QUALITY WHEAT
CRC PROJECT REPORT

Project 3.4.1 - Process measurement and control for dough mixing and makeup plants

Effects of processing parameters on Dough sheet properties

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Effects of processing parameters on dough sheet properties

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1 Executive summary

This report focuses on research to understand the relationship between dough rheological properties and the outcomes of sheeting processes. In a number of experiments, using a custom-built sheeter, information was gathered on the effects of dough properties, such as consistency and elasticity, and the effects of sheeting parameters, such as roll diameter and speed, on the outcome of sheeting processes.

Interaction between roll speed and dough elasticity
Elasticity is important in sheeting. For applications with severe sheeting (such as moulding), the speed at which the rolls operate greatly affects final sheet thickness. Air bubbles affect sheeting in the same way as elasticity. Thus, for yeasted dough, the level of fermentation influences the sheeting process.

For less severe sheeting (reduction ratio < 3.5) roll speed did not affect the sheet thickness of an elastic dough. This implies that a number of less severe reductions are more predictable than one severe reduction. With less elastic materials, this does not hold. For pastry dough, for example, which contains a large proportion of non-elastic fat, roll speed is an important parameter, even for small reduction ratios.

Work input requirement for optimum bread quality
Passing bread dough through sheeting rolls repeatedly developed the dough similarly as in MDD mixing. The number of passes needed for optimum bread quality was between 7 and 9. There seemed to be little dependency on sheeter settings.

Work input (energy requirement for optimum bread quality) was less than 1% of the energy required in a typical MDD mixer. Work input went down with increasing roll diameter, went up with increasing roll surface speed and went down with increasing roll gap.

Best bread quality was obtained with a small roll diameter and high speed.

The work input rate increased with increasing roll diameter and decreased with increasing roll gap. Increasing the speed first increased the work input rate; the rate then decreased again on further speeding up.

Work input and bread quality are not directly related when dough is made using different sheeter settings. Since the number of sheeting passes needed to obtain optimum dough did not vary much, the number of passes required is a better parameter to use in practice.

Roll separation force and dough consistency

Dough consistency (extensional viscosity), decreased with roll speed, as expected for a pseudo plastic material. Dough relaxation time also decreased with roll speed. This means that speeding up an automated sheeting line shortens the relaxation time. This could be beneficial for pastry lines, where shrinkage occurs due to lack of dough relaxation. It may also explain why sheeting lines that operate at different production rates produce different product quality.

Roll separation force increased with roll speed for a weak flour, but was not affected by roll speed for a strong flour.

Rheological properties are dependent on roll speed and therefore a direct relationship between force and viscosity could not be derived. If force is to be used to predict viscosity, then more detailed information is needed about the nature of the roll speed dependency of force and viscosity.

Roll diameter did not significantly affect rheological properties or separation force.

2 Introduction

This report focuses on research to understand the relationship between dough rheological properties and the outcomes of sheeting processes. The research is part of project no 3.4.1 (Process measurement and control for dough mixing and makeup plants), which aims to "facilitate the ability of the Quality Wheat CRC's food manufacturing partners to add value to cereal-based food products, by defining, predicting and reducing the industrial processing requirements, and improving the quality of these foods".

Sheeting of dough is a common operation in the manufacture of a number of bakery products such as pastries, biscuits, bread or corn chips. It is a relatively simple process, usually done with a set of sheeting rolls rotating at the same speed. Proper setting of the sheeter parameters is important for optimum product quality and minimum product waste. The outcome of the sheeting process is determined by parameters such as roll speed, roll separation and roll diameter, and by the rheological properties of the dough. However, the rheological properties change as a result of sheeting, making it complex to predict final sheet properties.

Many aspects of sheeting are poorly understood. The research is addressing these with the aim of applying the information to scaling issues, dough development and air bubble dynamics. The approach is experimental, using a custom-built research sheeter, designed to enable sheeter parameters, such as roll speed and roll separation force, to be controlled and measured.

When dough passes through sheeting rolls, the gluten is developed into an elastic network, thus forming a visco-elastic dough. The elastic component makes it difficult to predict dough thickness after sheeting. Section 3 explores the role of elasticity in dough sheeting.

The use of sheeting rolls for dough development is very energy efficient. Section 4 presents data on the effects of different sheeter settings on dough development (work input).

Control of dough rheological properties is important for optimum processing. There is a relationship between dough rheological properties and the quality of final products, such as bread or pastry. Dough viscosity (consistency) is linked to the force exerted on the dough by the sheeting rolls. Section 5 explores the relationship between this force and extensional viscosity.

3 The role of elasticity in dough sheeting

Scientists have a good understanding of what happens when a viscous material is sheeted between rolls, but when the material contains a significant elastic component it is more difficult to predict the outcome of the process. This is a problem at scale-up, for example when a product developed on a small benchtop sheeter is to be processed on an automated sheeting line. Wheat flour dough has an elastic component due to the formation of a gluten network during dough mixing or sheeting.

A viscous (non-elastic) material flows when a force is applied to it. As soon as the force is removed it stops flowing. When elasticity is added to the material, it takes some time for the material to stop flowing after the force is removed. (relaxation). This relaxation time is a material property and affects the outcome of the sheeting process. If the sheeting time is short (high roll speed) compared to the relaxation time of the dough, then the dough does not have time to relax during sheeting and will behave more like an elastic material. If, on the other hand, the sheeting time is longer than the relaxation time, the dough will have time to relax and the behaviour is much more like a viscous material. Thus, by changing the roll speed and observing the effects on sheet properties we can determine the importance of elasticity during sheeting.

To demonstrate the role of elasticity, an experiment was done using two dough sheets with different visco-elastic properties. One dough was based on a bread dough recipe and the other on a play-dough recipe. Play dough is not used in food manufacturing, but because it does not have a gluten network, it has severely reduced elastic properties. Using an extreme case demonstrates the effects more clearly than small variations on a bread recipe.

