INVESTIGATIONS OF THE LINEAR ELASTICITY COEFFICIENT OF WHEAT GRAIN WITH THE METHOD OF STRETCHING

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INTRODUCTION

The introduction of mechanization in agricultural requires the production of highly productive machines. The designing of a machine of optimum productivity requires the knowledge of the physico-mechanical properties of the material the machines are to process. In the case of harvesting machines the material processed is straw and hay.

The world level of knowledge about these materials is insufficient, particularly concerning grain, which is a small object of complex shape. Among cereals dominates wheat, which is sown on the largest areas in all the continents except for Asia which is dominated by rice.

The physico-mechanical properties of wheat grains are of intereset not only the constructors of harvesting machines; they are necessary as preliminary data in the construction of millingmachines and in the storage of cereals in grain elevators.

In the investigations of wheat grain two main directions should be separated:

1. Relative investigations of the immediate resistance of wheat grains of different varieties under certain conditions of loading.

2. Absolute investigations tending to the determination of the universal physical coefficients characterizing the mechanical properties of the investigated material.

Investigations of the physical constants, like the coefficient of linear elasticity E, the coefficient of formal elasticity G, the coefficient of volumetric elasticity Q and the Poisson's coefficient, is a complex problem in respect of methodology, since it requires the simultaneous measurement of several parameters with sufficient accuracy. The object of investigation is of its nature small, exteremely heterogenous, and of compex shape, and moreover, like all plant materials, it has elasto-visco-plastic properties, and so requires investigating in the rheological approach. The values of all the enumerated coefficients, even in the case of construction materials, are not complete in physical tables. Most often only the most often needed coefficient of linear elasticity E and the Poisson's coefficient are giveen.

In the investigations of wheat grains all the so far published works are limited to the determination of the linear elasticity E, [4].

All the investigations, because of the small size of wheat grains, consisted in loading them with compressing forces in different systems with the application of adequate theories.

The results of investigations were shockingly varied, and the value of the linear elasticity coefficient assumed values from 1000 kg/mm^2 [7] to 20 kg/mm^2 [3]. Such a range of results can only partly be justified by objective factors like variety, moisture, or the vegetation conditions of the plant. That is why Prof. Mohsenin [1] carried out a series of investigations aiming at the checking out of the methodologies applied. He investigated identical material, the Seneca wheat, of the moisture content of 10% d.m. He obtained results from 100 kG/mm^2 to 500 kG/mm^2 for the value of the linear elasticity coefficient in dependence on the way of compressing the grain. In this way he proved that the applied methods are dubious and he did not have any criteria for priviledging any of them. Formally all of them were valid.

In further investigations, in order to achieve the aim, a radical change should be made in the methodology of investigations. Then appeared the idea of loading grain with stretching forces. This, however, required the solving of many measurement and technological problems.

METHODOLOGY OF INVESTIGATIONS AND THE APPARATI

In order to load grains with stretching forces it must be adequately fastened. The specific shape of grain makes it impossible to apply any mechanical mounts, and therefore we decided to glue the investigated grains into fastening sleeves. After many attemts we succeeded in choosing a glue and in working out a technology of gluing grains enabling the loading of grains to the point of destruction, while the glue gets deformed only slightly and does not influence chemically the grains, even at a many hours'contact with them. It is the K-115 glue used in aircraft industry. Grain is glued by its ends into the sleeves so that its middle part of the length of 1—1.5 mm where the intersection is practically constant can be loaded. Such a system of fastening enables the stretching of grains with a simultaneous measuring of lengthening. Applying the Hook's law it is possible to calculate directly the Young modulus E. In this system it is possible to eliminate completely the mechanically weaking influence of the grain furrow and its shape.

For the measurements of very little lengthenings a tensometric transformer was worked out (Fig. 1), which after calibration enables measurements with the accuracy of 0.5 μm. Thanks to the fact that the transformer is fitted directly on the sleeves in which the grain is fastened all the clearances in the loading system are eliminated from the measurement.

