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EVALUATION OF SOME RHEOLOGICAL PROPERTIES OF TWO NATIVE POLISH AND ONE CANADIAN (AMBER DURUM) WHEAT GRAIN VARIETIES

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The rheological properties of grains of two Polish and one Canadian (Amber Durum) wheat varieties were examined with a Hoeppler consistometer. The changes of relative strain, variable in time, were determined. The rheological properties of grains under load on cross-sections showed greatest differentiation. The initial stage of the creep curve is the best characteristic measurement of grain properties.

During intensification of the milling industry's productivity it is particularly important to learn about the rheological properties of the initial raw material, i.e. grain. When the properties are known it is possible to select the most appropriate and economical technological parameters of cost (power consumption, installation wear, etc.) and yield.

The basic operation in the milling process is breaking. It subjects grains to striking, crushing, and shearing forces [1, 3, 4, 5, 6, 8]. The literature on the mechanics of the disintegrating of grain structures is relatively scanty. Actually, no data are available on the physical premises for the technological parameters applied in milling practice [3, 8].

The structural and mechanical properties of grain appear as the resultant of their given chemical and chemo-physical states. Grain structure is not uniform. Next to the hard, elastic, and brittle structure of endosperm there is the pliant, pasty structure of the germ and the elastic structure of the perisperm [3, 6, 7, 8, 9].

Girszson [2], in his investigations of the strength of particular sections of a grain, proved that endosperm was most resistant to compression. Assuming the resistance to compression equals 1, the resistance to tensile, splitting and shearing forces appears as the following ratios:

Hard wheat	1	0.42	0.22	0.14
Vitroeous wheat	1	0.36	0.22	0.16
Loury wheat	1	0.86	0.43	0.19

The value of the disintegrating load for grain of one variety and of uniform moisture content ranges within a very wide interval. Many authors have confirmed this [2, 9] stressing that it is in a single grain that individual features such as its shape, cohesion of endosperm. porousness, and dimensions of the grain (length, width, and thickness, and mutual ratios of these) are particularly conspicuous.

For these reasons all the phenomena concerning grain and all the investigations on the rheological properties of it should be registered and conducted statistically within the varieties being the subject of our immediate interest.

The process of breaking the wheat grain in total as an elastic and plastic structure may be regarded in three stages:
Stage One — characterized by domination of elastic strains,
Stage Two — domination of plastic strains,
Stage Three — the total disintegration of structure.

The aim of the present paper is an attempted characterization of the rheological properties of three varieties of wheat grain of different hardness exposed to certain values of load.

MATERIALS AND METHODS

In the course of the experiment two native Polish varieties of wheat grain (Ostka Popularna and Nagradowicka) and one Canadian (Amber Durum) with identical 15 per cent moisture level were used. The moisture level in the varieties was determined by means of the dryer method, according to the Polish standard PN-65/R-74006. Singular grains of wheat were subjected to uniaxial static loads by means of a Hoeppler consistometer. The grain was also exposed to a constant load $P = 1750$ G.

The grains were loaded in two directions: along the longer axis and transversely (the loaded grain was resting on its crease). The cross-section was optically determined each time for particular singular grains. In the case of loads applied to the crease the cross-section was assumed equal to the cross-section of the consistometer's bolt.

To compute the stress δ in grain it was assumed that it was equal with the ratio of load to a given cross-section. When determining the relative strain the initial length (l_0) and the increment of length (Δl) in time were measured.

In the case of the longitudinal loads the l_0 value was considered equal to the height of a grain sample; during loads applied to the crease the l_0 marked the grain's thickness. The number of tests was sufficiently high in order that the obtained mean average results of the measurements could be considered representative of a given variety of wheat grain. The experiments was conducted for 20 to 25 minutes for each grain. Initially the readings were made at 5 second intervals and then the intervals were gradually extended up to 5 minutes.

The methods of investigating the changes of such rheological parameters as stress, strain and strain rate may, in principal, be reduced to three cases, assuming that one of the above parameters is constant [10].

