# EFFECT OF ADDITIVES ON THE ELASTIC AND PLASTIC PROPERTIES OF BREAD-CRUMB

## I. EFFECT OF MASHED POTATOES

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On qualifying bread and other products of the baking industry the physical properties (elasticity, strength, porosity etc.) of the bread-crumb are of great importance. In practice the determination of these characteristics is mostly carried out by organoleptic methods in a subjective manner. Thus, *e.g.* PELSHENKE [1] on basis of the physical properties of the crumb, differentiates the following qualities:

1. elastic crumb,
2. damp and sticky crumb,
3. well aerated but inelastic crumb,
4. slightly dense but inelastic crumb,
5. dense, dry, inelastic crumb.

Evaluations in such a subjective manner require a great routine on the part of the qualifying person, but even so, contradictory judgements are very common. In order to eliminate these defects, all over the world investigations are made with the intention of determining the physical properties of the crumb in an objective way.

One of the most important physical crumb-properties is elasticity. The measurement resp. determination of this property seems to be performable in the simplest way by measuring the stretching and compression strain, at a given deforming force, and by calculating the elastic modulus with the aid of Hook's law. The situation is, however, not so simple because in case of crumb-deformation under the influence of some external force a number of special factors have to be taken into consideration. The crumb is formed from a dough having the properties of a liquid. While baking, the dough warmed up nearly to 100° C is transformed through the coagulation of the gluten proteins and the partial gelatinization of the starch into a porous mass not having any more the properties characteristic of liquids. Between the organic gels — among which also the bread-crumb can be ranged — and the solids similarities can be found in many respects. These gels can also be stretched and are elastic. In consequence of the porous structure of the crumb, the deformation taking place under the influence of the force acting on the crumb, depends not only on the quality of the starch partially gelatinized and of the coagulated gluten proteins forming the framework of the crumb, but on the following factors too :

1. the dimensions of the crumb-pores and the thickness of the pore-walls,
2. the even resp. uneven distribution of the pores,
3. the position of the investigated crumb-sample within the loaf (being close to or far from the crust).

Namely during the process of baking the temperature of the crumb is not the same at all points. Parts being closer to the crust get more warm and therefore the physical properties of these crumb-parts are in some degree different from those of the middle part of the crumb. This statement especially relates to the layer in the proximity of the crust.

Difficulties are caused furthermore by the fact that, because of the porous structure of the crumb, under the influence of the deforming forces not only compressive resp. tensile stresses occur, but even flexural and sheering stresses may simultaneously appear. Thus, by reason of the complexity of the deformation process, the mathematical formulation of the correlation between the stress and deformation encounters difficulties.

Moreover, as stated by the investigations of several authors (BICE and GEDDES, NIKOLAYEV) [2, 3] the crumb generally behaves differently from the ideal elastic bodies and it has, beside the elastic properties, simultaneously plastic properties, too. Under the influence of the deforming force, in fresh crumb plastic deformation of a considerable degree occurs, while old crumb approaches better the properties of an ideal elastic body.

The elastic modulus of an ideal elastic body is a constant value. This fact means that, when plotting the diagram stress against stretching resp. compression, a straight line is obtained. In case of crumblike substances the elastic modulus cannot be taken as a constant characteristic of the substance. In case of these substances the correlation between the stress and stretching (resp. compression) can be characterized by a curve, which means that the elastic modulus is a variable. In such cases the elastic modulus can be expressed by the following equation :

$$E = \frac{d\sigma}{d\varepsilon}$$

where $E$ = Young's modulus
$\sigma$ = stress
$\varepsilon = \frac{l_1}{l_0}$ = relative length of the sample
$l_1$ = length of the sample
$l_0$ = original length of the sample

Plotting stress graphically against stretching resp. compression, the momentary value of $E$ is equal to the slope of the tangent drawn to a given point of the curve.

