Structural Analysis of Gingerbread

Engineering Design Project Term 2

Y_o Engineering
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Executive Summary

A series of testing protocols are designed that will determine the structural strength of gingerbread. The baking must be completed with standard baking equipment and the tests must produce accurate and straightforward results. The gingerbread must maintain its functionality as food.

Tensile, cantilever beam, compression and density tests were considered. The cantilever test was determined to be the most important as it directly corresponds to typical gingerbread applications.

The tensile test affixed one side of an “I” shaped piece of gingerbread to a stationary mount. Weight was then incrementally applied to the bottom of the sample until it failed. The cantilever beam test placed a gingerbread beam across a known span and was centrally loaded. Both of these tests were analyzed to obtain the respective failure stress and strains.

The test case presented in this report varies the fat content to optimize gingerbread structural strength. The results from the tensile and cantilever beam tests were accurate assuming density was constant among all the samples. The density and compressive tests only produced qualitative results. The accuracy of all of these tests could be improved by increasing the number of samples tested to better understand the inconsistencies that appeared. Also, access to sensitive testing machinery would allow for more precise data.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Brief History

For centuries, Europeans have been baking gingerbread. It became a popular treat at European fairs (Farrow, p. 4) and government-recognized guilds baked all the gingerbread to ensure quality control and to limit competition. Cutting gingerbread into shapes and lightly dusting it with sugar became popular later in Europe (Farrow, p. 4). Gingerbread has since made its way across the world and baking it at Christmastime has become a popular tradition. Gingerbread baking competitions have wide variety of categories, drawing many entries. A few common categories are; entirely edible, largest house and structural likeness.

1.2 Problem Description

There are few sources that share complete, detailed analyses of how baking ingredients affect the structural properties of gingerbread. Most gingerbread "how-to's" share the authors' personal findings for specific cases, however, different sources contradict each other. The public would appreciate a series of tests to help decide which recipe best suits their needs.

1.3 Objectives and Constraints

Objectives

- Design a series of repeatable tests that can be used to determine the structural properties of gingerbread.
  - o Tensile sample test
  - o Cantilever beam test
  - o Compression test
  - o Density test
- Present a simple method of evaluating tests to obtain results

Constraints

- Baking must be performable with household baking equipment
- Results must be accurate and straightforward
- Tests must be completed within a budget of $200
- Gingerbread must retain its functionality as food

To satisfy the objectives outlined according to the constraints, Y_o Engineering has designed four tests that will examine gingerbread for tensile, cantilever beam, and compressive strengths and also measure its density. For the test case, only the fat used was varied while all other variables were kept constant to model the testing process.

1.4 Ranking of Requirements

The cantilever beam and tensile tests were decided to be the most important tests and contain the most important results needed to determine the structural properties of gingerbread. A table showing how ranking of requirements was conducted can be found in Appendix B.

2.0 Project Management

Firstly, a project definition and analysis were completed. A detailed analysis of the problem can be found in Section 1. Once the problem was fully defined and understood, a list of tasks was created, assigned to members of Y_o Engineering, and budgeted for time (Appendix A). Once this had been completed, a Gantt chart and PERF box flow chart were created and presented to the clients, and is also included in Appendix A. After this, an initial project budget was created (Table XXX).

Item	Cost
Precise Digital Scale	$60.00
Ingredients	$80.00
The Science of Cooking	$65.00

This budget was modified as the project progressed, and the final budget (Table XXX) still came in under budget.

Item	Cost
Precise Digital Scale	$46.49
Ingredients	< $50.00
Baking Supplies	$35.01
Testing Supplies	$32.94

A risk management plan was then developed, and three primary risks were identified:

- Burns and related heat injuries
- Salmonella and food related illnesses
- Choking

To manage these risks three corresponding contingencies were also implemented:

- Proper oven safety equipment and heat protection will be used
- Hand washing, egg washing and other Food-Safe practices will be observed
- To safeguard against choking a First Aid Level 1 trained individual will be on site during all consumption. Also, food should be adequately chewed.

The project progressed overall on time throughout the term, though preliminary testing extended beyond its allotted time due baking difficulties, and inconsistent results. This was made up for by decreasing the allotted time for analysis of the results, and the final demonstration and report were both delivered on time.

As a retrospective look at the project, it was mostly a success. The primary errors elaborated on below could be solved with a larger budget, such that better machinery and testing supplies could be used. Also, the earlier purchase of reference books could have potentially mitigated the baking difficulties and allowed Y_o to stay on schedule

3.0 Design

3.1 Conceptual Design

Research proved that preferred recipes and baking requirements varied from source to source. Each baker seems to have a personal preference for how gingerbread should be baked and what to avoid. A list of testable properties is included in Appendix B, though many were discounted to feasibility and practicality. It was determined that cantilever properties were the most important design function. Tensile and compressive responses, as well as density were also determined to be important.

3.1.1 Need for Consistency

When baking structural gingerbread, the affects of the variables listed below must be taken into account:

- Recipe
    - Quality and quantity of sweetening agent, fat, baking agent and flour
- Duration and temperature of chilling and baking
- Humidity of environment
- Baking equipment used

- Dimensions
- Thickness

All of these need to be considered to ensure uniformity throughout the gingerbread. Jann Johnson, in *Sweet Dreams of Gingerbread*, notes that "consistency throughout a project insures that all pieces fit together correctly" (p. 21). A flowchart outlining possible parameter decisions can be found in Appendix B.

3.1.2 Maintaining Consistency

In our test scenario, a timer was used to keep baking and chilling durations constant. Because Aaron Morgan emphasizes that "the colder your dough, the better it will retain its shape" (p. 12) we ensured the dough was thoroughly chilled before baking. Baking and chilling temperatures were kept constant by using the same appliances each time. Stencils were created to ensure constant dimensions when the piece entered the oven. As recommended by Aaron Morgan in *Making Great Gingerbread Houses* the procedure of cutting out the pieces before baking them was followed. Gingerbread, like most cookies, expands while baking (p. 14). To ensure the shape of the pieces is still consistent with the shape of the stencil, "place the template over the piece and trim the edges with a sharp, serrated knife before the dough cools, while it is still soft" (Matheson & Chatterman, p. 10).

Another common suggestion is to roll the gingerbread dough out on parchment paper for easy transfer to and from the baking sheet. Noonie Cargas, in *Gingerbread Houses: Baking & Building Memories*, explains how "if you have to move your pieces from the place where you're cutting them out to the pan on which they'll be baking, cut them out on parchment paper and then move the whole ensemble, then there is no distortion" (p. 14). In a further attempt to prevent distortion of the pieces, excess strips of dough from the cut cookies (Figure 1) were trimmed off after baking (Johnson, p. 21).

