ABSTRACT

Three dough formulations with increasing salt content were examined using the SpecTech DSR. Strain sweeps at 25°C, 45°C, and 65°C were done in triplicate using a 25mm diameter parallel plate geometry and a 1mm gap. Complex modulus and phase degree were measured in the strain range of 0.01-15% and the linear viscoelastic range of each dough was determined. As salt level increased, the LVR increased. This indicated that the dough had become stronger and more elastic with salt addition. The SpecTech was found to provide reproducible data that could help a baker better understand and monitor dough quality and method reproducibility. In addition, the formulation with the highest salt content (10g) was tested on the Bohlin VOR Rheometer and compared to SpecTech results. Fundamental properties were shown to be independent of the machine used to test them.

INTRODUCTION

The production of wheat dough is a process in which raw materials (mainly flour, water, and yeast) are mixed and subjected to a large range of strain situations. Dough is a complex mixture of starch, protein, fat, salts, etc. and its rheological properties include viscosity, elastic modulus and relaxation time. Rheological properties and stress conditions change during every stage of bread making as the dough is mixed. Stress conditions are high when the dough is mixed in high-speed mixers at which point it becomes an elastic and coherent mass. When the dough is subjected to lamination and rolling, the stress conditions are intermediate. Finally, stress conditions are lowest during proofing. In theory, knowledge of the fundamental rheological properties of any dough can be an indication of how the dough is going to behave under various process conditions. For the miller fundamental properties are an indication of the characteristics of the flour and its composition (Faridi, 1985).

Wheat dough is usually tested using empirical procedures that have become standardized. These procedures include the Mixograph, Farinograph, Extensograph, and Alveograph. These tests subject the dough to medium through high deformations. The results of these tests are in empirical units. A relation of the results to fundamental properties, such as the elasticity modulus or the complex modulus is very hard to make. (Bushuk, 1985)

The use of small strain rheometry has been proposed as a method to determine dough fundamental properties - especially oscillatory dynamic rheometers (Weipert, 1990). The use of oscillatory dynamic rheometers has been investigated by several authors and some of the advantages they have found are: (1) the tests use small samples, (2) the results act as a tool in calculating the optimal absorption of water, (3) the optimal mixing time can be determined, and (4) the behavior of the dough in several stages of the bread making process can be analyzed. On the other hand, the equipment can be expensive and some stickiness issues need to be addressed. The use of sand paper in the surface of the parallel plates or the cone and plate was found to solve this issue (Safari-Ardi and Phan-Tien, 1998).

The measurement of the storage modulus (G') and the loss (G") modulus, together with the phase angle (δ) are a good indication of the stiffness and extensibility of the dough. A high value of G' and a low G'' will indicate a stiff dough, while a lower G' will indicate a softer and more extensible dough (Weipert, 1987). The amount of mixing of dough is a very important parameter and oscillatory tests could indicate under- and overmixing (Wehrle, *et. al*. 1997).

The presence of salt is known to affect the properties of dough - salt toughens the protein and helps in conditioning the dough by improving the tolerance to mixing (Galal *et. al*.,1978). Small increases in the salt content can affect the quality of the dough greatly. Galal *et. al*. (1978) and Wehrle *et. al*. (1997) investigated the affect of acid and salt content in the rheological properties of dough, and found that the addition of salt produced a more stable and stiff dough. Dough is considered to be more stable when its structure does not break if the mixing time is longer than the ideal mixing time. The complex modulus (G*) also increased and δ decreased compared to a basic formulation.

The SpecTech DSR is a quality control instrument that was especially designed to meet the requirements of the asphalt industry (Anonymous, 2000a). The SpecTech also has potential for the analysis of foods, pharmaceuticals, polymers and solutions, and paints and coatings (Anonymous, 2000b). The objective of this experiment was to determine the feasibility of using the SpecTech as a device for dough quality assurance assessment. To make this determination, doughs of different salt contents were tested and analyzed using the SpecTech and Bohlin VOR Rheometer.

MATERIALS AND METHODS

Three formulations of dough were prepared using the following measurements:

1. 100g Wheat Flour, 60g Deionized Water and 2g Salt
2. 100g Wheat Flour, 60g Deionized Water and 6g Salt
3. 100g Wheat Flour, 60g Deionized Water and 10g Salt

A KitchenAid mixer with a dough hook was used. The dry ingredients were blended and water was slowly added during the first minute of mix. The ingredients were mixed at speed 5 for a total of ten minutes. Samples were then loaded into the SpecTech DSR (Dynamic Shear Rheometer) and the Bohlin VOR Controlled Strain Rheometer (CSR) for analysis.

