# FACTORS AFFECTING MECHANICAL DOUGH DEVELOPMENT. V. INFLUENCE OF REST PERIOD ON MIXING AND "UNMIXING" CHARACTERISTICS OF DOUGH[1,2]

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**ABSTRACT**

Mixing studies were carried out on doughs containing flour-water, flour-water-salt, and full baking formula. When a rest period (*e.g.*, 2–16 min) was introduced between an initial short premix and continuation of dough mixing to optimum development, consistency level (torque) was markedly higher when the mixer was restarted, then dropped somewhat before increasing to a peak level. Introduction of the rest period reduced the time subsequently required to mix to peak consistency. These effects were more pronounced with longer rest periods and at higher absorptions (*e.g.*, 80 and 100%). When dough was mixed to peak consistency, rested, and the mixer restarted, consistency immediately dropped sharply (suggesting a disorientation or "unmixing" effect), before increasing again to a peak. Baking studies confirmed that a rest period exaggerates the unmixing effect, which may take place even when a developed dough is subsequently remixed for a very short time at high speed. This "destructive" phase, marked by a deterioration in dough and bread properties, was not observed when rested doughs were processed directly with sheeting rolls.

Previous studies (1,2) have stressed the importance of both energy and mixing speed or intensity when doughs are mixed for baking methods that depend on adequate dough development for the achievement of maximum potential bread quality, particularly loaf volume.

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[2]Presented at the 60th Annual Meeting, Kansas City, Mo., Oct. 1975.

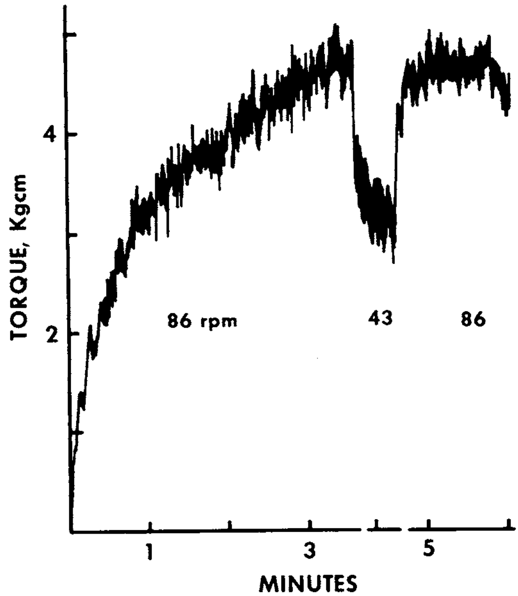


Fig. 1. Trace of torque against mixer head revolutions (horizontal axis shows time equivalent) for flour-water dough (66% absorption) mixed to peak consistency on the mixograph at 86 rpm, followed immediately by 1 min of slow-speed mixing at 43 rpm and 1.5 min at 86 rpm.

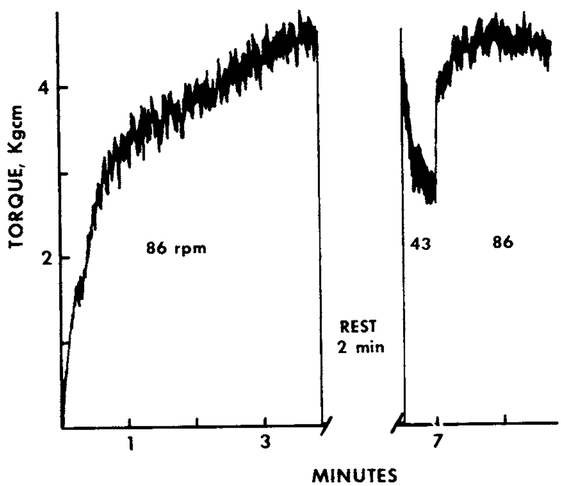


Fig. 2. As for Fig. 1, except mixer was switched off and dough was rested for 2 min between the initial mixing to peak at 86 rpm and the 1 min of slow-speed mixing at 43 rpm.

When a dough is mixed, following the initial stage where ingredients are brought together into a homogeneous mass, a "lag phase" is often observed where the rate of increase in dough consistency slows down, and the mixing curve then levels off or even decreases before increasing to a peak value. This lag phase is less apparent for weaker flours, but may still be seen if the mixing curve is expanded (*e.g.*, recorder chart speed increased). It has been suggested (3) that hydration must proceed to a sufficient extent before the dough becomes cohesive

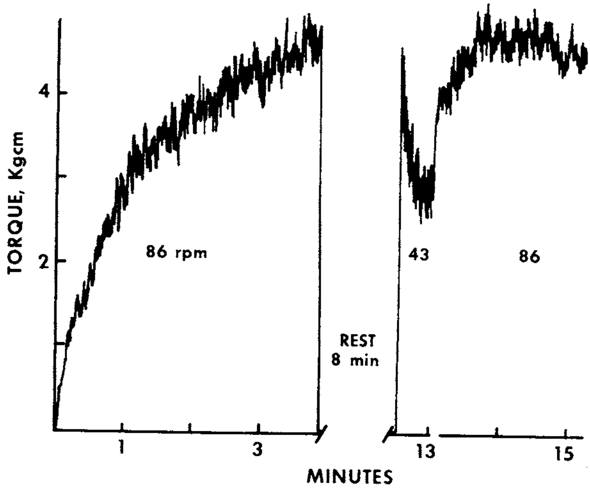


Fig. 3. As for Fig. 2, except with an 8-min rest period.

