	0.0329	0.1086	0.2752	0.1195
					Average:		**0.1123**
					Std Dev:		**0.0048**
					% Dev:		**4.24**

Table C.29: Radial Density Measurements for Each Core Taken from Sample 20 (D3)

Batch D3: 65C Small Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3708	2.5352	0.0294	0.1080	0.2738	0.1074
2	0.38	0.3712	2.5403	0.0311	0.1082	0.2748	0.1132
3	0.38	0.3664	1.9126	0.0225	0.1054	0.2017	0.1116
4	0.38	0.3670	2.5375	0.0296	0.1058	0.2685	0.1103
5	0.38	0.3718	2.5346	0.0294	0.1086	0.2752	0.1068
6	0.59	0.3724	1.3621	0.0170	0.1089	0.1484	0.1146
7	0.59	0.3712	2.5378	0.0309	0.1082	0.2746	0.1125
8	0.59	0.3708	2.5381	0.0312	0.1080	0.2741	0.1138
9	0.59	0.3683	1.6326	0.0194	0.1065	0.1739	0.1115
10	0.77	0.3705	2.5413	0.0310	0.1078	0.2740	0.1131
11	0.77	0.3670	2.5422	0.0328	0.1058	0.2690	0.1219
12	0.77	0.3689	2.5467	0.0319	0.1069	0.2722	0.1172
13	0.77	0.3651	2.5384	0.0320	0.1047	0.2658	0.1204
					Average:		**0.1134**
					Std Dev:		**0.0044**
					% Dev:		**3.90**

Table C.30: Radial Density Measurements for Each Core Taken from Sample 17 (D4)

Batch D4: 85C Small Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3876	2.5502	0.0308	0.1180	0.3009	0.1024
2	0.38	0.3912	2.5527	0.0300	0.1202	0.3068	0.0978
3	0.38	0.3927	2.5509	0.0312	0.1211	0.3089	0.1010
4	0.38	0.3950	2.5375	0.0298	0.1225	0.3109	0.0959
5	0.38	0.3871	2.5453	0.0303	0.1177	0.2996	0.1012
6	0.59	0.4013	2.5504	0.0328	0.1265	0.3226	0.1017
7	0.59	0.4003	2.5499	0.0329	0.1259	0.3209	0.1025
8	0.59	0.3901	2.5357	0.0306	0.1195	0.3031	0.1009
9	0.59	0.3985	2.5364	0.0318	0.1247	0.3164	0.1005
10	0.77	0.3907	2.5461	0.0337	0.1199	0.3052	0.1104
11	0.77	0.3876	2.5692	0.0337	0.1180	0.3032	0.1112
12	0.77	0.3894	2.5471	0.0335	0.1191	0.3033	0.1104
13	0.77	0.3871	2.5311	0.0315	0.1177	0.2979	0.1057
					Average:		**0.1032**
					Std Dev:		**0.0049**
					% Dev:		**4.70**

Table C.31: Radial Density Measurements for Each Core Taken from Sample 18 (D4)

Batch D4: 85C Small Mold Size Sample #18							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3813	2.5453	0.0295	0.1142	0.2906	0.1015
2	0.38	0.3843	2.5509	0.0308	0.1160	0.2959	0.1041
3	0.38	0.3868	2.5568	0.0310	0.1175	0.3005	0.1032
4	0.38	-	-	-	-	-	-
5	0.38	0.3886	2.5486	0.0319	0.1186	0.3023	0.1055
6	0.59	0.4003	2.5362	0.0322	0.1259	0.3192	0.1009
7	0.59	0.3861	2.5512	0.0316	0.1171	0.2987	0.1058
8	0.59	0.3884	2.5540	0.0311	0.1185	0.3025	0.1028
9	0.59	0.3846	2.5479	0.0313	0.1161	0.2959	0.1058
10	0.77	0.3962	2.5479	0.0336	0.1233	0.3142	0.1069
11	0.77	0.3835	2.5448	0.0312	0.1155	0.2940	0.1061
12	0.77	0.3805	2.5667	0.0327	0.1137	0.2918	0.1120
13	0.77	0.3960	2.5486	0.0339	0.1232	0.3139	0.1080
					Average:		0.1052
					Std Dev:		0.0031
					% Dev:		**2.90**

Table C.32: Radial Density Measurements for Each Core Taken from Sample 19 (D4)

Batch D4: 85C Small Mold Size Sample #19							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3780	2.5474	0.0284	0.1122	0.2858	0.0994
2	0.38	0.3807	2.5448	0.0307	0.1139	0.2897	0.1060
3	0.38	0.3767	2.5438	0.0294	0.1114	0.2835	0.1037
4	0.38	0.3787	2.5514	0.0304	0.1126	0.2874	0.1058
5	0.38	0.3772	2.5512	0.0301	0.1117	0.2851	0.1056
6	0.59	0.3884	2.5509	0.0309	0.1185	0.3022	0.1023
7	0.59	0.3807	2.5476	0.0318	0.1139	0.2901	0.1096
8	0.59	0.3805	2.5441	0.0300	0.1137	0.2893	0.1037
9	0.59	0.3901	2.5428	0.0315	0.1195	0.3040	0.1036
10	0.77	0.3785	2.5387	0.0324	0.1125	0.2856	0.1134
11	0.77	-	-	-	-	-	-
12	0.77	-	-	-	-	-	-
13	0.77	0.3927	2.5395	0.0333	0.1211	0.3076	0.1083
					Average:		**0.1056**
					Std Dev:		**0.0038**
					% Dev:		**3.62**

Table C.33: Radial Density Measurements for Each Core Taken from Sample 20 (D4)

Batch D4: 85C Small Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3774	2.5370	0.0270	0.1119	0.2839	0.0951
2	0.38	0.3724	2.5423	0.0278	0.1089	0.2769	0.1004
3	0.38	0.3736	2.5364	0.0274	0.1096	0.2781	0.0985
4	0.38	0.3703	2.5390	0.0275	0.1077	0.2735	0.1006
5	0.38	0.3736	2.5380	0.0280	0.1096	0.2783	0.1006
6	0.59	0.3757	2.5288	0.0282	0.1108	0.2803	0.1006
7	0.59	0.3716	2.5314	0.0285	0.1085	0.2745	0.1038
8	0.59	0.3708	2.5433	0.0279	0.1080	0.2747	0.1016
9	0.59	0.3810	2.5448	0.0297	0.1140	0.2901	0.1024
10	0.77	0.3785	2.5517	0.0304	0.1125	0.2870	0.1059
11	0.77	-	-	-	-	-	-
12	0.77	0.3810	2.5034	0.0302	0.1140	0.2854	0.1058
13	0.77	0.3754	2.5512	0.0305	0.1107	0.2824	0.1080
					Average:		**0.1019**
					Std Dev:		**0.0035**
					% Dev:		**3.47**

Table C.34: Radial Density Measurements for Each Core Taken from Sample 17 (D5)

Batch D5: 25C Medium Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3754	2.5182	0.0280	0.1107	0.2787	0.1005
2	0.27	0.3731	2.5260	0.0286	0.1093	0.2762	0.1035
3	0.27	0.3729	2.5141	0.0282	0.1092	0.2745	0.1027
4	0.27	0.3734	2.5217	0.0299	0.1095	0.2761	0.1083
5	0.27	0.3724	2.5131	0.0286	0.1089	0.2737	0.1045
6	0.42	0.3696	2.5403	0.0285	0.1073	0.2725	0.1046
7	0.42	0.3698	2.5179	0.0279	0.1074	0.2705	0.1032
8	0.42	0.3711	2.5174	0.0283	0.1082	0.2723	0.1039
9	0.42	0.3729	2.5248	0.0285	0.1092	0.2757	0.1034
10	0.57	0.3660	2.5372	0.0292	0.1052	0.2670	0.1094
11	0.57	0.3734	2.5283	0.0284	0.1095	0.2768	0.1026
12	0.57	0.3698	2.5098	0.0284	0.1074	0.2696	0.1053
13	0.57	0.3708	2.5072	0.0287	0.1080	0.2708	0.1060
14	0.71	0.3683	2.4943	0.0302	0.1065	0.2657	0.1136
15	0.71	0.3703	2.5232	0.0312	0.1077	0.2718	0.1148
16	0.71	0.3721	2.5131	0.0293	0.1088	0.2733	0.1072
17	0.71	0.3716	2.5400	0.0309	0.1085	0.2755	0.1122
18	0.86	0.3719	2.5395	0.0385	0.1086	0.2758	0.1396
19	0.86	0.3696	2.5136	0.0338	0.1073	0.2696	0.1254
20	0.86	0.3696	2.5458	0.0365	0.1073	0.2731	0.1337
21	0.86	0.3716	2.5121	0.0356	0.1085	0.2724	0.1307
					Average:		**0.111188**
					Std Dev:		**0.011372**
					% Dev:		**10.23**

Table C.35: Radial Density Measurements for Each Core Taken from Sample 18 (D5)

Batch D5: 25C Medium Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3724	2.5154	0.0284	0.1089	0.2739	0.1037
2	0.27	0.3711	2.4976	0.0291	0.1082	0.2701	0.1077
3	0.27	0.3744	2.5105	0.0295	0.1101	0.2764	0.1067
4	0.27	0.3711	2.5204	0.0292	0.1082	0.2726	0.1071
5	0.27	0.3716	2.5060	0.0288	0.1085	0.2718	0.1060
6	0.42	0.3719	2.5065	0.0325	0.1086	0.2722	0.1194
7	0.42	0.3680	2.5237	0.0294	0.1064	0.2685	0.1095
8	0.42	0.3668	2.5006	0.0284	0.1057	0.2642	0.1075
9	0.42	0.3716	2.5009	0.0293	0.1085	0.2712	0.1080
10	0.57	0.3711	2.4836	0.0299	0.1082	0.2686	0.1113
11	0.57	0.3680	2.5159	0.0292	0.1064	0.2677	0.1091
12	0.57	0.3693	2.5263	0.0304	0.1071	0.2706	0.1123
13	0.57	0.3691	2.5161	0.0305	0.1070	0.2692	0.1133
14	0.71	0.3736	2.5319	0.0324	0.1096	0.2776	0.1167
15	0.71	0.3680	2.5232	0.0302	0.1064	0.2684	0.1125
16	0.71	0.3724	2.4989	0.0317	0.1089	0.2721	0.1165
17	0.71	0.3711	2.5009	0.0312	0.1082	0.2705	0.1153
18	0.86	0.3734	2.5270	0.0351	0.1095	0.2767	0.1269
19	0.86	0.3719	2.4823	0.0359	0.1086	0.2696	0.1332
20	0.86	0.3696	2.5182	0.0356	0.1073	0.2701	0.1318
21	0.86	0.3708	2.5433	0.0404	0.1080	0.2747	0.1471
					Average:		**0.1153**
					Std Dev:		**0.0109**
					% Dev:		**9.49**

Table C.36: Radial Density Measurements for Each Core Taken from Sample 19 (D5)

Batch D5: 25C Medium Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3711	2.5309	0.0295	0.1082	0.2737	0.1078
2	0.27	0.3670	1.9286	0.0225	0.1058	0.2041	0.1103
3	0.27	0.3711	2.5293	0.0298	0.1082	0.2736	0.1089
4	0.27	0.3686	2.5286	0.0299	0.1067	0.2698	0.1108
5	0.27	0.3706	2.5230	0.0292	0.1079	0.2721	0.1073
6	0.42	0.3729	2.5047	0.0303	0.1092	0.2735	0.1108
7	0.42	0.3703	2.5319	0.0302	0.1077	0.2727	0.1107
8	0.42	0.3696	2.5321	0.0298	0.1073	0.2716	0.1097
9	0.42	0.3744	2.5288	0.0304	0.1101	0.2784	0.1092
10	0.57	0.3729	2.5337	0.0307	0.1092	0.2767	0.1110
11	0.57	0.3736	2.5319	0.0301	0.1096	0.2776	0.1084
12	0.57	0.3708	2.5324	0.0314	0.1080	0.2735	0.1148
13	0.57	0.3734	2.5326	0.0313	0.1095	0.2773	0.1129
14	0.71	0.3731	2.5357	0.0341	0.1093	0.2773	0.1230
15	0.71	0.3719	2.5375	0.0350	0.1086	0.2756	0.1270
16	0.71	0.3749	2.5466	0.0352	0.1104	0.2811	0.1252
17	0.71	0.3744	2.5372	0.0357	0.1101	0.2793	0.1278
18	0.86	0.3716	2.1613	0.0321	0.1085	0.2344	0.1369
19	0.86	0.3731	1.7432	0.0269	0.1093	0.1906	0.1411
20	0.86	0.3729	2.5397	0.0383	0.1092	0.2773	0.1381
21	0.86	0.3749	2.5413	0.0395	0.1104	0.2805	0.1408
					Average:		**0.1187**
					Std Dev:		**0.0120**
					% Dev:		**10.15**

Table C.37: Radial Density Measurements for Each Core Taken from Sample 20 (D5)

Batch D5: 25C Medium Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3581	1.7008	0.0222	0.1007	0.1713	0.1296
2	0.27	0.3592	2.4940	0.0318	0.1013	0.2527	0.1259
3	0.27	0.3571	2.5022	0.0317	0.1002	0.2506	0.1265
4	0.27	0.3645	2.4930	0.0318	0.1043	0.2601	0.1222
5	0.27	0.3607	1.7262	0.0218	0.1022	0.1764	0.1236
6	0.42	0.3706	2.5072	0.0323	0.1079	0.2704	0.1194
7	0.42	0.3708	2.5156	0.0324	0.1080	0.2717	0.1192
8	0.42	0.3373	2.5230	0.0285	0.0894	0.2255	0.1264
9	0.42	0.3673	2.5171	0.0321	0.1059	0.2667	0.1204
10	0.57	0.3721	2.5243	0.0325	0.1088	0.2745	0.1184
11	0.57	0.3721	2.5080	0.0328	0.1088	0.2727	0.1203
12	0.57	0.3731	2.5108	0.0328	0.1093	0.2745	0.1195
13	0.57	0.3721	2.5230	0.0342	0.1088	0.2744	0.1246
14	0.71	0.3696	2.5105	0.0343	0.1073	0.2693	0.1274
15	0.71	0.3724	2.5143	0.0357	0.1089	0.2738	0.1304
16	0.71	0.3703	2.5250	0.0363	0.1077	0.2720	0.1335
17	0.71	0.3724	2.5184	0.0351	0.1089	0.2743	0.1280
18	0.86	0.3731	1.8948	0.0283	0.1093	0.2072	0.1366
19	0.86	0.3729	2.5232	0.0387	0.1092	0.2755	0.1405
20	0.86	0.3686	2.5108	0.0366	0.1067	0.2679	0.1366
21	0.86	0.3686	2.5133	0.0366	0.1067	0.2681	0.1365
					Average:		**0.1269**
					Std Dev:		**0.0067**
					% Dev:		**5.27**

Table C.38: Radial Density Measurements for Each Core Taken from Sample 17 (D6)

Batch D6: 40C Medium Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3736	2.5489	0.0282	0.1096	0.2795	0.1009
2	0.27	0.3757	2.5585	0.0277	0.1108	0.2836	0.0977
3	0.27	0.3780	2.5568	0.0292	0.1122	0.2868	0.1018
4	0.27	0.3787	2.5479	0.0279	0.1126	0.2870	0.0972
5	0.27	0.3792	2.5489	0.0283	0.1129	0.2879	0.0983
6	0.42	0.3767	2.5603	0.0284	0.1114	0.2853	0.0995
7	0.42	0.3754	2.5499	0.0278	0.1107	0.2822	0.0985
8	0.42	0.3792	2.5530	0.0296	0.1129	0.2883	0.1027
9	0.42	0.3744	2.5466	0.0283	0.1101	0.2804	0.1009
10	0.57	0.3734	2.5377	0.0285	0.1095	0.2779	0.1026
11	0.57	0.3693	2.5654	0.0296	0.1071	0.2748	0.1077
12	0.57	0.3706	2.5433	0.0293	0.1079	0.2743	0.1068
13	0.57	0.3749	2.5514	0.0297	0.1104	0.2817	0.1054
14	0.71	0.3731	2.5657	0.0305	0.1093	0.2805	0.1087
15	0.71	0.3724	2.5613	0.0308	0.1089	0.2789	0.1104
16	0.71	0.3721	2.5499	0.0314	0.1088	0.2773	0.1132
17	0.71	0.3706	2.5347	0.0291	0.1079	0.2734	0.1064
18	0.86	0.3696	2.5552	0.0337	0.1073	0.2741	0.1229
19	0.86	0.3711	2.5629	0.0330	0.1082	0.2772	0.1191
20	0.86	0.3719	2.5829	0.0320	0.1086	0.2805	0.1141
21	0.86	0.3703	2.5560	0.0324	0.1077	0.2753	0.1177
					Average:		**0.1063**
					Std Dev:		**0.0075**
					% Dev:		**7.09**

Table C.39: Radial Density Measurements for Each Core Taken from Sample 18 (D6)

Batch D6: 40C Medium Mold Size Sample #18							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3749	2.5629	0.0286	0.1104	0.2829	0.1011
2	0.27	0.3741	2.5649	0.0286	0.1099	0.2820	0.1014
3	0.27	0.3721	2.5603	0.0286	0.1088	0.2784	0.1027
4	0.27	0.3731	2.5662	0.0285	0.1093	0.2806	0.1016
5	0.27	0.3731	2.5639	0.0293	0.1093	0.2803	0.1045
6	0.42	0.3729	2.5677	0.0289	0.1092	0.2804	0.1031
7	0.42	0.3754	2.5527	0.0294	0.1107	0.2826	0.1040
8	0.42	0.3691	2.5720	0.0291	0.1070	0.2751	0.1058
9	0.42	0.3749	2.5664	0.0293	0.1104	0.2833	0.1034
10	0.57	0.3703	2.5690	0.0282	0.1077	0.2767	0.1019
11	0.57	0.3731	2.5679	0.0295	0.1093	0.2808	0.1051
12	0.57	0.3744	2.5601	0.0296	0.1101	0.2818	0.1050
13	0.57	0.3741	2.5654	0.0298	0.1099	0.2820	0.1057
14	0.71	0.3711	2.5603	0.0316	0.1082	0.2769	0.1141
15	0.71	0.3719	2.5585	0.0308	0.1086	0.2779	0.1108
16	0.71	0.3731	2.5524	0.0315	0.1093	0.2791	0.1129
17	0.71	0.3741	2.5771	0.0323	0.1099	0.2833	0.1140
18	0.86	0.3749	2.5674	0.0351	0.1104	0.2834	0.1238
19	0.86	0.3767	2.5575	0.0334	0.1114	0.2850	0.1172
20	0.86	0.3734	2.5725	0.0343	0.1095	0.2817	0.1218
21	0.86	0.3703	2.5766	0.0352	0.1077	0.2775	0.1268
					Average:		**0.1089**
					Std Dev:		**0.0080**
					% Dev:		**7.31**

Table C.40: Radial Density Measurements for Each Core Taken from Sample 19 (D6)

Batch D6: 40C Medium Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3759	2.5514	0.0293	0.1110	0.2832	0.1035
2	0.27	0.3747	2.5509	0.0297	0.1102	0.2812	0.1056
3	0.27	0.3724	2.5560	0.0292	0.1089	0.2783	0.1049
4	0.27	0.3716	2.5563	0.0286	0.1085	0.2772	0.1032
5	0.27	0.3696	2.5484	0.0290	0.1073	0.2734	0.1061
6	0.42	0.3696	2.5466	0.0297	0.1073	0.2732	0.1087
7	0.42	0.3706	2.5573	0.0296	0.1079	0.2758	0.1073
8	0.42	0.3721	2.5517	0.0289	0.1088	0.2775	0.1041
9	0.42	0.3706	2.5568	0.0301	0.1079	0.2758	0.1091
10	0.57	0.3716	2.5497	0.0301	0.1085	0.2765	0.1089
11	0.57	0.3673	2.5464	0.0301	0.1059	0.2698	0.1116
12	0.57	0.3708	2.5593	0.0303	0.1080	0.2764	0.1096
13	0.57	0.3706	2.5436	0.0307	0.1079	0.2744	0.1119
14	0.71	0.3719	2.5535	0.0325	0.1086	0.2773	0.1172
15	0.71	0.3719	2.5585	0.0328	0.1086	0.2779	0.1180
16	0.71	0.3711	2.5466	0.0326	0.1082	0.2754	0.1184
17	0.71	0.3703	2.5474	0.0322	0.1077	0.2744	0.1174
18	0.86	0.3706	2.5555	0.0357	0.1079	0.2756	0.1295
19	0.86	0.3731	2.5397	0.0350	0.1093	0.2777	0.1260
20	0.86	0.3734	2.5624	0.0367	0.1095	0.2806	0.1308
21	0.86	0.3686	2.5502	0.0340	0.1067	0.2721	0.1250
					Average:		**0.1132**
					Std Dev:		**0.0087**
					% Dev:		**7.71**

Table C.41: Radial Density Measurements for Each Core Taken from Sample 20 (D6)

Batch D6: 40C Medium Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3747	2.5306	0.0290	0.1102	0.2790	0.1040
2	0.27	0.3785	2.5232	0.0293	0.1125	0.2838	0.1032
3	0.27	0.3782	2.5359	0.0294	0.1123	0.2849	0.1032
4	0.27	0.3747	2.5286	0.0288	0.1102	0.2788	0.1033
5	0.27	0.3780	2.5382	0.0288	0.1122	0.2848	0.1011
6	0.42	0.3731	2.5395	0.0289	0.1093	0.2777	0.1041
7	0.42	0.3757	2.5217	0.0300	0.1108	0.2795	0.1073
8	0.42	0.3734	2.5149	0.0291	0.1095	0.2754	0.1057
9	0.42	0.3741	2.5517	0.0238	0.1099	0.2805	0.0848
10	0.57	0.3757	2.5182	0.0289	0.1108	0.2791	0.1035
11	0.57	0.3749	2.5436	0.0301	0.1104	0.2808	0.1072
12	0.57	0.3757	2.5270	0.0305	0.1108	0.2801	0.1089
13	0.57	0.3782	2.5067	0.0291	0.1123	0.2816	0.1033
14	0.71	0.3759	2.5230	0.0324	0.1110	0.2800	0.1157
15	0.71	0.3787	2.5199	0.0333	0.1126	0.2839	0.1173
16	0.71	0.3769	2.5522	0.0327	0.1116	0.2848	0.1148
17	0.71	0.3734	1.6002	0.0198	0.1095	0.1752	0.1130
18	0.86	0.3734	2.5212	0.0328	0.1095	0.2761	0.1188
19	0.86	0.3724	2.5514	0.0347	0.1089	0.2778	0.1249
20	0.86	0.3762	2.5339	0.0349	0.1111	0.2816	0.1239
21	0.86	0.3772	2.5136	0.0339	0.1117	0.2809	0.1207
					Average:		**0.1090**
					Std Dev:		**0.0093**
					% Dev:		**8.57**

Table C.42: Radial Density Measurements for Each Core Taken from Sample 17 (D7)

Batch D7: 65C Medium Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3734	2.5547	0.0272	0.1095	0.2797	0.0972
2	0.27	0.3736	2.5502	0.0277	0.1096	0.2796	0.0991
3	0.27	0.3703	2.5657	0.0278	0.1077	0.2764	0.1006
4	0.27	0.3696	2.5535	0.0267	0.1073	0.2739	0.0975
5	0.27	0.3749	2.5530	0.0274	0.1104	0.2818	0.0972
6	0.42	0.3741	2.5550	0.0283	0.1099	0.2809	0.1007
7	0.42	0.3767	2.5598	0.0282	0.1114	0.2853	0.0989
8	0.42	0.3757	2.5588	0.0276	0.1108	0.2836	0.0973
9	0.42	0.3736	2.5725	0.0285	0.1096	0.2821	0.1010
10	0.57	0.3767	2.5657	0.0297	0.1114	0.2859	0.1039
11	0.57	0.3736	2.5555	0.0291	0.1096	0.2802	0.1039
12	0.57	0.3792	2.5535	0.0294	0.1129	0.2884	0.1019
13	0.57	0.3747	2.5537	0.0293	0.1102	0.2815	0.1041
14	0.71	0.3747	2.5446	0.0294	0.1102	0.2805	0.1048
15	0.71	0.3769	2.5626	0.0291	0.1116	0.2860	0.1018
16	0.71	0.3774	2.5466	0.0302	0.1119	0.2849	0.1060
17	0.71	0.3769	2.5580	0.0296	0.1116	0.2855	0.1037
18	0.86	0.3759	2.5667	0.0314	0.1110	0.2849	0.1102
19	0.86	0.3772	2.5446	0.0310	0.1117	0.2843	0.1090
20	0.86	0.3749	2.5514	0.0319	0.1104	0.2817	0.1133
21	0.86	0.3762	2.5618	0.0323	0.1111	0.2847	0.1134
					Average:		**0.1031**
					Std Dev:		**0.0050**
					% Dev:		**4.84**

Table C.43: Radial Density Measurements for Each Core Taken from Sample 18 (D7)

