Włodzimierz Szewczyk

Determination of the Elasticity Range of Paper

Technical University of Łódź
ul. Żeromskiego 116, 90-543 Łódź, Poland

Abstract
This research work presents a method for the determination of the limit of elasticity of paper considered as a variable dependent on stress and the time of its duration. For plane stress it was found that in the case of a low share of permanent strain in the total strain, we can assume that the highest value of its share appears on one of the principal axes of stress. Such an assumption allowed to use a one-dimensional rheological model to define the permanent range in a two dimensional state of stresses for paper.

Key words: *paper, limit of elasticity, orthotropy, viscoelastic material.*

Introduction

In this research work, the range of elasticity for any direction in paper denotes the limit determining the area in a two-dimensional space of time and stress, in which for engineering calculations the fibrous structure can be considered as elastic material.

It should be emphasised that the limit determined in this way differs from the limit of elasticity (determined for elastic materials), that is, a material constant defining a boundary value of the stress above which the material cannot be considered as elastic.

Determination of the limit of elasticity using the unidirectional tensile test in a short period of time is justified for materials for which longer applied stress does not cause any noticeable increases in the permanent strain.

In such a case, regardless of changes in stress over time, the limit of elasticity is connected with the appearance of a specific stress value that causes specific values of the permanent strain. In other words, provided that the material is under the influence of stress, whose values does not exceed the limit of elasticity, we can use Hooke's law to analyse the material's behaviour.

However, for fibrous materials these type of analyses cannot be used to describe the specific state of stress without considering the impact of time. For paper under stress of a high level, the increase of the time of action even by several dozens of seconds, may cause a significant growth in the permanent strain. (***Figures 2*** and ***3***).

Viscoelastic strains (also known as delayed elastic strains) in paper, which disappear when the load is removed, are classified as elastic strains for the purpose of range of elasticity determination for paper. Such a strain classification allows to have clear categories in terms of the problem analysed.

As paper is an anisotropic body, the range of elasticity, defined as a stress-time function, is different for various directions in the material. The anisotropy of the mechanical properties of a fibrous structure and the impact of time on stress - strain relationships make it difficult to determine the range of elasticity of paper. For this reason, the method suggested is restricted only to the most common types of loading.

A large majority of loads occurring in practice cause a uni- or bi-directional state of stress in the paper plane. A typical example of a unidirectional state of stress is the paper web. When moving in the machine during the converting process, it is subjected to tensile stresses of varying values in the machine direction. In the case of paper laminates used for the production of packaging, such as corrugated board or multilayer solid board, we usually analyse their strength under a static load considering uni- or bi-directional states of stress in each layer of the material. It should also be stated that in typical states of stresses in paper, the principal axes of stress do not change position towards the main orthotropy directions in the material; they usually overlap.

This work will analyse plane stress in a co-ordinate system with directions consistent with the principal axes of stress in a paper plane. This fact allows us to develop a method for the determination of an range of elasticity for paper, which is simple in practical use.

Criterion for determination of an range of elasticity for paper

In any type of forced change (load changes in time), the number of permanent changes in the fibrous structure increases with an increase in the stress level and stress application time. A permanent strain can only be registered in the case of a very low stress level and short application time, which does not mean that in such a case permanent strain does not occur. For low stresses and short time of their application, the permanent strains are so low that for technical reasons it is difficult to determine their values. Even for stresses lower than 20% of the breaking stress, when, according to some researchers [1], permanent strains do not appear, they can be observed provided that the load application time was long enough.

Despite the fact that each stress is accompanied by a permanent strain, in many cases its impact on paper behaviour is so minor that, from a practical point of view, it can be disregarded, hence paper can be treated as if it was a elastic material.

In engineering calculations, as criterion for the determination of an range of elasticity for paper, we may take a specific value of the permanent strain in the total strain below which paper will be considered as an elastic body.

When restricting the discussion to the plane stress appearing in the paper plane, such criterion can be formulated : If, as a result of loading, for any direction in the paper plane, there does not appear a state in which the share of permanent strains in the overall strains is higher than the assumed value defining the range of elasticity, the paper can be considered as an elastic body.

For various materials (including metal) the range of elasticity and the limit of proportionality are determined on the basis of the share of permanent strain in the overall strain. It is agreed that an acceptable share of the permanent strain determining the limit of proportionality of such materials as steels is 0.02% [2]. For paper, which has a significantly less homogeneous structure, is characterised by a lower repeatability of mechanical properties and as a result of mechanical loading it can be strained much more easily, the acceptable share of permanent strain defining the range of elasticity may be significantly higher.

