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THE INVESTIGATIONS OF CREEP PHENOMENON OF SUGAR BEET TISSUE

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A b s t r a c t. The investigations aiming at the analysis of the phenomenon of creep of sugar beet roots with the use of the resistance machine INSTRON 6022 were carried out. The samples of root tissue were exposed to rapid load (deformation) up to the stress of 1.273 MPa and then were held under constant stress for 24 min. The experiment was performed for roots of PN Mono 1 variety, in 3 measuring zones of different location in the root and different wooden bundles arrangement. The creep phenomenon was described with a standard, triparameter model equations. As a result of the experiment the graphs of relative deformation dependence on time were obtained and the rheological model constants were calculated by means of the least squares method. There were: modulus elasticity, modulus of deformation relaxation and viscosity coefficient. Low matching errors and high correlation coefficients testify high consistence of experimental and theoretical results. The mechanical beet root tissue parameters are different in higher and lower part of root due to its untypical, diversified anatomical structure.

K e y w o r d s: sugar beet, creep phenomenon, mechanical parameters

INTRODUCTION

Under the conditions of mechanical harvest, transport and storage the root of sugar beet is subjected to mechanical stress which causes the strain of tissue.

Though classical methods of research used in physics, mechanics and resistance of materials have a limited applicability for plant products, the application of fundamental principles of mechanics and rheology is a good start for the study of mechanical behaviour in biological systems [7,8].

In principles of rheology, the strain in bodies is made in different ways of their constraints: at constant deformation speed, creeping of material, stress relaxation, in dynamic tests and at loading an unloading of materials (hysteresis). The sugar beet root was already subject of observation in compression test at constant deformation speed [2,3], stress relaxation [3,4], hysteresis [3,4] and dynamic tests [1]. In order to analyse the creep phenomenon of sugar beet root, the investigations were carried out at the Institute of Agrophysics in Lublin.

The deformation that occurs at creep can cause damage, even at relative lower stress, when we lengthen over much the time of loading. In this test, loading (stress) is suddenly applied (beginning deformation constrained at great speed) and next held constant (at constant value of stress) while deformation is measured as a function of time.

MATERIALS AND METHODS

The roots of PN Mono 1 variety were the object of investigations. The experiments were made directly after beets harvest (mean value of water potential was equal to 22.92 10^5 Pa) in their technical ripeness.

The samples (cylindrical shape: diameter - 20 mm, height - 20 mm) were cut out from the widest part of root, parallel to its longitudinal axis (zone A) and perpendicularly to this axis (zone B), and also from the lower part of the root along its axis (zone C), [2].

The investigations were carried out on universal resistance machine INSTRON 6022.

The basic program of the machine was modified in order to obtain the parameters necessary to make the creep tests. The total error of apparatus does not exceed 0.5 %.

The beet sample was compressed between two flat plates and it was exposed to a very quick deformation (with speed 200 mm/min) until the stress equal to 1.273 MPa was obtained, at which it does not still reveal nonlinear of the function $\sigma=f(\Delta l)$ [2]). The value of this stress was fixed after determination of a rupture point of sample. The samples under constant stress were held for 24 min. In consideration of a character of creep course, the measurement of strain at the beginning of curve was done at intervals of time 0.2 min (the first 9 measurements) and next at 2 min intervals.

RESULTS AND DISCUSSION

Figure 1 presents the typical run of the interdependence of relative strain and the time of test for the 3 zones of root.

Rheological behaviour of beet root at the phenomenon of creep is described by equation of triparameter standard model [4-7]. In a special case, when the stress $\sigma_{(t)}=\sigma_0>0$ and $\varepsilon(0)=\varepsilon_0$ the equation of creep curve (Fig. 2) is expressed as follows:

$$\varepsilon(t) = \frac{\sigma_0}{E_{2P}} + \left(\varepsilon_0 - \frac{\sigma_0}{E_{2P}}\right) e^{-\frac{t}{\tau_\varepsilon}} \qquad (1)$$

where σ_0 - constant stress, ε_0 - relative strain in time t_0, E_{2P} - elastic relaxation modulus of strain, t - time, τ_ε - time constant of creep.

