IQP SYS - 1830

Correlation of Textural qualities in a pound cake to the mechanical behavior

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Degree of Bachelor of Science

By

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Michael Blaess

Advisor

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Professor Satya Shivkumar

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Abstract

The texture of a pound cake is determined by the mechanical and physical properties of the overall product. While the effects of ingredients and baking conditions on various types of cakes have been studied previously, a mechanical model for the development of properties has not been established. The purpose of this project was to correlate the textural properties of pound cakes produced under various conditions to their mechanical behavior. Samples were baked at temperatures of 175 °C, 200 °C, and 225 °C and aged for 0, 1, 3, and 6 days. The compressive and viscoelastic properties of these cakes were estimated and correlated to texture. Various changes occurring during the baking of cake were demonstrated and the time needed to transition from a brittle to plastic foam was established. The data can be used to assess the effects of baking on texture and highlight the changes occurring during storage.

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1. Introduction

In recent years, Food Engineering has progressed dramatically as research teams have conducted studies examining the changes in physical and mechanical behavior with varied ingredients and processes. Specifically, research in pound cakes has examined the roles of starch, gluten, and protein of the functionality of the pound cake system and the changes in the mechanical properties. In order to advance the understanding of pound cakes, the temperature and aging of the sample were examined the changes in the stress-strain relationship, maillard reaction, and volume expansion.

The pound cake a simple recipe in which all standard ingredients are within a 1:1 ratio with one another. Pound cake is a cellular solid, a recurring material in nature and industry in which the basic structural unit is a repeating unit. The standard pound cake recipe utilizes both mechanical and chemical agents to incorporate air into the batter. The incorporation of air causes the resulting cellular solids to form a foam. The known behavior of cellular foams can be used to determine the physical and mechanical properties of the pound cake system under varied temperature and time after baking. For example, the behavior of the stress-strain relationship for brittle and non-brittle cellular foams is known.

In any study, the adherence to a standard is necessary to produce reliable data and allow the repeatability of the study. The standards set by the American Association of Cereal Chemists (AACC) were followed in order to achieve this.

2. Background Research

In recent years, the study of pound cakes has examined the effect of proportions or modified of ingredients on the physical and mechanical properties. Previous research on pound cake systems have focused on the variance the modification of different ingredients

2.1 Pound Cake

A Pound cake made of butter, eggs, sugar, and flour in a 1:1 ratio. The name Pound cake is derived from the traditional recipe containing roughly one pound of the four ingredients. Other ingredients are added for mechanical purposes (i.e. baking power) and taste (i.e. vanilla extract, ect.).

Figure 1 - Standard Pound Cake [1]

2.2 Cellular Solids

A cellular solid constitutes “an interconnected network of solid struts or plates which form the edges and faces of cells” or three-dimensional structural networks with repeating units [2]. Foams, a subgroup of cellular solids, are unique because gas is introduced mechanically or chemically into the mix prior to formation. The process to create a foam principally involves (1) mixing cake batter (mechanical stirring) and (2) adding baking powder (chemical blowing agents) to incorporate air into the mixture resulting in the creation of a foam. Figure 2 shows examples of the cellular solid structure of foams.

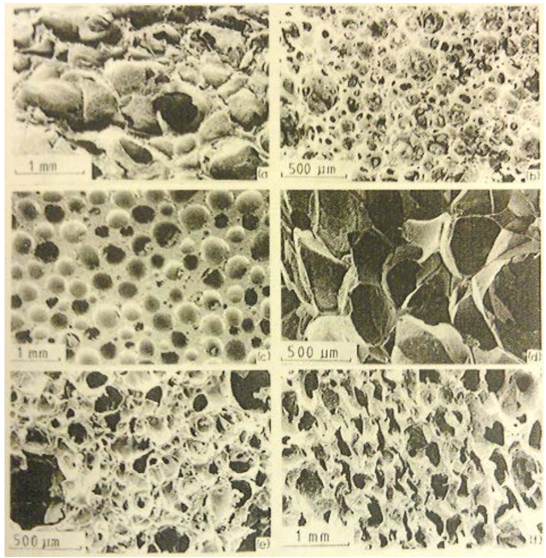

Figure 2 - Examples of Food Foams: (a) Bread, (b) Meringue, (c) Chocolate Bar, (d) Junk Food Crisp, (e) Malteser, (f) Jaffa Cake [2]

Altering the variables of the prepared mixture prior to and during the formation of a foam determines the mechanical properties. The cubic model of an open faced cell foam undergoes is represented in Figures 3-5 and the stress strain relationship is modeled in Figures 6 – 8.

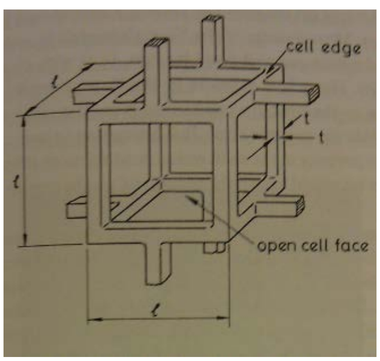

Figure 3 - Open Cell Foam Formation

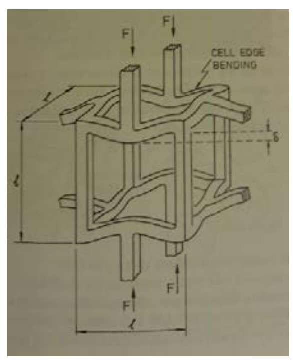

Figure 4 - Open Cell under Compression

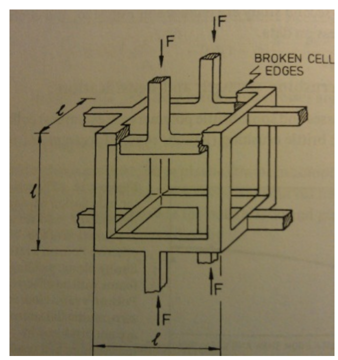

Figure 5 - Brittle Open Cell Foam under Compression

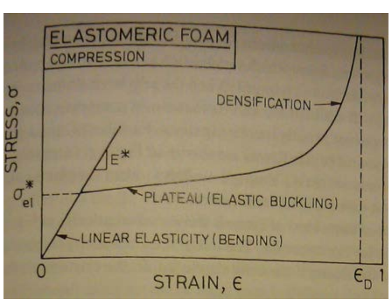

Figure 6 - Elastomeric Foam Stress Strain Curve

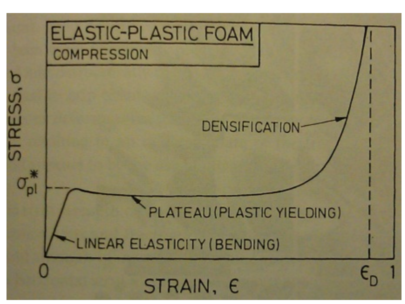

Figure 7 - - Elastic-Plastic Foam Stress Strain Curve

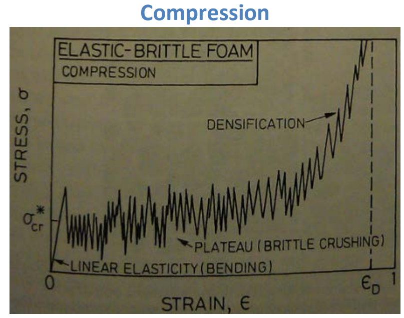

Figure 8 - - Elastic-Brittle Foam Stress Strain Curve [3]

2.3 Maillard Reaction

The occurrence of the maillard reaction or commonly known as the browning effect is cause by the thermal processing of the amino acids (found in eggs) and sugars [4]. Previous research has discovered the primary mechanism of control for this reaction to be the thermal energy. Therefore control of the temperature during baking controls the extent of the maillard reaction. Another type of browning is caramelization which only utilizes sugar, but not the amino acids during the reaction.

