http://www.moderntechno.de/index.php/meit/article/view/meit25-01-012
DOI: 10.30890/2567-5273.2023-25-01-012

UDC 621.798:620.197.3

MATERIAL SCIENTIFIC ASPECTS OF CARDBOARD CONTAINERS

МАТЕРІАЛОЗНАВЧІ АСПЕКТИ КАРТОННОЇ ТАРИ

Kolianovska L./Коляновська Л.
C.t.s., senior lecturer / К.т.н., старший викладач
ORCID: 0000-0002-8645-3515
Vinnytsia National Agrarian University (Vinnytsia, Ukraine) /
Вінницький національний аграрний університет (Вінниця, Україна)

Abstract. *Almost all enterprises that use corrugated cardboard boxes for packaging their products face problems of transportation and storage. The main factor influencing the quality of cardboard during operation is the deformation and destruction of materials under the action of applied forces - these are the main phenomena that determine the mechanical behavior of materials.*

The paper analyzes the main properties that form the quality of corrugated cardboard. The fiber of technical cellulose is characterized by six properties. These are the average fiber length, the ability to compact in the wet state, the actual strength of the fiber, the cohesive ability, the coarseness of the fiber and the ability to grind.

We also conducted a study on the effect of humidity on corrugated board samples. The strength properties of corrugated board samples were determined and the effect of humidity on them was studied.

Attention is focused on the evaluation of the influence of fiber properties on the cardboard property. This property is defined as the "critical" fiber length.

Recommendations are proposed to reduce the likelihood of corrugated cardboard consumer claims related to the collapse or subsidence of corrugated boxes during stacking.

Key words: *corrugated board, humidity, properties, strength.*

Introduction.

Before the military invasion of the "country on the swamps" into the territory of sovereign Ukraine, the production of paper and cardboard consisted of about 200 enterprises.

Thus, Kharkiv region - 41; the city of Kyiv - 31; Dnipropetrovsk region - 18; Zhytomyr region - 16; Lviv region - 11; Odesa region - 9; Volyn region - 8; Kyiv region - 8; Zaporizhzhya region - 6; Rivne region - 5; Ivano-Frankivsk region - 5; Kirovohrad region - 4; Kherson region - 4; Kherson region - 4; Khmelnytsky region - 4; Transcarpathian region - 4; Cherkasy region - 3; Ternopil region - 3; Luhansk region - 3; Donetsk region - 3; Crimea - 2; Chernivtsi region - 2; Chernihiv region - 1; the city of Sevastopol - 1; Vinnytsia region - 1; Mykolaiv region - 1; Sumy region - 1.

Paper and cardboard production in Ukraine in January-May 2022 decreased by 44.7% compared to the same period in 2021 - to 198.2 thousand tons, corrugated packaging - by 57%, to 126.9 million square meters. This was reported by Interfax-Ukraine with reference to the data of the UkrPapir Association [11,27].

According to her, if in January this year, the production of paper and cardboard lagged behind the last year's by 4.6%, and corrugated boxes exceeded by 3.5%, then in January-March, taking into account the suspension of many enterprises with the beginning of the full-scale war of the Russian Federation against Ukraine, the production of these products decreased by 44% and 54%, respectively.

At the same time, some enterprises that stopped their work at the beginning of the war have not resumed it - in particular, due to the destruction in Rubizhne, the largest Ukrainian producer of corrugated packaging - Rubizhne Cardboard and Packaging Plant - has stopped working (but its "daughter" in the Kyiv region - Trypillia Packaging Plant - is working) [11,27].

Also, the damaged Rohan Cardboard Factory in Kharkiv region has not resumed work (and does not plan to).

Among the producers of corrugated packaging, Dunapak Tavria LLC, located in Kherson region (produced boxes for Nova Poshta), is also not working, and Mena Pak in Chernihiv region, according to the information available to the Association, was able to resume work in May.

After three months of forced downtime in May, Zmiiv Paper Mill (Kharkiv region) reported the production of 1863 tons of recycled paper against 783 tons in May-2021.

At the same time, after the February suspension of production, the industry leader Kyiv Cardboard and Paper Mill (the second after Rubizhne PPM in corrugated packaging production last year), Zhydachiv Pulp and Paper Mill (Lviv region) and Izmail Cardboard Mill (Odesa region), Malyn Paper Mill and Paper-Mal (Zhytomyr region) have been operating since March.

In addition, according to the statistics, the Lviv Cardboard and Paper Company did not stop working, keeping the production of paper and cardboard in January-May at the level of the previous year, Poninkiv (Khmelnytsky region) and Lutsk (Volyn region) cardboard and paper mills, Kokhavyn paper mill (Lviv region) [11,27].

