The object of this study is the processes of deformation of the root polymer plate reinforced with stitches of threads with preliminary tension in book blocks sewn with threads. The analytical and experimental studies reported here are based on the application of the methodology for developing a simulation model of the process of deforming the adhesive polymer plate. The basic assumption of the study is that the use of information support for simulation modeling will contribute to the improvement of the structural and technological parameters of the root part of the book blocks sewn with threads. This cannot be achieved without analyzing and decomposition of the technical system of the book block, classifying subsystems and describing them in the form of a finite set of classes and the connections between them. A procedure for determining the mechanism of interaction of elements of the root part of book blocks sewn with threads is proposed. It is shown that the residual cyclic deformation of the adhesive plate and the stitches of the implanted threads depends on the strength of the bonds between the elements of the joined structure of the materials. It also depends on the number of cycles of discrete loads heterogeneous in terms of dimensional indicators and the place of their application. This is due to the fact that stitches of threads are only partially implanted into the structure of the adhesive plate, the other part that fastens the folds of notebooks is outside the adhesive plate. The influence of cyclic loads applied at different angles relative to the stitches of the threads was revealed. The angular discrepancy fluctuates, in the case of using PVAD D51C glue, in the range of 0.735–0.907, and, for Technomelt GE3636 thermal glue, 0.913–0.940. The developed simulation model of the processes of deformation of the root polymer plate makes it possible to determine the mechanism of interaction of the elements of the root part of the book blocks and predict the durability of the product

Keywords: simulation model, root adhesive plate, implanted thread stitches, discrete loads

UDC 686.1.019
DOI: 10.15587/1729-4061.2022.265869

DEVELOPMENT OF INFORMATION SUPPORT FOR SIMULATION OF THE PROCESS OF DEFORMATION OF ROOT POLYMER PLATE IN BOOK BLOCKS SEWED WITH THREADS

Oleksandr Paliukh
Corresponding author
Doctor of Technical Sciences, Professor, Head of Department
Department of Reprography
Educational and Scientific Publishing and Printing Institute*
E-mail: alekspalyuh@gmail.com
Petro Kyrychok
Doctor of Technical Sciences, Professor, Director
Educational and Scientific Publishing and Printing Institute*
Yevheniy Shtefan
Doctor of Technical Sciences, Professor
Department of Reprography
Educational and Scientific Publishing and Printing Institute*
Andrii Titov
PhD, Associate Professor
Department of Applied Hydroaeromechanics and Mechatronics
Mechanical Engineering Institute*
*National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»
Peremohy ave., 37, Kyiv, Ukraine, 03056

Received date 08.07.2022
Accepted date 20.09.2022
Published date 31.10.2022

How to Cite: *Paliukh, O., Kyrychok, P., Shtefan, Y., Titov, A. (2022). Development of information support for simulation of the process of deformation of root polymer plate in book blocks sewed with threads. Eastern-European Journal of Enterprise Technologies, 5 (1 (119)), 62–73. doi: https://doi.org/10.15587/1729-4061.2022.265869*

1. Introduction

The quality of book products, like any other printing products, first of all, depends on the quality indicators of consumables, which affect not only the representativeness of the publication but also the preservation of the strength of the book block during long-term consumer use.

Book blocks, sewn with threads and connected to bindings, belong to printing products of the highest degree of complexity. The manufacture of such products involves the use of a significant number of technological operations with strict tolerances of dimensional deviations and materials of different properties. Cardboard, offset and coated papers, threads, adhesive polymer compositions have heterogeneous strength indicators.

The structure of the book consists of a significant number of details (Fig. 1) – a book block, forzac and nahzats, fastening root elements, endband, cardboard sidewalls, finishing material of binding, etc. Book details in the process of technological transformations take on the structural appearance of each element of the publication's construction. The integral spatial design of the book is formed using adhesive polymer dispersions. For example, after joining with threads of folded notebooks, edging with glue and paper tape, trimming on three sides, a book block of the selected format is obtained. The block is glued with forzats into a pre-made binding.

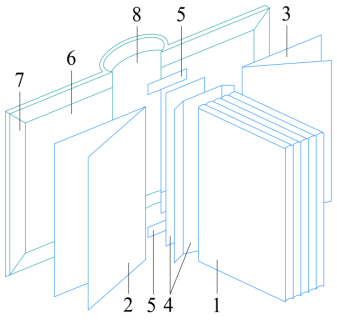

Fig. 1. Spatial structure of the book:
1 — book block sewn with threads; 2 — forsatz; 3 — nahzats;
4 — fastening root elements; 5 — endband; 6 — cardboard
sidewalls; 7 — finishing material of the binding;
8 — the root part of the binding

Taking into consideration the heterogeneity in terms of strength of binding materials and the peculiarities of the movable spatial design of book blocks sewn with threads, it is possible to observe an increase in damage in places of the greatest impact of operational loads. First of all, it concerns the destruction of adhesive polymer dispersion films of the root part of the book blocks. In the structure of the films, on the side of the inner surface, tangent to the folds of the notebooks, the stitches of the threads of the pre-stitching of the block are integrated. Paper tapes that increase the strength and surface tension of the W-shaped root part of the block are integrated from the outside of the adhesive films. Common compatible components – adhesive dispersions, multi-fold threads, tear-resistant paper – form a composite polymer dispersion plate with a non-homogeneous anisotropic structure of components.

Stochastic or sequentially cyclic bending of such a root dispersed polymer plate, during the period of reader turning of the pages of the book, occurs under the mode of elastic-viscous-plastic deformation. Specifications and industry standards for the manufacture of book products do not contain indicators by which it is possible to predict the processes of nonequilibrium deformation of adhesive dispersed materials of the root part of book blocks sewn with threads.

To obtain such indicators and reliable results of research, the structural, mechanical, and rheological parameters of the components of the adhesive composite dispersed plate should be taken into consideration [1]. In addition, to obtain the reliable results of numerical modeling of nonequilibrium processes of deformation of composite adhesive plates, there are no determining ratios for calculating the structural-mechanical and rheological parameters of the corresponding materials [2].

Therefore, research aimed at developing a simulation model of the processes of deformation of the book root adhesive dispersed plate, into the structure of which sewing threads with pre-tension are integrated, should be considered relevant.

2. Literature review and problem statement

It is obvious that the period of use of book products and the intensity of its wear are influenced by a number of factors. Such factors may include the destruction of the root part of the book block, fastened with sewing stitches of threads with pre-tension. The crosslinking joint is reinforced with a layer of glue of one of the used adhesive polymer compositions. As a result, a composite anisotropic plate is formed, which, in the process of opening the book blocks, is subjected to prolonged bending in an indefinite predetermined sequence, frequency and places of the applied destructive efforts.

A study reported in [3] has shown that the advantages of adhesive compounds relate to the low dependence of the bonding strength on the thickness of the fastened parts. In the absence of violations of the integrity of the joints, high elasticity of most adhesive seams, satisfactory durability, and reliability. However, the problems arising from the formation of anisotropic adhesive compounds of materials of different physical and mechanical properties, such as paper, adhesive polymer compositions and binding threads, are not highlighted.

The purpose of investigating adhesive polymer compositions [4] based on polyvinyl acetate (PVA) dispersions (PVA DF 51/15 VP (Ukraine), PVA Akzo Nobel (The Netherlands)) is to identify the effect of activating surface treatment of bonding on the strength of adhesive compounds. The results of the research showed that when surfaces are treated with activating substances, the roughness of the gluing surfaces increases. Active centers are formed on the treated surface, which interact with the molecules of the adhesive material, which leads to an increase in the adhesion strength of the adhesive joint. However, despite the advantages in the research results [4], the durability of the use of adhesive compounds under the condition of their cyclic deformation remains undetermined.

According to the authors of [5], the interfacial adhesion of natural fibers to the adhesive polymer matrix remains a critical problem, which generally affects the duration of use of composites. To overcome this problem, studies have been conducted on the chemical treatment of natural fibers with alkalis before using them in the creation of composite adhesive plates. It is shown that thanks to the proposed technology for improving the surface properties of natural fibers, a positive effect on their interphase adhesion becomes possible. However, it should be noted that in the list of factors under study there is no consideration of profile adhesive polymer plates in the structures of which stitches of threads with pre-tension are implanted.