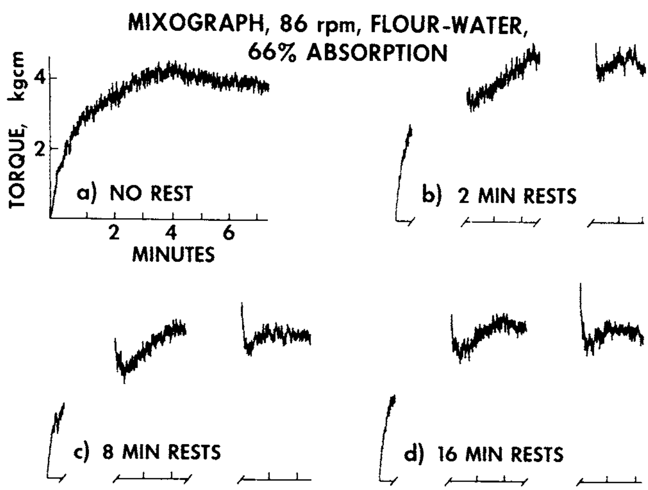


Fig. 4. Mixograph curves for flour-water doughs (66% absorption) mixed at 86 rpm, a, with no interruption; and b, c, and d, with rest periods (of 2, 8, and 16 min, respectively) introduced at the stages shown.

enough to respond to further stretching and development.

The object of this paper is to report on a study of the effect of the introduction of rest periods on subsequent mixing properties of the dough and on bread quality. Rest periods were introduced between an initial premix stage and subsequent mixing to peak consistency. In addition, developed doughs were rested before remixing and the effect of this second rest period on remixing characteristics was studied. Previous works (3) showed the dramatic disorientation that occurs when developed doughs are mixed further at a speed well below the "critical speed" for that mixing situation. Part of this present study was therefore aimed at examining the effect of rest periods introduced between dough development and subsequent slow-speed "unmixing".

## MATERIALS AND METHODS

### Flour

The flour used for this study was a straight-grade flour milled on a Buhler laboratory mill from a sample of No. 1 Canada Western red spring wheat of 13.0% protein. Flour extraction was 73.5%, and the flour had the following characteristics:

*(14% moisture basis)*

| | |
|---|---|
| Protein (N × 5.7) | 12.3% |
| Ash | 0.45% |
| Damaged starch | 31 Farrand units |
| Gassing power | 325 mm |
| Farinograph absorption | 63.5% |

### Baking

The GRL-Chorleywood method described previously (4) was used, except that oxidation level was 37.5 ppm ascorbic acid + 30 ppm potassium bromate. Mixing was carried out in a variable speed GRL 200 mixer (5) with mixing times and speeds as shown in the tables. An absorption of 66% was used for all baking tests with this flour. Baking results were averages for duplicate mixes carried out on separate days. Two loaves were obtained from each mix.

### Mixing Curves

All curves shown represent torque against turns made by the mixer used. A 35-g mixograph with strain gauge modification (6) which detects torque at the mixing bowl, and a GRL-200 mixer fitted with strain gauges at the motor (5) were used for obtaining the mixing curves. Both mixers were driven by 1/4 h.p. motors operated by SCR controls. A Daytronic amplifier 300D type 93 was used to amplify the strain gauge signal to a Riken Denshi recorder. A pulse synchronized chart feed and magnetic pick-up at the motor provided chart speeds which were directly proportional to mixer speed. In this way, when doughs were mixed at different mixing speeds, the curves could be compared directly. A given length of x axis always corresponds to the same number of turns of the mixer, whereas with a fixed time base higher speed mixing curves may become too contracted. The magnetic pickup also supplied pulses to a frequency counter to give digital read out in mixer rpm (± 1 rpm) using a time base of 0.6 sec for the mixograph and 1.0 sec for the GRL-200. Therefore, it was possible to vary the speed of the mixer and observe the change in rpm within the limits of 2 × time base (*e.g.*, 1.2 sec and 2 sec).

Doughs contained 35 g flour in the mixograph and 200 g flour in the GRL-200 mixer. Dough formulas used included flour-water, flour-water-1% salt, and full baking formula.

## EXPERIMENTAL AND RESULTS

### Flour-Water Doughs

*Effect of Rest Period on Slow-Speed "Unmixing."* When doughs were mixed on the mixograph with 66% absorption (based on flour = 100 on a 14% moisture basis) at a mixing speed of 86 rpm (speed of mixograph head) and a temperature of 26° ± 1° C, peak consistency was reached after 3.5 min. Figure 1 shows a trace of torque against number of turns of the mixer head (for convenience, the corresponding times are shown on the horizontal axis) for a dough mixed to slightly beyond peak consistency, then mixed for a further 1 min at a speed of 43 rpm, and finally for 1.5 min at 86 rpm. There was only a suggestion of a lag phase around the 0.5-min mark in an otherwise continuous curve to peak for the initial mix. The immediate sharp drop in curve height at 43 rpm was due to the speed change. The continuing further drop in curve height was due to a lowering of dough consistency associated with an "unmixing" effect. On switching back to 86 rpm for the remix stage, the initial rise in curve height was again due to speed

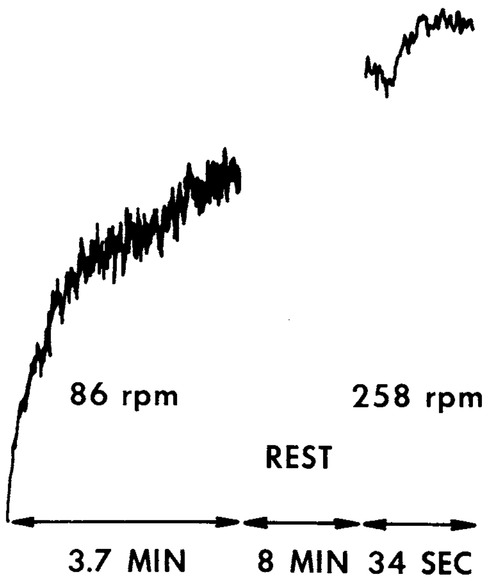


Fig. 5. Trace of torque against mixer head revolutions for flour-water dough (66% absorption) mixed on the mixograph to peak consistency at 86 rpm, rested for 8 min, and remixed for 34 sec at 258 rpm.

change. The consistency started at a slightly lower level than when 86 rpm mixing was interrupted, but peak consistency was regained after 0.6 min.