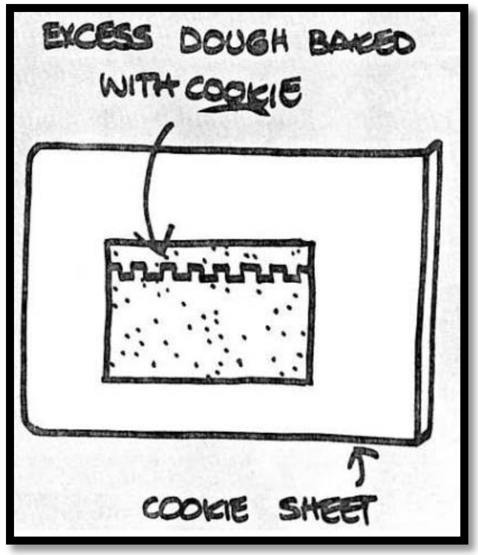

Figure 1 - Baking with Excess Dough (Johnson, p. 21)

Stencils and trimming ensure the size and shape of the piece. Using guides to ensure even thickness is also important. One way to produce an even thickness is “to use two yard sticks or other straight wooden sticks (Figure 2). Place them on the sides of your dough and roll flat. “The yardsticks prevent the rolling pin from pressing the dough flatter than the desired height” (Cargas, p. 17).

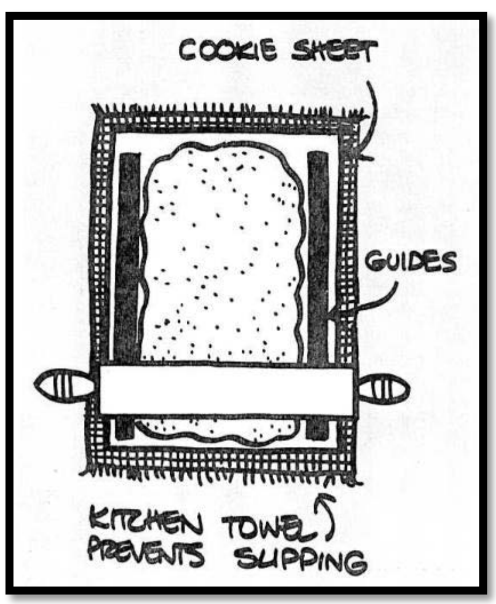

Figure 2 - Baking with Guides (Johnson, p. 20)

During baking cookies not only spread but also rise a slight amount. In an effort to restrict this rise to ensure a perfectly uniform thickness, compressing the gingerbread between two baking sheets while baking was tried. It was discovered, however, that it was better to let the gingerbread rise and measure its thickness again after baking since the rise was near uniform along the top surface.

Christa Currie, in *Gingerbread Houses*, cautions that one should keep baked cookies away from any high moisture producing source, such as a boiling teapot or a dishwasher in mid-cycle (p. 25). In an attempt to keep humidity constant, all cookies were baked on the same day and therefore susceptible to the same humidity. Further, it was ensured that no high moisture producing sources were in use.

According to the recipe chosen (Appendix C) baking time should be “about 10-20 minutes” (Johnson, p. 17). Baking guidelines in recipes are extremely tentative due to the wide variations in people’s ovens. Noonie Cargas suggests, “keep a close eye on your gingerbread, and when the sides begin to brown slightly, remove from the oven and cool” (Cargas, p. 16). After a few practice pans of gingerbread were baked, it was determined that the gingerbread should remain in the oven for exactly 10 minutes at 350°F, based on the size of the pan. It is important to wait until the pieces of gingerbread have completely cooled to check their strength, as they are always soft when warm. It was decided that allowing the gingerbread to cool on level, wire cooling racks for 45 minutes would be sufficient. Recipes from many sources were considered and a chart detailing ingredients in each is attached in Appendix B.

3.2 Detailed Design

When evaluating an architectural material, there are three main properties that should be considered; the tensile strength per density, the cantilever or shear stress per density, and the compressive strength. In order to correctly evaluate all of these, density, tensile, three-point bending and compression tests should be performed. In addition to these tests, a particle density test was performed in order to gain further insight into the compressive strength of the materials.

3.2.1 Density Testing

Density is a property that expresses the mass of an object per unit of volume. As such, to calculate density, the rectangular density samples were each measured and weighed. The ratio of the two measured constants gave overall density.

Gingerbread, however, is a porous material where a portion of its volume is occupied by air. Under compression, a porous material often reduces in volume without failure, though the change in dimensions can cause failure at other locations of the structure. Porosity testing was therefore decided as an effective test to perform. Testing for empty space is significantly more difficult than testing for occupied space, and considering the linear combination characteristic of heterogeneous density (Callister, p. 34), porosity can be easily derived from a density test and a particle density test. Particle density is identical to density, with the exception that the volume is calculated without air. This can be achieved by pulling a vacuum through the gingerbread and compressing it, or by submersing the gingerbread in water and measuring displacement. In Figure 3, it is evident that submersed gingerbread released a gas, the air trapped inside the porous bread, and once all the air has been liberated, the remaining displacement was only be the volume of the gingerbread particles.

Figure 3 - Density Test

With these obtained values, particle density can be found by: $Particle\ Density = \frac{\Delta\, mass\ of\ water}{displacement}$

The danger of utilizing experimental density in calculating porosity is that an error in density testing will propagate into an error in the particle density as well. Within a reasonable budget and without access to complex porosity testing machines, this is the only feasible method of testing. To account for the dependency on density, ample iterations to attempt to verify accurate density calculations was ensured.

3.2.2 Tensile Testing

In tensile testing, a sample was loaded in tension and the load and amount of elongation was measured. This load and elongation was then converted into stress and strain for ease of material comparison. When applying the basic principles of tensile testing to gingerbread (Callister, p. 144), however, an extremely brittle nature was immediately noticed. As such, the elastic portion of the stress strain curve is near vertical, and measuring any elastic characteristics is near-impossible without highly precise instruments. As such, failure stress and failure strain were the ideal values to calculate. The failure point of an architectural material without elastic elongation is also the most important property.

To ensure the stress on a sample was localized to one area, sample geometry was considered. As per standard practice (Callister, p. 137) an “I” shaped sample was used to localize the stress on the narrow neck. The other main aspect in tensile test design was the method of loading. One end of a sample needed to remain fixed while the other was loaded and free to extend. In our vertical tensile test (see 4.0 Optimization for rationale), the upper part of the sample was clamped in place and the lower end was attached to a hanging water container to be loaded (see Figure 4). Because the load was free hanging, a symmetric load needed to be maintained throughout the test to ensure equal loading. Using a fluid to load the sample, such as water, satisfied this criterion.