When investigating the physical properties of the crumb, most frequently, the total deformation called "compressibility" occurring under the influence of the deforming force, is measured. Several authors have measured the so-called plastic deformation that is the deformation permanent after discontinuing the loadings, as well as the elastic deformation derived from the difference between the total and the plastic deformations. In general the investigations are performed with the aid of the following two principal methods :

1. the continuous compressing force and the time of compression are given, the value of deformation shall be determined ;

2. the deforming force and the degree of deformation are given, and the time necessary to reach the given deformation shall be determined.

Besides these two methods, a third method may be theoretically used, in case of which the time and degree of deformation are given, and the deforming force pertaining to them should be determined. Because of its lengthiness and circumstantiality this method is, however, not used in practice. Owing to the above-mentioned difficulties, in general, the experimental results are not expressed in absolute physical units but in practical units of the employed instrument. Several apparatuses have been constructed for such measurements. The first apparatus was completed by KATZ. Other instruments were subsequently constructed by FLEMING and PLATT [4], BAILEY [5], PYLER [6], NIKOLAYEV [3], SZŐKE [7], HAMPEL [8], COMBS [9] etc. The predominant part of the investigations thus performed is connected with the problem of bread-staling, and only few investigations were carried out in order to determine the correlations between the physical properties of the crumb and the quality of fresh bread.

The object of the present investigations is the determination of the effect of additives (mashed potatoes, milk, powdered milk, fats, mono- and diglycerides etc.) used in the baking industry on the mechanical properties of the fresh crumb. The additive agents used in the baking industry change not only the alimentary value of the bread, but at the same time the physical properties of the crumb, too. Our investigations started with the examination of the effect of mashed potatoes which are one of the most frequently employed additives. The consumers generally have a preference for this type of bread and on the basis of organoleptic experience the crumb of this bread is considered to be more elastic, but no objective measurements are known in this field.

## Experimental

Our investigations were made with "Fbl"* flour obtained from a mill; its farinographic quality was $B_2$ and its water-absorbing capacity amounted to 64,3%. The experimental breads were made according to the standard prescriptions [10] except for the fact that the baking was performed in a tinplate iron form of 16 × 5 × 8 cm. Thus it became possible to cut from each experimental bread more crumb samples of a regular form, and consequently to perform several parallel measurements. Calculated from the quantity of the flour used the experimental breads were prepared with a

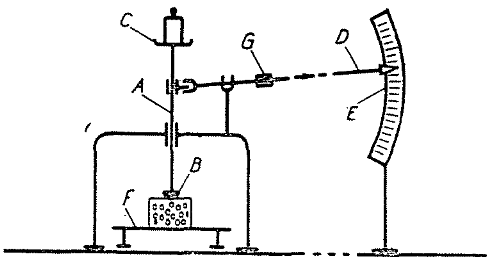


*Fig. 1*

potato content of 0—20%. Before beginning the investigations of the crumb the breads were stored at 20° C for two hours. There exist no uniformly accepted measuring method and apparatus for measuring the physical properties of the crumb; therefore an apparatus constructed by the authors and finished in the workshop of the University was used for the experiments (see Fig. 1). The apparatus is relatively simple and sensitive. Its pressing body has the form of a hemisphere and consequently it cannot indent the investigated crumb-piece as a pressing body having sharp edges (disk, plate).

The main part of the apparatus is the bar (*A*) ending at the bottom in a pressing body (*B*) having the form of a hemisphere and on the top in a flaring out small glass vessel (*C*). The bar is provided with mm graduation for the movings while reading of measurings. In order to allow more correct readings a pointer (*D*) is connected with the bar by the aid of which the moving of the bar can be read magnified on the scale (*E*). The crumb sample is placed onto the plate (*F*) and the loading weight is put into the small glass vessel (*C*). The weight of the bar (*A*) is balanced by the rider (*G*) to be found on the pointer. The pressing body is interchangeably mounted, thus it can be changed for a pressing body of other form or size if another measurement

* (Wheat flour ash content 0,95)

is to be performed with the apparatus. In such a case the changed weight of the bar can be balanced by the rider.