When a rest period was introduced between the end of initial mixing to peak consistency at 86 rpm and the start of slow-speed mixing at 43 rpm, the "unmixing" effect became more pronounced, as indicated by a more rapid initial drop in consistency during the early part of slow-speed mixing and a longer time taken to regain peak consistency during subsequent remixing at the high speed. This is illustrated by the curves shown in Figs. 2 and 3. Rest periods of 2 and 8 min were introduced between initial mixing and slow-speed "unmixing". Remixing time required to reachieve peak consistency increased to 0.9 min and 1.2 min, respectively, for the 2-min and 8-min rest periods. Dough relaxation during the rest period augmented the "unmixing" effect, indicating that the critical speed was higher and the dough was more easily disoriented than a developed, unrested dough.

One further effect caused by the rest period was a markedly higher consistency level at the start of slow-speed mixing. A possible reason for this will be discussed later.

*Effect of Rest Periods Introduced during Mixing.* A further series of doughs was prepared where rest periods were introduced, first after a 43-turn (0.5-min) premix, and second, between mixing to peak consistency at 86 rpm and remixing at the same speed. Rest periods used were 2, 8, and 16 min, and the corresponding mixing curves are shown in Fig. 4, curves b, c, and d. For comparison, Fig. 4, a, shows the recorder trace for a dough mixed at 86 rpm to well past peak consistency.

In this figure and in subsequent figures we have not shown the vertical lines marking the path of the recorder pen to zero when the mixer was switched off. Similarly, to avoid clutter, we have not shown the return of the trace from zero when the mixer was switched on again.

On starting up the mixer after the first rest period, the torque was initially at a markedly higher level than it was at the end of the 30-sec premix. The longer the rest period, the higher was the start-up trace. That this large change in consistency (higher trace) at start-up was not due to motor surge was confirmed

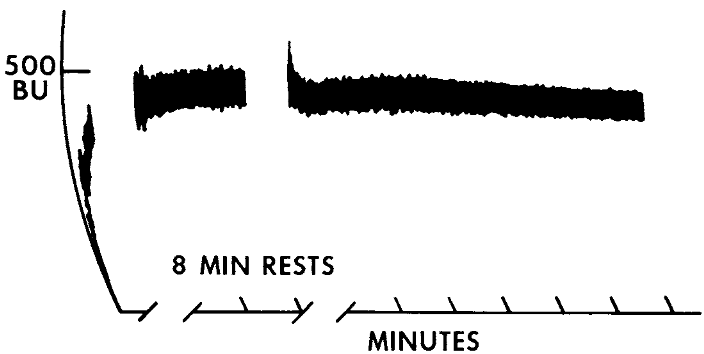


Fig. 6. Farinograph curve for flour-water dough (66% absorption) mixed at normal farinograph speed, with 8-min rest periods introduced at stages shown.

by the absence of "spikes" when the mixer motor was switched off until the motor stopped, and immediately switched on again (total interruption about 1 sec). All samples were prevented from drying out by wrapping the mixing bowl in moisture-proof film wrap during the rest period, and weighings confirmed that the higher start-up trace could not be attributed to a loss of dough water.

Immediately after start-up following the first rest period, consistency level decreased somewhat before increasing to a peak level. Mixing time to peak was reduced with increasing rest period (*e.g.*, 2.4 min for 2-min rest to 1.9 min for 16-min rest), indicating that the rest period had brought the dough into a more suitable state to respond to mechanical mixing and develop to peak consistency. Before the build-up to peak, the immediate drop in consistency (more pronounced with longer rest periods) suggested that a destructive phase occurred, similar to the disorientation effect of "unmixing".

When the developed dough was rested and then remixed at 86 rpm, dough consistency was initially as high as or higher than the level before the rest period. As rest period was increased, the start-up trace level became progressively higher. As mixing progressed, consistency dropped sharply to a minimum level before again increasing to a maximum, or peak level. This initial decrease in consistency, or "hole," again suggested a disorientation or "unmixing" effect.

The hole effect was also noted even when remixing speed was greatly increased. For example, Fig. 5 shows the recorder trace for a dough mixed to peak on the mixograph at 86 rpm, rested 8 min, and remixed at 258 rpm (the highest speed available). The initial decrease in consistency was again noted, reaching a minimum level after about 10 sec (43 turns) before increasing to peak.

That these effects are not peculiar to pin-type mixers is shown in Fig. 6, which is a farinograph curve run at 66% absorption on the same flour and where two 8-min rest periods were used. The higher start-up trace and the "unmixing" effect are readily apparent after both rest periods.

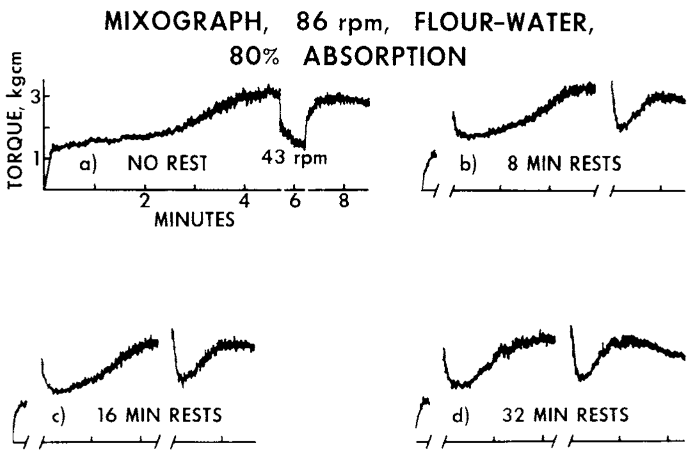


Fig. 7. Mixograph curves for flour-water doughs (80% absorption) mixed at 86 rpm (except for 1 min at 43 rpm at point shown in a) with rest periods introduced as indicated.