The problem of increasing the adhesion strength of the adhesive joint is well considered in [6]. The researchers describe an effective method for obtaining high-strength adhesive compounds, based on PVA dispersions, by exposing them to electric fields of a given intensity and temperature. With the same time of fixation of the edge wetting angle, its value in the treated glue (34°13′) is less than that of the untreated (39°47′), thereby improving the wetting and spreading of glue on the surface of the binding materials. Despite the positive value of the above results, the influence of driving factors on the duration of use of adhesive plates obtained in this way remains unexplored.

In [7], the influence of the fractal structure of paper on the formation of the adhesion seam of the root part of the book block is investigated. The authors prove that the maximum strengthening of the adhesion seam is achieved with the maximum filling of microdefects on the surface of the paper. However, the presence of air cavities at the interface of the adhesive substrate leads to the concentration of stresses in these areas. As a result, not only does the actual contact area decrease but potential areas for the destruction of the adhesion bond also arise, which leads to a loss of strength and destruction of the book. In addition, under such conditions, the influence of stitches of the stitching threads of the root part of the book blocks on the overall strength of the adhesive seam has not been investigated.

A study into the properties of composite adhesive polymer plates reinforced with natural fibers is reported in [8]. The authors consider the destruction of polymer composites in terms of mechanical damage, such as impaired communication between the fiber and the matrix, cracks in the matrix, fragments of reinforcing fiber, etc. However, unlike the results obtained, studies of the processes of obtaining mechanical damage and dimensional indicators of deforming forces are not given.

It is known [9] that natural fibers, which are used for the manufacture of sewing binding threads, have some drawbacks. High moisture absorption, low wettability, low thermal stability, and change in quality leads to deterioration of the properties of the composite. At the same time, the cited work proved the positive effect of using natural fibers as a successful reinforcing material in hybrid adhesive composites. Nevertheless, despite the advantages of using natural fibers for reinforcing polymer compositions, there are no comparable studies of the use of artificial fibers for the objectivity of the results obtained.

In particular, it was established [10] that due to the modification of natural fibers, using special treatment, which focuses on the use of functional groups of reagents. The ability to respond to fiber structures and change their composition increases. This suggests an improvement in the bond between natural fibers and polymers. The causes of inefficient transmission of stresses at the interface of the components formed by adhesive composites due to different chemical structure of fibers and matrices have been eliminated. However, the proposed description of the functional bond in adhesive composites (fiber+matrix) does not take into consideration the clustering parameter, which requires the maximum volume fraction of the composite fiber, which is the basis of the modification.

In [11], a comparative analysis of tensile strength indicators of various adhesive composites reinforced with natural fibers was carried out. The indicators obtained by means of mathematical modeling and experimental means turned out to be close to each other. However, only destructive factors and their consequences arising in the process of stretching the composite plates reinforced with fibers are taken into consideration, and there are no indicators of the destructive consequences obtained in the process of bending the plates.

Study [12] showed that adhesive polymer composites can be obtained by adding light natural fibers to the polymer. Using a wide range of methods, including spraying, casting with melt transfer, etc. These methods involve wetting, or saturating, reinforcing the fibers and creating a matrix together, which leads to the bonding of the fiber and polymer matrix into a rigid plastic structure through a chemical and thermal reaction. At the same time, there are no studies of the advantages of the above methods for obtaining adhesive polymer composites on the root part of book blocks sewn with threads.

In order to study the processes of destruction of the root adhesive plates that affect the operational duration, the method of mathematical modeling of the calculation of the stress-strain state of the root adhesive polymer plate is proposed in [13]. The influence of various technological factors on the strength of the adhesive joint, which lead to the occurrence of a stress state when opening the book, is taken into consideration. In support of the results reported in [13], work [14] used the method of modeling the deformation processes of the book publication developed by the authors when opening blocks. It was revealed and experimentally confirmed that the geometric dimensions, types of glue, the thickness of the adhesive film and its deforming characteristics have a significant impact on the size of the opening angles of the blocks. However, the approach used in [13, 14] to model the process of deforming the root plates is based on the technology of fastening book blocks with adhesive plates, which do not have reinforcement with stitches of threads. In addition, adhesive plates fasten sheets of pre-cut book block, rather than rounded folds of book notebooks. Accordingly, the geometric cross-sectional shape of the studied plates in [13, 14] has a linear, not a W-shaped form.

The development of views on modeling the processes of deformation of W-shaped root plates can be found in work [15], which shows that the appearance of damage and destruction of the plate is caused by the alternating nature of the loads. Analysis of the stages of modeling the deformation of the edging adhesive layer of the book block sewn with threads revealed the processes of stretching and compression necessary for practical consideration. Despite the apparently correct identification and analysis of deformation factors and recommendations for calculating the number of adhesive compositions, W-shaped adhesive plates were investigated as an isotropic body, without taking into account the reinforcement with thread stitches.

Given this, it turns out that despite the practical significance of the research, the processes of deformation of book root adhesive dispersed plates whose structure includes sewing threads with preliminary tension are not sufficiently considered.

Therefore, there is reason to believe that the lack of appropriate determining ratios of the phenomena of the stressed-strained state of the root joints in the book blocks sewn with threads, which were considered to a limited extent, necessitates research in this area.

3. The aim and objectives of the study

The aim of this work is to develop information support for studying deformation processes of root book dispersed edging polymer plates with a W-shaped contour geometry, reinforced with stitches of binding threads with pre-tension. The revealed physical and mechanical regularities of the structure of the root plates of book blocks will contribute to the formation of adequate elastic-viscous-plastic models of materials of these elements in the process of their reader use.

To accomplish the aim, the following tasks have been set:

– to create model representations of the behavior of the elements of the composite plate for typical operating conditions, taking into consideration the existing structural and technological parameters of the adhesive polymer edging plates of the root part of the book blocks;

– to carry out simulation based on the formalization of the description of the mutual influence of the deforming parameters of adhesive root plates reinforced with thread stitches.

4. The study materials and methods

The object of this study is the processes of deformation of the root polymer plate reinforced with stitches of threads with preliminary tension in book blocks sewn with threads. The main assumption of study is that the use of information support for simulation modeling will contribute to the improvement of the structural and technological parameters of the root part of the book blocks sewn with threads. The

conducted analytical and experimental studies are based on the application of the methodology for developing a simulation model of the process of deforming the adhesive polymer plate. Problems of destruction of the root adhesive plates reinforced with stitches of binding threads with pre-tension arise due to the physical and mechanical features of the materials forming the composite plate. Unfavorable features of materials can be investigated and eliminated by simulating the processes of deformation of the root polymer plate of a sample of book blocks of common formats.

For the experimental part of our study, book blocks with a spine length of 200 mm were used, selected and stitched from notebooks made of offset paper by Amber Graphic (Arctic Paper Group, Sweden) weighing 100 g/m^2. The volume of notebooks is 64 pages, 8.32 mm thick. Measurements were made using a professional digital paper thickness gauge SK200 with a measurement range of 0–12.95 mm (0.01 mm) (Kelilong Instruments, China). Polyamide multi-threaded threads 29 tex×1×2 (TU U 17.1–00204048–160:2006) were used for sewing blocks. The root part of the blocks after stitching with threads is fixed with adhesive polymer compositions – polyvinyl acetate (PVA) dispersion PVAD D51C (Ukraine) and Technomelt GA 3636 thermoglue (Germany). The listed polymer compositions contribute to the observance of a fixed thickness of the adhesive plate (in the variants provided for by the research conditions). The compositions provide the strength of the connection of the surface of the folds of notebooks, stitches of threads and edging paper tapes. Fig. 2 shows the stages of testing the root book adhesive plate for strength: *a* – longitudinal and *b* – angular stretching of the root adhesive polymer plate opened in the middle of the book block.