The following data have been determined by the apparatus:

1. total deformation (compressibility),
2. permanent or plastic deformation,
3. elastic deformation,
4. relative elasticity.

In determining the individual data the following methods were employed:

1. Total deformation. — The crust and the parts in near proximity to it were cut from a crumb-piece of 4 × 4 × 3,5 cm and then this sample was set under the pressing body of the apparatus to be just in contact with the surface of the piece of bread (the plate *(F)* should be set in such a way that in this position the pointer of the instrument be exactly on 0). Then a weight of 180 g was put into the small glass vessel and after exactly 2 minutes have elapsed the position of the pointer was read. The obtained value expresses the value of the total deformation in the units of the instrument.

2. Plastic deformation. — After 2 minutes had elapsed the weight was removed from the small glass vessel and after an additional 1½ minutes

**Table 1**

| Series | Compressibility | | | | | Permanent deformation | | | | | Elastic deformation | | | | | Relative elasticity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Potato content % | | | | | | | | | | | | | | | | | | | |
| | 0 | 5 | 10 | 15 | 20 | 0 | 5 | 10 | 15 | 20 | 0 | 5 | 10 | 15 | 20 | 0 | 5 | 10 | 15 | 20 |
| 1 | 5,0 | 7,5 | 7,9 | 8,5 | 9,0 | 1,2 | 3,2 | 3,5 | 3,1 | 4,3 | 3,8 | 4,3 | 4,4 | 5,4 | 4,7 | 76 | 57 | 56 | 63 | 52 |
| 2 | 5,0 | 6,8 | 8,6 | 8,9 | 11,3 | 1,0 | 3,6 | 2,4 | 4,6 | 5,7 | 4,0 | 3,2 | 6,2 | 4,3 | 5,6 | 80 | 48 | 72 | 49 | 50 |
| 3 | 4,8 | 7,0 | 8,8 | 8,0 | 10,8 | 1,1 | 2,6 | 3,2 | 3,5 | 6,9 | 3,7 | 4,4 | 5,6 | 4,5 | 4,9 | 77 | 63 | 64 | 57 | 45 |
| 4 | 5,2 | 7,9 | 8,8 | 8,4 | 8,8 | 0,9 | 2,6 | 4,0 | 3,6 | 4,1 | 4,3 | 5,3 | 4,8 | 4,8 | 4,7 | 83 | 67 | 55 | 57 | 54 |
| 5 | 4,9 | 9,1 | 8,7 | 8,8 | 9,4 | 0,9 | 3,6 | 3,6 | 3,3 | 4,1 | 4,0 | 5,5 | 5,1 | 5,5 | 5,3 | 82 | 60 | 58 | 63 | 56 |
| 6 | 5,1 | 8,1 | 9,0 | 9,0 | 9,3 | 1,0 | 4,0 | 3,4 | 3,5 | 3,6 | 4,1 | 4,1 | 5,6 | 5,5 | 5,7 | 80 | 51 | 62 | 61 | 61 |
| 7 | 5,0 | 8,5 | 8,2 | 9,9 | 9,8 | 1,0 | 3,3 | 4,2 | 5,1 | 5,0 | 4,0 | 5,2 | 4,0 | 4,8 | 4,8 | 80 | 61 | 49 | 48 | 49 |
| 8 | 5,1 | 8,1 | 8,5 | 8,1 | 11,2 | 1,3 | 3,1 | 3,0 | 4,0 | 3,5 | 3,8 | 5,0 | 5,5 | 4,1 | 7,7 | 74 | 62 | 65 | 51 | 68 |
| 9 | 5,0 | 8,2 | 9,2 | 8,1 | 11,1 | 0,8 | 2,9 | 3,7 | 2,8 | 4,1 | 4,2 | 5,3 | 5,5 | 5,3 | 7,0 | 84 | 65 | 60 | 65 | 63 |
| 10 | 5,2 | 8,6 | 7,8 | 9,0 | 10,0 | 1,0 | 2,9 | 2,9 | 3,1 | 3,7 | 4,2 | 5,7 | 4,9 | 5,9 | 6,3 | 81 | 67 | 63 | 66 | 63 |
| 11 | 4,7 | 6,8 | 6,7 | 9,7 | 9,8 | 1,0 | 2,0 | 2,5 | 2,5 | 3,0 | 3,7 | 4,8 | 4,2 | 7,2 | 6,8 | 78 | 71 | 63 | 74 | 69 |
| 12 | 5,2 | 7,2 | 7,0 | 10,0 | 10,0 | 0,7 | 3,1 | 2,8 | 3,5 | 3,6 | 4,5 | 4,1 | 4,2 | 6,5 | 6,4 | 87 | 57 | 60 | 65 | 64 |
| 13 | 5,5 | 5,8 | 9,2 | 9,2 | 8,5 | 1,2 | 1,5 | 3,0 | 3,5 | 3,1 | 4,3 | 4,3 | 6,2 | 5,7 | 5,4 | 78 | 74 | 67 | 62 | 64 |
| 14 | 4,8 | 6,0 | 9,9 | 11,0 | 10,5 | 0,9 | 2,2 | 3,2 | 4,1 | 5,0 | 3,9 | 3,8 | 6,7 | 6,9 | 5,5 | 81 | 63 | 68 | 63 | 52 |
| 15 | 5,7 | 6,5 | 6,7 | 7,0 | 9,0 | 1,3 | 2,5 | 2,5 | 2,0 | 3,0 | 4,4 | 4,0 | 4,2 | 5,0 | 6,0 | 77 | 62 | 63 | 71 | 67 |
| 16 | 5,6 | 6,0 | 6,2 | 8,0 | 9,0 | 1,2 | 1,8 | 2,9 | 3,0 | 3,8 | 4,4 | 4,2 | 3,3 | 5,0 | 5,2 | 78 | 70 | 53 | 63 | 58 |