According to the production method, European and Ukrainian producers divide cardboard and cardboard products into four main types.

1. Cardboard of SBB class (SBS). This type of cardboard is a coated cardboard made of bleached pulp, which we have repeatedly mentioned in our articles. SBS class cardboard consists of 2-4 layers. The main feature of this type of cardboard is the presence of two coated layers. Thus, the front and back sides of SBB cardboard are always chalked. This type of cardboard has not only an average specific weight, but also the best printing properties. Such features and properties directly affect the scope of application of this type of cardboard. SBB cardboard is the main packaging material for the manufacture of luxury products in various industries. For example, SBS cardboard is actively used for packaging expensive perfumes, tobacco products and many types of food products and dishes.

2. SUB class cardboard. SUB class cardboard is a pure cellulose chalkboard made of unbleached cellulose. An interesting feature of this type of cardboard is its use in the manufacture of kraft paper, which is also a common packaging material as such. Due to this, the front side of the SUB class cardboard has a brown color. The main field of application of this type of cardboard is the packaging of frozen and chilled products, detergents, various types of shoes, toys and sets for children, as well as various food products.

3. FBB class cardboard. FBB cardboard is a boxboard or chrome-erzac cardboard designed primarily for the manufacture of containers. This type of cardboard consists of 3, rarely 4 layers. The upper and lower layers are made of

bleached pulp, and the middle layer is made of mechanical pulp, which we described in previous articles. The coating is applied, of course, on the top layer and usually has a white or cream color. The material used for the manufacture of this type of cardboard must have a low specific gravity and a high index of cruelty. Due to this, FBB cardboard is used in the confectionery, pharmaceutical and tobacco industries, as well as for packaging frozen and chilled products.

4. WLC class cardboard. The last type of cardboard that will be discussed today. WLC cardboard is a cardboard consisting of 3-4 layers containing at least 60% waste paper. The top layer usually consists of the highest quality waste paper. WLC cardboard is used to make packaging for shoes, toys, children's construction sets, etc. Also, some companies use WLC cardboard to make packaging for frozen or chilled products and some types of cereals. However, it should be noted that according to sanitary standards, this type of cardboard should not be allowed to come into direct contact with food due to the raw materials used in its manufacture. But the use of food stretch film for packaging products makes it possible to comply with sanitary standards and use WLC cardboard for packaging products [1-5, 31].

The evolution of cardboard manufacturing technology continues. Every year there are new know-how related either to material science and improving the quality of cardboard, or to other technical aspects of the production of this type of packaging material.

Main text. The main factor influencing the quality of cardboard during operation is the deformation and destruction of materials under the action of applied forces - these are the main phenomena that determine the mechanical behavior of materials.

Cardboard is a complex object for the analysis of properties, because, possessing only its inherent features, it shows at the same time the features of polymeric and composite material.

The basic ideas about the structure of cardboard can be reduced to the following:

- cardboard is a set of fibers that differ significantly in length and have differences in thickness; characteristic is the difference in strength of individual components of the structure (fibers) and the bonds between the fibers. This determines the whole range of physical and mechanical properties of cardboard as well as all fibrous pulp and paper materials;
- specific features of the mechanical behavior of cardboard are determined by the flexibility of the fibers, which is determined by many factors. Thus, the structure of the paperboard is determined primarily by the properties of the fibers and the bonding forces between the fibers.

The paper structure is composed of fibres and fibre fragments (it should also be remembered that other components of the paperboard composition, including fillers and various chemical additives, will influence the properties of the paperboard). Fibre material is the most heterogeneous of these components. It is believed that the fiber of technical pulp can be characterized by six properties [17-25]. These are the average fiber length, the ability to compact in the wet state, the fiber strength itself, the cohesive ability, the fiber coarseness and the grindability. In our opinion, the property defined as the "critical" fiber length is useful to evaluate the influence of fiber properties on the paperboard property.

The fibrous semi-finished product after cooking contains a mixture of fibrous and non-fibrous elements of different lengths: from 0.1 to 5.0 mm and more. For the most part, these are tracheids - in the mass of coniferous wood, libriform and vessels - from deciduous wood. Elements of non-fibrous nature are present in the form of parenchymal cells, epidermal cells, fragments of fibers, vessels and are small in size particles, about 0.1 mm, which are partially removed with washing water during the washing of fibrous semi-finished products. Losses of small particles depend on anatomical elements, mesh number and washing intensity.

The length of the fibers is determined under a microscope or with the help of other optical devices and expressed in millimeters by arithmetic mean or weighted average. The arithmetic mean length of fibers is determined by dividing the total conditional length of all fibers by their number. When determining the weighted average length, the mass fraction of fractions with different lengths is taken into account.