2.4 Standards

2.4.1 AAC 1090.01

The AACC has developed standards for cake batter preparation, cooking, and testing. The AACC 10-90.01: Baking Quality of Cake Flour is a method for producing and evaluating cakes, but requires a large quantity of ingredients in order to produce iterations of samples.

2.4.2 Micro Method for Cake Baking

Another standard developed by the AACC entitled “A Micro Method for Cake Baking (High Ratio, White Layer)” utilizes 2.5% (by weight) of the amount of ingredients in the AACC 10-90.01 method [5]. This method is ideal because it produces similar quality samples while being more economical and able to produce more iterations of samples. This method utilizes a non-stick muffin pan instead of a baking pan. Another advantage of this method is the production of up to 12 samples subjected to the same baking conditions, allowing for further analysis of the pound cake baking process.

3. Objectives

1. Understand cake structure

2. Understand the stress-strain relationship of pound cake

3. Study the effect of baking temperature and time on the stress-strain relationship and maillard reaction of pound cake.

4. Study the effect of baking temperature on the maillard reaction and volume expansion of pound cake.

4. Materials and Methods

A modified procedure of the AACC micro method for cake baking was adhered to as well as the practices performed and documented by previous research groups.

4.1 Materials and Equipment

The use of fresh ingredients in this study was essential in order to obtain reliable data. All ingredients were purchased from commercial suppliers. These supplies were all-purpose flour, granulated sugar, butter, egg whites obtained from large brown eggs, baking powder, and ionized salt.

A standard kitchen and commercial products was used to produce the samples while the produced samples were tested in Washburn Laboratories using an Instron Model 4201 Table Top Electromechanical Test System.

Figure 9 - Equipment Used during Baking Process

Figure 10 - Thermal Couple in Commercial Convection Oven

4.2 Cake Batter Preparation

The cake batter was prepared in a methodical process similar to the methods used by previous research teams. The ingredients were weighed in increments according to Table 1 in order to prepare a batch of samples. The dry ingredients (flour, sugar, butter, baking powder, and ionized salt) were added and mixed on setting 3 of the electric mixer for 3 minutes. The wet ingredients (egg whites) were then added and mixed on setting 3 of the electric mixer for 7 minutes. The cake batter was added to the sections of the muffin pan in 40 gram increments. The weight increments used in the cake batter preparation produced 8 viable samples.

Ingredient	Weight (g)
Flour	100
Sugar	100
Butter	100
Eggs	100
Baking Powder	2
Ionized Salt	1

Table 1- Cake Batter Ingredients by Weight

Figure 11 - Cake Batter Preparation

Figure 12 - Cake Batter undergoing convection cooking in non-stick muffin pan

4.3 Cooking

The samples were placed equidistant from all sides and heating elements to ensure regulated baking among iterations of samples. A thermal couple was used to monitor the temperature in the oven prior to baking. 15 minutes was chosen to be the standard time after observances of the Micro Method for cake baking adapted for pound cake samples. The baking temperatures were chosen to be (175, 200, and 225)°C. Samples were removed easily because of the implementation of a non-stick muffin pan.

Figure 13 - Post Cooked Pound Cake Samples

4.4 Compression Testing

The compression tests were conducted using the Instron experimental setup, a metric ruler, and HD video recorder. The pound cake samples were prepared by cutting the rounded or conical shaped tops to create a rough cylinder. The video recorder was used to determine the initial and final heights of the samples and the expansion rate after compression. The samples were compressed between a range of 30% and 50% of the original volume. The compression testing was only repeated twice for samples subjected to the same temperature and aging conditions.

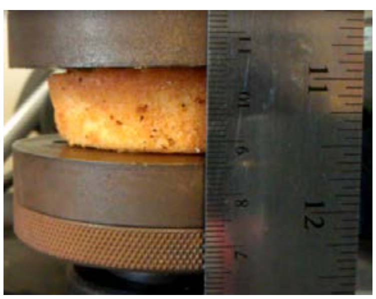

Figure 14 - Sample before compression

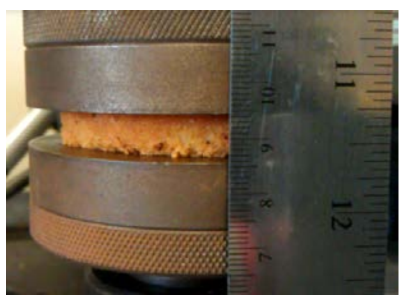

Figure 15 - Sample during compression

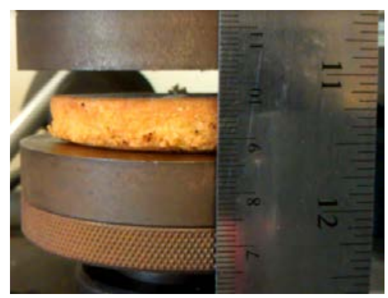

Figure 16 - Sample after compression

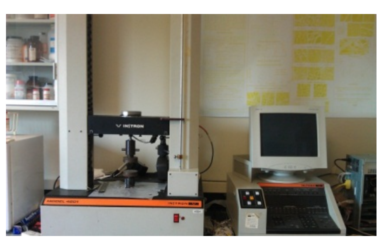

Figure 17 - Instron Model 4201 Table Top Electromechanical Test System in Washburn Laboratories

4.5 Measuring the Maillard Reaction

In order to measure the maillard reaction or browning effect of the crust of the pound cake samples, MATLAB software was utilized to measure the relative intensity of the color against a known color. The same MATLAB coding was used in adherence to the research team studying "Textural Variation of Pizza in Commercial Establishments" [6]. A standard color intensity equation was used in which colors closest to white had higher values than those closer to black. The MATLAB setup is displayed below in Figure 18. The test was repeated five times for multiple samples to ensure accuracy and precision.