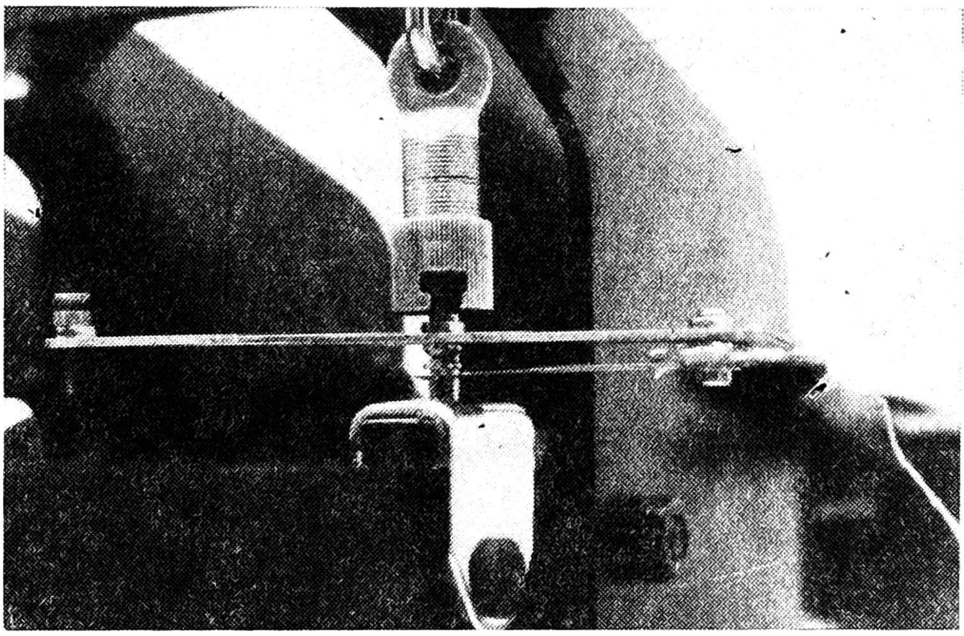

Fig. 1. The tensometric transformer for measurements of lengthening of grain fitted on sample

The measurement of the initial length of sample is carried out under a laboratory microscope (Fig. 2) with the accuracy of 5 μm. At the same time the uniaxiality of sample fastening is controlled. After the breaking the intersection of sample is photographed under the microscope in a proper scale and planimetered. Thus we obtain the exact surface of the intersection of the sample with the consideration of the sometimes very complex shape of the inner part of the grain furrow.

The Hook's law can be applied only in the case when there is the uniaxial system of strains in the sample. Our sample is of necessity untypical, since its irregular diameter deformed by the furrow is about three times the value of the length. We had to carry out additional investigations aiming at the obtaining of information about the complexity of the state of strains in the sample. First of all we carried out elasto-optical investigations on a model made of organic glass with the preservation of the dimentions of length and width of the sample. It was found that in the case of gluing the investigation material into the sleeves of material of much higher elasticity coefficient the phenomenon