Determined in the same conditions for various test pieces made of one paper grade, the breaking stress often exceeds the limit ± 10% of the average value. Even a higher scatter of results is obtained when determining the elongation at rupture or breaking energy. With such a heterogeneity of the material, when determining the range of elasticity it is accepted to estimate the share of permanent strain in the overall paper strain at a level of several percent, As with analyses of strains this will not cause errors higher than those which result from the determination of the inaccuracy of material constants.

Paper is an anisotropic body, which significantly complicates analysis of its strains, particularly in the case of complex states of stress, variable in time.

The strains of different types of paper and board under stress have been analysed in numerous research works. Some examples are listed from [3] to [15]. However, those works were focused mainly on unidirectional states of stress.

Research works analysing bidirectional states of stress in paper usually examined paper as an elastic body. Very few works [4] have tried to take into consideration the impact of the loading time. Presently, one-dimensional rheological models are used to describe paper behaviour in practice. They are usually 4-parameter-models.

This research work describes the strains in a system of axes connected with the directions of principal stresses, provided that they do not change position towards the main axes of paper orthotropy in the time of the test. With this type of coordinate system, there are only principal stresses in the directions of the system axis.

Subsequent parts of this research work show that in the case of a low share of permanent strains in the overall strains, it can be assumed (without any serious error) that the largest value of the share of permanent strain in the overall strains occurs for one of the principal stress directions in the paper plane. After having considered the strains in the direction perpendicular to the stress, such an assumption allows us to use a one-dimensional rheological model when determining the range of elasticity of paper in a bidirectional state of stress.

Determination of the share of permanent strain in the overall paper strain

This research work presents a determination method for the share of permanent strains in the overall strains of paper for the most common plane stresses.

For any direction the α share Ud_α of permanent strains $\varepsilon_{t\alpha}$ in the overall paper strain $\varepsilon_{c\alpha}$ is expressed by the following relationship:

$$Ud_\alpha = \frac{\varepsilon_{t\alpha}}{\varepsilon_{c\alpha}}. \tag{1}$$

For a complex state of stresses in the paper plane, strain analysis can be made on the basis of the diagram shown in ***Figure 1***.

The diagram depicts the strain of segment *l,* reaching length *l'* under the stress. Assuming that $\Delta\alpha \approx 0$, the elongation Δl_α of segment *l*,sloping towards axis *x* at angle α*,* can be expressed by the following relationship:

$$\begin{gathered}\Delta l_\alpha = l' - l = -l + \\ + \sqrt{(l\cdot\cos(\alpha)+\Delta x)^2 + (l\cdot\sin(\alpha)+\Delta y)^2}\end{gathered} \tag{2}$$

The elongation for the principal axes of stress (*x* and *y*) can be expressed by the following relationships:

$$\Delta x = \varepsilon_x \cdot l \cdot \cos(\alpha), \tag{3}$$

$$\Delta y = \varepsilon_y \cdot l \cdot \sin(\alpha), \tag{4}$$

Assuming that under the stress the principal axes of stress *x* and *y* do not change position towards the main directions in the paper, using relationships (2), (3) & (4), the elongation in direction α can be determined by the following formula:

$$\begin{gathered}\Delta l_\alpha = -l + \\ + l\cdot\sqrt{[\cos(\alpha)\cdot(1+\varepsilon_x)]^2 + [\sin(\alpha)\cdot(1+\varepsilon_y)]^2}\end{gathered} \tag{5}$$

Using formula (5), for direction α the overall elongation Δlc_α and the permanent elongation Δlt_α can be determined from the following relationships:

$$\begin{gathered}\Delta lc_\alpha = -l + \\ + l\cdot\sqrt{[\cos(\alpha)\cdot(1+\varepsilon_{cx})]^2 + [\sin(\alpha)\cdot(1+\varepsilon_{cy})]^2}\end{gathered} \tag{6}$$

$$\begin{gathered}\Delta lt_\alpha = -l + \\ + l\cdot\sqrt{[\cos(\alpha)\cdot(1+\varepsilon_{tx})]^2 + [\sin(\alpha)\cdot(1+\varepsilon_{ty})]^2}\end{gathered} \tag{7}$$

The share Ud_α of the permanent strain $\varepsilon_{t\alpha}$ in the overall strain $\varepsilon_{c\alpha}$ is defined by the relationship:

$$\begin{gathered}Ud_\alpha = \frac{\varepsilon_{t\alpha}}{\varepsilon_{c\alpha}} = \frac{\dfrac{\Delta lt_\alpha}{l}}{\dfrac{\Delta lc_\alpha}{l}} = \\ = \frac{1-\sqrt{[\cos(\alpha)\cdot(1+\varepsilon_{tx})]^2 + [\sin(\alpha)\cdot(1+\varepsilon_{ty})]^2}}{1-\sqrt{[\cos(\alpha)\cdot(1+\varepsilon_{cx})]^2 + [\sin(\alpha)\cdot(1+\varepsilon_{cy})]^2}}\end{gathered} \tag{8}$$