Batch D7: 65C Medium Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3754	2.5552	0.0267	0.1107	0.2828	0.0944
2	0.27	0.3767	2.5438	0.0264	0.1114	0.2835	0.0931
3	0.27	0.3724	2.5413	0.0269	0.1089	0.2767	0.0972
4	0.27	0.3711	2.5497	0.0271	0.1082	0.2758	0.0983
5	0.27	0.3703	2.5512	0.0264	0.1077	0.2748	0.0961
6	0.42	0.3782	2.5522	0.0282	0.1123	0.2867	0.0984
7	0.42	0.3769	2.5453	0.0283	0.1116	0.2840	0.0996
8	0.42	0.3734	2.5408	0.0276	0.1095	0.2782	0.0992
9	0.42	0.3734	2.5504	0.0273	0.1095	0.2793	0.0978
10	0.57	0.3782	2.5497	0.0286	0.1123	0.2864	0.0998
11	0.57	0.3774	2.5527	0.0290	0.1119	0.2856	0.1015
12	0.57	0.3744	2.5578	0.0287	0.1101	0.2816	0.1019
13	0.57	0.3787	2.5425	0.0292	0.1126	0.2864	0.1020
14	0.71	0.3787	2.5491	0.0304	0.1126	0.2871	0.1059
15	0.71	0.3785	2.5601	0.0301	0.1125	0.2880	0.1045
16	0.71	0.3736	2.5517	0.0302	0.1096	0.2798	0.1079
17	0.71	0.3744	2.5448	0.0311	0.1101	0.2802	0.1110
18	0.86	0.3736	2.5535	0.0318	0.1096	0.2800	0.1136
19	0.86	0.3759	2.5375	0.0311	0.1110	0.2816	0.1104
20	0.86	0.3729	2.5641	0.0330	0.1092	0.2800	0.1179
21	0.86	0.3774	2.5486	0.0322	0.1119	0.2852	0.1129
					Average:		**0.1030**
					Std Dev:		**0.0069**
					% Dev:		**6.69**

Table C.44: Radial Density Measurements for Each Core Taken from Sample 19 (D7)

Batch D7: 65C Medium Mold Size Sample #19							
Core #	**Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3767	2.5616	0.0271	0.1114	0.2855	0.0949
2	0.27	0.3731	2.5639	0.0277	0.1093	0.2803	0.0988
3	0.27	0.3731	2.5575	0.0275	0.1093	0.2797	0.0983
4	0.27	0.3696	2.5588	0.0271	0.1073	0.2745	0.0987
5	0.27	0.3747	2.5616	0.0280	0.1102	0.2824	0.0992
6	0.42	0.3754	2.5550	0.0279	0.1107	0.2828	0.0987
7	0.42	0.3749	2.5611	0.0282	0.1104	0.2827	0.0997
8	0.42	0.3716	2.5601	0.0284	0.1085	0.2776	0.1023
9	0.42	0.3734	2.5588	0.0284	0.1095	0.2802	0.1014
10	0.57	0.3757	2.5636	0.0295	0.1108	0.2841	0.1038
11	0.57	0.3774	2.5601	0.0289	0.1119	0.2864	0.1009
12	0.57	0.3767	2.5598	0.0290	0.1114	0.2853	0.1017
13	0.57	0.3769	2.5629	0.0291	0.1116	0.2860	0.1018
14	0.71	0.3772	2.5667	0.0298	0.1117	0.2868	0.1039
15	0.71	0.3785	2.5629	0.0302	0.1125	0.2883	0.1047
16	0.71	0.3774	2.5601	0.0302	0.1119	0.2864	0.1054
17	0.71	0.3741	2.5563	0.0293	0.1099	0.2810	0.1043
18	0.86	0.3731	2.5575	0.0318	0.1093	0.2797	0.1137
19	0.86	0.3703	2.5565	0.0314	0.1077	0.2754	0.1140
20	0.86	0.3747	2.5669	0.0321	0.1102	0.2830	0.1134
21	0.86	0.3772	2.5641	0.0318	0.1117	0.2865	0.1110
					Average:		**0.1034**
					Std Dev:		**0.0055**
					% Dev:		**5.28**

Table C.45: Radial Density Measurements for Each Core Taken from Sample 20 (D7)

Batch D7: 65C Medium Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3774	2.5547	0.0275	0.1119	0.2859	0.0962
2	0.27	0.3736	2.5565	0.0278	0.1096	0.2803	0.0992
3	0.27	0.3762	2.5530	0.0282	0.1111	0.2837	0.0994
4	0.27	0.3744	2.5565	0.0276	0.1101	0.2814	0.0981
5	0.27	0.3724	2.5560	0.0270	0.1089	0.2783	0.0970
6	0.42	0.3823	2.5497	0.0286	0.1148	0.2926	0.0977
7	0.42	0.3762	2.5565	0.0288	0.1111	0.2841	0.1014
8	0.42	0.3734	2.5486	0.0285	0.1095	0.2791	0.1021
9	0.42	0.3721	2.5565	0.0280	0.1088	0.2780	0.1007
10	0.57	0.3774	2.5448	0.0294	0.1119	0.2847	0.1033
11	0.57	0.3757	2.5537	0.0301	0.1108	0.2831	0.1063
12	0.57	0.3719	2.5502	0.0294	0.1086	0.2770	0.1062
13	0.57	0.3744	2.5502	0.0293	0.1101	0.2807	0.1044
14	0.71	0.3757	2.5540	0.0307	0.1108	0.2831	0.1084
15	0.71	0.3747	2.5479	0.0303	0.1102	0.2809	0.1079
16	0.71	0.3785	2.5568	0.0302	0.1125	0.2876	0.1050
17	0.71	0.3744	2.5448	0.0296	0.1101	0.2802	0.1057
18	0.86	0.3744	2.5530	0.0313	0.1101	0.2811	0.1114
19	0.86	0.3721	2.5537	0.0315	0.1088	0.2777	0.1134
20	0.86	0.3736	2.5524	0.0319	0.1096	0.2799	0.1140
21	0.86	-	-	-	-	-	-
					Average:		**0.1039**
					Std Dev:		**0.0053**
					% Dev:		**5.14**

Table C.46: Radial Density Measurements for Each Core Taken from Sample 17 (D8)

Batch D8: 85C Medium Mold Size Sample #17							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3703	2.5466	0.0269	0.1077	0.2743	0.0981
2	0.27	0.3818	2.5522	0.0276	0.1145	0.2921	0.0945
3	0.27	0.3805	2.5651	0.0285	0.1137	0.2917	0.0977
4	0.27	0.3772	2.5700	0.0284	0.1117	0.2872	0.0989
5	0.27	0.3553	2.5530	0.0262	0.0992	0.2532	0.1035
6	0.42	0.3792	2.5486	0.0287	0.1129	0.2879	0.0997
7	0.42	0.3810	2.5530	0.0281	0.1140	0.2911	0.0965
8	0.42	0.3782	2.5585	0.0283	0.1123	0.2874	0.0985
9	0.42	0.3785	2.5530	0.0288	0.1125	0.2872	0.1003
10	0.57	0.3780	2.5631	0.0287	0.1122	0.2876	0.0998
11	0.57	0.3820	2.5527	0.0285	0.1146	0.2926	0.0974
12	0.57	0.3787	2.5476	0.0285	0.1126	0.2870	0.0993
13	0.57	0.3787	2.5550	0.0294	0.1126	0.2878	0.1022
14	0.71	0.3797	2.5502	0.0294	0.1133	0.2888	0.1018
15	0.71	0.3769	2.5654	0.0300	0.1116	0.2863	0.1048
16	0.71	0.3767	2.5464	0.0305	0.1114	0.2838	0.1075
17	0.71	0.3780	2.5453	0.0287	0.1122	0.2856	0.1005
18	0.86	0.3774	2.5588	0.0307	0.1119	0.2863	0.1072
19	0.86	0.3805	2.5479	0.0322	0.1137	0.2897	0.1111
20	0.86	0.3772	2.5626	0.0315	0.1117	0.2863	0.1100
21	0.86	0.3807	2.5654	0.0312	0.1139	0.2921	0.1068
					Average:		**0.1017**
					Std Dev:		**0.0046**
					% Dev:		**4.52**

Table C.47: Radial Density Measurements for Each Core Taken from Sample 18 (D8)

Batch D8: 85C Medium Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3782	2.5390	0.0273	0.1123	0.2852	0.0957
2	0.27	0.3774	2.5535	0.0272	0.1119	0.2857	0.0952
3	0.27	0.3792	2.5466	0.0285	0.1129	0.2876	0.0991
4	0.27	0.3772	2.5489	0.0286	0.1117	0.2848	0.1004
5	0.27	0.3785	2.5385	0.0281	0.1125	0.2856	0.0984
6	0.42	0.3792	2.5474	0.0289	0.1129	0.2877	0.1004
7	0.42	0.3785	2.5441	0.0280	0.1125	0.2862	0.0978
8	0.42	0.3754	2.5591	0.0278	0.1107	0.2833	0.0981
9	0.42	0.3782	2.5453	0.0281	0.1123	0.2860	0.0983
10	0.57	0.3769	2.5555	0.0289	0.1116	0.2852	0.1013
11	0.57	0.3698	1.5377	0.0176	0.1074	0.1652	0.1066
12	0.57	0.3800	2.5479	0.0294	0.1134	0.2889	0.1018
13	0.57	0.3795	2.5436	0.0302	0.1131	0.2877	0.1050
14	0.71	0.3749	2.5352	0.0302	0.1104	0.2799	0.1079
15	0.71	0.3797	2.5448	0.0295	0.1133	0.2882	0.1024
16	0.71	0.3858	2.5568	0.0306	0.1169	0.2989	0.1024
17	0.71	0.3734	2.5471	0.0304	0.1095	0.2789	0.1090
18	0.86	0.3754	2.1770	0.0252	0.1107	0.2410	0.1046
19	0.86	0.3782	2.5438	0.0319	0.1123	0.2858	0.1116
20	0.86	0.3787	2.5288	0.0307	0.1126	0.2849	0.1078
21	0.86	0.3741	2.5527	0.0306	0.1099	0.2806	0.1090
					Average:		**0.1025**
					Std Dev:		**0.0047**
					% Dev:		**4.62**

Table C.48: Radial Density Measurements for Each Core Taken from Sample 19 (D8)

Batch D8: 85C Medium Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3795	2.5499	0.0269	0.1131	0.2884	0.0933
2	0.27	0.3767	2.5499	0.0283	0.1114	0.2842	0.0996
3	0.27	0.3762	2.5448	0.0284	0.1111	0.2828	0.1004
4	0.27	0.3741	2.5517	0.0277	0.1099	0.2805	0.0987
5	0.27	0.3757	2.5486	0.0283	0.1108	0.2825	0.1002
6	0.42	0.3734	2.5425	0.0280	0.1095	0.2784	0.1006
7	0.42	0.3785	2.5476	0.0284	0.1125	0.2866	0.0991
8	0.42	0.3787	2.5410	0.0286	0.1126	0.2862	0.0999
9	0.42	0.3780	2.5423	0.0290	0.1122	0.2852	0.1017
10	0.57	0.3780	2.5458	0.0290	0.1122	0.2856	0.1015
11	0.57	0.3731	1.3437	0.0142	0.1093	0.1469	0.0966
12	0.57	0.3813	2.5535	0.0292	0.1142	0.2915	0.1002
13	0.57	0.3736	1.2598	0.0138	0.1096	0.1381	0.0999
14	0.71	0.3724	1.3716	0.0157	0.1089	0.1494	0.1051
15	0.71	0.3731	1.2545	0.0137	0.1093	0.1372	0.0999
16	0.71	-	-	-	-	-	-
17	0.71	0.3741	2.5464	0.0293	0.1099	0.2800	0.1047
18	0.86	0.3797	2.5458	0.0314	0.1133	0.2883	0.1089
19	0.86	0.3734	2.5687	0.0313	0.1095	0.2813	0.1113
20	0.86	0.3757	2.1085	0.0250	0.1108	0.2337	0.1070
21	0.86	0.3749	1.5776	0.0190	0.1104	0.1742	0.1091
					Average:		**0.1019**
					Std Dev:		**0.0045**
					% Dev:		**4.39**

Table C.49: Radial Density Measurements for Each Core Taken from Sample 20 (D8)

Batch D8: 85C Medium Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3747	2.5705	0.0270	0.1102	0.2834	0.0953
2	0.27	0.3762	2.5718	0.0271	0.1111	0.2858	0.0948
3	0.27	0.3780	2.5560	0.0271	0.1122	0.2868	0.0945
4	0.27	0.3772	2.5690	0.0272	0.1117	0.2871	0.0948
5	0.27	0.3780	2.5751	0.0277	0.1122	0.2889	0.0959
6	0.42	0.3731	2.5626	0.0274	0.1093	0.2802	0.0978
7	0.42	0.3731	2.5613	0.0273	0.1093	0.2801	0.0975
8	0.42	0.3767	2.5682	0.0279	0.1114	0.2862	0.0975
9	0.42	0.3787	2.5509	0.0276	0.1126	0.2873	0.0961
10	0.57	0.3769	2.5563	0.0289	0.1116	0.2853	0.1013
11	0.57	0.3764	2.5517	0.0278	0.1113	0.2840	0.0979
12	0.57	0.3767	2.5636	0.0282	0.1114	0.2857	0.0987
13	0.57	0.3772	2.5705	0.0282	0.1117	0.2872	0.0982
14	0.71	0.3769	2.5626	0.0295	0.1116	0.2860	0.1032
15	0.71	-	-	-	-	-	-
16	0.71	-	-	-	-	-	-
17	0.71	0.3759	2.5568	0.0300	0.1110	0.2838	0.1057
18	0.86	0.3754	2.5530	0.0304	0.1107	0.2826	0.1076
19	0.86	0.3780	2.5522	0.0305	0.1122	0.2863	0.1065
20	0.86	0.3787	2.5565	0.0308	0.1126	0.2880	0.1070
21	0.86	0.3757	2.5712	0.0309	0.1108	0.2850	0.1084
					Average:		**0.0999**
					Std Dev:		**0.0049**
					% Dev:		**4.89**

Table C.50: Radial Density Measurements for Each Core Taken from Sample 17 (D9)

Batch D9: 25C Large Mold Size Sample #17							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3658	2.5429	0.0271	0.1051	0.2672	0.1014
2	0.22	0.3693	2.5416	0.0268	0.1071	0.2722	0.0985
3	0.22	0.3661	2.5394	0.0272	0.1053	0.2673	0.1018
4	0.22	0.3673	2.5390	0.0269	0.1060	0.2691	0.1000
5	0.22	0.3689	2.5422	0.0270	0.1069	0.2718	0.0993
6	0.33	0.3673	2.5448	0.0281	0.1060	0.2697	0.1042
7	0.33	0.3712	2.5479	0.0281	0.1082	0.2757	0.1019
8	0.33	0.3683	2.5419	0.0281	0.1065	0.2708	0.1038
9	0.33	0.3673	2.5378	0.0284	0.1060	0.2690	0.1056
10	0.45	0.3702	2.5375	0.0284	0.1076	0.2731	0.1040
11	0.45	0.3680	2.5476	0.0281	0.1064	0.2709	0.1037
12	0.45	0.3699	2.5448	0.0282	0.1075	0.2734	0.1031
13	0.45	0.3686	2.5387	0.0277	0.1067	0.2709	0.1022
14	0.57	0.3677	2.5406	0.0292	0.1062	0.2697	0.1083
15	0.57	0.3683	2.5381	0.0279	0.1065	0.2704	0.1032
16	0.57	0.3677	2.5460	0.0293	0.1062	0.2703	0.1084
17	0.57	0.3699	2.5460	0.0293	0.1075	0.2736	0.1071
18	0.69	0.3686	2.5489	0.0302	0.1067	0.2720	0.1110
19	0.69	0.3696	2.5416	0.0313	0.1073	0.2726	0.1148
20	0.69	0.3680	2.5362	0.0296	0.1064	0.2697	0.1097
21	0.69	0.3705	2.5352	0.0297	0.1078	0.2734	0.1086
22	0.81	0.3680	2.5559	0.0329	0.1064	0.2718	0.1210
23	0.81	0.3686	2.5555	0.0344	0.1067	0.2726	0.1262
24	0.81	0.3683	2.5438	0.0341	0.1065	0.2710	0.1258
25	0.81	0.3708	2.5344	0.0354	0.1080	0.2737	0.1293
26	0.90	0.3627	2.5476	0.0371	0.1033	0.2632	0.1409
27	0.90	0.3698	2.5552	0.0379	0.1074	0.2745	0.1381
28	0.90	0.3678	2.5372	0.0370	0.1062	0.2696	0.1373
29	0.90	0.3711	2.5624	0.0364	0.1082	0.2771	0.1313
					Average:		**0.1121**
					Std Dev:		**0.0130**
					% Dev:		**11.61**

Table C.51: Radial Density Measurements for Each Core Taken from Sample 18 (D9)

Batch D9: 25C Large Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3589	2.5319	0.0268	0.1012	0.2561	0.1046
2	0.22	0.3680	2.5311	0.0269	0.1064	0.2693	0.0999
3	0.22	0.3703	2.5349	0.0274	0.1077	0.2730	0.1003
4	0.22	0.3693	2.5359	0.0279	0.1071	0.2717	0.1027
5	0.22	0.3683	2.5319	0.0279	0.1065	0.2697	0.1034
6	0.33	0.3696	2.5349	0.0279	0.1073	0.2719	0.1026
7	0.33	0.3686	2.5255	0.0278	0.1067	0.2694	0.1032
8	0.33	0.3706	2.5364	0.0283	0.1079	0.2736	0.1034
9	0.33	0.3668	2.5337	0.0269	0.1057	0.2677	0.1005
10	0.45	0.3678	2.5395	0.0282	0.1062	0.2698	0.1045
11	0.45	0.3680	2.5382	0.0277	0.1064	0.2700	0.1026
12	0.45	0.3680	2.5243	0.0277	0.1064	0.2686	0.1031
13	0.45	0.3665	2.5225	0.0274	0.1055	0.2661	0.1030
14	0.57	0.3680	2.5184	0.0286	0.1064	0.2679	0.1067
15	0.57	0.3658	2.5349	0.0287	0.1051	0.2663	0.1078
16	0.57	0.3668	2.5281	0.0285	0.1057	0.2671	0.1067
17	0.57	0.3668	2.5171	0.0288	0.1057	0.2659	0.1083
18	0.69	0.3640	2.5210	0.0303	0.1041	0.2623	0.1155
19	0.69	0.3627	2.5352	0.0305	0.1033	0.2620	0.1164
20	0.69	0.3678	2.5298	0.0297	0.1062	0.2688	0.1105
21	0.69	0.3642	2.5143	0.0304	0.1042	0.2620	0.1160
22	0.81	0.3680	2.5230	0.0327	0.1064	0.2684	0.1218
23	0.81	0.3673	2.5314	0.0339	0.1059	0.2682	0.1264
24	0.81	0.3647	2.5192	0.0332	0.1045	0.2632	0.1261
25	0.81	0.3653	2.5474	0.0323	0.1048	0.2669	0.1210
26	0.90	0.3571	2.5486	0.0355	0.1002	0.2553	0.1391
27	0.90	0.3668	2.5433	0.0369	0.1057	0.2687	0.1373
28	0.90	0.3670	2.5141	0.0361	0.1058	0.2660	0.1357
29	0.90	0.3670	2.5210	0.0350	0.1058	0.2667	0.1312
					Average:		**0.1124**
					Std Dev:		**0.0122**
					% Dev:		**10.89**

Table C.52: Radial Density Measurements for Each Core Taken from Sample 19 (D9)

Batch D9: 25C Large Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3744	2.5484	0.0277	0.1101	0.2806	0.0987
2	0.22	0.3741	2.5580	0.0283	0.1099	0.2812	0.1006
3	0.22	0.3719	2.5601	0.0273	0.1086	0.2780	0.0982
4	0.22	0.3736	2.5563	0.0278	0.1096	0.2803	0.0992
5	0.22	0.3708	2.5535	0.0271	0.1080	0.2758	0.0983
6	0.33	0.3706	2.5568	0.0286	0.1079	0.2758	0.1037
7	0.33	0.3711	2.5575	0.0282	0.1082	0.2766	0.1019
8	0.33	0.3744	2.5527	0.0284	0.1101	0.2810	0.1011
9	0.33	0.3729	2.5575	0.0282	0.1092	0.2793	0.1010
10	0.45	0.3711	2.5504	0.0284	0.1082	0.2758	0.1030
11	0.45	0.3744	2.5568	0.0290	0.1101	0.2815	0.1030
12	0.45	0.3719	2.5588	0.0285	0.1086	0.2779	0.1026
13	0.45	0.3754	2.5489	0.0285	0.1107	0.2821	0.1010
14	0.57	0.3759	2.5497	0.0295	0.1110	0.2830	0.1042
15	0.57	0.3744	2.5530	0.0289	0.1101	0.2811	0.1028
16	0.57	0.3795	2.5537	0.0298	0.1131	0.2888	0.1032
17	0.57	0.3759	2.5542	0.0294	0.1110	0.2835	0.1037
18	0.69	0.3754	2.5535	0.0309	0.1107	0.2826	0.1093
19	0.69	0.3767	2.5552	0.0315	0.1114	0.2848	0.1106
20	0.69	0.3774	2.5588	0.0312	0.1119	0.2863	0.1090
21	0.69	0.3795	2.5560	0.0317	0.1131	0.2891	0.1097
22	0.81	0.3759	2.5542	0.0338	0.1110	0.2835	0.1192
23	0.81	0.3769	2.5568	0.0337	0.1116	0.2853	0.1181
24	0.81	0.3729	2.5530	0.0324	0.1092	0.2788	0.1162
25	0.81	0.3749	2.5641	0.0331	0.1104	0.2831	0.1169
26	0.90	0.3729	2.5611	0.0379	0.1092	0.2797	0.1355
27	0.90	0.3696	2.5575	0.0359	0.1073	0.2743	0.1309
28	0.90	0.3691	2.3711	0.0324	0.1070	0.2537	0.1277
29	0.90	0.3759	2.5484	0.0370	0.1110	0.2828	0.1308
					Average:		**0.1090**
					Std Dev:		**0.0109**
					% Dev:		**10.00**

Table C.53: Radial Density Measurements for Each Core Taken from Sample 20 (D9)

Batch D9: 25C Large Mold Size Sample #20							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3645	2.5255	0.0296	0.1043	0.2635	0.1123
2	0.22	0.3693	2.5283	0.0303	0.1071	0.2708	0.1119
3	0.22	0.3683	2.5298	0.0297	0.1065	0.2695	0.1102
4	0.22	0.3683	2.5230	0.0288	0.1065	0.2688	0.1071
5	0.22	0.3589	2.5245	0.0286	0.1012	0.2554	0.1120
6	0.33	0.3678	2.5268	0.0305	0.1062	0.2685	0.1136
7	0.33	0.3693	2.5268	0.0303	0.1071	0.2707	0.1119
8	0.33	0.3706	2.5217	0.0302	0.1079	0.2720	0.1110
9	0.33	0.3660	2.5273	0.0306	0.1052	0.2659	0.1151
10	0.45	0.3708	2.5187	0.0313	0.1080	0.2720	0.1151
11	0.45	0.3706	2.5243	0.0309	0.1079	0.2723	0.1135
12	0.45	0.3673	2.5258	0.0309	0.1059	0.2676	0.1155
13	0.45	0.3696	2.5298	0.0313	0.1073	0.2714	0.1153
14	0.57	0.3696	2.5337	0.0326	0.1073	0.2718	0.1199
15	0.57	0.3706	2.5321	0.0315	0.1079	0.2731	0.1153
16	0.57	0.3678	2.5197	0.0316	0.1062	0.2677	0.1180
17	0.57	0.3696	2.5225	0.0318	0.1073	0.2706	0.1175
18	0.69	0.3673	2.5143	0.0327	0.1059	0.2664	0.1228
19	0.69	0.3696	2.5314	0.0333	0.1073	0.2715	0.1226
20	0.69	0.3665	2.5349	0.0330	0.1055	0.2675	0.1234
21	0.69	0.3729	2.5232	0.0333	0.1092	0.2755	0.1209
22	0.81	0.3678	2.5283	0.0342	0.1062	0.2686	0.1273
23	0.81	0.3698	2.1438	0.0293	0.1074	0.2303	0.1272
24	0.81	0.3673	2.5199	0.0335	0.1059	0.2670	0.1255
25	0.81	0.3706	2.5344	0.0345	0.1079	0.2734	0.1262
26	0.90	0.3647	2.5149	0.0358	0.1045	0.2628	0.1362
27	0.90	0.3658	2.5184	0.0348	0.1051	0.2646	0.1315
28	0.90	0.3665	2.5121	0.0369	0.1055	0.2650	0.1392
29	0.90	0.3635	2.5103	0.0352	0.1038	0.2605	0.1351
					Average:		**0.1198**
					Std Dev:		**0.0084**
					% Dev:		**10.00**

Table C.54: Radial Density Measurements for Each Core Taken from Sample 17 (D10)