The bread dough was made from a commercial bread flour (100%), water (56%) and salt (2%). All ingredients were mixed for 2 min in a high-speed z-arm mixer to obtain a fully developed bread dough. The dough was then sheeted out to the required thickness. As the water content was about 4% lower than in a standard bread dough, the resulting dough was very elastic.

The play dough was made from the same bread flour (2 cups), water (2 cups), salt (1 cup), cooking oil (2 tablespoons) and tartaric acid (3 teaspoons). The ingredients were mixed to a smooth paste and slowly heated to form a cohesive dough. After cooling, the play dough was treated in the same way as the bread dough.

Experiments were done using a custom-built sheeter, consisting of a pair of counter-rotating sheeting rolls and two conveyor belts (see Figure 1). Roll diameter D was 270 mm and roll rotation speed N was 2 or 20 rpm. The inlet conveyor belt speed was set at the roll surface speed ($\pi DN/60$ in m/s). The outlet conveyor belt speed was set at an estimated outlet dough speed. Dough was fed through a 4 mm gap between the rolls and dough thickness was measured before and after sheeting.

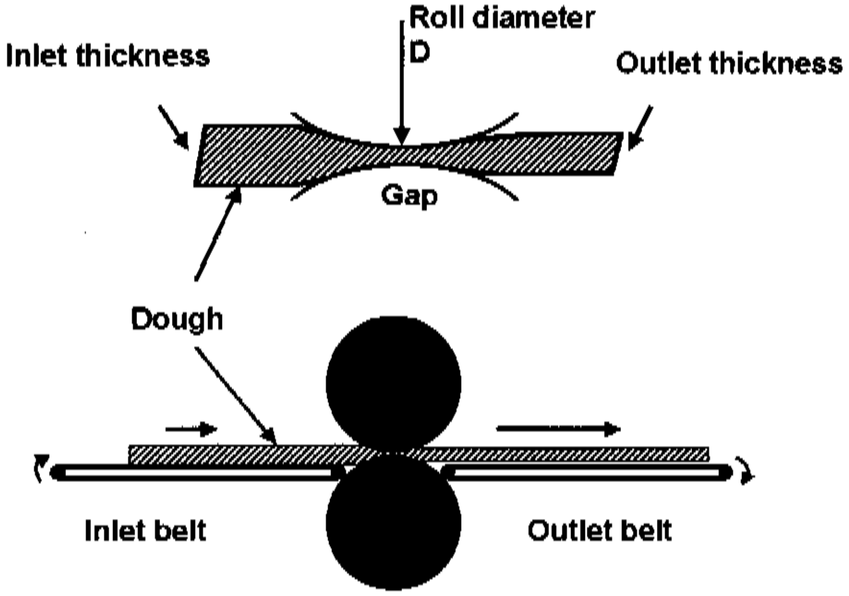

Figure 1. Set-up for the dough sheeting experiment.

The experiment was repeated for a range of different inlet thicknesses. Since both inlet thickness and roll gap could not be controlled accurately, but could be determined accurately, the thickness measurements were divided by the roll gap. Inlet thickness divided by roll gap is defined as the 'reduction ratio'.

The results are summarised in Figure 2 by drawing smooth lines through the data points (Morgenstern et al. 2000).

Sheet thickness after sheeting is always larger than the roll gap (Figure 2) and increases with increasing reduction ratio. For play dough, the outlet thickness levelled off for experiments with reduction ratios larger than about 3.5, but at higher speeds this spring back is larger. It is interesting to see that for bread dough the difference between slow and fast sheeting is negligible when the initial sheet is thin. It appears that the effects of elasticity are small when sheeting is less severe. Play dough has much reduced elasticity. Again, faster sheeting results in thicker sheets, but the effect of speed is considerably less than for bread dough. It follows that even much reduced elasticity still influences the sheeting process greatly.

These results show that elasticity is important in sheeting. For applications with severe sheeting (such as moulding), the speed at which the rolls operate greatly affects the sheet thickness. If air bubbles are present in the dough, the dough becomes compressible. This affects sheeting in the same way as elasticity (Morgenstern et al. 2000). Thus, for yeasted dough, the level of fermentation influences the sheeting process. In a batch process, dough is processed at different times after mixing and fermentation can change the properties within one batch significantly.

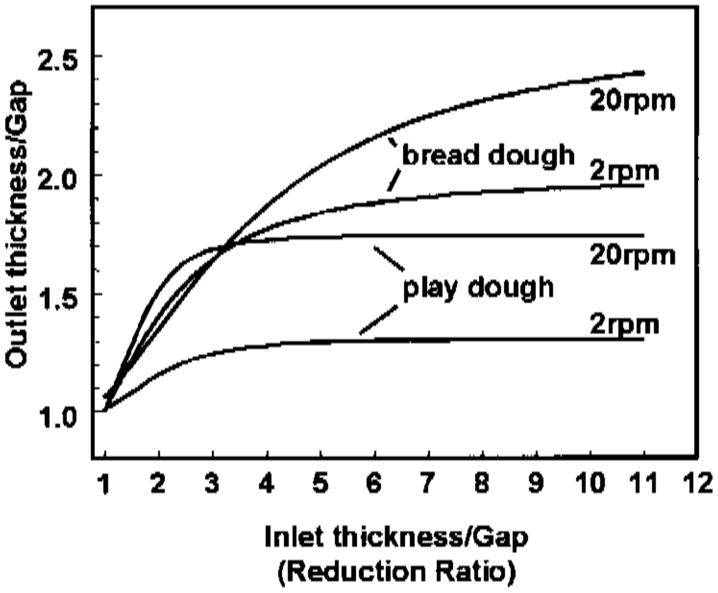

Figure 2. Outlet thickness as a function of inlet thickness for bread dough and play dough at two roll speeds. Note that thickness is made dimensionless by dividing it by the gap between the rolls.

For less severe sheeting roll speed does not affect the sheet thickness of bread dough. This response is different from the response for severe sheeting (non-linear behaviour). This implies that a number of less severe reductions (reduction ratio < 3.5) are more predictable than one severe reduction. For less elastic materials, though, this does not hold. For pastry dough, for example, which contains a large proportion of non-elastic fat, roll speed is an important parameter.