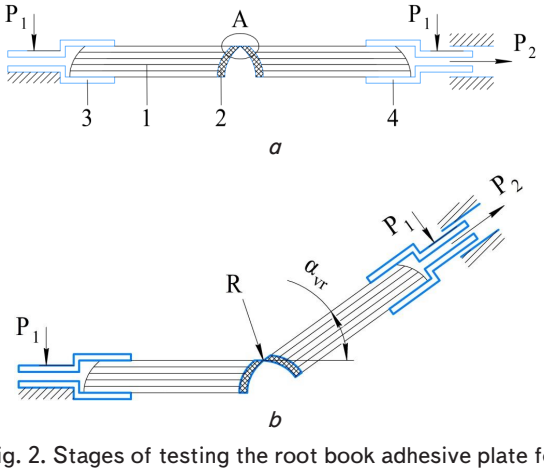

Fig. 2. Stages of testing the root book adhesive plate for strength: *a* — longitudinal stretching; *b* — angular stretching; 1 — book block; 2 — root adhesive plate reinforced with threads, 3 — fixed clamps, 4 — movable clamps, P_1 — clamping force of parts of the block, P_2 — stretching force of the root plate, *A* — zone of destruction of the adhesive plate; α_{vr} — variable stretching angle, *R* — angular bending retainer of the adhesive plate

Testing and calculation of the specific force of destruction of adhesive polymer root plates reinforced with stitches of binding threads with pre-tension was carried out on an automatic breaking machine Labthink XLW (EC) (China). Its conditional scheme of work, in the process of breaking book blocks between notebooks, is presented in Fig. 2. This device meets the requirements of the international standard for the quality of manufacturing printing products ISO 9001:2015. The test was carried out with a maximum load of 2000 N using clamps with a length of 250 mm and a working stroke speed of 60 mm/min.

5. Results of investigating the processes of deformation of the root polymer plate in book blocks sewn with threads

5. 1. Results of investigating the behavior of elements of the root adhesive composite plate under typical operating conditions

In order to be able to take into consideration the maximum number of parameters of the structure and operation of book root polymer plates reinforced with stitches of binding threads with preliminary tension, a method for determining the mechanism of interaction of elements of the root part of book blocks was proposed. Analysis of the relevant parameters of this mechanism will make it possible to give recommendations for increasing the durability of the book block (Fig. 3). The analysis tool adopted in the developed methodology is a simulation model of the process of deforming the root polymer plate in book blocks sewn with threads.

In the development of the presented methodology (Fig. 3), an object-oriented approach to conducting simulation computational experiments was used [16]. This makes it possible to effectively decompose the technical system of the book block, classify subsystems, and describe them in the form of a finite set of classes and connections between them. Formalization of information about each element of the book block is carried out as a separate object of research.

Generalization and systematization of certain information messages between the elements of this technical system makes it possible to build an information model of the object of research within the accepted problem orientation. The problem orientation, for the above model, is to increase the durability of consumer exploitation of adhesive composite polymer plates of the root part of book blocks sewn with threads (Fig. 3). Physical and mechanical regularities of creation and operation of composite polymer plates are considered. The components of the destructive factors include the structural structure of the plate, the parameters of the cyclic load, the modes of deformation, the features of adhesion and delamination in the system «adhesive polymer – stitches of threads».

The next stage involves the justification of the choice and expediency of improving the structural and technological parameters of the root part of the book blocks. This contributes to the development of a reliable calculation scheme of behavior of the root part of the book blocks under the conditions of consumer exploitation.

The block of analysis tools takes into consideration the methods of simulation modeling based on the sequential creation of an analytical model, an algorithmic model, a digital model that contribute to full-scale and simulation computational experiments. The proposed information model makes it possible to determine the mechanism of interaction of the elements of the root part of the book blocks and predict the durability of the product with the reliable indicators necessary for production use.

The procedure of technological process of forming book root polymer W-shaped composite plates reinforced with binding threads with pre-tension is different from the formation of other polymer composite plates in the printing industry.

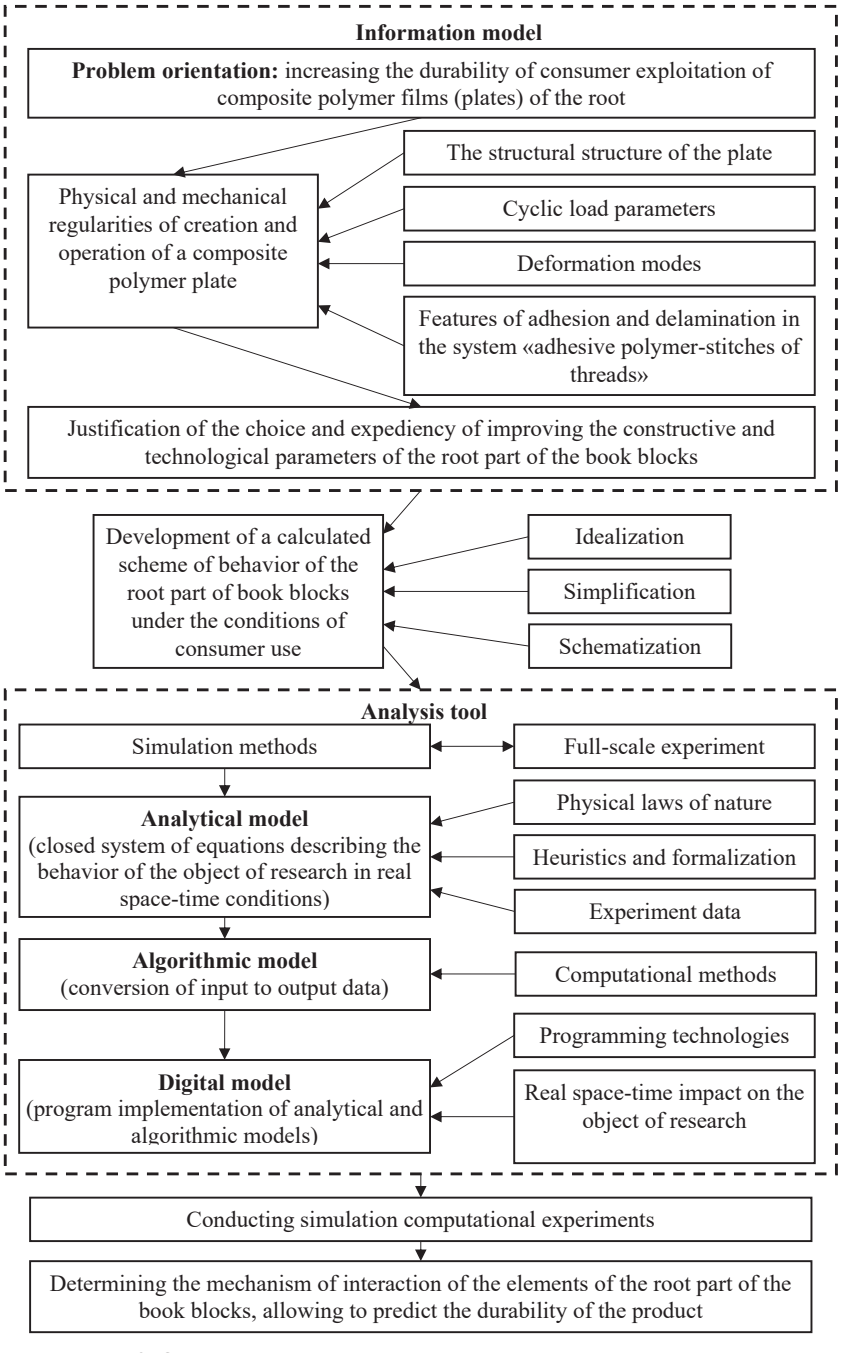

Fig. 3. Scheme of procedure for determining the mutual influence of the parameters of the root part of book blocks

First of all, for the root bonding of book blocks in an unstitched way, adhesive polymer compositions with high surface adhesion to different types of paper are used. In addition, the peculiarities of their application to the root end surfaces of the book blocks cut into a certain format are also taken into consideration. In addition, to increase the surface area of gluing in the cut root part of the book block, profile depressions are formed. After applying an adhesive polymer composition to the profile surface of the root part of the book block, some of its insignificant part, tightly fitted, is integrated into the thickness of the glue. Such a polymer plate, on the one hand, has a part of the block integrated into the thickness of the glue, on the other hand, a solid adhesive polymer structure free from paper reinforcement. For polymer plates with a relative division into the reinforced part and into parts with no reinforcement, they form the phenomena of elastic-plastic deformation inherent in the opening of the block.

Common for composite polymer plates reinforced with artificial and natural fibers are structures in which a spatial mesh structure woven from filaments with cells of various sizes is filled with a melt of polymer. Accordingly, the reinforcing fibers are dispersed proportionally in the thickness of the polymer plate. Therefore, the bending of such composite plates and the phenomena of elastic-plastic deformation that occur, proceeds taking into consideration the spatial homogeneity of reinforcement with threads.