The properties of paperboard are largely influenced by fiber properties such as elastic modulus, twisting, bending and microcompression. As a rule, paper pulp fibers have a full range of these deformations. The difference between twisting and bending is that fibers during twisting are bent to a lesser extent, while during bending there are sharp changes in the direction of the fiber segment and a larger bending angle. Microcompression is understood as large sections of the fiber with a violation of the surface structure.

One of the most important indicators of paper-forming properties of fibrous semi-finished product is fiber thickness. This indicator depends both on the morphological structure of the wood and on the method of obtaining the WFP. The idea of the thickness of the fibers will give, on the one hand, the ratio of the cross-sectional area of the fibers and their lumens, on the other - the degree of their delignification. The measure of thickness is the thickness of the cell membrane. J. Clark proposed to determine the thickness of the fibers by the mass of the conventional unit of their length, in milligrams of absolutely dry fibers [17-25]. The range of fiber coarseness of different fiber semi-finished products is in the range from 7 to 30 mg more per 100 m.

An example of coarse fibers are fibers obtained from late wood with thick shells and small cavity. During processing, they retain their round shape, giving the paper sheet its looseness. An example of elastic fibers are fibers obtained from early wood with thin shells and a large cavity. Such fibers during processing take the form of ribbons, forming a dense sheet.

There is a high correlation between the content of late wood fibers and mechanical strength. It should be noted that longer fibers are almost always coarser, semi-finished products from hardwood have less coarse fibers than semi-finished products from softwood [17-25].

Strength of fibers. Plant fibers have high mechanical strength, which is not inferior in most cases to the strength of metal. The strength of fibers can be determined directly by the breaking force related to the breaking area. However, for cellulose fibers, such a definition is time-consuming. Indirectly, the strength of vegetable fibers can be judged by the zero-breaking length, i.e. the breaking length of the paper obtained as a result of determining this indicator at zero distance between the clamps of the breaking machine. Zero breaking length is calculated in kilometers or meters. It is known that for hardwood pulp samples it is 4/10 and for softwood pulp samples 1/3 of the tensile strength of individual fibers [17-25].

The ability of the fibers to compact during the formation of a sheet of paper is also one of the most important vapor-forming properties. It determines the bound surface area of the fibers and the presence of air spaces between them and, consequently, the optical and strength properties of the paper.

The best characteristic of the ability of the fibers to compact is the density of the paper (the inverse value is the looseness). Density is calculated by the ratio of the mass of 1 m^2 of paper to its thickness, and is expressed in grams per centimeter cubed or kilograms per meter cubed. The main factors that determine this property are: the flexibility of the fibers, the thickness of their cell wall, the ability of the fibers to split into fibrils and acquire plasticity during the grinding process.

Grinding increases the flexibility and plasticity of the fibers, so as the degree of grinding increases, so does their ability to compact.

The bonding ability of the fibers is the most important factor in determining the strength of the paper sheet. Interfiber bonding forces are mainly characterized by hydrogen bonds, van der Waals forces and friction forces between fibers. The ratio between them is different and depends on the physical and mechanical properties of the fibers and the degree of their development during the grinding process. For example, in paper castings made from well-ground pulp, hydrogen bonds provide approximately 75% of the strength of all the bonds between the fibers, while in paper castings made from the same pulp not subjected to milling, they make up only 20%.

An important role in the formation of hydrogen bonds between the fibers is played by the surface tension forces of water, which pull thin and flexible fibers together and bring them into close contact with each other during the pressing and drying of the paper.

It is believed that the value of interfiber bonding forces is determined by the contact area between the fibers and the concentration of bonds on it or the specific bonding force per unit surface. The number of contacts between the fibers depends on the total length of the fibrous material in the sheet, the width of the fibers and their flexibility and does not depend on the length of the individual fibers. Cutting fibers during grinding, accompanied by their shortening, theoretically does not reduce the total number of contacts in the sheet, but only reduces the number of contacts of one fiber [28-32].

Nowadays, the method of determining the interfiber bonding forces proposed by Dr. J. Clark [17] is used.

The ability of fibrous semi-finished products to be milled. Grinding is one of the main operations in the preparation of paper pulp.

Its purpose is to give the fibrous semi-finished product a certain size of fibers in length and thickness, to provide the desired structure of the paper web and a certain degree of hydration, which largely determines the adhesion forces between them.

By changing the grinding mode: specific pressure, concentration and temperature of the mass, as well as the type of semi-finished products subjected to grinding and grinding equipment, it is possible to obtain different properties of the manufactured paper. Variable grinding factors are widely used in production.