*Effect of High Absorption.* The curves in Fig. 7 are for doughs mixed at 80% absorption. At this higher absorption, the dough was more fluid and offered less resistance to the mixer pins, so that a higher speed would have been required to

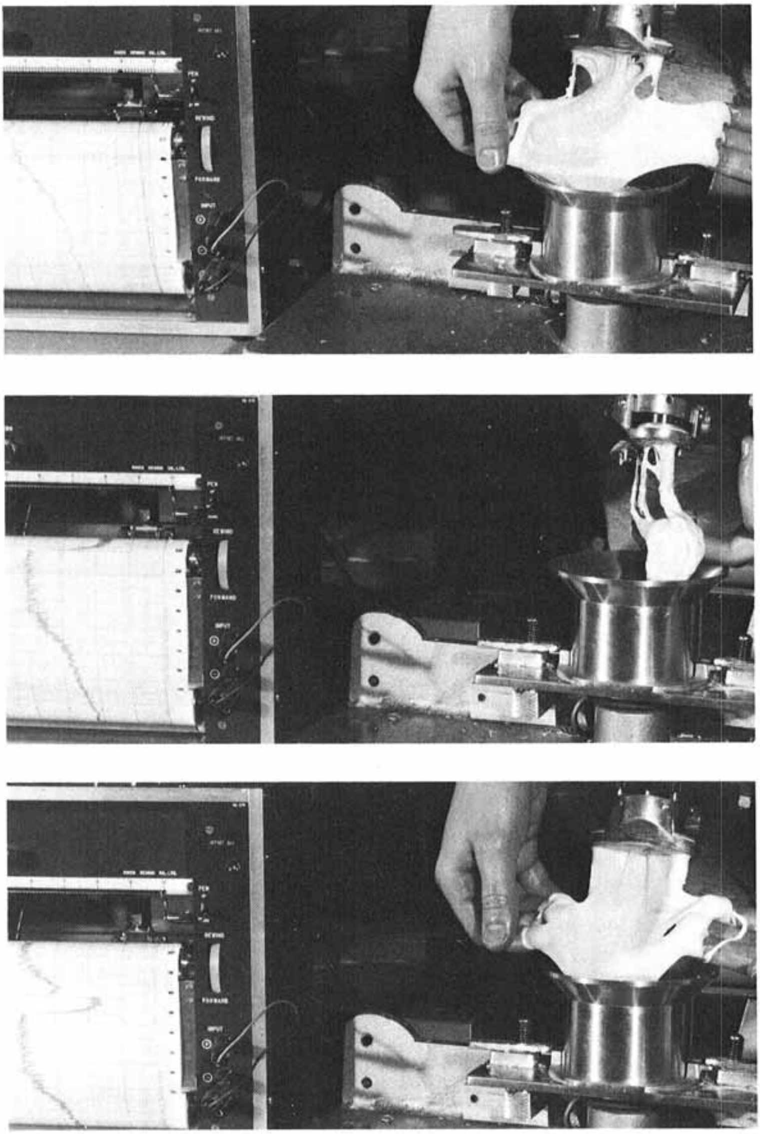

Fig. 8. Appearance of flour-water doughs (100% absorption) mixed on the mixograph. Top, mixed to peak consistency at 215 rpm; center, mixed to peak consistency at 215 rpm, followed immediately by a 1-min "unmix" at 43 rpm; bottom, mixed to peak at 215 rpm, "unmixed" at 43 rpm for 1 min, then remixed to peak consistency at 215 rpm.

subject the dough to a given degree of stress. Therefore, when the same speed (86 rpm) was used, the mixing curve became flatter and the "lag" phase during uninterrupted mixing was longer and more pronounced.

The "unmixing" effect, noted at 66% absorption, was more marked, consistent with a higher critical speed requirement at higher absorption. The hole effect on remixing, after both the initial and second rest periods, was amplified. The higher start-up trace following the initial rest period was again evident and increased with increasing rest period. After the second rest period, the start-up trace was only slightly higher than when mixing was interrupted.

A further series of doughs was mixed using 100% absorption. To develop these doughs, a mixing speed of 215 rpm was used. That the doughs were, in fact, developed can be seen in Fig. 8, which shows dough mixed to peak consistency (top), then "unmixed" (center), and remixed to peak (bottom).

Rest periods used after the initial 30-sec premix were 2, 8, 32, and 128 min, and 16.5 hr. The mixing curves obtained are shown in Fig. 9. The most striking observation was the reduction in development time (from 9.9 min to 1.9 min) with increasing length of rest period. The maximum (peak) consistency was the same for all mixes, which confirmed that the doughs did not lose water during the

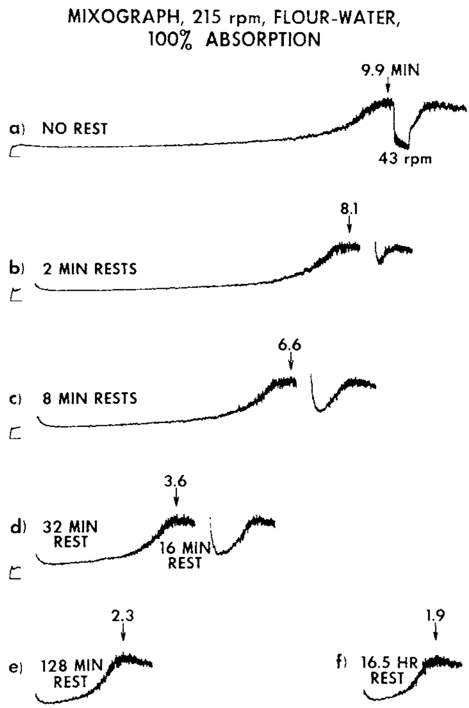


Fig. 9. Mixograph curves for flour-water doughs (100% absorption) mixed at 215 rpm (except for 1 min at 43 rpm at point shown in a), with rest periods introduced as indicated. Arrows show total mixing time (including initial 30-sec premix) required to achieve peak consistency.