Unlike the previously mentioned polymer reinforced plates, the formation of the composite structure of the W-shaped root part of the book blocks, sewn with threads with pre-tension, is carried out in several stages, separated in time. In addition, the structural construction of the formed edging plates has a separate character and operational features that determine the stages of an elastically deformed state and factors influencing its transformation.

In the process of sewing book blocks, stitches of threads are formed, which tighten sheets of paper in the center of the folds of notebooks (Fig. 4) through pre-punctured holes. The quantitative indicator of folded sheets forms the volume of notebooks, determined by the format of the publication.

Analyzing the cross-section of the folds of notebooks, it is possible to note the slight elasticity and mobility of folded sheets, in the area of the fold, due to the absence of their tight fit to each other after folding. Therefore, the first preliminary tension formed by the stitches of the threads occurs in the process of stitching each individual notebook from the total number of selected in the book block. It can be noted that the tightening density, the number and types of binding stitches used are affected by the elasticity of the paper in book notebooks and the quality indicators provided by the accuracy of folding.

The next part of the preliminary tension of the stitching threads occurs in the process of attaching notebooks to each other in the root part. The adjustment of the stitching apparatus should provide the necessary and sufficient tension of the threads for strong fastening of the root part of the blocks without destroying the holes previously formed by puncture needles. Thus, after the stitching of the book blocks is completed, before the start of their reader's opening, the pre-tension is acquired with stitching threads, which ensures the relative strength of the fastening of the blocks.

Additionally, to enhance the bonding strength of the root part of the book blocks, a profile layer of adhesive polymer compositions is applied to the surface of the folds of book notebooks. The thickness of the adhesive layer is adjusted in proportion to the format of the publication, the number

of notebooks, the mass of paper, the types of sewing stitches and the threads used to create them. In such circumstances, the design of the book block is determined by the elasticity and flexibility provided by the materials involved in the manufacture of a particular publication. Before the opening of the book block, its strengthening root part is presented in the form of a wavy W-shaped adhesive plate in the structure of which the stitches of the stitching threads are partially implanted. The rest of the stitches of the threads are located outside the adhesive plate, preserving the integrity of the stitching joint with the implanted part.

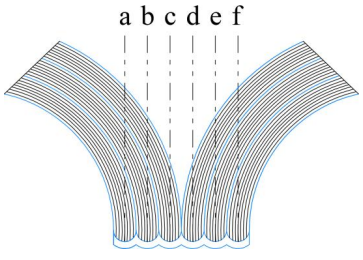

Fig. 4. The cross-section of the book block partially opened in the middle: *a*—*g* — coordinates of the stitches of threads in the root part

Fig. 5 shows a fragment of the cross-section of the root part of the book block sewn with threads with preliminary tension (*a* – with fragments of notebook folds, *b* – without fragments of notebook folds, 1 – a fragment of the fold of a separate notebook; 2 – sheets; 3 – part of the stitches of threads partially implanted in the adhesive polymer plate, 4 – part of the stitches of threads for fastening the folds of notebooks 5 – adhesive W-shaped polymer dispersed plate; 6 – section of the fold of the notebook).

It should be noted that part of the stitches of the threads, which fastens the sheets of folded paper h_{fs} (Fig. 5, pos. 4), and part of the stitches of the threads implanted in the adhesive polymer plate (Fig. 5, pos. 3), before the start of consumer use, have the same pre-tension anywhere in the stitches. In addition, part of the elongation of threads (from the maximum possible, before the beginning of destruction), which occurs in thread sewing equipment, is achieved in the process of stitching book blocks. Therefore, the reader's operating loads on the stitches of the threads and the adhesive plate are distributed to the residual elongation of the threads. The residual elongation is due to the materials for the manufacture of threads, the number of folds, preliminary surface destruction and a decrease in strength during the stitching of blocks. From this it follows that the book blocks in the root part, fastened in the above way, have a more rigid compositional connection than the initial properties of the materials that are included in the compound. First of all, it is the plasticity and stretchability of the root adhesive polymer plates and threads made of natural and artificial fibers.

5. 2. Results of simulation modeling based on the formalization of the description of the mutual influence of deforming parameters of adhesive root plates reinforced with threads

In the process of stitching book notebooks, the efforts applied to the tightening of the folds of notebooks are directed perpendicular to the root part of the stitched blocks, as shown in Fig. 6. The shown fragment of the root part of the stitched threads is isolated from the book block, which is in a static state before the reader's turning of pages. Therefore, the geometry of the adhesive plate and the stitches of the threads have a rectilinear balanced shape. In such circumstances, the numerical values of the thread tension vectors in different parts of the root part of the block fluctuate. From the minimum – $\vec{P}_{md-1}$, $\vec{P}_{md+1}$ (part of the stitches of threads in the adhesive plate) to the maximum – $\vec{P}_{st-1}$, $\vec{P}_{st}$, $\vec{P}_{st+1}$ (part of the stitches of the threads that connects the folds of the notebooks).

The residual cyclic deformation of such a root W-shaped adhesive plate, the stitches of the threads implanted in its structure, as well as the folds of the notebooks depends on the strength of the bonds between the elements of the connected structure of the materials.

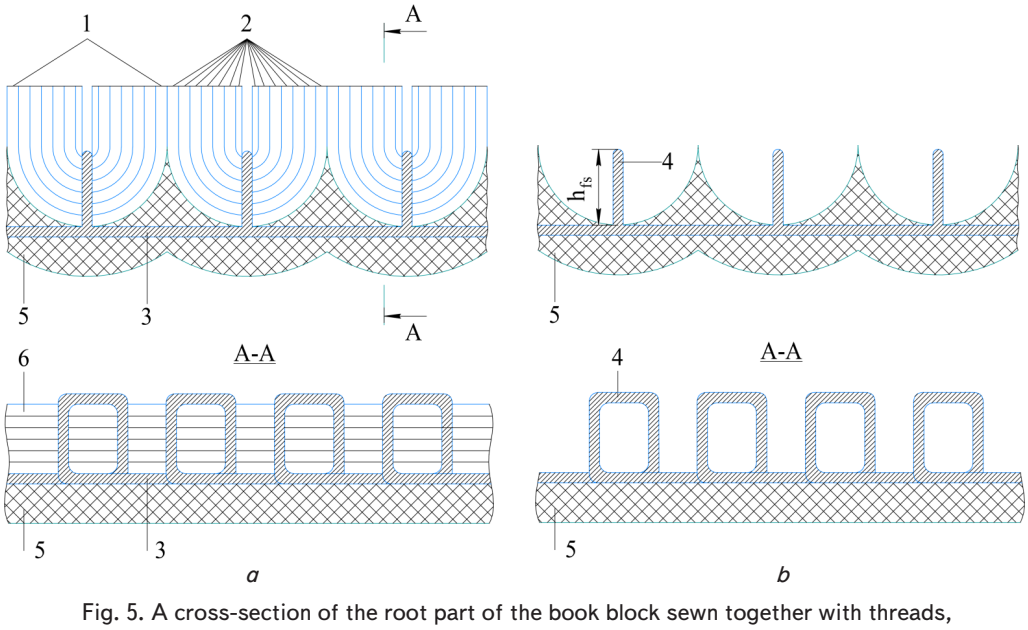

Fig. 5. A cross-section of the root part of the book block sewn together with threads, *a* — with fragments of folds of book notebooks; *b* — without fragments of folds of notebooks, 1 — fragment of the fold of a separate notebook, 2 — sheets, 3, 4 — parts of thread stitches, 5 — adhesive W-shaped plate, 6 — cross-section of the notebook fold, h_{fs} — size of the free stitch fragment

In addition, residual deformation depends on the number of cycles of discrete loads that are heterogeneous both in terms of dimensional indicators and the place of their application in each cycle.

