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RESEARCH OF CHANGES OF STRENGTH INDICATORS OF SEMI-RIGID COVERS GLUED BY MODIFIED ADHESIVE COMPOSITIONS

Об'єктом дослідження є процеси отримання модифікованих клейових композицій, на основі PVA (полівініл-ацетатних) дисперсій, для використання в технологічних процесах виготовлення напівжорстких книжково-журнальних обкладинок. Проведені експериментальні дослідження ґрунтуються на застосуванні порівняльної методики визначення розривної міцності склеєних, без зсуву, зразків палітурних матеріалів, за допомогою модифікованих клейових композицій та тотожних композицій без модифікування. Основне припущення дослідження полягає в тому, що використання полімерних згущувачів і емульгаторів, сумісних з PVA латексами, які активно використовуються в технологічних процесах папероробної та поліграфічної галузей, сприятимуть утворенню додаткової міцності напівжорстких обкладинок. Цього не можливо досягнути без аналізу та обирання можливих компонентів, з врахуванням механічних властивостей, що виникають після застосування таких модифікаторів, які суттєво залежать від адгезійної міцності між матеріалом зовнішньої частини обкладинки та клейовою сполучною. Запропоновано для експериментального дослідження використання речовин з високими адгезійними властивостями до щільних крейдованих паперів і тонких палітурних картонів, із яких виготовляють напівжорсткі книжково-журнальні обкладинки. Визначені структурні особливості клейових плівок, отриманих з полі-вініл-ацетатного латексу, які мають поліпшену гнучкість, пружність, високу адгезію та водостійкість в тому випадку, коли до них додані водорозчинні модифікатори. Забезпечено експериментальне визначення можливостей підвищення структурної міцності напівжорстких книжково-журнальних обкладинок, після склеювання модифікованими палітурними клеями, що суттєво не збільшують товщину клейового шару та не змінюють контурну геометрію виготовлених обкладинок. Доведено, що клейові суміші, використані для модифікування PVA дисперсії, не вплинули на структурну однорідність склеєної просторової конструкції напівжорстких обкладинок, і не вплинули на появу зовнішніх дефектів у вигляді площинної неоднорідності, або точкових потовщень поверхні обкладинок. Отримані результати досліджень склеювання конструктивних деталей розгорток напівжорстких обкладинок модифікованими клейовими композиціями створюють додаткові можливості в плануванні використання витратних матеріалів, при виготовленні обкладинок, для отримання показників міцності, за попередньо визначеними розмірними умовами застосування речовин-модифікаторів. Експериментальні дослідження показали дискретність – зростання, падіння розмірних показників міцності напівжорстких обкладинок, склеєних модифікованими клейовими композиціями, що сприяє практичному застосуванню отриманих результатів, як в плануванні технологічних процесів, так і в розрахунках собівартості книжкової продукції.

Ключові слова: *ПВА (полі-вініл-ацетатні) дисперсії, напівжорсткі обкладинки, клейові композиції, показники міцності.*

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1. Introduction

Semi-rigid glued covers, as an innovative type of book frames, correspond to the properties of representativeness and hardness inherent in binding, although they are manufactured using simplified edged cover technologies significantly lower than cost [1]. One of the significant advantages of joining materials due to the use of adhesive polymer compositions, as shown in the results of studies [2], is the ability to adhere materials according to the physicochemical parameters without significant changes in their geometric and volume structure. The advantages of using adhesive polymer compositions are confirmed [3] by improving the strength indicators of glued products, as well as their indicators of resistance to destructive factors, reduce the duration of use and storage. It is possible to note that in the printing industry there is a tendency for a quantitative increase in book titles with a simultaneous reduction in their circulation [4]. Insignificant circulations of books made include the introduction of manufacturing techniques for simplified ergonomic and resource-saving covers, as well as the widespread use of

