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GEOMETRY OF CEREAL STALK CROSS-SECTION

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A b s t r a c t. Accuracy of determining mechanical properties of the stalk depends, to a large extent, on the accuracy of determining characteristics of the sample cross -sectional geometry. Accurate calculations are very difficult due to geometrically complex shape of this cross -section. Generally, the cross-section is assumed to be shaped like a filled hollow or hollow ellipse and the stalk material to be homogeneous and mechanically isotropic. The paper presents two new, more accurate methods for determining cross-sectional area and the moment of inertia of the stalk cross-section. The first method is an application of a measuring microscope, the second one an application of a PC image analysis programme.

K e y w o r d s: cereal stalk, mechanical properties, image analysis

INTRODUCTION

Almost all technological processes expose agricultural products to different mechanical loads cause all kinds of deformations. In order to design these processes properly, it is necessary to find rules determining behaviour of plant materials affected by loading, that is to find mechanical properties of these materials. Generally, it is assumed that the methods used for testing construction materials can be simply adapted for testing most agricultural products. In the case of crop and grass stalks bending or shear tests are mostly used, together with occasional torsion and tensile tests.

Accuracy of determining mechanical properties of the stalk such as the tensile strength, modulus of elasticity, shear and bending strength, depends, to a large extent, on the accuracy of determining sample cross-sectional area and the moment of inertia of the cross-section (the second moment of the area). Accurate calculations are very difficult due to geometrically complex shapes of this cross-section. Generally, the cross-section is assumed to be shaped like a filled hollow or hollow ellipse and the stalk material to be homogeneous and mechanically isotropic [2-5].

During tensile and bending tests of wheat stalks carried out earlier by the present author [1], an interesting relation has been observed: namely, tensile strength and the modulus of elasticity are the higher the smaller the sample cross-sectional area is (Fig. 1). If the stalk material was not homogeneous, such a relationship could not occur. It is supposed that this is due to

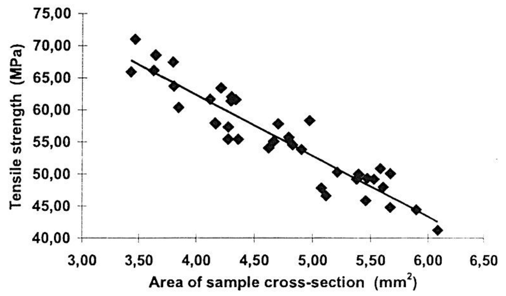

Fig. 1. Wheat stalk tensile strength vs. its cross-section area - an example of relation which should not occur to such extent. Correlation coefficient close to 0.9 [1].

the mentioned simplification above in determining the cross-sectional geometry of the sample.

METHODS

The paper presents two new methods for measuring the area and the moment of inertia of the stalk cross-section. The first method is an application of a measuring microscope, the second one an application of PC image analysis programme. Both methods assumed, again with some simplification, that a stalk is made of two materials which differ in mechanical properties. The material of greater strength, called the mechanical tissue, is composed of rind and sclerenchyma cells. The second material of significantly less strength is parenchyma. The parenchyma tissue is reinforced by vascular bundles surrounded by the mechanical tissue (Fig. 2).

By means of a measuring microscope, the magnitude of a_i, a_o, b_i, b_o, as they are shown in Fig. 3 are measured. The part of the sample cross-section area occupied by the mechanical tissue A_m is calculated from the formula:

$$A_m = \pi(a_o b_o - a_i b_i), \qquad (1)$$

and the moment of inertia I_m from the formula:

$$I_m = \frac{\pi}{4}\left(a_o^3 b_o - a_i^3 b_i\right). \qquad (2)$$

For complex shapes (Fig. 4) the area of cross-section should rather be evaluated from the formula:

$$A = \int_{y_{\min}}^{y_{\max}} \mathrm{d}A, \qquad (3)$$

and the moment of inertia about the major axis (x in Fig. 4) from the formula:

$$I = \int_{y_{\min}}^{y_{\max}} y^2 \mathrm{d}A. \qquad (4)$$

The moment of inertia of the cross-sectional area is the sum of the products of each infinitesimally small area dA and the square of the distance y of each of the areas from the major axis. Therefore, that distance is a more significant value in calculating the moment of inertia than the area itself. It is really very significant in the calculations for cereal stalk cross-section as the mechanical tissue occupies the outer part of the cross-section.

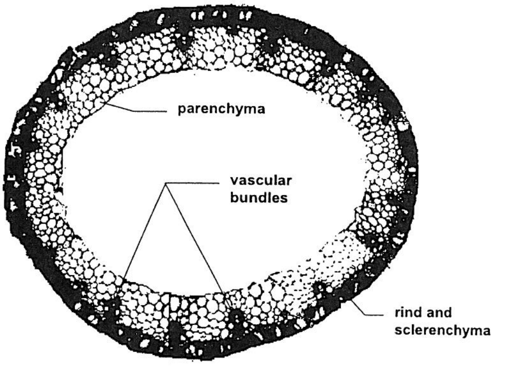

Fig. 2. Cross-section of wheat stalk.

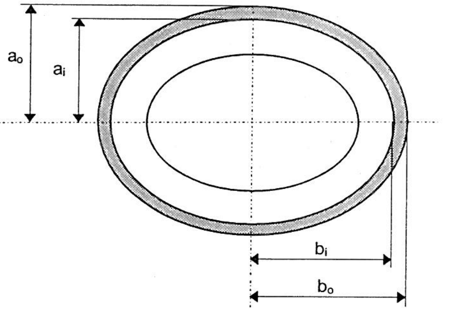

Fig. 3. Schematic diagram of stalk cross-section - symbols used in formulae (1) and (2).