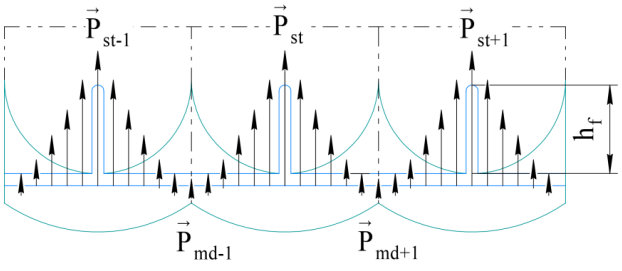

Fig. 6. Scheme of direction of vectors of tension forces of thread stitches after stitching the root part of book blocks, $\vec{P}_{md-1}$, $\vec{P}_{md+1}$ – vectors of tension forces of threads in the median (deltoid) part of the adhesive plate; $\vec{P}_{st-1}$, $\vec{P}_{st}$, $\vec{P}_{st+1}$ – vectors of tension forces of thread stitches in the central part of the sewn folds of notebooks; h_f – height of the stitch of the seam fastening threads

Since the initial reader turning pages and opening the book block, the straightforwardness of the root part of the book changes. The W-shaped adhesive plate of the book block and the root part of the binding begin to bend in opposite directions. The spatial design of the root part of the book, obtained as a result of opening the block, forms the shape of an arched vault with a constantly variable curvature of the adhesive plate while maintaining its linear length (Fig. 7).

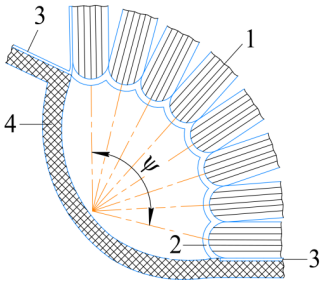

Fig. 7. Cross-section of the root part of the book block: 1 – fragments of notebooks; 2 – adhesive W-shaped plate; 3 – forzats; 4 – the root part of the binding; ψ – angular bending zone of the adhesive plate

The strength of the stitches of the threads and the connections between them, after stitching the blocks, in the areas of contact with the paper of the notebook folds, as well as in the places of interweaving, depends primarily on the friction forces and the adhesion of the threads. In addition, the strength of the thread stitches is proportional to the number of stitches, the quantitative composition of which depends on the format and thickness of the publication and the destructive loads that increase with the growth of the size indicators of the book block. Additionally, it is necessary to take into consideration the fact that the threads in the process of passing the mechanism of the sewing apparatus undergo a significant elongation, at the limit of breaking force, and mechanical friction, on the verge of destruction of the surface layer.

Therefore, under the influence of long discrete reading loads, the structure and properties of all materials of the root part of the book block change: paper, threads, adhesive polymer plates. It should be noted that the change in the structure and properties of materials occurs not only in proportion to the time of their use in the structure of the book block. It also occurs in proportion to the co-dependent destructive effect of one material on another.

For folds of notebooks and a root adhesive W-shaped plate, loads that are applied for a long time at different angles relative to the stitches of the threads lead to the accumulation in them of a different proportion of residual deformation (Fig. 8). If the load is directed at a small angle other than the angle of 90° (angle α_{st}, Fig. 8, *b*) of the initial direction of the thread stitches, it is transmitted mainly to the system of thread stitches and the structure of the adhesive plate located in the direction of the active force. Thanks to this, there is a slight change in the structure of the threads and a relatively slow accumulation of residual deformation in the root adhesive plate.

During the sequential numerical turning of the pages of the book block, a spatial change in the orientation of the notebooks occurs (Fig. 7), and, accordingly, that part of the stitches of the threads that fasten their folds. Depending on the sequence of turning pages, from beginning to end, or from end to beginning, the angles of inclination of the thread stitches change: the angle α_{vr-1} – from 180° to 0°, and the angle α_{vr-2} – from 0° to 180° (Fig. 8).

In addition, there is a rotation of the stitches of the threads, the part that fastens the folds (h_f, Fig. 6), with a change in the angles between the stitches and the W-shaped adhesive plate. With discrete cyclic loads (vectors of stitch tension forces $\overrightarrow{P_{st}}$, $\overrightarrow{P_{vr-1}}$, $\overrightarrow{P_{vr-2}}$, (Fig. 6), which are directed in the ranges of angles of 135°–180° (Fig. 8, *a*, *d*) and 45°–0° (Fig. 8, *c*, *e*), a process occurs that leads to the rapid accumulation of residual cyclic deformation in the root adhesive plate. Moreover, the closer the loads are directed, the vectors of which approach the angles of 45° and 135°, the more intensive is the process of accumulation of residual cyclic deformation in the W-shaped adhesive layer.

Thus, during long and sequential stretching of the stitches of the threads at angles in different directions (alternating loads) and stretching of the root adhesive plate, there is a gradual delamination and separation of the fibers of the threads and plate (Fig. 8, *d*–*f*).

The formation of destructive zones in adhesive W-shaped plates and delamination zones with thread stitches is discrete, relatively predictable, for the general case, but unsystematic in nature. In notebooks close to the middle part of the book block, the delamination of the adhesive plate, in the area with implanted stitches of threads, is directed relative to the center of the stitch along the vector of destructive forces $\overrightarrow{P_{st}}$ (Fig. 8, *e*). Accordingly, the linear size of the delamination area $L_{zd(st)}$ is also distributed relatively symmetrically to the center of the stitch.

In the part of the notebooks, the counting of which is possible from the beginning, or from the end of the book block to the middle, the delamination of the adhesive plate occurs in the direction of vectors of destructive forces $\overrightarrow{P_{vr-1}}$ and $\overrightarrow{P_{vr-2}}$ directed at angles α_{vr-1} and α_{vr-2} (Fig. 8, *d*, *f*). Linear dimensions of the delamination areas $L_{zd(vr-1)}$ and $L_{zd(vr-2)}$ are also formed in accordance with the direction of the vectors of destructive efforts. In addition, it should be noted that the dimensional values of the vectors of the destructive forces $\overrightarrow{P_{st}}$, $\overrightarrow{P_{vr-1}}$, $\overrightarrow{P_{vr-2}}$, the angles of their direction α_{st}, α_{vr-1}, α_{vr-2}, linear and vertical sections of delamination of adhesive W-shaped

plates $L_{zd(st)}$, $L_{zd(vr-1)}$, $L_{zd(vr-2)}$, t_{st}, t_{vr-1}, t_{vr-2} take stochastic values determined by the operating conditions of each book block. Accordingly:

$$\overrightarrow{P_{st}}, \overrightarrow{P_{vr-1}}, \overrightarrow{P_{vr-2}} \neq \text{const};$$

$$L_{zd(st)}, L_{zd(vr-1)}, L_{zd(vr-2)} \neq \text{const};$$

$$t_{st}, t_{vr-1}, t_{vr-2} \neq \text{const};$$

$\alpha_{st}, \alpha_{vr-1}, \alpha_{vr-2}$ – change range (0°–180°).

It should be noted that the main destructive components that arise in the process of reader application of book blocks sewn with threads are characterized by various factors affecting operational durability. It should be noted that the use of an information approach in the formation and identification of destructive components that affect the duration of use of book products implies an understanding of their consistent accumulation. As a result of the generalization of this fact, it is possible to determine the projected final indicators [17] of the destruction of book blocks sewn together with threads. Indicators are distinguished from the determining set of factors related to systematization and ranking. To such a set of factors affecting the duration of use of book blocks stitched together by threads, according to an indirect assessment of the impact, it is possible to attribute the components shown in Fig. 9. The main components indicate the structural structure of the adhesive plate reinforced with stitches, the parameters of the cyclic load on the plate, the modes of its deformation, and the features of the adhesion of the plate materials.

