628. Analysis of vibrations and stability of flock printing material

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Abstract. The problem of plane strain is analyzed by assuming a single layer of Lagrange quadratic elements with linear variation of the modulus of elasticity and of the density, assuming that both of them take zero values on the upper surface of the structure. The first eigenmodes are calculated. Investigation of the problem of initial stability is performed as well. On the basis of results of numerical investigations an experimental method for non-destructive evaluation of defects is proposed and it is applied for qualitative evaluation of the status of flock material and in the process of design of the elements of packages made from flock material.

Keywords: flock printing material, vibrations, plane strain, eigenmode, finite elements, initial stability, stability eigenmode, quality control, non-destructive evaluation, quality of flock material, experimental procedure.

Introduction

In recent years flock materials find wider and increasing applications. Due to more beautiful aesthetic view such materials are used for production of exceptional packages, specific clothing materials and other products [1].

The glued flock is the distribution of small particles (flock) in the glue layer on a background material. Flock may be produced from materials of various types and glued to the surface of the material in several different ways. The production process of flock material may be implemented on the surfaces of various materials (paper, paperboard, film, plastic and others) by using the mechanical (see Fig. 1a) or electrostatical (see Fig. 1b) methods and also by the simultaneous application of both methods [2].

The process of flock gluing in all cases consists from the following constituent technological processes [3]:

- pasting of the glue composition on the surface of the material;
- process of the gluing of flock – distribution of flock in the layer of glue on the surface of the material;
- removal of the remains of the flock that has not adhered to the surface;
- drying of flock and its fastening in the layer of glue.

When there are violations at least in one of the constituent technological processes the product with defect is produced – the background material is inappropriately coated with a layer of glue and also by the flock. The plies may be incorrectly located, glued together with one another, possess inappropriate shape and may have other similar defects (see Fig. 2a and Fig.2b). It is known that the quality of the product depends not only on the suitability of the constituent technological processes. The materials used in the process have great influence to the quality of the product: the type of the glue and the flock itself (see Table 1) [1].

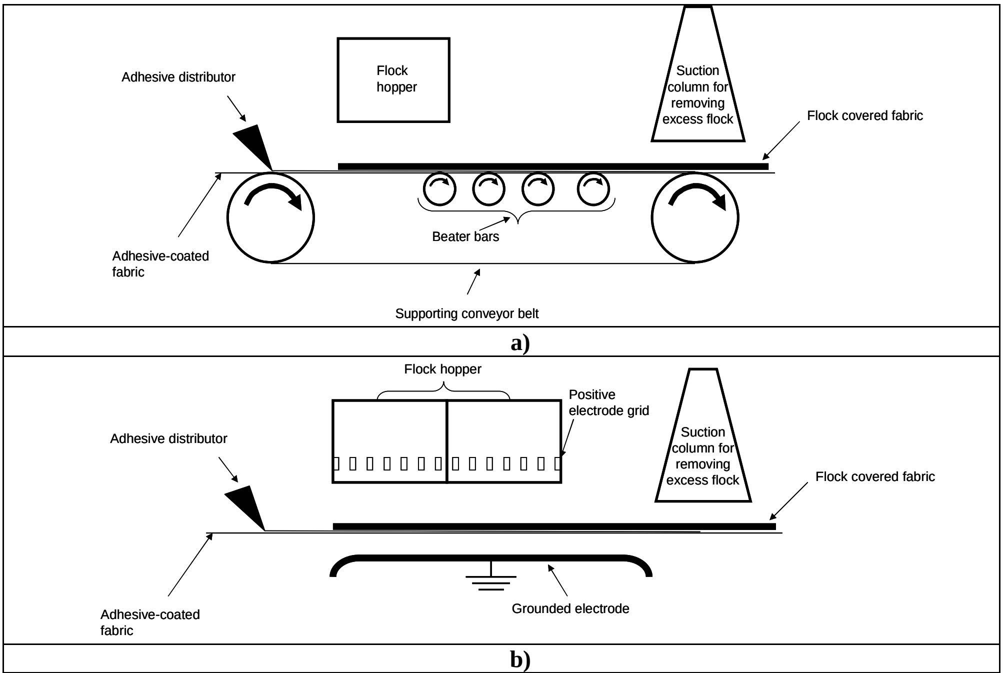

Fig. 1. Simplified diagram of the technological process of flock gluing: a) flock gluing by applying the vibrational method; b) flock gluing by applying the electrostatic method