Batch D10: 40C Large Mold Size Sample #17							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3711	2.5588	0.0269	0.1082	0.2768	0.0972
2	0.22	0.3683	2.5436	0.0270	0.1065	0.2710	0.0996
3	0.22	0.3680	2.5682	0.0269	0.1064	0.2732	0.0985
4	0.22	0.3698	2.5585	0.0272	0.1074	0.2748	0.0990
5	0.22	0.3696	2.5644	0.0269	0.1073	0.2751	0.0978
6	0.33	0.3711	2.5641	0.0272	0.1082	0.2773	0.0981
7	0.33	0.3698	2.5601	0.0269	0.1074	0.2750	0.0978
8	0.33	0.3703	2.5654	0.0273	0.1077	0.2763	0.0988
9	0.33	0.3670	2.5712	0.0267	0.1058	0.2720	0.0981
10	0.45	0.3683	2.5629	0.0270	0.1065	0.2730	0.0989
11	0.45	0.3683	2.5677	0.0271	0.1065	0.2735	0.0991
12	0.45	0.3721	2.5644	0.0280	0.1088	0.2789	0.1004
13	0.45	0.3724	2.5649	0.0279	0.1089	0.2793	0.0999
14	0.57	0.3729	2.5679	0.0274	0.1092	0.2804	0.0977
15	0.57	0.3734	2.5593	0.0280	0.1095	0.2802	0.0999
16	0.57	0.3724	2.5631	0.0281	0.1089	0.2791	0.1007
17	0.57	0.3703	2.5707	0.0282	0.1077	0.2769	0.1018
18	0.69	0.3686	2.5720	0.0289	0.1067	0.2744	0.1053
19	0.69	0.3757	2.5641	0.0292	0.1108	0.2842	0.1027
20	0.69	0.3683	2.5575	0.0289	0.1065	0.2725	0.1061
21	0.69	0.3754	2.5654	0.0294	0.1107	0.2840	0.1035
22	0.81	0.3703	2.5664	0.0322	0.1077	0.2764	0.1165
23	0.81	0.3736	2.5613	0.0314	0.1096	0.2808	0.1118
24	0.81	0.3706	2.5695	0.0307	0.1079	0.2771	0.1108
25	0.81	0.3696	2.5728	0.0314	0.1073	0.2760	0.1138
26	0.90	0.3754	1.4981	0.0195	0.1107	0.1658	0.1176
27	0.90	0.3711	2.5728	0.0320	0.1082	0.2783	0.1150
28	0.90	0.3686	2.5575	0.0314	0.1067	0.2728	0.1151
29	0.90	0.3734	2.5606	0.0327	0.1095	0.2804	0.1166
					Average:		**0.1041**
					Std Dev:		**0.0071**
					% Dev:		**6.80**

Table C.55: Radial Density Measurements for Each Core Taken from Sample 18 (D10)

Batch D10: 40C Large Mold Size Sample #18							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3647	2.5357	0.0266	0.1045	0.2649	0.1004
2	0.22	0.3683	2.5400	0.0270	0.1065	0.2706	0.0998
3	0.22	0.3683	2.5448	0.0271	0.1065	0.2711	0.1000
4	0.22	0.3724	2.5433	0.0273	0.1089	0.2770	0.0986
5	0.22	0.3658	2.5382	0.0266	0.1051	0.2667	0.0997
6	0.33	0.3708	2.5530	0.0274	0.1080	0.2757	0.0994
7	0.33	0.3696	2.5423	0.0273	0.1073	0.2727	0.1001
8	0.33	0.3653	2.5347	0.0264	0.1048	0.2656	0.0994
9	0.33	0.3660	2.5397	0.0266	0.1052	0.2672	0.0995
10	0.45	0.3711	2.5362	0.0268	0.1082	0.2743	0.0977
11	0.45	0.3731	2.5448	0.0271	0.1093	0.2783	0.0974
12	0.45	0.3686	2.5522	0.0275	0.1067	0.2723	0.1010
13	0.45	0.3749	2.5413	0.0270	0.1104	0.2805	0.0962
14	0.57	0.3665	2.5339	0.0270	0.1055	0.2673	0.1010
15	0.57	0.3706	2.5413	0.0280	0.1079	0.2741	0.1022
16	0.57	0.3716	2.5499	0.0279	0.1085	0.2765	0.1009
17	0.57	0.3708	2.5446	0.0279	0.1080	0.2748	0.1015
18	0.69	0.3721	2.5326	0.0286	0.1088	0.2754	0.1038
19	0.69	0.3711	2.5301	0.0280	0.1082	0.2736	0.1023
20	0.69	0.3696	2.5512	0.0288	0.1073	0.2737	0.1052
21	0.69	0.3665	2.5466	0.0287	0.1055	0.2687	0.1068
22	0.81	0.3647	2.5375	0.0295	0.1045	0.2651	0.1113
23	0.81	0.3647	2.5547	0.0307	0.1045	0.2669	0.1150
24	0.81	0.3668	2.5497	0.0302	0.1057	0.2694	0.1121
25	0.81	0.3703	2.5331	0.0292	0.1077	0.2729	0.1070
26	0.90	0.3660	2.5301	0.0323	0.1052	0.2662	0.1213
27	0.90	0.3693	2.5301	0.0325	0.1071	0.2710	0.1199
28	0.90	0.3655	2.5568	0.0322	0.1049	0.2683	0.1200
29	0.90	0.3698	2.5657	0.0317	0.1074	0.2756	0.1150
					Average:		**0.1046**
					Std Dev:		**0.0074**
					% Dev:		**7.07**

Table C.56: Radial Density Measurements for Each Core Taken from Sample 19 (D10)

Batch D10: 40C Large Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3696	2.5364	0.0260	0.1073	0.2721	0.0956
2	0.22	0.3721	2.5344	0.0266	0.1088	0.2756	0.0965
3	0.22	0.3807	2.5382	0.0269	0.1139	0.2890	0.0931
4	0.22	0.3731	2.5382	0.0266	0.1093	0.2775	0.0958
5	0.22	0.3774	2.5321	0.0266	0.1119	0.2833	0.0939
6	0.33	0.3762	2.5408	0.0269	0.1111	0.2824	0.0953
7	0.33	0.3759	2.5339	0.0270	0.1110	0.2812	0.0960
8	0.33	0.3749	2.5377	0.0269	0.1104	0.2801	0.0960
9	0.33	0.3769	2.5512	0.0271	0.1116	0.2847	0.0952
10	0.45	0.3774	2.5420	0.0275	0.1119	0.2844	0.0967
11	0.45	0.3754	2.5408	0.0277	0.1107	0.2812	0.0985
12	0.45	0.3820	2.5375	0.0275	0.1146	0.2908	0.0946
13	0.45	0.3772	2.5364	0.0276	0.1117	0.2834	0.0974
14	0.57	0.3780	2.5359	0.0277	0.1122	0.2845	0.0974
15	0.57	0.3731	2.5428	0.0280	0.1093	0.2780	0.1007
16	0.57	0.3838	2.5372	0.0286	0.1157	0.2935	0.0974
17	0.57	0.3807	2.5268	0.0282	0.1139	0.2877	0.0980
18	0.69	0.3759	2.5283	0.0291	0.1110	0.2806	0.1037
19	0.69	0.3769	2.5476	0.0298	0.1116	0.2843	0.1048
20	0.69	0.3830	2.5438	0.0299	0.1152	0.2931	0.1020
21	0.69	0.3780	2.5281	0.0297	0.1122	0.2836	0.1047
22	0.81	0.3780	2.5372	0.0321	0.1122	0.2847	0.1128
23	0.81	0.3800	2.5337	0.0310	0.1134	0.2873	0.1079
24	0.81	0.3772	2.5458	0.0312	0.1117	0.2845	0.1097
25	0.81	0.3754	2.5372	0.0319	0.1107	0.2808	0.1136
26	0.90	0.3708	2.5232	0.0332	0.1080	0.2725	0.1218
27	0.90	0.3734	2.5166	0.0331	0.1095	0.2756	0.1201
28	0.90	0.3749	2.5357	0.0331	0.1104	0.2799	0.1183
29	0.90	0.3767	2.5491	0.0333	0.1114	0.2841	0.1172
					Average:		**0.1026**
					Std Dev:		**0.0088**
					% Dev:		**8.57**

Table C.57: Radial Density Measurements for Each Core Taken from Sample 20 (D10)

Batch D10: 40C Large Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3647	2.5563	0.0272	0.1045	0.2671	0.1018
2	0.22	0.3665	2.5725	0.0272	0.1055	0.2714	0.1002
3	0.22	0.3691	2.5695	0.0268	0.1070	0.2749	0.0975
4	0.22	0.3708	2.5733	0.0275	0.1080	0.2779	0.0989
5	0.22	0.3668	2.5682	0.0273	0.1057	0.2713	0.1006
6	0.33	0.3670	2.5672	0.0277	0.1058	0.2716	0.1020
7	0.33	0.3655	2.5700	0.0274	0.1049	0.2697	0.1016
8	0.33	0.3668	2.5705	0.0278	0.1057	0.2716	0.1024
9	0.33	0.3670	2.5662	0.0273	0.1058	0.2715	0.1006
10	0.45	0.3660	2.5763	0.0279	0.1052	0.2711	0.1029
11	0.45	0.3670	2.5700	0.0279	0.1058	0.2719	0.1026
12	0.45	0.3691	2.5730	0.0272	0.1070	0.2753	0.0988
13	0.45	0.3640	2.5730	0.0273	0.1041	0.2677	0.1020
14	0.57	0.3708	2.5613	0.0287	0.1080	0.2766	0.1037
15	0.57	0.3686	2.5738	0.0284	0.1067	0.2746	0.1034
16	0.57	0.3678	2.5733	0.0284	0.1062	0.2734	0.1039
17	0.57	0.3686	2.5690	0.0288	0.1067	0.2741	0.1051
18	0.69	0.3678	2.5715	0.0294	0.1062	0.2732	0.1076
19	0.69	0.3706	2.5720	0.0302	0.1079	0.2774	0.1089
20	0.69	0.3668	2.5705	0.0293	0.1057	0.2716	0.1079
21	0.69	0.3698	2.5695	0.0302	0.1074	0.2760	0.1094
22	0.81	0.3693	2.5712	0.0314	0.1071	0.2754	0.1140
23	0.81	0.3711	2.5667	0.0317	0.1082	0.2776	0.1142
24	0.81	0.3686	2.5776	0.0322	0.1067	0.2750	0.1171
25	0.81	0.3719	2.5745	0.0324	0.1086	0.2796	0.1159
26	0.90	0.3622	2.5768	0.0325	0.1030	0.2655	0.1224
27	0.90	0.3668	2.5791	0.0330	0.1057	0.2725	0.1211
28	0.90	0.3678	2.5728	0.0329	0.1062	0.2733	0.1204
29	0.90	0.3673	2.5728	0.0321	0.1059	0.2726	0.1178
					Average:		**0.1071**
					Std Dev:		**0.0075**
					% Dev:		**7.00**

Table C.58: Radial Density Measurements for Each Core Taken from Sample 17 (D11)

Batch D11: 65C Large Mold Size Sample #17							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3716	2.5425	0.0252	0.1085	0.2757	0.0914
2	0.22	0.3706	2.5375	0.0255	0.1079	0.2737	0.0932
3	0.22	0.3698	2.5451	0.0254	0.1074	0.2734	0.0929
4	0.22	0.3711	2.5438	0.0256	0.1082	0.2751	0.0930
5	0.22	0.3721	2.5458	0.0261	0.1088	0.2769	0.0943
6	0.33	0.3719	2.5491	0.0258	0.1086	0.2768	0.0932
7	0.33	0.3696	2.5425	0.0259	0.1073	0.2727	0.0950
8	0.33	0.3757	2.5451	0.0258	0.1108	0.2821	0.0915
9	0.33	0.3719	2.5425	0.0258	0.1086	0.2761	0.0934
10	0.45	0.3711	2.5372	0.0262	0.1082	0.2744	0.0955
11	0.45	0.3721	2.5415	0.0263	0.1088	0.2764	0.0952
12	0.45	0.3698	2.5458	0.0261	0.1074	0.2735	0.0954
13	0.45	0.3736	2.5433	0.0268	0.1096	0.2789	0.0961
14	0.57	0.3708	2.5524	0.0268	0.1080	0.2757	0.0972
15	0.57	0.3708	2.5359	0.0258	0.1080	0.2739	0.0942
16	0.57	0.3716	2.5337	0.0267	0.1085	0.2748	0.0972
17	0.57	0.3686	2.5476	0.0269	0.1067	0.2718	0.0990
18	0.69	0.3716	2.5522	0.0275	0.1085	0.2768	0.0994
19	0.69	0.3721	2.5509	0.0275	0.1088	0.2774	0.0991
20	0.69	0.3744	2.5476	0.0272	0.1101	0.2805	0.0970
21	0.69	0.3724	2.5296	0.0273	0.1089	0.2755	0.0991
22	0.81	0.3769	2.5415	0.0287	0.1116	0.2836	0.1012
23	0.81	0.3769	2.5311	0.0270	0.1116	0.2824	0.0956
24	0.81	0.3767	2.5512	0.0283	0.1114	0.2843	0.0995
25	0.81	0.3767	2.5563	0.0292	0.1114	0.2849	0.1025
26	0.90	0.3741	2.5522	0.0306	0.1099	0.2806	0.1091
27	0.90	0.3731	2.5319	0.0301	0.1093	0.2768	0.1087
28	0.90	0.3769	2.5466	0.0294	0.1116	0.2842	0.1035
29	0.90	0.3759	2.5514	0.0304	0.1110	0.2832	0.1074
					Average:		**0.0976**
					Std Dev:		**0.0049**
					% Dev:		**4.98**

Table C.59: Radial Density Measurements for Each Core Taken from Sample 18 (D11)

Batch D11: 65C Large Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3696	2.5309	0.0252	0.1073	0.2715	0.0928
2	0.22	0.3653	2.5258	0.0252	0.1048	0.2646	0.0952
3	0.22	0.3706	2.5309	0.0253	0.1079	0.2730	0.0927
4	0.22	0.3698	2.5331	0.0254	0.1074	0.2721	0.0933
5	0.22	0.3696	2.5298	0.0249	0.1073	0.2714	0.0918
6	0.33	0.3716	2.5349	0.0252	0.1085	0.2749	0.0917
7	0.33	0.3724	2.5255	0.0250	0.1089	0.2750	0.0909
8	0.33	0.3703	2.5235	0.0248	0.1077	0.2718	0.0912
9	0.33	0.3724	2.5357	0.0249	0.1089	0.2761	0.0902
10	0.45	0.3724	2.5372	0.0252	0.1089	0.2763	0.0912
11	0.45	0.3731	2.5301	0.0258	0.1093	0.2767	0.0933
12	0.45	0.3716	2.5197	0.0249	0.1085	0.2733	0.0911
13	0.45	0.3721	2.5270	0.0251	0.1088	0.2748	0.0913
14	0.57	0.3716	2.5199	0.0256	0.1085	0.2733	0.0937
15	0.57	0.3769	2.5357	0.0255	0.1116	0.2830	0.0901
16	0.57	0.3759	2.5372	0.0265	0.1110	0.2816	0.0941
17	0.57	0.3731	2.5197	0.0263	0.1093	0.2755	0.0956
18	0.69	0.3782	2.5311	0.0274	0.1123	0.2844	0.0964
19	0.69	0.3757	2.5161	0.0273	0.1108	0.2789	0.0979
20	0.69	0.3759	2.5321	0.0266	0.1110	0.2810	0.0946
21	0.69	0.3772	2.5509	0.0273	0.1117	0.2850	0.0958
22	0.81	0.3736	2.5408	0.0283	0.1096	0.2786	0.1016
23	0.81	0.3729	2.5194	0.0291	0.1092	0.2751	0.1058
24	0.81	0.3747	2.5194	0.0284	0.1102	0.2777	0.1023
25	0.81	0.3774	2.5415	0.0285	0.1119	0.2844	0.1002
26	0.90	0.3759	2.5382	0.0292	0.1110	0.2817	0.1037
27	0.90	0.3734	2.5591	0.0303	0.1095	0.2802	0.1081
28	0.90	0.3706	2.5222	0.0293	0.1079	0.2721	0.1077
29	0.90	0.3724	2.5293	0.0297	0.1089	0.2754	0.1078
					Average:		**0.0963**
					Std Dev:		**0.0058**
					% Dev:		**6.01**

Table C.60: Radial Density Measurements for Each Core Taken from Sample 19 (D11)

Batch D11: 65C Large Mold Size Sample #19							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3670	2.5425	0.0249	0.1058	0.2690	0.0926
2	0.22	0.3658	2.5522	0.0252	0.1051	0.2682	0.0940
3	0.22	0.3602	1.1913	0.0114	0.1019	0.1214	0.0939
4	0.22	0.3691	2.5474	0.0247	0.1070	0.2725	0.0906
5	0.22	0.3645	2.5489	0.0253	0.1043	0.2660	0.0951
6	0.33	0.3640	2.5413	0.0251	0.1041	0.2644	0.0949
7	0.33	0.3658	2.5497	0.0248	0.1051	0.2679	0.0926
8	0.33	0.3653	2.5530	0.0252	0.1048	0.2675	0.0942
9	0.33	0.3691	2.5479	0.0251	0.1070	0.2726	0.0921
10	0.45	0.3660	2.5489	0.0256	0.1052	0.2682	0.0955
11	0.45	0.3653	2.5499	0.0255	0.1048	0.2672	0.0954
12	0.45	0.3658	2.5509	0.0246	0.1051	0.2680	0.0918
13	0.45	0.3660	2.5471	0.0250	0.1052	0.2680	0.0933
14	0.57	0.3668	2.5481	0.0259	0.1057	0.2692	0.0962
15	0.57	0.3640	2.5466	0.0262	0.1041	0.2650	0.0989
16	0.57	0.3653	2.5504	0.0263	0.1048	0.2672	0.0984
17	0.57	0.3683	2.5433	0.0262	0.1065	0.2710	0.0967
18	0.69	0.3691	2.5497	0.0274	0.1070	0.2728	0.1005
19	0.69	0.3693	2.5441	0.0266	0.1071	0.2725	0.0976
20	0.69	0.3660	2.5476	0.0272	0.1052	0.2681	0.1015
21	0.69	0.3673	2.5502	0.0275	0.1059	0.2702	0.1018
22	0.81	0.3670	2.5512	0.0282	0.1058	0.2699	0.1045
23	0.81	0.3678	2.5537	0.0287	0.1062	0.2713	0.1058
24	0.81	0.3693	2.5484	0.0259	0.1071	0.2730	0.0949
25	0.81	0.3736	1.7744	0.0198	0.1096	0.1946	0.1018
26	0.90	0.3686	2.5466	0.0290	0.1067	0.2717	0.1067
27	0.90	0.3678	2.5489	0.0297	0.1062	0.2708	0.1097
28	0.90	0.3665	2.5352	0.0293	0.1055	0.2675	0.1095
29	0.90	0.3665	2.5395	0.0293	0.1055	0.2679	0.1094
					Average:		**0.0984**
					Std Dev:		**0.0058**
					% Dev:		**5.91**

Table C.61: Radial Density Measurements for Each Core Taken from Sample 20 (D11)

Batch D11: 65C Large Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3668	2.5484	0.0247	0.1057	0.2693	0.0917
2	0.22	0.3660	2.5537	0.0249	0.1052	0.2687	0.0927
3	0.22	0.3640	2.5512	0.0246	0.1041	0.2655	0.0927
4	0.22	0.3678	2.5555	0.0257	0.1062	0.2715	0.0947
5	0.22	0.3653	2.5509	0.0255	0.1048	0.2673	0.0954
6	0.33	0.3645	2.5517	0.0253	0.1043	0.2662	0.0950
7	0.33	0.3627	2.5509	0.0255	0.1033	0.2636	0.0967
8	0.33	0.3645	2.5504	0.0251	0.1043	0.2661	0.0943
9	0.33	0.3670	2.5537	0.0255	0.1058	0.2702	0.0944
10	0.45	0.3655	2.5578	0.0257	0.1049	0.2684	0.0958
11	0.45	0.3642	2.5502	0.0262	0.1042	0.2657	0.0986
12	0.45	0.3678	2.5461	0.0257	0.1062	0.2705	0.0950
13	0.45	0.3683	2.5550	0.0254	0.1065	0.2722	0.0933
14	0.57	0.3668	2.5575	0.0249	0.1057	0.2702	0.0921
15	0.57	0.3670	2.5560	0.0265	0.1058	0.2704	0.0980
16	0.57	0.3647	2.5461	0.0256	0.1045	0.2660	0.0962
17	0.57	0.3632	2.5514	0.0255	0.1036	0.2644	0.0965
18	0.69	0.3665	2.5517	0.0274	0.1055	0.2692	0.1018
19	0.69	0.3670	2.5542	0.0267	0.1058	0.2702	0.0988
20	0.69	0.3640	2.5578	0.0279	0.1041	0.2661	0.1048
21	0.69	0.3673	2.5448	0.0270	0.1059	0.2696	0.1001
22	0.81	0.3668	2.5514	0.0284	0.1057	0.2696	0.1054
23	0.81	0.3691	2.5403	0.0276	0.1070	0.2717	0.1016
24	0.81	0.3670	2.5484	0.0275	0.1058	0.2696	0.1020
25	0.81	0.3658	2.5591	0.0278	0.1051	0.2689	0.1034
26	0.90	0.3640	2.5509	0.0290	0.1041	0.2654	0.1093
27	0.90	0.3635	2.5555	0.0283	0.1038	0.2652	0.1067
28	0.90	0.3630	2.5461	0.0278	0.1035	0.2634	0.1055
29	0.90	0.3655	2.5433	0.0275	0.1049	0.2669	0.1031
					Average:		**0.0985**
					Std Dev:		**0.0049**
					% Dev:		**5.02**

Table C.62: Radial Density Measurements for Each Core Taken from Sample 17 (D12)

Batch D12: 85C Large Mold Size Sample #17							
Core #	% Radial Position	Diameter (cm)	Height (cm)	Mass (g)	(CS) Area (cm^2)	Volume (cm^3)	Density (g/cm^3)
1	0	0.3668	2.5321	0.0269	0.1057	0.2675	0.1005
2	0.22	0.3686	2.5441	0.0272	0.1067	0.2714	0.1002
3	0.22	0.3686	2.5382	0.0268	0.1067	0.2708	0.0990
4	0.22	0.3673	2.5428	0.0271	0.1059	0.2694	0.1006
5	0.22	0.3647	2.5461	0.0273	0.1045	0.2660	0.1026
6	0.33	0.3729	2.5349	0.0272	0.1092	0.2768	0.0983
7	0.33	0.3698	2.5491	0.0263	0.1074	0.2738	0.0960
8	0.33	0.3731	2.5565	0.0273	0.1093	0.2795	0.0977
9	0.33	0.3708	2.5486	0.0274	0.1080	0.2753	0.0995
10	0.45	0.3696	2.5387	0.0268	0.1073	0.2723	0.0984
11	0.45	0.3716	2.5370	0.0274	0.1085	0.2751	0.0996
12	0.45	0.3744	2.5560	0.0277	0.1101	0.2814	0.0984
13	0.45	0.3736	2.5712	0.0274	0.1096	0.2819	0.0972
14	0.57	0.3731	2.5606	0.0280	0.1093	0.2800	0.1000
15	0.57	0.3706	2.5499	0.0278	0.1079	0.2750	0.1011
16	0.57	0.3736	2.5281	0.0283	0.1096	0.2772	0.1021
17	0.57	0.3749	2.5425	0.0281	0.1104	0.2807	0.1001
18	0.69	0.3744	2.5298	0.0297	0.1101	0.2785	0.1066
19	0.69	0.3767	2.5446	0.0300	0.1114	0.2836	0.1058
20	0.69	0.3772	2.5552	0.0291	0.1117	0.2855	0.1019
21	0.69	0.3721	2.5375	0.0292	0.1088	0.2760	0.1058
22	0.81	0.3716	2.5560	0.0298	0.1085	0.2772	0.1075
23	0.81	0.3721	2.5359	0.0290	0.1088	0.2758	0.1052
24	0.81	0.3729	2.5794	0.0299	0.1092	0.2817	0.1062
25	0.81	0.3736	2.5535	0.0304	0.1096	0.2800	0.1086
26	0.90	0.3716	2.5687	0.0322	0.1085	0.2786	0.1156
27	0.90	0.3741	2.5260	0.0308	0.1099	0.2777	0.1109
28	0.90	0.3721	2.5397	0.0302	0.1088	0.2762	0.1093
29	0.90	-	-	-	-	-	-
					Average:		**0.1027**
					Std Dev:		**0.0048**
					% Dev:		**4.63**

Table C.63: Radial Density Measurements for Each Core Taken from Sample 18 (D12)

Batch D12: 85C Large Mold Size Sample #18							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3673	2.5027	0.0264	0.1059	0.2652	0.0996
2	0.22	0.3686	2.5103	0.0265	0.1067	0.2678	0.0990
3	0.22	0.3680	2.5143	0.0261	0.1064	0.2675	0.0976
4	0.22	0.3691	2.5052	0.0261	0.1070	0.2680	0.0974
5	0.22	0.3708	2.5133	0.0271	0.1080	0.2715	0.0998
6	0.33	0.3680	2.5103	0.0271	0.1064	0.2671	0.1015
7	0.33	0.3691	2.5222	0.0269	0.1070	0.2698	0.0997
8	0.33	0.3721	2.5187	0.0268	0.1088	0.2739	0.0978
9	0.33	0.3665	2.5136	0.0267	0.1055	0.2652	0.1007
10	0.45	0.3691	2.5072	0.0269	0.1070	0.2682	0.1003
11	0.45	0.3716	2.5136	0.0274	0.1085	0.2726	0.1005
12	0.45	0.3698	2.5207	0.0276	0.1074	0.2708	0.1019
13	0.45	0.3691	2.5143	0.0272	0.1070	0.2690	0.1011
14	0.57	0.3668	2.5141	0.0272	0.1057	0.2656	0.1024
15	0.57	0.3731	2.5047	0.0272	0.1093	0.2739	0.0993
16	0.57	0.3696	2.5118	0.0274	0.1073	0.2694	0.1017
17	0.57	0.3660	2.5169	0.0268	0.1052	0.2648	0.1012
18	0.69	0.3708	2.5004	0.0284	0.1080	0.2701	0.1052
19	0.69	0.3741	2.5004	0.0279	0.1099	0.2749	0.1015
20	0.69	0.3696	2.5123	0.0279	0.1073	0.2695	0.1035
21	0.69	0.3721	2.5194	0.0284	0.1088	0.2740	0.1037
22	0.81	0.3706	2.5019	0.0277	0.1079	0.2699	0.1026
23	0.81	0.3719	2.5161	0.0281	0.1086	0.2733	0.1028
24	0.81	0.3706	2.4991	0.0289	0.1079	0.2696	0.1072
25	0.81	0.3716	2.5072	0.0293	0.1085	0.2719	0.1078
26	0.90	0.3729	2.5131	0.0304	0.1092	0.2744	0.1108
27	0.90	0.3696	2.4996	0.0291	0.1073	0.2681	0.1085
28	0.90	0.3708	2.5105	0.0289	0.1080	0.2712	0.1066
29	0.90	0.3711	1.4135	0.0170	0.1082	0.1529	0.1112
					Average:		**0.1025**
					Std Dev:		**0.0037**
					% Dev:		**3.66**