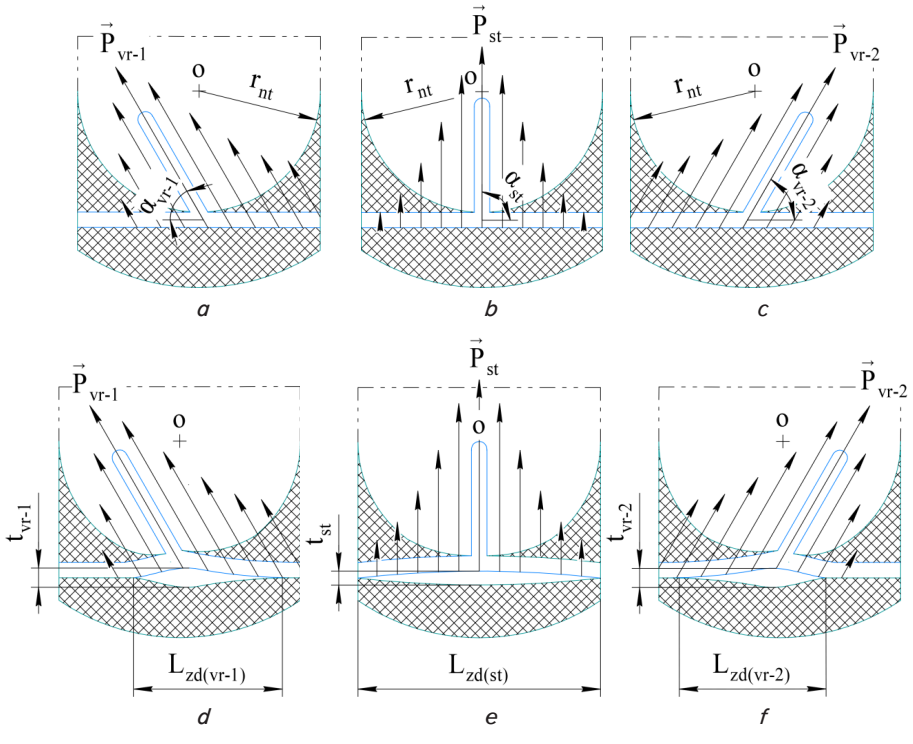

Fig. 8. Stages of destruction of the composite plate reinforced with stitches of threads, r_{nt} – radius of folds of book notebooks; $L_{zd(st)}$, $L_{zd(vr-1)}$, $L_{zd(vr-2)}$ – linear dimensional indicators of the fracture zones, t_{st}, t_{vr-1}, t_{vr-2} – dimensional indicators of the delamination zones of thread stitches and adhesive polymer plate; $\overrightarrow{P_{st}}$, $\overrightarrow{P_{vr-1}}$, $\overrightarrow{P_{vr-2}}$ – vectors of tension forces of thread stitches; α_{st}, α_{vr-1}, α_{vr-2} – angles of direction of vectors of tension forces of thread stitches

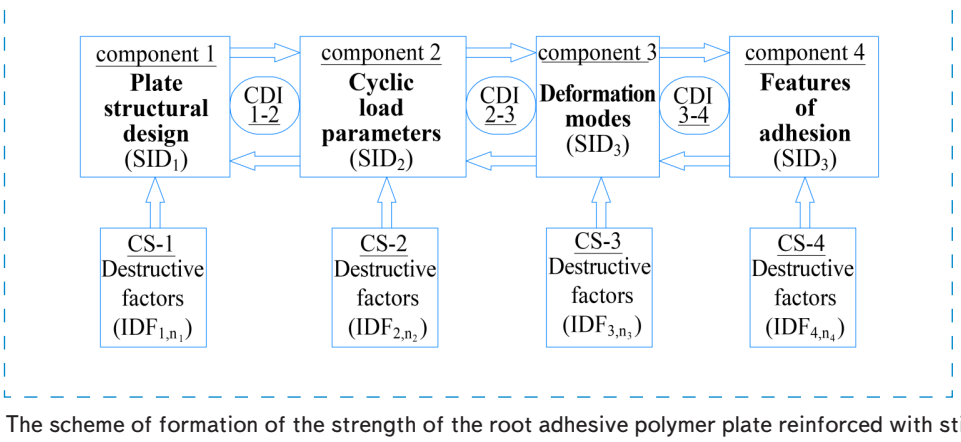

Fig. 9. The scheme of formation of the strength of the root adhesive polymer plate reinforced with stitches of threads with pre-tension under cyclic load conditions

According to the information approach procedure [17], to predict the processes of destruction of the root part of book blocks sewn with threads with preliminary tension and formalized interpretation of the results, it is possible to introduce the following symbols. The result of the interpretation of destructive factors for the components of simulation modeling (CS-1, CS–2, CS-3, CS-4), each of which is a fraction of the total assessment, is indicated by the information indicator of destruction $IDF_{i,n}$ (indicator destructive factor). Where $i=1...4$, and n_i determines the number of factors of each component (Fig. 9). Accordingly, a separate indicator of destruction is indicated as SID. At the output and input of each block of destruction components (1, 2, 3, 4), we denote the current destruction indicator CDI (1–2, 2–3, 3–4). With dimensional indicators corresponding to the moment of fixing the results of the indicator measurement. For each isolated component of destruction, it is possible to apply successive mathematical dependences:

$$SID_1 = IDF_{1,1} \cup IDF_{1,2} \cup ... \cup IDF_{1,n_1} = \bigcup_{j=1}^{n_1} IDF_{1,j}; \quad (1)$$

$$SID_2 = IDF_{2,1} \cup IDF_{2,2} \cup ... \cup IDF_{2,n_2} = \bigcup_{j=1}^{n_2} IDF_{2,j}; \quad (2)$$

$$SID_3 = IDF_{3,1} \cup IDF_{3,2} \cup ... \cup IDF_{3,n_3} = \bigcup_{j=1}^{n_3} IDF_{3,j}; \quad (3)$$

$$SID_4 = IDF_{4,1} \cup IDF_{4,2} \cup ... \cup IDF_{4,n_4} = \bigcup_{j=1}^{n_4} IDF_{4,j}, \quad (4)$$

which, in general, for a separate indicator of destruction of each component of the total assessment of the destructive effect on the thread-reinforced root adhesive plate is:

$$SID_i = \bigcup_{j=1}^{n_s} IDF_{i,j}. \quad (5)$$

Given that the structural structure of the plate is the first component of the factors of destructive influence, the first separate indicator of destruction coincides with the current indicator of destruction (CDI_{1-2}):

$$CDI_{1-2} = SID_1 = \bigcup_{j=1}^{n_s} IDF_{1,j}. \quad (6)$$

After each subsequent component of the destructive effect on the adhesive root plate, the following current indicator of destruction CDI_{2-3} and CDI_{3-4} is added to obtain the total result. It should be noted that the accumulation of destructive factors during the period of reader use of the book, transportation and storage conditions is a dynamic process that is carried out in successive stages, as shown in Fig. 9. In the case of violation of the sequence of stages of opening book blocks, certain destructive factors will affect the operational strength of the book block with higher dimensional indicators than others. Therefore, the vectors of influence of current indicators of destruction (CDI) in Fig. 9 are aimed at meeting the neighboring components of destruction. In each case, for each book block, the sequence of influence of destructive factors may be different. In addition, the dimensional definition of each component is associated with a set of factors that determine the distinctive features, the measure of influence, and the final result.

To determine the force of breaking the block (destruction of the root adhesive polymer plate reinforced with stitches of threads), one notebook, or part of the block opened in the middle, is fixed in a fixed clamp (Fig. 2) of the breaking machine. Accordingly, another part of the book block is fixed in the movable clamp, which with the previous part form an angle of 180° (Fig. 2, *a*). After turning on the breaking machine, the forces that led to the destruction of the root adhesive plate of the binding threads reinforced with stitches are recorded. The specific tensile force is determined from the formula $P=Q/L$, where Q is the breaking force, N; L – the length of the block root, mm. Tests simulating the angular tension of the stitches of the threads, to determine the tensile force of the parts of the block fixed in the breaking machine at an angle to each other, are carried out according to the scheme presented in Fig. 2, *b*. The direction of stretching the parts of the block at an angle of α_{vr} (Fig. 2, *b*), which can be changed during the experiment, is provided by the angular retainer *R*.

Indicators of the specific forces of rupture of book blocks (root adhesive polymer plates reinforced with stitches of threads with pre-tension) are presented in Table 1.