Figure 4 - Tensile Test

The failure stress of the material is given as; $\sigma = \frac{Load\ Inducing\ Failure}{Cross\ Sectional\ Area}$, where the area is given by the initial dimensions. To calculate the failure strain, $\varepsilon = \frac{\Delta\ Length}{Initial\ Length}$ where length pertains to the length of the neck of the sample (Callister, p. 137)

In evaluating the success of a tensile test, two aspects were verified. Firstly, the sample saw failure occur along the narrower neck, ideally in the center. Secondly, throughout the test the sample had no slippage with the clamps. To verify this, sandpaper was placed between the clamps and the sample, and after the test it was verified that there was no abrasion to the clamped portions of the sample.

3.2.3 Cantilever Testing

To evaluate the bending strength of a material, either a one-point bending or a three point bending test may be performed. The prime advantage to using a one-point bending test is that the deflection becomes significantly easier to measure. For a brittle material, however, deflection is always minimal, and therefore a three-point bending test was chosen in order to take advantage of its simpler and more consistent test design, as a three-point bending test does not require any clamps.

In three-point bending (Figure 5), a beam spanned a know distance and was loaded in the middle of the span. An important consideration to the bending tests was that the load needed to be applied consistently across the centre of the sample, and was designed to be as close to a line load as possible. A Zip-tie was used to support the load as its width was large enough that it wouldn't slice the sample during loading, but was also small enough to be reasonably assumed as a line load.

Figure 5 - Cantilever Beam Test

Using the dimensions of the beam, the distance of the span, the load and the maximum vertical deflection, failure stress and failure strain was respectively calculated as $\sigma = \frac{3*Load*Span}{2*width*depth^2}$, $\varepsilon = \frac{6*deflection*depth}{Load^2}$ (Callister, p. 144).

Evaluating this test was basic; as long as your loading device was consistent across the beam and failure occurs near the middle of the beam the test was considered adequate. The only other concern encountered was the effect of creep, and only for the more ductile samples. Ductility is an undesirable characteristic in an architectural recipe, however, so when severe creep was detected it was concluded that the gingerbread would be ineffective. Quicker loading practices overcame the creep, though accuracy was decreased.

3.2.4 Compressive Testing

Compressive testing involved subjecting the material to crushing forces until failure was induced. Pressure was used as the quantifying measurement, which is simply $P = \frac{Load}{Area}$ (Hibbeler, p. 22). The difficulty with gingerbread in compression, however, was being able to identify when failure occurred. Internal fractures were frequently observed after the load was removed, which discounted many results. Without precision-grade testing equipment, the best that compressive testing could supply was a qualitative comparison when a consistent load was applied to each of the samples that were being tested. Observations of the material were then compared with data from the other tests to draw conclusions.

4.0 Optimization

When considering tensile tests, one of the decisions that needed to be made was the angle at which the test would be performed at. Metal and construction material tests are typically performed horizontally, though with a material as sensitive as gingerbread this causes some difficulties. Factors such as the shear gravity of the sample, the frictional losses and gravitational losses become apparent when they are normally of a magnitude small enough to be neglected in metals. The shear gravity is the magnitude of force being applied vertically because of the sample's, and is derived trigonometrically (Appendix D). The frictional losses are proportional to the gravitational shear. Lastly, an inclined sample receives a loss in its weight in the vertical direction. This is found trigonometrically in Appendix D. Summing all of these drawbacks allowed for the optimization of the system, with the minimum being preferable. Figure 6 represents this optimization and shows that at 90° the drawbacks are minimized, thus a vertical tensile test was chosen.

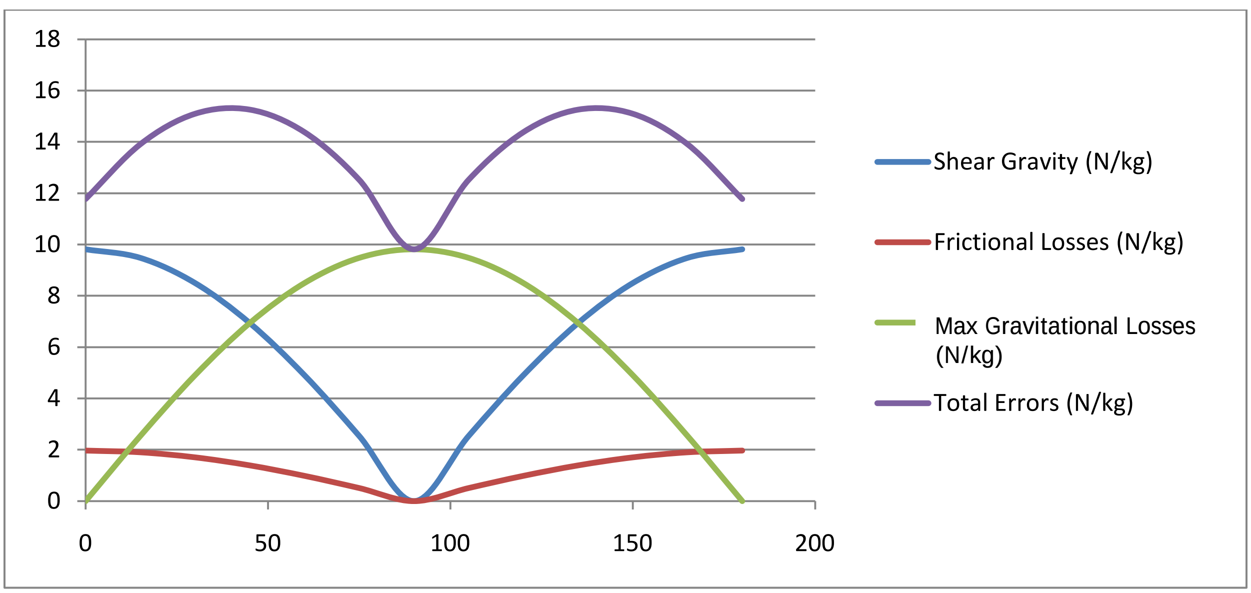

Figure 6 - Optimization

5.0 Environmental Impacts

An environmental impact assessment ensures that all likely effects of a new development on the environment are fully understood and taken into account before the development is allowed to go ahead. Overall, the impact of this project is negligibly small. All materials and testing equipment are found already present in the standard kitchen. The excess gingerbread baked to ensure that size of the piece is uniform is the only waste produced but is biodegradable and very delicious with icing. To reduce the impact gingerbread has on the environment, it can be baked with all local, organic ingredients. Figure 7 (Andropogon Associates, 2007) shows a purely environmental gingerbread house that includes sustainable and recycled materials, a water harvesting and storm water management as well as reduced resource consumption and waste.