Table C.64: Radial Density Measurements for Each Core Taken from Sample 19 (D12)

Batch D12: 85C Large Mold Size Sample #19							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3747	2.4841	0.0264	0.1102	0.2739	0.0964
2	0.22	0.3762	2.4790	0.0258	0.1111	0.2755	0.0936
3	0.22	0.3729	2.4851	0.0262	0.1092	0.2714	0.0965
4	0.22	0.3724	2.4874	0.0261	0.1089	0.2709	0.0964
5	0.22	0.3741	2.4717	0.0246	0.1099	0.2717	0.0905
6	0.33	0.3724	2.4887	0.0263	0.1089	0.2710	0.0970
7	0.33	0.3696	2.4816	0.0259	0.1073	0.2662	0.0973
8	0.33	0.3759	2.4780	0.0260	0.1110	0.2750	0.0945
9	0.33	0.3729	2.4920	0.0263	0.1092	0.2721	0.0966
10	0.45	0.3698	2.4920	0.0266	0.1074	0.2677	0.0994
11	0.45	0.3774	2.4839	0.0264	0.1119	0.2779	0.0950
12	0.45	0.3698	2.4747	0.0265	0.1074	0.2658	0.0997
13	0.45	0.3724	2.4671	0.0258	0.1089	0.2687	0.0960
14	0.57	0.3724	2.4691	0.0262	0.1089	0.2689	0.0974
15	0.57	0.3747	2.4775	0.0265	0.1102	0.2731	0.0970
16	0.57	0.3747	2.4905	0.0268	0.1102	0.2746	0.0976
17	0.57	0.3716	2.4773	0.0268	0.1085	0.2687	0.0998
18	0.69	0.3706	2.4623	0.0266	0.1079	0.2656	0.1002
19	0.69	0.3785	2.4166	0.0264	0.1125	0.2718	0.0971
20	0.69	0.3703	2.4816	0.0270	0.1077	0.2673	0.1010
21	0.69	0.3711	2.4879	0.0258	0.1082	0.2691	0.0959
22	0.81	0.3759	2.4963	0.0289	0.1110	0.2771	0.1043
23	0.81	0.3820	2.2794	0.0272	0.1146	0.2613	0.1041
24	0.81	0.3985	2.4242	0.0281	0.1247	0.3024	0.0929
25	0.81	0.3741	2.4712	0.0288	0.1099	0.2717	0.1060
26	0.90	0.3769	2.4699	0.0302	0.1116	0.2756	0.1096
27	0.90	0.3729	2.4900	0.0292	0.1092	0.2719	0.1074
28	0.90	0.3749	2.4867	0.0292	0.1104	0.2745	0.1064
29	0.90	0.3721	2.5029	0.0289	0.1088	0.2722	0.1062
					Average:		**0.0992**
					Std Dev:		**0.0047**
					% Dev:		**4.73**

Table C.65: Radial Density Measurements for Each Core Taken from Sample 20 (D12)

Batch D12: 85C Large Mold Size Sample #20							
Core #	**% Radial Position**	**Diameter (cm)**	**Height (cm)**	**Mass (g)**	**(CS) Area (cm^2)**	**Volume (cm^3)**	**Density (g/cm^3)**
1	0	0.3686	2.5540	0.0253	0.1067	0.2725	0.0929
2	0.22	0.3754	2.5568	0.0260	0.1107	0.2830	0.0919
3	0.22	0.3721	2.5575	0.0256	0.1088	0.2781	0.0920
4	0.22	0.3734	2.5530	0.0259	0.1095	0.2795	0.0927
5	0.22	0.3741	2.5560	0.0255	0.1099	0.2810	0.0907
6	0.33	0.3686	2.5504	0.0254	0.1067	0.2721	0.0934
7	0.33	0.3683	2.5555	0.0261	0.1065	0.2723	0.0959
8	0.33	0.3711	2.5560	0.0255	0.1082	0.2765	0.0922
9	0.33	0.3680	2.5524	0.0255	0.1064	0.2716	0.0939
10	0.45	0.3673	2.5514	0.0259	0.1059	0.2703	0.0958
11	0.45	0.3703	2.5512	0.0265	0.1077	0.2748	0.0964
12	0.45	0.3686	2.5530	0.0261	0.1067	0.2724	0.0958
13	0.45	0.3754	2.5504	0.0267	0.1107	0.2823	0.0946
14	0.57	0.3711	2.5491	0.0268	0.1082	0.2757	0.0972
15	0.57	0.3731	2.5486	0.0275	0.1093	0.2787	0.0987
16	0.57	0.3696	2.5489	0.0264	0.1073	0.2734	0.0966
17	0.57	0.3693	2.5560	0.0266	0.1071	0.2738	0.0971
18	0.69	0.3721	2.5537	0.0281	0.1088	0.2777	0.1012
19	0.69	0.3716	2.5578	0.0283	0.1085	0.2774	0.1020
20	0.69	0.3736	2.5542	0.0286	0.1096	0.2801	0.1021
21	0.69	0.3734	2.5423	0.0274	0.1095	0.2784	0.0984
22	0.81	0.3749	2.5555	0.0290	0.1104	0.2821	0.1028
23	0.81	0.3736	2.5509	0.0291	0.1096	0.2797	0.1040
24	0.81	0.3706	2.5479	0.0281	0.1079	0.2748	0.1022
25	0.81	0.3754	2.5560	0.0299	0.1107	0.2829	0.1057
26	0.90	0.3721	2.5573	0.0286	0.1088	0.2781	0.1028
27	0.90	0.3749	2.5352	0.0289	0.1104	0.2799	0.1033
28	0.90	0.3719	2.5568	0.0295	0.1086	0.2777	0.1062
29	0.90	-	-	-	-	-	-
					Average:		**0.0978**
					Std Dev:		**0.0046**
					% Dev:		**4.75**

APPENDIX D

STRESS-STRAIN CURVES & MECHANICAL PROPERTIES

The following figures and tables summarize the results of the mechanical properties. Table D.1 through Table D.3 show the results for the average normalized mechanical properties, including the first and second standard deviations, for each foam batch. The outliers have been removed from the results using a 95% probability. Figure D.1 through D.16 show the actual stress-curves for each batch. Each figure represents one batch of foam with sixteen tested samples. The reference batch (Figure D.13 through Figure D.16) is separated by levels with twelve samples from each level. Table D.4 through Table D.19 report the raw mechanical data, before normalization, taken from the stress-strain curves.

Table D.1: Summary of Average Normalized Modulus of Elasticity Data

Modulus of Elasticity									
Batch Number	**Mold Temp (deg C)**	**Mold Size**	**Average Modulus (Mpa)**	**Std Dev (Mpa)**	**Dev %**	**(+) First Std Dev (Mpa)**	**(+) Second Std Dev (Mpa)**	**(-) First Std Dev (Mpa)**	**(-) Second Std Dev (Mpa)**
D1		Small	63.38	11.06	11.72	74.44	85.50	41.26	52.32
D5	25	Medium	86.11	10.71	8.27	96.82	107.53	64.70	75.40
D9		Large	89.68	7.65	6.21	97.33	104.98	74.37	82.02
D2		Small	65.81	4.87	4.83	70.69	75.56	56.06	60.94
D6	40	Medium	74.20	6.14	5.52	80.33	86.47	61.92	68.06
D10		Large	83.44	7.39	6.21	90.83	98.22	68.65	76.04
D3		Small	74.24	17.38	15.86	91.62	109.00	39.47	56.86
D7	65	Medium	73.64	15.73	14.48	89.37	105.09	42.18	57.91
D11		Large	86.30	9.63	7.58	95.93	105.56	67.05	76.68
D4		Small	49.87	10.47	14.48	60.35	70.82	28.92	39.40
D8	85	Medium	58.51	11.18	13.10	69.69	80.88	36.14	47.33
D12		Large	65.45	9.23	9.65	74.68	83.91	47.00	56.23
Ref	25 Air	4 Liter	35.75	3.90	10.91	39.65	43.56	27.94	31.85

Table D.2: Summary of Average Normalized Peak Yield Stress Data

Peak Yield Stress									
Batch Number	Mold Temp (deg C)	Mold Size	Average Peak Yield (Mpa)	Std Dev (Mpa)	Dev %	(+) First Std Dev (Mpa)	(+) Second Std Dev (Mpa)	(-) First Std Dev (Mpa)	(-) Second Std Dev (Mpa)
D1		Small	1.03	0.09	6.21	1.12	1.21	0.85	0.94
D5	25	Medium	1.14	0.02	1.38	1.17	1.19	1.10	1.12
D9		Large	1.17	0.06	3.45	1.23	1.30	1.05	1.11
D2		Small	1.02	0.07	4.83	1.09	1.16	0.88	0.95
D6	40	Medium	1.10	0.05	3.45	1.14	1.19	1.00	1.05
D10		Large	1.13	0.06	4.14	1.19	1.25	1.01	1.07
D3		Small	1.21	0.11	6.21	1.32	1.43	0.99	1.10
D7	65	Medium	1.13	0.09	5.52	1.22	1.31	0.95	1.04
D11		Large	1.21	0.08	4.83	1.30	1.38	1.05	1.13
D4		Small	1.11	0.13	8.27	1.24	1.37	0.85	0.98
D8	85	Medium	1.13	0.13	8.27	1.26	1.39	0.87	1.00
D12		Large	1.12	0.13	7.58	1.25	1.38	0.85	0.99
Ref	25 Air	4 Liter	0.97	0.07	7.21	1.03	1.10	0.83	0.90

Table D.3: Summary of Average Normalized Collapse Stress Data

Collapse Stress									
Batch Number	**Mold Temp (deg C)**	**Mold Size**	**Average Collapse (Mpa)**	**Std Dev (Mpa)**	**Dev %**	**(+) First Std Dev (Mpa)**	**(+) Second Std Dev (Mpa)**	**(-) First Std Dev (Mpa)**	**(-) Second Std Dev (Mpa)**
D1	25	Small	0.96	0.09	6.21	1.05	1.14	0.78	0.87
D5		Medium	1.08	0.08	4.83	1.16	1.23	0.93	1.01
D9		Large	1.10	0.06	3.45	1.17	1.23	0.98	1.04
D2	40	Small	0.95	0.04	3.45	0.99	1.03	0.87	0.91
D6		Medium	1.01	0.04	2.76	1.05	1.09	0.92	0.97
D10		Large	1.03	0.06	3.45	1.09	1.14	0.92	0.98
D3	65	Small	1.11	0.11	6.90	1.22	1.33	0.89	1.00
D7		Medium	1.04	0.10	6.21	1.14	1.23	0.85	0.94
D11		Large	1.10	0.08	4.83	1.19	1.27	0.94	1.02
D4	85	Small	1.06	0.12	7.58	1.19	1.31	0.81	0.94
D8		Medium	1.08	0.12	8.27	1.21	1.33	0.83	0.96
D12		Large	1.07	0.12	7.58	1.19	1.32	0.82	0.94
Ref	25 Air	4 Liter	0.88	0.05	5.68	0.94	0.99	0.77	0.83

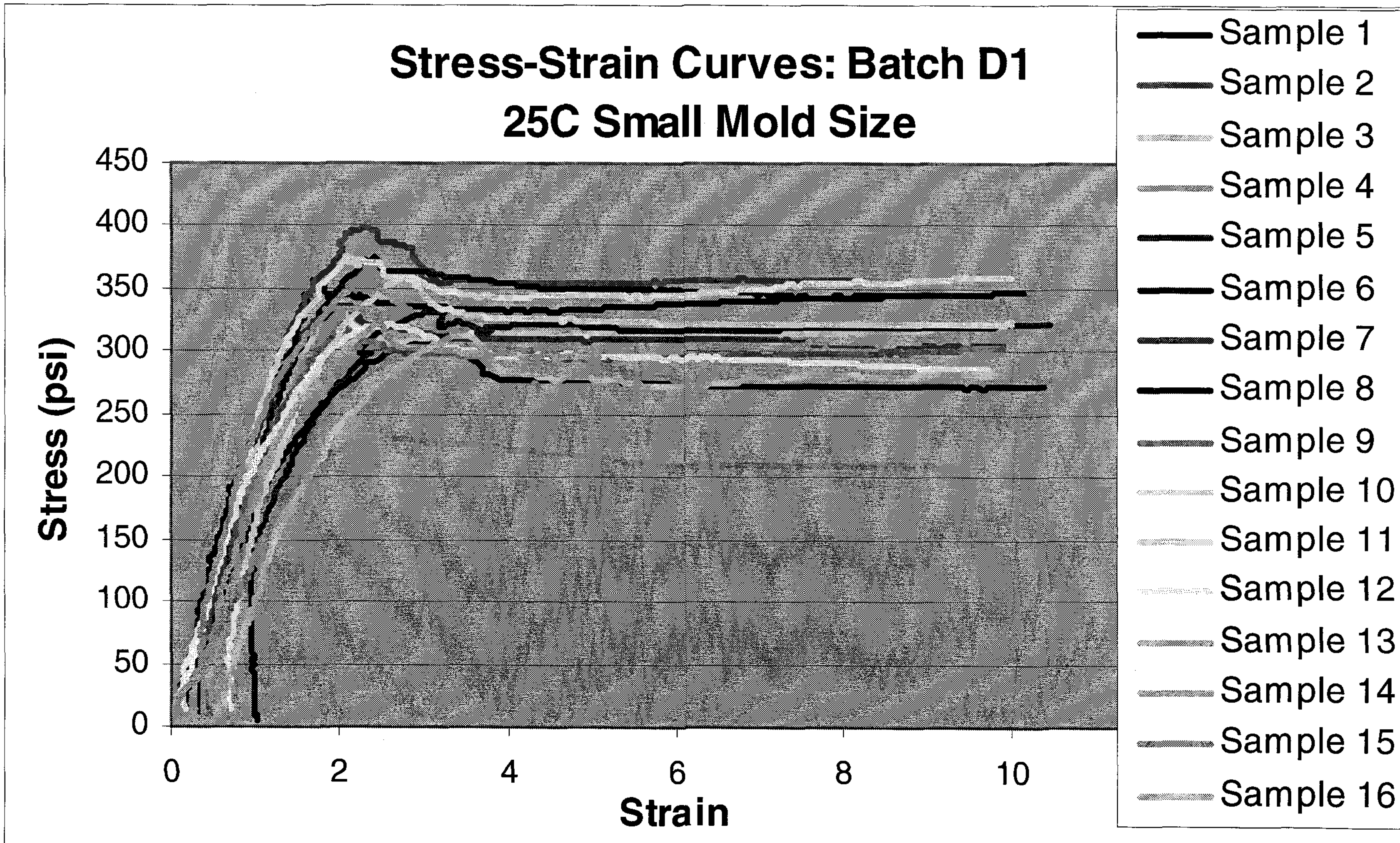


Figure D.1: Stress-Strain Curves for 25°C Small Mold Samples

Table D.4: Mechanical Property Data for 25°C Small Mold Size Samples

Batch D1: 25C Small Mold Size								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10547	RC-1	2.5217	6.4310	0.1490	140.63	2.42	2.36	72.61	1.07	1.04
10548	RC-2	2.5606	6.5161	0.1490	152.68	2.75	2.45	78.84	1.22	1.08
10549	RC-3	2.5377	6.5116	0.1500	125.48	2.33	2.20	64.06	1.02	0.96
10550	RC-4	2.5281	6.5116	0.1520	94.29	2.12	1.90	47.06	0.90	0.80
10551	RC-5	2.5260	6.4426	0.1480	82.29	2.28	2.21	42.98	1.02	0.99
10552	RC-6	2.5006	6.4645	0.1490	146.15	2.56	2.39	75.46	1.13	1.05
10553	RC-7	2.5359	6.4735	0.1490	142.67	2.30	2.10	73.66	1.02	0.93
10554	RC-8	2.5448	6.4761	0.1500	104.99	2.10	1.88	53.60	0.92	0.82
10555	RC-9	2.5580	6.6213	0.1470	125.37	2.15	2.05	66.24	0.98	0.93
10556	RC-10	2.5370	6.6464	0.1490	150.44	2.57	2.45	77.68	1.14	1.08
10557	RC-11	2.5489	6.6477	0.1490	137.03	2.45	2.22	70.75	1.08	0.98
10558	RC-12	2.5131	6.6522	0.1490	121.42	2.21	2.01	62.69	0.98	0.89
10559	RC-13	2.5464	6.6174	0.1480	113.14	2.16	2.12	59.09	0.97	0.95
10560	RC-14	2.5423	6.6581	0.1480	106.35	2.46	2.29	55.55	1.10	1.03
10561	RC-15	2.5560	6.6606	0.1480	118.36	2.31	2.10	61.82	1.04	0.94
10562	RC-16	2.5537	6.6722	0.1500	101.84	2.14	1.93	51.99	0.93	0.84
			Average		**122.70**	**2.33**	**2.16**	**63.38**	**1.03**	**0.96**
			Std Dev		**21.18**	**0.19**	**0.19**	**11.06**	**0.09**	**0.09**
			% Dev		**11.9%**	**5.6%**	**6.0%**	**12.0%**	**5.9%**	**6.4%**

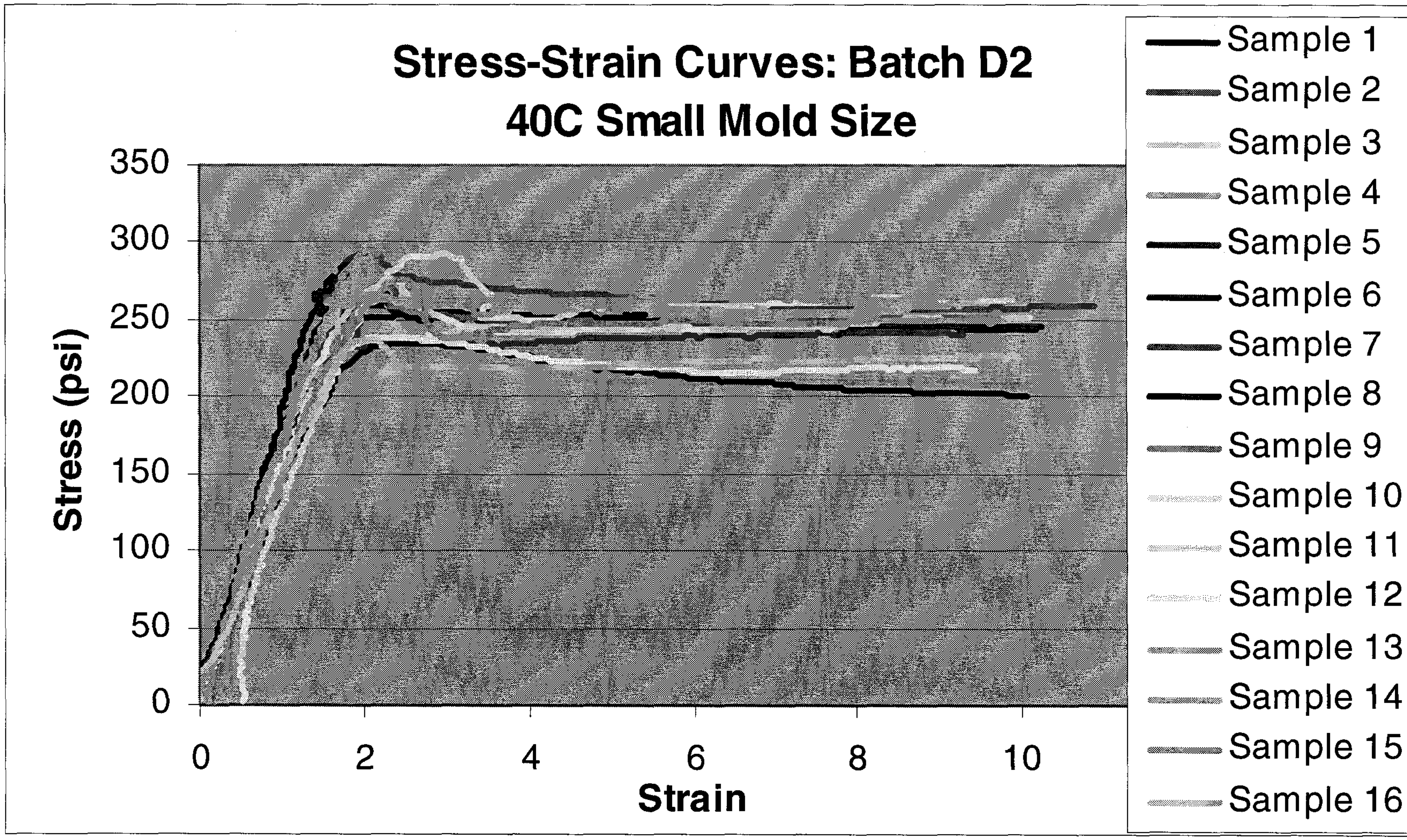


Figure D.2: Stress-Strain Curves for 40°C Small Mold Samples

Table D.5: Mechanical Property Data for 40°C Small Mold Size Samples

Batch D2: 40C Small Mold Size								**Normalized**		
Testing Number	**Sample Number**	**Height**	**Area**	**Density**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**
		(cm)	**(cm^2)**	**(g/cc)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**
10567	RC-1	2.5306	6.4806	0.1337	131.63	1.89	1.71	81.71	1.05	0.95
10568	RC-2	2.5606	6.5045	0.1342	109.87	1.98	1.78	67.77	1.09	0.98
10569	RC-3	2.5263	6.5058	0.1332	97.39	1.79	1.72	60.84	1.00	0.96
10570	RC-4	2.5484	6.5032	0.1324	92.60	1.61	1.45	58.44	0.91	0.82
10571	RC-5	2.5331	6.4735	0.1327	111.57	1.81	1.69	70.15	1.02	0.95
10572	RC-6	2.5524	6.4716	0.1338	110.57	1.97	1.72	68.55	1.09	0.95
10573	RC-7	2.5464	6.4793	0.1330	108.90	1.79	1.65	68.20	1.01	0.92
10574	RC-8	2.5220	6.4748	0.1332	95.58	1.62	1.39	59.71	0.91	0.78
10575	RC-9	2.5547	6.6432	0.1329	99.72	1.88	1.73	62.54	1.06	0.97
10576	RC-10	2.4666	6.6522	0.1330	98.35	2.01	1.82	61.60	1.13	1.02
10577	RC-11	2.5349	6.6535	0.1331	107.73	1.88	1.70	67.39	1.05	0.95
10578	RC-12	2.5083	6.6581	0.1315	103.30	1.64	1.51	65.96	0.94	0.87
10579	RC-13	2.5276	6.6581	0.1338	114.78	1.86	1.77	71.16	1.03	0.98
10580	RC-14	2.5540	6.6619	0.1344	114.31	2.03	1.83	70.33	1.12	1.01
10581	RC-15	2.5649	6.6664	0.1329	118.29	1.88	1.72	74.18	1.06	0.96
10582	RC-16	2.5397	6.6677	0.1326	95.80	1.63	1.54	60.31	0.92	0.87
			Average		**106.90**	**1.83**	**1.67**	**66.80**	**1.02**	**0.93**
			Std Dev		**10.30**	**0.14**	**0.13**	**6.16**	**0.07**	**0.07**
			% Dev		**6.6%**	**5.4%**	**5.4%**	**6.4%**	**4.8%**	**5.0%**