Denoting the share of permanent strain in the overall strain as Ud_x for axis *x* and Ud_y for axis *y* and taking into account that:

$$Ud_x = \frac{\varepsilon_{tx}}{\varepsilon_{cx}}, \tag{9}$$

$$Ud_y = \frac{\varepsilon_{ty}}{\varepsilon_{cy}}, \tag{10}$$

the share of permanent strain in the overall strain for direction α can be expressed by the formula 11:

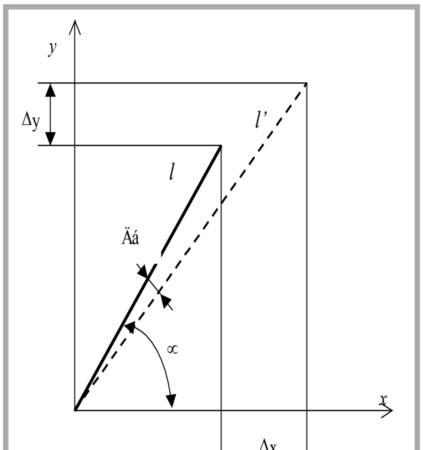

Figure 1. *Diagram of segment l displacement as a result of plane's state of stress.*

In order to find a maximal value of permanent strains in the overall strain, changes Ud_α in function α have to be analysed. Precise analysis of the strain distribution in the paper plane can be made in specific cases after substituting the specific values of parameters Ud_y, Ud_x, $\varepsilon_{c\,x}$ i $\varepsilon_{c\,y}$.

As the values of parameters Ud_y, Ud_x, $\varepsilon_{c\,x}$ and $\varepsilon_{c\,y}$ are around several percent, not making any significant error, we can develop relationship (11) into a Taylor series. Including only the first term, we have:

$$Ud_\alpha \approx$$

$$\approx \frac{Ud_x \cdot \varepsilon_{cx} \cos^2(\alpha) + Ud_y \cdot \varepsilon_{cy} \sin^2(\alpha)}{\varepsilon_{cx} \cos^2(\alpha) + \varepsilon_{cy} \sin^2(\alpha)} \qquad (12)$$

Evaluating the first derivative Ud_α (12) at α, we obtain:

$$\frac{d}{d\alpha} Ud_\alpha =$$

$$= \frac{2 \cdot \varepsilon_{cx} \cdot \varepsilon_{cy} \cdot \left(Ud_y - Ud_x\right) \cdot \sin(\alpha) \cdot \cos(\alpha)}{\left[\left(\varepsilon_{cx} - \varepsilon_{cy}\right)\cos^2(\alpha) - \varepsilon_{cy}\right]^2} \qquad (13)$$

In the examined range of variation $\alpha\ \langle 0, \pi/2 \rangle$, the derivative reaches value 0 at the ends of the range. Therefore, the maximal value $Ud_{\alpha\ max}$ equals the higher value of Ud_y and Ud_x, what can be expressed by:

$$Ud_{\alpha\ \max} = \max(Dd_x, Ud_y) \qquad (14)$$

This means, without significant error, that we can assume that the highest share of permanent strains in the overall strain appears in one of the principal axes of stress in the paper plane.

Calculation of paper strains in a unidirectional state of stresses

A simple unidirectional state of stress is very common in practice during paper manufacture, converting and utilisation. Using the relationships describing strains in the form of a time and stress function for Burgers rheological model, assuming that in the initial moment $t = 0$ strains equal to 0, we obtain a formula that allows us to define the overall paper strain $\varepsilon_{cj\,x}$ in a unidirectional state of stress towards axis x [12]:

$$Ud_\alpha = \frac{1 - \sqrt{\left[\cos(\alpha) \cdot \left(1 + Ud_x \cdot \varepsilon_{c\,x}\right)\right]^2 + \left[\sin(\alpha) \cdot \left(1 + Ud_y \cdot \varepsilon_{c\,y}\right)\right]^2}}{1 - \sqrt{\left[\cos(\alpha) \cdot \left(1 + \varepsilon_{cx}\right)\right]^2 + \left[\sin(\alpha) \cdot \left(1 + \varepsilon_{c\,y}\right)\right]^2}} \qquad (11)$$

Formula 11.

$$\varepsilon_{cjx} = \frac{\sigma_x(t)}{E_{1x}} +$$

$$+ \frac{1}{\eta_{2x}} \int_0^t \sigma_x(t - \theta) \cdot e^{-\frac{E_{2x} \cdot \theta}{\eta_{2x}}} d\theta + \frac{1}{\eta_{1x}} \int_0^t \sigma_x(\theta)\, d\theta \qquad (15)$$

where:

E_{1x}, E_{2x}, η_{1x}, η_{2x} – rheological parameters of Burgers model for axis x,

θ – integration variable.