To compare the properties of different semi-finished products, grinding and casting are carried out under standard conditions. In domestic practice, it is customary to use a laboratory centrifugal grinding machine for standard grinding, and a Rapid-type machine for casting.

To characterize the milled pulp, the degree of grinding, the time spent on grinding to achieve a certain degree of grinding, and indicators of the main paper-forming properties are used. A good idea of the milled semi-finished product will give its specific surface, which is closely related to the properties of the fibers of the raw material and depends on the methods of obtaining the semi-finished product.

An important effect of milling is to increase the flexibility of the fiber. Sometimes this can occur as a result of reduced interchange. Strong compression of the fibers can improve the mechanical strength by forming a "bristle" on the surface of the fibers. The change of shape in twisted and curved structures improves the adhesion in suspensions and paper. At the same time, it complicates molding.

Mechanical processing of fibers during grinding often also changes their geometric structure. The chemical structure may also change.

Ultimately, these changes lead to the splitting of the secondary wall after the formation of breaks in it as a result of grinding. The crystal structure of the fibers may be disturbed as a result of processing and the angles of the microfibrils in the wall may change. This in turn affects the mechanical strength of the finished paper fibers.

Pulp and paper material cannot be manufactured unless there is a sufficiently high level of interfibre bonds between the fibres in the structure. Thus, weak interfibre forces - Van der Waals forces and hydrogen bonds, as well as friction forces - are of great importance in paperboard production.

Van der Waals forces. The existence of these weak forces of attraction in the structure of the cardboard can be explained by two reasons: first, it is the presence of a permanent dipole in the molecules, that is, in the case of any polarized molecules in the case of simple electrostatic attraction of two dipoles, weak interaction forces arise; second, the interaction of dipole - induced dipole. The latter arises due to polarization of molecules by dipoles of surrounding molecules.

Hydrogen bonding. It is known that a hydrogen atom can simultaneously interact with two negatively charged atoms. In this case, the hydrogen atom serves as a bridge between the two particles and can be considered as the cause of the bond between the atoms. This bond is weaker than the covalent bond, but its presence affects many physical and structural properties of the material.

Mechanical adhesion of fibers (friction forces). The forces acting between tangent solids, generally speaking, are not applied along the normal to the interface of the tangent bodies. The acting force P, as a rule, is directed at an angle to the surface of contact of the fibers. The magnitude and direction of the acting force depends not only on the elastic properties of the fibers, but also on the state of the fiber surface (its roughness).

In the structure of the cardboard there is dry and liquid friction. The nature of the velocity dependence for friction forces between two solids and friction forces between a solid and a liquid (or gas) is completely different. The most significant difference in this difference is absolutely different behavior of these and other forces at low speeds.

Namely, in the case of a collision of solids, no matter how small the velocity of their relative motion, the frictional forces always have a finite value and retain a finite value when the relative velocity of motion falls to zero. In the case of a solid body colliding with a liquid or gas, the frictional and drag forces of the medium also decrease with decreasing velocity and fall to zero when the velocity of the body relative to the medium falls to zero [10, 12-16].

Micro- and macrostructure of cardboard Any material consisting of several substances is a system, the strength of which largely depends on three factors: adhesion, autogensis and cohesion.

Adhesion is the adhesion of two dissimilar liquids or solids. It is caused by the molecular forces of adhesion of dissimilar molecules in the surface layer of the contacting bodies (phases). These forces are called adhesion forces.

Autoghesis is the adhesion of homogeneous bodies. Unlike adhesion, self-adhesion is due to the molecular bonding between the surfaces of homogeneous bodies in contact. The forces of adhesion in this case are called the forces of autoghesis.

Cohesion is the adhesion of substance molecules to each other in the body volume. Cohesion is caused by a variety of forces: Van der Waals forces, chemical, hydrogen bonds, etc. These forces are called cohesive forces.

The nature of deformation of the material.

According to rheological properties, materials are divided into three main classes: linear-elastic, elastic-plastic and viscoelastic [10, 12-16].

A material is called linear-elastic if only instantaneous elastic deformations develop in it during the application of mechanical stress until critical conditions are reached. The material is called elastic-plastic if during its loading, along with instantaneous elastic deformations, instantaneous plastic deformations also develop. Depending on the volume of material involved in plastic deformation, there are two types of elastic-plastic materials - pseudoelastic and plastic. A material is called pseudoelastic if during its loading instantaneous elastic deformations develop in the main volume, and instantaneous plastic deformations are localized only near the tops of existing defects (cracks), and the length of the zone of these deformations is small compared to the length of the cracks. If, when mechanical stress is applied, instantaneous plastic deformations develop throughout (or almost throughout) the entire volume, then such a material is considered plastic. Plastic materials also include materials, during deformation of which intense plastic deformations develop at the tops of existing defects, and the length of the zone of these deformations exceeds 20% of the original crack length. Elastic-plastic materials, in which plastic deformations have the character of viscous flow (Eyring model), are called elastic-ecoplastic, or simply viscoplastic.