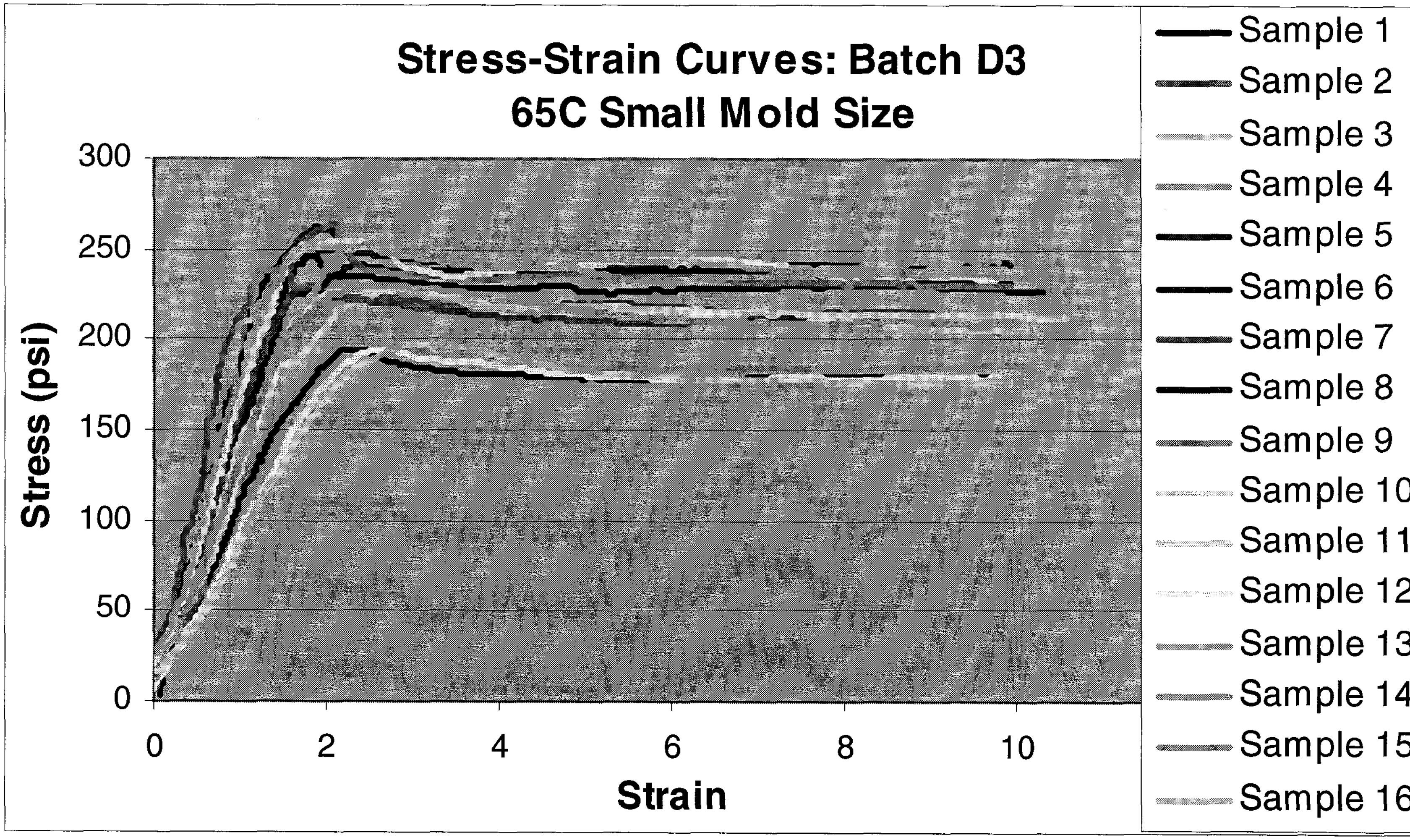


Figure D.3: Stress-Strain Curves for 65°C Small Mold Samples

Table D.6: Mechanical Property Data for 65°C Small Mold Size Samples

Batch D3: 65C Small Mold Size								Normalized		
Testing Number	**Sample Number**	**Height**	**Area**	**Density**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**
		(cm)	**(cm^2)**	**(g/cc)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**
10583	RC-1	2.5578	6.4064	0.1151	103.32	1.68	1.58	82.74	1.28	1.20
10584	RC-2	2.5375	6.4871	0.1145	157.17	1.64	1.48	126.98	1.26	1.13
10585	RC-3	2.5387	6.5032	0.1140	92.25	1.57	1.41	75.09	1.21	1.09
10586	RC-4	2.5476	6.5058	0.1137	73.99	1.37	1.27	60.50	1.07	0.99
10587	RC-5	2.5403	6.3677	0.1160	131.03	1.79	1.66	103.55	1.34	1.24
10588	RC-6	2.5540	6.4587	0.1153	100.82	1.70	1.57	80.49	1.29	1.19
10589	RC-7	2.5425	6.4658	0.1158	108.83	1.58	1.47	86.26	1.18	1.10
10590	RC-8	2.5588	6.4716	0.1145	72.42	1.34	1.24	58.51	1.03	0.95
10591	RC-9	2.5497	6.6213	0.1152	189.77	1.79	1.59	151.74	1.36	1.21
10592	RC-10	2.5489	6.6464	0.1161	109.41	1.75	1.62	86.33	1.31	1.21
10593	RC-11	2.5283	6.6522	0.1158	84.58	1.57	1.47	67.03	1.18	1.10
10594	RC-12	2.5626	6.6581	0.1138	61.80	1.34	1.23	50.45	1.04	0.96
10595	RC-13	2.5601	6.6097	0.1160	129.04	1.74	1.66	101.97	1.30	1.24
10596	RC-14	2.5390	6.6606	0.1166	90.67	1.72	1.62	71.03	1.27	1.20
10597	RC-15	2.5514	6.6639	0.1164	88.50	1.58	1.44	69.53	1.17	1.07
10598	RC-16	2.5453	6.6755	0.1156	57.56	1.37	1.21	45.76	1.03	0.91
			Average		**103.20**	**1.60**	**1.47**	**82.37**	**1.21**	**1.11**
			Std Dev		**34.99**	**0.16**	**0.16**	**27.88**	**0.11**	**0.11**
			% Dev		**23.4%**	**7.0%**	**7.4%**	**23.3%**	**6.4%**	**6.8%**

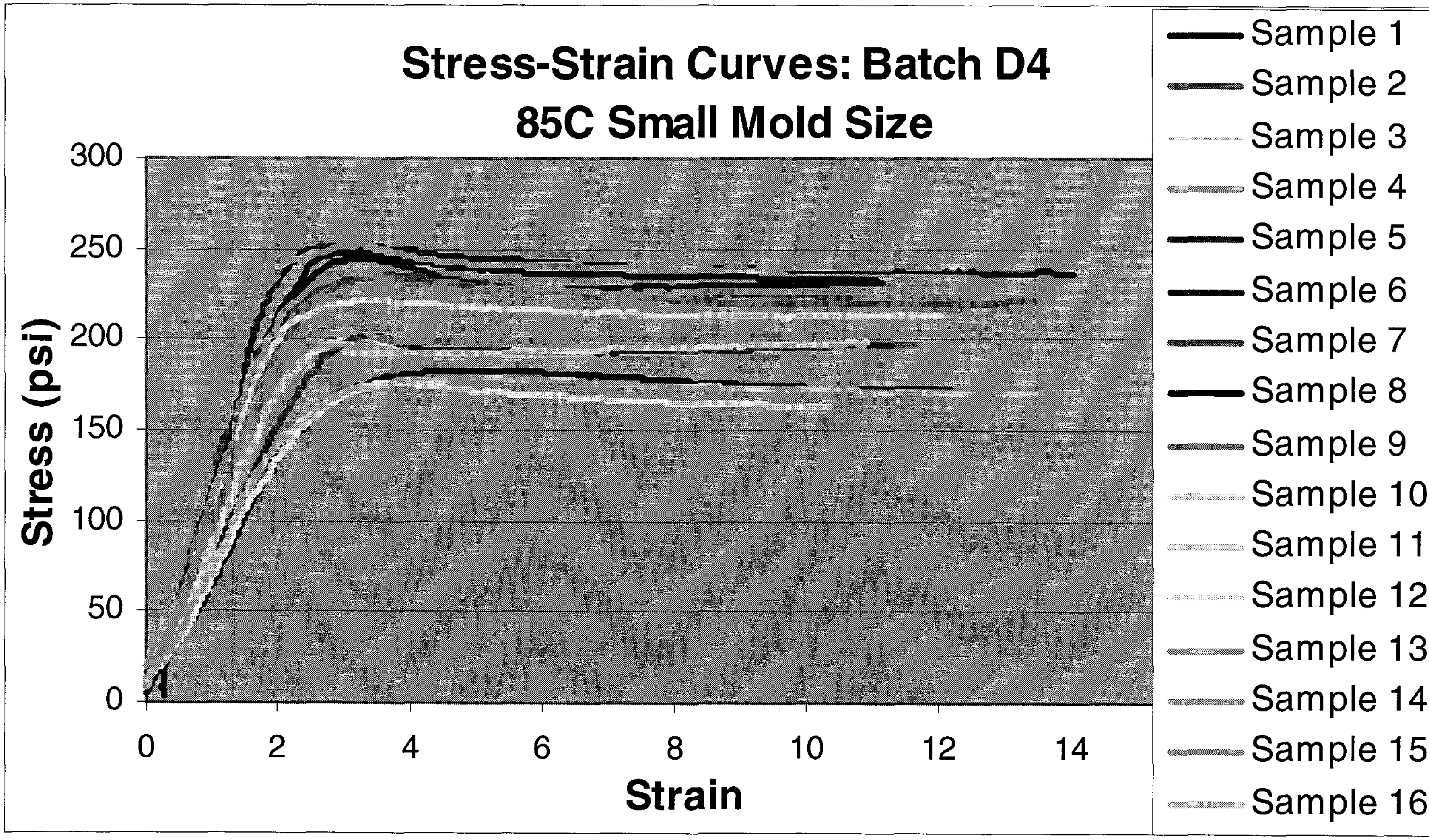


Figure D.4: Stress-Strain Curves for 85°C Small Mold Samples

Table D.7: Mechanical Property Data for 85°C Small Mold Size Samples

Batch D4: 85C Small Mold Size								Normalized		
Testing Number	**Sample Number**	**Height**	**Area**	**Density**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**
		(cm)	**(cm^2)**	**(g/cc)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**
10603	RC-1	2.5339	6.4561	0.1152	79.46	1.71	1.61	63.53	1.30	1.22
10604	RC-2	2.5410	6.4864	0.1168	79.25	1.61	1.54	61.90	1.19	1.14
10605	RC-3	2.5626	6.5026	0.1168	54.45	1.38	1.35	42.53	1.02	1.00
10606	RC-4	2.5550	6.4871	0.1150	48.08	1.27	1.19	38.56	0.97	0.90
10607	RC-5	2.5446	6.4587	0.1168	84.18	1.73	1.64	65.75	1.28	1.21
10608	RC-6	2.5484	6.4516	0.1186	76.35	1.68	1.59	58.11	1.20	1.13
10609	RC-7	2.5400	6.4619	0.1168	50.57	1.39	1.36	39.50	1.03	1.00
10610	RC-8	2.5606	6.4600	0.1159	45.32	1.25	1.19	35.87	0.94	0.89
10611	RC-9	2.5438	6.5606	0.1142	68.70	1.61	1.52	55.75	1.25	1.18
10612	RC-10	2.5288	6.6329	0.1148	67.42	1.52	1.47	54.23	1.16	1.12
10613	RC-11	2.5453	6.6271	0.1157	57.70	1.37	1.36	45.80	1.03	1.02
10614	RC-12	2.5616	6.6316	0.1136	45.60	1.21	1.15	37.34	0.95	0.90
10615	RC-13	2.5573	6.6329	0.1165	102.86	1.74	1.65	80.70	1.29	1.22
10616	RC-14	2.5433	6.6303	0.1175	74.70	1.64	1.56	57.76	1.19	1.13
10617	RC-15	2.5657	6.6348	0.1179	67.37	1.44	1.41	51.79	1.04	1.02
10618	RC-16	2.5575	6.6503	0.1145	49.06	1.23	1.18	39.63	0.94	0.91
			Average		**65.69**	**1.49**	**1.42**	**51.80**	**1.11**	**1.06**
			Std Dev		**16.60**	**0.19**	**0.18**	**12.72**	**0.13**	**0.12**
			% Dev		**17.4%**	**8.9%**	**8.5%**	**16.9%**	**8.3%**	**7.9%**

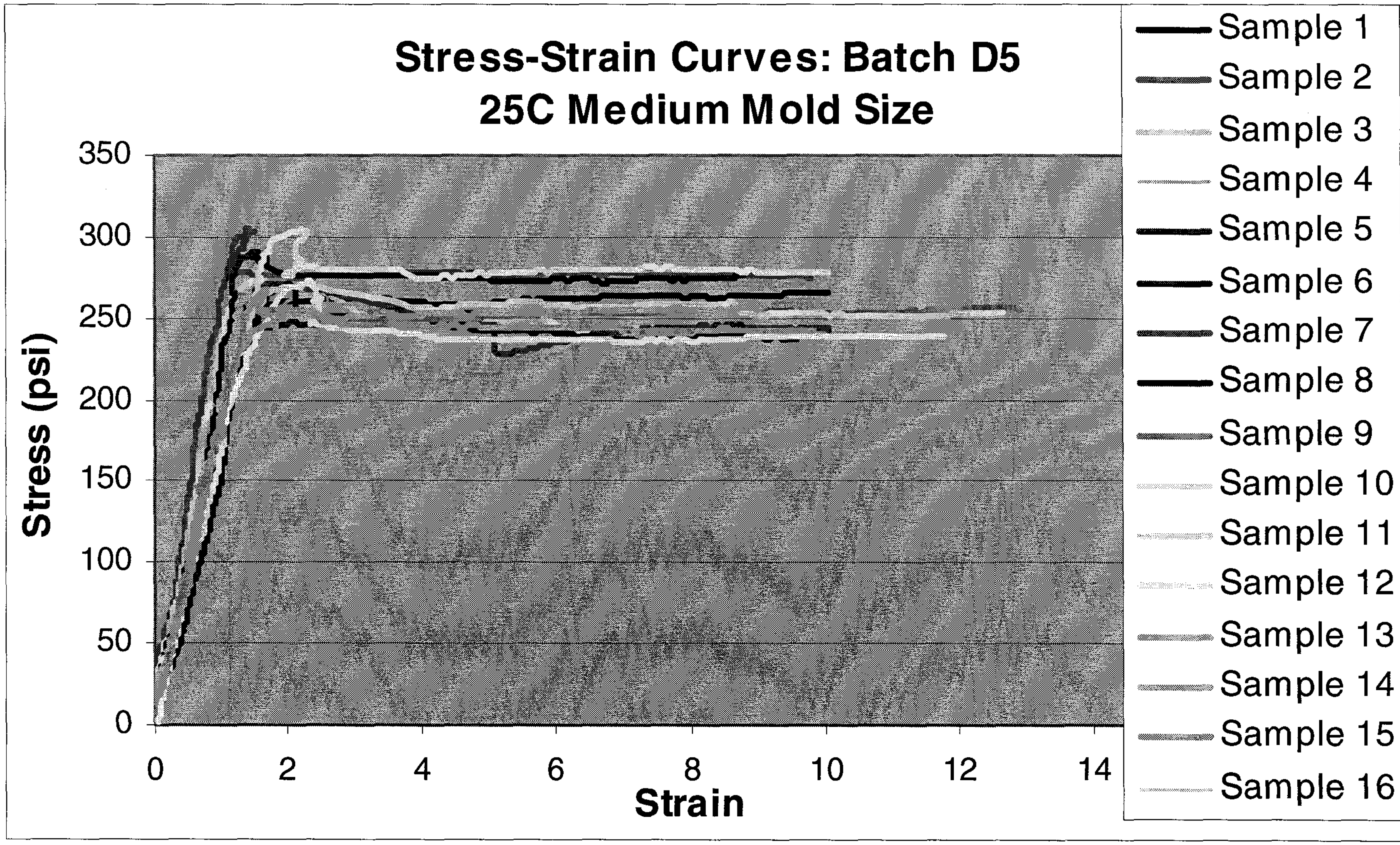


Figure D.5: Stress-Strain Curves for 25°C Medium Mold Samples

Table D.8: Mechanical Property Data for 25°C Medium Mold Size Samples

Batch D5: 25C Medium Mold Size								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10627	RC-1	2.5306	13.1980	0.1254	121.40	1.79	1.81	84.04	1.13	1.15
10628	RC-2	2.5337	13.2258	0.1263	177.65	2.11	1.91	121.49	1.32	1.19
10629	RC-3	2.5260	13.2245	0.1262	157.61	1.88	1.68	107.93	1.18	1.05
10630	RC-4	2.5390	13.2226	0.1268	116.82	1.83	1.68	79.36	1.14	1.04
10631	RC-5	2.5542	13.0187	0.1254	94.83	1.76	1.72	65.64	1.12	1.09
10632	RC-6	2.5395	13.0303	0.1264	149.95	1.99	1.89	102.41	1.24	1.18
10633	RC-7	2.5471	13.0303	0.1260	124.70	1.87	1.69	85.62	1.17	1.06
10634	RC-8	2.5133	13.0251	0.1265	113.81	1.84	1.64	77.62	1.15	1.02
10635	RC-9	2.5408	12.9477	0.1257	132.94	1.78	1.75	91.65	1.12	1.11
10636	RC-10	2.5624	12.9974	0.1266	121.22	2.09	1.93	82.56	1.30	1.20
10637	RC-11	2.5283	13.0109	0.1265	129.62	1.85	1.74	88.40	1.16	1.08
10638	RC-12	2.5624	12.9974	0.1272	112.03	1.87	1.64	75.69	1.15	1.01
10639	RC-13	2.5436	12.9084	0.1259	135.39	1.70	1.48	93.09	1.07	0.93
10640	RC-14	2.5397	12.9200	0.1265	126.86	1.81	1.77	86.52	1.13	1.10
10641	RC-15	2.5649	12.9116	0.1263	124.34	1.83	1.68	85.03	1.15	1.05
			Average		**129.28**	**1.87**	**1.73**	**88.47**	**1.17**	**1.08**
			Std Dev		**20.14**	**0.12**	**0.12**	**13.78**	**0.07**	**0.07**
			% Dev		**10.7%**	**4.3%**	**4.7%**	**10.7%**	**4.1%**	**4.7%**

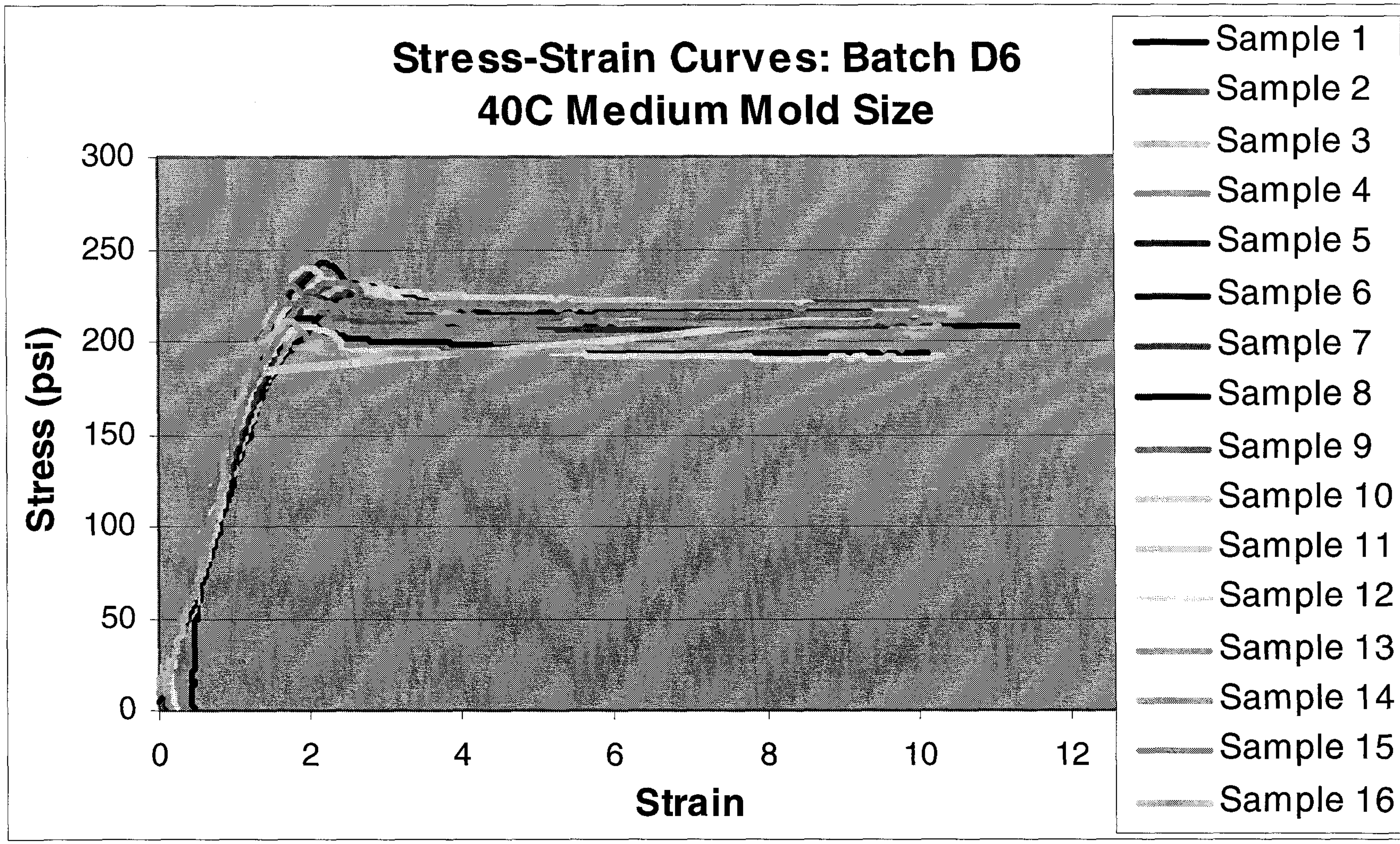


Figure D.6: Stress-Strain Curves for 40°C Medium Mold Samples

Table D.8: Mechanical Property Data for 25°C Medium Mold Size Samples

Batch D5: 25C Medium Mold Size								**Normalized**		
Testing Number	**Sample Number**	**Height**	**Area**	**Density**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**
		(cm)	**(cm^2)**	**(g/cc)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**
10627	RC-1	2.5306	13.1980	0.1254	121.40	1.79	1.81	84.04	1.13	1.15
10628	RC-2	2.5337	13.2258	0.1263	177.65	2.11	1.91	121.49	1.32	1.19
10629	RC-3	2.5260	13.2245	0.1262	157.61	1.88	1.68	107.93	1.18	1.05
10630	RC-4	2.5390	13.2226	0.1268	116.82	1.83	1.68	79.36	1.14	1.04
10631	RC-5	2.5542	13.0187	0.1254	94.83	1.76	1.72	65.64	1.12	1.09
10632	RC-6	2.5395	13.0303	0.1264	149.95	1.99	1.89	102.41	1.24	1.18
10633	RC-7	2.5471	13.0303	0.1260	124.70	1.87	1.69	85.62	1.17	1.06
10634	RC-8	2.5133	13.0251	0.1265	113.81	1.84	1.64	77.62	1.15	1.02
10635	RC-9	2.5408	12.9477	0.1257	132.94	1.78	1.75	91.65	1.12	1.11
10636	RC-10	2.5624	12.9974	0.1266	121.22	2.09	1.93	82.56	1.30	1.20
10637	RC-11	2.5283	13.0109	0.1265	129.62	1.85	1.74	88.40	1.16	1.08
10638	RC-12	2.5624	12.9974	0.1272	112.03	1.87	1.64	75.69	1.15	1.01
10639	RC-13	2.5436	12.9084	0.1259	135.39	1.70	1.48	93.09	1.07	0.93
10640	RC-14	2.5397	12.9200	0.1265	126.86	1.81	1.77	86.52	1.13	1.10
10641	RC-15	2.5649	12.9116	0.1263	124.34	1.83	1.68	85.03	1.15	1.05
			Average		**129.28**	**1.87**	**1.73**	**88.47**	**1.17**	**1.08**
			Std Dev		**20.14**	**0.12**	**0.12**	**13.78**	**0.07**	**0.07**
			% Dev		**10.7%**	**4.3%**	**4.7%**	**10.7%**	**4.1%**	**4.7%**