If the strains towards axis x are constant and have value σ_{xo}, substituting relationship $\sigma_x(t) = \sigma_{xo}$ to formula (15), after the reduction we have:

$$\varepsilon_{cjx}\left(t\right) = \frac{\sigma_{xo}}{E_{1x}} + \frac{\sigma_{xo} \cdot t}{\eta_{1x}} + \frac{\sigma_{xo}}{E_{2x}}\left(1 - e^{-\frac{E_{2x} \cdot t}{\eta_{2x}}}\right) \qquad (16)$$

The permanent strain of Burgers model $\varepsilon_{tj\,x}$ for unidirectional states of stress towards axis x is described by the third addend in formula (15).

If the stresses towards axis x are constant and have value σ_{xo}, we get:

$$\varepsilon_{tjx}\left(t\right) = \frac{\sigma_{xo} \cdot t}{\eta_{1x}}. \qquad (17)$$

Carrying out the analogical operation, we can define the strains for any direction in the paper plane.

Calculation of paper strains in bidirectional states of stress

When defining the range of elasticity, calculations are made in the range of strains in which paper may be considered as an elastic body. In such a case, in a bidirectional state of stress, the overall strains in the principal axes of stresses $\varepsilon_{c\,x}$ and $\varepsilon_{c\,y}$ in the paper plane can be calculated using the relationships which are valid for the elastic body:

$$\varepsilon_{c\,x} = \varepsilon_{cj\,x} - \nu_{xy} \cdot \varepsilon_{cj\,y} \qquad (18)$$

$$\varepsilon_{c\,y} = -\ \nu_{yx} \cdot \varepsilon_{c\,jx} + \varepsilon_{c\,jx} \qquad (19)$$

where:

ν_{xy},ν_{yx} – Poisson's ratios (the first index defines the direction of transverse strain, and the other one – the direction of the stress which triggers off the strain).

According to the assumed relationship for range of elasticity evaluation, two types of strains making up the overall paper strain were distinguished. With this assumption, in a bi-dimensional state of stress, the overall strains in the principal axes of stresses $\varepsilon_{c\,x}$ and $\varepsilon_{c\,y}$ in the paper plane can be calculated with formulas:

$$\varepsilon_{c\,x} = \varepsilon_{t\,x} + \varepsilon_{s\,x} \qquad (20)$$

$$\varepsilon_{c\,y} = \varepsilon_{t\,y} + \varepsilon_{s\,y} \qquad (21)$$

where:

$\varepsilon_{t\,x}$, $\varepsilon_{t\,y}$ – permanent strain in the principal axes of stress,

$\varepsilon_{s\,x}$, $\varepsilon_{s\,y}$ – elastic strain in the principal axes of stress.

In a bidirectional state of stress, the elastic strain in the principal axes of stress $\varepsilon_{s\,x}$ and $\varepsilon_{s\,y}$ in the paper plane can be calculated using the correct relationships for the elastic body:

$$\varepsilon_{s\,x} = \varepsilon_{sj\,x} - \nu_{xy} \cdot \varepsilon_{sj\,y} \qquad (22)$$

$$\varepsilon_{s\,y} = -\ \nu_{yx} \cdot \varepsilon_{s\,jx} + \varepsilon_{s\,jx} \qquad (23)$$

Rearranging (20) and (21), we get:

$$\varepsilon_{t\,x} = \varepsilon_{c\,x} + \varepsilon_{s\,x} \qquad (24)$$

$$\varepsilon_{t\,y} = \varepsilon_{c\,y} + \varepsilon_{s\,y} \qquad (25)$$

After substituting (18), (19), (22) and (23) to (24) and (25) we get relationships allowing us to determine the permanent strains in a state of bidirectional stress in the principal axes of stresses $\varepsilon_{c\,x}$ and $_{c\,y}$ in the paper plane:

$$\varepsilon_{t\,x} = \varepsilon_{cj\,x} - \nu_{xy} \cdot \varepsilon_{cj\,y} + \\ -\ (\varepsilon_{sj\,x} - \nu_{xy} \cdot \varepsilon_{sj\,y}) \qquad (26)$$

$$\varepsilon_{t\,y} = -\ \nu_{xy} \cdot \varepsilon_{cj\,x} + \varepsilon_{cj\,y} + \\ -\ (-\ \nu_{yx} \cdot \varepsilon_{sj\,x} + \varepsilon_{sj\,y}) \qquad (27)$$

Comparison between experimental and theoretical results of range of elasticity determination

In order to determine the paper range of elasticity, tests were carried out on paper used for the production of corrugated board.

