BASIC TESTING AND STANDARDS OF CORRUGATED BOARD

Florin Ionuț BOACĂ[1], Sorin CĂNĂNĂU[2], Georgiana CHIȘIU[3]

The purpose of this study is to investigate methods of testing corrugated cardboard, used in product packaging, packaging that is used to transport them, both by means of land (rail or road), sea and air transport. The main objective of corrugated cardboard packaging is to protect the packaged products during the entire transport period, from the supplier to the destination. During transport, the packaging is subjected to multiple loads and during storage, they are subjected to stationary compression forces because they are stacked to make space efficient in warehouses. The strength tests carried out in this work are for paper and corrugated board of different types, in relation to the international standards.

Keywords: corrugated cardboard, packaging, stiffness, tensile strength, ultimate tensile stress

1. Introduction

In many cases, a large number of products are transported over long distances, and temperature variation, stacking of products in sea containers, truck trailers, or train cars are just a few problems that manufacturers have to solve when making corrugated cardboard packaging. That is why manufacturers treat the corrugated cardboard and decide which type of cardboard they use for the final packaging. One thing is for sure, without proper packaging, products have a real problem, and corrugated board strength testing helps ensure that the product reaches the end customer in the best possible condition. A clear understanding of the packaging's behavior under static or dynamic loading conditions can be determined using ISO or FEFCO test methods [1]. Many studies focus on the characteristics and behavior of materials used in consumer packaging. Various researchers have conducted significant studies in this field. One of these studies, conducted by Fadiji T. [2], focuses on investigating the mechanical properties of corrugated cardboard packaging used for fresh produce. He used experimental methods and finite element

[1] PhD student, Dept. of Machine design and Tribology, University POLITEHNICA of Bucharest, Romania, e-mail: florin.ionut.boaca@gmail.com
[2] Professor, Dept. of Machine design and Tribology, University POLITEHNICA of Bucharest, Romania, e-mail: sorin.cananau@upb.ro
[3] Associate Professor, Dept. of Machine design and Tribology, University POLITEHNICA of Bucharest, Romania, e-mail: georgiana.chisiu@upb.ro

modeling to gain a more detailed understanding of the behavior of this material under different environmental conditions such as humidity and temperature. Therefore, the results revealed reduced elasticity of the paper and cardboard, with a significant decrease ranging from 20% to 53% under low-temperature transportation conditions. Furthermore, the researcher identified that the direction of machine displacement can significantly influence the elasticity of corrugated packaging. In another study, Talbi N. [3], addressed the use of advanced finite element methods to simulate the behavior of corrugated cardboard. He applied the concept of homogenization to obtain the average mechanical properties of the material and analyzed the geometry and characteristics of the cardboard. He also developed a detailed analytical model to better understand the structures within corrugated cardboard. By comparing the simulation results with experimental data, the researcher demonstrated the validity and efficiency of his model in analyzing material behavior. Another important aspect addressed in research is the impact of bending on the structural strength of corrugated boxes. Garbowski proposed an innovative method for estimating compression strength, considering the effects of bending [4]. This work highlights the importance of understanding the bending phenomenon and its role in determining the strength of corrugated packaging. Through these significant studies, essential contributions are made to understanding the characteristics and behavior of the materials used in corrugated packaging. This multidisciplinary approach, combining experimental methods and numerical analysis, provides a comprehensive perspective on the performance and strength of such packaging.

In this work, the main methods of testing corrugated cardboard and packaging made of this material will be applied in accordance with the standards established by the European Union. Like any material, paper is subjected to tensile, compression or moisture resistance tests when it is used as a raw material for packaging. To determine all these factors, it is necessary to test the corrugated cardboard sandwich structure in specialized laboratories. The main stages of making a package are followed according to a principle that we use whenever we make products that require testing or verification. In other words, we follow the same stages of making a product that requires research to reach the store shelves. These stages can be seen in Fig. 1.

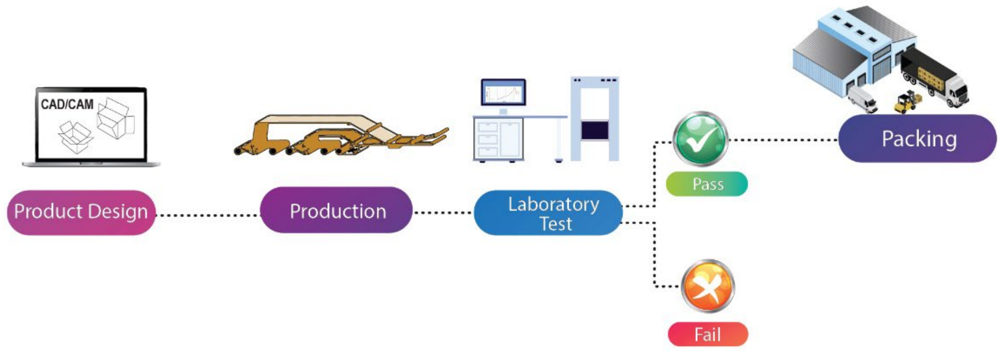

Fig. 1. The main stages for making the packaging.