the position of the pointer was read again. The value read gives the measure of the plastic deformation in units of the instrument.

3. Elastic deformation. — The difference between the total deformation and the plastic one gives the value of the elastic deformation.

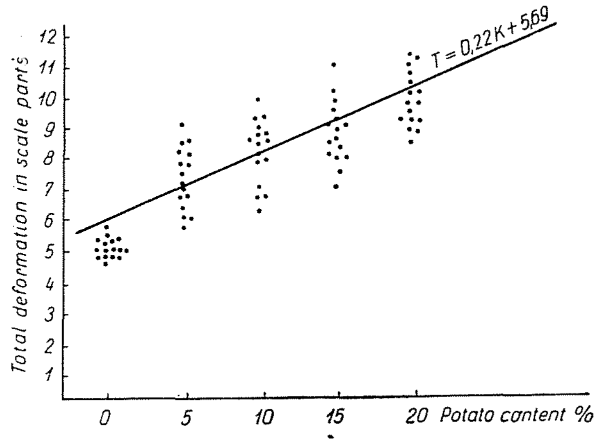


*Diagram No. 1.* Total deformation

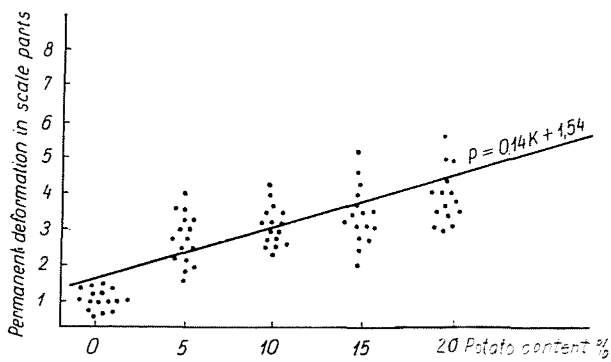


*Diagram No. 2.* Permanent deformation

4. Relative elasticity. — The elastic deformation expressed in per cents of the total deformation.

In carrying out the measurements, the experiences of SUSITZKY's [11] investigations have also been taken into consideration. Three samples were collected from each bread and the average of three measurements was accepted as an observation of the total value.