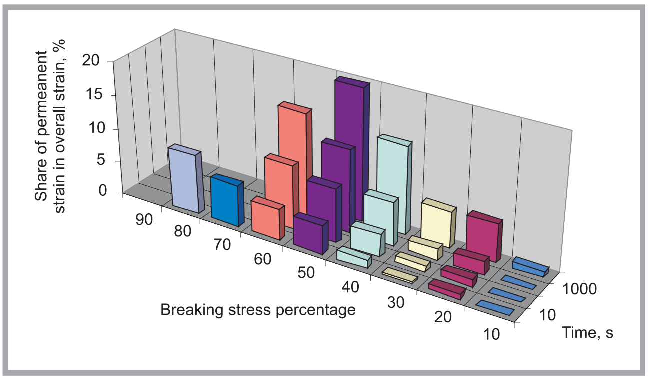

Figure 2. *Share of permanent strains in the overall strains for the teste paper in the machine direction.*

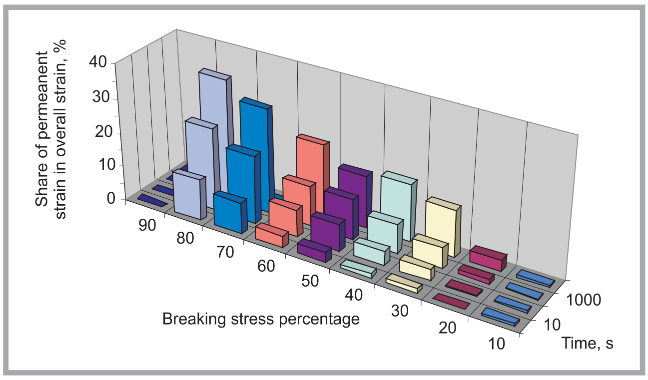

Figure 3. Share of permanent strains in the overall strains in the cross direction for the paper tested.

Because of the similarity between the results obtained for the paper tested, the article presents only results obtained for a liner of grammage 220 g/m^2 and thickness 0.35 mm for the machine and cross directions. The tests included the measurement and calculation of the overall strains and permanent strains depending on the level and time of the stress applied. The stresses varied from 10% to 90% of the breaking stress and the application time from 1 s to 10000 s.

The tests involved stretching paper to the stress value required at a speed of 20 mm/min, holding the stress for 1 second and then reducing the stress value to 0. After having waited 20 minutes, the cycle was repeated, increasing the time of the test piece held under the load ten times. Five cycles were performed for each test piece (provided it did not break), which means that in the last cycle the creep time was 1000 s. The first cycle was treated as mechanical conditioning.

The overall strains and permanent strains were determined for all the stress times and levels tested.

Calculation results for the share of permanent strains in the overall paper strains for all the cases tested are illustrated in ***Figures 2*** & ***3***.

In the range of stresses and times of application tested, the share of permanent strains in the overall strains is higher for the cross direction than for the machine direction. The higher values of permanent strains in the cross direction result from the orientation of fibres in the paper web.

The area, for which the values of paper strains could not be determined because of the test pieces breaking, is higher for the machine direction. For the time range of stress application tested, in the case of the machine direction, the test pieces broke at 60% of the breaking stress determined in a standard tensile test, whereas for the cross direction it was at 70% of the breaking stress. Both in the machine direction and cross direction, the state of permanent strain in the overall strain grows along with an increase in the stress and its application time. In order to determine the range of elasticity of the paper in a bidirectional state of stress, the results of strain measurements were used, which were obtained in the tests described above, as well as the results of calculations obtained with the Burgers model. Using the rheological parameters of the Burgers model of the paper tested, determined on the basis of the creep test, in accordance with the method presented here [16], the values of the overall strains and permanent strains for the levels of stress analysed, their application times in the machine and cross directions were calculated. Formulae (16) and (17) were used to calculate the strains. The share of permanent strains in the overall strains were determined using values of the strains calculated and measured with relationships (9) and (10).

On the basis of the calculation and measurement results, the range of elasticity of the paper was determined for two areas in which the levels of the permanent strains in the overall strains do not exceed 2% and 10%.

Results of the measurements and calculations are presented in ***Figures 4*** and ***5***.

