24.3 Attrition Treatment of Flour

J. Bode and A. Lange

24.3.1 Attrition – an Innovative Milling Technology

Impact grinding mills are very effective in crushing mill products. Nevertheless they did not succeed in getting into milling flow sheets because conventional equipment delivered a higher yield of the desired light, low-ash flours. To a larger extent they were used to finely crush wheat flours which were then protein shifted by air classification. The effective sifting in the "finest particle" range < 16 µm, possible only with the newly developed high performance air classifier, made it possible for the first time to produce flours with a very high or very low protein content. These flours then allowed and initiated novel applications. Effectiveness and economy of the process were perfected through further development of classifier mills and high performance air classifiers.

The main demands on this new technology were modification of the protein-related processing properties of wheat flour and increased water absorption.

Increased water absorption can be achieved through mechanical damage to the starch granules. One or two additional percent can be realised by increasing the pressure and the differential speed of the cylinders in a conventional mill, but the resulting consumption of energy and intolerable wear and tear cause additional costs which cannot be cancelled out by better prices for the only slightly modified flour.

Several researchers have achieved a high level of damaged starch in wheat flour by means of ball mills, but these flours no longer have satisfactory baking properties, probably because of the heat-denatured wheat protein. Energy calculations show that in a vertical ball mill the temperature increase can quite easily be limited. So wheat flour can now be treated in a flow-through procedure without thermal deterioration.

24.3.2 Defined Higher Water Absorption through Attrition Treatment

The performance of the attrition procedure can be assessed on the basis of water absorption, using the Farinograph. This method corresponds well to the water absorption in practical baking. Unfortunately the enzymatic method for determining damaged starch, e.g. according to ICC method 164, does not correlate sufficiently with this water absorption.

After attrition treatment a deformation of the starch granules can be observed with the light microscope. But only the scanning electron microscope (SEM) reveals numerous hairline cracks (Fig. 240), which are regarded as the main reason for the effects of starch damage. Water and dissolved amylases easily penetrate the starch granules when the dough is made up. Subsequently the granules swell and the amylases increase the dextrination of the starch.

24.3.3 Attrition Treatment – a Smart Procedure

A vertical ball mill is the heart of the mechanical installation (Fig. 241). Milling pearls and flour are fed from feeding bins in a fixed ratio. This mix is agitated by a vertical axle with horizontal stirring elements. Additionally, gravity causes the mix to move from the top inlet to the bottom outlet. Pressure and shear forces result in an energy input which is dependent on the kind of material to be milled. At the optimum circumferential speed, which also depends on the material being milled, the energy input is

Fig. 240: SEM of a starch granule in attrition-treated flour

optimally converted into an increase in water absorption. This optimum is represented by the peak in Fig. 242. At a higher speed no additional shear is achieved and more and more of the product is taken along with the stirrer.

The increase in water absorption ability depends on the wheat variety. That is why the coordinates in Fig. 243 are not labelled. The effect of attrition treatment on a hard wheat is greater than on a soft wheat. The proteins adhering to the starch granules that can be observed in harder wheat may influence this effect as they possibly act as a mediator for the power transfer to the starch granule. With German soft wheat flour, an additional water absorption of 30 per cent points[46] can be achieved by applying a specific energy input of 200 kWh/t. Although a higher energy input increases the water absorption, the objective is to establish the highest possible ratio of water absorption increase to specific energy input. Operation is most economical when this ratio (designated as efficiency in Fig. 243) reaches its peak. If the mixture of milling pearls and flour contains less flour, the energy input is not very efficiently "transformed" into water absorption because impacts and shear between the pearls themselves – without the involvement of flour particles – convert most of the energy into heat. In a mix with a high flour content, impacts and shear of the flour between the pearls occur too rarely to be effective in the desired sense.