If during the loading of a material, at any load, along with instantaneous elastic deformations, inelastic deformations develop in it, the value of which depends on the duration or speed of

load, then such materials are called viscoelastic. Depending on whether the relationship between stress and strain rate is linear or nonlinear, linear and nonlinear viscoelastic materials are distinguished.

A viscoelastic material is considered to be ideal nonlinear-elastic, if during the application of mechanical load only reversible deformations develop in it - instantaneous elastic and time-dependent viscoelastic (elastic) deformations, and the sessile deformation of such a material occurs under the action of constant stress, then the reversible viscoelastic component of the deformation tends over time to some limit (equilibrium) value (Kelvin-Feucht model). In an ideal linear viscoelastic material, under the action of an applied stress, along with reversible (instantaneous elastic and time-dependent elastic) deformations, irreversible deformations of the ideal (Newtonian) flow also develop, which, under the action of a constant load, grow unlimitedly with time (Maxwell's model). In a nonlinear viscoelastic material, the flow deformations are Newtonian. The most complex is the behavior of the material in which viscoelastic deformations develop before or after the yield point or in the entire load range, depending on the duration or rate of loading.

The nature of the material fracture.

According to the nature of fracture, materials are usually divided into brittle and non-brittle. When assigning a material to a particular group, it is taken into account how the material element breaks when a crack passes through it. In general, each element of the material can be in one of the following states: solid, torn or intermediate between them.

A material is called ideally brittle if, upon reaching critical conditions, its elements adjacent to the surfaces (banks) of the crack immediately go from a solid state to a torn one. In this sense, ideally brittle can be a material with any deformation properties: linear-elastic, elastic-plastic, viscoelastic, etc.

A material is called non-brittle if, when it is loaded, the destruction of the elements adjacent to the crack banks occurs in two stages. At first (at loads less than critical), the elements of the material pass from a solid state to some intermediate state characterized by a local violation of continuity. For example, due to the accumulation of damage during the plastic deformation of metals and alloys, craze formation in polymers, multiple cracking of the matrix and its peeling from the filler in fibrous composite materials, etc. At the second stage, the elements of the material, upon reaching critical conditions, pass from an intermediate to a completely destroyed state. In this sense, materials with any rheological properties can also be non-brittle (viscous).

Phase structure of materials.

According to the phase structure, materials in crack mechanics are divided into homogeneous and heterogeneous. Homogeneous materials are characterized by homogeneity of composition and identity of properties throughout the volume. In contrast, heterogeneous materials consist of two or more phases, each of which is a homogeneous part of the system, separated from the other parts by a clearly defined interface and differs from them in composition and properties. According to their rheological properties, both homogeneous and heterogeneous materials can be linear-elastic, elastic-plastic or viscoelastic, and according to the nature of destruction - brittle or viscous.

Special methods of measuring resistance to deformation.

Consumer properties of corrugated cardboard and boxes depend primarily on the type and combination of properties of the source materials.

This fact is beyond doubt, but the question of what properties of paper and cardboard and the indicators that characterize them should be used is not unambiguously solved in world practice.

The analysis of international and regional systems of standards and technical specifications of foreign producers of containerboard allows us to conclude that there are significant differences in approaches to assessing the quality of linerboard and fluting, especially in comparison with the requirements of national standards [8,9].

Table 1 - Nomenclature of physical and mechanical characteristics of packaging cardboard

Quality Characteristics	Methods of Determination:			
	DSTU	ISO	TAPPI	SCAN
1. Weight 1m^2 , g (Grammage)	13199	535	T410	P6
2. Thickness, mm (Thickness)	27015	534	T411	P7
3. Bursting strength, kPa (Bursting strength)	13525.8	2758	T403	P24
4. Water absorbency of Cobb$_{60}$, g/m^2 (Cobb sizing)	12605	535	T441	P12
5. Ring crush force in transverse direction, N (RCT, Ring crush test)	10711	-	T818 T822	P24
6. Moisture % (Moisture test)	13525.19	287	T412	P4
7. Short span compression resistance, kN/m (SCT - Short span compression test)	-	9895	T826	P46
8. Gurley air permeability (porosity), s/100ml (Air permeance, Gurley)	-	5636/5	T460	P19 P53
9. Tensile strength (rigidity), N/m (Tensile stength (tensile stiffness - S_t))	-	1924/2	T494	P38
10. Stiffness at bending (stiffness bending - Sb): *static method* *resonance method*	-	 2493 5629	 - T535	 P29 P64
11. Strength in the z-direction (energy Internal bond stength), J/m^2 or J, (Internal bond stength)	-	-	T883 T541	P80
12. Dsnisson surface strength, wax composition number	-	-	T459	-