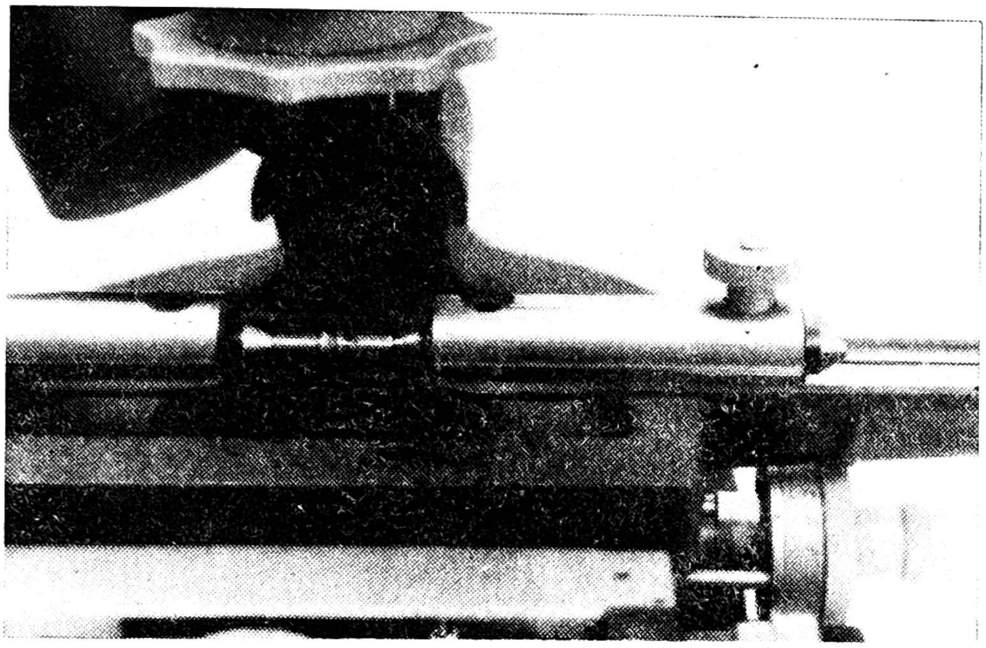

Fig. 2. Laboratory microscope for the measurement of the initial length of sample

of notch does not occur in the investigated material and the distribution of strains is even in the whole intersection. In this way we eliminated the doubts resulting from the untypical geometry of the sample.

There arose, however, the doubt resulting from the heterogenity of the sample. In the case when the axis of the operation of force was moved in relation to the resistance axis of the sample a bending momentum appeared. Investigations were carried out in this respect. It turned out that the fears were well founded, particularly in the case of glassy-floury wheat when the glassy inclusions are placed symmetrically in the loaded intersection. This is a random phenomenon. There are no methods enabling the investigation of the inner structure of grain without destroying it. In this situation we had to introduce the preliminary measurement enabling the elimination of samples with a coplex state of strains. The test is made in such a way that before the measurement proper grain is preliminary loaded to the level of about 30% of the destroying strain (twice) turning the grain by 90° along the longitudinal axis of the grain at each measurement. In the case when there is no bending in the sample the lengthenings will be identical. With some experience it is possible to evaluate the state of strains after its destruction by observing its intersection. In practice it turned out that only every third sample does not show bending.

Samples in which there was the uniaxial state of strains have a regular intersection, without any offsets, of slight roughness and perpendicular to the axis of the operation of the force.

In the case of investigating wheat varieties of uniform intersection it is easier to obtain the uniaxial state of strains in the stretched sample. But it is always necessary to carry out the preliminary investigations and to eliminate the samples showing hending.

The loading of samples is carried out on a simple apparatus consisting of 5 second-order balanced levers of the relation of arm lengths like 1 : 10 (Fig. 3). This enables the simultaneous loading of 5 samples, which

