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USAGE OF CRITERION OF STRAIN FAILURE IN CASE OF CARROT ROOTS

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A b s t r a c t. In this work an attempt was undertaken to verify the usage of criterion of strain failure for carrot roots. A compression test was conducted for different speed of deformation from the range between $8.33 \cdot 10^{-3}$ mm/s and 3.33 mm/s.

As a result of the carried out experiment absorbed energy, failure stress and strain were obtained. As a model of phenomenon of deformation was used a formula proposed by Murase and Merva which bases on distribution of absorbed energy. Changes of each ingredient of this formula in function of deformation rate was subjected to partly verification based on changes of total absorbed energy, strain and 'calculated energy'. The calculated energy was energy absorbed by rheological model describing viscoelastic behaviour of examined material.

The results of experiments and calculation showed disproportion between individual components of total energy. Difference between these components can be a predictor of amount of micro damages in studied material. The carried out investigations allow to confirm the adequacy of using the criterion of strain failure for carrot roots under conditions of experiment.

K e y w o r d s: carrot roots, failure strain, mechanical loading

INTRODUCTION

The failure resistance of plant tissue to different kind of mechanical loading influence on the size of losses at harvest, transportation and storing. Some of the resistance parameters are also used as the coefficients of storing quality and consumption quality. Carrot roots, like that of other crops of high water content, behaviour viscoelastic. In connection with this, the values of obtained parameters can be depended on the time in which mechanical interference take place into examined material.

Other problem is to answer the question what is the real cause of failure of plant tissue (strain, compressive stress, shear stress, etc.).

In this work the attempt was undertaken to verify the usage of criterion of strain failure for carrot roots. A compression test was conducted for different speed of deformation. As a result of carried out experiment energy, stress and strain at failure were obtained. Energy was the additional parameter to verify this criterion. Changes of ingredients of energy in function of deformation rate was subjected to partial verification based on changes of total energy, values of strain and W_c. W_c was the hypothetical absorbed energy calculated on the basis of earlier experiments on stress relaxation.

MATERIALS AND METHODS

The subject of investigations were carrot roots of the Perfekcja variety. Roots from the same field and picked at the same time underwent compression test one day after picking. The samples were cylindrical, with diameter of 12 mm and length 20 mm. They were cut out at the bottom part of the root perpendicularly to its axis. The samples were compressed between two parallel plates till the first breaking of structure was signaled by the rapid decrease of the reaction force. Seven different speeds of deformation from the range of $8.33 \cdot 10^{-3}$ mm/s to 3.33 mm/s were used. For each speed of deformation eight repetitions were carried out. In present report the results of earlier conducted experiment of stress relaxation were used. The results were presented by Gołacki and Sobechowicz [1] and were obtained in the same condition of the experiments. In that work viscoelastic properties were described by the Maxwell's model. Elastic and viscous moduli of the model by the inclusion of strain rate were calculated.

RESULTS AND DISCUSSION

The influence of the deformation speed on value of absorbed energy and strain at failure is shown in Figs 1 and 2.

The value of absorbed energy increased with the growth of the deformation speed. This increase was statistically significant, although we have not assertained significant dependence between speed of deformation and strain at failure (Fig. 2). The values of the stress at failure were characterized by the wide dispersion. Murase's *et al.* studies [2] on the course of deformation process of the plant material show the following equation for the total energy absorbed by the studied material during this process:

$$W_{tf} = W_{lf} + W_{ef} + W_{\varphi f} \quad (1)$$

where W_{tf} - total energy delivered to the body, W_{lf} - the energy causing viscous flow of material, W_{ef} - the energy causing elastic deformation of the cell walls, W_{ff} - the energy causing water flow through the cell walls.

The postulate of critical deformation comes from the assumption that the component of total energy W_{ef} that decides on the tissue resistance is constant and independent on speed. When its value is exceeded the cell wall gets damaged. The exceeding of the constant value W_{ef} can take place only by applying a certain deformation. Whereas the stress depends on the condition of loading and does have any constant value.

The results of carried out experiments confirm the lack of dependency between values of strain at failure for different speed of deformation. It seems possible to accept the assumption about constancy ingredient W_{ef} connected with the elastic deformation.