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non-sewn adhesive gluing of book blocks [5]. Let's consider the glued three-layer structure of a semi-rigid cover as an anisotropic composite medium in which the external – front and back parts are formed by binding materials from which the blank of the workpiece is carved [6]. And the inner part is filled with an adhesive polymer composition, the thickness and physico-chemical properties of which, together with binding materials, create a cover, with strength and hardness indicators substantially close to those in binding [7, 8]. A change in the thickness of the adhesive layer in the inhomogeneous anisotropic structure of the semi-rigid cover significantly affects the change in strength indicators, both up and down [9, 10]. In the process of gradual wear of materials under the influence of destructive loads, the specific interaction of the adhesive composition with the material of the outer part of the cover significantly affects the strength, structural density and wears resistance of the adhesive composition [11]. The operational stability and resource of use of the adhesive polymer composition depends and can change with fluctuations in the thickness and structural geometry of the semi-rigid cover [12]. For the manufacture of semi-rigid covers, only a part, albeit substantial, of binding materials is used, such as thin cardboards, chrome ersatz cardboards, dense coated papers (250–350 g/m^2), etc. Such materials ensure the integrity of the spatial geometry of the manufactured covers, without cracking at the folds. Therefore, to increase the strength and hardness of semi-rigid covers, the direction of increasing the thickness of binding materials is limited and not very promising for experimental studies. At the same time, the technology for modifying adhesive polymer compositions, by which structural parts of semi-rigid covers are glued, allows to keep the adhesive thickness unchanged compared to the use of adhesive compositions without modification [13, 14]. At the same time, they improve the physico-mechanical characteristics of the covers in strength, hardness and operational stability. Thus, *the object of research* is the processes for producing modified adhesive compositions based on PVA (poly-vinyl acetate) dispersions for use in technological processes for the manufacture of semi-rigid book and magazine covers. *The aim of research* is to experimentally determine the possibilities of increasing the structural strength of semi-rigid book and magazine covers after gluing with modified binding adhesives, which do not significantly increase the thickness of the adhesive layer and do not change the contour geometry of the manufactured covers.

2. Methods of research

The conducted experimental studies are based on the application of a comparative method [6] for determining the tensile strength of binding materials glued without bias, using modified adhesive compositions and identical compositions without modification. The main assumption of research is that the use of polymer thickeners and emulsifiers compatible with PVA latex, which are actively used in technological processes of the paper and printing industries, contribute to the formation of additional strength of semi-rigid covers [15]. This can be achieved after analysis and the selection of possible components, taking into account the mechanical properties that arise after the use of such modifiers, which substantially depend on the adhesive strength between the material of the outer part of the cover and the adhesive binder. Therefore, for experimental use, substances with high adhesive properties should be used for thick coated papers and thin binding boards [16], from which semi-rigid book and magazine covers are made. When planning an experimental study, in the preparation and testing of modified adhesive compositions, it was taken into account that films obtained from PVA latex have improved flexibility, elasticity, high adhesion and water resistance when water-soluble modifiers are added to them. The list proposed by the authors of thickeners and emulsifiers compatible with the dispersion of PVAD DF 51/15B as the basis for modification for experimental studies of the formulation of polymer mixtures is given in Table 1.

Table 1

Base and modifiers for experimental research

Code	Base for modification	Properties
N1	PVAD DF 51/15V	Polyvinyl acetate latex, a colloidal solution of high molecular weight polymer in water. High adhesion to paper, cardboard and artificial binding materials, resistant to external factors
N2	starch	A mixture of amylose and amylopectin polysaccharides, the monomer of which is alpha-glucose. It is applied in the pulp and paper industry
N3	carboxymethyl cellulose (CMC)	Cellulose glycolic acid. It is used to increase viscosity, as a binder, plasticizer, as well as delay set time, as an auxiliary agent
N4	cellulose powder	A finely divided cellulose degradation product, consists of particles that are aggregates of cellulose microcrystal. Determinants for use are morphology, microporosity of particles (1–500 microns), highly developed active surface, due to the degree of polymerization
N5	kaolin	Used as filler in the paper industry for coating especially high quality paper grades

Given the promise of improving the physic-mechanical properties of adhesive joints, through the modification of the adhesive base PVAD DF 51/15B (N1, Table 1) with highly dispersed particles, the introduction of even a small amount of highly dispersed modifiers leads to a significant change in the properties of the resulting adhesive composition. The additives listed in Table 1 lead to a change in the properties of semi-rigid covers, such as polymer composite structures, and the appearance of properties characteristic of finely dispersed particles. There is an improvement in the strength and cure rates of modified adhesive compositions compared to unmodified ones. This is especially important when using such adhesive compositions in high-speed brochure and palette equipment.