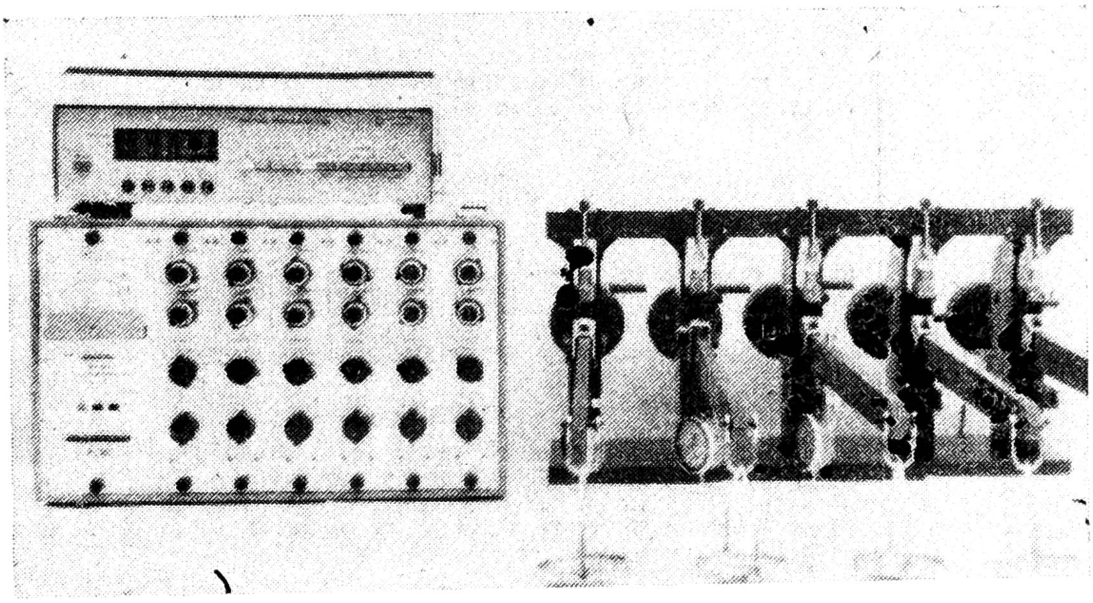

Fig. 3. Micro-creeper for the loading of investigated grains with the measuring system

is important at long term tests, like ex. the determination of the time of grain creep at different loadings. The sample is loaded gradually at every 0.2 kG, at 1 min intervals. The reading of the lengthening is done after 10 sec from the application of the loading. Data are compiled in a table on the basis of which we can draw the characterization $\varepsilon = f(\sigma)$ from the inclination of which in the range of low loadings in which elastic deformations occur it is possible to calculate the Young modulus. The strains in the sample are calculated from the force operating on the sample and from its intersection, which is measured only after the breaking of the sample.

The advantage of this method is the fact that we operate with a relatively simple mathematical model and do not introduce any simplefications to the theory. The obscure points arising during the realization of investigations are dealt with by introducing of auxiliary investigations, that is empirically. We investigated wheat of the Grana variety, which in our conditions gives the highest crops. The moisture of the investigated material was $14.5\% \pm 0.5\%$ d.m.

All the samples were loaded up to destruction. For the calculation of the Young modulus we considered only the initial part of the characterization (the most steep part) from 0 to 30% of the destroying strains. The experiment involved 50 grains. After the preliminary

Table

Data from measurements for the Grana wheat

No of sample	Initial length l mm	Intersection mm² S	Destroying force P_x kG	Destroying strains σ kG/mm²	Lengthening before and at destruction P_x — 0.2 kG	P_x	30% σ kG/mm²	Δl at 30% σ	E 30% kG/mm²	Working number
1	1320	8.09	3.4	0.4203	32.5	55.5	0.1236	3	65.3	G 2
2	1350	8.63	3.2	0.3708	46.5	57	0.1159	5	31.3	G 6
3	1170	7.12	3.0	0.4213	34.5	96.5	0.1124	3.5	37.5	G 4
4	1340	8.21	3.2	0.3898	50.5	60.5	0.0974	6	21.76	G 9
5	1400	8 08	3.0	0.3717	36.5	48.5	0.1238	7	24.8	G 10
6	1325	8.14	3.6	0.4423	42	61	0.1229	3.5	46.5	G 11
7	1270	7.07	3.2	0.4526	34	45.5	0.1414	4.5	39.9	G 12
8	1365	6.36	3.0	0,4717	30	57	0.1572	3.5	61.3	G 13
9	1280	7.54	3.4	0,4509	17	59	0.1326	3	56.6	G 14
10	1390	7.67	2.6	0.3390	31	44.5	0.1043	1.5	71.96	G 17
11	1400	7.37	3.2	0.4342	13	74	0.1357	2.5	76	G 18
12	1255	7.39	2.6	0.3518	21.5	27	0.1083	4.5	30.2	G 23
13	1370	7.18	2.4	0.3343	24.5	33	0.0836	4.5	25.4	G 24
14	1400	7.43	2.8	0.3769	54	80	0.1077	5.5	27.4	G 25
15	1300	8.40	3.6	0.4286	10.5	52.5	0.1190	1.5	103.2	G 29
16	1350	7.10	2.4	0.3380	8	69	0.1127	2.5	60.8	G 33
17	1305	8.51	3.8	0.4465	19.5	54	0.1410	2	92	G 34
18	1330	5.44	2.8	0.5147	29	128	0.1471	3	65.2	G 35
19	1310	7.32	2.6	0.3552	30.5	111	0.1093	2.5	57.3	G 36
20	1175	7.28	3.0	0.4121	23.5	64.5	0.1374	2	80.7	G 38
21	1320	7.05	3.4	0.4823	16	56	0.1418	2.5	74.9	G 39
22	1365	5.75	2.0	0.3478	24.5	51	0.1043	1.0	142.4	G 40
23	1110	7.42	4.0	0.5391	9	12.5	0.1617	2,0	89.7	G 42
24	1275	8.42	3.0	0.3563	8.5	57	0.1188	1.5	100.95	G 43