Other component of total energy $W_{\varphi f}$ is difficult to evaluate because depends on many material constants like: water potential, membrane resistance to water flow, etc. From theoretical consideration appears that its value should decrease with the increase of speed of deformation [2]. It showed that increase of the value W_{tf} in function of speed of deformation is caused the changes ofcomponentW_{lf}.

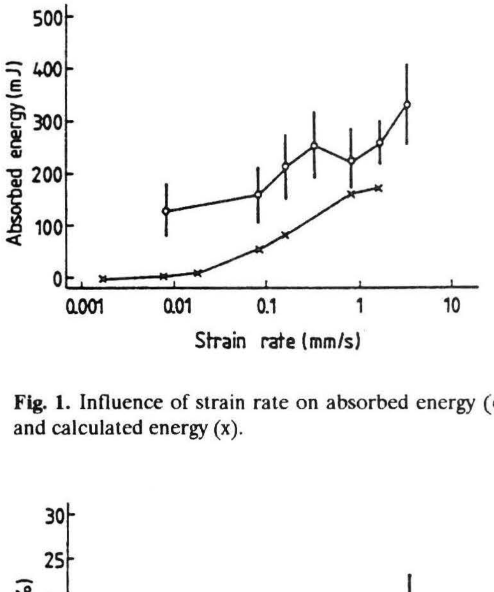

Fig. 1. Influence of strain rate on absorbed energy (o) and calculated energy (x).

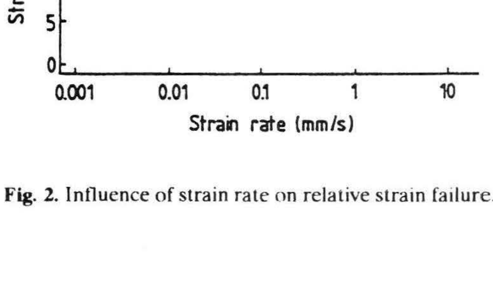

Fig. 2. Influence of strain rate on relative strain failure.

The other approach to distribution of energy at failure is to make use of rheological model. In paper [1], based on the stress relaxation experiment, moduli of elasticity and viscosity of Maxwell's model was obtained. The experiment was conducted for the same carrot variety and in the same conditions. The value of deformation was 10 % of initial sample length. Moduli of elasticity and viscosity were different for different speed of deformation through speed of deformation was taken into account in equation of this model.

In this work hypothetical energy W_c absorbed by model 'at failure' was calculated on the base of earlier experiments [1]. Failure point for carrot samples in current experiment is obtained at average relative deformation - 17.17 %.

Assuming the course of strain is a linear function:

$$\varepsilon(t) = at \tag{2}$$

where $\varepsilon(t)$ - strain, critical strain, a - rate of deformation.

The absorbed energy can be expressed as:

$$W_c(t) = \int_0^{\varepsilon crit} \sigma(t)\, d(\varepsilon) \tag{3}$$

where ε, ε_{crit} - strain, critical strain, $\sigma(t)$ - stress function (the solution of equation model for strain function described by Eq. (2)).

The results of calculation of energy W_c in which the samples shape were included are shown in Fig. 1. Calculated values were considerably lower than experimental values. The calculated and experimental energy show similar reciprocal dependence by the deformation not causing failure and equal 10 % of initial dimension of samples. Rheological model is evaluated based on the stress relaxation curve. It described the state of the examined material after the initial deformation. However, as early as during growth of deformation comes to many micro damages in the samples, the equation of assumed model does not take into account the energy causing micro damages during initial deformation.

In this work only approximate and hypothetical analysis was conducted. However, it showed that difference between values of energy W_{tf} and W_c can be indicator of the amount of micro damage in the studied material.

CONCLUSIONS

1. The lack of significant dependency between strain at failure and deformation speed (in the range between $8.33 \cdot 10^{-3}$ mm/s and 3.33 mm/s) showed that it is possible to assume strain at failure as a criterion of damage carrot root.
2. Difference between calculated energy W_c and energy which comes from experiment W_{tf} testifies inadequacy of using of Maxwell's model to describe the initial stage of carrot root.
3. Difference between energy absorbed and calculated based on stress relaxation experiment can be used as an indicator of the amount of micro damage during deformation below critical point.

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