The three dough formulations were first tested on the SpecTech DSR. After each sample was mounted on the lower plate, the upper plate was moved down, and the sample was trimmed. Mineral oil was used to seal the outer edges of each sample so dehydration would not compromise test results. Strain sweeps were performed using parallel plate geometry with a diameter of 25mm. The gap was set at 1.0 mm and 25 steps were measured between the strains, using the instrument's strain limits of 0.01-15%. Each sample was tested in triplicate at 25°C, 45°C, and 65°C. The data was copied into an Excel spreadsheet and graphs of Complex Modulus (G*) and Phase Degree were plotted against %Strain for comparison.

The third formulation was also tested in triplicate on the Bohlin VOR CSR. Strain sweeps were tested using parallel plate geometry with a diameter of 30 mm. The gap size was 1.0mm. Strain was measured in 50 steps with a range of 0.001 – 15%. Again, the data was copied into a spreadsheet (Excel) and Complex Modulus (G*) was plotted against %Strain.

RESULTS AND DISCUSSION

The SpecTech provided data for Linear Viscoelastic Range (LVR) determination as well as evidence of temperature affect on dough formation. The LVRs of doughs in this experiment fell within a strain range of 0.1-1% (Graphs 1-3). At strain levels greater than approximately 1%, the ratio of stress to strain was no longer constant and the relationship between complex modulus and percent strain was no longer linear. Among replicates there was little deviation within the LVR.

As temperature increased from 25°C to 45°C, there was little difference in LVR or the magnitude of complex modulus over the percent strain range (Graph 1). At 65°C however, the LVR was extended slightly and the complex modulus increased by an order of magnitude (Graph 1). This temperature effect is most likely due to the gelatinization of starch granules and disulfide interchange within the gluten proteins. These effects are induced in dough within the temperature range of 65°C-85°C. An increase in the magnitude of G* with temperatature was thus expected, as these physical and chemical changes typically help to create a stronger, more solid-like dough network. Additionally, SpecTech data was similar to Bohlin data (Graph 2). This reinforced the fact that fundamental parameter measurement is independent of the instrument used.

Graphs 3 showed the affect of salt on dough mechanical properties at 65°C. Phase degree was plotted against percent strain. As salt content increased, the percent strain of the LVR increased slightly. This indicated that salt helped to create a stronger, more elastic dough matrix – probably by aiding disulfide interchange and cross-linking (Galal *et. al*.,1978). Error bars outside of the LVR were large due to the fact that equations for phase degree, like all small strain calculations, assume the material to have been tested in the LVR.

The results show that knowledge of dough's LVR can be helpful to a baker in a quality control setting. Using a machine like the SpecTech allows a baker to understand how strong or elastic the dough is in addition to how reproducible the dough making methods are. For example, if the linear relationship of complex modulus and percent strain is seen to extend only into low strain ranges, the gluten matrix may not be fully developed. In this situation dough may not be strong enough to hold water vapor and carbon dioxide bubbles. Therefore, the dough may not properly rise or it may eventually fall. Alternatively, if the LVR is found to be too large, the dough may be too strong and elastic to obtain the desired bread texture. In this case, water vapor and carbon dioxide bubbles would not be able to form because the dough matrix is too tough. By understanding the relationship of the LVR and dough physical properties, a baker can use the SpecTech to quickly test new formulations and predict their strength and performance during proof and bake. In addition, a baker can use knowledge of the LVR to test the reproducibility of dough within a single mixing method or between several methods.

The evidence of temperature affect on dough formation obtained from the SpecTech could also be helpful to a baker in better understanding temperature affect on dough formation. As dough is heated, starch granules undergo gelatinization and the gluten matrix undergoes disulfide interchange. The result of these two chemical and physical changes is a stronger, more elastic dough matrix. An increasing complex modulus roughly correlates to this textural effect. Therefore, a baker can produce different dough formulations and test them at a range of temperatures using the SpecTech to compare how the formulations perform at different temperatures.

In its application to quality assurance purposes in the baking industry, the SpecTech provides numerous advantages. For example, the test is quick and easy – it takes only five minutes to test one sample and only a few buttons must be pressed. The actual strain test is already programmed as well. Loading and clean-up are also relatively fast and simple. In addition, a small amount of sample is needed for each test. The SpecTech can give reproducible LVR data that will help a baker to assess his or her dough quality or mixing method reproducibility. Dough formation at various temperatures can be analyzed also. Finally, the test truly measures fundamental properties.