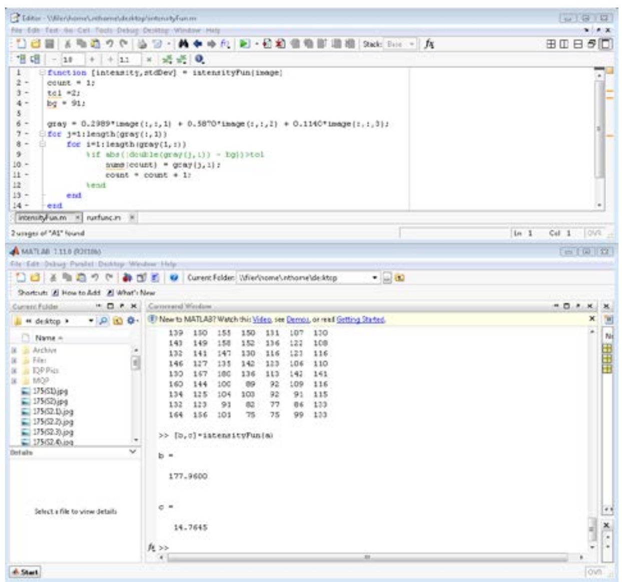

Figure 18 - Mathcad Software for Maillard Reaction Analysis

4.6 Height Expansion

The samples were allowed to cool for 30 minutes in order to reach thermal equilibrium. The height was measured at the apex of the sample three times in order to ensure accuracy of the measurement. The test was repeated five times for multiple samples.

5. Results and Discussion

5.1 Compression Tests

A plot of force over time was obtained from the Instron experimental setup and then converted into a stress-strain curve using the known cross head speed, diameter of the pound cake, and initial height of the sample. Examples of the resultant stress-strain curves are shown below in Figures 19 and 20 while the Appendices contain all other stress strain curves. The relationship is compliant to the example cases in Ashby's text. The pound cake sample baked at 175 °C, shown in Figure 19, was immediately tested after baking. The sample exhibited behavior of an Elastic-Plastic Foam as it transitioned smoothly from the regions of linear elasticity, plastic yielding, and densification. The other stress-strain curve represented in this section underwent the same aging conditions, but was baked at 200 °C. The sample exhibited behavior of an Elastic-Brittle Foam because the plateau region was characterized by brittle crushing.

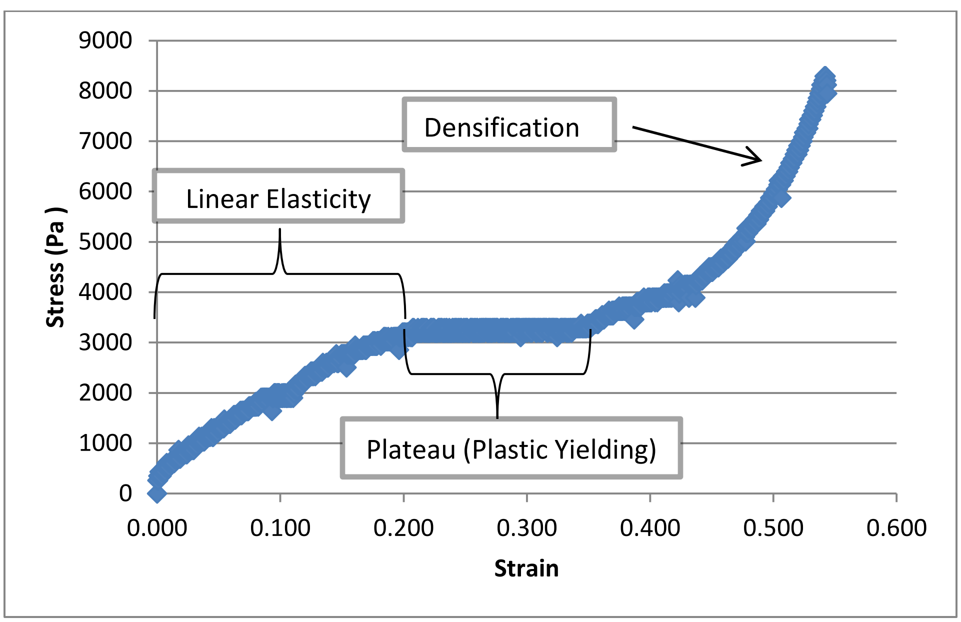

Figure 19 - Stress - Strain Curve (0 Days, 175 °C, Sample 2)

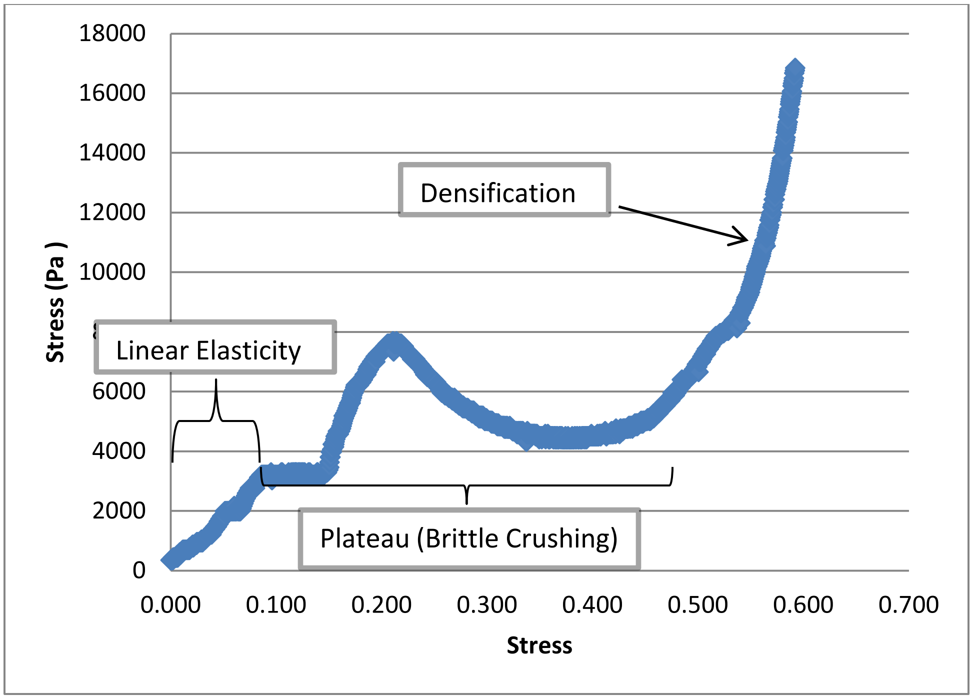

Figure 20 - Stress - Strain Curve (0 Days, 200 °C, Sample 1)

Figures 21 – 23 demonstrate the process undergone by a sample baked at 225°C with no aging. The outer layer forms a very brittle material which fails when compressed. The same outer layer was achieved by samples baked at 225°C with no aging, shown in Figure 24 below.

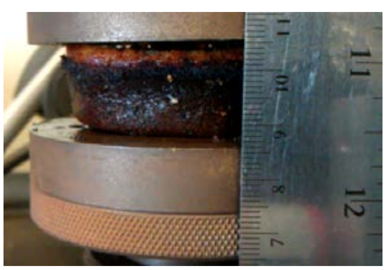

Figure 21 - Sample Baked at 225°C and No Aging Before Compression

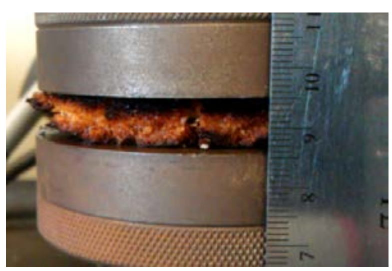

Figure 22 - Sample Baked at 225°C and No Aging During Compression

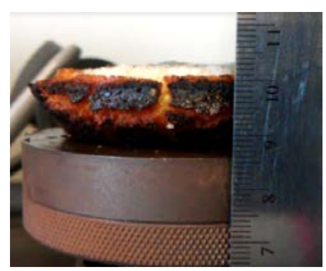

Figure 23 - S ample Baked at 225°C and No Aging After Compression

Figure 24 - Samples Baked at 200 °C and No Aging

5.1.1 Analysis of Temperature and Aging on Strain

The effect of temperature and aging for samples baked at 175 °C and 225 °C on the elastic strain was inversely proportional. Table 2 and 3 demonstrate the relationship between temperature sample aging and elastic strain. As baking temperature and aging increases, the region of linear elasticity is reduced causing the sample becomes brittle.