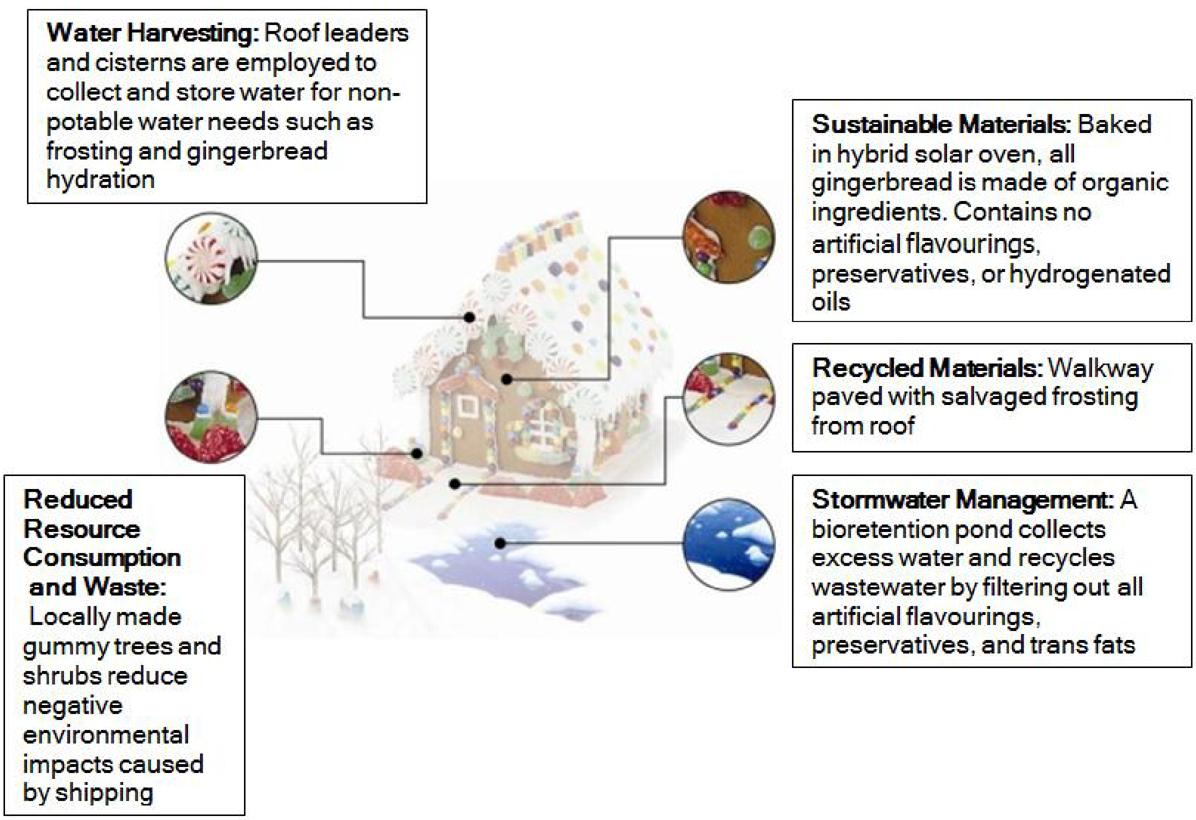

Figure 7 - Environmental Gingerbread House (Andropogon Associates, 2007)

6.0 Testing

As a demonstration of the presented testing protocol, Y_o Engineering has done an optimization on the variety of fat used to make gingerbread. Holding every other ingredient constant, the type of fat was varied as per the recipe attached in Appendix C. In order to maintain constant baking time, temperature and conditions, all of the samples for each test needed to be baked simultaneously. This limited the number of iterations for some of the tests; however the values were amply consistent to not require more. After conducting vertical tensile tests and three-point bending tests as per the previous sections, the values represented in Table 1 were received. The three-point bending and tensile tests are also fully laid out in Appendix F.

Table 1 - Average Test Values

	Tensile Testing		Cantilever Testing	
	Stress (kPa)	Strain (unitless)	Stress (kPa)	Strain (unitless)
Butter	22.935	0.06663	31.072	0.4816
Margarine	122.017	0	62.146	0.0448
Shortening	219.028	0.02237	66.130	0.0768

Compressive tests with a load of 336.46 kPa were also performed and the reactions of butter (Figure 7), margarine (Figure 8), and shortening (Figure 9) are included. Neither butter nor shortening failed under load, though the butter deformed significantly, which was interpreted as a structural failure.

Figure 8 - Butter Compressive

Figure 9 - Margarine Compressive

Figure 10 - Shortening Compressive

Density tests and particle density tests both yielded inconsistent results between the samples, which led us to believe that our equipment for measuring volume was not precise enough for the purpose. The entire sample set, however, returned values within the same range, so the rest of the comparison can be performed considering constant density across the samples.

It was observed that butter exhibited a very ductile condition throughout compression, and this was later supported with the largest strain values for both tension and bending. As well, the comparative loading on the butter to induce failure was significantly lower, lending the conclusion that butter is the worst structural gingerbread fat. Margarine and shortening performed similarly in bending, but because of the higher tensile strength of shortening, and considering that margarine failed under compression whereas shortening did not, it was concluded that shortening was the best fat for architectural gingerbread.

Gingerbread was also compared to a sand based concrete (data from (Callister, p. A14)) in an attempt to create a model material. As noticed in Figure 10 and Figure 11, the only recipe to quantitatively model concrete was butter, however qualitatively butter was quite ductile which directly contradicted the brittle concrete. As such, it was also concluded that gingerbread was not an adequate model for a sand-based concrete.