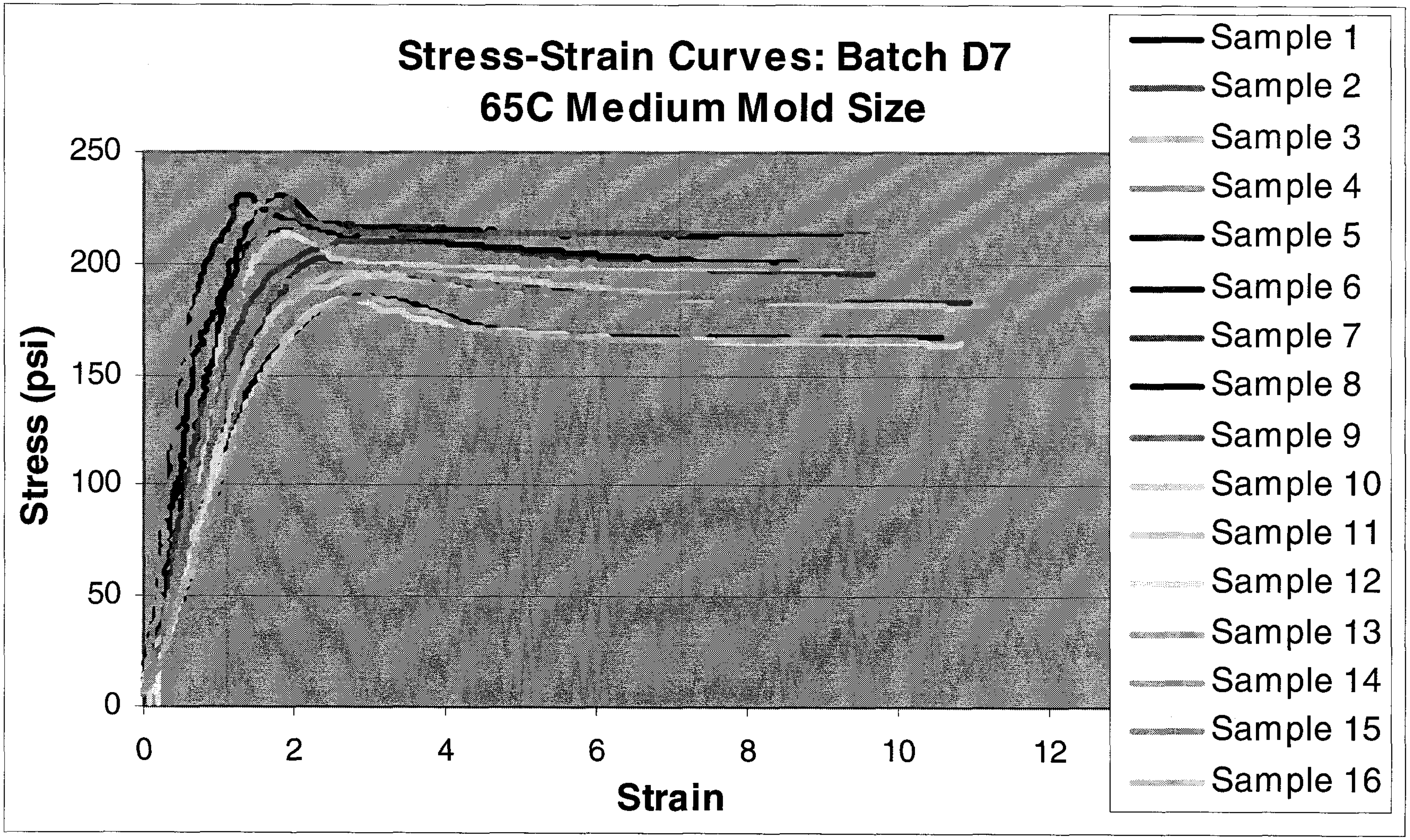


Figure D.7: Stress-Strain Curves for 65°C Medium Mold Samples

Table D.9: Mechanical Property Data for 40°C Medium Mold Size Samples

Batch D6: 40C Medium Mold Size								**Normalized**		
Testing Number	**Sampie Number**	**Height**	**Area**	**Density**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**
		(cm)	**(cm^2)**	**(g/cc)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**
10642	RC-1	2.5530	13.2309	0.1195	91.11	1.58	1.44	68.46	1.11	1.01
10643	RC-2	2.5641	13.2458	0.1205	97.89	1.65	1.52	72.51	1.14	1.05
10644	RC-3	2.5664	13.2374	0.1197	87.69	1.61	1.43	65.70	1.12	1.00
10645	RC-4	2.4849	13.2322	0.1188	103.49	1.44	1.32	78.53	1.02	0.94
10646	RC-5	2.5524	13.0787	0.1191	99.12	1.57	1.44	74.90	1.11	1.02
10647	RC-6	2.5441	13.0380	0.1204	88.07	1.67	1.48	65.33	1.15	1.02
10648	RC-7	2.5499	13.0497	0.1199	93.92	1.59	1.43	70.16	1.11	1.00
10649	RC-8	2.5331	13.0432	0.1192	104.54	1.46	1.33	78.88	1.03	0.94
10650	RC-9	2.5695	12.9245	0.1199	112.73	1.54	1.45	84.22	1.07	1.01
10651	RC-10	2.5489	12.9245	0.1206	98.37	1.64	1.52	72.76	1.13	1.05
10652	RC-11	2.5603	12.9684	0.1200	94.44	1.60	1.48	70.45	1.11	1.03
10653	RC-12	2.5260	12.9213	0.1196	107.17	1.43	1.32	80.40	1.01	0.92
10654	RC-13	2.5639	12.8329	0.1204	109.49	1.59	1.45	81.22	1.10	1.00
10655	RC-14	2.4501	12.8567	0.1206	98.91	1.68	1.51	73.16	1.15	1.04
10656	RC-15	2.5649	12.8600	0.1201	90.87	1.60	1.48	67.70	1.11	1.03
10657	RC-16	2.5420	12.8522	0.1197	110.45	1.43	1.41	82.75	1.00	0.98
			Average		**99.27**	**1.57**	**1.44**	**74.20**	**1.09**	**1.00**
			Std Dev		**8.04**	**0.08**	**0.07**	**6.14**	**0.05**	**0.04**
			% Dev		**5.6%**	**3.6%**	**3.1%**	**5.7%**	**3.2%**	**2.6%**

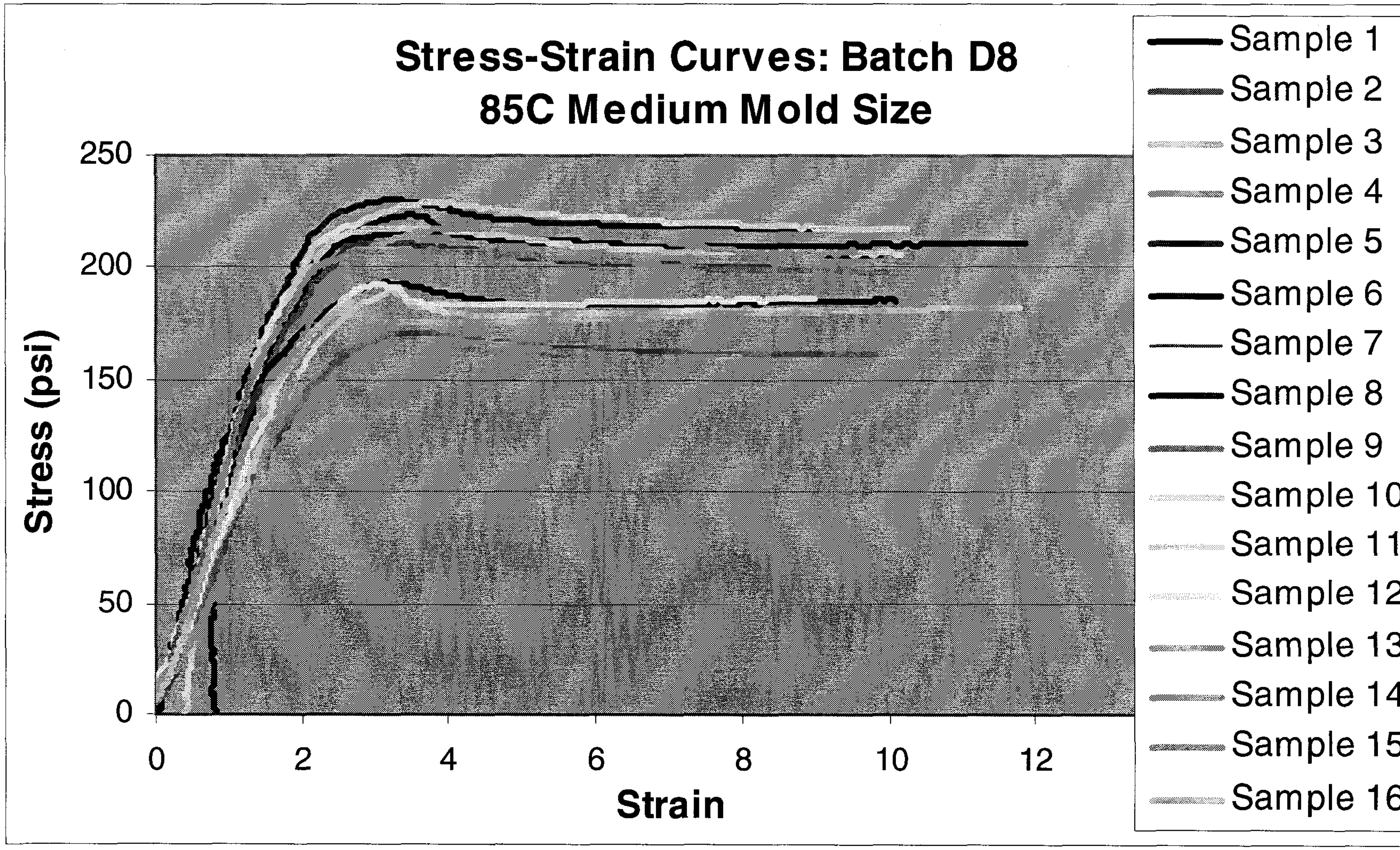


Figure D.8: Stress-Strain Curves for 85°C Medium Mold Samples

Table D.10: Mechanical Property Data for 65°C Medium Mold Size Samples

Batch D7: 65C Medium Mold Size								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10642	RC-1	2.5624	13.0832	0.1136	118.20	1.58	1.48	96.79	1.23	1.15
10643	RC-2	2.5347	13.1709	0.1125	105.94	1.45	1.35	88.20	1.15	1.08
10644	RC-3	2.5387	13.2038	0.1125	80.45	1.35	1.25	66.98	1.08	1.00
10645	RC-4	2.5641	13.2058	0.1127	75.58	1.28	1.15	62.73	1.02	0.91
10646	RC-5	2.5276	12.9355	0.1132	181.90	1.59	1.47	149.85	1.25	1.16
10647	RC-6	2.5314	12.9961	0.1129	148.70	1.49	1.38	123.05	1.18	1.09
10648	RC-7	2.4895	13.0142	0.1130	79.98	1.39	1.26	66.08	1.10	1.00
10649	RC-8	2.5095	13.0122	0.1124	68.13	1.28	1.15	56.81	1.02	0.92
10650	RC-9	2.5370	12.8445	0.1129	107.09	1.54	1.48	88.62	1.22	1.17
10651	RC-10	2.5235	12.8767	0.1126	111.29	1.47	1.37	92.51	1.17	1.09
10652	RC-11	2.5001	12.8948	0.1125	74.36	1.34	1.25	61.91	1.07	1.00
10653	RC-12	2.5080	12.8987	0.1123	68.50	1.27	1.14	57.20	1.02	0.91
10654	RC-13	2.5314	12.7335	0.1121	185.67	1.61	1.49	155.51	1.30	1.20
10655	RC-14	2.5362	12.7922	0.1125	111.89	1.50	1.38	93.15	1.20	1.10
10656	RC-15	2.5464	12.8161	0.1125	85.56	1.38	1.27	71.23	1.10	1.01
10657	RC-16	2.5502	12.8103	0.1122	65.91	1.28	1.14	55.12	1.02	0.92
			Average		**104.32**	**1.43**	**1.31**	**86.61**	**1.13**	**1.04**
			Std Dev		**38.49**	**0.12**	**0.13**	**31.86**	**0.09**	**0.10**
			% Dev		**25.4%**	**5.9%**	**6.7%**	**2.4%**	**5.6%**	**6.5%**

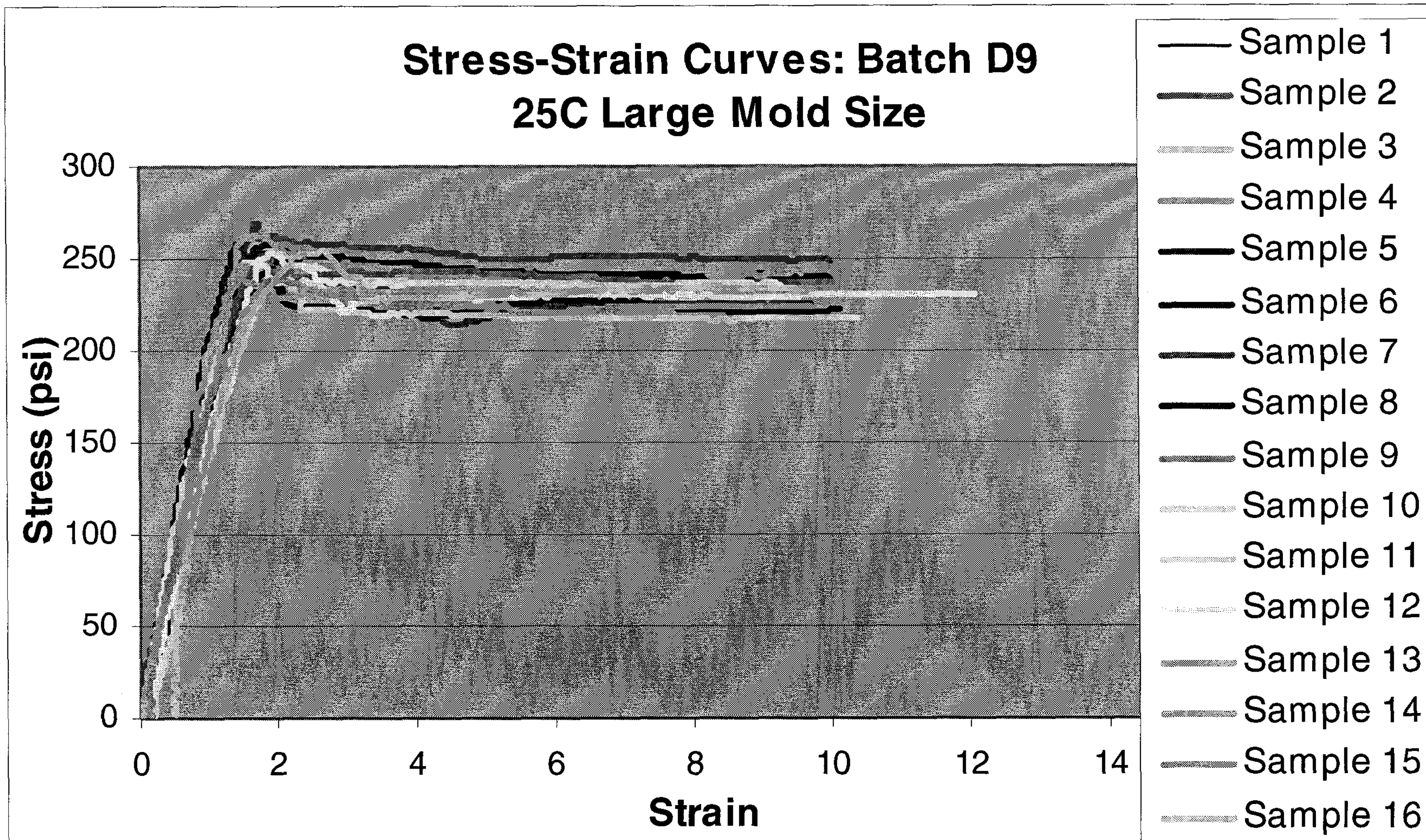


Figure D.9: Stress-Strain Curves for 25°C Large Mold Samples

Table D.12: Mechanical Property Data for 25°C Large Mold Size Samples

Batch D9: 25C Large Mold Size								Normalized		
Testing Number	**Sample Number**	**Height**	**Area**	**Density**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**	**Modulus**	**Peak Yield Stress**	**Collapse Stress**
		(cm)	**(cm^2)**	**(g/cc)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**	**(Mpa)**
10698	RC-1	2.5499	20.3412	0.1222	130.93	1.61	1.59	94.70	1.08	1.06
10699	RC-2	2.5512	20.3903	0.1238	123.01	1.83	1.73	87.03	1.19	1.13
10700	RC-3	2.5283	20.4000	0.1238	118.28	1.75	1.63	83.68	1.14	1.07
10701	RC-4	2.5530	20.4187	0.1265	131.26	1.65	1.54	89.52	1.03	0.96
10702	RC-5	2.5580	20.3800	0.1188	146.11	1.74	1.66	110.88	1.24	1.18
10703	RC-6	2.5649	20.3961	0.1196	121.84	1.78	1.66	91.41	1.25	1.17
10704	RC-7	2.5575	20.3761	0.1191	127.77	1.65	1.56	96.54	1.17	1.10
10705	RC-8	2.5517	20.3883	0.1208	118.73	1.67	1.52	87.58	1.15	1.05
10706	RC-9	2.5588	20.4122	0.1187	116.72	1.72	1.64	88.70	1.23	1.17
10707	RC-10	2.5547	20.3922	0.1193	118.09	1.71	1.63	88.97	1.21	1.15
10708	RC-11	2.5433	20.3677	0.1190	107.41	1.63	1.50	81.27	1.16	1.06
10709	RC-12	2.4625	20.3858	0.1210	108.64	1.74	1.59	79.91	1.19	1.09
10710	RC-13	2.5557	20.5735	0.1187	123.93	1.68	1.61	94.18	1.19	1.14
10711	RC-14	2.5387	20.6122	0.1201	115.16	1.81	1.68	85.78	1.26	1.17
10712	RC-15	2.5448	20.6038	0.1202	126.43	1.65	1.55	94.05	1.14	1.08
10713	RC-16	2.5359	20.6225	0.1216	110.42	1.75	1.61	80.54	1.19	1.09
			Average		**121.54**	**1.71**	**1.61**	**89.67**	**1.18**	**1.10**
			Std Dev		**9.80**	**0.07**	**0.06**	**7.65**	**0.06**	**0.06**
			% Dev		**5.6%**	**2.6%**	**2.7%**	**5.9%**	**3.6%**	**3.7%**

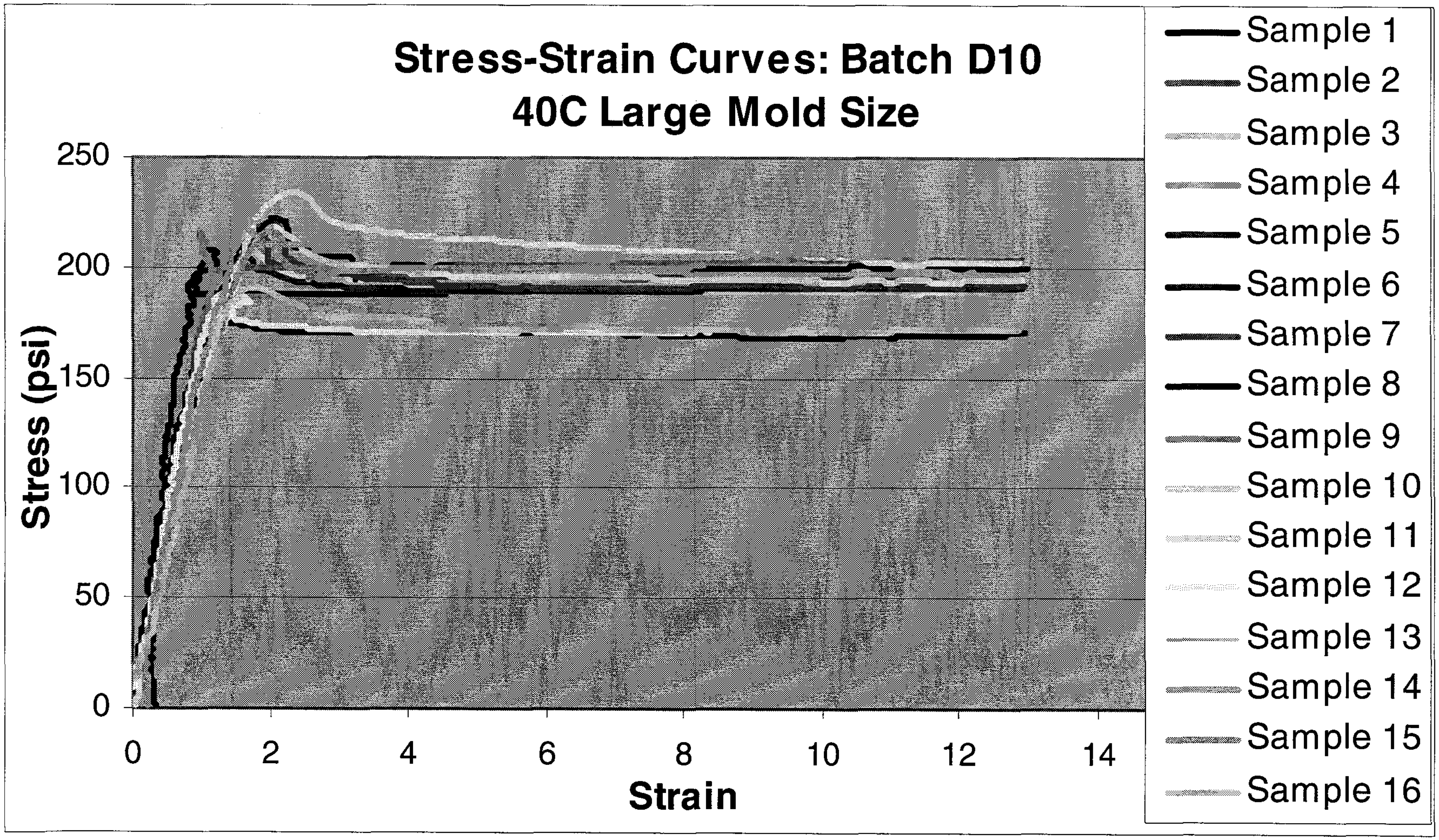


Figure D.10: Stress-Strain Curves for 40°C Large Mold Samples

Table D.13: Mechanical Property Data for 40°C Large Mold Size Samples

Batch D10: 40C Large Mold Size								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10714	RC-1	2.5504	20.3922	0.1125	153.27	1.41	1.29	127.60	1.13	1.03
10715	RC-2	2.5733	20.4064	0.1131	112.68	1.49	1.34	92.96	1.17	1.05
10716	RC-3	2.5517	20.4064	0.1129	100.51	1.46	1.31	83.17	1.16	1.04
10717	RC-4	2.5573	20.3922	0.1119	93.47	1.29	1.16	78.53	1.04	0.93
10718	RC-5	2.5613	20.3554	0.1131	150.49	1.41	1.33	124.16	1.11	1.05
10719	RC-6	2.5669	20.4025	0.1135	104.18	1.52	1.38	85.44	1.19	1.08
10720	RC-7	2.5641	20.4025	0.1129	94.78	1.45	1.33	78.43	1.15	1.05
10721	RC-8	2.5651	20.3922	0.1120	106.45	1.27	1.18	89.29	1.02	0.95
10722	RC-9	2.5451	20.3716	0.1140	116.72	1.46	1.41	95.01	1.13	1.10
10723	RC-10	2.5535	20.3335	0.1145	95.59	1.61	1.39	77.23	1.23	1.07
10724	RC-11	2.5563	20.3819	0.1135	90.38	1.49	1.34	74.12	1.17	1.05
10725	RC-12	2.5649	20.3677	0.1122	113.64	1.30	1.17	95.04	1.04	0.94
10726	RC-13	2.5555	20.5580	0.1139	136.54	1.41	1.37	111.31	1.10	1.07
10727	RC-14	2.5657	20.6090	0.1143	99.86	1.56	1.42	80.92	1.20	1.10
10728	RC-15	2.5136	20.6064	0.1137	94.04	1.49	1.38	76.89	1.16	1.08
10729	RC-16	2.4882	20.5967	0.1123	92.94	1.31	1.19	77.61	1.05	0.95
			Average		**109.72**	**1.43**	**1.31**	**90.48**	**1.13**	**1.03**
			Std Dev		**20.27**	**0.10**	**0.09**	**16.83**	**0.06**	**0.06**
			% Dev		**12.7%**	**4.8%**	**4.7%**	**12.8%**	**3.9%**	**3.8%**

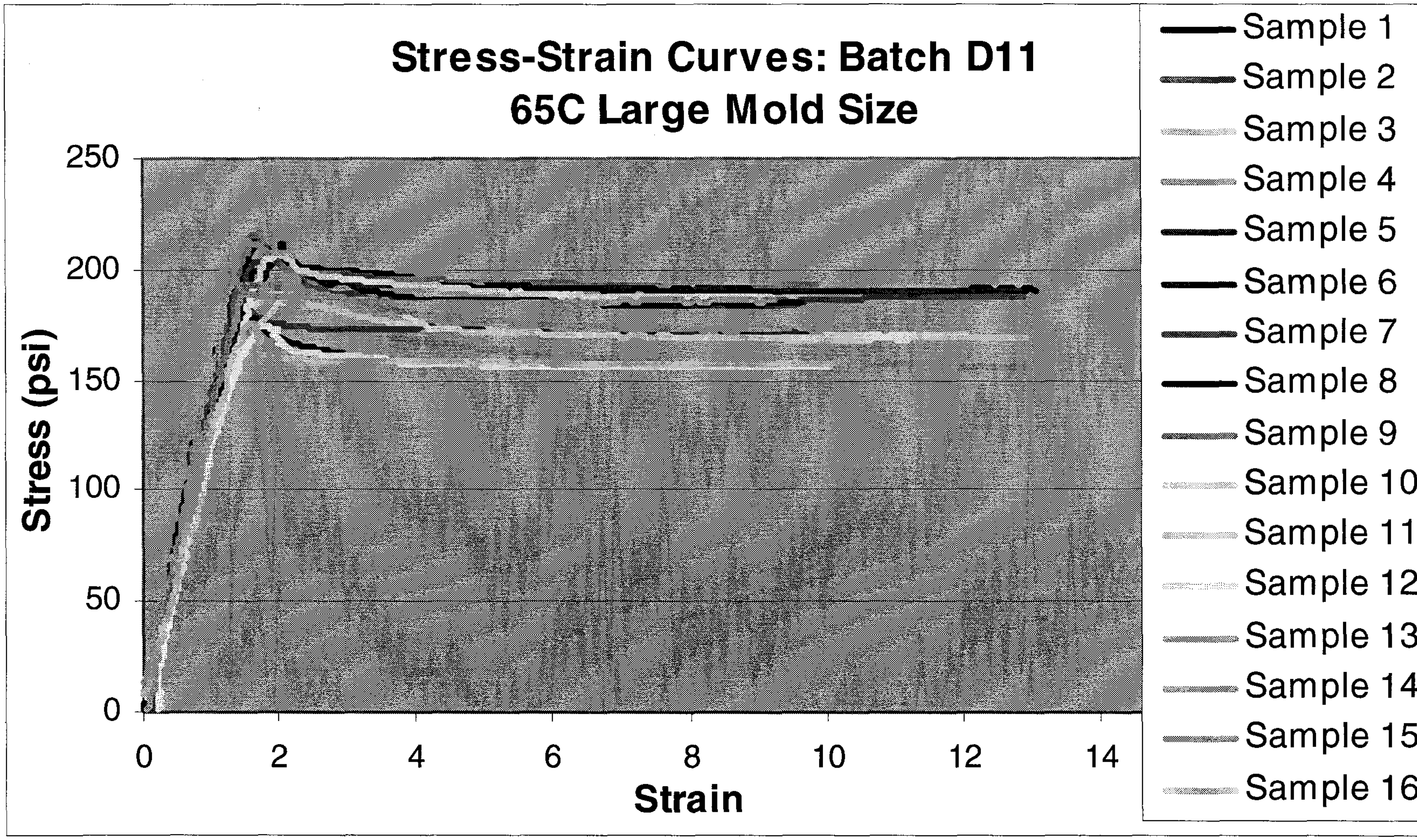


Figure D.11: Stress-Strain Curves for 65°C Large Mold Samples

Table D.14: Mechanical Property Data for 65°C Large Mold Size Samples

Batch D11: 65C Large Mold Size								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10730	RC-1	2.5484	20.2258	0.1067	102.56	1.46	1.32	93.42	1.30	1.17
10731	RC-2	2.5491	20.2296	0.1062	88.03	1.41	1.30	80.83	1.27	1.17
10732	RC-3	2.5458	20.2400	0.1059	93.68	1.30	1.17	86.43	1.18	1.05
10733	RC-4	2.5522	20.2380	0.1054	96.22	1.20	1.08	89.49	1.10	0.98
10734	RC-5	2.5593	20.2135	0.1073	84.47	1.42	1.32	76.21	1.25	1.16
10735	RC-6	2.5568	20.2277	0.1062	87.12	1.42	1.28	80.00	1.28	1.15
10736	RC-7	2.5141	20.2135	0.1056	104.87	1.30	1.18	97.22	1.19	1.07
10737	RC-8	2.5476	20.2458	0.1049	101.58	1.22	1.08	95.24	1.13	0.99
10738	RC-9	2.5639	20.2483	0.1061	99.36	1.45	1.33	91.38	1.31	1.20
10739	RC-10	2.5375	20.2458	0.1060	81.92	1.43	1.30	75.46	1.29	1.17
10740	RC-11	2.5512	20.2135	0.1056	74.69	1.30	1.17	69.24	1.18	1.07
10741	RC-12	2.5433	20.2361	0.1052	85.02	1.20	1.08	79.33	1.10	0.99
10742	RC-13	2.5179	20.4471	0.1061	113.78	1.46	1.34	104.64	1.32	1.21
10743	RC-14	2.5334	20.4509	0.1059	102.44	1.40	1.28	94.52	1.27	1.16
10744	RC-15	2.5631	20.4329	0.1057	96.33	1.34	1.19	89.17	1.22	1.08
10745	RC-16	2.5497	20.4471	0.1054	84.19	1.19	1.09	78.30	1.09	1.00
			Average		**93.52**	**1.34**	**1.22**	**86.31**	**1.22**	**1.10**
			Std Dev		**10.38**	**0.10**	**0.10**	**9.63**	**0.08**	**0.08**
			% Dev		**7.7%**	**5.2%**	**5.7%**	**7.7%**	**4.6%**	**5.1%**