Days after Baking	Elastic Strain
1	0.0640 ± 0.0057
3	0.0560 ± 0.3281
6	0.0325 ± 0.0035

Table 2 - Measure of Strain on aged 225 °C Samples

	Elastic Strain		
T (°C)	**1 Days**	**3 Days**	**6 Days**
175	0.1035 ± 0.0035	0.1235 ± 0.0375	0.0990 ± 0.0127
200	0.0675 ± 0.0078	0.1240 ± 0.0071	0.1195 ± 0.0247
225	0.0640 ± 0.0057	0.0560 ± 0.3281	0.0325 ± 0.0035

Table 3 - Measure of Strain on Various Samples

5.1.2 Analysis of Elastic Modulus

The elastic modulus increases with temperature, reflected in Table 4 below. The primary reason for the increased elastic modulus in the samples baked at 225 °C is the stress relief exhibited by the pound cake's cellular foam as the Gibbs free energy is reduced over time. More data is needed to analyze the effect of aging in samples baked at 175 °C and 200 °C due to inconsistencies.

	Elastic Modulus (kPa)		
T (°C)	**1 Days**	**3 Days**	**6 Days**
175	15.88 ± 2.67	19.29 ± 5.91	17.11 ± 4.17
200	21.81 ± 1.95	24.03 ± 0.80	20.03 ± 0.69
225	25.56 ± 2.63	24.29 ± 0.99	34.30 ± 1.66

Table 4 - Measure of Elastic Modulus on Various Samples

5.2 Height Expansion

The heights of the pound cake samples increased as the temperature increases. During a qualitative assessment, it was observed the samples cooked at 200 °C and 225 °C achieved a well formed and conical structure while the sample cooked at 175 °C achieved a less structured dome shape.

T (°C)	h_0 (cm)	h_1 (cm)	%Increase
175	**1.5**	3.3833	125.5555556
200	**1.5**	3.4	126.6666667
225	**1.5**	3.5167	134.4444444

Table 5 - Average Heights Before and After Baking

Figure 25- Illustration of Heights with Temperature; from left to right (225, 200, 175)°C

5.3 Maillard Reaction

The relative intensity of the color was measured and listed in Table 7 to measure the browning effect. Lower intensities are indicative of a greater browning effect or maillard reaction. As expected, the temperature decreased the intensity of the sample and increased the extent of the maillard reaction. This was measured using the intensity coding in MATLAB and the relative thickness of the crust. The mechanical behavior of the crust was observed during the compression testing which is further investigated in this section.

Temp (°C)	Intensity	Crust Thickness (mm)
175	180.54 ± 10.39	1.0
200	175.42 ± 4.90	3.0
225	156.65 ± 25.83	5.0

Table 6 - Intensity Values with varied Temperature

Figure 26 - Differences in Crust Thickness with variation of Temperature ; from left to right (225, 200, 175)°C

Figure 27 - Differences in Browning Effect ; from left to right (175, 200, 225)°C

5.3.1 Relationship between Brittle Material and Maillard Reaction

A relationship between the maillard reaction and mechanical behavior of the brittle crust is examined after cross referencing observations made during the compression tests. During the compression tests, the brittle material created during baking temperatures of 200 °C and 225 °C was caused by the maillard reaction. This material was different from the foam material inside the core. However, the samples did not exhibit brittle behavior after aging.

5.3.2 Relationship between Height Expansion and Maillard Reaction

A relationship between the baking temperatures is examined after cross referencing observations made during the height expansion. The samples subjected to higher baking temperatures had lower intensities, thicker crusts, greater height expansions, and better formed shapes. Therefore there is a relationship between the height or volume expansion and the maillard reaction.

5. Conclusion

The primary discovery made in this study is the dominant role baking temperature has on the number of material properties of the pound cake. The temperature is the key controlling factor of the maillard reaction decreasing the intensity of the color by 23.89 when the temperature was increased from by 50 °C. The role of aging on pound cakes samples was also important because of the difference in stress-strain behavior when aging was allowed to occur for samples baked at 200 °C and 225 °C. The pound cake samples no longer exhibited the Elastic-Brittle Foam behavior after 1 day of aging and behaved like an Elastic-Plastic Foam. Temperature and aging have an inverse relationship with the elastic strain and contribute to the brittleness of pound cake. It was observed temperature and the elastic modulus of pound cake also have a direct relationship. However, the relation between aging and elastic modulus was unable to be determined. The validity of existing data could determine the relationships between aging and elastic modulus at specific temperatures with current data. The internal forces and state of the different cellular foams could cause different behaviors in the elastic modulus at different baking temperatures.

References

[1] "Pound Cake." Word Press. Available from http://giniann.files.wordpress.com/2006/02/pound%20cake.jpg. Internet; accessed 26 April 2011.

[2] Gibson, Lorna J. and Ashby, Michael E. *Cellular solids: Structure and Properties*. Cambridge: University of Cambridge, 1997.

[3] (Gibson, 1997, 24-175)

[4] Jaeger, H et al. "The Maillard reaction and its control during food processing. The potential of emerging technologies." Pathologie Biologie. 58, no 3 (2010).

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Wilderjans, Edith et al. "A model approach to starch and protein functionality in a pound cake system." *Journal of Food Chemistry*. 120, no 1 (2010): 44-51

Appendix A – Extended Tables

Temp (°C)	Sample	Intensity	STDV
175	1	172.858	9.2254
	2	169.9375	8.6415
	3	196.5869	12.3702
	4	181.5116	11.3781
	5	181.7803	13.5554
200	1	172.4893	13.7689
	2	180.114	10.1827
	3	179.375	11.4804
	4	168.4832	15.4641
	5	176.642	16.759
225	1	134.5138	19.2693
	2	174.0261	15.0194
	3	173.727	15.3998
	4	177.96	14.7645
	5	122.9963	14.0679

Table 2 - Intensity (Extended)

Final Height (cm)						
Temp (°C)	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
175	3.4	3.3	3.3	3.3	3.4	3.6
200	3.3	3.5	3.4	3.4	3.4	3.4
225	3.6	3.5	3.5	3.4	3.5	3.6

Table 3 - Final Heights of Baked Samples (Extended)