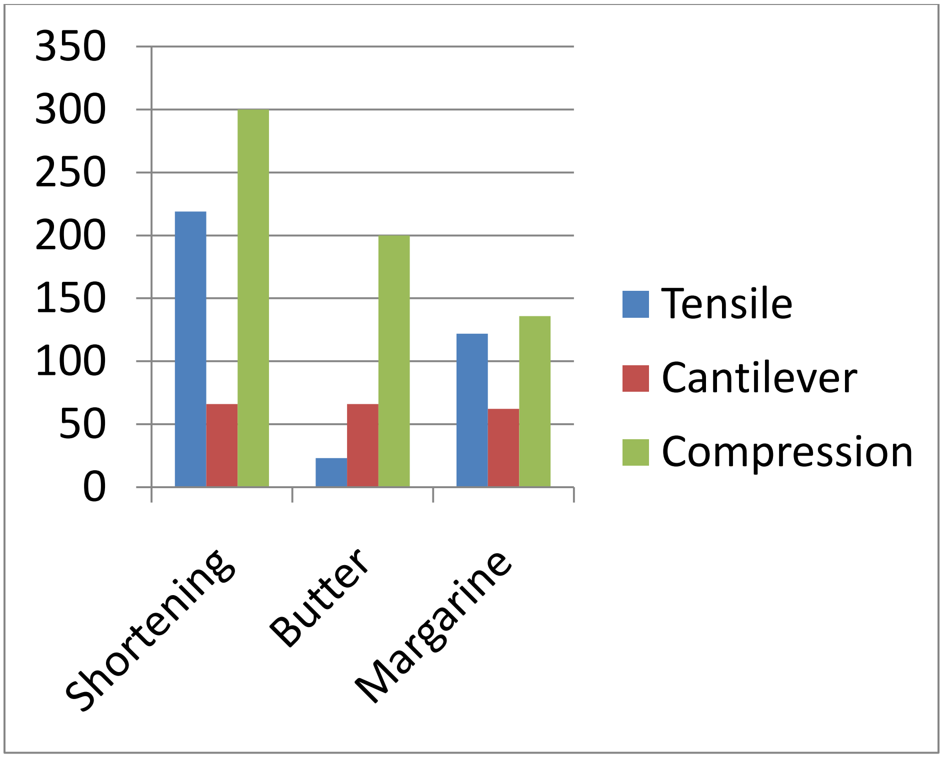

Figure 11 - Relative Strengths of Gingerbread

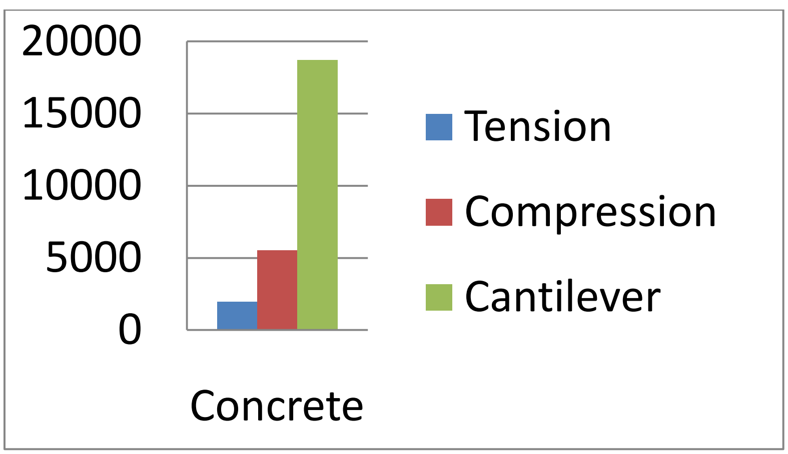

Figure 12 - Relative Strength of Concrete

All data from this test scenario can be found in Appendix E.

7.0 Conclusion

Y_o Engineering was requested to design a series of tests to analyze the strength of structural gingerbread. The designed tests allow for the user to test for tensile, cantilever and compressive strengths as well as the density. Y_o Engineering considered many test parameters and following discussion and practice testing, these four tests were finalized and carried out to demonstrate the effectiveness of the designed tests. The tests completed by Y_o Engineering show an optimization on the variety of fat used within the recipe. The analysis of the test results required simple formulas and can easily be applied to any other batch of gingerbread tested according to the outlined methods. The designed tests output the necessary information and are valid to use at home when trying to decide which recipe will best suit any individuals' gingerbread baking needs.

8.0 References

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Matheson, S., & Chatterman, L. (2008). *The Gingerbread Architect: Recipes and Blueprints.* New York: Random House Inc.

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9.0 Appendix

9.1 Appendix A: Project Management Overview

Table XXX - Task Definition and Division

Task	**Task Owner**	**Task Duration** (day is not 24 hrs)
Presentation #1	Sean	2 days
Decide on ingredient to optimize	Sean & Mercedes	1 day
Chose a recipe	Mercedes	1 day
Design multiple tests	Sean & Mercedes	4-6 days
Shop for necessary ingredients/supplies	Sean & Mercedes	1-2 days
Presentation #2	Mercedes	2 days
Complete tests	Sean & Mercedes	4-6 days
Document tests	Mercedes	4-6 days
Analyze results	Sean & Mercedes	2-3 days
Presentation #3	Sean	2 days
Document results	Sean	1-2 days
Prepare for final demonstration	Sean & Mercedes	2-3 days or 6-8 days
Final presentation	Sean & Mercedes	3 days
Create gingerbread in SolidWorks	Sean	3-4 days
Compile results and create final report	Sean & Mercedes	4-6 days