Several disadvantages of the SpecTech exist, but are more directed towards using the instrument as an all-around rheometer. For example, only one gap is possible on the SpecTech. Therefore, foods with large aggregates may not be tested. In addition, only one frequency can be tested with the SpechTech. When an understanding of rheological properties during cook is desired, one must resort to the more expensive Bohlin Rheometer. The Bohlin Rheometer has the capability to do such temperature ramps. In addition, the SpecTech cannot probe into strain percentages below 0.01. Therefore, it may be difficult to determine the LVR of more fragile foods. Finally, it was observed that during SpecTech testing, product actually flowed out of the parallel plates to some extent. This shape change is not accounted for in the calculations and could result in inaccurate results.

CONCLUSIONS

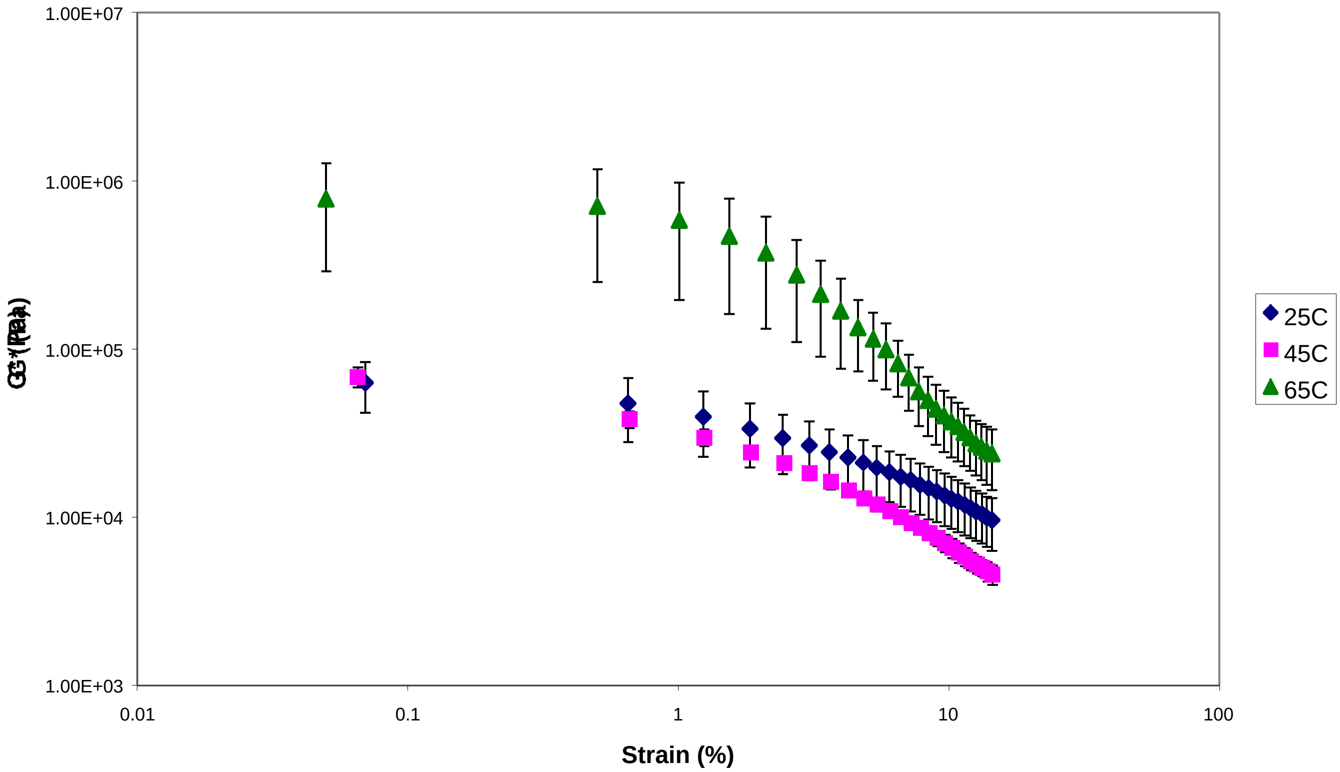
The SpecTech could be a useful instrument for quality assurance purposes in the baking industry. The instrument measures fundamental properties that can help a baker better predict bread quality and texture. The instrument also allows for assessment of mixing method reproducibility. The SpecTech does in one test what might require several individual empirical tests to measure. It provides a quick and easy means to obtaining dough strength, stability, and elasticity in a quality-type setting. In this experiment the effectiveness of the SpecTech was seen. As salt level increased in dough, the resulting LVR was also increased. This indicated that the dough was more strong and elastic with salt addition.