4 Optimum work input of sheeted bread dough

When flour and water are mixed or kneaded, a visco-elastic cohesive dough is formed (mechanical dough development or MDD). The mechanical action assists the formation of a gluten network, which is necessary for creating the familiar bubble structure in bread. If mixing or kneading is carried on for too long, then the gluten network breaks down, which generally results in poorer quality bread. There is an optimum amount of mixing or kneading, which is generally expressed as the amount of energy (work input) needed to mix to this optimum state. A typical value for the work input of a bread flour mixed to optimum in a Tweedy mixer is 11 Wh/kg.

Dough development can also be achieved by passing a dough sheet repeatedly through rolls. The energy requirement for optimum dough development (work input) has been reported to be much lower than 11 Wh/kg (Kilborn & Tipples 1974; Morgenstern et al. 1999), but this has never been measured accurately. Moreover, it is not known how roll settings affect the energy efficiency of dough development.

An experiment was done to establish the work input requirement of sheeted dough at different roll settings.

4.1 Method

A full bread dough (Table 1) was prepared in an ECS35 high speed mixer (Electrical Control Systems, Christchurch), by mixing for 45 seconds at low speed (15% of normal speed). This produced a cohesive un-developed dough.

Table 1. Ingredients for full bread dough

Ingredient	**Level**
Flour*	100%
Water	62.5%
Yeast	3%
Salt	2%
Improver**	1.2%
Sugar	0.75%
Ascorbic Acid	50ppm

*WI=9.1Wh/kg, WA=64.7%

**20% (w/w) SSL, 15% (w/w) TEM, 20% (w/w) enzyme active soy flour and 45% (w/w) flour

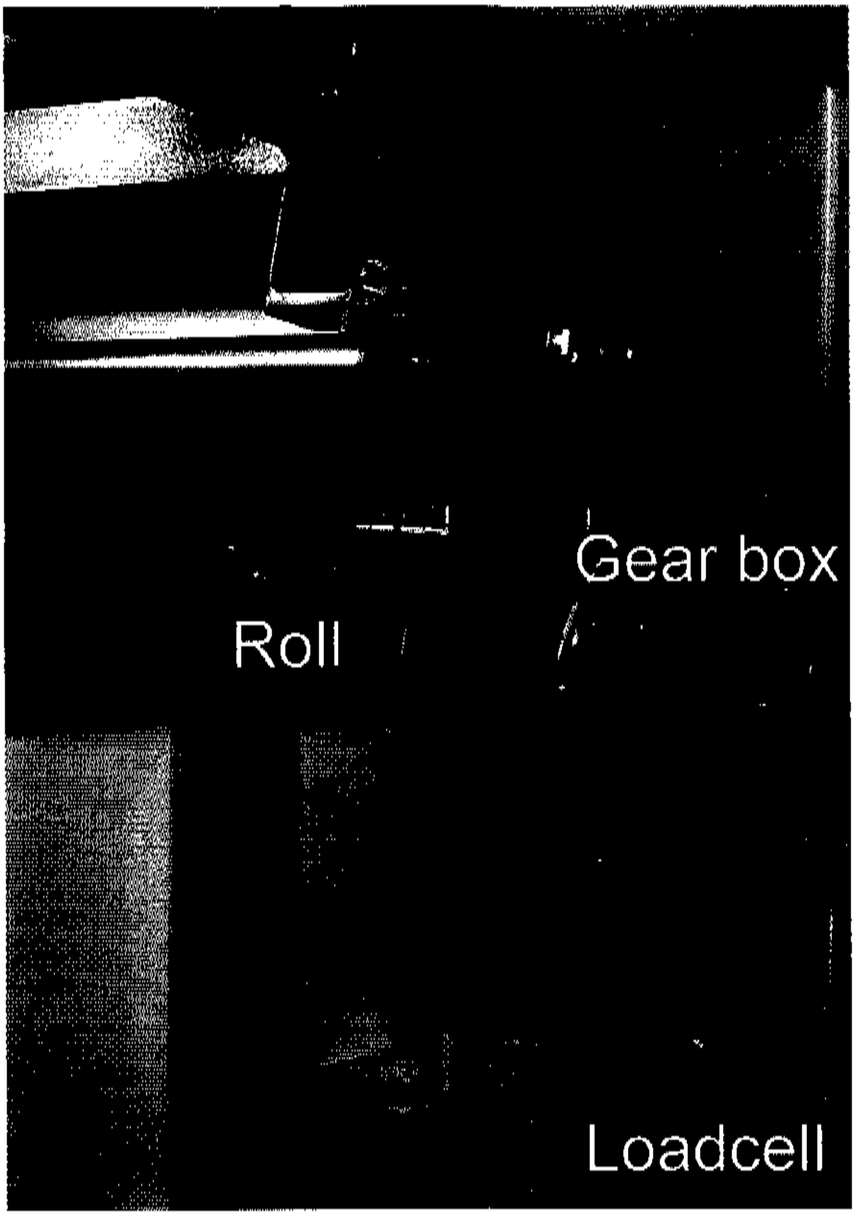

Photo 1. Close up of rolls with loadcell arrangement on the gearbox of the bottom roll.

Water addition was chosen a few percent lower than the water absorption to avoid problems with stickiness during sheeting. Dough temperature after mixing was controlled at 30±1ºC. Room temperature was controlled at 25±1ºC and all equipment was at room temperature when used. After mixing, the dough was formed into a slab and weighed. This slab was then passed through sheeting rolls for a set number of times. During sheeting, the force on the bottom roll, the torque on the bottom roll, and the gap between the rolls were recorded. The bottom roll was mounted with a loadcell and one of the gearboxes was also mounted with a loadcell (Photo 1). Roll gap was measured with callipers mounted on the moveable top roll. Readings from the loadcells and callipers were recorded at a fixed rate depending on the roll speed (sample period (in ms) $\Delta t = 1200/N$, e.g. for a roll speed of 20 rpm $\Delta t = 60$ ms). Sampling at this rate ensured sufficient data points for calculating average roll separation force and torque. Sheet thickness after sheeting was measured with a custom-built device, consisting of a rotary encoder with an arm and a small roller that rests on the dough when passing (Figure 3). Readings from the encoder were recorded at the same sampling rate as roll force, torque and gap.