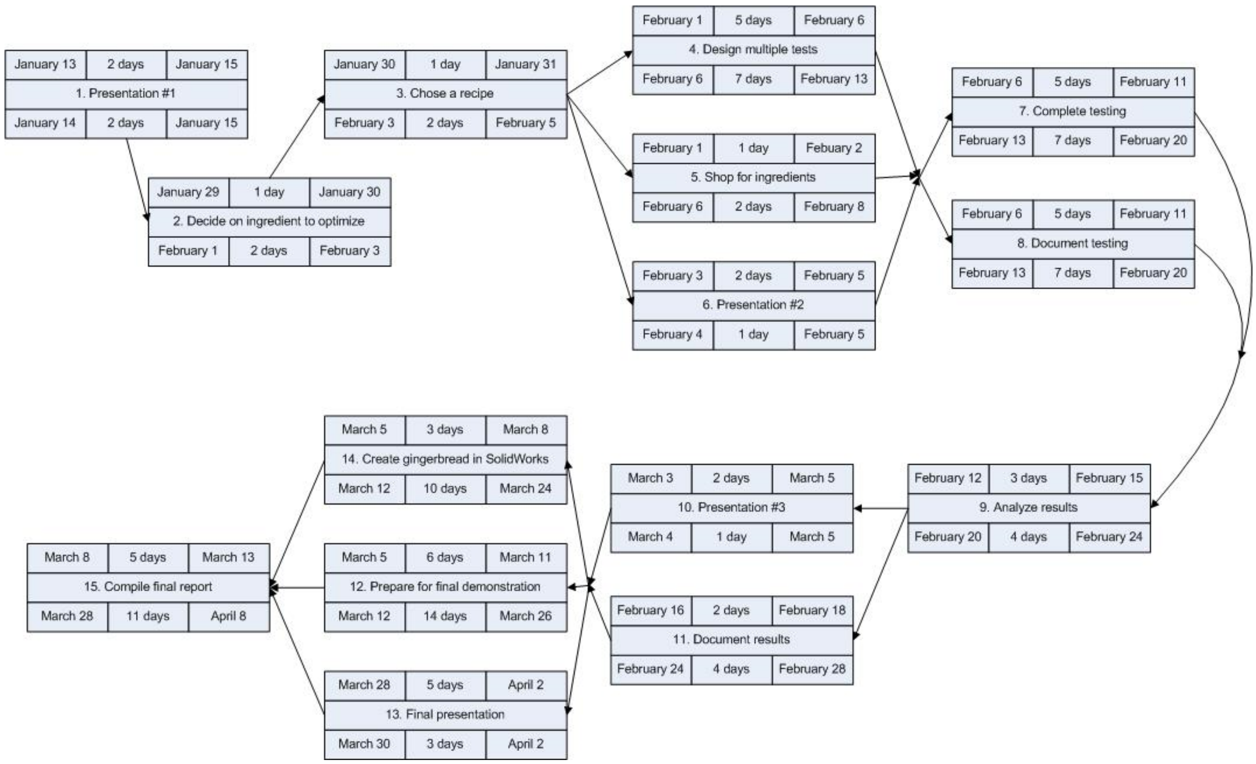


Figure XXX - PERF Box Flow Chart

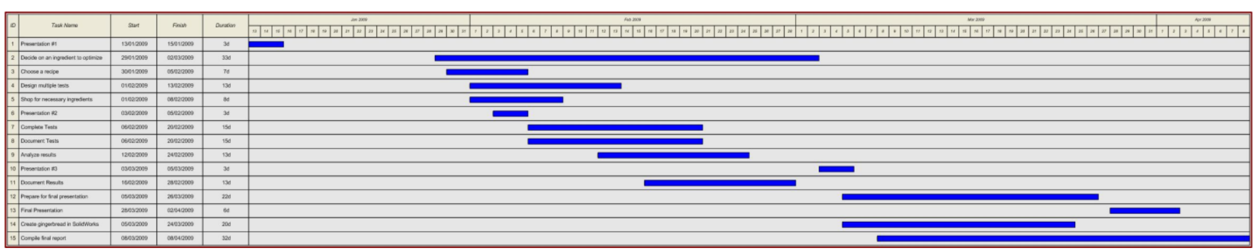


Figure XXX - Project Gantt Chart

9.2 Appendix B: Test Design Considerations

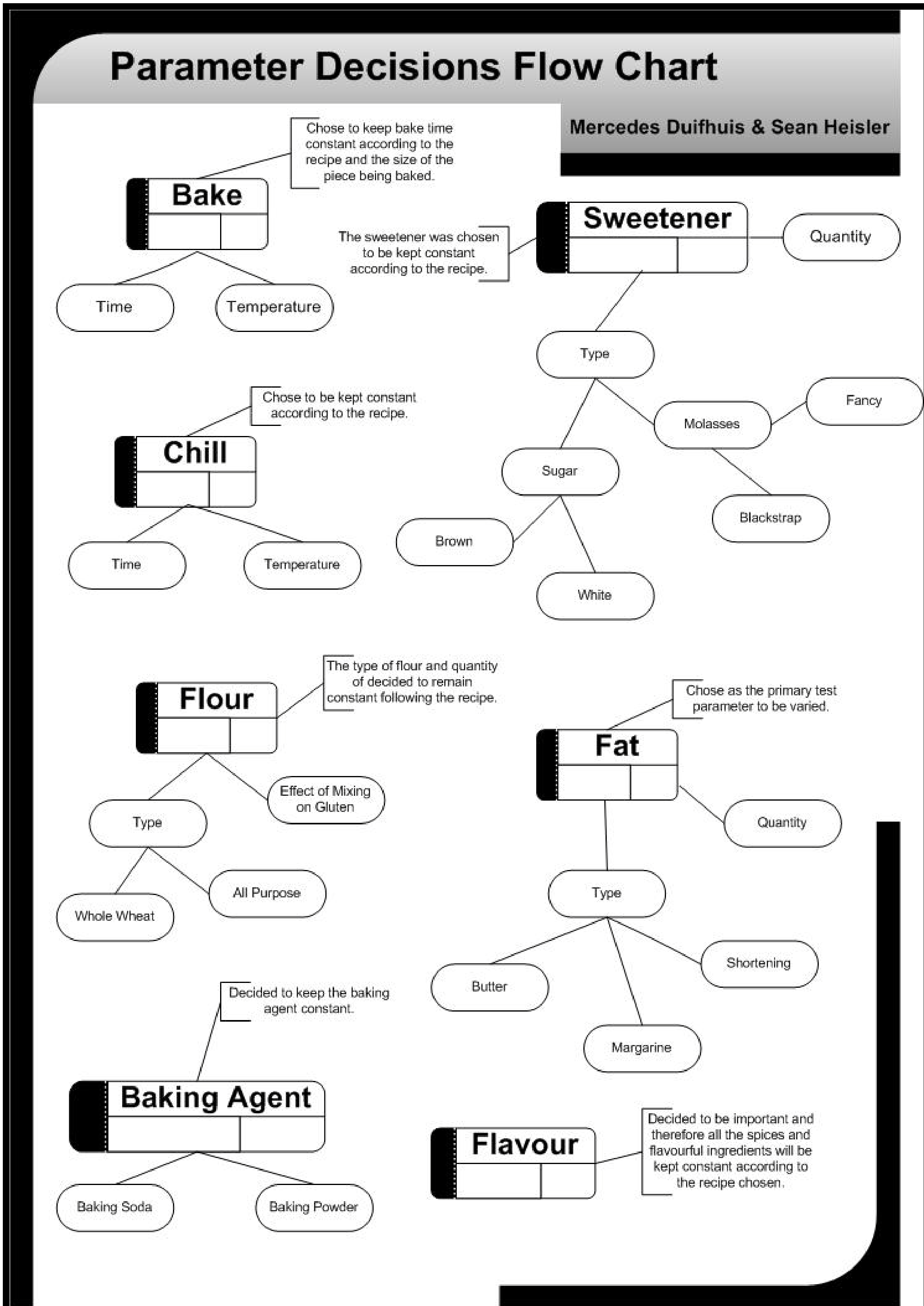


Figure A 1 - Parameter Decisions Flow Chart

Table A 1 - Ranking of Requirements (Tests)