In the future, a standard method of testing dough on the SpecTech could be developed for the industry. An instrument with varying gaps might be more useful to a wider application of food products. The ability to probe lower strain ranges may also be helpful in understanding the LVR. In addition, the ability to test at several frequencies would allow a baker to do frequency ramps and therefore obtain better fingerprints of dough rheological characteristics.

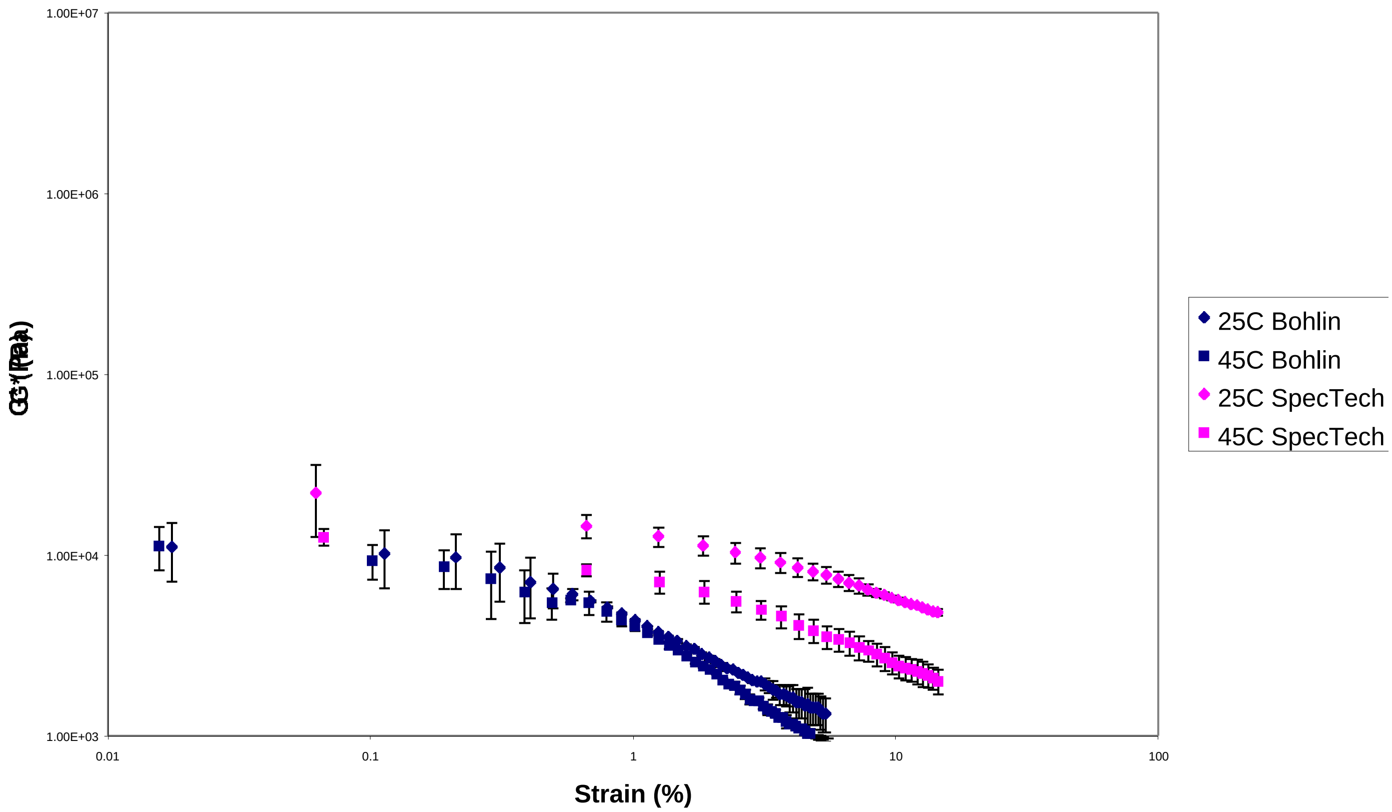
REFERENCES

1. Amemiya J.I., Menjivar J.A., Comparison of Small and Large Deformation Measurements to Characterize the Rheology of Wheat Flour Doughs. Journal of Food Engineering 16, pp. 91-108
2. Faridi H., ed. ,1985 Rheology of Wheat Products, AACC.
3. Galal A.M., Varriano-Marston E., Johnson J.A., 1978. Rheological Dough Properties as Affected by Organic Acids and Salt. Cereal Chem. 55, pp. 683-691