3. Research results and discussion

For the manufacture of semi-rigid covers, with significantly improved indicators of hardness and strength, modified polymer adhesive polyvinyl acetate latex compositions PVAD DF 51/15B are used (N1, Table 2). For this adhesive composition, it is necessary to provide an experimentally defined range of proportionality in the use of components selected according to the technological properties. Long-term tests of formulated mixtures, bases and

modifiers have determined the weight range of the content of each substance in the final adhesive composition for use in the manufacture of semi-rigid covers (10 options listed in Table 2).

Modified adhesive polymer compositions obtained as a result of experimental studies, in the general prescription case, can be represented as:

$$PK_{\Sigma1} = N1(100) + N2(27.6) + N3(7.4) + N4(3.5) + N5(31.5) + H_2O(110),$$

$$PK_{\Sigma2} = N1(100) + N2(28.6) + N3(6.4) + N4(11.6) + N5(23.4) + H_2O(100),$$

$$PK_{\Sigma3} = N1(100) + N2(31.8) + N3(8.2) + N4(4.0) + N5(36.0) + H_2O(110),$$

$$PK_{\Sigma4} = N1(100) + N2(32.4) + N3(7.6) + N4(13.3) + N5(26.7) + H_2O(110),$$

$$PK_{\Sigma5} = N1(100) + N2(37.5) + N3(7.5) + N4(8.0) + N5(72.0) + H_2O(220),$$

$$PK_{\Sigma6} = N1(100) + N2(38.8) + N3(6.2) + N4(26.6) + N5(53.4) + H_2O(220),$$

$$PK_{\Sigma7} = N1(100) + N2(45.8) + N3(4.2) + N4(10.0) + N5(90.0) + H_2O(270),$$

$$PK_{\Sigma8} = N1(100) + N2(46.9) + N3(3.1) + N4(33.30) + N5(66.7) + H_2O(270),$$

$$PK_{\Sigma9} = N1(100) + N2(43.5) + N3(11.5) + N4(11.0) + N5(99.0) + H_2O(280),$$

$$PK_{\Sigma10} = N1(100) + N2(45.5) + N3(9.5) + N4(36.6) + N5(73.4) + H_2O(280),$$

where $PK_{\Sigma1}...PK_{\Sigma10}$ – selected, from the experimental array, modified polymer adhesive compositions based on the dispersion PVAD DF 51/15B (N1, Table 2), by which fragments of semi-rigid covers corresponding to the strength indices are glued, more than the strength indices of glued by PVA dispersion without modification.

Fig. 1, 2 show the graphical dependences of the weight constituents used to modify the adhesive polymer compositions based on PVA dispersion in order to increase the strength and hardness of the composite structure of semi-rigid covers.

The effect presented in Table 2, adhesive polymer compositions for the strength of semi-rigid covers were investigated on a tensile testing machine RMB-30-2M (Ukraine), with a maximum load force of 300 N (30.5 kgf). The mechanical system of the tensile testing machine complies with the test requirements of ASTM, ISO, DIN, TAPPI, GB, JIS, ANSI, etc.

Table 2

Weight range of modifiers for the manufacture of polymer adhesive compositions based on dispersion PVAD DF 51/15V

Components / Options	Modified polymer adhesive compositions, %									
	1	2	3	4	5	6	7	8	9	10
N1	100	100	100	100	100	100	100	100	100	100
Polymer composition A (PK-A) (PK-A = N2+N3) (Total amount)	35	35	40	40	45	45	50	50	55	55
N2	27.6	28.6	31.8	32.4	37.5	38.8	45.8	46.9	43.5	45.5
N3	7.4	6.4	8.2	7.6	7.5	6.2	4.2	3.1	11.5	9.5
Polymer composition B (PK-B = N4+N5) (Total amount)	35	35	40	40	80	80	100	100	110	110
N4	3.5	11.6	4.0	13.3	8.0	26.6	10.0	33.3	11.0	36.6
N5	31.5	23.4	36.0	26.7	72.0	53.4	90.0	66.7	99.0	73.4
H_2O	110	100	110	110	220	220	270	270	280	280
Temperature, °C (PK-A+PK-B+H_2O)	35	35	35	35	45	45	65	65	85	85
Rotary press rolls temperature, °C	80	80	85	85	105	105	130	130	135	135