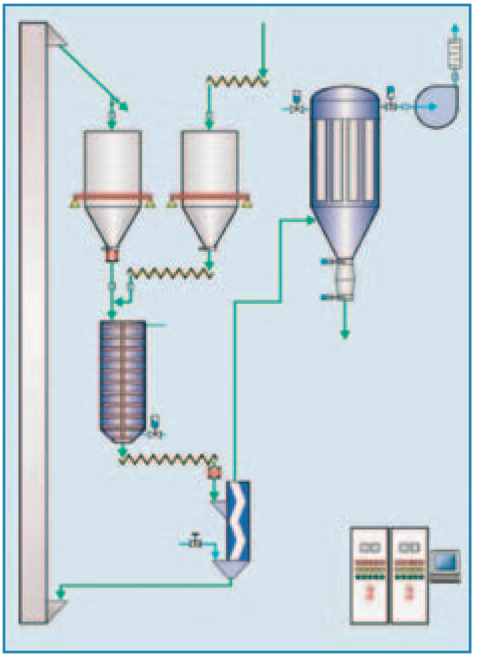

Fig. 241: Flow sheet with a vertical ball mill type ATR

As peak efficiency is influenced by machine parameters as well as by flour properties, the coordinates in Fig. 243 are not labelled. In almost all cases when a new plant is installed or essentially different flours are used, trials have to be performed to determine the position of optimum efficiency.

There are numerous ways of achieving the desired product properties by adjusting the pearls-to-flour ratio and the energy input. The latter can be modified not only by changing the stirrer speed but also by varying the throughput, i.e. the resting time in the milling bin. The resting time is controlled by a conveyor screw at the outlet. The mix is subsequently separated by a zigzag classifier (Fig. 241).
The large amount of air used in this process cools the flour and pearls effectively.

Over 95% of the energy input is converted into heat. Most of this is removed with the milling mix, but some is transferred to and thus lost

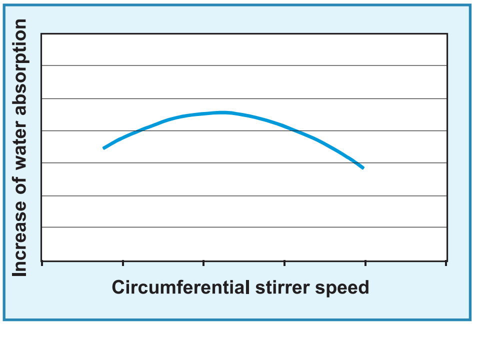

Fig. 242: Dependence of water absorption on circumferential stirrer speed

[46] *For instance from 60 to 90 baker's percent*

through the surface of the equipment. In the area of the highest energy input the temperature of the milling mix reaches about 50 °C. This is in line with predictions based on an energy calculation, taking the composition and the specific heat of the milling into account.

However, the circulating pearls must have enough time to cool down in a reservoir. The required time can easily be prolonged by increasing the amount of pearls in the circuit. In trials, the treated flour had a temperature of approx. 40 °C immediately after separation, i.e. it cooled down from 50 °C to 40 °C in a very short time. It is known from other processes (e.g. drying of flour) that temperatures of this magnitude do not have a negative effect on flour properties.

A thermographic photo (Fig. 244) of the milling bin was taken to detect local areas of overheating. It shows a very even temperature distribution; a lighter red colour in the area near the bottom outlet indicates a slightly higher temperature.

24.3.4 Integration of the Process into a Milling Flow Sheet

The attrition unit can be installed in various positions in the milling flow sheet. The position and size of the unit depend only on the customer's requirements. Experience to date has shown that two main designs are preferred. The first model is shown in Fig. 245. After the collecting conveyor, a variable amount of flour is branched off the main flour stream, treated with the attrition unit in the bypass and then mixed with the main flour stream again. The exact adjustment of the process to the desired increase in water absorption is controlled with the Farinograph.

The second model is shown in Fig. 246. Not only the flour stream behind the collecting conveyor but also passage flours and special flours such as low protein fractions resulting from a protein shifting process (see chapter 24.2.2, page 371) can be treated with the attrition unit. Here again, exact process control involves determining the water absorption to ensure the correct properties of the interim product that is used as a functional component in various flour-related products, including bread improvers. The size of the unit depends on the desired capacity and water absorption.

24.3.5 Damaged Starch is Activated Starch

It may be assumed that mechanical effects are the main reasons for starch damage. Thermal and chemical influences and even high energy radiation are also conceivable. The extent of starch damage can be measured by different methods. In most cases they are based either on the reaction of soluble starch with iodine or on the conversion of the damaged starch, which is soluble in cold water, into glucose by enzymes. Unfortunately, the correlation of the results is not satisfying.