	Tensile Test	Cantilever Beam Test	Compression Test	Density Test	Score
Tensile Test	X	0	1	1	2
Cantilever Beam Test	1	x	1	1	3
Compression Test	0	0	x	1	1
Density Test	0	0	0	x	0

Table A 2 - Ranking of Requirements (Results Analysis)

	Tensile Analysis	Cantilever Analysis	Compression Analysis	Density Analysis	Score
Tensile Analysis	X	0	0	1	1
Cantilever Analysis	1	x	1	1	3
Compression Analysis	1	0	x	1	2
Density Analysis	0	0	0	x	0

Table A 3 - Comparison of Ingredients for Various Recipes

	1	2	3	4	5	6	7
butter	x			x			x
shortening	x	x			x	x	
margarine	x		x				
granulated sugar	x	x			x	x	x
brown sugar	x	x	x	x			
salt	x	x	x	x	x	x	x
baking soda	x	x		x	x		x
ginger	x	x	x	x	x	x	x
cinnamon	x	x	x	x	x	x	x
nutmeg	x				x		
molasses	x	x		x	x	x	
water	x			x		x	
all-purpose flour	x	x	x	x	x	x	x
baking powder		x				x	
eggs		x					x (yolk only)
white vinegar		x					
corn syrup			x				

Legend for Table A 3 - Comparison of Ingredients for Various Recipes

1 - Architectural Dough (Johnson, p. 17)

2 - Gingerbread Dough (Matheson & Chatterman, p. 83)

3 - Gingerbread Dough (Layman & Morgenroth, p. 12)

4 - Gingerbread Dough (Morgan, p. 34)

5 – Gingerbread (Currie, p. 26)

6 – Gingerbread Recipe (Cargas, p. 16)

7 – Golden Gingerbread (Farrow, p. 6)

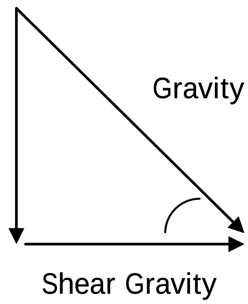
Considered Testable Properties:

- Tensile Strength
- Elastic Modulus
- Thermal Conductivity
- Thermal Expansion
- Density
- Compressive Strength
- Specific Heat
- Shear Modulus
- Poisson’s Ratio
- Bending Strength

9.3 Appendix C: Test Case Recipe

9.4 Appendix D: Equations and Derivations

Considering a right triangle:

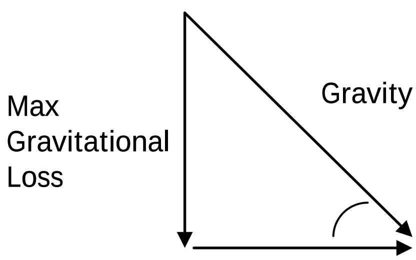


Shear Gravity = Gravity * cos (angle)

Magnitude of Shear Gravity = abs (Gravity * cos (angle)), with Gravity = 9.81 N/kg

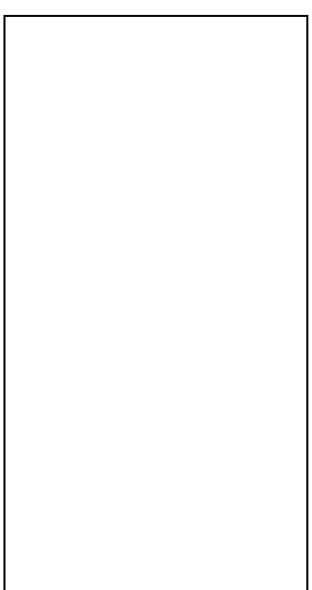
Frictional losses = Magnitude of Shear Gravity * Frictional Coefficient

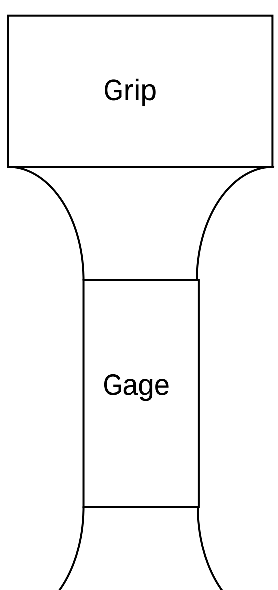
For an inclined sample, the maximum gravitational loss is given by the vertical component of the sample’s weight



9.5 Appendix E: Test Case Data

Stencil Templates





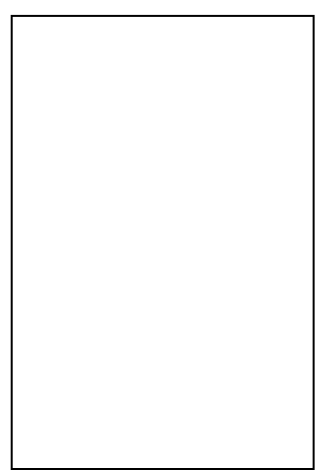


Figure XXX - Density and Compressive Stencil

Table A 4 - Tensile Test Results

Trial	Mass (kg)	Force (N)	Area (m^2)	Stress (Pa)	Initial Length (m)	Final Length (m)	Strain ( )	Valid?
S1	1.807	17.73	0.000075	236400	0.045	0.047	0.044	Yes
S2	1.593	15.62	0.000075	208300	0.044	0.045	0.023	Yes
S3	Failed in Transport				0.045			No
S4	1.892	18.56	0.000075	247500	0.045	0.045	0	Yes
S5	Failed In Transport				0.046			No
S6	1.406	13.79	0.000075	183900	0.046	0.047	0.022	Yes
S7	1.783	17.49	0.000075	233200	0.044	0.044	0	Yes
S8	1.665	16.34	0.000075	217800	0.044	0.046	0.045	Yes
S9	1.576	15.46	0.000075	206100	0.045	0.046	0.022	Yes
M1	0.950	9.32	0.000090	103600	0.042	0.042	0	Yes
M2	0.995	9.77	0.000090	108500	0.045	0.045	0	Yes
M3	1.236	12.12	0.000090	134700	0.046	0.046	0	Yes
M4	0.282	2.77	0.000090	30730	0.041	0.042	0.024	No, Defect
M5	1.173	11.51	0.000090	127900	0.045	0.045	0	Yes
M6	0.164	1.61	0.000090	17870	0.043	0.045	0.047	No, Defect
M7	Failed in Transport							No
M8	1.161	11.39	0.000090	126500	0.047	0.047	0	Yes
M9	1.201	11.78	0.000090	130900	0.043	0.043	0	Yes
B1	Failed in Transport							No
B2	Failed in Transport							No
B3	0.191	1.88	0.000070	26790	0.046	0.049	0.065	Yes
B4	0.177	1.74	0.000070	24820	0.045	0.047	0.044	Yes
B5	0.140	1.37	0.000070	19600	0.047	0.05	0.064	Yes
B6	0.093	0.91	0.000070	13050	0.042	0.043	0.024	No, Defect
B7	Failed in Transport							No
B8	0.146	1.44	0.000070	20530	0.043	0.047	0.093	Yes
B9	0.068	0.67	0.000070	9560	0.047	0.050	0.064	No, Defect