The final estimation of this model gives confrontation of the results obtained from the analysis of the model and result of experimental investigations. For accurate matching of theoretical function with the experimental data, the values of the matching error were minimized by means of the least squares method. The coefficient of correlation between experimental and theoretical data and secondary error was calculated. A low matching error (0.2901 %) and secondary error (1.239 %) and also a high correlation coefficient (0.9548) testify the significant consistence of experimental and theoretical results, which confirms usefulness of the proposed rheological model for the description of creep phenomenon in the beet root pattern. Divergence between theoretical and experimental curves are not important (2.00-0.66 %).

In standard model, rheological behaviour of beet roots can be described by three parameters: elasticity modulus E_{1P}, elastic

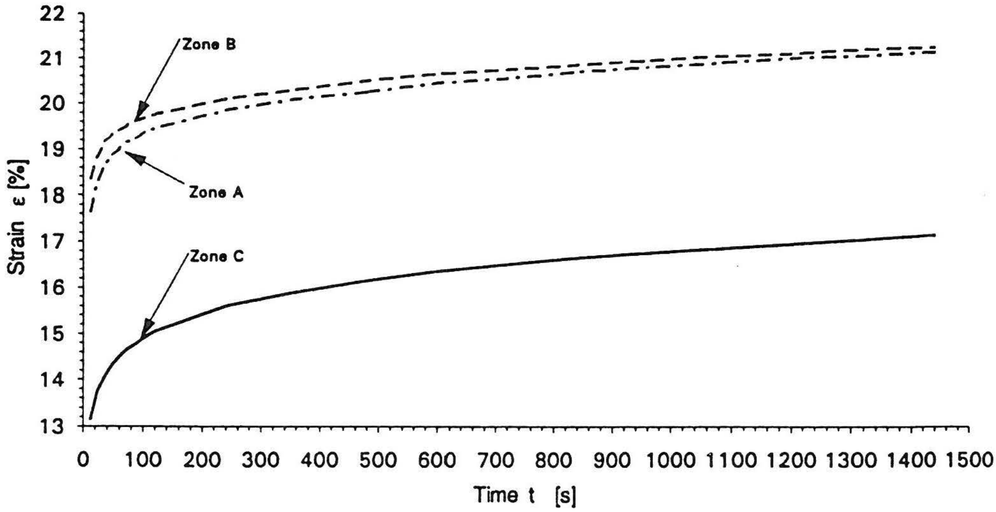

Fig. 1. Experimental curves of creep for A, B, C zones of sugar beet root.

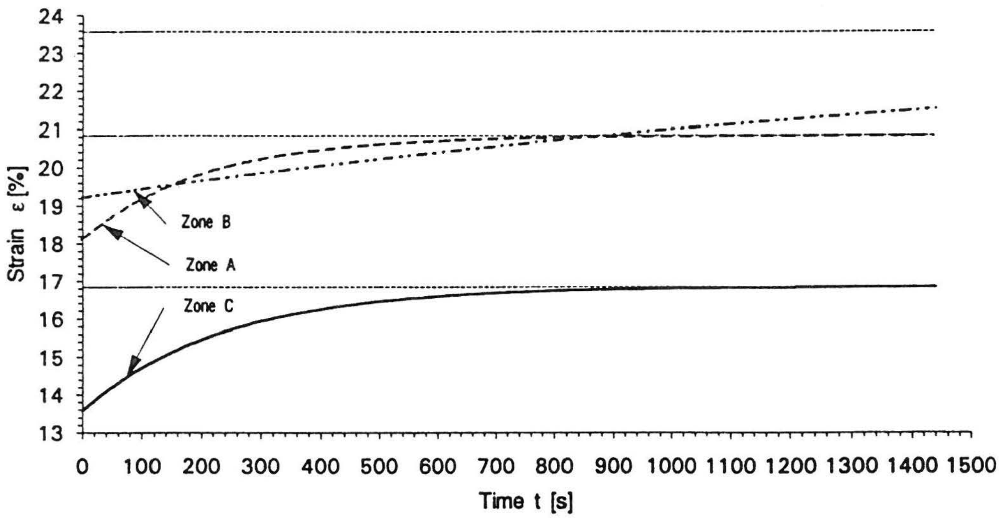

Fig. 2. Theoretical curves of creep for A, B, C zones of sugar beet root.

relaxation modulus of strain E_{2P} and viscosity coefficient η_P. This model can be also characterized with the aid of a proportionality coefficient W_p [5] and time constant τ_ε, which characterize the run of curves in a simpler way.