Both for the machine and cross directions, the values of permanent strains in theoverall strains theoretically calculated do not depend on the stress level, which can be easily proved by substituting relationships (16) and (17) to formula (9), and after the reduction we have:

$$Ud_x(t) = \frac{t}{\eta_{1x} \cdot \left[\frac{1}{E_{1x}} + \frac{t}{\eta_{1x}} + \frac{1}{E_{2x}} \left(1 - e^{-\frac{E_{2x} \cdot t}{\eta_{2x}}} \right) \right]} \tag{28}$$

As ***Figures 2 - 5*** show, relationship (28) (valid for the Burgers model) does not correspond with the real paper behaviour. This inconsistency results from the imperfection of matching between the model and the material described. This is one of the reasons for the differences between the real and theoretically determined area of elasticity of the paper, as shown in ***Figures 4*** and ***5***. These differences also result from the measurement and calculation errors of the model's rheological parameters. The presented measurement and calculation results of the range of elasticity of paper show that theoretical determination of the limit using the Burgers model1) may contain a serious error.

The measurement results obtained prove that in the case of very short loading times, the paper may be considered as an elastic body in the entire range of stresses, including damage.

With the low levels of stress at 30% of the breaking stress, the paper pieces tested maintained the properties of an elastic body for a time of 1000 s, and for the lowest level of stress tested - even to 10 000 s.

On the basis of measurement results of the strain in the machine direction and cross direction, using relationships (18), (19), (26) and (27), the elasticity areas of the paper tested were determined for selected stress levels during a bidirectional state of loading in its plane. The

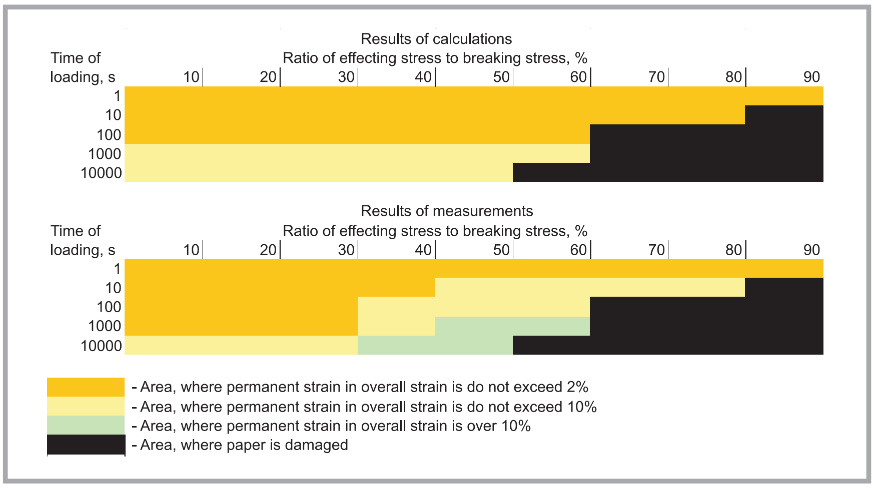

Figure 4. *Elasticity areas of the test paper under tensile forces in the machine direction.*

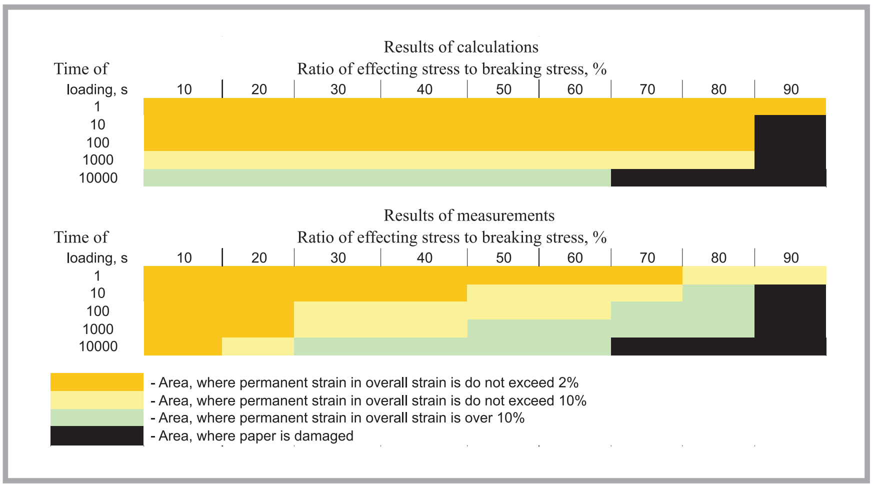

Figure 5. *Elasticity areas of the test paper under tensile forces in the cross direction.*