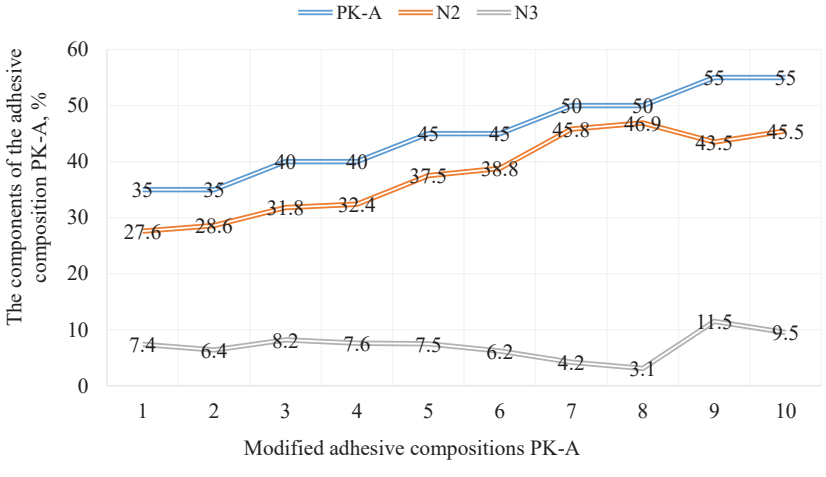

Fig. 1. Weight components N2 and N3 in the adhesive composition PK-A

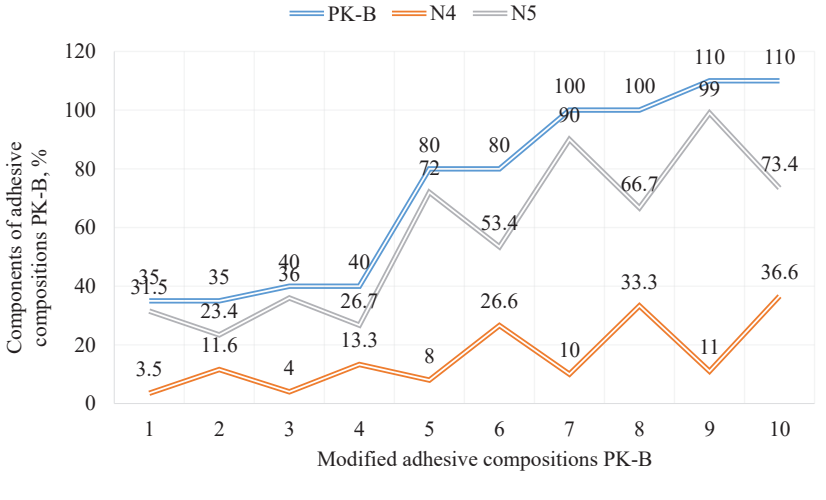

Fig. 2. Weight components N4 and N5 in the adhesive composition PK-B

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For testing, the fragments of glued covers are selected, which are strips of thin cardboard chrome ersatz, 0.6 mm thick, 100 mm long and 15 mm wide [1].

The samples are glued in two directions: using PVAD DF 51/15B dispersion (N1, Table 2) without modification, as well as using modified adhesive polymer compositions based on the specified PVA dispersion. The research results are listed in Table 3. Numbering of options of modified adhesive mixtures in Table 3 corresponds to the numbering with Table 2.

A comparative analysis of tensile strength indicators demonstrates an increase in the strength glued by fragments of modified adhesives from 4.8 %, in position 2 (Table 2), to 12.2 %, in position 10 (Table 2), in contrast to glued fragments by dispersion of PVAD DF 51/15B (N1, Table 2) without modification.

Growth of indicators, according to the graph in Fig. 3, is carried out not in a proportional sequence, but in a discrete one, with separate sections of growth and fall. This requires further studies of the structural features of semi-rigid covers, the details of which are glued with modified adhesive polymer compositions.

The most favorable for use were modified adhesive polymer compositions based on PVAD DF 51/15B, indicated in Tables 2, 3 positions 7, 8, 9, 10, with significant results involved an increase in the strength of covers, in tension, by 9.8 %, 10.9 %, 11.3 %, 12.2 %. Additionally, it is necessary to note some positive features of the formed polymer adhesive compounds.

The high porosity and friability of powder pulp particles (N4, Table 2), which is used in addition to using a mineral additive in the form of kaolin in the mixture (N5, Table 2), provides a significant decrease in the content of water in the non-aligned state in the adhesive mixture. And this, in turn, contributes to a uniform and rapid thickening of the polymer adhesive composition.