Appendix B – Stress - Strain Curves after 0 Days of Baking

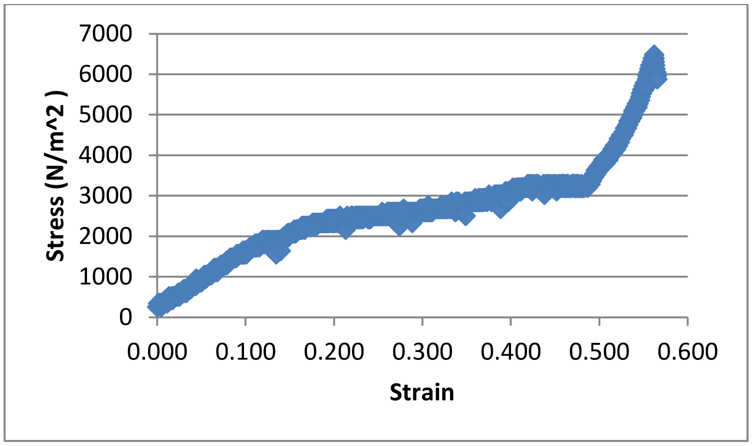

Figure 28 - (0 Days, 175 °C, Sample 1)

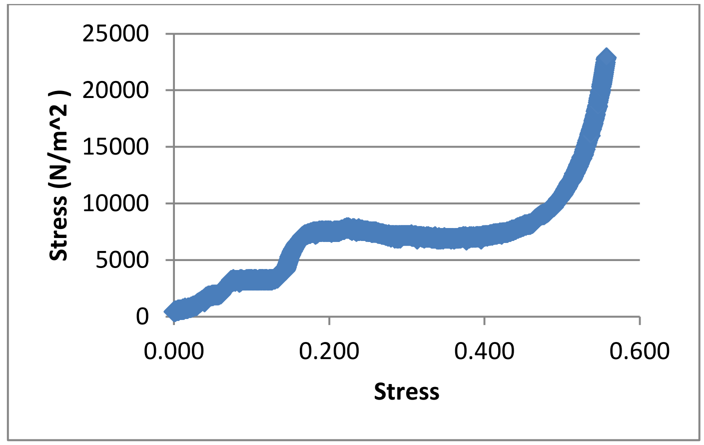

Figure 29 -(0 Days, 200 °C, Sample 2)

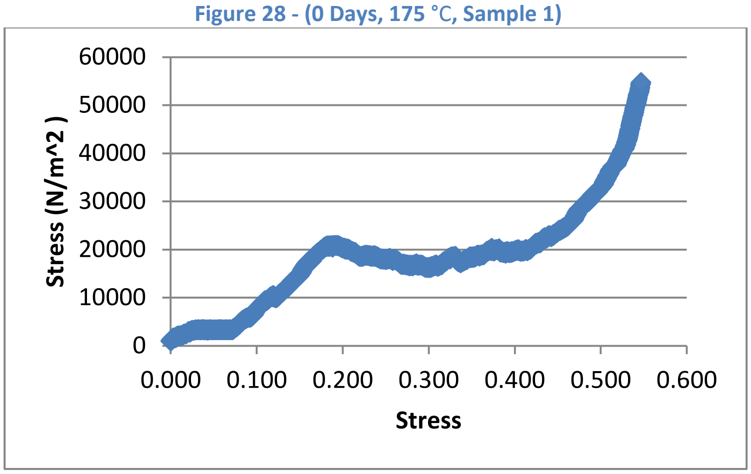

Figure 30 - (0 Days, 225 °C, Sample 1)

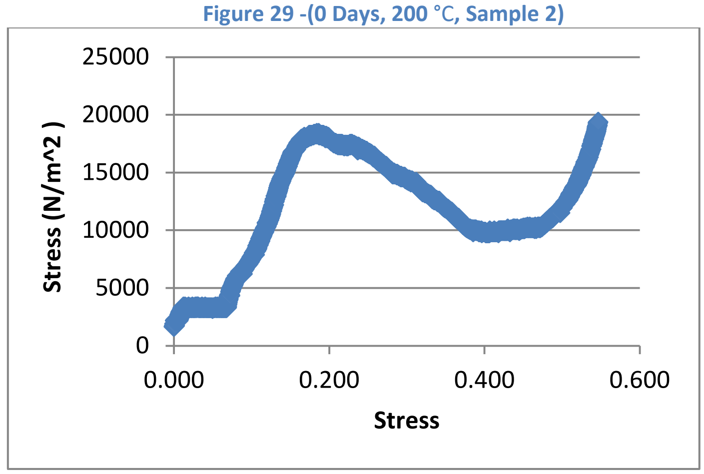

Figure 31 - (0 Days, 225 °C, Sample 2)

Appendix C – Stress - Strain Curves after 1 Day of Baking

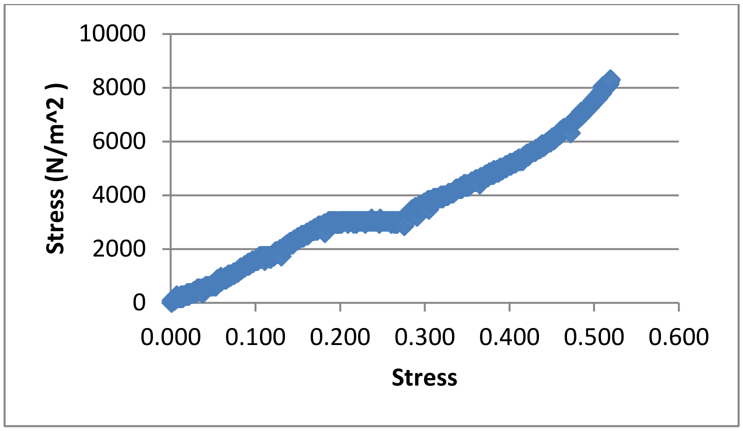

Figure 32 - (1 Day, 175 °C, Sample 1)

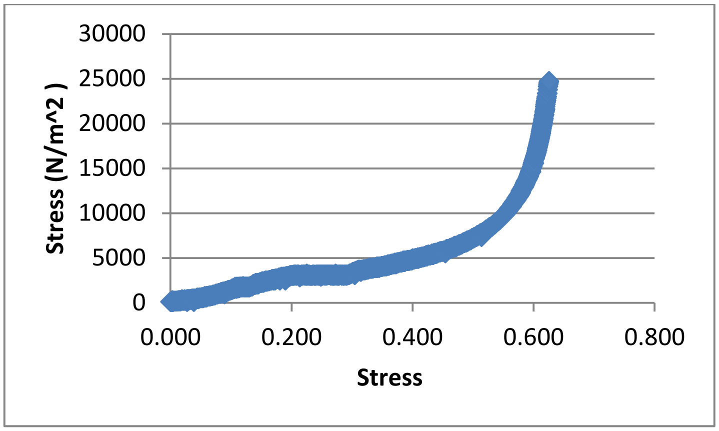

Figure 33 - (1 Day, 175 °C, Sample 2)