rest periods. When the mixer was restarted after the second rest period (only 2-, 8-, and 16-min rest periods were used), the initial start-up trace level was only slightly higher than it was at peak consistency. This suggested that at 100% absorption the effect seen at lower absorption was either less marked or was

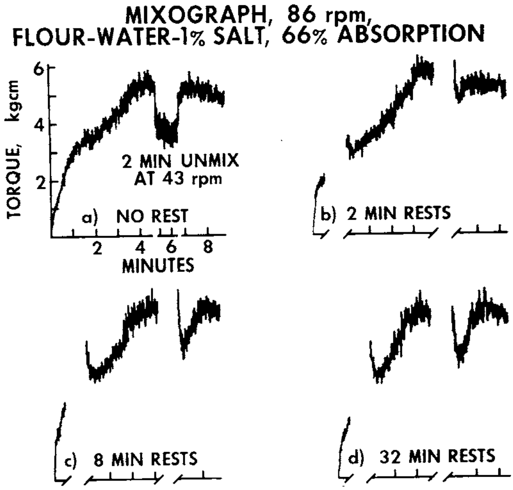


Fig. 10. Mixograph curves for flour-water-1% salt doughs mixed at 86 rpm, with rest periods introduced as indicated.

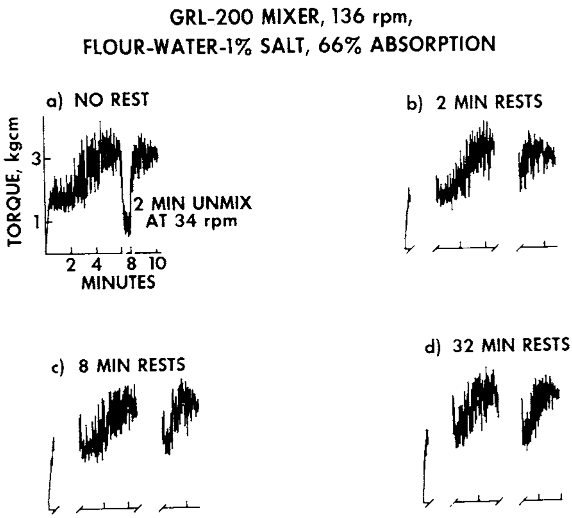


Fig. 11. Torque curves for flour-water-1% salt doughs mixed on the GRL-200 mixer at 136 rpm (except for 2 min at 34 rpm at point shown in a), with rest periods introduced as indicated.

masked by the high water content in the dough.

The higher consistency level at start-up following the initial rest period again indicated that considerable changes occurred in the dough during resting. It is concluded that development occurs as a product of time and work intensity. That both time and mechanical work are required and interact in bringing the dough to a "developed" state is demonstrated in this example. While the higher water absorption used provides more lubrication and makes the imparting of work to the dough more difficult, the importance of time is illustrated by the marked reduction in the lag phase and shortening of mixing time required for peak consistency following increasing periods of rest after the premix. The longer the rest period, the more development by mechanical mixing is facilitated.

**Flour-Water-Salt Doughs**

In order to study baking properties, it was necessary to make a transition from the mixograph to the GRL-200 mixer, in which sufficient dough can be mixed for baking pup loaves. With flour-water doughs there is a tendency for the dough to paste against the side of the GRL-200 mixing bowl. With 1% salt added this problem does not occur. To form a bridge between doughs mixed with flour-water only in the mixograph, and with full baking formula in the GRL mixer, both mixers were used to mix doughs containing 1% salt and 66% water. Mixing speed was 86 rpm for the mixograph and 136 rpm for the GRL-200. Mixing curves are shown in Figs. 10 and 11. Results for the mixograph (Fig. 10) were similar to those obtained with flour-water doughs. There was more of a lag in the initial mixing curve than with the flour-water dough. The initial rest period caused a marked increase in curve height when the mixer was restarted and the hole effect was even more pronounced after both rest periods. However, the

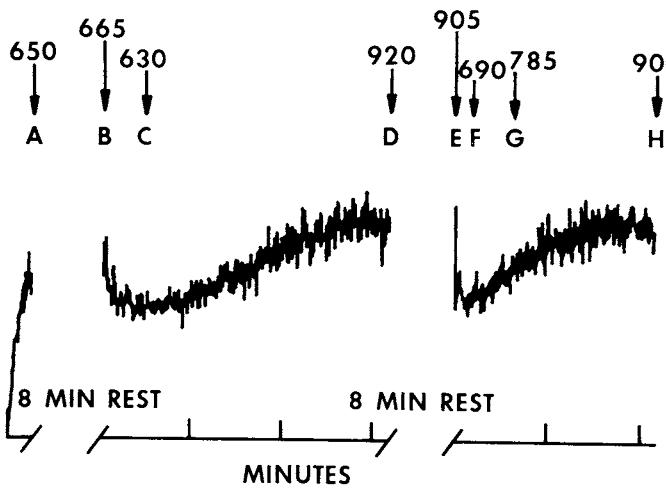


Fig. 12. Mixing curves for doughs containing full baking formula mixed on the GRL-200 mixer at 136 rpm, with 8-min rest periods introduced as indicated. Letters refer to stages at which doughs were taken for make-up and panning by the GRL-Chorleywood method. Numbers above are loaf volumes obtained (in cc/100 g flour).

initial higher trace seen with flour-water doughs at commencement of remixing following the second rest period (see Fig. 4, c and d) was not as marked when 1% salt was used.