Due to the dispersing component, which is powder cellulose (N4, Table 2), it is possible to ensure stable homogenization and structuring of the constituents of the adhesive mixture in a bulk mass.

As a result of this, conditions are created for a completely-uniform deposition of a layer of adhesive composition, without the formation of clots, unjustifiably thin adhesive sections and planar tears.

4. Conclusions

As a result of experimental studies of glued fragments of semi-rigid covers with modified polymer adhesive compositions based on dispersion PVAD DF 51/15B, an increase in strength indicators is noted. Growth is fixed depending on the weight proportionality of the substances used for the modification, compared with the glued fragments of the covers of the compositions without modification. The growth of tensile strength indices for fracture of cover fragments glued by experimental modified adhesives ranges from 4.8 % to 12.2 %, unlike glued fragments by dispersion of PVAD DF 51/15B, without modification.

The highest tensile strength was found in glued cover fragments with the following adhesive composition: N1 – dispersion PVAD DF 51/15B (100 %), N2 – starch (45.5 %), N3 – carboxymethyl cellulose (9.5 %), N4 – cellulose powder (36.6 %), N5 – kaolin (73.4 %), H_2O (280 %).

The features of applying modified adhesive compositions to the structural elements of semi-rigid covers are revealed, which indicate the absence of a significant increase in the thickness of the adhesive layer, and the absence of influence on the change in the contour geometry of the manufactured covers.

During experimental studies, it was proved that the adhesive mixtures used to modify the PVAD DF 51/15B dispersion did not affect the structural uniformity of the glued spatial structure of the semi-rigid covers. And also did not affect the appearance of external defects in the form of planar inhomogeneity, or point thickenings of the surface of the covers. Modified adhesive compositions are recommended for use based on PVAD DF 51/15B, indicated in the Tables 2, 3 with positions 7, 8, 9, 10, with significant results involved an increase in the strength of covers, in tension, by 9.8 %, 10.9 %, 11.3 %, 12.2 %.

The obtained research results create additional opportunities in planning the use of consumables, in the manufacture of semi-rigid covers for taking into account strength indicators, predefined dimensional conditions for the use of modifier substances.

Experimental studies have shown discreteness – growth, drop in the strength indicators of semi-rigid covers glued with modified adhesive compositions, contributes to the targeted use of the results, both in the planning of technological processes and in the calculation of the cost of book production.

Table 3

Strength indices of glued fragments of semi-rigid covers

Adhesive polymer compositions	PVAD DF 51/15B	Modified PVAD DF 51/15B – options									
		1	2	3	4	5	6	7	8	9	10
Tensile strength, kgf/cm	20.13	21.34	21.09	21.24	21.43	21.86	21.62	22.10	22.32	22.40	22.59

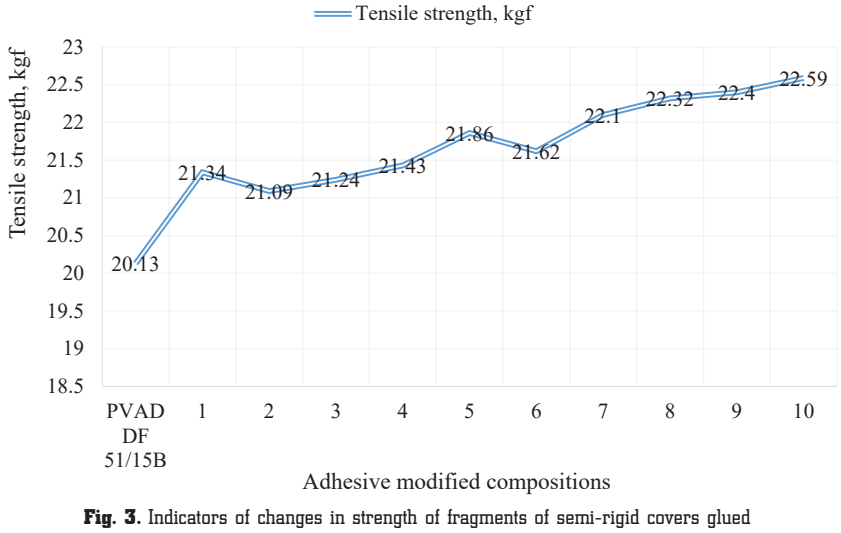

Fig. 3. Indicators of changes in strength of fragments of semi-rigid covers glued with modified adhesives