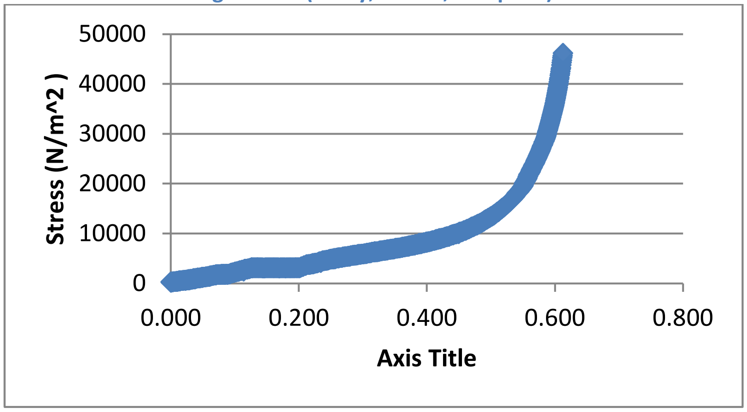

Figure 34 - (1 Day, 200 °C, Sample 1)

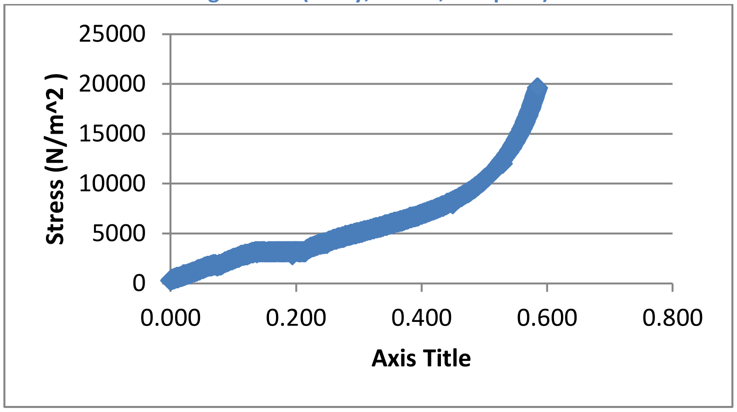

Figure 35 -(1 Day, 200 °C, Sample 2)

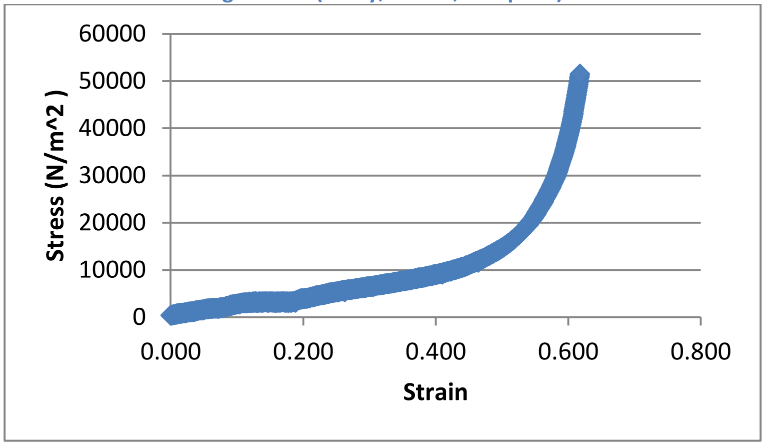

Figure 36 - (1 Day, 225 °C, Sample 1)

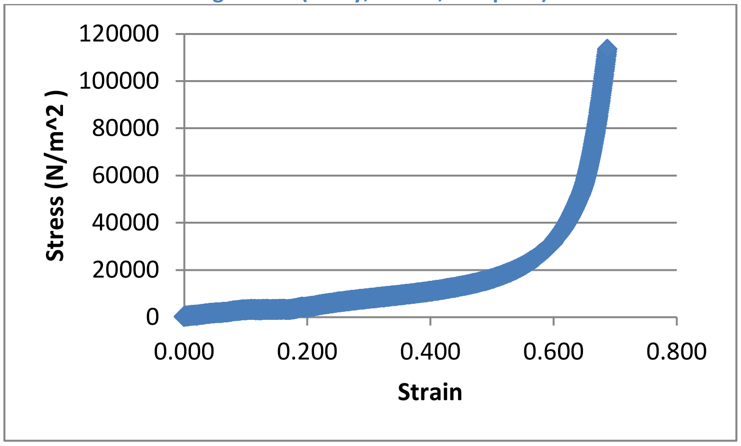

Figure 37 - (1 Day, 225 °C, Sample 2)

Appendix D – Stress - Strain Curves after 3 Days of Baking

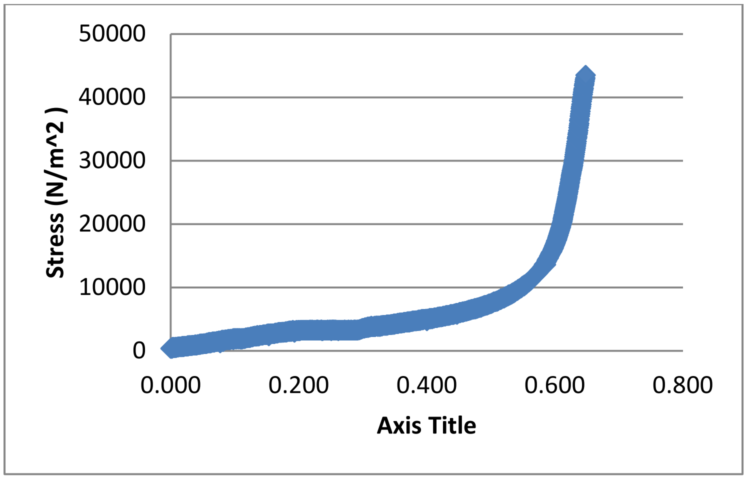

Figure 38 - (3 Days, 175 °C, Sample 1)

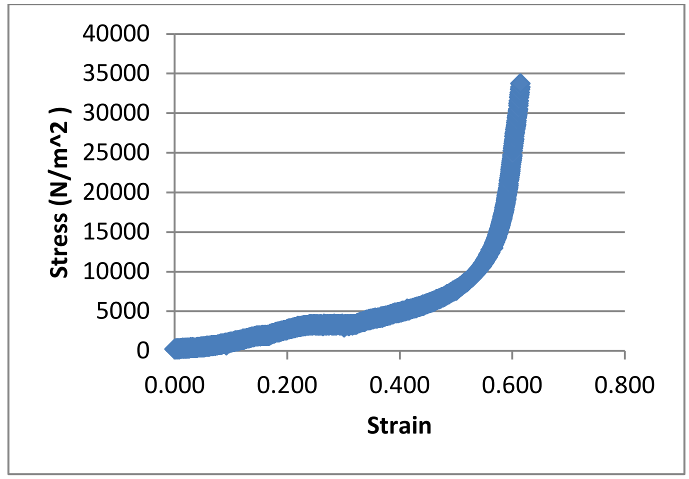

Figure 39 - (3 Days, 175 °C, Sample 2)