Consequently, it is possible to give the following three methods of measuring:

— the measurement of the relative strain ε to time when the load P = const (the creep test),

— the measurement of stress σ to the relative strain at a steady rate of strain v = const,

— the measurement of the stress σ to its persistence time τ at a constant strain Δl = const (the relaxation test).

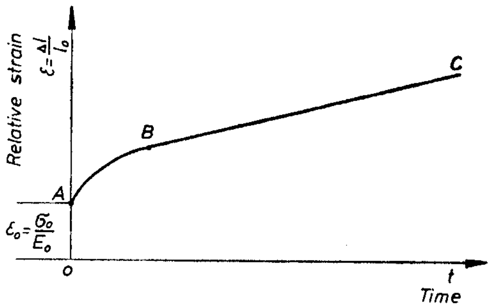

Fig. 1. The creep curve

In the course of the experiment for the determination of the rheological properties of grain the creep test was applied. During this test the investigated sample is exposed to a rapid load and then observations are made on the relative strain in the function of time.

The theoretical creep curve is given below in Fig. 1.

The section OA corresponds to immediate elastic strains, which occur within the range of applicability of Hooke's law. In accordance with the theory of elastic strains, the relative strain is equal $\varepsilon_0 = \frac{\delta_o}{E_o}$, where E_0 represents the coefficient of direct elasticity dependent on the elastic properties of the body under study.

During the next period (Section AB in the graph) the direction coefficient of the creep curve equal to the rate of relative strains shows variability. This period is called the period of transient creep. As can be seen in the diagram, the rate of variable strains reaches its maximum at point A to drop with time to a certain value corresponding to a stress σ = const (Section BC).

Section BC corresponds to the steady creep. The variable value of the rate of relative strains in Section AB may be accounted for by the occurence of the phenomenon of elastic retardation in the case of co-occurence of elastic and plastic strains.

THE RESULTS

The results of measurements of the relative strains ε, variable in time, for the three investigated types of grain conducted within a period up to 25 minutes, are listed in Table.

Table The Variable-in-Time Relative Strain for Ostka Popularna, Nagradowicka, and Amber Durum (Load

Wheat variety and Type of load	P	$\delta = \frac{P}{S}$	l_0	5''	10''	20''	30''	45''	1'	1'15''	1'3''	1'45''
				$\varepsilon = \frac{\Delta l}{l_0}$								
	mm²	kG/mm²	mm	mm/mm								
Ostka Popularna (the cross-section loads)	min. 6.05	max. 0.286	1.69	0.032	0.033	0.034	0.035	0.036	0.036	0.037	0.037	0.037
	max. 9.88	min. 0.176	2.15	0.015	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
	aver. 8.62	aver. 0.201	1.89	0.032	0.032	0.033	0.033	0.034	0.034	0.034	0.034	0.035
The crease load	12.56	0.138	3.30	0.014	0.015	0.015	0.015	0.015	0.015	0.015	0.016	0.016
Nagradowicka (the cross-section loads)	min. 8.52	max. 0.203	2.24	0.032	0.033	0.034	0.034	0.034	0.035	0.035	0.035	0.035
	max. 11.11	min. 0.163	2.54	0.015	0.015	0.015	0.016	0.016	0.016	0.016	0.016	0.016
	aver. 9.63	aver. 0.180	2.17	0.028	0.029	0.029	0.029	0.029	0.030	0.030	0.030	0.030
The crease load	12.56	0.138	3.17	0.015	0.015	0.016	0.016	0.016	0.016	0.017	0.017	0.017
Amber Durum (the cross-section loads)	min. 5.43	max. 0.319	1.95	0.015	0.015	0.015	0.015	0.016	0.016	0.016	0.016	0.016
	max. 8.89	min. 0.195	2.22	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.013
	aver. 6.77	aver. 0.256	2.05	0.014	0.014	0.014	0.015	0.015	0.015	0.015	0.015	0.015
The crease load	12.56	0.138	3.08	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012

S — the cross-section of a grain (for longitudinal loads

σ — the cross-section of the bolt (for grains resting on crease) .