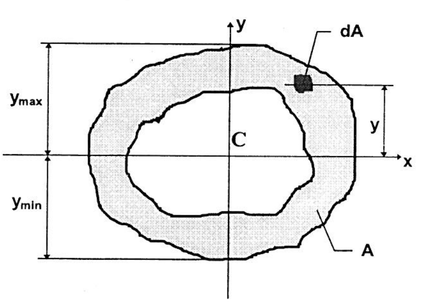

Fig. 4. Geometry of sample cross-section area. C - center of gravity, A - area of cross-section, dA - infinitesimally small area.

A computer algorithm was written to calculate A and I from a digitised image of the sample cross-section, according to the formulae (3) and (4). Such an image, taken by a CCD camera, is loaded into computer and prepared for analysis by means of any image processing programme (Fig. 5). The colour depth is then decreased to 2 colours - black and white (Fig. 5b) and the image of the parenchyma is eliminated (Fig. 5c). Images prepared in this way are analysed by the computer programme „Planimeter" developed by the author. First the program evaluates the area of the cross-section and the coordinates of its gravity center. Then, the moments of inertia about vertical and horizontal centroidal axes are calculated and finally, the programme finds the orientation of the principal axes of inertia and the values of the principal moments of inertia. The programme can also calculate the section moduli and the polar moment of inertia.

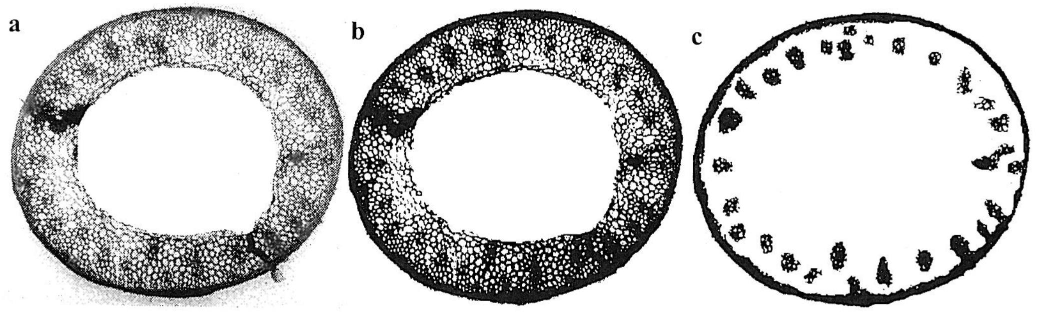

Fig. 5. Steps in the preparation of the camera images for analysis by a computer programme: image of stalk cross-section taken by CCD camera (a), colour depth decreased to black and white (b) and parenchyma tissue removed (c).

APPLICATIONS AND RESULTS

To compare the new methods proposed with the method used so far, 20 samples of wheat stalks with significantly different outside diameter were chosen. The outside and inside diameters of samples - d_o and d_i, respectively - were measured and the cross-sectional area A calculated from the formula:

$$A = \frac{\pi}{4}\left(d_o^2 - d_i^2\right), \tag{5}$$

and the moment of inertia of the cross-section I from the formula:

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right). \tag{6}$$

Then the measuring microscope was used and values of A_m and I_m calculated from formulae (1) and (2), respectively. Finally, the cross-sectional area and the moment of inertia were calculated for the same samples applying the computer programme. The results are presented in Fig. 6.

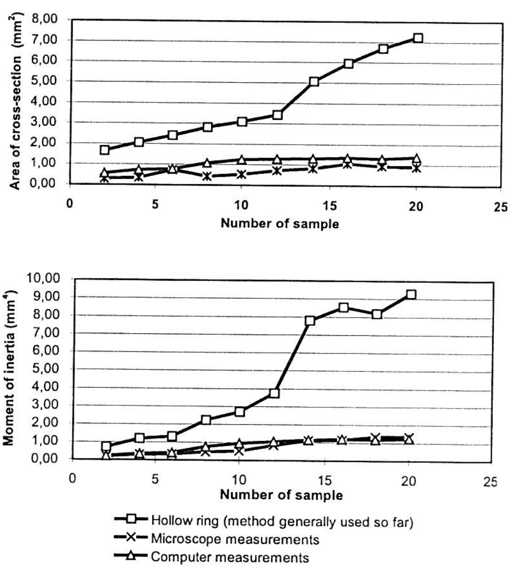

Fig. 6. Area and moment of inertia of the area of wheat stalk cross-section measured by means of the proposed method and by the method used so far. Samples numbered in the ascending order of the outside diameter value.

CONCLUSIONS

It was found out that both the cross-sectional area and the moment of inertia calculated considering a cross-section to be a filled hollow (with parenchyma) decreased along with the decrease of the outside diameter. However, the same quantities calculated considering only the rind and the sclerenchyma band do not depend or just slightly depend on the value of outside stalk diameter. It means that the higher the content of mechanical tissue in the stalk structure, the smaller the stalk diameter is. This explains higher strength levels observed in the stalks with smaller cross-sectional areas while calculating both sclerenchyma and parenchyma.

The experiments proved that for mechanical testing characteristics of the cross-sectional geometry of cereal stalks should be determined more precisely than it has been done so far. The results obtained using both of the new methods proposed are only slightly different. Therefore, in mass tests, the microscopic method, which appears to be a bit less accurate, could be applied. If, however, higher accuracy is needed a more time consuming method of image analysis should be used.

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