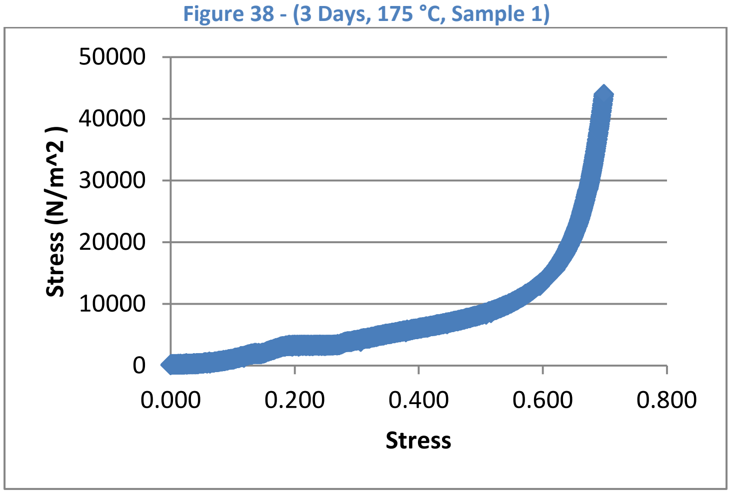

Figure 40 - (3 Days, 200 °C, Sample 1)

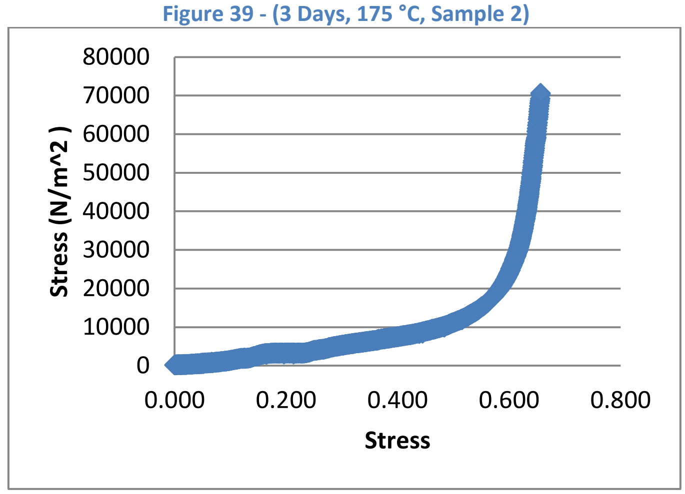

Figure 41 -(3 Days, 200 °C, Sample 2)

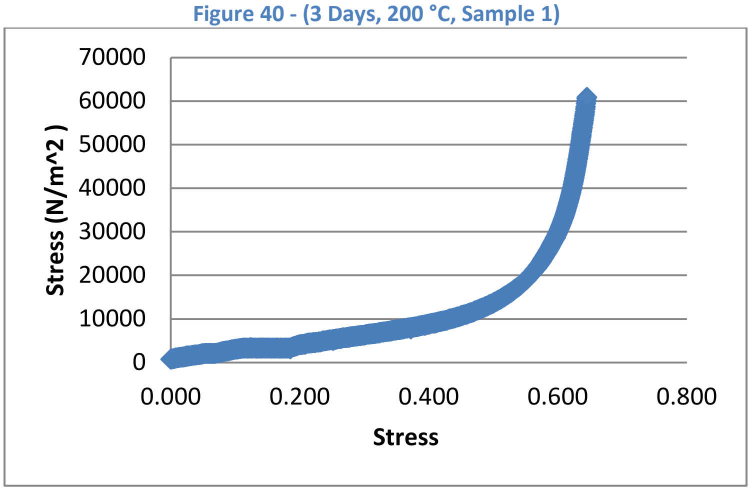

Figure 42 - (3 Days, 225 °C, Sample 1)

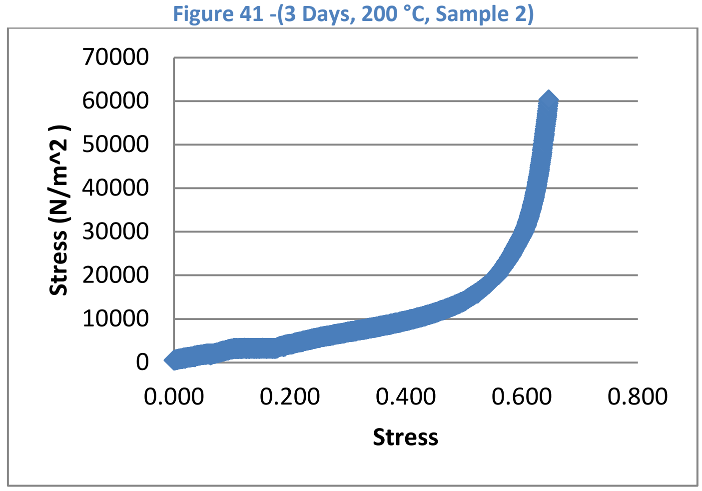

Figure 43 - (3 Days, 225 °C, Sample 2)

Appendix E – Stress - Strain Curves after 6 Days of Baking

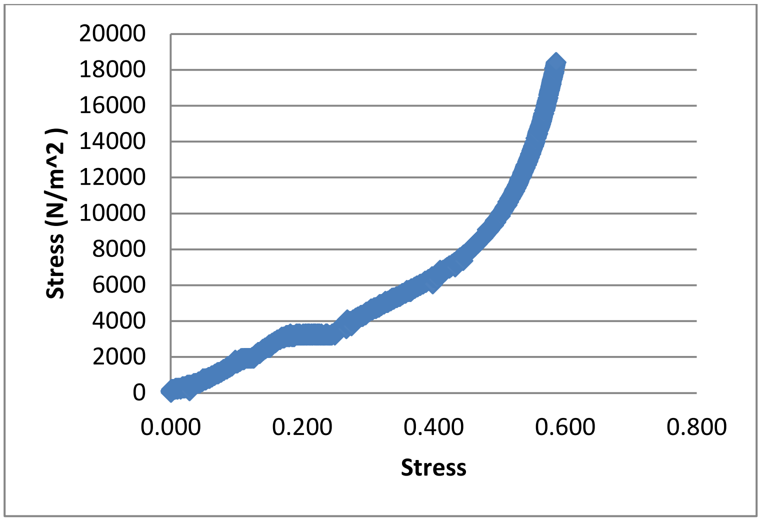

Figure 44 - (6 Days, 175 °C, Sample 1)

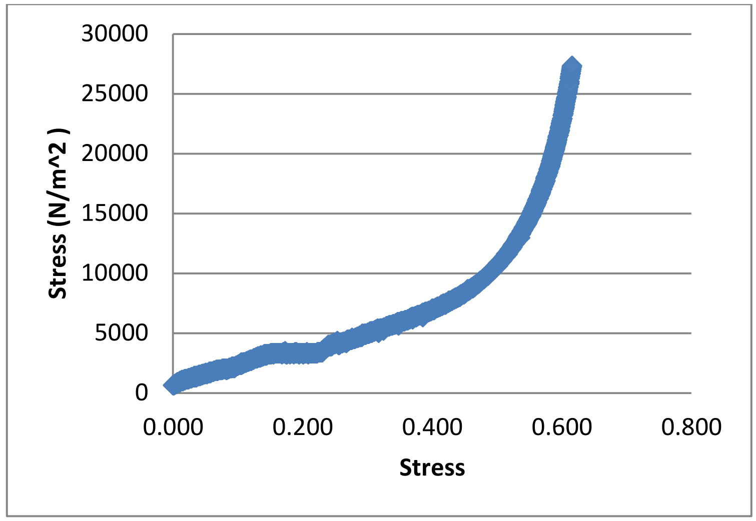

Figure 45 - (6 Days, 175 °C, Sample 2)