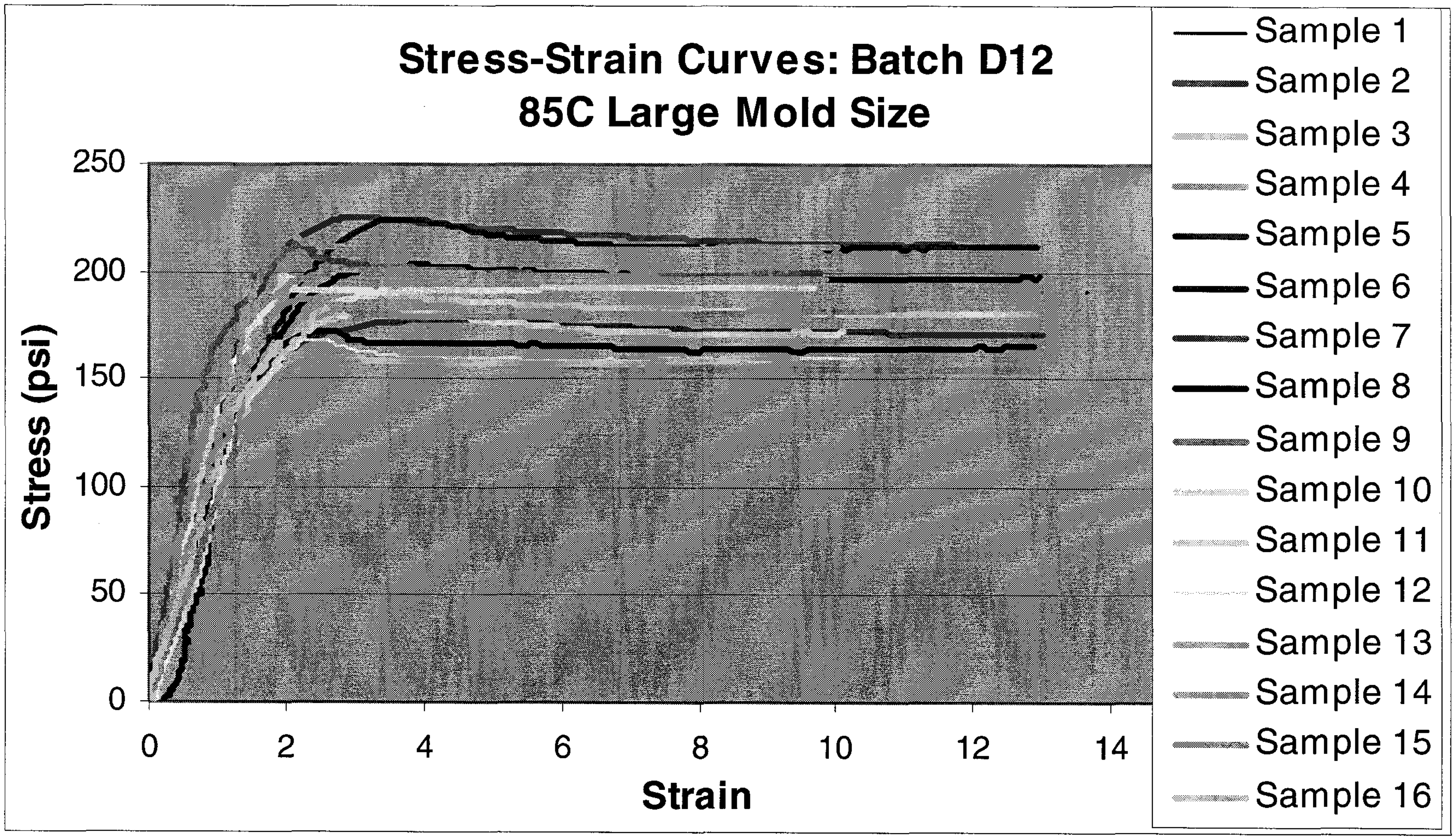


Figure D.12: Stress-Strain Curves for 85°C Large Mold Samples

Table D.15: Mechanical Property Data for 85°C Large Mold Size Samples

Batch D12: 85C Large Mold Size								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10746	RC-1	2.5524	20.2296	0.1099	82.19	1.55	1.46	71.20	1.30	1.22
10747	RC-2	2.5631	20.2174	0.1101	66.17	1.41	1.35	57.14	1.17	1.13
10748	RC-3	2.5169	20.2342	0.1116	66.40	1.30	1.25	56.04	1.06	1.01
10749	RC-4	2.5639	20.2600	0.1093	66.22	1.11	1.07	57.90	0.94	0.91
10750	RC-5	2.5441	20.2032	0.1084	85.30	1.54	1.46	75.64	1.33	1.26
10751	RC-6	2.5260	20.2238	0.1086	66.96	1.39	1.36	59.19	1.19	1.17
10752	RC-7	2.5461	20.2400	0.1104	67.43	1.23	1.17	57.96	1.02	0.97
10753	RC-8	2.5588	20.2154	0.1098	70.89	1.19	1.12	61.51	1.00	0.94
10754	RC-9	2.5535	20.3071	0.1083	124.73	1.45	1.37	110.78	1.26	1.18
10755	RC-10	2.5479	20.2664	0.1090	92.24	1.37	1.33	81.03	1.16	1.13
10756	RC-11	2.5502	20.2645	0.1102	71.42	1.24	1.18	61.58	1.03	0.98
10757	RC-12	2.5377	20.2277	0.1088	72.75	1.17	1.10	64.11	1.00	0.94
10758	RC-13	2.5606	20.4471	0.1098	84.75	1.52	1.45	73.53	1.27	1.21
10759	RC-14	2.5639	20.4529	0.1104	96.84	1.38	1.37	83.24	1.14	1.13
10760	RC-15	2.5588	20.4509	0.1113	66.14	1.29	1.24	56.08	1.05	1.01
10761	RC-16	2.5390	20.4432	0.1094	75.20	1.12	1.08	65.65	0.95	0.92
			Average		**78.48**	**1.33**	**1.27**	**68.29**	**1.12**	**1.07**
			Std Dev		**15.86**	**0.15**	**0.14**	**14.42**	**0.13**	**0.12**
			% Dev		**13.9%**	**7.6%**	**7.5%**	**14.6%**	**7.9%**	**7.8%**

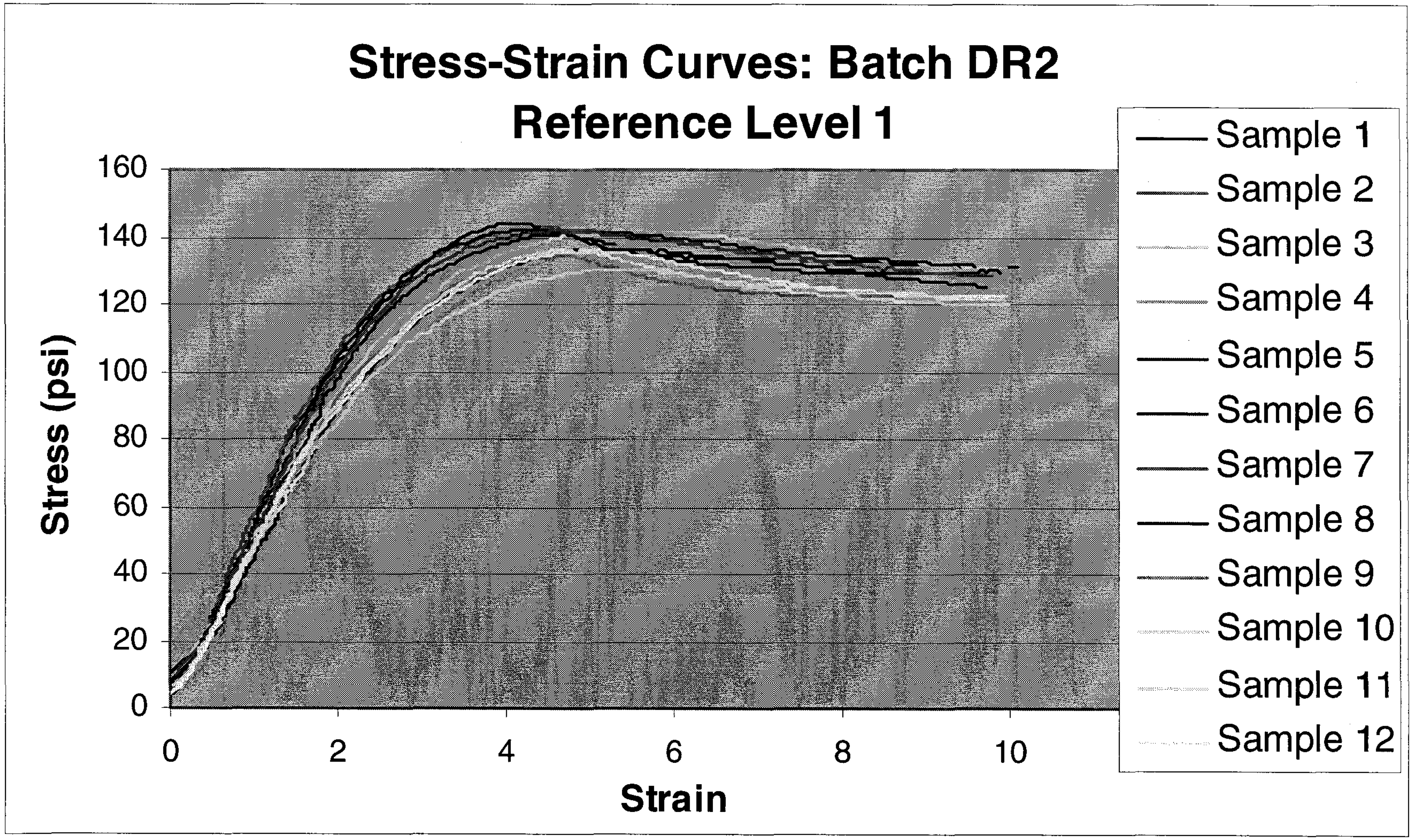


Figure D.13: Stress-Strain Curves for Reference Level 1 Samples

Table D.16: Mechanical Property Data for Reference Batch Level 1 Samples

Batch DR2: Reference Level 1								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10783	RC-1	2.5466	6.0200	0.1002	36.65	0.99	0.90	37.14	1.01	0.92
10784	RC-2	2.5552	6.0181	0.0990	38.33	0.99	0.89	39.66	1.03	0.93
10785	RC-3	2.5593	6.0413	0.0998	31.76	0.98	0.90	32.41	1.00	0.93
10786	RC-4	2.5644	6.0477	0.0984	31.30	0.94	0.88	32.72	1.00	0.93
10787	RC-5	2.5606	6.0355	0.0996	32.61	0.97	0.91	33.39	1.00	0.94
10788	RC-6	2.5603	6.0090	0.1001	36.16	0.98	0.90	36.71	1.00	0.91
10789	RC-7	2.5298	6.0413	0.1003	34.85	0.98	0.89	35.27	0.99	0.90
10790	RC-8	2.5486	6.0632	0.0980	30.39	0.94	0.87	31.99	1.00	0.93
10791	RC-9	2.5641	6.0368	0.0973	32.21	0.92	0.84	34.32	1.00	0.91
10792	RC-10	2.5575	6.0413	0.0977	31.90	0.94	0.84	33.75	1.01	0.90
10793	RC-11	2.5499	6.0522	0.0969	29.56	0.90	0.83	31.72	0.98	0.90
10794	RC-12	2.5588	6.0368	0.0978	33.43	0.94	0.84	35.31	1.00	0.90
			Average		**33.26**	**0.96**	**0.87**	**34.53**	**1.00**	**0.92**
			Std Dev		**2.69**	**0.03**	**0.03**	**2.40**	**0.01**	**0.01**
			% Dev		**5.6%**	**2.2%**	**2.3%**	**0.05%**	**0.8%**	**1.0%**

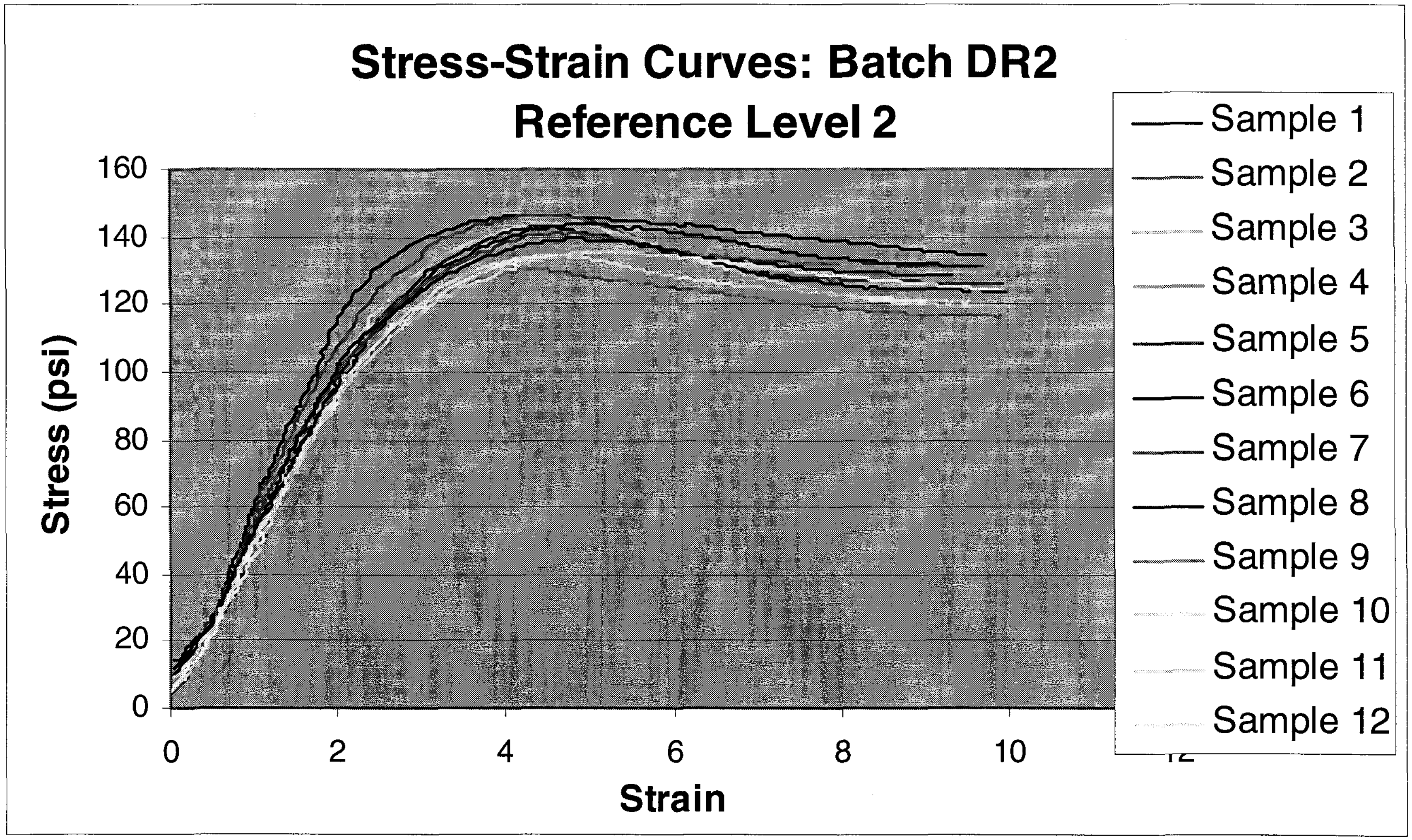


Figure D.14: Stress-Strain Curves for Reference Level 2 Samples

Table D.17: Mechanical Property Data for Reference Batch Level 2 Samples

Batch DR2: Reference Level 2								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10795	RC-1	2.5624	6.0368	0.1013	38.00	1.01	0.93	37.81	1.00	0.93
10796	RC-2	2.5651	6.0077	0.1013	37.76	1.01	0.90	37.57	1.00	0.90
10797	RC-3	2.5591	6.0710	0.1023	34.97	0.99	0.89	34.22	0.97	0.87
10798	RC-4	2.5651	6.0735	0.1029	33.97	0.99	0.89	32.91	0.95	0.86
10799	RC-5	2.5166	6.0477	0.1011	31.64	0.99	0.89	31.59	0.98	0.89
10800	RC-6	2.5649	6.0303	0.1007	32.74	0.99	0.91	32.90	1.00	0.92
10801	RC-7	2.5662	6.0426	0.0998	35.40	0.97	0.87	36.12	1.00	0.89
10802	RC-8	2.5639	6.0645	0.1004	35.56	0.96	0.85	35.93	0.97	0.87
10803	RC-9	2.5540	6.0432	0.0950	32.19	0.90	0.80	35.72	1.02	0.91
10804	RC-10	2.5535	6.0568	0.0985	30.75	0.92	0.83	32.09	0.97	0.88
10805	RC-11	2.5598	6.0477	0.0986	32.38	0.93	0.82	33.73	0.98	0.86
10806	RC-12	2.5527	6.0200	0.0966	32.83	0.93	0.86	35.42	1.02	0.95
			Average		**34.02**	**0.97**	**0.87**	**34.67**	**0.99**	**0.89**
			Std Dev		**2.34**	**0.04**	**0.04**	**2.07**	**0.02**	**0.03**
			% Dev		**4.8%**	**2.6%**	**3.1%**	**4.1%**	**1.5%**	**2.2%**

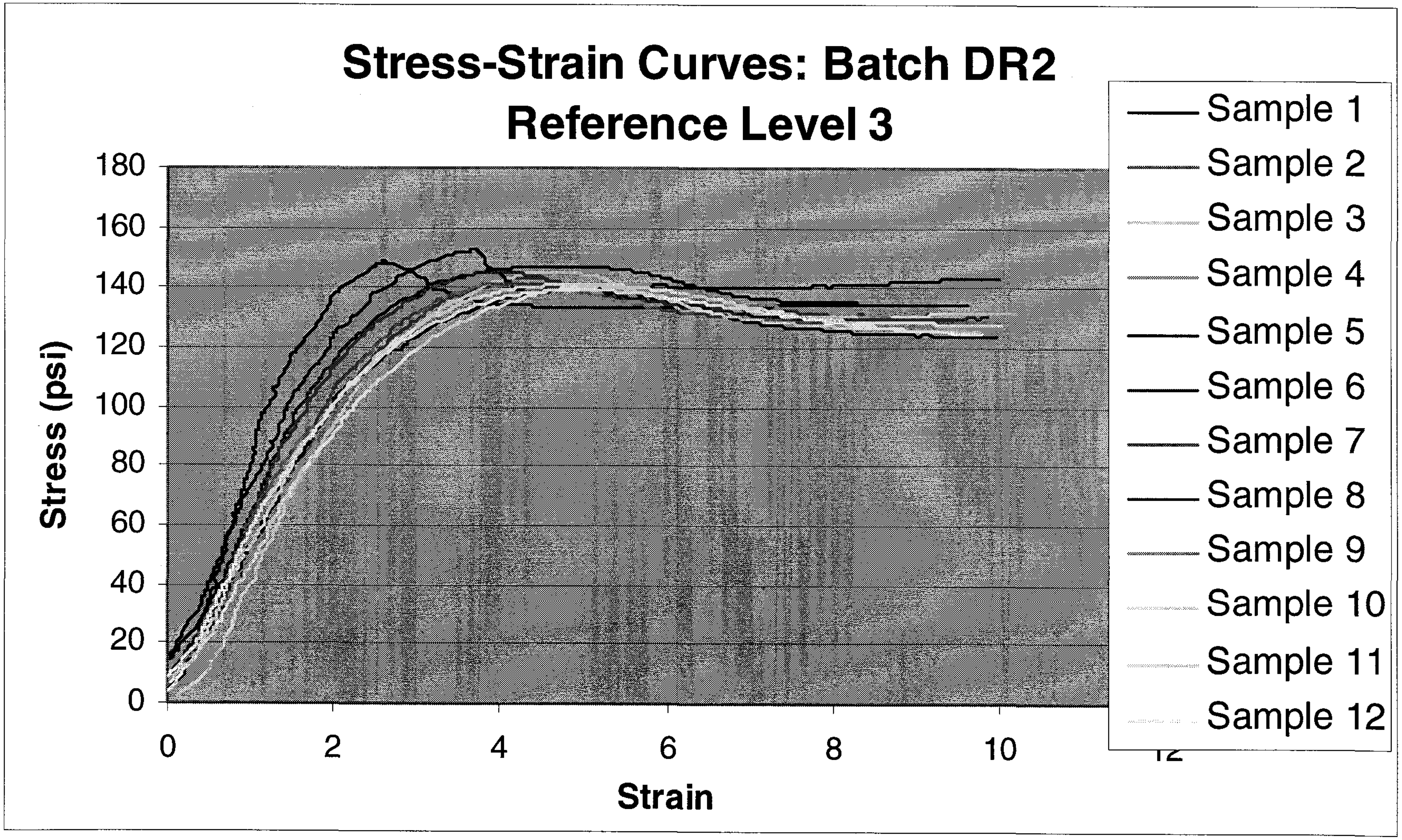


Figure D.15: Stress-Strain Curves for Reference Level 3 Samples

Table D.18: Mechanical Property Data for Reference Batch Level 3 Samples

Batch DR2: Reference Level 3								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10807	RC-1	2.5624	6.0935	0.1039	51.70	1.02	0.92	49.27	0.96	0.87
10808	RC-2	2.5448	6.0877	0.1032	34.58	0.99	0.90	33.33	0.94	0.86
10809	RC-3	2.5550	6.0735	0.1005	34.97	0.99	0.89	35.27	1.00	0.90
10810	RC-4	2.5552	6.0581	0.0992	33.76	0.96	0.88	34.80	1.00	0.92
10811	RC-5	2.5563	6.0703	0.1014	39.92	1.01	0.93	39.65	1.01	0.92
10812	RC-6	2.5593	6.0910	0.1043	45.55	1.05	0.97	43.13	0.99	0.91
10813	RC-7	2.5618	6.0510	0.1003	41.38	1.00	0.90	41.87	1.01	0.91
10814	RC-8	2.5540	6.0658	0.0982	33.78	0.94	0.85	35.44	1.00	0.91
10815	RC-9	2.5306	6.0413	0.0987	36.69	0.97	0.89	38.15	1.02	0.93
10816	RC-10	2.5560	6.0690	0.0977	31.83	0.97	0.88	33.68	1.04	0.95
10817	RC-11	2.5573	6.0742	0.0976	35.78	0.97	0.87	37.93	1.04	0.93
10818	RC-12	2.5420	6.0458	0.0982	34.85	0.96	0.86	36.56	1.02	0.91
			Average		**37.90**	**0.99**	**0.90**	**38.26**	**1.00**	**0.91**
			Std Dev		**5.81**	**0.03**	**0.03**	**4.64**	**0.03**	**0.02**
			% Dev		**10.6%**	**2.2%**	**2.5%**	**8.4%**	**2.0%**	**1.8%**