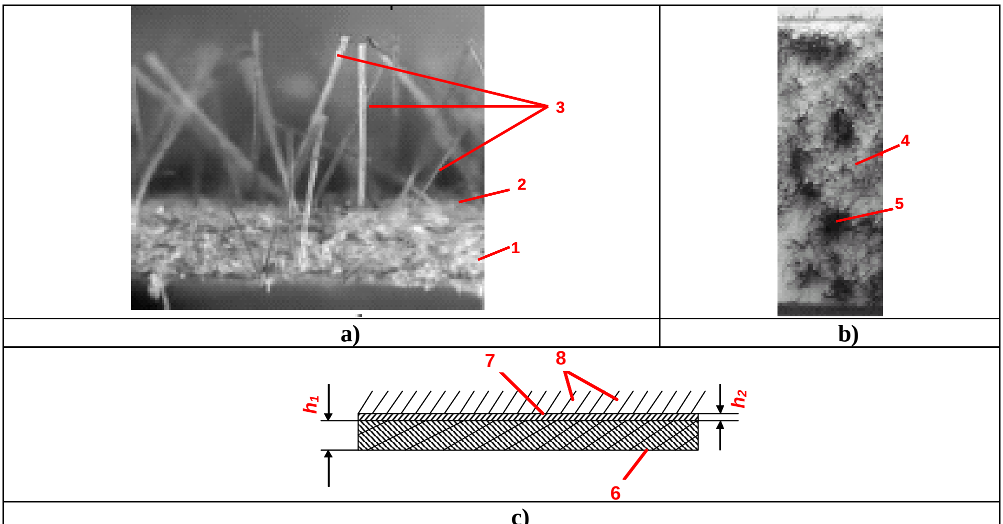

Fig. 2. Images of the background material with the glued flock: a) image of the material with glued flock enlarged by the electronic microscope, where 1 – the background material, 2 – the layer of glue, 3 – the glued flock; b) the defects observed by using the electronic microscope, where 4 – the background fully coated by flock, 5 – area of the background not coated by flock; c) simplified diagram of the material with glued flock, where 6 – the tape of paper, 7 – the layer of glue, 8 – the flock, h_1 – thickness of the paper, h_2 – thickness of the layer of glue

Flock may be produced from natural as well as synthetic materials, such as cotton, viscose, polyester, nylon and various other materials. Flock may be produced in two ways:

- milled;
- cut (sawed) (see Table 1).

The milled flock is produced from cotton or from synthetic materials of a second sort. While the cut (sawed) – only from the threads of synthetic material of the highest quality [4].

In [5-7] the successful application of the electro-flocking technology for coating of the surface of paper by flock is analyzed. It is fairly expensive to produce paper coated by flock, but the looks are exceptionally beautiful and may be used for packaging of presents and souvenirs.

Table 1. Characteristics of the flock printing materials

Material	Type of flock	Flock length, mm	Flock thickness, μm	Characteristic
Cotton	Milled	Not uniform	0,7-30,3	Lowest in cost and the softest, but has the least abrasion and wear resistance
	Cut	0,3-5		Least abrasion and wear resistance
Rayon	Milled	Not uniform		Normal resistance to abrasion
	Cut	0,3-5		Least expensive with the least wear resistance
Polyester	Milled	Not uniform		Basically used for industrial applications
	Cut	0,3-5		Basically used for industrial applications
Nylon	Milled	Not uniform		The best wear resistance
	Cut	0,3-5		The best grade of flock and produces a good feel, but most expensive

In [8-10] the authors with the electronic microscope investigated the influence of the structure of the surface of the paper and paperboard on the flock type and its parameters as well as on various additives in the coated material to the orientation of the glued flock.