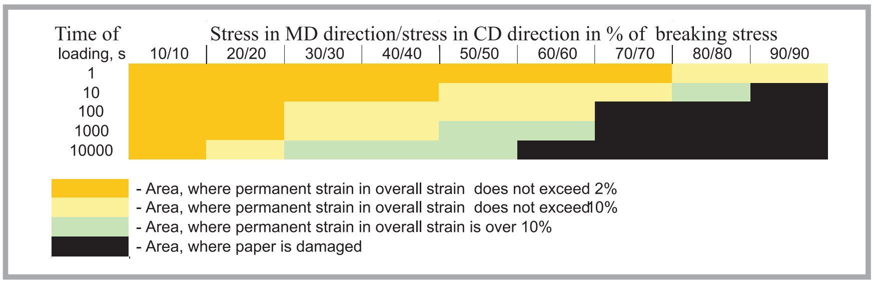

Figure 6. *Elasticity areas of test paper in a bidirectional state of stress s with different stress values (different in relation to the breaking stress in a given direction) for both directions of principal stress in the paper plane.*

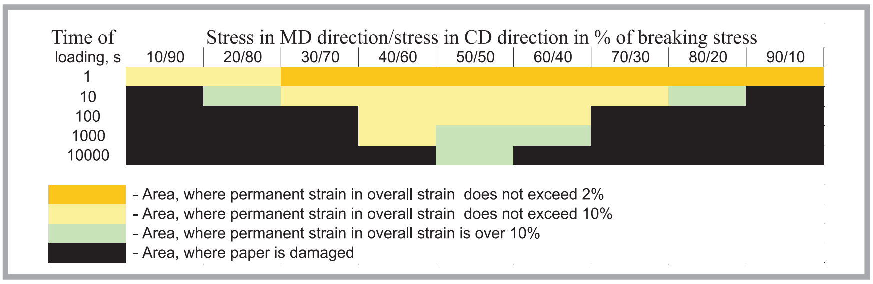

Figure 7. *lEasticity areas of test paper in a state of bidirectional stress with the same stress levels (the same in relation to breaking stress in a given direction) for both directions of principal stress in the paper plane.*

elasticity area of paper was determined for a case in which the principal axes of stress overlap with the machine direction and cross direction. The stress levels for both directions were determined as a percentage of the breaking stress determined for a given direction in a unidirectional standard tensile test. ***Figures 6*** and ***7*** show calculation results of the ranges of elasticity of the test paper for a share of the permanent strain in the overall strain of 2% and 10%.

In complex states of stress in the paper plane, as for unidirectional stresses, in cases of short application times, the fibrous material may be considered as an elastic body, practically until the moment of breaking.

If, for both principal axes of stress, the stress values (in relation to the breaking stress in a given direction) are identical, the range of elasticity of the material is similar to the unidirectional state of stresses.

Conclusions

1) In engineering calculations for short times (several seconds) of stresses applied, even if their value is close to the breaking stress), the papers and boards may be considered as elastic bodies.

2) In the case of low stress levels (up to around 20% of the breaking stress), we do not make serious errors when treating paper and the board as elastic bodies, even if the time of stresses applied is long, e.g. 10 000 s.

3) In stress states of the plane, we can assume that the maximal share of the permanent set in the overall strain appears in one of the principal stress directions in the paper plane. On the basis of the strains in this direction, we can determine whether the range of elasticity of paper is exceeded in a given state of stress.

Editorial note

1) *Problems connected with the selection of a rheological model which better reflects paper behaviour are discussed in a separate research project going beyond the subject of this article, where the model is used as a tool describing various types of strain.*