References

1. Kyrychok, P. O., Paliukh, O. O. (2019). Pat. No. 134723 UA. *Napivzhorstka knyzhkovo-zhurnalna obkladynka dlia kryttia blokiv, pidibranykh pozoshytno i proshytykh nytkamy, okantovanykh i obrizanykh z trokh storin*. MPK: V42D 3/00. declareted: 16.05.2018; published: 10.06.2019, Bul. No. 11.
2. Arnett, J. A. (2019). The Art of Bookbinding. *Bibliopegia; or, The Art of Bookbinding in All Its Branches,* 1–8. doi: http://doi.org/10.4324/9780429030420-1
3. Chen, K.-N. (2019). Polymer Adhesive Bonding. *Encyclopedia of Packaging Materials, Processes, and Mechanics,* 1–13. doi: http://doi.org/10.1142/9789811209680_0001
4. Wilson-Higgins, S. (2018). *Trends in book manufacturing on-demand*. The Impact of Print-On-Demand on Academic Books, 119–132. doi: http://doi.org/10.1016/b978-0-08-102011-1.00009-2
5. Havenko, S. F. (2012). Kynetyka poshkodzhennia i ruinuvannia kleiovykh ziednan pry ekspluatatsii. *Polihrafiia i vydavnycha sprava, 3,* 91–96.
6. Paliukh, O. O. (2017). Eksperymentalne vyznachennia mitsnosti skleienykh zrazkiv paperu i kartonu dlia vyhotovlennia knyzhkovo-zhurnalnykh obkladynok i paliturok riznykh konstruktsii. *Tekhnolohiia i tekhnika drukarstva, 4,* 11–24.
7. Havenko, S. F., Kulik, L. Y., Koniukhova, I. I. (1998). Pat. No. 23330 UA. *Kleiova kompozytsiia*. MPK: B42C 9/00. declareted: 23.04.1996; published: 31.08.1998, Bul. No. 4.
8. Koniukhova, I. I., Havenko, S. F., Onishchenko, T. I. (1998). Pat. No. 23331 UA. *Kleiova kompozytsiia*. MPK: B42C 9/00. declareted: 23.04.1996; published: 31.08.1998, Bul. No. 4.
9. Havenko, S. F., Koniukhova, I. I., Fedorova, V. O., Tkachuk, V. O. (1998). Pat. No. 23329 UA. *Kleiova kompozytsiia*. MPK: B42C 9/00. declareted: 23.04.1996; published: 31.08.1998, Bul. No. 4.
10. Odukha, M. A., Yushchenko, O. A., Velychko, O. M. (2006). Pat. No. 76065 UA. *Kleiova kompozytsiia na osnovi polivinilovoho spyrtu*. MPK: B42C 9/00. declareted: 25.01.2005; published: 15.06.2006, Bul. No. 6.
11. Clark, T. (2007). *Bookbinding with adhesives*. GRAW-HILL Book Company Europe, 53.
12. Jerman, P. *Reflections on Book Structure-Part 3-Spine Control*. Available at: https://www.pinterest.com/pin/194358540139328159/
13. Gaiduk, S. S. (2012). Issledovanie prochnosti i vodostoikosti kleevykh soedinenii na osnove PVA-dispersii. *Trudy BGTU. Lesnaia i derevoobrabatyvaiuschaia promyshlennost, 2,* 172–174.
14. Krivoshei, V. N., Primakova, L. A. (2002). Krakhmalnii klei dlia gofrokartona. *Tara i upakovka, 1,* 68–69.
15. Tretiak, P. P., Herasymenko, I. I., Yakovenko, V. P. (2003). Pat. No. 56521 UA. *Kleiova kompozytsiia dlia skleiuvannia derevynnykh vyrobiv, paperu i kartonu*. MPK: 7C09J 103/00. declareted: 08.07.2002; published: 15.05.2003, Bul. No. 5.
16. Kibirkstis, E., Havenko, S., Gegeckienė, L., Khadzhynova, S., Kadyliak, M. (2019). Influence of Structure and Physical-Mechanical Characteristics of Threads on the Strength of Binding the Books. *Mechanics, 25 (4),* 313–319. doi: http://doi.org/10.5755/j01.mech.25.4.22774

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