Table 1

Indicators of the specific forces of the angular gap of book blocks, depending on the thickness of the adhesive layer

No. of adhesive layer	Adhesive layer thickness t_i, mm	Specific tensile force, N/mm					
		Adhesive PVAD D51C			Thermoglue Technomelt GA 3636		
		Angle 180°	Angle 45°	CI	Angle 180°	Angle 45°	CI
1	$t_1=0.20$	1,470	1,313	0.893	2,058	1,926	0.935
2	$t_2=0.30$	1,519	1,352	0.890	2,107	1,982	0.940
3	$t_3=0.40$	1,568	1,370	0.873	2,156	2,023	0.938
4	$t_4=0.50$	1,617	1,375	0.850	2,401	2,192	0.913
5	$t_5=0.60$	1,682	1,479	0.879	2,460	2,283	0.928
6	$t_6=0.70$	1,715	1,547	0.902	2,479	2,292	0.925
7	$t_7=0.80$	1,813	1,646	0.907	2,597	2,411	0.928
8	$t_8=0.90$	2,274	1,862	0.818	2,744	2,516	0.917
9	$t_9=1.00$	2,430	1,911	0.786	3,136	2,872	0.916
10	$t_{10}=1.10$	2,665	1,960	0.735	3,283	3,076	0.937

The comparative indicator (CI) (Table 1), showing the angular divergence of indicators of the specific forces of rupture of book blocks, varies depending on the stretching angles. In the case of using PVAD D51C adhesive – in the range of 0.735–0.907, and in the case of using Technomelt GA 3636 thermoglue – 0.913–0.940, which shows the adhesive difference between the composite joints of the applied adhesives and thread stitches.

6. Discussion of results of the development of information support for simulation of the process of deformation of the root polymer plate in book blocks sewn with threads

The results of our study of the processes of deformation of the root polymer plate in book blocks sewn with threads showed that from the point of view of spatial structure, book blocks belong to printing products of the highest degree of complexity. The manufacture of such products involves the

use of a significant number of technological operations with strict tolerances of dimensional deviations.

This is due to the heterogeneity of the strength indicators of binding materials and the peculiarities of the movable spatial design of book blocks sewn with threads shown in Fig. 1. In places of greatest influence of operational loads, which include adhesive polymer plates of the root part of the blocks reinforced with stitches of threads with pre-tension, an increase in damage can be observed. Dimensional indicators of damage to adhesive root plates are partially described and published according to the results of research in works [1, 2].

In order to take into consideration the maximum number of parameters of the structure and operation of the root adhesive plates, a procedure for determining the mechanism of interaction of the elements of the root part of the book blocks is proposed, shown in Fig. 3. Analysis of the structural design of the plate, parameters of cyclic load, modes of deformation, as well as features of adhesion and delamination in the system «adhesive polymer – stitches of threads», expands the list of recommendations given in [6, 7]. When developing the presented methodology (Fig. 3), an object-oriented approach was used, which makes it possible to effectively decompose the technical system of the book block, classify subsystems, and describe them in the form of a finite set of classes and connections between them. Formalization of information about each element of the book block is carried out as a separate object of research.

Formalization of information contributes to the development of a reliable calculation scheme of behavior of the root part of book blocks under the conditions of consumer exploitation. In this sense, of particular interest is the block of analysis tools, taking into consideration the methods of simulation modeling. Simulation methods involve the sequential creation of an analytical model, an algorithmic model, a digital model that contributes to full-scale, and simulation computational experiments.

It should be noted that the widespread structure of composite polymer plates reinforced with artificial and natural fibers implies the presence of a spatial mesh structure woven from filaments of cells of various sizes filled with polymer melt. Accordingly, the reinforcing fibers are dispersed proportionally in the thickness of the polymer plate.

Therefore, the stretching or bending of such composite plates and the phenomena of elastic-plastic deformation, which occur during this, occur taking into consideration the spatial homogeneity of reinforcement with threads. The given circumstances do not diverge from the results of studies known from works [10, 11], the authors of which carried out a comparative analysis of the tensile strength of adhesive composites reinforced with natural fibers in proportion to the thickness of the plates. However, it is impossible not to note that the process of forming book root adhesive plates reinforced with stitches of threads with pre-tension is different from the formation of any other polymer composite plates in the printing industry.

Before the opening of the book block, its strengthening root part is represented in the form of a wavy W-shaped adhesive plate in the structure of which the stitches of the stitching threads are partially implanted. The rest of the stitches of the threads h_{fs} (Fig. 5) is located outside the adhesive plate, preserving the integrity of the stitching joint with the implanted part.

The numerical values of the thread tension vectors (Fig. 6) in different parts of the root part of the block, under such circumstances, range from the minimum – $\vec{P}_{md-1}$, $\vec{P}_{md+1}$ (part of the stitches of the threads in the adhesive plate) to the maximum – $\vec{P}_{st-1}$, $\vec{P}_{st}$, $\vec{P}_{st+1}$ (part of the stitches of the threads that connects the folds of the notebooks).

For folds of notebooks and a root adhesive W-shaped plate, loads that are applied for a long time at different angles relative to the stitches of the threads lead to the accumulation in them of a different proportion of residual deformation (Fig. 8). If the load is directed at a small angle other than the angle of 90° (angle α_{st}, Fig. 8, of the initial direction of the thread stitches, it is transmitted mainly to the thread stitch system and the adhesive plate structure located in the direction of the active force.

During the sequential turning of the pages of the book block, a spatial change in the orientation of the notebooks occurs (Fig. 7), and, accordingly, that part of the stitches of the threads that fasten the folds. Depending on the sequence of turning pages, from beginning to end, or from end to beginning, the angles of inclination of the thread stitches change: the angle α_{vr-1} – from 180° to 0°, and the angle α_{vr-2} from 0° to 180° (Fig. 8).

In addition, there is a rotation of the stitches of the threads, the part that fastens the folds (h_f, Fig. 6), with a change in the angles between the stitches and the W-shaped adhesive plate. With discrete cyclic loads (vectors of tension forces of stitches $\vec{P}_{st}$, $\vec{P}_{vr-1}$, $\vec{P}_{vr-2}$, Fig. 6), which are directed in the ranges of angles of 135°–180° (Fig. 8, *a*, *d*) and 45°–0° (Fig. 8, *c*, *f*), a process occurs that leads to the rapid accumulation of residual cyclic deformation in the root adhesive plate. Moreover, the closer the loads are directed, the vectors of which approach the angles of 45° and 135°, the more intensive is the process of accumulation of residual cyclic deformation in the W-shaped adhesive plate.

Thus, during long and consecutive stretching of the stitches of the threads at angles in different directions (alternating loads) and stretching of the root adhesive plate, there is a gradual delamination and separation of the fibers of the threads and plate (Fig. 8, *d*–*f*).

In the part of notebooks, the counting of which is possible from the beginning, or from the end of the book block to the middle, the delamination of the adhesive plate occurs in the direction of vectors of destructive forces $\vec{P}_{vr-1}$ and $\vec{P}_{vr-2}$ directed at angles α_{vr-1} and α_{vr-2} (Fig. 8, *d*, *f*). Linear dimensions of the delamination areas $L_{zd(vr-1)}$ and $L_{zd(vr-2)}$ are also formed in accordance with the direction of the vectors of destructive efforts. In addition, it should be noted that the dimensional values of the vectors of the destructive forces $\vec{P}_{st}$, $\vec{P}_{vr-1}$, $\vec{P}_{vr-2}$, the angles of their direction α_{st}, α_{vr-1}, α_{vr-2}, linear and vertical sections of delamination of adhesive W-shaped plates $L_{zd(st)}$, $L_{zd(vr-1)}$, $L_{zd(vr-2)}$, t_{st}, t_{vr-1}, t_{vr-2} take stochastic values determined by the operating conditions of each book block.

Attention should be paid to the fact that the accumulation of destructive factors in the period of reader use of the book, transport and storage conditions is a dynamic process carried out in successive stages, as shown in Fig. 8. Therefore, the vectors of influence of current indicators of destruction (CDI) in Fig. 8 are aimed at meeting the neighboring components of destruction. The sequence of components of destruction in each individual case for each book block may be different. In addition, the dimensional definition of each component is associated with a set of factors that determine the distinctive features, the measure of influence, and the final result.

Comparative indicators (CI) (Table 1), calculated on the basis of the results of experimental studies of modeling the angular tension of the stitches of threads to determine the breaking force of book blocks, show dimensional differences

depending on the angles of stretching. In the case of using PVAD D51C adhesive – in the range of 0.735–0.907, and in the case of Technomelt GA 3636 thermoglue – 0.913–0.940, which shows the adhesive difference between the composite joints of the applied adhesives and thread stitches.

The discrepancy in the specific forces of breaking book blocks formalizes the features of operational loads and conditions for angular discrete destruction of adhesive polymer plates. The obtained indicators of destruction of the root adhesive plate will assist in the selection and technological planning of the thickness of the adhesive layer for book blocks of the selected formats, based on the conditions of application of the publication.