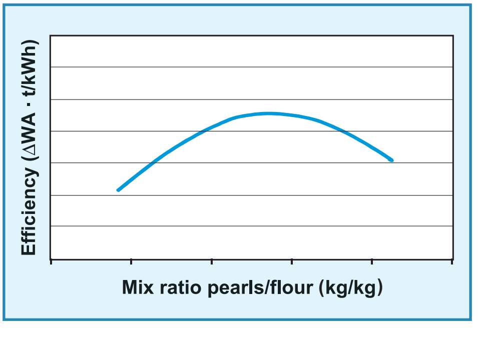

Fig. 243: Effect of the ratio of milling pearls to flour on milling efficiency

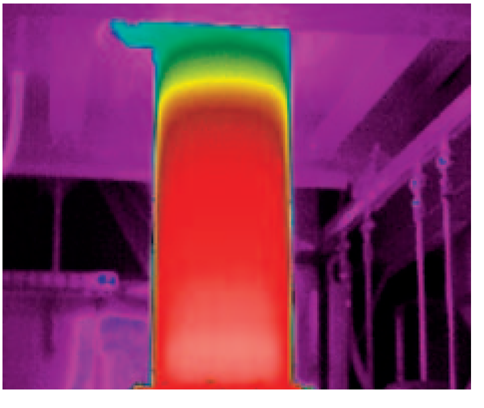

Fig. 244: Thermographic photograph of a vertical ball mixer. Red: space filled with flour and pearls

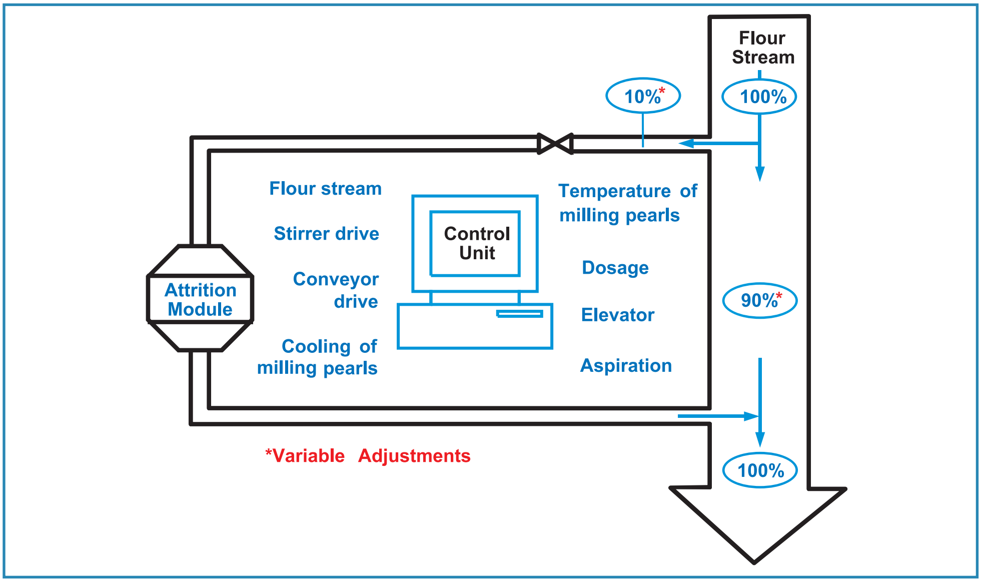

Fig. 245: Diagram for integrating a ball mill into the mill (1)