investigations we eliminated 22 grains in which there occured bending discovered in the preliminary tests. 4 grains underwent destruction during their fastening in the measuring system. The measurement results for the remaining 24 samples are presented in the table. The linear elasticity coefficient E of the Grana wheat was calculated as the arithmetical mean from the particular results. It is 657 N/mm². The linear elasticity coefficient according to the simple relation of Hook's law is as follows

$$E = \frac{Pl}{S\Delta l}$$

where:

E — the Young modulus in kG/mm²,
P — force in kG,
l — initial length of sample in mm,
Δl — increase of the length under the load in μm,
S — intersection of sample in mm².

To simplify things, since for the loading we used kilogramme weights, in the proceedings we operated with the force unit kG (force). The final results are given in the system SI, where the force unit is Newton.

$$1 \text{ kG (force)} = 9.81 \text{ N}$$

ANALYSIS OF RESULTS OF MEASUREMENTS

The mean linear elasticity coefficient E is relatively low in comparison with results obtained in other centers. This is so for several reasons.

First — the relatively high moisture content of the investigated material, which in the case of plant materials is of decisive influence on their resistance. Second — the investigated wheat of the Grana variety of glassy-floury intersection is much weaker than the hard varieties. Hence also the considerable distribution of the values of E for particular samples. Grains intersections of which have more glassy inclusions are decidedly stronger from the floury grains. The investigation of material of moisture content equivalent to the moisture of air without an artificial drying is appropriate since grains will be loaded in similar conditions in the case of harvesting with a combined harvester even at a higher moisture. Moreover the measurement itself is simpler, because we do not have to carry it out in air-conditioned places.

The elasticity coefficient E was determined on the basis of loadings of about 30% of the destroying loadings. The lengthening of sample in this range of loadings is relatively slight, about 10% of the lengthening the sample reaches at the moment of destruction, i.e. about 5 μm. For so little deformations error of the order of $\pm 10\%$ is possible in the measurement of lengthening. The error decrease at the analysis of a larger amount of samples, but it is the highest in comparison with the measurement errors in the case of other parameters necessary for the calculation of the linear elasticity coefficient E. That is why our investigations move in the direction of increasing the accuracy of measurements of lengthening at least five times, i.e. to measurements with the accuracy of 0.1 μm.

FINAL CONCLUSIONS

In the designing of machines and devices processing wheat grain the constructors should choose the parameters of the working elements loading the grain so as not to exceed the limit of resistance of grain assuming that the elasticity coefficient of grain is not higher than 100 kG/mm^2. In the case of loading dry grain ex. in milling, and 50 kG/mm^2 in the case of wet grain during its processing in the threshing system of combined harvester.

Coming back to the problem posed by Prof. Mohsenin as to privileging one of the grain investigation methods consisting in compressing we should think that the best is the method which gave the lowest results of the linear elasticity coefficient E. The values of about 100 kG/mm^2 Mohsenin obtained while loading the grain of the Seneca wheat of the moisture content of about 10% d.m. with the help of a cylindrical pin of flat base and diameter small in comparison with the sizes of grains (ϕ = 0.016 inch = about 0.4 mm), for the calculations using Boussinesq's method for semi-infinite bodies. Our result of the linear elasticity coefficient, although lower from that given by Prof. Mohsenin, is with it comparable, considering the moisture of the investigated material. It is little probable that the Grana wheat differs radically in respect to mechanical resistance from the Seneca wheat. Moreover it seems intuitionally impossible that the mechanical resistance of wheat grain be comparable to the resistance of wood alone the fibers, as is suggested by Szpolańska. The methods of investigations for wood made on typical resistance machines do not cause any doubt and there are no significant differences in the data given by different sources.