Having the knowledge of the experimental pattern of creep (strain relaxation) curves the parameters of standard model were calculated:

$$E_{1P} = \frac{\sigma_0 - E_{2P}\varepsilon_0}{\varepsilon_0} \quad (2)$$

$$E_{2P} = \frac{\sigma_0}{\varepsilon_\infty} \quad (3)$$

$$\eta_P = \tau_\varepsilon E_{1P} \quad (4)$$

$$W_P = \frac{\varepsilon_\infty}{\sigma_0} \quad (5)$$

The performed variance analysis for the single classification allowed to determine the significance of differences between model constants for individual zones of sugar beet roots.

It results from the presented data (Table 1) that the samples cut from the lower part of the root (zone C) showed significantly higher values of elasticity modulus E_{1P} and lower values of beginning strain ε_0 in comparison with remaining zones.

The differences in values of modulus E_{1P} and strain ε_0 results from different arrangements of fibrous and wooden bundles in particular zones. In zones A and B (high part of root) prevail lateral, thin bands of fibrous and wooden bundles. They are built of younger tissues with higher parenchyma content. In zone C the thickest and the oldest bands of conductive system are situated in which there is higher density of rings of fibrous and wooden bundles. In literature [3], in the zone C, lower values of compressive strength and higher values of elasticity modulus are published. In creep investigations this accordance is confirmed. The material under the influence of application of constant stress is not deformed by a constant value. The beginning relative strain of samples cut out from the lower part of root (zone C) was smaller than those of zones A and B, and what is connected with it, modulus E_{1P} of measuring zone C was larger by 11 %.

The right branch of standard model (Fig. 3) is Hook's model, so the observed reaction

Table 1. Rheological model constants and beginning strain ε_0 (in time t_0) of sugar beet root tissue for the creep test

Root zone	E_{1P} 10^{-2} (MPa)	E_{2P} 10^{-2} (MPa)	η_P (MPa s)	ε_0 (%)	τ_ε (s)	W_P
A	1.345	5.848	20.256	18.10	1178	17.3170
B	1.980	5.823	18.456	18.36	1272	17.4340
C	2.016	6.603	35.544	15.59	1556	16.3153
YP	1.519	5.591	24.750	17.34	1336	17.0221
LSD	0.652	-	-	2.41	-	-

LSD - the least significant difference at α=0.05.

of the samples of zone C, expressed by modulus E_{1P} in creep process, confirms the results obtained in a static compression test [2]. However, the values of modulus (E_{1P}), viscosity (η_P) and proportion coefficient (W_P), time constant of creep (τ_ε) of the left branch of the standard model do not differentiate the zones of sugar beet root.

The reaction of samples of root in creep process can be described by Eq. (1) however, one should take into account other significant different values E_{1P} for low and high measuring zones of root.

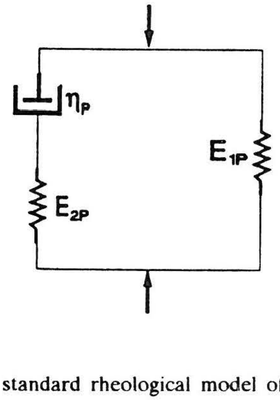

Fig. 3. The standard rheological model of sugar beet root tissue.

CONCLUSIONS

1. The standard model applied as the mathematical description of state equation of sugar beet root tissue in a creep test serves its turn. Low matching error and high correlation coefficient testify high consistence of experimental and theoretical results.

2. Anatomical structure of sugar beet root determines its rheological behaviour. The test of creep is another proof that the sugar beet is an anizotropic body. The mechanic parameters of rheological model applied to analysis of creep process (modulus E_{1P} and beginning strain ε_0) are different for low and high parts of root.

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