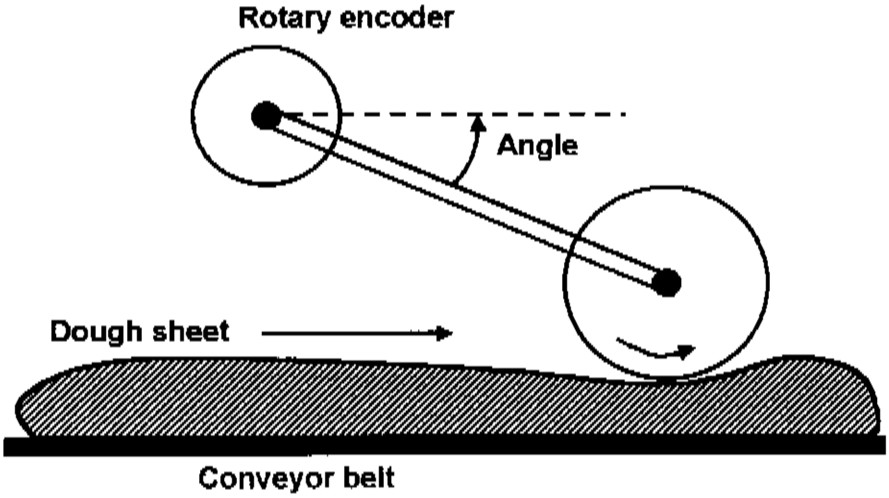

Figure 3. Sheet thickness measurement device. A light perspex freely rotating roll rests on the dough while it passes. The angle of the arm is a direct measure of dough thickness.

After the final sheeting pass, two dough strips of 210 g were cut and passed through a Mono table moulder, bypassing the sheeting rolls. The dough pieces thus formed were then deposited into baking tins and proved and baked according to an in-house standard procedure (Swallow & Baruch 1986).

Force and torque data for a typical sheeting pass are presented in

Figure 4 Force and torque are zero before sheeting and quickly increase when the dough touches the rolls and is pressed between them. The start and finish of sheeting are easily identified. Sheeting energy is calculated form the torque curve as follows:

$$E = 2\int \tau\omega dt = 2\int \frac{2\pi N}{60}\tau dt = \frac{\pi N}{15}\int \tau dt \qquad \text{(Equation 1)}$$

where τ is torque (Nm), ω is rotation frequency (s^{-1}), t is time (s), N is roll speed (rpm) and the integral is taken from the start to the end of sheeting. The unit is Nm or J and can be converted to Wh through dividing by 3600. The factor 2 before the integral takes the torque contribution from the top roll into account, assuming it is equal to the torque on the bottom roll.

From the force curve (Figure 4), the average force during sheeting (between start and end of sheeting) is calculated.

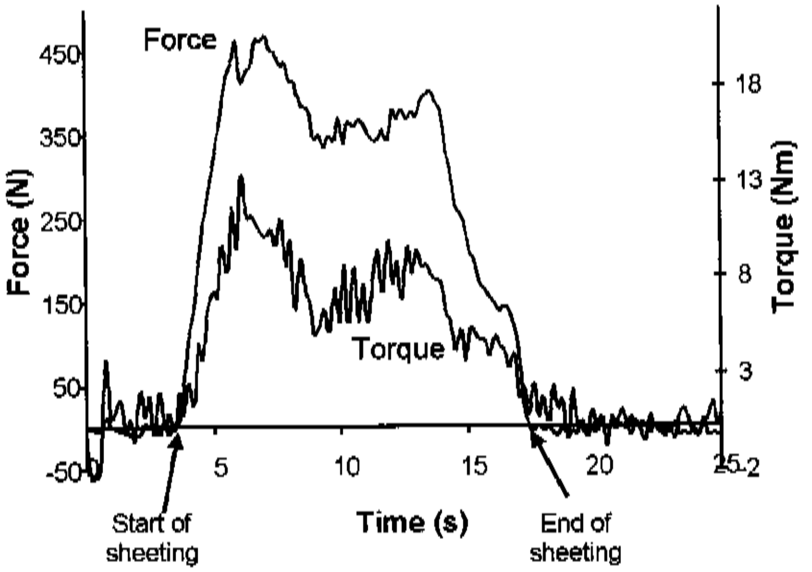

Figure 4. Typical force and torque vs time curves for one sheeting pass.

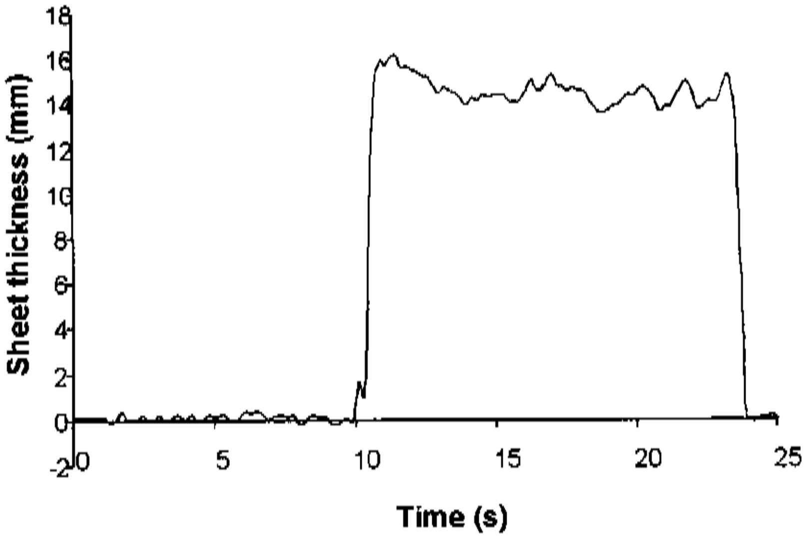

Figure 5. Typical sheet thickness vs time curve. Note that the curve is shifted in time compared to force and torque values (Figure 4). This time lag is the time needed for the dough sheet to travel from the rolls to the thickness measuring device.