It should be assumed that even is the case of the hardest wheat varieties the linear elasticity coefficients will not exceed 150 kG/mm^2 at forces operating along the longitudinal axis of grain, considering the middle part os grain.

After analyzing the characterizations $\varepsilon = f(\sigma)$ it is clearly seen that the material of which grain is composed has rheological properties, where elasticity is only one of the elements of the model, and the model must include, apart from elasticity and viscosity, also palsticity, since no sample broke immediately after the application if destroying strains. The process of descruction lasted from several to several hundred seconds revealing the plasticity of the sample.

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Z. Staszczak

BADANIE REOLOGICZNYCH WŁAŚCIWOŚCI ZIARNA PSZENICY

Streszczenie

Obiektem badań jest ziarno pszenicy jako przykład do opracowania metodyki badań płodów rolnych w ujęciu reologicznym, szczególnie ziarniaków roślin uprawnych, które ze względu na swoje wymiary i kształt sprawiają najwięcej trudności. Świadczą o tym wartości współczynnika sprężystości liniowej ziarna pszenicy *E*, podawane przez różnych badaczy, a zawarte w granicach od 17 do 1000 kG/mm^2.

Oryginalność naszej metody polega na tym, że badamy ziarno siłami rozciągającymi, dzięki temu uniknięto daleko idących uproszczeń geometrycznych, jakie są niezbędne przy obciążeniu ziarna siłami ściskającymi w różnych układach.

W badaniach wprowadzono parametr czasu celem określenia własności lepko--plastycznych ziarna. W obliczeniach przyjęto model reologiczny ciała Binghama, najbardziej odpowiedni do wyników doświadczalnych.

Badano też współczynnik Poissona za pomocą „szczypiec tensometrycznych".

Otrzymane wyniki z badań pszenicy odm. Kaukaz o wilgotności 10% s:

Współczynnik sprężystości liniowej *E* — 50 kG/mm^2

Współczynnik Poissona — 0,2—0,23
Naprężenie niszczące — 0,48 kG/mm²
Wydłużenie względne do momentu zniszczenia A — 12%
Czas pełzania — do 30 min. i jest funkcją obciążenia.

Stwierdzono wewnętrzne pęknięcia w ziarnach przy nienaruszonej okrywie zewnętrznej, oglądając je „pod światło".

З. *Стащак*

ИССЛЕДОВАНИЯ РЕОЛОГИЧЕСКИХ СВОЙСТВ ПШЕНИЧНОГО ЗЕРНА

Резюме

Предметом исследований является зерно пшеницы, как пример для разработки методики исследований сельскохозяйственных продуктов с реологической точки зрения, в особенности зерновок культурных растений, доставляющих из-за своих размеров и формы самые большие затруднения. Свидетельствуют об этом величины коэффициента линейной упругости пшеничного зерна E, приводимые различными авторами и колеблющиеся в пределах 17-1000 кГ/мм².

Оригинальность нашего метода состоит в том, что мы исследуем зерно растягивающими силами, благодаря чему избегаем далеко идущих геометрических упрощений, необходимых при нагрузке зерна сжимающими силами различных систем.

В исследованиях был введен параметр времени для определения липко-пластических свойств зерна. В расчетах была принята реологическая модель тела Бингама, наиболее подходящая для экспериментальных результатов.

Исследовался также коэффициент Пуассона при помощи „тензометрических щипцов".

В исследованиях пшеницы „Кавказ" влажности 10% с.м. были получены следующие результаты:

коэффициент линейной упругости E	50 кГ/мм²
коэффициент Пуассона	0,2-0,23
разрушающее напряжение	0,48 кГ/мм²
относительное удлинение до момента разрушения A	12%
время ползания, являющееся функцией нагрузки	до 30 мин.

Были обнаружены внутренние трещины в зернах при ненарушенной внешней оболочке, рассматривавшейся „под свет".

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