The same general effects occurred with the GRL-200 mixer as with the mixograph, and the hole effect was seen after both rest periods. Curve height was again greater after the first rest period, but not to the same extent as with the mixograph. After the second rest period, the curve height showed no increase and started at the same level as, or slightly lower than, when mixing was interrupted. One possible explanation for this apparent discrepancy is that with the 1/4 h.p. SCR motors used, the much heavier load imposed by the GRL-200 mechanism results in a somewhat slower windup to operating speed. This means that at the immediate onset of remixing, the speed (and hence consistency) is lower, and even after the very short time required to reach operating speed, the "unmixing," or hole effect has already started.

**Baking**

Doughs incorporating full baking formula were mixed using the GRL-200 mixer. Figure 12 shows the mixing and rest period combinations used. Doughs taken at the stages shown were processed using the GRL-Chorleywood baking method. Mixing and processing temperature was 35° C. Loaf volumes obtained are given at each point.

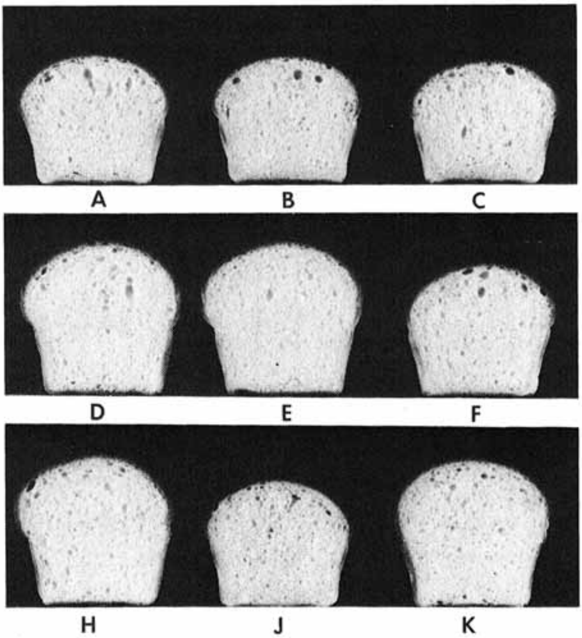


Fig. 13. Longitudinal sections through pup loaves obtained from doughs mixed to stages shown in Fig. 12 (A–H) and Fig. 14 (J and K). Make-up and panning were as for the GRL-Chorleywood baking method.

Figure 13 shows longitudinal sections through the pup loaves and Table I gives the detailed data for loaf appearance, crumb structure, and crumb color. The destructive "unmixing" phase was verified both by the appearance of the dough and by the bread obtained, particularly when the rested, developed dough was remixed into the hole (F). That it was the mixing and not the rest period that caused the deterioration was confirmed by the fact that developed dough rested 8 min and then processed (E) gave virtually the same bread quality as the dough processed immediately following peak development (D). By contrast, when the 8-min-rested dough was remixed for less than 0.5 min before processing (F), loaf volume was reduced by over 200 $cm^3$. Maximum loaf volume was regained on remixing 2 min to or beyond peak consistency (H). Remixing short of this stage (G), while giving significantly higher loaf volume than at minimum consistency (F), still produced bread that was over 100 cc lower in volume than the maximum potential.

The destructive effect of mixing following the first rest period of the premixed dough was shown by the deterioration in bread quality after mixing the rested, premixed dough for 1 min (C).

Since sheeting roll treatment had previously been shown to be a very efficient way of imparting "useful" energy to a dough (7) it was of interest to see whether

**TABLE I**
**Bread Data for Loaves Baked from Doughs Processed to the Stages Shown in Fig. 12 Prior to "Make-up" for GRL-Chorleywood Baking Method**

| Stage | Mixing/Rest Treatment | Loaf Volume cc | External Appearance | Crumb Texture[a] | Crumb Color[a] |
|---|---|---|---|---|---|
| A | Mix 30 sec at 136 rpm | 650 | 4.5 | 5.5o | 3.5yg |
| B | As above + 8-min rest | 665 | 5.0 | 5.8o | 3.5yg |
| C | As above + mix to minimum consistency (1 min) | 630 | 4.5 | 4.5co | 3.5yg |
| D | As above + continue mixing to slightly past peak consistency | 920 | 8.0 | 6.8o | 7.2 |
| E | As above + 8-min rest | 905 | 8.0 | 7.0o | 7.0 |
| F | As above + remix to minimum consistency (25 sec) | 690 | 5.5 | 5.8o | 4.5yg |
| G | As above + remix continued for further 1 min (well short of peak) | 785 | 6.0 | 6.2o | 5.0yd |
| H | As above + remix continued to past peak consistency (total remix 4 min 20 sec) | 900 | 7.0 | 6.5o | 7.5 |

[a]o = open, y = yellow, g = gray, d = dull.

the hole effect occurred when developed, rested doughs were processed with sheeting rolls rather than with a dough mixer. Doughs were mixed to peak consistency and then rested for 8 min. The sheeting roll technique previously described (7) was then used to give 0, 6, 10, 14, and 18 sheetings. The same sequence of sheeting was also applied to a series of doughs that had been mixed to peak, rested 8 min, and then remixed for 0.5 min (*i.e.*, to the point of lowest consistency on the remix curve). All doughs were then processed into pup loaves using the GRL-Chorleywood method. The sheeting rolls were prewarmed so that all work was done at 35° ± 1°C. Results are shown in Fig. 14 and Table II, and internal loaf structure is shown in Fig. 13 (J and K) and Fig. 15. Bread of high volume was obtained from all doughs processed with sheeting rolls immediately following the rest period, showing that sheeting rolls did not cause the destructive "unmixing" effect. The presence of gas holes in the loaves baked from doughs receiving a high number of sheetings indicates that the dough was already in its optimum state with the minimum number of sheetings and further sheeting roll treatment only served to incorporate air into the full-developed dough.