The mechanical strength of linerboard and corrugating paper is a crucial factor that determines their ability to be processed on a corrugating machine and the subsequent consumer properties of corrugated cardboard containers. It is important to note that the behavior of materials under mechanical stress consists of the ability to deform (stiffness during tension and bending, viscoelastic properties, stability, etc.

There are two types of loads on boxes: dynamic, due to impact during free fall, and static, caused by compression and tension during stacking and movement [12-16].

With the improvement of loading and unloading operations, the likelihood of dynamic loads has decreased significantly, while the requirements for the rigidity of containers have increased sharply. This is due to the fact that the capacity of vehicles and warehouses tend to increase by increasing the height of the stack.

A classification of products and products was developed according to their ability to perceive external static and dynamic loads with the subsequent extension of the established requirements to cardboard containers and cardboard for flat layers. According to this classification, the entire range of paperboard is divided into two types: rigid - for products that are not able to perceive external mechanical loads, and strength - for products that are able to perceive such loads without affecting their consumer properties.

Indicators of mechanical properties of corrugated cardboard components are regulated by national standards. Mechanical properties of paper for corrugating according to DSTU 7798:2021 Paper for corrugating. Technical specifications. are characterized by absolute resistance to punching (P); resistance to end compression of the corrugated sample in the transverse direction, determined by the CCT method (corrugated crush test); resistance to in-plane compression determined by the CMT method (concora medium test); specific tensile strength. The properties of the linerboard in accordance with DSTU GOST 9142:2019 are expressed by two mechanical indicators - absolute resistance to pressing (P) and the destructive force during compression of the ring in the transverse direction, determined by the RCT (ring crush test) method.

Analysis of standard methods used by European consumers to characterize the mechanical properties of linerboard and fluteboard shows that they have undergone significant changes. For example, some consumers refuse to use the crush resistance to evaluate the mechanical properties, preferring indicators that characterize the compressive strength in the transverse direction, although the importance of a high level of crush resistance is not denied.

Since there is a close correlation between the compression resistance along the plane of the outer and corrugated layers and the compression resistance of corrugated board and boxes, the compression resistance of the original components is undoubtedly one of their most important properties.

Therefore, it is necessary that the methods used to measure this property really make it possible to determine the compression resistance independently of other material properties.

Various materials are now used for transportation, storage and identification of products - from traditional cardboard and glass to innovative polypropylene with a barrier layer. In accordance with the requirements of Art. 7 p. 7 of the Technical Regulation of the Customs Union of the EU "On food safety" (TR CU 021/2011), the materials used for the manufacture of packaging of products in contact with food must comply with the requirements of the sectoral technical regulation TR CU 005/2011 "On packaging safety".

When choosing cardboard for food products, one should take into account not only the features of cardboard as a packaging material and its environmental friendliness, but also the ability to resist deformation. In addition, if the cardboard is used for storing frozen and chilled products, milk, etc., the surface of the cardboard should have a special coating that resists the absorption of fat, moisture and other substances. In the case of storage of baked goods, confectionery, pizza, the cardboard must be breathable, i.e. not chalky [1,2].

Corrugated cardboard is one of the most popular materials for the production of packaging. The main components of corrugated cardboard are two types of materials: cardboard for flat layers of corrugated cardboard (liner); paper for corrugation (fluting). The flat layers of corrugated cardboard fix the position of the corrugated layer, work for compression, tension, resistance to punching.

One of the reasons that contributes to the destruction of corrugated boxes in almost 100% of cases is high humidity. An increase in relative humidity entails an increase in the humidity of corrugated cardboard, accompanied by a decrease in all strength characteristics: end compression resistance, delamination resistance, bending rigidity, tensile strength.

The strength properties of corrugated cardboard were determined on a universal testing machine IP 5158-0,5 in accordance with DSTU ISO 3781:2005 Paper and cardboard. Determination of tensile strength after immersion in water (ISO 3781:1983, IDT). To determine the effect of humidity on the strength properties, the samples were pre-exposed in conditions of 95% relative humidity for different times.