σ — strain

l_0 — initial lenght

— relative strain

The data from Table concerning the individual types of grain with loads applied to the cross-sections are given in Figs. 2, 3 and 4. Figures 5, 6 and 7 represent the creep curves for the same types of grain with loads applied to the crease. In Figs. 8 and 9 there are collective creep-curves for the investigated types of grain with loads applied longitudinally and transversely (on the crease). It follows from these collective curves in Figs. 8 and 9 that the range of immediate strains stays within the interval of about 5 seconds. Within the range of these strains the relative strain ε reflects upon the hardness of grain. Hardness of a body, in this case, of a grain, is its resistance to plastic deformation. Harder grain under a steady load has a lower ε value, that is to say, greater forces must be applied to effect a specific relative strain.

The creep curve of Amber Durum wheat is below the creep curves of the remaining varieties of wheat. It also follows from the figures above that the mean average limits of the proportionality of deformations of grain are reached at different times for different wheats which means that the direction coefficients of the lines of proportional strains are different for different types of wheat. This value depends on the ratio of the elastic strains and the co-occurring plastic strains, for which the plas-

P = 1735 G)

2′0	2′5″	3.0′	3.5′	4.0′	4.5′	5.0′	6.0′	7.0′	8.0′	9.0′	10′	12′	15′	20′	25′
0.037	0.037	0.037	0.037	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.039	0.040	0.040	
0.016	0.016	0.016	0.016	0.016	0.016	0.017	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.018	
0.035	0.035	0.035	0.035	0.035	0.036	0.036	0.036	0.036	0.037	0.037	0.037	0.037	0.037	0.038	
0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.017	0.017	0.017	0.017	0.017	0.017	0.017
0.035	0.035	0.035	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.037	0.037	0.037	0.037	
0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.017	0.017	0.017	0.017	
0.030	0.030	0.030	0.030	0.030	0.031	0.031	0.031	0.031	0.031	0.031	0.032	0.032	0.032	0.032	
0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.019
0.016	0.016	0.016	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.019	0.019	0.019	
0.013	0.013	0.013	0.013	0.013	0.013	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	
0.015	0.015	0.015	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.017	0.017	0.017	
0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.014	0.014	0.014

ticity threshold is in the vicinity of zero. Thus, the angle of incidence of the first straight-line section of the creep curve to time axis is the second parameter which characterizes the physico-chemical features of grain. The tangent of this angle is equal to the ratio of the relative strains within the discussed range (the first straight-line section of the creep curve) to the corresponding time.

In relation to the load used in the experiment the relative variability of length within proportionality limits is 0.032 mm/mm 0.028 mm/mm and 0.013 mm/mm for Ostka Popularna, Nagradowicka and Amber Durum, respectively, with the load applied to the transverse cross-section.

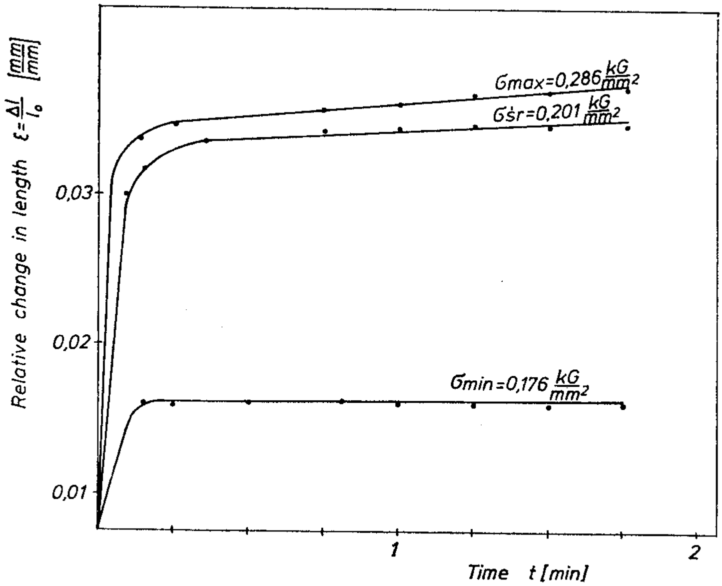

Fig. 2. Creep curve for "Ostka Popularna" variety (the cross-section loads) σśr. = σmed