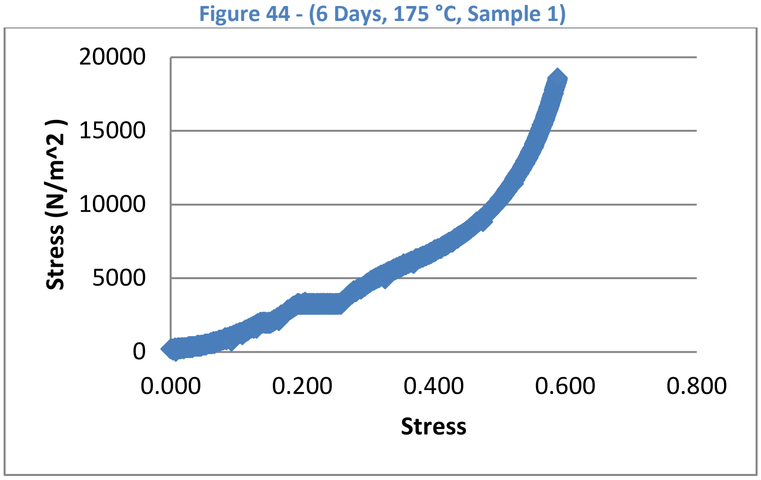

Figure 46 - (6 Days, 200 °C, Sample 1)

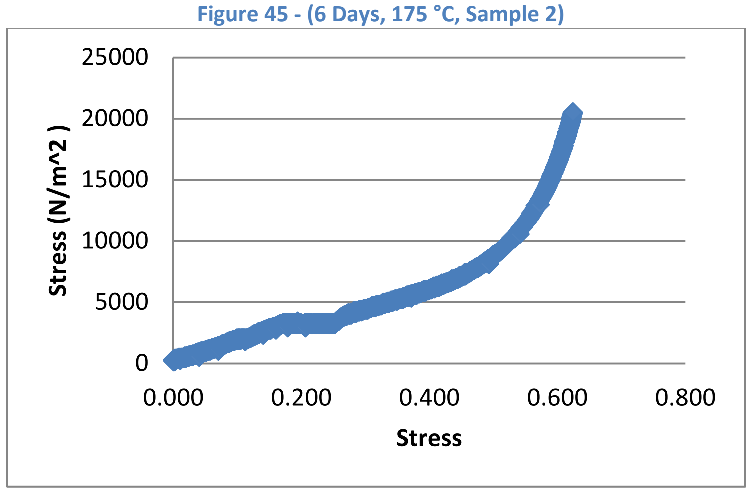

Figure 47 -(6 Days, 200 °C, Sample 2)

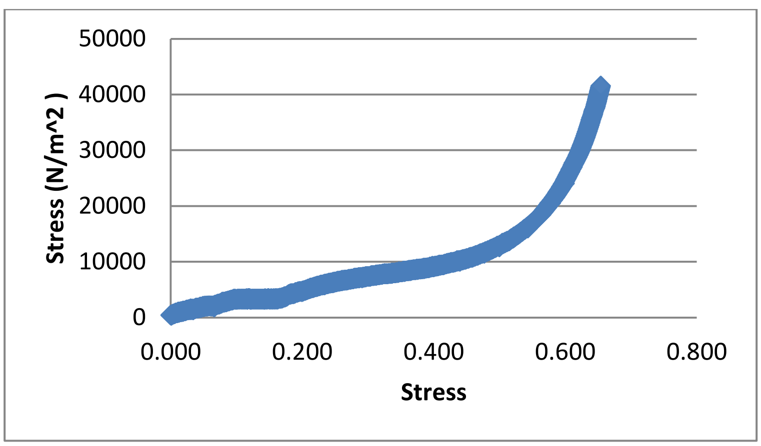

Figure 48 - (6 Days, 225 °C, Sample 1)

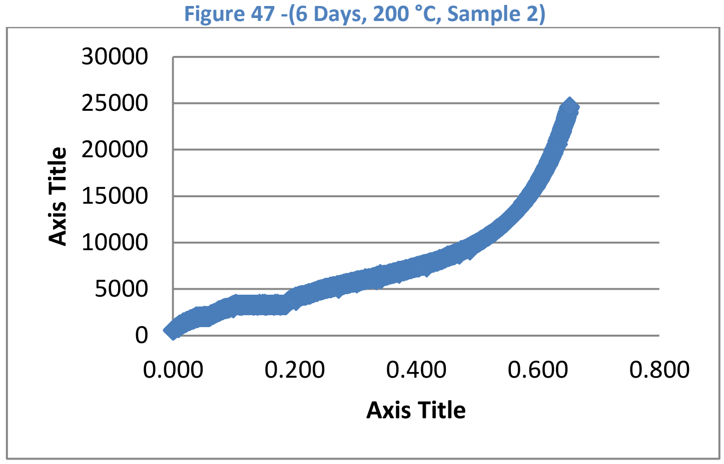

Figure 49 - (6 Days, 225 °C, Sample 2)

Appendix G – Measurement of Temperature in Sample

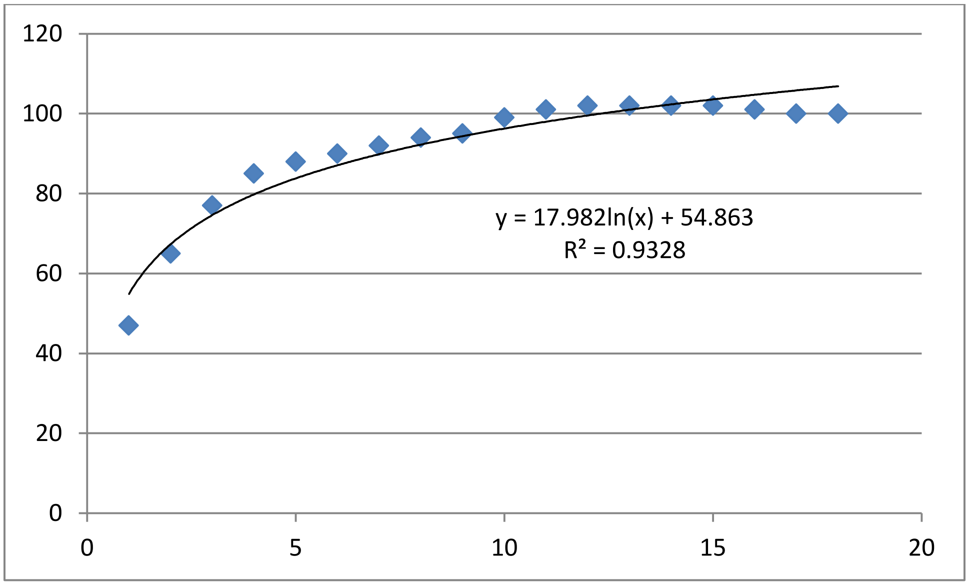

Figure 50 - Internal Temperature of Cake Batter during 175 C Baking