References

1. Brecht W., Göttsching L., Baumgarten H. L.; „Beiträge zur Rheologie des Papiers". Das Papier 25, nr 10, 1971 pp. 569-582.
2. Magnucki K., Szyc W.; „Wytrzymałość materiałów w zadaniach. Pręty, płyty i powłoki obrotowe". Wyd. Nauk. PWN, Warszawa-Poznań, 1999 p. 28.
3. Uesaka T., Murakami K., Imamura R.; „Biaxial tensile behaviour of paper". Tappi J 62 (8), 1979 pp. 111-114.
4. Marcinkowski M.; „Analiza własności mechanicznych papieru w oparciu o dwuwymiarowy model reologiczny". Praca doktorska, Politechnika Łódzka, Łódź, 2000.
5. Frołow M. B.; „Strukturalnaja mechanika bumagi", Moskwa, 1982, pp.15-18.
6. Vargic L., Bakos D.; „Kompozitnè materiály na báze papièra". Papir a celulóza 45, nr 6, 1990 pp. 35-38.
7. Ivarsson B.; "Paper as a Viscoelastic-Body. VI – Mechanical Conditioning of Paper and Interpretation of Stress-Strain curves". Svensk Papperstidn. 51 (17), 1948 pp. 383-388.
8. Stenberg N., Fellers C., Östlund S.; „Measuring the Stress-Strain Properties of Paperboard in the Thickness Direction". Journal of Pulp and Paper Science 27, nr 6, 2001 pp. 213-221.
9. Gullichsen J., Paulapuro H.; "Papermaking Science and Technology. Book 16, Paper Physics". Fapet Oy, Helsinki, 2000, pp.151-161.
10. Stachowicz S., Kamieńska M.; „Opakowania z tektury falistej". Opakowanie, 11, 2005 p. 36.
11. Urbanik T. J.; "Method analyses analogue plots of paperboard stress-strain data". Tappi 65, nr 4, 1982 pp. 104-108.
12. Stera S.: „Wpływ procesu wykończania papieru na użytkowe oraz strukturalno-reologiczne własności papieru workowego". Praca habilitacyjna, Politechnika Łódzka, 1981.
13. Rance H. F.; "The formulation of methods and objectives appropriate to the rheological study of paper". Tappi 39, nr 2, 1956 pp. 104-115.
14. Andersson O., Sjöberg L.; "Tensile studies of paper at different rates of elongation". Svensk Papperstidn. 56, nr 16, 1953 pp. 615-624.
15. Fulmański Z.: „Badania nad własnościami reologicznymi warstw papieru poddanych działaniu naprężeń ściskających oraz wykorzystanie wyników tych badań w procesie wykonywania elastycznych walców kalandrowych". Praca doktorska, Politechnika Łódzka, Łódź, 1984.
16. Szewczyk W., Marynowski K., Głowacki K.; "Experimental Identification of the Rheological Model of Paper". Przegląd Papierniczy, 64, nr 3, 2008 pp.157- 160.

Received 07.10.2009 Reviewed 06.01.2010

13th International Triennial of Tapestry, Łódź 2010

Opening of the Main Exhibition: **10th of May 2010 at 1.00 p.m.**
The exhibition will be on show till the **31st of October 2010**

General organiser: Central Museum of Textiles, Łódź, Poland

Norbert Zawisza, Chairman of the Programming Board of the International Triennial of Tapestry in Łódź and Director of the Central Museum of Textiles, appointed the Programming Board of the 13th International Triennial of Tapestry, Łódź 2010. Outstanding representatives of the Polish textile art community, Central Museum of Textiles, Łódź, Poland – organiser of the event, organisers of important events associated with the 13 International Triennial of Tapestry, standing sponsors of the event are its members: Liliana Andrzejczak, Krystyna Dyrda-Kortyka, Elżbieta Fuchs, Dorota Grynczel, Wojciech Jaskółka, Aurelia Mandziuk, Teresa Michałowska, Marcin Oko, Krystyna Onak, Jolanta Piwońska (Secretary), Małgorzata Siwek, Małgorzata Wróblewska-Markiewicz, Norbert Zawisza.

Participants from the following 51 countries will take part in the 13th Triennial: Argentina, Australia, Belgium, Bolivia, Brazil, Bulgaria, Canada, Chile, PR China, Croatia, Cyprus, Czech Rep., Denmark, Estonia, Finland, Finland, France, Georgia, Germany, Great Britain, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Korea South, Latvia, Lithuania, Mexico, Moldova, The Netherlands, New Zeland, Norway, Peru, Poland, Romania, RSA, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan, Turkey, Ukraine, USA.

National consultants together with the programming board have selected 138 participants from the countries mentioned above.

In 2010 the International Triennial of Tapestry will be accompanied by other international, national, regional and one-man shows. Due to their artistic level and character, the Programming Board of the 13th International Triennial of Tapestry has decided to grant them the title of ‚exhibition/event associated with the 13th international Triennial of Tapestry'. The most important are the following: 8th International Baltic Triennial of Miniature Textiles, VI International Biennial of Linen Art Textiles ‚From the loom to Loom', XXXVII International Symposium ‚Creative Workshop – Kowary' within the framework of the Fibre Art Festival in Lower Silesia, III International Textile Art Festival in Cracow, 11th National Exhibition of Polish Tapestry, 9th National Exhibition of Polish Miniature Textiles, and many others.

It is our intention to make the future events more versatile and imposing than the triennial in 2007.
Hereby we would like to request prompt submission of proposals. The entry should contain a description of the character of the event (exhibition, retreat, show), the final version of the title, names of main organisers, name of the curator as well as data of contact, place (name of institution and its full address), and duration (day and hour of opening, closing date).

Thank you
Norbert Zawisza
Chairman of the Programming Board
of the 13th International Triennial of Tapestry

Contact:

Organizational bureau:
Jolanta Piwońska: j.piwonska@muzeumwlokiennictwa.pl
Barbara Ziemnicka–Darnowska: b.darnowska@muzeumwlokiennictwa.pl