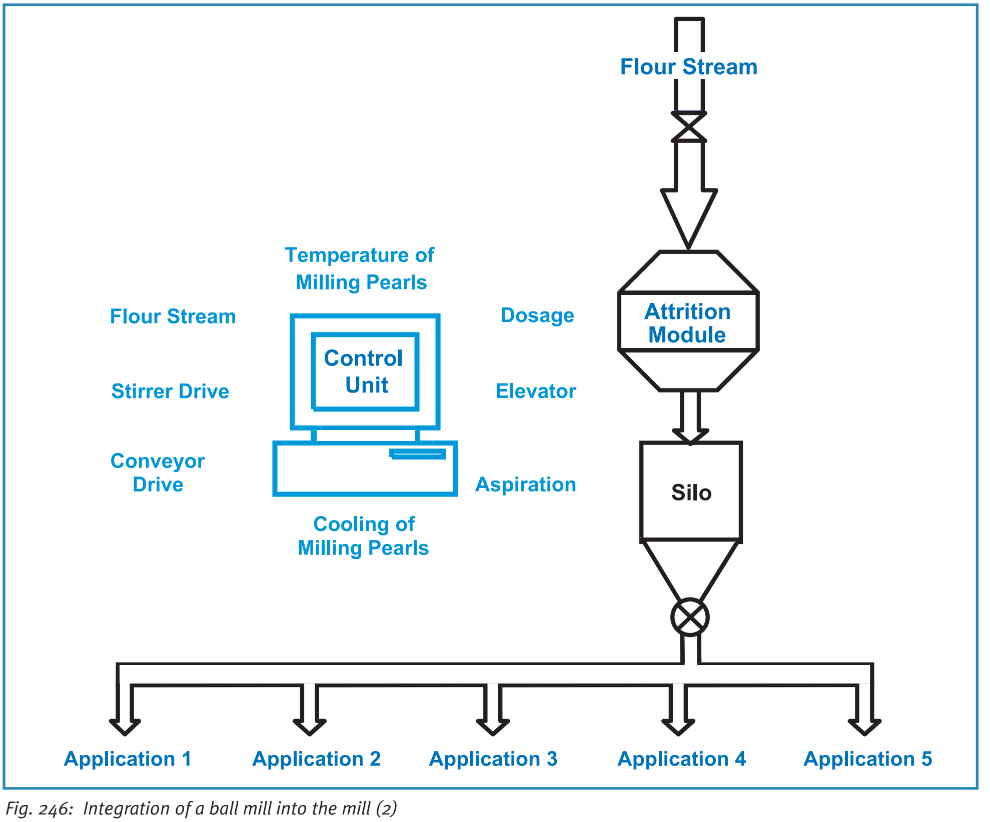

Fig. 246: Integration of a ball mill into the mill (2)

Nevertheless, all experts agree that starch damage resulting from mechanical treatment causes an increase in water absorption and that this increase is beneficial to the baking properties of the flour and the overall quality of the baked bread. These benefits are:

- Dryer dough surface
- Better machinability of dough
- Increased bread yield
- Improved fermentation
- Better taste
- Softer crumb
- Delayed staling
- Friendly labelling
- Longer shelf-life.

24.3.6 New Potential for Baking Technology

The Farinogram, Extensogram and Amylogram, the sedimentation value, Falling Number and various other methods are well accepted means of predicting the results of baking. But even with identical flour parameters, differences in baking results may occur if, for instance, the flours to be compared were milled from different wheat varieties. Furthermore, the bandwidth of the normal milling procedure must not be exceeded. Attrition treatment is clearly outside this scope. The Farinogram curve of a flour with a water absorption of 90% does not differ much in appearance from that of the original flour. But in practice a dough with such an amount of water can hardly be baked. So attrition-treated flour should not be tested exclusively by the above secondary methods. "Back to the roots" is the consequence, i.e. test baking which permits an assessment of the baking properties of a flour even under modern technical conditions.

The German split roll, produced by rolling a sheeted piece of dough into a bar, is a good subject for this purpose. Besides the volume, the crust colour, crumb properties, shape of the roll and opening of the split (crease) permit conclusions as to the tension and surface properties of the dough immediately before and in the early stages of baking.

In a normal procedure, (5% yeast, 10 min bowl and 15 min desk fermentation, 40 min first proof or 70 min second proof, 20 min baking at 230 °C) the effect of attrition flour is not spectacular (Fig. 247). The addition of 10 or 20% attrition-treated flour (with a Farinogram water absorption of 88%), corresponding to an additional water pouring of +3 or +6 per cent points respectively, caused no remarkable difference as compared to the standard rolls, apart from a slightly darker colour of the test rolls. If, however, the water addition rate was increased by means of attrition flour to