Sheeting roll treatment of doughs that were first mixed to peak, rested, then remixed 0.5 min, gave bread which increased in volume as the number of sheetings increased. This indicated that the dough had, indeed, been disoriented, or "unmixed" during the short period of mixing, and was being redeveloped by the sheeting rolls. The extent of the destructive action of the mixer was emphasized by the fact that even after a sheeting roll treatment of 8 folds or 18 sheetings (U), the maximum loaf volume had still not been regained.

## DISCUSSION

The results presented in this paper may be discussed under two main headings. First there is the effect of a rest period on a premixed, grossly undermixed dough;

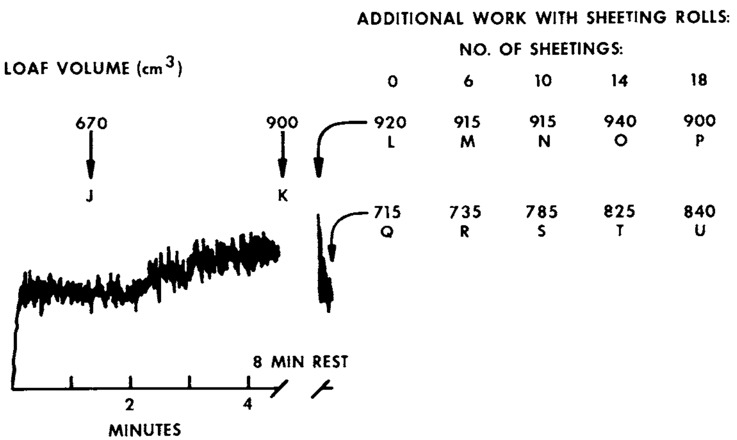


Fig. 14. Mixing curves for dough, containing full baking formula, mixed to peak on the GRL-200 mixer at 136 rpm, rested 8 min, and remixed for 30 sec at the same speed. Two series of doughs were processed with sheeting rolls before make-up. The first series (L—P) were taken immediately following the 8-min rest period, while the second series (Q—U) were taken after the 30-sec remix. Loaf volumes obtained (in cc/100 g flour) are indicated.

and secondly there is the effect of a rest period on the subsequent behavior during remixing of a developed dough.

**The Constructive Nature of Changes Occurring during Resting**

When dough ingredients were mixed just enough to form a homogeneous mass and this dough was then rested, changes occurred as indicated by a higher consistency level when the mixer was restarted. Presumably, this was partly because free water that initially served to lubricate the dough and cause consistency to be low was absorbed by dough constituents during the rest period. The immediate decrease in consistency that followed suggested an "unmixing" effect similar to that described previously (3). The inference was that if destructive "unmixing" occurred at this stage, then some degree of constructive change related to dough development occurred during the rest period. This is further suggested by the baking data for B and C in Table I. Although the dough was grossly undermixed and not developed after the premix and ensuing rest period, mixing to minimum consistency caused a deterioration in dough properties and subsequent bread quality.

**TABLE II**
**Bread Data for Loaves Baked from Doughs Processed to the Stages Shown in Fig. 14 Prior to "Make-up" for the GRL-Chorleywood Baking Method**

| Stage | Mixing/Rest/Sheeting Treatment | Loaf Volume cc | Loaf Appearance | Crumb Texture[a] | Crumb Color[a] |
|---|---|---|---|---|---|
| J | Mix at 136 rpm to minimum consistency (2.5 min) | 670 | 5.0 | 5.5 | 4.5yd |
| K | As for J + continue mixing to slightly past peak consistency (total 9 min) | 900 | 8.0 | 6.8o | 7.5 |
| L | As for K + 8 min rest | 920 | 8.0 | 6.8o | 7.2 |
| M | As for L + 6 sheetings | 915 | 8.0 | 7.0 | 7.5 |
| N | As for L + 10 sheetings | 915 | 8.0 | 7.2 | 7.2 |
| O | As for L + 14 sheetings | 940 | 8.0 | 7.2 | 7.5 |
| P | As for L + 18 sheetings | 900 | 7.8 | 7.2sgh | 7.2 |
| Q | As for L + remix 0.5 min to minimum consistency | 715 | 6.8-old | 6.0cl | 5.2yd |
| R | As for Q + 6 sheetings | 735 | 6.8-old | 6.8cl | 6.0yd |
| S | As for Q + 10 sheetings | 785 | 7.0 | 7.0cl | 6.0yd |
| T | As for Q + 14 sheetings | 825 | 7.5 | 7.5 | 6.8y |
| U | As for Q + 18 sheetings | 840 | 7.5 | 7.0 | 6.5y |

[a]o = open, sgh = small gas holes, cl = close, yd = yellow dull.

That constructive changes during resting may be a form of dough development is further substantiated by the observation that the rest period caused a marked reduction in the time subsequently required to mix the dough to peak consistency. This was particularly evident at higher levels of absorption and the effect is well illustrated in Fig. 9. At all three levels of absorption used with the flour-water system (66, 80, and 100%), introduction of an 8-min rest period caused total mixing time to peak consistency with the mixograph to be reduced by about 35%. By comparison, there was a 25% reduction for 1% salt-doughs on the mixograph, an 18% reduction for 1% salt-doughs on the GRL-200 mixer, and a 23% reduction for full-baking-formula doughs on the GRL-200. These effects of an initial rest period were more pronounced with longer rest periods.