The results of our investigations are shown in Table 1 and in Diagrams 1, 2, 3, 4, respectively.

The values obtained were evaluated by mathematical statistical methods [12, 13]. The equations of regression lines in function of the potato content,

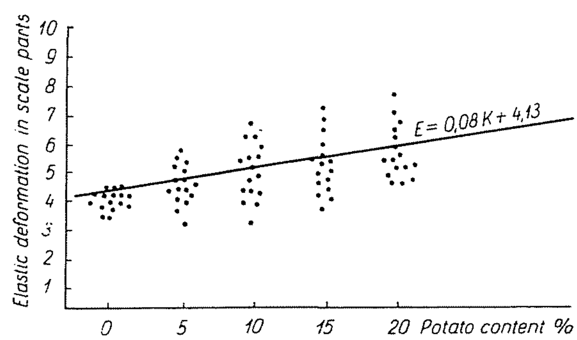


*Diagram No. 3.* Elastic deformation

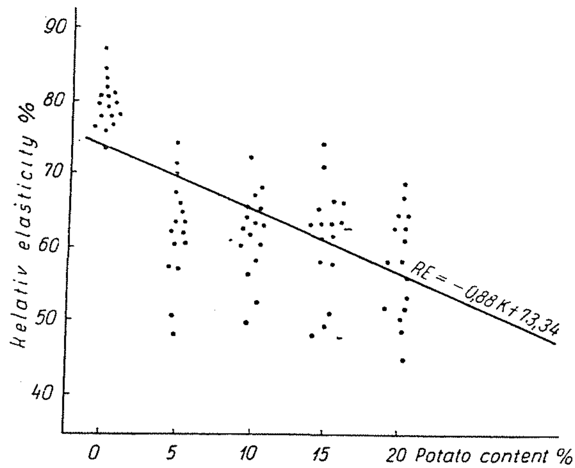


*Diagram No. 4.* Relative elasticity

as well as the correlation between the individual data and the potato content were calculated. On the basis of our observations the following regression equations were computed:

1. Total deformation $T = 0{,}22K + 5{,}69$
2. Plastic deformation $P = 0{,}14K + 1{,}54$
3. Elastic deformation $E = 0{,}08K + 4{,}13$
4. Relative elasticity $RE = -\ 0{,}88K + 73{,}34$

where $K$ = potato content in %.

The linear correlation coefficients corresponding to these values are :

$r_t$ = 0,846

$r_p$ = 0,516

$r_e$ = 0,223

$r_{re}$ = —0,703

The data obtained show that the degree of total deformation increases with the potato content. The correlation is very good. The degree of the plastic deformation similarly increases with the potato content, but the correlation is not so good as in the case of total deformation.

The correlation between the elastic deformation and the potato content gives a less definite picture. The values of the elastic deformation show a dispersion of high degree. To some extent this fact can be attributed to the addition of the measuring errors of the total plastic deformations. Though the calculated regression line shows a small rise, the correlation is relatively small and statistically just significant.

The relative elasticity is in inverse correlation with the potato content. The correlation is quite good.

## Summary

The total, plastic, and elastic deformations, as well as the relative elasticity of bread-crumb prepared with the addition of mashed potatoes were investigated. It may be stated that under the influence of added potato the skeleton of the coagulated gluten loses its strength ; this fact manifests itself in the higher compressibility. It has been established that the observed values of all three deformations increase with the potato content. The increase of the total deformation is caused chiefly by the plastic deformation and only in a smaller degree by the elastic deformation. Accordingly the relative elasticity of the crumb decreases with increasing potato content. The results of the investigations have been evaluated by mathematical statistical analysis.

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