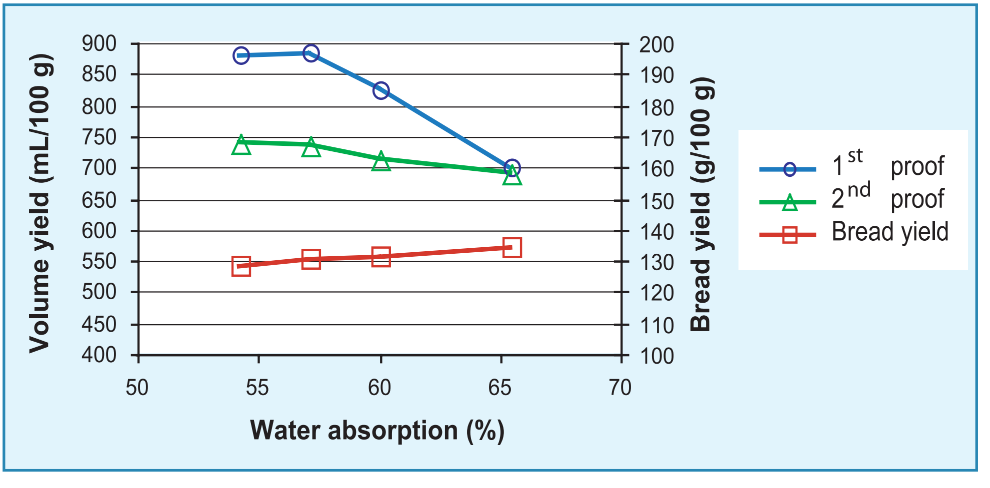

Fig. 247: Specific volume and bread yield as a function of water absorption

exceed an additional 10 per cent points, the swollen starch was not completely integrated into the gluten network. The volume was reduced, the crease wide open and flat, the colour too dark.
As expected, the bread yield increased with the amount of attrition flour added. Of the additional water only about 30% was lost during baking, whereas with normal water addition, the loss is generally about 50%.

The dough softening due to the slackening of the gluten network is compensated for or, in certain cases, even over-compensated, by swelling of the damaged starch and to a certain extent probably by leakage of soluble starch out of the damaged starch granules. But this is a slow process and is not apparent in a short dough making and proofing procedure. The addition of attrition-treated flour, combined with increased water addition, must therefore be expected to offer advantages in longer procedures with their sophisticated demands on dough stability.

The financial success of the baking business in Europe in recent years is connected with products made by such procedures. Baguettes, ciabatta, pide etc. only turn out well if processed in this way. The advent of chain stores with bake-off equipment and pressure to rationalize have led to a chronological separation of dough making and baking (freezing of dough, dough retarding, long proofing times) and created new demands on the baking performance of the flours. Such demands can only be met by adding vital gluten or special bread improvers. Unfortunately, such measures have resulted in an undesirable, excessively high volume in conjunction with poor crumb elasticity, off-splintering of the crust and rapid drying out.

With the addition of attrition-treated flour, dough for French bread (baguette) can be made with up to 6 per cent points more water (Tab. 145, Fig. 248). It has a good consistency and even re-stiffens, and the baking results are improved in various respects. Even at longer proofing times the dough pieces do not flatten, so the baguettes obtain their characteristic shape and appearance. The loaves have a better colour and stay fresh longer.

This can be attributed to the damaged starch which is open to attack by amylases, resulting in increased formation of dextrins. The addition of large amounts of amylolytic enzymes, especially, and the use of flour from sprouted wheat should therefore be avoided.

For the following trials a standard dough and a dough containing 15% attrition-treated flour in the flour mix (corresponding to an additional water uptake of 4 per cent points) were made and shaped into dough pieces which were then subjected to a storage period of 17.5 h at 7 °C. Subsequently the dough pieces were proved for a further 30 or 70 min. Another set of trials was carried out using the same formulas but with intermittent mixing. Tab. 146 summarizes all the parameters and baking results. The

Tab. 145: Trial parameters and baking results for French baguette with attrition treated flour

Code	Orig. flour %	ATR flour %	Proof min	Dough yield %	Bread yield %	Volume yield mL/100 g
A	100	-	90	154	120.6	452.0
B	90	10		157	124.5	456.0
C	80	20		160	127.3	450.4
D	100	-	120	154	n.d.	456.5
E	90	10		157	n.d.	400.7
F	80	20		160	n.d.	436.0

n.d. = not determined

A B C D E F

Fig. 248: Results of baking with an admixture of different amounts of attrition-treated flour (for trial parameters see Tab. 146)

rather strong browning observed with all the rolls (Fig. 249) is not relevant and can quite easily be reduced by baking at a lower temperature for a slightly longer time.

At a proof time of 30 min (Fig. 249, A & B) the majority of the rolls (16 out of 30) made from the standard dough did not form a crease, whereas in the case of the rolls made with attrition treated flour only 6 out of 30 did not open. The higher volume of the test rolls and their rounder shape indicated a superior stability and hence a better proving tolerance, resulting in a better crease formation.

In further trials, the dough pieces were additionally stressed by extending the proof to 70 min (Fig. 249, C & D). The crease of the dough did not open because the overlapping dough stuck firmly to the body of the dough piece.

Tab. 146: Trial parameters and baking results for breakfast rolls made from retarded dough with attrition flour. All data relate to flour with a 14% moisture content.