Figure 5 shows typical sheet thickness data. Sheets are usually slightly thicker at the beginning and then fairly constant. This shows the importance of using sheets long enough to reach this plateau.

4.2 Experimental design

Dough was repeatedly sheeted up to 20 passes. As the work progressed an estimate of the optimum number of passes was made from the baking data and more experiments were done around that optimum number. An experiment with 10 passes was always included so that work input rates could be compared. Two roll diameters (150 mm and 270 mm), two gap settings (6 mm and 10 mm) and three speed settings (roll surface speed 0.085 m/s; 0.141 m/s and 0.283 m/s) were used. Surface speed was chosen as the controlled parameter rather than roll speed (rpm) so throughput rate would be the same for small and large roll settings. The total number of different combinations used was 12. All settings are summarised in Table 2.

Table 2. Chosen values for sheeter parameter settings

Roll diameters (mm)	**Gap settings (mm)**	**Roll surface speeds (m/s)**
150	6	0.085
270	10	0.141
		0.283

4.3 Results

A typical result for loaf volume as a function of the number of sheeting passes is given in

Figure 6 for a roll gap of 6 mm, roll speed of 0.085 m/s and two roll diameters. Loaf volume increased from about 500 ml to 750 ml after 7 passes. It then decreased. Such a trend is very similar to results obtained from MDD mixing with increasing work input. Loaf texture score (a subjective measure of cell structure) showed a similar trend (Figure 7). The highest texture score was around 7 units. For comparison, loaf volume for an MDD mixed dough was 767.5 ml and the texture score was 8.5. From these data we can determine the optimum number of sheeting passes to produce a high volume and high texture score.

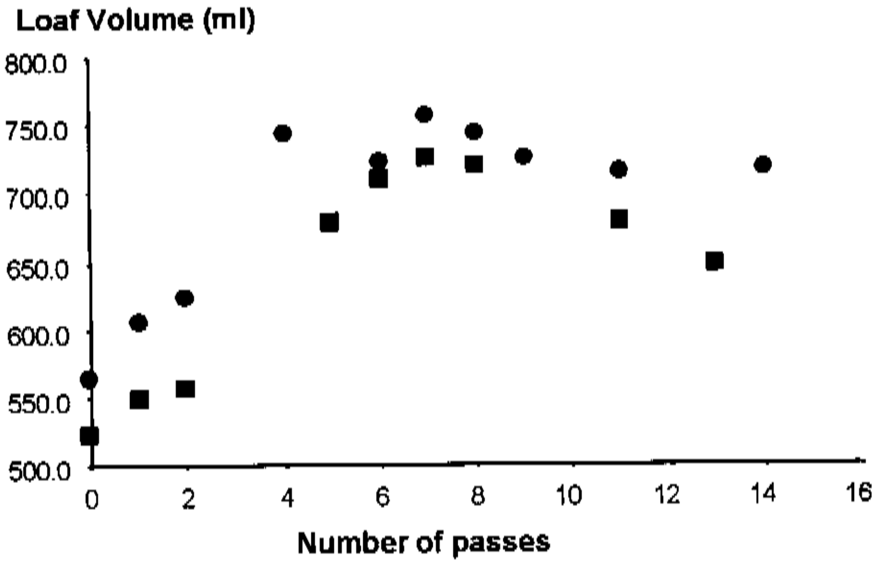

Figure 6. Typical loaf volume vs. number of sheeting passes. Roll gap was 6 mm and surface speed was 0.085 m/s. ● 150 mm roll diameter, ■ 270 mm roll diameter.

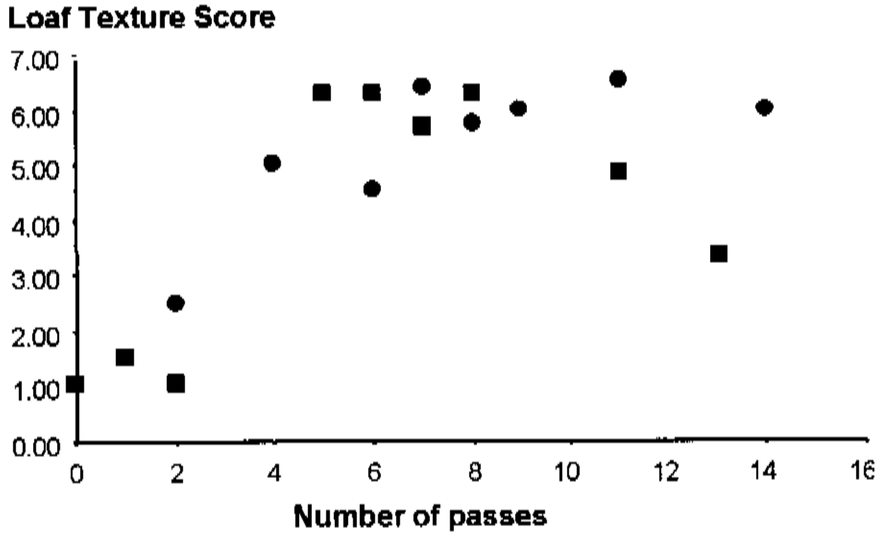

Figure 7. Typical loaf texture score vs. number of sheeting passes. Roll gap was 6 mm and surface speed was 0.085 m/s.● 150 mm roll diameter, ■ 270 mm roll diameter.

The results for the optimum number of sheeting passes determined for the different sheeter settings are given in Table 3 The number of sheeting passes required to obtain optimum bread quality is between 7 and 9. The differences are small and not significantly different for the different sheeter settings. Texture scores ranged between 6 and 8, with one outlier at 4. A range of 2 score units is small and it is difficult to observe any clear trends from texture data. If texture is analysed as a function of one parameter by averaging all values across the other two parameters, then increasing roll diameter lowers the score on average by one point (from 7 to 6).