The results of determining the end compression resistance of conditioned samples and samples exposed to 95% humidity for 15 days are shown in Table 2.

Exposure of corrugated cardboard in conditions of high relative humidity leads to a decrease in the resistance to end compression of all samples to 56-74%. During the operation of filled boxes in high humidity conditions, made of corrugated cardboard, due to the loss of strength properties, the stack may collapse. This leads to large losses and costs for both the corrugated cardboard manufacturer and its consumer. Therefore, for strength during stacking, the box must have sufficient compression resistance.

Conclusions. So, cardboard is a set of fibers that differ significantly in length and have differences in thickness; characterized by a difference in the strength of individual components of the structure (fibers) and the bonds between the fibers. This determines the whole range of physical and mechanical properties of cardboard, as well as all fibrous pulp and paper materials; specific features of the mechanical behavior of cardboard are determined by the flexibility of the fibers, which is determined by many factors. Thus, the structure of the paperboard is determined primarily by the properties of the fibers and the bonding forces between the fibers.

To reduce the likelihood of corrugated cardboard consumer claims related to collapse or sagging of corrugated boxes during stacking, the following recommendations should be taken into account: - maintaining the relative humidity in warehouses within 60-70%; - periodically check the quality of papers and cardboards for compliance with the certificate presented by the manufacturer; - control the quality of the corrugated cardboard produced with the issuance of a corresponding certificate to the consumer.

Table 2 - Resistance to end compression

№	End compression resistance, kN/m		Decrease in end compression resistance, %	General view of the sample
	specimens after conditioning	samples after 15 days exposure at 95% RH		
Г-1	3,3	0,9	73	
Г-2	3,4	1,3	62	
Г-3	3,4	1,5	56	
Г-4	3,3	1,4	56	
Г-5	3,4	0,9	74	
Г-6	3,4	1,0	70	

References.

1. Anon. Waste Reduction and Recycling Initiative / PUBL-IE-041, Wisconsin Department of Natural Resources, Madison, 1993. - №2

2. Anon. Informatian from Internet Web-Site of American Forest & Paper Ass. Available [online] http:www.afandpa.org. 1998.

3. Analysis of Waste Paper Recycling and Disposal Option in Germany / Gottsching L., Hamm U., Platzer E., et al. Towards a Sustainable Paper Cycle, IIED, London, 1996. 185 p.

4. Carbonnier S. Paper Recycling and the Waste Paper Business in Japan. Towards a Sustainable Paper Cycle, IIED, London, 1996. - 113 p.

5. C. Moss. Tappi J, 1997. № 4 p.69.

6. Gorazdova V., Dernova E. Influence of fibrillation and fiber shortening induced by refining on the softwood pulp. Colloquium 592 Deformation and damage mechanisms of wood-fibre network materials and structures. KTH, Stockholm, Sweden, 2017. C. 24-26.

7. Derzhavna sluzhba statistiki Ukrayini [Elektronnij resurs]. Rezhim dostupu : http://www.ukrstat.gov.ua.

8. DSTU 8401:2015 Karton. Pakuvannya, markuvannya, transportuvannya i zberigannya.

9. DSTU GOST 9142:2019 Yashiki z gofrovanogo kartonu. Zagalni tehnichni umovi (GOST 9142-2014, IDT).

10. Dunska A. R. Innovacijnij mehanizm rozvitku pidpriyemstv celyulozno-paperovoyi promislovosti: avtoref. dis. ... d-ra ekon. nauk : 08.00.04. Nac. tehn. un-t Ukrayini "Kiyiv. politehn. in-t im. Igorya Sikorskogo". Kiyiv, 2018. 45 s.

11. Inter-faks [Elektronnij resurs]. Rezhim dostupu : https://interfax.com.ua/

12.Furdichko O. I. Efektivnist resursno-virobnichogo potencialu lisogospodarskogo kompleksu. Lviv, 1995. 287 s.

13.Fiziko-mehanicheskie svojstva kartona, obrabotannogo biomodificirovannym glyutenom. / I.V. Zaharov i dr. Lesn. zhurn. 2017. № 6. S. 135-144.

14. Ganiyeva A.R. Formuvannya innovacijnoyi strategiyi rozvitku pidpriyemstv celyulozno-paperovoyi promislovosti : dis... kand. ekon. nauk: 08.06.01. Nacionalnij tehnichnij un-t Ukrayini "Kiyivskij politehnichnij in-t". K., 2005. 250 ark.

15. Gorazdova V.V., Dernova E.V. Vliyanie mnogoslojnogo formovaniya na harakteristiki prochnosti, deformativnosti i treshinostojkosti kartona. Lesnoj zhurnal» 2017. № 6. S. 160–169.