Code (for Fig. 249)		A	B	C	D	E	F	G	H
Attrition flour[a]	%	0	15	0	15	0	15	0	15
Water absorption	%	55.9	59.9	55.9	59.9	55.9	59.9	55.9	59.9
Kneading break	min	0	0	0	0	0	10	0	10
Final proof	min	30	30	70	70	40	40	70	70
Volume yield	mL/100 g flour	583	627	781	767	840	831	798	904
Bread yield	g/100 g flour	117.3	128.5	121.4	126.1	126.3	132.0	127.3	131.0
Rolls without crease	out of 30	16	6	30	30	0	0	12	0

[a] *% of total flour*

Blue: *modified parameters as compared to reference sample A*

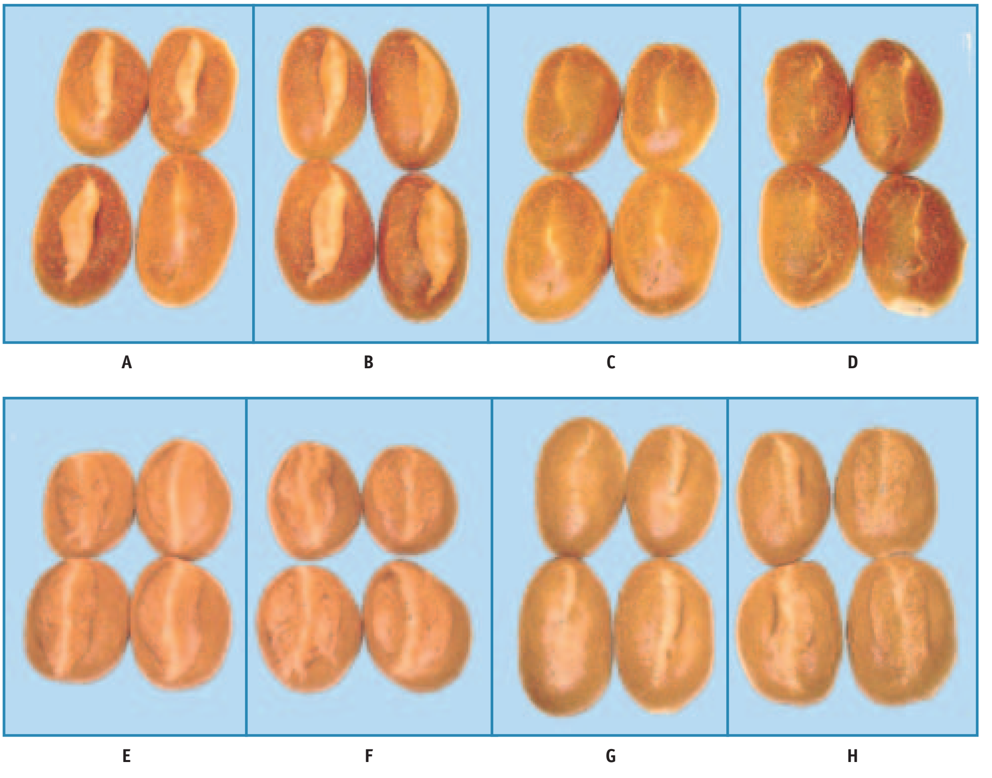

Fig. 249: Rolls after 17.5 h retardation at 7 °C with attrition flour, mixing interruption and varying final proof times. For trial parameter settings and volume yields see Tab. 146.

Without attrition flour the flat dough pieces did not recover (C), whereas rolls with attrition flour (D) still developed a round shape indicating a "reserve" of proving tolerance.

The positive but retarded effect of attrition flour on the dough properties could probably be shifted to an earlier phase of production by means of an additional dough rest or the like. Introducing a kneading break might help to "activate" the damaged starch and complete its hydration during the final mixing. For this purpose the kneading was interrupted after 3 min for 10 min and then continued to a total of 6 min. The standard dough was made without this break (Fig. 249, E through H). The proof time was 40 min. At shaping, the standard dough behaved normally, whereas the dough containing attrition flour was smoother and dryer. Because of this the crease opened at an early stage of baking and was wider than with the standard dough (Fig. 249, E & F).

The advantage of adding attrition-treated flour combined with a kneading break became even more obvious with the extended proof of 70 min (Fig. 249, G & H). The crease of rolls with attrition flour was now good and indicated a better proving tolerance. The standard flour yielded many rolls without a crease. The remarkable volume increase of the test rolls was another result of the enhanced proving tolerance.

As a consequence of the above results the benefits of attrition flour should be supported by modifying the baking process suitably to obtain optimum results. But even without modification, there still remains enhanced water absorption and the higher bread yield.