On the basis of the conducted analytical and experimental research, information support for simulation modeling was developed to justify the choice and expediency of improving the structural and technological parameters of the root part of the book blocks. This makes it possible to increase the durability of consumer exploitation of adhesive composite polymer plates reinforced with threads with pre-tension.

At the same time, it should be noted that the proposed procedure of simulation modeling of the process of deformation of adhesive plates does not take into consideration some important criteria for studying the mechanism of interaction of elements of the root part of book blocks, namely:

– properties of materials for book blocks and edging ribbons;

– indicators of pre-tension of fastener thread stitches, their thickness, number of twists, material, and breaking capacity;

– indicators of deforming cyclic loads arising in the process of operational use of book blocks sewn with threads.

Therefore, these circumstances indicate the existing shortcomings of the proposed method. The main purpose of the information model of the root part of the book block is to develop its (or its components) estimation scheme. Therefore, further research will be aimed at the development of estimation schemes for the elements of the root part of the book block, followed by the creation of appropriate simulation models for specified scenarios of consumer exploitation.

7. Conclusions

1. An information model and a scheme for determining the mutual influence of operational parameters on the root adhesive polymer plate in the structure of which stitches of threads with pre-tension are implanted have been developed. A distinctive feature of the model is that it is based on an object-oriented approach to conducting simulation computational experiments. In accordance with it, the peculiarities of the formation of W-shaped adhesive edging composite plates have been identified.

Unlike composite plates, in which the reinforcing fibers are dispersed proportionally in the thickness of the plate, stitches of stitching threads are only partially implanted into the structure of the W-shaped adhesive plate. The rest of the stitches of the threads are located outside the adhesive plate, preserving the integrity of the stitching joint with the implanted part. In accordance with this, the stages of the elastic-deformed state of the plate in the process of its operational bending and the factors influencing its transformation were determined.

2. Simulation modeling was carried out on the basis of formalization of the description of the mutual influence of deforming parameters of W-shaped adhesive root plates reinforced with stitches of threads with pre-tension. The dependence of the delamination of the adhesion joint, which occurs in the direction of the vectors of destructive forces with a change in the angles between the stitches of the threads and the adhesive plate, was built. It was established that the closer the directed loads, the vectors of which approach the angles of 45° and 135°, the more intense the process of accumulation of residual cyclic deformation in the adhesive plate. A scheme for the formation of the strength of the root adhesive plate reinforced with stitches of threads with pre-tension under cyclic load has been developed. A comparison of the angular rupture forces of book blocks depending on the thickness of the adhesive layer found that in the case of using PVAD D51C adhesive, the discrepancy is in the range of 0.735–0.907, and in the case of Technomelt GA 3636 thermal glue, the discrepancy is 0.913–0.940.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

References

1. Kyrychok, P., Paliukh, O., Oliynyk, V. (2020). Determining the influence of the thickness of an adhesive layer on a change in the angles of contact and tangent angles. Eastern-European Journal of Enterprise Technologies, 3 (1 (105)), 52–67. doi: https://doi.org/10.15587/1729-4061.2020.203439
2. Shtefan, E., Pashchenko, B., Blagenko, S., Yastreba, S. (2018). Constitutive Equation for Numerical Simulation of Elastic-Viscous – Plastic Disperse Materials Deformation Process. Advances in Design, Simulation and Manufacturing Proceedings of the International Conference on Design, Simulation, Manufacturing: The Innovation Exchange, DSMIE–2018. Springer International Publishing AG. Part of Springer Nature, 1, 356–363. doi: https://doi.org/10.1007/978-3-319-93587-4_37
3. Petković, G., Pasanec Preprotić, S., Vukoje, M. (2018). The quality assessment of bookbinding strength for polyvinyl acetate adhesive (PVAc) and nano-modified PVAc adhesives. Proceedings of 9th International Symposium on Graphic Engineering and Design. doi: https://doi.org/10.24867/grid–2018-p13
4. Mukhurova, E. A., Gaiduk, S. S., Shetko, S. V. (2014). Uvelichenie prochnosti kleevogo soedineniia aktiviruiushchei obrabotkoi poverkhnostei skleivaniia. Trudy BGTU, 2 (166), 125–127.
5. Jaafar, J., Siregar, J. P., Mohd Salleh, S., Mohd Hamdan, M. H., Cionita, T., Rihayat, T. (2019). Important Considerations in Manufacturing of Natural Fiber Composites: A Review. International Journal of Precision Engineering and Manufacturing-Green Technology, 6 (3), 647–664. doi: https://doi.org/10.1007/s40684-019-00097–2

6. Kaushik, V. K., Kumar, A., Kalia, S. (2013). Effect of Mercerization and Benzoyl Peroxide Treatment on Morphology, Thermal Stability and Crystallinity of Sisal Fibers. International Journal of Textile Science, 1 (6), 101–105. doi: https://doi.org/10.5923/j.textile.20120106.07
7. Slotska, L. S., Zatserkovna, R. S. (2018). The research of adhesive films' physical-mechanical features during gluing of spines of book blocks, sewn with threads. Printing and Publishing, 2 (76), 20–26. doi: https://doi.org/10.32403/0554-4866-2018-2-76-20-26
8. Karthikeyan, S., Rajini, N., Jawaid, M., Winowlin Jappes, J., Thariq, M., Siengchin, S., Sukumaran, J. (2017). A review on tribological properties of natural fiber based sustainable hybrid composite. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 231 (12), 1616–1634. doi: https://doi.org/10.1177/1350650117705261
9. Suriani, M. J., Rapi, H. Z., Ilyas, R. A., Petrů, M., Sapuan, S. M. (2021). Delamination and Manufacturing Defects in Natural Fiber-Reinforced Hybrid Composite: A Review. Polymers, 13 (8), 1323. doi: https://doi.org/10.3390/polym13081323
10. Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composite and Its Applications. International Journal of Polymer Science, 2015, 1–15. doi: https://doi.org/10.1155/2015/243947
11. Khalid, M. Y., Imran, R., Arif, Z. U., Akram, N., Arshad, H., Al Rashid, A., García Márquez, F. P. (2021). Developments in Chemical Treatments, Manufacturing Techniques and Potential Applications of Natural-Fibers-Based Biodegradable Composites. Coatings, 11 (3), 293. doi: https://doi.org/10.3390/coatings11030293
12. Abral, H., Ariksa, J., Mahardika, M., Handayani, D., Aminah, I., Sandrawati, N. et. al. (2020). Transparent and antimicrobial cellulose film from ginger nanofiber. Food Hydrocolloids, 98, 105266. doi: https://doi.org/10.1016/j.foodhyd.2019.105266
13. Petryashvyly, H. H. (2007). Matematycheskaia model napriazhenno-deformyrovannoho sostoianyia kleevoho soedynenyia knyzhnoho bloka. Polihrafiia i vydavnycha sprava, 1 (45), 181–185.
14. Havenko, S. F., Lohaziak, I. Yu., Turiab, L. V. (2012). Doslidzhennia faktoriv vplyvu na kuty rozkryvannia knyzhkovykh blokiv. Tekhnolohiia i tekhnika drukarstva, 1, 67–73. Available at: http://nbuv.gov.ua/UJRN/Titd_2012_1_12
15. Kyrychok, P., Paliukh, O. (2020). Simulation of Deformation of the Adhesive Layer of the Spine of the Book Back of the Thread-Stitched Book Block. Mechanics, 26 (2), 114–119. doi: https://doi.org/10.5755/j01.mech.26.2.25854
16. Hetman, I. A., Vasylieva, L. V. (2017). Tekhnolohii proektuvannia informatsiinykh system. Computer Sciences and System Sciences (CS&SS–2017), 76–79. Available at: http://dspace.puet.edu.ua/bitstream/123456789/5499/1/09%20%D0%93%D0%B5%D1%82%D1%8C%D0%BC%D0%B0%D0%BD%20%D0%92%D0%B0%D1%81%D0%B8%D0%BB%D1%8C%D1%94%D0%B2%D0%B0.pdf
17. Senkivskyi, V. M., Pikh, I. V., Senkivska, N. Ye. (2016). Theoretical bases of quality assurance of publishing and printing processes (Part 1: introduction general principles). Naukovi zapysky Ukrainska akademiia drukarstva, 1 (52), 22–31. Available at: http://nbuv.gov.ua/UJRN/Nz_2016_1_4