16. Kolyada L.G., Tarasyuk E.V., Koshevaya A.O. Izuchenie vliyaniya vlazhnosti na prochnostnye svojstva gofrokartona. Aktualnye problemy sovremennoj nauki, tehniki i obrazovaniya. 2010. T. 1. № 1. S. 83-86.

17. Kibat K. Wochcn bl.Papicrfabr, 1996. № 14-15. 656 p.

18. Kibat K. Wochenbl. Papierfabr, 1998. №16. 742 p.

19. Libin F. I. Tendenciyi rozvitku celyulozno-paperovoyi promislovosti yevropejskih krayin i integraciya CBP v yevropejskij rinok : tezi dopovidej. Lviv : Svit, 2007. 198 s.

20. Metody ocenki kachestva komponentov gofrirovannogo kartona / A.V.Gurev i dr. Cellyuloza. Bumaga. Karton. 1996. №7-8. S.16- 18.

21. Pishevaya upakovka: vidy, tehnologii proizvodstva i tendencii razvitiya otrasli [Elektronnyj resurs]: https://www.kp.ru/guide/pishchevaja-upakovka.html

22. Povyshenie ustojchivosti kartona k stareniyu propitkoj biomodificirovannym glyutenom / I.V. Zaharov i dr. SPb.2018. Vyp. 222. S.216-227.

23. Papermaking Science and Technology. Boo 7. Recycled Fiber and Dcinking. Book editor Gottsching L., Pakarinen H. Jyvaskyla, Finland, 2000. 649 p.

24. Regulirovanie vlagoprochnosti kartona obrabotkoj biomodificirovannym glyutenom. / I.V. Zaharov i dr. Lesn. zhurn. 2018. № 5. S. 181-190.

25. Sominskij V. Z. Investiciyi v svitovij celyulozno-paperovij promislovosti. Celyuloza. Papir. Karton. H., 2008. 45 s.

26. Shvorob G.M. Celyulozno-paperova promislovist Ukrayini [Elektronnij resurs]. Rezhim dostupu: http://ukrexport.gov.ua/ukr/prom/ukr/25.

27. Ukrpapir. [Elektronnij resurs]. Rezhim dostupu : http://www.ukrpapir.org/

28. Vliyanie reologicheskih svojstv biomodificirovannogo glyutena na prochnostnye i deformacionnye svojstva kartona / I.V. Zaharov i dr. Les. Ekologiya. Prirodopolzovanie. 2018. №3 (39). S. 60-67.

29. Vliyanie uslovij pressovaniya na formirovanie struktury i fiziko-mehanicheskih svojstv flyutinga / V.V. Gorazdova i dr. Lesnoj zhurnal» 2016. № 5. S. 177-188.

30. Vliyanie fibrillirovaniya i ukorocheniya volokon pri razmole na harakteristiki prochnosti, deformativnosti i treshinostojkosti cellyuloznyh materialov / Gorazdova V.V. i dr. Lesnoj zhurnal. 2018. № 2. S. 109-118.

31. Waste Management / Bilitewski B., Hardtle G., Marck K., et. ai. // Springer - Verlag, Berlin, 1994.-699 p.

32. Zaharov I.V. Razrabotka plenochnyh materialov na osnove biomodificirovannogo glyutena dlya laminirovaniya kartona. Zhurnal «Derevoobrabatyvayushaya promyshlennost». 2018. № 3. S. 56-61.

Анотація: *Практично всі підприємства, що використовують для пакування своєї продукції ящики з гофрованого картону, стикаються з проблемами транспортування та складування. Головним фактором впливу на якість картону в процесі експлуатації є деформація та руйнування матеріалів під дією прикладених сил - це основні явища, що визначають механічну поведінку матеріалів.*

У роботі проведено аналіз основних властивостей, що формують якість гофрокартону. Волокно технічної целюлози характеризується шістьма властивостями. Це середня довжина волокна, здатність до ущільнення у вологому стані, власне міцність волокна, когезійна здатність, грубість волокна і здатність до розмелювання.

Також нами проведено дослідження із впливу вологості на зразки гофрокартону. Визначено міцнісні властивості зразків гофрокартону та вивчено вплив вологості на них.

Акцентовано увагу на оцінку впливу властивостей волокна на властивість картону. Ця властивість, визначається як «критична» довжина волокна.

Запропоновано рекомендації для зменшення ймовірності виникнення претензій споживача гофрокартону, пов'язаних з обваленням або просіданням гофроящиків під час штабелювання.

Ключові слова: *гофрокартон, вологість, властивості, міцність.*

Стаття відправлена: 17.01.2023 г.