In [11,12,16] vibrations of non-defected and defected paper and paperboard have been investigated and the method of non-destructive diagnostics that evaluates the quality of the material has been proposed. The research paper [13] also has definite relation with this research work.

The vibrations and stability of the material with glued flock are investigated in the present study. The method of non-destructive testing for such materials is proposed. It takes into account the quality of coating of the glue layer, i.e. its non-uniformity is considered.

The problem of plane strain is analyzed by assuming a single layer of Lagrange quadratic elements with linear variation of the modulus of elasticity and of the density assuming that both of them acquire zero values on the upper surface of the structure. The analysis is based on the relationships described in [14, 15]. The first eigenmodes are calculated.

Also the problem of initial stability is investigated. Firstly, the static problem is solved by assuming the prescribed displacement of the lower right node in the negative direction of the x axis. Then stability is analyzed for the investigated structure because of the additional stiffness due to the static displacements determined beforehand.

The obtained results are important in the process of design of the elements of packages made from the flock printing material.

Model for the analysis of vibrations of flock printing material

Further x and y denote the axes of coordinates. The element has two nodal degrees of freedom: the displacements u and v in the directions of the axes x and y. ξ and η are the local coordinates of the finite element.

The mass matrix has the form:

$$[M] = \int [N]^T \left.\rho\right|_{\eta=-1} \frac{1-\eta}{2} [N] dxdy, \tag{1}$$

where $\rho|_{\eta=-1}$ is the density of the material on the lower surface of the structure and:

$$[N]=\begin{bmatrix} N_1 & 0 & \dots \\ 0 & N_1 & \dots \end{bmatrix}, \tag{2}$$

where N_i are the shape functions of the finite element.

The stiffness matrix has the form:

$$[K]=\int [B]^T \left[D|_{\eta=-1}\right]\frac{1-\eta}{2}[B]\,dxdy, \tag{3}$$

where:

$$[B]=\begin{bmatrix} \frac{\partial N_1}{\partial x} & 0 & \dots \\ 0 & \frac{\partial N_1}{\partial y} & \dots \\ \frac{\partial N_1}{\partial y} & \frac{\partial N_1}{\partial x} & \dots \end{bmatrix}, \tag{4}$$

$$\left[D|_{\eta=-1}\right]=\begin{bmatrix} K|_{\eta=-1}+\frac{4}{3}G|_{\eta=-1} & K|_{\eta=-1}-\frac{2}{3}G|_{\eta=-1} & 0 \\ K|_{\eta=-1}-\frac{2}{3}G|_{\eta=-1} & K|_{\eta=-1}+\frac{4}{3}G|_{\eta=-1} & 0 \\ 0 & 0 & G|_{\eta=-1} \end{bmatrix}, \tag{5}$$

where:

$$K|_{\eta=-1}=\frac{E|_{\eta=-1}}{3(1-2\nu)}, \tag{6}$$

$$G|_{\eta=-1}=\frac{E|_{\eta=-1}}{2(1+\nu)}, \tag{7}$$

where $E|_{\eta=-1}$ is the modulus of elasticity on the lower surface of the structure and ν is the Poisson’s ratio.

Results of analysis of vibrations of flock printing material

A rectangular structure meshed by a single layer of elements is analyzed. Displacements of the lower nodes on the left and right sides of the structure are assumed equal to zero. Length of the structure is 0.2 m and its height is 0.02 m. The following values of parameters are assumed: $E|_{\eta=-1}$ = 0.6·10^9 N/m^2, ν = 0.3, $\rho|_{\eta=-1}$ = 785 kg/m^3.

The first eigenmode is presented in Fig. 3, the second eigenmode is presented in Fig. 4, …, the sixth eigenmode is presented in Fig. 8.

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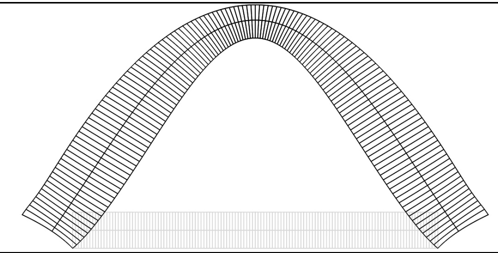

Fig. 3. The first eigenmode.