4. Sfardi-Ardi M., Phan-Thien N., 1998. Stress Relaxation and Oscillatory Tests to Distinguish Between Doughs Prepared from Wheat Flours of Different Varietal Origin. Cereal Chem. 75, pp. 80-84
5. Wehrle K., Grau H., Arendt E.K., 1997. Effects of lactic Acid, Acetic Acid and Table Salt on Fundamental Rheological Properties of Wheat Dough. Cereal Chem. 74, pp. 739-744
6. Weipert D., 1990. The Benefits of Basic Rheometry in Studying Dough Rheology. Cereal Chem. 67, pp. 311-317
7. Anonymous, ATS RheoSystems – Rheology , Rheometer, Viscometer, Rheometric, Viscometers, Rheometers [Online] Available. http://www.njcc.com/~ats/spectech-dsr.htm (2000a).
8. Anonymous. , ATS RheoSystems – Rheology , Rheometer, Viscometer, Rheometric, Dynamic Oscillatory. [Online] Available. http://www.njcc.com/~ats/applications.html (2000b).

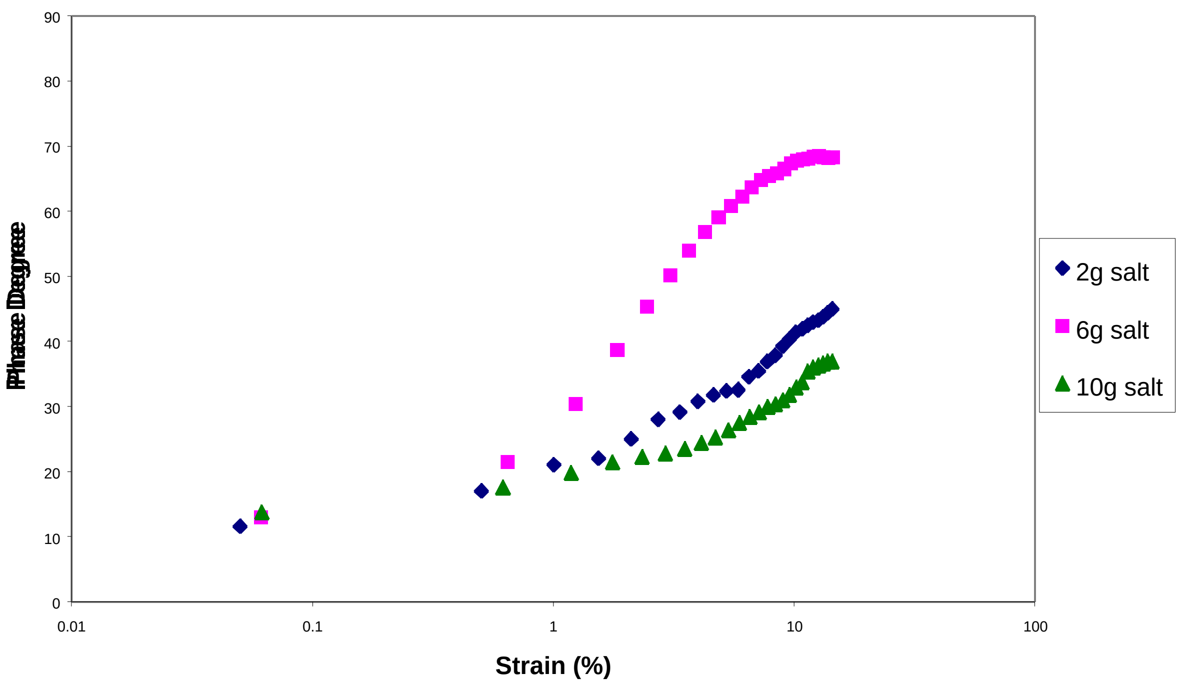
Graph 1: % Strain vs. Complex Modulus for the 10g Dough



Graph 2: % Strain vs. Complex Modulus
for SpecTech and Bohlin Rheometer Comparison



Graph 3: Salt Effects on LVR at 65C



Graph 3: Salt Effects on LVR at 65C