**The Hole Effect and "Unmixing" of Rested Doughs**

The second aspect of this work is the effect of a rest period on the remixing characteristics of a developed dough. The hole effect during the early stages of remixing following 2.75 hr fermentation in the Remix baking test has been well known for several years (8). We have demonstrated that even a short rest period after development makes a dough very susceptible to an initial destructive effect when the mixer is subsequently restarted, regardless of speed. This was illustrated by a drop in loaf volume from 905 cc to 690 cc after only 30-sec remixing of a developed, rested dough (see Fig. 12).

This deleterious effect, observed with conventional laboratory dough mixers,

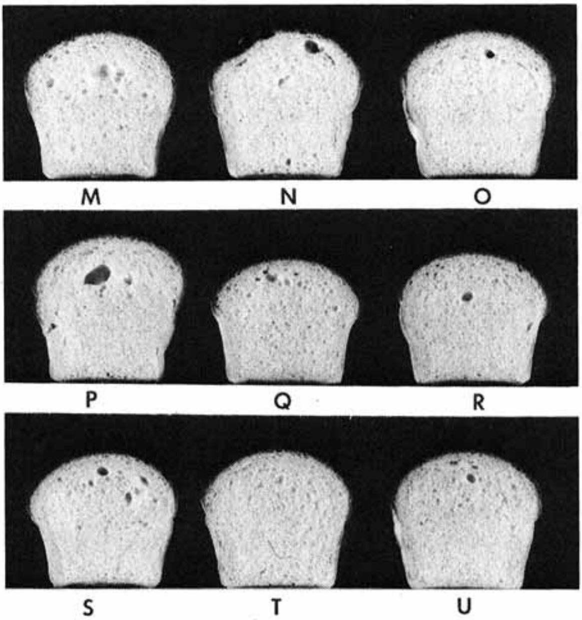


Fig. 15. Longitudinal sections through pup loaves obtained from doughs processed as indicated in Fig. 14. Make-up and panning were as for the GRL-Chorleywood baking method.

was not found when sheeting rolls were used to rework the developed, rested dough, because mixing (and the opportunity for random interchange of dough cohesive and adhesive forces) is required for the "unmixing" effect to occur. With sheeting roll treatment, there is little opportunity for random interchange. Only a squeezing and stretching action is imparted, which serves to tighten the relaxed dough back to its fully developed state without first going through a disorientation stage.

It appears that an intense stretching action is required in order to align the dough microfibrils (9) laterally to a sufficient extent to bring about a high degree of development. If there is mixing (and the concomitant random interchange of cohesive forces) without sufficient stress, then "unmixing" will result. "Conventional" mixing provides opportunity for both stretching and interchange. Depending on which is dominant, either "unmixing" or development may take place at a rate related to the extent of the dominance. Mixing of a rested, relaxed dough initially causes random interchange and associated disorientation to occur before the microfibrils can be brought under sufficient stress to redevelop them into a highly oriented structure.

The initially higher trace observed when the mixer was restarted after the second rest period (*e.g.*, see Fig. 4, d) may have been due to a further uptake of free water when the dough was at rest. On further mixing past the hole, the dough consistency peaked at about the same level as the first peak, indicating that the amount of free water available for lubrication was approximately the same at peak consistency in both cases. It is therefore thought that the higher trace may represent an absorption, during resting, of some free water in such a weakly bound state that it is unstable to mixing and is released on remixing.

The "higher trace" phenomenon was much less marked at higher absorptions, either because the loosely bound water was more stable to mixing at higher absorption or, more likely, because the effect was masked by the higher amount of free water present in the dough. The phenomenon was also less pronounced in doughs containing salt (see Fig. 12), suggesting that salt either prevented the uptake of the loosely bound water or stabilized it and prevented its release on mixing. That an uptake of free water occurs following mixing of doughs containing full baking formula is indicated by our experience with the GRL-Remix baking test, where there is a 1-min rest period between the end of mixing and the rounding stage. We observe that during this short rest period, the dough surface becomes noticeably drier and less sticky and offers more resistance to stretching and hand manipulation (indicating an increase in consistency).

Whether there is a further release of bound water during "unmixing" or whether the phenomenon is entirely related to changes in the physical characteristics of dough components is a matter for further research. Certainly, the loose, porridge-like appearance of an "unmixed" dough suggests an increase in free water. Frazier *et al.* (10) have noted that the release of bound water which may occur during mixing (*past* peak consistency) could result in a considerable decrease in consistency as mixing proceeds.

The effects we have described were observed with both leavened and unleavened doughs, and with and without salt. Therefore, they were not primarily due to fermentation, but were caused by changes in the basic characteristics of dough on resting. The extent to which "hydration" may be involved in these changes is a matter for conjecture at this stage. Even the meaning of the word is not clear at present, just as the term "development" may mean different things to different people. Further work is required to facilitate a fuller understanding of the nature of the physical and chemical changes that occur in dough during processing.

While the data we have used for illustration were for one (average Canadian wheat) flour, we have observed the same general behavior in doughs from flours of widely differing quality. The magnitude of the changes is largely related to the strength and mixing requirements of the particular flour. Flours with a higher critical speed requirement tend to exhibit a greater hole effect on remixing at a given speed or intensity. Conversely, a lower mixing speed would have to be used to show a comparable effect with flours requiring less intense mixing for adequate development.

The results presented in this paper serve to underline the warning that developed doughs for baking should not be abused mechanically, particularly after a rest period. Also, in processes involving delayed addition of ingredients during mixing, unduly long interruption of the mixing process could have undesirable effects. This study also serves to stress that the "make-up" stages of dividing, rounding, resting (intermediate proof), sheeting, and molding, which all occur after dough mixing, are critical steps in bringing dough to an optimum state in the pan during the baking process.

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