Table 3. Results for optimum loaf quality and work input rate for the different sheeter settings.

Roll D diameter (mm)	Roll speed (m/s)	Roll gap (mm)	Optimum work input (Wh/kg)	Optimum number of passes	Optimum loaf volume (ml)	Optimum texture score	Work input rate (mWh/kg/pass)
150	0.085	6	0.044	7	760	7	6.88
150	0.141	6	0.078	9	797.5	6.5	8.81
150	0.283	6	0.107	8	835	8	7.74
150	0.085	10	0.025	8	820	6.25	3.88
150	0.141	10	0.054	9	740	7.5	6.29
150	0.283	10	0.044	9	787.5	7	5.70
270	0.085	6	0.045	8	720.0	6.25	6.42
270	0.141	6	0.034	7	715.0	4.00	13.21
270	0.283	6	0.056	8	767.5	6.75	10.00
270	0.085	10	0.024	8	730.0	6.00	4.21
270	0.141	10	0.022	7	782.5	7.00	7.65
270	0.283	10	0.023	7	760.0	7.00	6.13

Loaf volume ranged from 715 to 835 ml. Repeatability of volume was within 15 ml. Roll diameter had the greatest effect on loaf volume: on average, volume decreased from 790 to 745 ml for increasing roll diameter. Speed affected the volume slightly (increase from 757.5 to 787.5 ml with increasing speed). Using a different gap did not, on average, affect loaf volume. Thus, maximum volume is achieved using a small roll, running at high speed. Using a smaller roll and higher speed also resulted in dough that was easier to handle and less prone to tearing.

Optimum work input ranged from 0.022 to 0.107 Wh/kg. These values are very low compared with MDD mixing in a Tweedy-type dough mixer (around 11 Wh/kg). The data show that dough development can be achieved using an energy input of less than 1% of that used in an MDD mixer. Previous data estimated that sheeting uses 10%-15% of the energy used in a mixer (Kilborn & Tipples 1974; Morgenstern et al. 1999). Optimum work input decreased on average with increasing roll diameter (from 0.058 to 0.034 Wh/kg). Increasing speed increased work input from 0.034 to 0.057 Wh/kg. A smaller gap also decreased work input (from an average 0.060 to 0.032 Wh/kg).

Work input rate, which was calculated by dividing the cumulative sheeting energy at the 10th pass by 10, ranged from 3.88 to 13.21 mWh/kg. Work input rate always decreased with increasing gap (on average from 8.8 to 5.6 mWh/kg). Increasing roll surface speed increased the work input rate at medium speed. It then decreased again at the highest speed. Increasing roll diameter generally increased the work input rate (on average from 6.6 to 8.0 mWh/kg).

4.4 Conclusion

A research sheeter was used to measure the energy required to produce bread dough by repeated sheeting. The energy requirement and bread quality were determined for different combinations of roll diameter, roll gap and roll speed settings.

Passing bread dough through sheeting rolls repeatedly developed it similarly as in MDD mixing, such as in a Tweedy mixer. The number of passes needed for optimum bread quality was between 7 and 9. This is a small range and there seemed to be little dependency on sheeter settings.

Work input (energy requirement for optimum bread quality) was much less than the energy required in a typical MDD mixer. Values were less than 1% of MDD mixer values. This is more than 10 times lower than has been reported before. Work input went down with increasing roll diameter, went up with increasing roll surface speed and went down with increasing roll gap.

Loaf volume did not show a clear trend with the different parameter settings. Increasing roll diameter appeared to have the largest effect, generally resulting in decreased volume. Best bread quality was obtained with a small roll diameter and high speed.

The rate at which energy is imparted to the dough showed a clear trend with the different parameter settings. The rate increased with increasing roll diameter and decreased with increasing roll gap. Increasing the speed first increased the work input rate; the rate then decreased again on further speeding up.

It follows that work input and bread quality are not directly related when dough is made using different sheeter settings. This is very similar to comparing work input in different mixers. The amount of energy used to mix a dough relates to the bread quality produced by a particular mixer, but it is not directly related to energy requirements in another mixer. Since the number of sheeting passes needed to obtain optimum dough did not vary much, the number of passes required is a better parameter to use in practice.

5 Predicting viscosity from on-line roll separation force measurement

Accurate measurement and control of the rheological properties of dough are considered important in automated bread making. There is an optimum consistency for dough, which is affected by the way it is mixed and further handled. It has been shown that the rheological properties of dough sheets are related to dough development in a similar way. Extensional viscosity increases with dough development by sheeting and decreases when the gluten network in dough breaks down after continued sheeting (Morgenstern et al. 1999).

When dough is passed through sheeting rolls, it exerts a force on the rolls. This force depends on the rheological properties of the dough and on sheeter settings, such as roll speed and roll gap (Levine 1985). Roll separation force can easily be measured on-line in contrast to rheological properties. Understanding how sheeter settings affect roll separation force may enable us to measure rheological dough properties on-line.

An experiment was done to establish the relationship between dough rheological properties and roll separation force for different sheeter settings.

5.1 Method

A dough was prepared by mixing all ingredients in a Hobart mixer (model E200) for 10 minutes at speed 1. The formulation consisted of flour, water, salt and improver (Table 4). Six kilos of the formed dough was sheeted on a Sinmag benchtop sheeter (roll diameter 90 mm) to form a sheet approximately 10 mm thick (Table 4).

Table 4. Ingredients and reduction table for dough preparation.

Ingredients	**Level (% of flour weight)**	**Pass number**	**Roll gap (mm)**
Flour	100%	1	25
Water	57%	2	25
Salt	2%	3	15
Improver*	1.2%	4	15
		5	7
		6	7

*20% (w/w) SSL, 15% (w/w) TEM, 20% (w/w) enzyme active soy flour and 45% (w/w) flour

The dough sheet was placed on the conveyor belt of the research sheeter (see 4.1) and cut into a rectangle 38 cm wide.