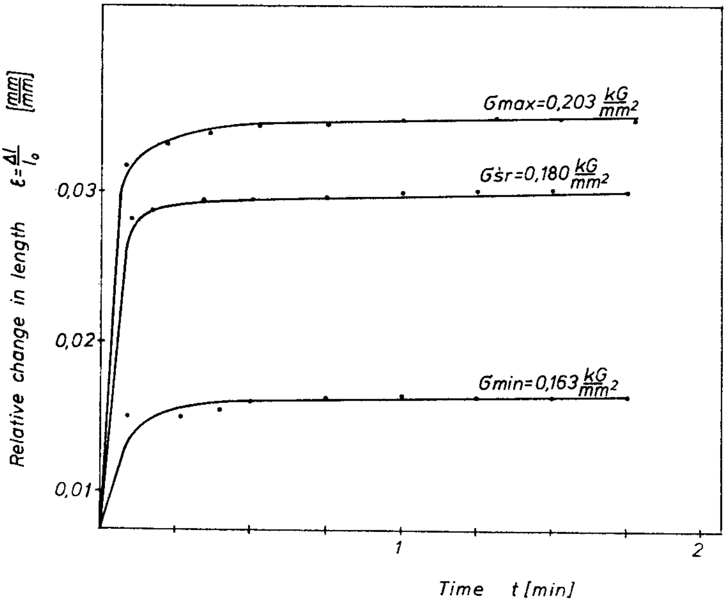

Fig. 3. Creep curve for "Nagradowicka" variety (the cross-section loads) σśr. = σmed

Analogically, during the load of grain on the stria the relative changes in the length of these wheat varieties are, respectively: 0.015 mm/mm, 0.013 mm/mm, 0.01 mm/mm.

The experiments indicate that more accurate results are obtained with the use of loads applied to the transverse cross-section of grain (the longitudinal loads).

