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Determination of rheological properties of fibrous structures

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Abstract: *Determination of rheological properties of fibrous structures.* This paper presents information related to measurement of rheological properties of papermaking fibrous structures. Mathematical model of compression of fibrous structures is presented.

Keywords: rheology, fibrous suspension, pulp

INTRODUCTION

After being formed and partly drained in the wire section, a paper web is moved to the paper machine press section formed by a complex of rolls of different design.

The pressing is aimed at:

- ✓ Further dewatering of the paper web,
- ✓ Thickening and smoothing of paper web structure,
- ✓ Smoothing and finishing of paper web surface,
- ✓ Tight bonding of paper web layers (multi-layer products).

In the paper machine press section, usually consisting of 2÷4 presses, the web dryness is increased from 15÷25% to 40÷50%. These values show that 1.5÷4.6 m^3 of water is removed by 1 t of paper in the press section.

RHEOLOGICAL MODELS USED TO DESCRIBE FIBROUS STRUCTURES

The literature lacks accurate analyses of deformations occurring in the pressed paper web. Some of the old publications [1,2] mention that in 1939 Seborg, Simmonds and Baird tested compactability of wet fibres. The researchers determined a relationship between strength properties of paper and ability of the paper web to expand after removing compressive stress. As the access to the original works was impossible, the above remark was based on the material quoted by more recent authors [3,4] considering it rather as historical information than using it for research purposes.

The other source refers to the effect of compression time of the wet web on its deformation. From this source, it can be concluded that, after exceeding the pressing time of above 0.04 s, plastic strain of the web is not increased.

When analyzing strains of the pressed paper web, the web can be considered as a viscoelastic solid body [5,6]. Under influence of compressive stress in the pressing section, the paper web is to some extent affected by plastic strain (irreversible) or elastic strain (reversible).

The changes presented above, occurring in the paper web, can be illustrated more accurately by the stress and strain curve (Fig.1).

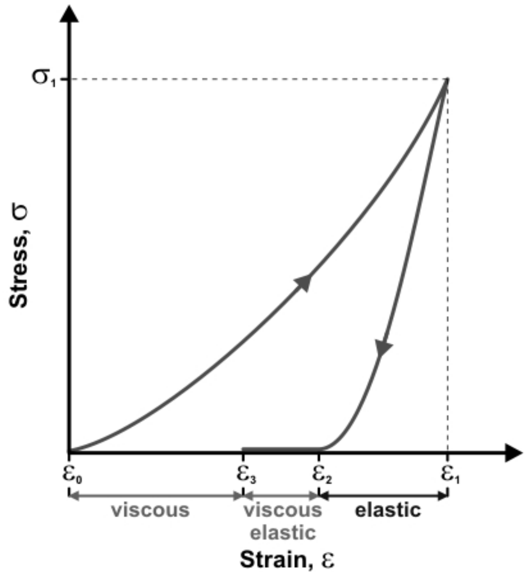

Fig.1. Changes in strain of pressed paper web presented in the stress –strain system

An important advantage in the quantitative description of processes occurring when pressing fibrous structures is their mathematical description. A reliable method is being searched to estimate experimental results, taking into consideration the properties of fibrous material and technological factors. For this purpose various mathematical models are used [4].

RHEOLOGICAL MODELS USED FOR PAPER

The scientific literature [7,9] presents the numerous rheological models used to describe how paper behaves when it is stretched. The authors suggested the models consisting of 3 or 4 combined ideal rheological elements. When reviewing the literature, any references to testing of paper or wet fibrous structures in compression by means of classical analyses of the stress and strain curve have not been found. Wilder's work presented the tests on creeping during compression of wet fibrous structures. However, this work focused its attention only on the measurement of changes of structure thickening level and just noted that an important scientific development of would be the description of creeping for wet fibrous structures using the rheological model.

On the other hand, the available literature shows many rheological models used to describe how paper behaves when it is stretched [8,9,10]. Due to the fact, that the properties of the material itself and its structures for paper and wet fibrous layer are very similar, it can be assumed that the rheological models used for paper may be applied to describe the relationship between the stress and the strain for compression of the wet fibrous structures.

RESULTS OF EXPERIMENTS

Attempts to describe the compression of a structure made of pulp showed that it is impossible to use single rheological elements.