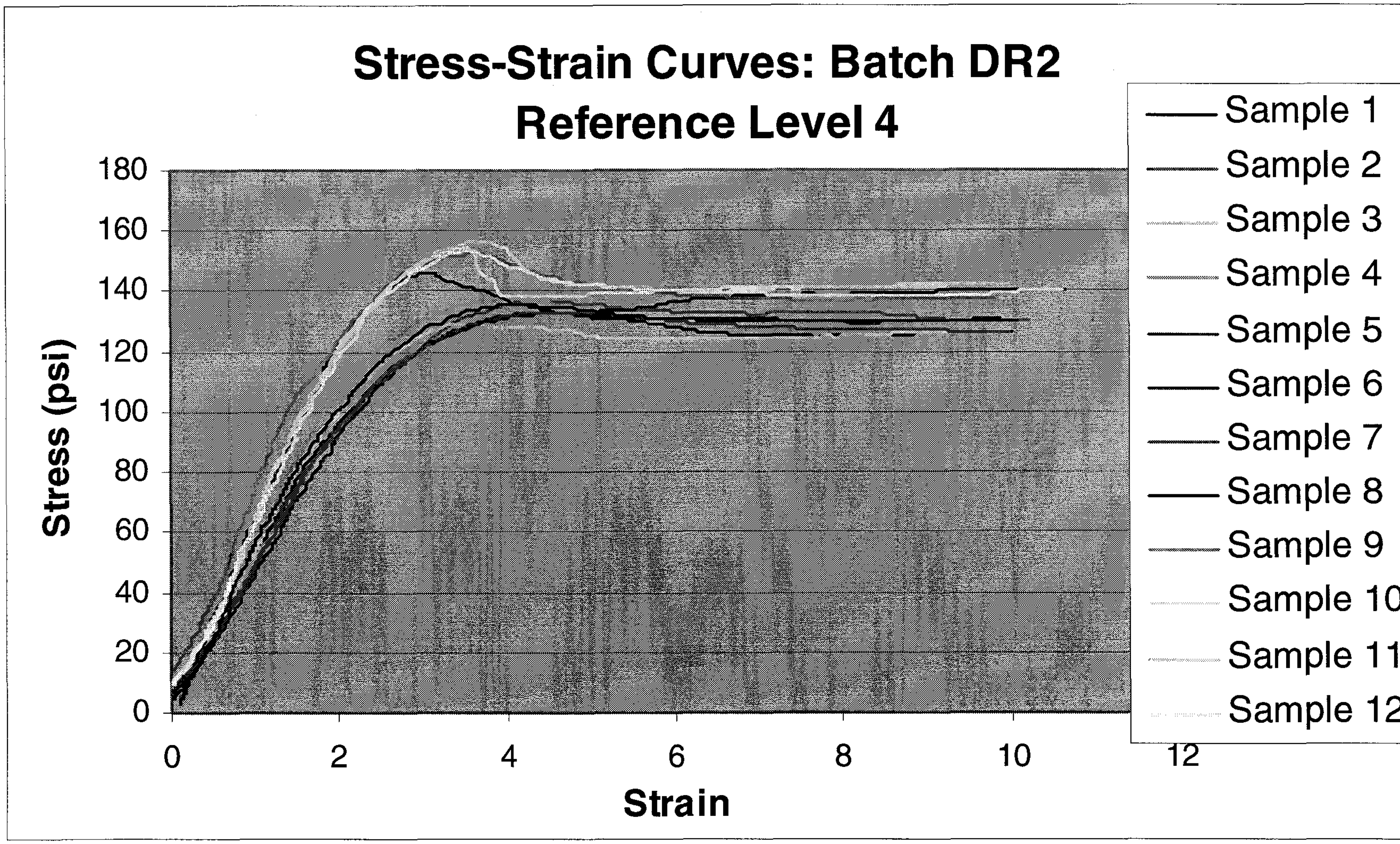


Figure D.16: Stress-Strain Curves for Reference Level 4 Samples

Table D.19: Mechanical Property Data for Reference Batch Level 4 Samples

Batch DR2: Reference Level 4								Normalized		
Testing Number	Sample Number	Height	Area	Density	Modulus	Peak Yield Stress	Collapse Stress	Modulus	Peak Yield Stress	Collapse Stress
		(cm)	(cm^2)	(g/cc)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(Mpa)
10819	RC-1	2.5486	6.0426	0.1065	34.09	0.92	0.87	31.16	0.82	0.78
10820	RC-2	2.5560	6.0645	0.1094	32.42	0.94	0.90	28.30	0.80	0.76
10821	RC-3	2.5591	6.0600	0.1070	36.19	0.89	0.87	32.81	0.79	0.77
10822	RC-4	2.5550	6.0348	0.1074	37.54	0.94	0.88	33.82	0.83	0.77
10823	RC-5	2.5550	6.0677	0.1099	31.25	0.92	0.90	27.07	0.77	0.75
10824	RC-6	2.4994	6.0710	0.1094	43.34	1.00	0.97	37.84	0.85	0.82
10825	RC-7	2.5591	6.0464	0.1064	43.34	1.00	0.97	39.67	0.90	0.87
10826	RC-8	2.5568	6.0800	0.1052	39.14	0.93	0.90	36.52	0.85	0.82
10827	RC-9	2.5618	6.0568	0.1056	45.71	1.05	0.95	42.38	0.95	0.87
10828	RC-10	2.4950	6.0645	0.1055	42.52	1.05	0.98	39.48	0.96	0.89
10829	RC-11	2.5377	6.0368	0.1068	43.60	1.08	0.97	39.65	0.96	0.86
10830	RC-12	2.5649	6.0619	0.1058	40.91	1.05	0.96	37.81	0.96	0.87
			Average		**39.17**	**0.98**	**0.93**	**35.54**	**0.87**	**0.82**
			Std Dev		**4.83**	**0.07**	**0.05**	**4.88**	**0.07**	**0.05**
			% Dev		**8.5%**	**4.6%**	**3.4%**	**9.5%**	**5.8%**	**4.4%**

APPENDIX E

CHEMICAL FORMULATON

DOCUMENTATION

SHEETS

The following figures are copies of the chemical formulation documentation sheets for each batch of foam made during this study, including the references batches (Figure E.13 and Figure E.14). Each sheet notes the date, batch number, processing conditions (water bath temperature and mold size), and laboratory conditions (temperature and humidity). The small mold batches (Figure E.1 through Figure E.4) use a mix size of 1500 g/cc, the medium and large mold size batches use a mix size of 2500 g/cc, and the reference batches use a mix size of 3000g/cc. The sheets also indicate the ideal mass for each constituent and the actual mass used in the formulation.

DATE: 1-29-02
BATCH NUM: D1
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: (Dacia's Batch #1) 25C WB (1.13 Tubes)
~~B150~~ TEMP: 38 F LV ~~B150~~ HUMIDITY: 44 %
~~B150~~ BAROMETRIC PRESSURE: 29.92 in

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 1500

Computed Factor 2

Part Volume	(cc)	1500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	84.24	84.3
DC 193 Surfactant	(g)	2.13	2.2
Polycat 17 Amine Catalyst	(g)	0.49	0.50
Distilled Water	(g)	0.98	0.98
Rubinate 1680	(g)	128.51	125.0
Mix Size	(g)	216.35	212.98
Pour Size	(g)	158.66	

TIME CHEMICAL MIX WAS FINISHED: 9:25 am
TIME FOAM WAS PUT INTO OVEN: 9:55 Am
TIME FOAM WAS TAKEN OUT OF OVEN: 2:00 PM
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.50 min

Figure E.1: Chemical Formulation Documentation Sheet for 25°C Small Mold Size

DATE: 2-4-02
BATCH NUM: D2
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 40C WB FR (1.13" ID Tubes)
~~B150~~ TEMP: 33°F ~~B150~~ HUMIDITY: 41%
~~B150~~ BAROMETRIC PRESSURE: 30.30 in

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 1500

Computed Factor 2

Part Volume	(cc)	1500	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	84.24	86.0
DC 193 Surfactant	(g)	2.13	2.16
Polycat 17 Amine Catalyst	(g)	0.49	0.53
Distilled Water	(g)	0.98	0.98
Rubinate 1680	(g)	128.51	129.
Mix Size	(g)	216.35	218.67
Pour Size	(g)	158.66	

TIME CHEMICAL MIX WAS FINISHED: 9:09 AM
TIME FOAM WAS PUT INTO OVEN: ~~9:37 AM~~ 10 AM
TIME FOAM WAS TAKEN OUT OF OVEN: 2:00 PM
MIX TIME W/ SPATULA 2.00 min MIX TIME W/MIXER 1.50 min

Figure E.2: Chemical Formulation Documentation Sheet for 40°C Small Mold Size

DATE: 2-11-02
BATCH NUM: D3
CHEMICALS: [illegible]
ASSISTANTS: Dacia
ADDTL INFO: 65C WB FR
B150 TEMP: 36F B150 HUMIDITY: 27%
B150 BAROMETRIC PRESSURE: 30.48"

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 1500

Computed Factor 2

Part Volume	(cc)	1500	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	84.24	84.3
DC 193 Surfactant	(g)	2.13	2.13
Polycat 17 Amine Catalyst	(g)	0.49	0.50
Distilled Water	(g)	0.98	1.03
Rubinate 1680	(g)	128.51	128.3
Mix Size	(g)	216.35	216.26
Pour Size	(g)	158.66	

TIME CHEMICAL MIX WAS FINISHED: 9:32 AM
TIME FOAM WAS PUT INTO OVEN: 10:02 AM
TIME FOAM WAS TAKEN OUT OF OVEN: 2:05 PM
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure E.3: Chemical Formulation Documentation Sheet for 65°C Small Mold Size

DATE: 2-19-02
BATCH NUM: D4
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 85C WB FR (1.13" tubes)
~~B150~~ TEMP: 46°F ~~LVB150~~ HUMIDITY: 40%
~~B150~~ BAROMETRIC PRESSURE: 30.15 in

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 1500

Computed Factor 2

Part Volume	(cc)	1500	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	84.24	86.2
DC 193 Surfactant	(g)	2.13	2.13
Polycat 17 Amine Catalyst	(g)	0.49	0.5
Distilled Water	(g)	0.98	0.98
Rubinate 1680	(g)	128.51	128.91
Mix Size	(g)	216.35	218.72
Pour Size	(g)	158.66	

TIME CHEMICAL MIX WAS FINISHED: 9:50A
TIME FOAM WAS PUT INTO OVEN: 10:41A
TIME FOAM WAS TAKEN OUT OF OVEN: 2:45P
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure E.4: Chemical Formulation Documentation Sheet for 85°C Small Mold Size

DATE: 2-25-02
BATCH NUM: 05
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 25C WB FR
B150 TEMP: 72.9°F B150 HUMIDITY: 31%
B150 BAROMETRIC PRESSURE: used hygrometer

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	140.40	139
DC 193 Surfactant	(g)	3.55	3.6
Polycat 17 Amine Catalyst	(g)	0.82	0.84
Distilled Water	(g)	1.63	1.65
Rubinate 1680	(g)	214.18	217
Mix Size	(g)	360.58	362.09
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 9:26 A
TIME FOAM WAS PUT INTO OVEN: 10:05 A
TIME FOAM WAS TAKEN OUT OF OVEN: 2:05 P
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure E.5: Chemical Formulation Documentation Sheet for 25°C Medium Mold Size

DATE: 3-4-02
BATCH NUM: D6
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 40C WB Cyl FR (1.6" Tubes)
B150 TEMP: ~71.6F B150 HUMIDITY: ~28% (Temp + Hum taken @ 3:00pm)
~~B150~~ BAROMETRIC PRESSURE: 30.36in (Foam made @ 11:00am)

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	140.40	137.8
DC 193 Surfactant	(g)	3.55	3.54
Polycat 17 Amine Catalyst	(g)	0.82	0.85
Distilled Water	(g)	1.63	1.63
Rubinate 1680	(g)	214.18	214.8
Mix Size	(g)	360.58	
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 11:15
TIME FOAM WAS PUT INTO OVEN: 11:45
TIME FOAM WAS TAKEN OUT OF OVEN: 2:30
MIX TIME W/ SPATULA 2.0 MIX TIME W/MIXER 1.5

Figure E.6: Chemical Formulation Documentation Sheet for 40°C Medium Mold Size

DATE: 3-11-02
BATCH NUM: D7
CHEMICALS: Cameron
ASSISTANTS:
ADDTL INFO: 65C FRWB (1.6" tubes)
B150 TEMP: 68.7°F B150 HUMIDITY: 24%
~~B150~~ BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	140.40	140.6
DC 193 Surfactant	(g)	3.55	3.5
Polycat 17 Amine Catalyst	(g)	0.82	0.84
Distilled Water	(g)	1.63	1.65
Rubinate 1680	(g)	214.18	213.3
Mix Size	(g)	360.58	359.89
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 10:04 am
TIME FOAM WAS PUT INTO OVEN: 10:40 am
TIME FOAM WAS TAKEN OUT OF OVEN: 2:40 pm
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure E.7: Chemical Formulation Documentation Sheet for 65°C Medium Mold Size

DATE: 3-18-02
BATCH NUM: D8
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 85C WB FR (1.6" tubes)
B150 TEMP: 72.7°F B150 HUMIDITY: 26%
B150 BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	140.40	137.4
DC 193 Surfactant	(g)	3.55	3.57
Polycat 17 Amine Catalyst	(g)	0.82	0.835
Distilled Water	(g)	1.63	1.64
Rubinate 1680	(g)	214.18	217.4
Mix Size	(g)	360.58	360.85
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 11:17A
TIME FOAM WAS PUT INTO OVEN: 11:54A
TIME FOAM WAS TAKEN OUT OF OVEN: 4:02pm
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure E.8: Chemical Formulation Documentation Sheet for 85°C Medium Mold Size

DATE: 4-2-02
BATCH NUM: D-9
CHEMICALS: Cameron
ASSISTANTS: Pacia
ADDTL INFO: 25CWR (2.0" Tubes)
B150 TEMP: 71.4 F   B150 HUMIDITY: 30%
B150 BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) | 2500 |

Computed Factor | 1.2 |

Part Volume	(cc)	2500	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	140.40	139.3
DC 193 Surfactant	(g)	3.55	3.6
Polycat 17 Amine Catalyst	(g)	0.82	0.84
Distilled Water	(g)	1.63	1.65
Rubinate 1680	(g)	214.18	212.6
Mix Size	(g)	360.58	357.99
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 9:36 AM
TIME FOAM WAS PUT INTO OVEN: 10:06 AM
TIME FOAM WAS TAKEN OUT OF OVEN: 2:10 PM
MIX TIME W/ SPATULA 2.0 min   MIX TIME W/MIXER 1.5 min

Figure E.9: Chemical Formulation Documentation Sheet for 25°C Large Mold Size

DATE: 4/9/02
BATCH NUM: D10
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: (2.0" dia tubes) 40°C WB
B150 TEMP: 77.4 B150 HUMIDITY: 28 %
B150 BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	140.40	140.4
DC 193 Surfactant	(g)	3.55	3.56
Polycat 17 Amine Catalyst	(g)	0.82	0.82
Distilled Water	(g)	1.63	1.65
Rubinate 1680	(g)	214.18	213.8
Mix Size	(g)	360.58	360.23
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 12:03pm
TIME FOAM WAS PUT INTO OVEN: 12:33pm
TIME FOAM WAS TAKEN OUT OF OVEN: 4:33pm
MIX TIME W/ SPATULA 2.0 MIX TIME W/MIXER 1.5

Figure E.10: Chemical Formulation Documentation Sheet for 40°C Large Mold Size

DATE: 4-16-02
BATCH NUM: D11
CHEMICALS: Cameron
ASSISTANTS: Darig
ADDTL INFO: 65C 2.0" Tubes WB FR
B150 TEMP: 76.1 B150 HUMIDITY: 23%
B150 BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	140.40	141.0
DC 193 Surfactant	(g)	3.55	3.78
Polycat 17 Amine Catalyst	(g)	0.82	.86
Distilled Water	(g)	1.63	1.67
Rubinate 1680	(g)	214.18	213.0
Mix Size	(g)	360.58	360.21
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 9:40A
TIME FOAM WAS PUT INTO OVEN: 10:10A
TIME FOAM WAS TAKEN OUT OF OVEN:
MIX TIME W/ SPATULA 2.0min MIX TIME W/MIXER 1.5min

Figure E.11: Chemical Formulation Documentation Sheet for 65°C Large Mold Size

DATE: 4-22-02
BATCH NUM: D12
CHEMICALS: Cameron
ASSISTANTS: Mike
ADDTL INFO: 85°C WR FR (2.0" tubes)
B150 TEMP: 72.3°F B150 HUMIDITY: 22%
B150 BAROMETRIC PRESSURE: In Wood:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 2500

Computed Factor 1.2

Part Volume	(cc)	2500
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	140.40	145.1
DC 193 Surfactant	(g)	3.55	3.65
Polycat 17 Amine Catalyst	(g)	0.82	.84
Distilled Water	(g)	1.63	1.65
Rubinate 1680	(g)	214.18	225 ←
Mix Size	(g)	360.58	376.24
Pour Size	(g)	264.43	

TIME CHEMICAL MIX WAS FINISHED: 10:34 A
TIME FOAM WAS PUT INTO OVEN: 11:10 A
TIME FOAM WAS TAKEN OUT OF OVEN: 3:05 P
MIX TIME W/ SPATULA 2.0 MIX TIME W/MIXER 1.5

Figure E.12: Chemical Formulation Documentation Sheet for 85°C Large Mold Size

DATE: 5/21/02
BATCH NUM: DR-1
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 25C Air Gallon for DA
B150 TEMP: 74.1°F B150 HUMIDITY: 23%
B150 BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 3000

Computed Factor 1

Part Volume	(cc)	3000
Polymer Foam Density	(lb/ft3)	6.00
	(g/cc)	0.096
Packing Factor	(1 <= PF <= 2)	1.0

			ACTUAL
Voranol 490	(g)	168.48	168.89
DC 193 Surfactant	(g)	4.26	4.3
Polycat 17 Amine Catalyst	(g)	0.98	1.0
Distilled Water	(g)	1.96	2.0
Rubinate 1680	(g)	257.01	255
Mix Size	(g)	432.69	430.3
Pour Size	(g)	317.31	

TIME CHEMICAL MIX WAS FINISHED: 11:27A
TIME FOAM WAS PUT INTO OVEN: 12:00A
TIME FOAM WAS TAKEN OUT OF OVEN: 4:00P
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.50 min

Figure E.13: Chemical Formulation Documentation Sheet for Reference Batch 1

DATE: 5-28-02
BATCH NUM: DR-2
CHEMICALS: Cameron
ASSISTANTS: Dacia
ADDTL INFO: 25C Air Mech Tests
B150 TEMP: 73 % B150 HUMIDITY: 24%
B150 BAROMETRIC PRESSURE:

Polyurethane RE-CRETE Foam Formula Generator
Free Rise
Polyol Master Batch -- Part Volume

USE CAUTION IF POUR SIZE > 1000g

Note: It is recommended that the mix size be greater than or equal to 200g

Please enter the Part Volume desired (cc) 3000

Computed Factor 1

Part Volume	(cc)	3000	
Polymer Foam Density	(lb/ft3)	6.00	
	(g/cc)	0.096	
Packing Factor	(1 <= PF <= 2)	1.0	
			ACTUAL
Voranol 490	(g)	168.48	167.3
DC 193 Surfactant	(g)	4.26	4.32
Polycat 17 Amine Catalyst	(g)	0.98	0.99
Distilled Water	(g)	1.96	1.99
Rubinate 1680	(g)	257.01	250.6
Mix Size	(g)	432.69	425.2
Pour Size	(g)	317.31	

TIME CHEMICAL MIX WAS FINISHED: 11:45A
TIME FOAM WAS PUT INTO OVEN: 12:15P
TIME FOAM WAS TAKEN OUT OF OVEN: 4:15P
MIX TIME W/ SPATULA 2.0 min MIX TIME W/MIXER 1.5 min

Figure E.14: Chemical Formulation Documentation Sheet for Reference Batch 2

REFERENCES

[1] Goods, S.H., Whinnery, L.L., *The Effect of Thermal Aging on the Mechanical Properties of Stockpile Polyurethane Foam*, Sandia National Laboratory Report 2000-8245, June 2000.

[2] Goods, S.H., Neuschwanger, C.L., Henderson, C.C., Skala, D.M., *Mechanical Properties and Energy Absorption Characteristics of a Polyurethane Foam*, Sandia National Laboratory report 97-8490, March 1997.

[3] Goods, S.H., Neuschwanger, C.L., Henderson, C.C., and Skala, D.M., "Mechanical Properties of CRETE, a Polyurethane Foam," *Journal of Applied Polymer Science*, V. 68, 1045-1055, 1998.

[4] Whinnery, L.L, Goods, S.H., Irvin, D.J., Skala, D.M., and Leonard, C.M.,"A Replacement Polyurethane Foam for Stockpile Applications", *Proceedings of the 22nd Aging, Compatibility and Stockpile Stewardship Conference*, Oak Ridge, TN, April 27-30, 1999.

[5] Kadippili, G., Sheld, E., Riccio, K.K.C., Benincasa, F., Nelson, M.C., et al., "Thermal Aging and IR Study of Polyurethane Foams," presented at the Polyurethanes Conference 2002 Poster Session, Salt Lake City, UT, October, 2002.

[6] M. Nicol, D. Pepper, A. Chopelas, A. Cornelius, C. Chen, A. Johnson, et al., "Scientific and Engineering Studies of Materials at High Static and Dynamic Pressures for Stockpile Stewardship," technical report for DOE, April 2001.

[7] O'Toole, B., Nelson, M.C., Mullin, M., Jackovich, D., Mohan, R., Sapochak, L. et al., "Density Gradient Effects in a Polyurethane Foam System," unpublished paper.

[8] O'Toole, B., Sapochak, L., Hatchett, D., "Correlation of Processing Temperature, Density Gradients, Chemistry, and Mechanical Properties in a Molded Polyurethane Foam System," presentation at the UNLV High Pressure Science and Engineering Center (HiPSEC) Annual Review, Las Vegas, NV, November 2002.

[9] Brachos, V. and Douglas, C.D., "Energy Absorption Characteristics for Hybrid Composite Structures," *Proceedings of the 27th International SAMPE Technical Conference*, Albuquerque, NM, 1995.

[10] Gupta, V.K., Khakhar, D.V., "Formation of Integral Skin Polyurethane Foams," *Polymer Engineering and Science*, Vol. 39, pp. 164-176, 1999.

[11] Harbron, D.R., Page, C.J., Scarrow, R.K., "Methods of Minimising Density Gradients in Rigid Polyurethanes Foams," *Journal of Cellular Plastics*, V. 37, 43-57, June 2001.

[12] Gere, J.M. and Timoshenko, S.P., *Mechanics of Materials*, 4th ed., PWS Publishing Company, Boston, MA, 1997.

[13] Mallick, P.K., *Fiber-Reinforced Composites*, 2nd ed., Marcel Dekker, Inc., New York, 1993.

[14] Nelson, M.C., "The Effects of Skin on Polyurethane Foam," unpublished report for National Science Foundation Research Program (NSF), December 2000.

[15] O'Toole, B., Mullin, M., Nelson, M.C., Jackovich, D. and Mohan, R., "Effect of Mold Size on the Average Density and Density Gradients in a Polyurethane Foam System," *Proceedings of the Annual Technical Conference for the Plastics Industry* (ANTEC), San Francisco, CA, May 5-9, 2002.

[16] O'Toole, B., Nelson, M.C., Mullin, M., Jackovich, D., Mohan, R. et al., "Correlation of Processing Temperature, Density Gradients, and Mechanical Properties in a Molded Polyurethane Foam System," *Proceedings of the Annual Technical Conference for the Plastics Industry* (ANTEC), San Francisco, CA, May 5-9, 2002.

[17] Johnson, A.L., O'Toole, B.J., Sapochak, L.S., Lindle, D.W., Whinnery, L.L., Goods, S.H., Martin, M.C., "Aging of Polyurethane Foams: IR", unpublished paper.

[18] ASTM Standards, "Standard Test Method for Compressive Properties of Rigid Cellular Plastics," Designation: D 1621-94, Vol. 03.01, pp.346-348.

[19] ASTM Standards, "Standard Test Method for Apparent Density of Rigid Cellular Plastics," Designation: D 1622-93, Vol. 14.02, pp. 349-351.

[20] United Optical Extensometer (EX-62-LOE) Manual, prepared by United Calibration Corporation.

[21] Gibson, L. J., and Ashby, M. F., 1988, *Cellular Solids-Structure and Properties*, Pergamon Press, New York.

[22] Figliola, R.S. and Beasley, D.E., *Theory and Design for Mechanical Measurements,* 2nd ed., Wiley & Sons, Inc., New York, 1995.

[23] Powers, M.T., "Material Characterization of Polyurethane Foam Under Hydrostatic Loading," *Proceedings of the American Institute of Aeronautics and Astronautics (AIAA) Mid-Atlantic Region I Student Conference*, Morgantown, WV,April 6-7, 2001.

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1. B. O'Toole, M.C. Nelson, M. Mullin, D. Jackovich, et al., "Correlation of Processing Temperature, Density Gradients, and Mechanical Properties in a Molded Polyurethane Foam System," *Proceedings of the Annual Technical Conference for the Plastics Industry* (ANTEC), San Francisco, CA, May 2002.
2. B. O'Toole, M. Mullin, M.C. Nelson, D. Jackovich, and R. Mohan, "Effect of Mold Size on the Average Density and Density Gradients in a Polyurethane Foam System," *Proceedings of the Annual Technical Conference for the Plastics Industry* (ANTEC), San Francisco, CA, May 2002.
3. D. Jackovich, R. Boehm, and Y. Baghzouz, "Energy Analysis of a Hybrid Electric Bus," *Proceedings of ECOS 2000*, Enschede, Nethlands, July 2000.

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