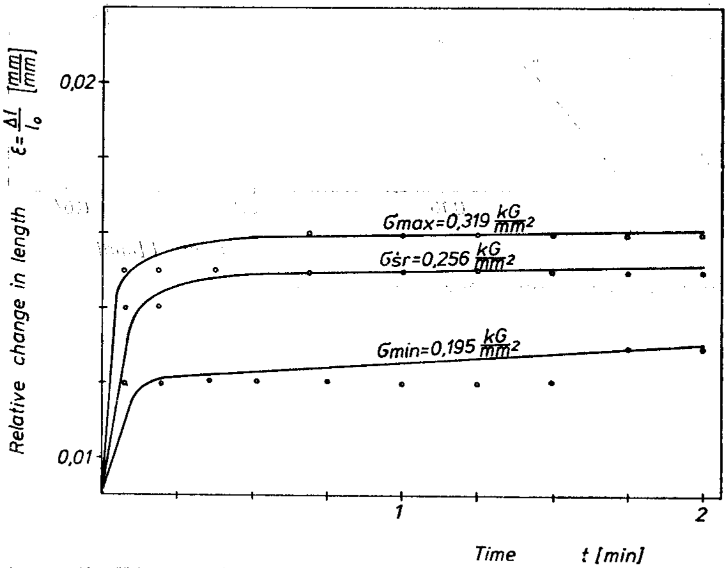

Fig. 4. Creep curve for "Amber Durum" (the cross-section loads) σśr = σmed

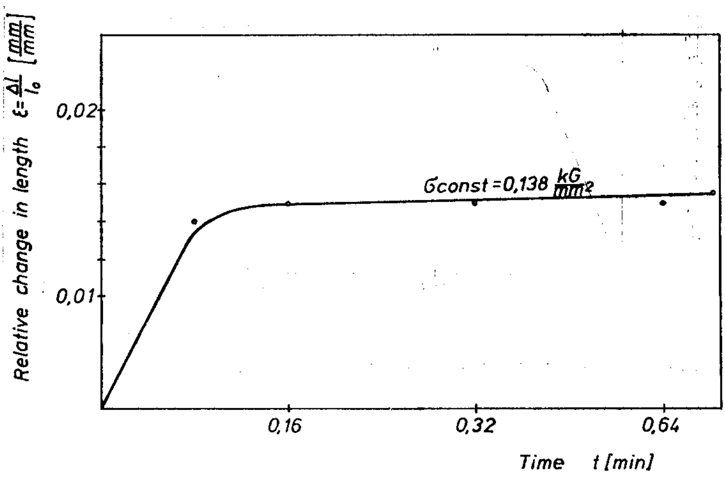

Fig. 5. Creep curve for "Nagradowicka" (crease loads)

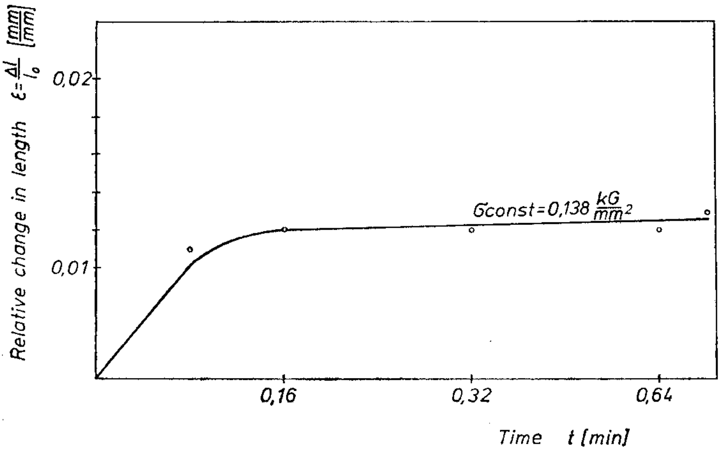

Fig. 6. Creep curve for "Amber Durum (crease loads)

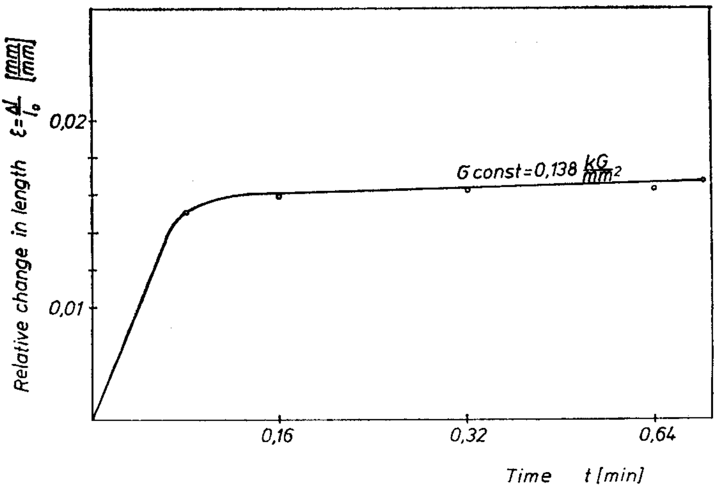

Fig. 7. Creep curve for "Ostka Popularna" (crease loads)