Table A 5 - Cantilever Beam Test Results

Trial	Mass (kg)	Force (N)	Width (m)	Depth (m)	Length (m)	Deflection (m)	Stress (Pa)	Strain ( )	Valid?
S1	0.221	2.17	0.004	0.042	0.150	0.007	69110	0.078	Yes
S2	0.212	2.08	0.004	0.042	0.150	0.005	66290	0.056	Yes
S3	0.176	1.73	0.004	0.042	0.150	0.006	55200	0.067	Yes
S4	0.187	1.83	0.004	0.042	0.150	0.008	58430	0.090	Yes
S5	0.044	0.43	0.004	0.042	0.150	0.001	13760	0.011	No, Defect
S6	0.231	2.26	0.004	0.042	0.150	0.007	72210	0.078	Yes
S7	0.216	2.12	0.004	0.042	0.150	0.009	67660	0.101	Yes
S8	0.237	2.32	0.004	0.042	0.150	0.006	74010	0.067	Yes
S9	Failed in Transport								No
M1	0.061	0.60	0.005	0.042	0.150	0.000	15300	0.000	No, Defect
M2	0.290	2.84	0.005	0.042	0.150	0.005	72460	0.056	Yes
M3	0.271	2.66	0.005	0.042	0.150	0.004	67940	0.045	Yes
M4	Failed in Transport								No
M5	Failed in Transport								No
M6	0.240	2.36	0.005	0.042	0.150	0.004	60130	0.045	Yes
M7	0.142	1.39	0.005	0.042	0.150	0.003	35430	0.034	No, Defect
M8	0.225	2.21	0.005	0.042	0.150	0.003	56370	0.034	Yes
M9	0.215	2.11	0.005	0.042	0.150	0.004	53830	0.045	Yes
B1	0.065	0.64	0.005	0.042	0.150	0.001	16280	0.011	No, Defect
B2	0.011	0.10	0.005	0.042	0.150	0.000	2670	0.000	No, Defect
B3	Failed in Transport								No
B4	0.110	1.08	0.005	0.042	0.150	0.043	27630	0.482	Yes
B5	0.140	1.37	0.005	0.042	0.150	0.047	34990	0.526	Yes
B6	0.131	1.28	0.005	0.042	0.150	0.039	32720	0.437	Yes
B7	Failed in Transport								No
B8	0.125	1.22	0.005	0.042	0.150	0.046	31170	0.515	Yes
B9	0.115	1.13	0.005	0.042	0.150	0.040	28850	0.448	Yes

Table A 6 - Density Test Results

Trial	Mass (kg)	Volume (m^3)	Density (kg/m^3)
S1	0.03	3.27E-05	917.38
S2	0.027	3.27E-05	825.64
S3	0.029	3.27E-05	886.80
S4	0.034	3.27E-05	1039.69
M1	0.031	4.14E-05	749.34
M2	0.033	4.14E-05	797.68
M3	0.041	4.14E-05	991.06
M4	0.028	4.14E-05	676.82
B1	0.025	4.09E-05	611.58
B2	0.024	4.09E-05	587.12
B3	0.031	4.09E-05	758.36
B4	0.035	4.09E-05	856.22

Table A 7 - Particle Density Test Results

Trial	Mass (kg)	Displacement (m)	Cylinder Area (m^2)	Volume (m^3)	Density (kg/m^3)
S1	0.076	0.023	0.00363	8.35E-05	909.89
S2	0.081	0.021	0.00363	7.63E-05	1062.11
S3	0.077	0.019	0.00363	6.90E-05	1115.94
S4	0.074	0.025	0.00363	9.08E-05	815.07
M1	0.076	0.022	0.00363	7.99E-05	951.25
M2	0.081	0.026	0.00363	9.44E-05	857.86
M3	0.082	0.018	0.00363	6.54E-05	1254.43
M4	0.073	0.016	0.00363	5.81E-05	1256.34
B1	0.069	0.022	0.00363	7.99E-05	863.64
B2	0.077	0.023	0.00363	8.35E-05	921.87
B3	0.074	0.026	0.00363	9.44E-05	783.72
B4	0.076	0.021	0.00363	7.63E-05	996.55

9.6 Appendix F: Sample Cantilever Test Documentation

Test: Gingerbread Cantilever Beam Test

Purpose of Test: Evaluate the bending strength of a beam-shaped cantilever sample

Test Procedure:

Measure the initial dimensions of the beam.

Length: ________________ Width: __________________ Depth: ___________________

Measure the length of the span.

Length: ________________

Place the beam over the span and ensure the beam is centered.

Are the lengths of gingerbread overlapping the support on each side of the span equal?

Yes No

Place the loading device at the center of the gingerbread sample.

Is the loading device also centered with respect to the span? **Yes** No

Load the sample incrementally, and record deflection with each increment. Continue until the sample fails.

Did the sample fail near the center? **Yes** No

Archive the largest load and corresponding deflection for analysis.

If any "No" response is circled, the test was defective. Disregard data.

Deviations from protocol:

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Tested By: ____ Date: __________________

Verified By: ____ Date: __________________

Test: Gingerbread Tensile Test

Purpose of Test: Evaluate the tensile strength of an "I" shaped gingerbread tensile sample

Test Procedure:

Measure the initial dimensions of the sample's gage section.

Length: ________________ Width: __________________ Depth: ___________________

Clamp one of the sample's grips to the supporting structure.

Is there sandpaper between the gingerbread and the clamp?	**Yes**	No
Is the sample hanging vertically (at 90° to level)?	**Yes**	No

Clamp the loading mechanism to the sample's lower grip.

Is the loading mechanism free hanging	**Yes**	No
Is the sample hanging vertically (at 90° to level)?	**Yes**	No

Carefully load the sample incrementally, and record new gage length with each increment. Continue until the sample fails.

Did the sample fail near the center of the gage?	**Yes**	No
Are both sides of both gingerbread grips free of abrasion?	**Yes**	No

Archive the largest load and corresponding gage length for analysis.

If any "No" response is circled, the test was defective. Disregard data.

Deviations from protocol:

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Tested By: ____ Date: ___________________

Verified By: ____ Date: ___________________