It was impossible to describe the stress during the compression of the tested fibrous structures made of bleached kraft pulp (SaBl) by means of the mechanical models presented above. As a result of the unsuccessful attempts, a hypothesis was formulated that the constant values of parameters describing behavior of an elastic element (modulus of elasticity – E) and viscous element (η) were the most likely reasons for that. The attention was paid to the fact that the density of fibrous structure was changed over ten times during the tests (from approx. 0.05g/cm^3 to approx. 0.5 g/cm^3). Such enormous changes had not been considered by the classical models as, for example, in similar cases the density change of metal was over 1%. Therefore the density change had to be included in the model. Considering that the compressed fibrous structures are much more similar to solids than liquids, the change in density was introduced in the form of the changes of modulus of elasticity E [kPa]. This parameter characterizes the elastic properties of pulp.

In this way, the following function was created:

$$E(\rho) = E_0 \cdot \left(\frac{\rho}{\rho_0} \right)^n \quad (1)$$

where:
E – modulus of elasticity for given density, kPa
E_0 – modulus of elasticity for fibrous structure with density of cellulose, kPa,
ρ – density of fibrous structure, g/cm^3,
ρ_0 – density of cellulose, 1,493 g/cm^3.

It was assumed, that ρ_0, will be the highest-possible-to-achieve density of the tested fibrous structure, under influence of infinitely high compressive stress, that is the density of cellulose =~1,493g/cm^3.

Introducing this modification, the models presented above are achieved in the form considering the changes of density during the compression.

According to the modeling rules, recommending the least possible number of variable parameters in the model, the analysis of the presented models was initiated with the Kelvin-Voigt model.

The tests on the compression of the fibrous structures were conducted for constant increase in strain (volume decrease).

In this way, on the basis of the analyses of the experiments results, the following values were obtained:

- ✓ E_0 = 26 380 kPa,
- ✓ η = 1 230 kPa·s.

To verify how the model fits to the experimental results, Fig. 2 shows both values in a primary co-ordinate system.

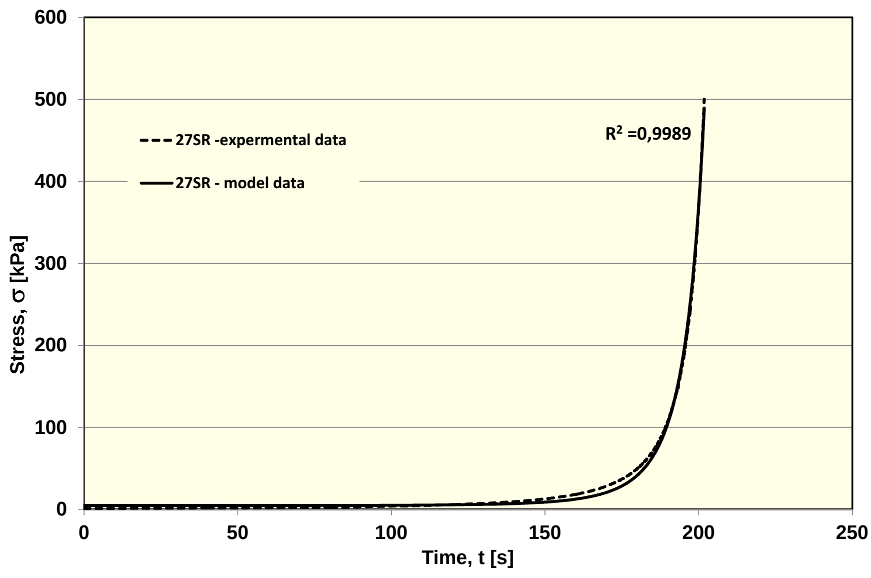

Fig. 2. Compression stress in function of time for experimental data and calculated from modified Kelvin-Voigt model

Determined in this way, the deviation between the experimental results and those resulting from the model is 0,86 kPa. For the low values of the compression stress, these are relatively high deviation values; however for values above 100 Pa, the error is in the region of per milles.

CONCLUSIONS

The developed mathematical model may be used for various pulp grades. The results obtained from the proposed model show strong correlation with the experimental data also for pulps with different refining degree. It speaks for the universal character of the presented mathematical model.

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Streszczenie: *„Badanie reologicznych właściwości struktur włóknistych"*
Artykuł zawiera informacje dotyczące pomiaru właściwości reologicznych mokrych struktur włóknistych z włókien celulozowych. Praca zawiera informacje dotyczące modelu matematycznego który może być zastosowany do opisu ściskania takich struktur.

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