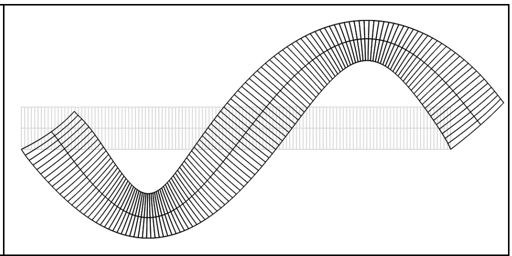

Fig. 4. The second eigenmode.

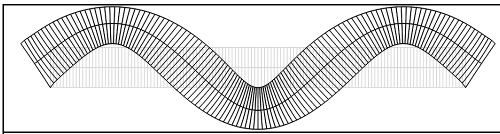

Fig. 5. The third eigenmode.

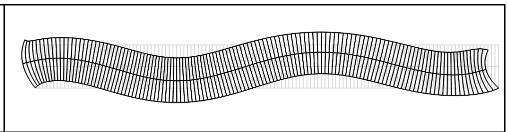

Fig. 6. The fourth eigenmode.

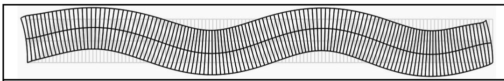

Fig.7. The fifth eigenmode.

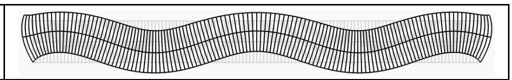

Fig. 8. The sixth eigenmode.

Model for the analysis of stability of flock printing material

Firstly, the static problem is solved by assuming the prescribed displacement of the lower right node in the negative direction of the x axis. Thus the loading vector is determined. Then the vector of displacements $\{\delta\}$ is calculated by solving the system of linear algebraic equations. In the second stage of the analysis the eigenproblem of stability of the structure with additional stiffness due to the static loading is solved.

The matrix of additional stiffness has the form:

$$[K_\sigma] = \int [G]^T \left[M\big|_{\eta=-1} \right] \frac{1-\eta}{2} [G]\, dxdy, \tag{8}$$

where:

$$[G] = \begin{bmatrix} \frac{\partial N_1}{\partial x} & 0 & \dots \\ 0 & \frac{\partial N_1}{\partial x} & \dots \\ \frac{\partial N_1}{\partial y} & 0 & \dots \\ 0 & \frac{\partial N_1}{\partial y} & \dots \end{bmatrix}, \tag{9}$$

$$\left[M\big|_{\eta=-1} \right] = \begin{bmatrix} \sigma_x\big|_{\eta=-1} & 0 & \tau_{xy}\big|_{\eta=-1} & 0 \\ 0 & \sigma_x\big|_{\eta=-1} & 0 & \tau_{xy}\big|_{\eta=-1} \\ \tau_{xy}\big|_{\eta=-1} & 0 & \sigma_y\big|_{\eta=-1} & 0 \\ 0 & \tau_{xy}\big|_{\eta=-1} & 0 & \sigma_y\big|_{\eta=-1} \end{bmatrix}, \tag{10}$$

where the stresses on the lower surface of the structure $\sigma_x\big|_{\eta=-1}$, $\sigma_y\big|_{\eta=-1}$, $\tau_{xy}\big|_{\eta=-1}$ are determined from the static problem:

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$$\begin{Bmatrix} \sigma_x\big|_{\eta=-1} \\ \sigma_y\big|_{\eta=-1} \\ \tau_{xy}\big|_{\eta=-1} \end{Bmatrix} = \left[D\big|_{\eta=-1} \right] [B] \{\delta\}. \tag{11}$$

Results of analysis of stability of the flock printing material

The first eigenmode of stability is presented in Fig. 9, the second eigenmode of stability is presented in Fig. 10, the third eigenmode of stability is presented in Fig. 11, the fourth eigenmode of stability is presented in Fig. 12.