The prepared sheet was then passed once through the sheeting rolls during which the separation force was recorded. Immediately after sheeting, 27 discs were cut out of each dough sheet and stored under a plastic cover to prevent drying. At intervals over a period of 80 minutes, a disc was taken for measurement of elongational viscosity. This was done by clamping the disc between two plates, placing this under an Instron testing machine and moving a probe through holes in the center of the plates (Morgenstern et al. 1996). This stretches the dough at a known elongation rate (0.07 s^{-1}). The stress at a certain elongation $\epsilon=1$ was determined. Since elongation rate is constant, this stress is proportional to (apparent) viscosity. All experiments were repeated on another day.

5.2 Experimental design

Experiments were performed with two types of flour, Epic - a strong flour used for bread making, and Halo - a weaker flour used for biscuits, both obtained from Champion Flour Mills in Christchurch. Two roll diameters were used and three different roll surface speeds for each roll and each flour type (see Table 5), giving a total of 12 different conditions.

Table 5. Experimental conditions.

Flour type	Roll diameter (mm)	Roll Surface speed (m/s)
Strong	150	0.057
Strong	150	0.113
Strong	150	0.170
Strong	270	0.057
Strong	270	0.170
Strong	270	0.283
Weak	150	0.057
Weak	150	0.113
Weak	150	0.170
Weak	270	0.057
Weak	270	0.170
Weak	270	0.283

Average force during sheeting was determined from the force-time curve (see 4.1).

Rheological properties change rapidly after sheeting. Previous experience suggested that this change is exponential, with a rapid change at first and then a slower levelling off to a constant state (Newberry et al. 1996). To estimate elongational viscosity during sheeting, stress was plotted versus time with the first measurement taken as soon as possible after sheeting. An exponential curve was then fitted to the data:

$$\sigma(t) = A_0 + A_1 \cdot e^{(-t/\tau)} \qquad \text{(Equation 2)}$$

where t is the time and τ is a time constant. The sum of A_0 and A_1 is the stress just after sheeting. A_0 is the relaxation stress, which is the stress measured when the dough is fully relaxed (see Figure 8).

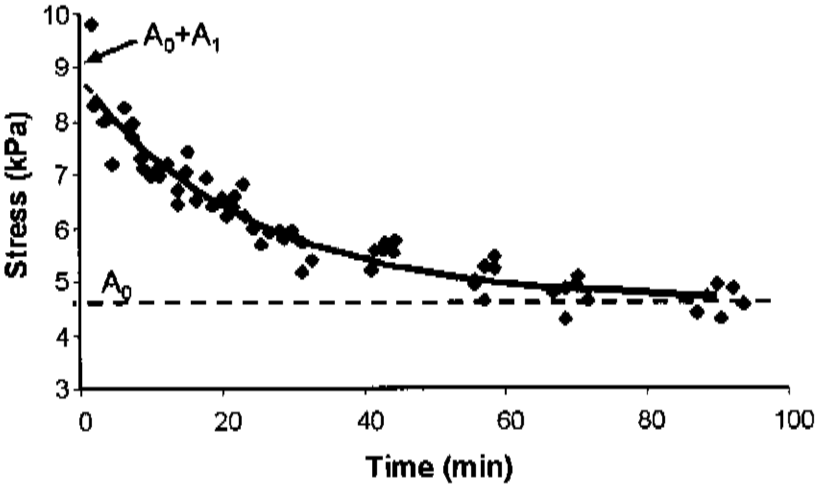

Figure 8. Typical stress relaxation curve for sheeted dough. Strong flour, 150 mm roll diameter and 0.057 m/s roll surface speed.

5.3 Results

Average force during sheeting as a function of speed is presented in Figure 9. For the weak flour, force increased with roll speed. There was no difference between small roll and large roll diameters. For the strong flour, there was no strong relationship between force and roll speed. For the small roll, the forces were higher, but this was probably caused by poor control of sheet thickness. Sheet thickness was higher than in the experiment with the larger rolls and therefore forces were higher. There was a large difference between flour types. The strong flour exerted higher forces on the rolls than the weak flour. Since the water content in both doughs was the same this was to be expected.

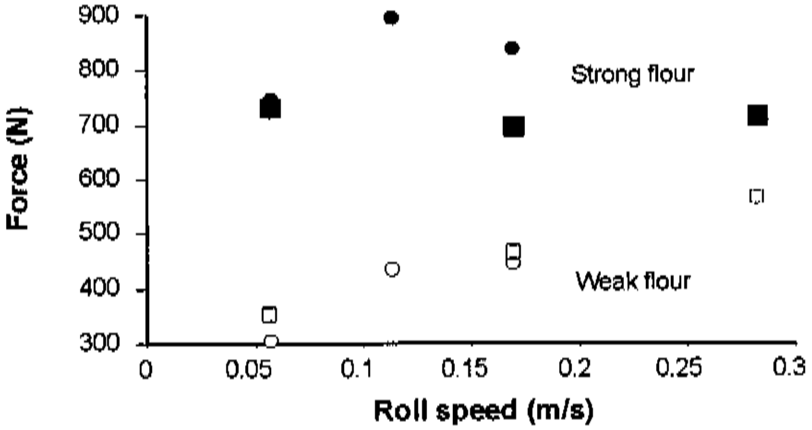

Figure 9. Roll separation force versus roll surface speed. Closed symbols are for the strong flour, open symbols are for the weak flour. ●,○ 150 mm roll diameter, ■, □ 270 mm roll diameter.