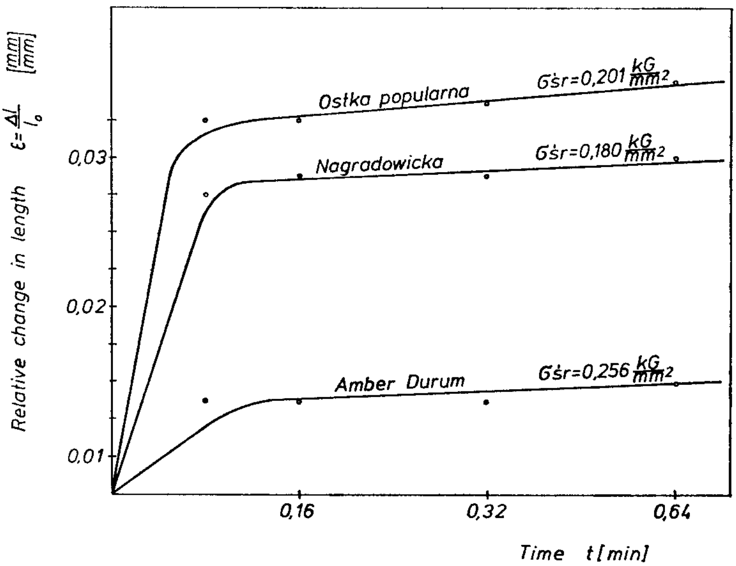

Fig. 8. Collective creep curves for three types of wheat (cross section) σśr = σmed

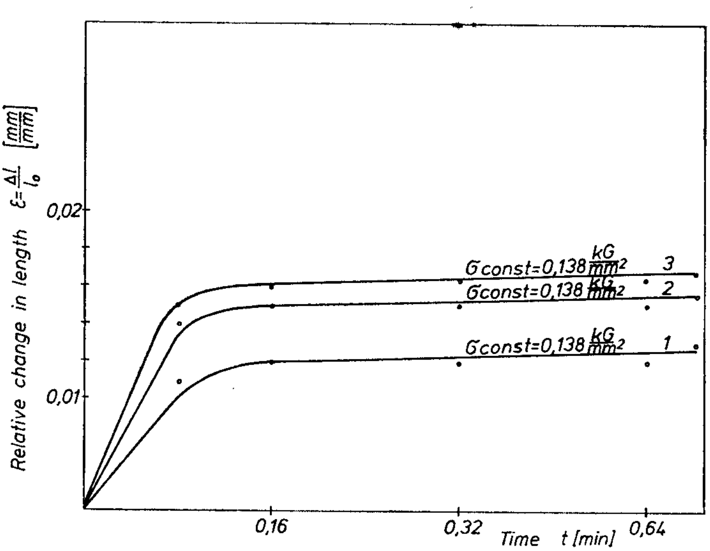

Fig. 9. Collective creep curves for three types of wheat (crease loads); *1* — "Amber Durum", *2* — "Nagradowicka", *3* — "Ostka Popularna"

CONCLUSIONS

1. The rheological and physico-mechanical properties of wheat grain can be determined by means of values of relative strains and the tangent of the slope angle of the initial section of the creep curve to time axis,

both when the load is applied to a grain along its axis as weel as transversely to the axis.

2. The rheological properties of wheat grain from particular varieties are more diversified at longitudinal loads.

3. Values of the parameters defining the rheological properties of wheat grain (the relative strain ε and tangent α) should be measured only within the first range of relative strains (the initial section of the creep curve), because the measurements of these parameters within this section are most representative and revealing the properties of grain in the state in which it is fed into the rolls.

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OCENA NIEKTÓRYCH WŁAŚCIWOŚCI REOLOGICZNYCH ZIARNA PSZENICY DWU ODMIAN KRAJOWYCH ORAZ KANADYJSKIEJ AMBER DURUM

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S t r e s z c z e n i e

Badano właściwości reologiczne ziarna pszenic krajowych Ostka Popularna i Nagradowicka oraz kanadyjskiej Amber Durum przy użyciu konsystometru Hoepplera. Pojedyncze ziarna pszenicy poddawane były jednoosiowym obciążeniom statycznym. Ziarno obciążone w dwu kierunkach, a mianowicie wzdłuż dłuższej osi ziarna oraz w kierunku poprzecznym (ziarno leżące na bruzdce). W pracy niniejszej podczas badania właściwości reologicznych ziarna poddawano je próbom pełzania, polegającym na szybkim obciążeniu badanej próbki i obserwacji odkształcenia względnego w funkcji czasu.

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