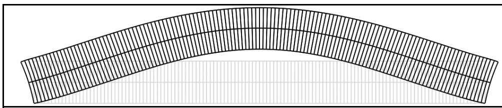

Fig. 9. The first stability eigenmode.

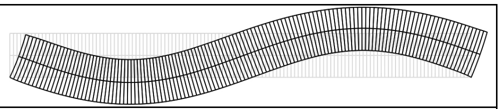

Fig. 10. The second stability eigenmode.

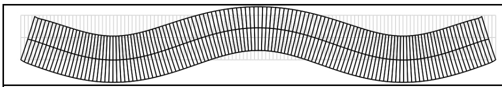

Fig. 11. The third stability eigenmode.

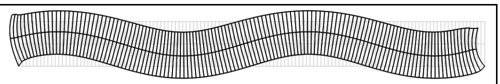

Fig. 12. The fourth stability eigenmode.

Analysis of vibrations of flock printing material with defect

As was described in the introduction of this paper, after violation of technological process of production of the material with glued flock defects may develop in the material (such as cracks of the layer of glue may occur, non-uniform distribution of flock in the layer of glue may take place and etc.). These defects may be investigated by applying the numerical model described previously.

The defect is located in the middle of the structure at its upper surface. The first eigenmode is presented in Fig. 13, the second eigenmode is presented in Fig. 14, …, the sixth eigenmode is presented in Fig. 18.

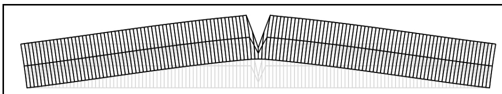

Fig. 13. The first eigenmode.

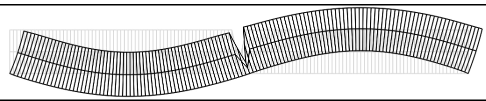

Fig. 14. The second eigenmode.

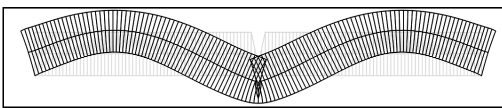

Fig. 15. The third eigenmode.

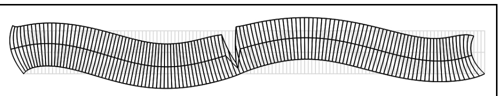

Fig. 16. The fourth eigenmode.

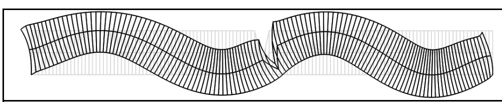

Fig. 17. The fifth eigenmode.

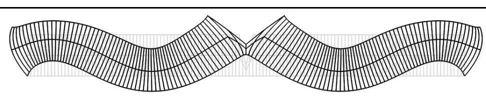

Fig. 18. The sixth eigenmode.

The obtained results of experimental investigation indicate that the character of some of the eigenmodes of vibrations under the influence of defect undergoes essential changes: for example the sixth eigenmode for the structure without defect (Fig. 8) and for the structure with the defect (Fig. 18) possess a fairly different character. Thus, though in the process of experimental investigation the defect itself may not be directly noticeable, but on the basis of essentially different character of the sixth eigenmode of vibrations it is possible to identify when the material is defected. For extensive study of such defects of material the experimental methods of speckle photography and time-averaged projection moiré are recommended.

Conclusions

The model for the analysis of vibrations of flock printing material is proposed by using the problem of plane strain and assuming a single layer of Lagrange quadratic elements with linear variation of the modulus of elasticity and of the density assuming that both of them take zero values on the upper surface of the structure. The first eigenmodes are obtained.

The problem of initial stability is investigated. Static problem was solved by assuming the prescribed displacement of the lower right node in the negative direction of the x axis. Then the first stability eigenmodes of the investigated structure are obtained considering the additional stiffness due to the static displacements determined in the previous stage of analysis.

A method of experimental evaluation of defects is proposed on the basis of the results of numerical investigation. It is applicable for the estimation of quality of materials with glued flock. For comprehensive investigation of such materials it is recommended to apply optical methods based on speckle photography and time-averaged projection moiré.

The results of this research work are applied in the process of design of the elements of packages made from the flock printing material.

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