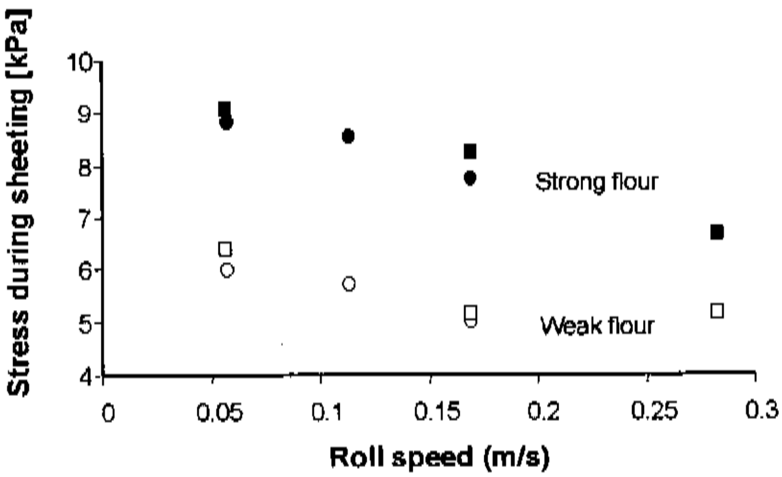

Figure 10. Stress during sheeting versus roll surface speed. Closed symbols are for the strong flour, open symbols are for the weak flour. ●,○ 150 mm roll diameter, ■, □ 270 mm roll diameter.

Values for A_0+A_1 (elongational stress at time of sheeting) decreases with roll speed (Figure 10). This trend is consistent with previously reported pseudo plastic ("shear thinning") behaviour of dough. Stress in the strong flour is higher than in the weak flour. Again, roll diameter does not affect stress in the dough sheet.

Relaxation time was affected by roll speed. With increasing roll surface speed, the relaxation time went down (Figure 11). This means that that when a lamination line is speeded up, the dough will relax faster. Again, roll diameter did not affect the relaxation time significantly. The weaker flour had slightly shorter relaxation times.

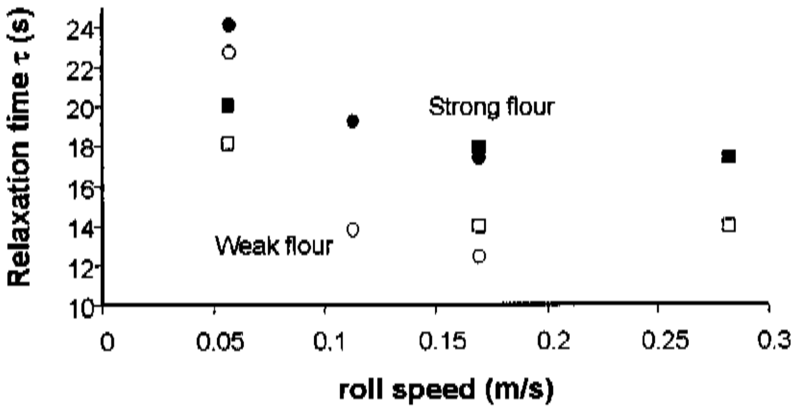

Figure 11. Dough relaxation time versus roll surface speed. Closed symbols are for the strong flour, open symbols are for the weak flour. ●,○ 150 mm roll diameter, ■, □ 270 mm roll diameter.

When roll separation force data and rheological data are combined it is clear that force cannot be used to predict viscosity of the dough directly (Figure 12). There is no direct relationship between the two and roll speed influences the results. If viscosity is a predictable function of roll speed (e.g. powerlaw behaviour), prediction of viscosity may be much better. There is not sufficient data in this trial, however, to test this case. Force and viscosity data do separate the weak flour from the strong flour. The weak flour has low viscosity and low separation force. The strong flour has high viscosity and high separation force. This proves that the measurements are sensitive to large differences, but being able to differentiate between such extremes without any detail in between has limited usefulness.

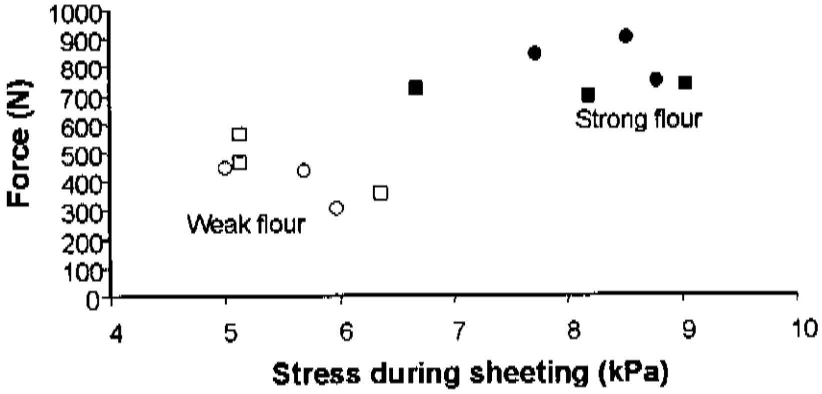

Figure 12. Roll separation force versus stress during sheeting. Closed symbols are for the strong flour, open symbols are for the weak flour. ●,○ 150 mm roll diameter, ■, □ 270 mm roll diameter.

5.4 Conclusion

The relationship between roll separation force and dough rheological properties during sheeting was determined in an experiment using different flour properties and sheeter settings.

Viscosity, measured in extension, decreased with roll speed, as expected for a pseudo plastic material. Dough relaxation time also decreased with roll speed. This means that speeding up an automated sheeting line shortens the relaxation time. This could be beneficial for pastry lines, where shrinkage occurs due to lack of dough relaxation. It may also explain why sheeting lines that operate at different production rates produce different product quality.

Roll separation force increased with roll speed. This was most obvious for the weaker flour. For the strong flour roll speed did not appear to affect roll separation force. The forces for the strong flour were generally larger than for the weak flour. This is explained by the fact that the recipe had a fixed water content and the strong flour has a higher water absorption than the weak flour. Thus, it produces a stiffer dough than the weak flour.

Since rheological properties are dependent on roll speed a direct relationship between force and viscosity could not be derived. There was a correlation between force and viscosity, but this was the result of the large differences generated by the flour types. A weak flour has lower viscosity and generates less force during sheeting. A strong flour has higher viscosity and generates a higher force. If force is to be used to predict viscosity, then more detailed information is needed about the nature of roll speed dependence on force and viscosity.

Roll diameter did not significantly affect rheological properties or separation force.

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