2. Test methodology

Corrugated cardboard testing methods follow the production of packaging with standardized properties so that they can ensure the protection of consumer goods packaged in different situations, without generating additional costs due to insufficiency or excess of material used to make them. Due to globalization, these testing methods are most effective for the distribution of consumer products, thus connecting countries and product trade at a high level so that productivity is at the highest possible level. Corrugated cardboard packaging is used to protect and preserve industrial products, as well as consumer goods. They are used for packaging chemicals, medicines, tobacco, food products and the list could go on as packaging has brought the world closer through the multitude of functions it performs. To meet all these requirements, the packaging is tested in accordance with European standards, and the purpose of the testing is to define the properties of a batch of corrugated cardboard by applying standardized methods for testing representative samples. Due to the structure of cellulosic materials, corrugated cardboard boxes are subject to compressive stress, especially if they are used to pack heavy products and the storage method is stacking. Both paper and corrugated board are subjected to tests to determine the strength parameters or characteristics and the quality of the tested assortment. The specific amount of paper used in the making/manufacturing of the corrugated cardboard expresses its mass, being a decisive factor when it comes to costs, but especially on the resistance factors of the made/manufactured assortment.

Paper has become the most important material as a raw material for making consumer packaging. The properties of the paper vary according to the way of use and for this aspect parameters such as stiffness, tensile strength, but only tensile strength and compressive strength are taken into account.

There are two common methods for measuring corrugated material strength in the paperboard industry: the bursting test (Mullen) Fig 2 (b) and Edge Crush Test, (ECT) Fig 2 (c). The Mullen test involves the application of hydraulic pressure at a low rate, following the pattern shown in Fig 2 (a), until the liner is destroyed by tearing. The ECT test identifies an equivalent, complex stiffness, due to the behavior of the two liners, but also of the core (corrugation). The FCT, Flat Crush Test, is like the ECT test only that, by placing the normal load on the plane of the cardboard, the stiffness (elastic behavior) of the core, of the corrugated liner, will be identified.

2.1. Determination of basis weight of corrugated board

Determining the basic weight is essential for all types of materials, any product is analyzed from the point of view of weight, so also in the case of packaging, the basic weight is very important when we ask the question of transport, and if we are strictly discussing the advantages, the weight of the corrugated cardboard it is by far the most suitable for a package in terms of weight. An important aspect is the standard temperature for the material to be tested, the conditioning of the samples must be followed in accordance with EN 20 187 (23°C± 1°C, 50 % ± 2% rh).

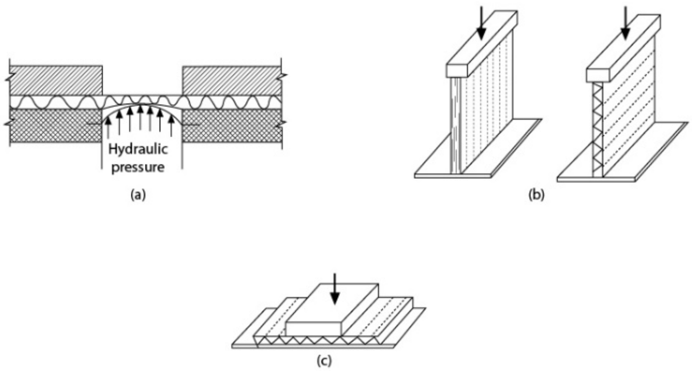

Fig. 2. Main standard tests used as industrial models [5]

2.1.1. Method

The paper or corrugated cardboard for determining the base weight is weighed on a scale/balance with an accuracy of 0.5g. The scales/balances, like all testing machines, are periodically metrologically checked to ensure that they do not deviate from the parameters established by the European ISO Standards. The specimens required for the necessary measurements were extracted from the raw material rolls, and their fundamental weights were subsequently determined. The base weight has the following expression:

$$G = \frac{g \cdot 10^6}{a \cdot b} \tag{1}$$

where G is base weight in g/m^2, g is the weight of the specimen to be tested in g, a is the length of the specimen in mm and b is width of specimen in mm.

2.2. Bursting Strenght Test (BST)

Determining the break of the corrugated cardboard is an important factor in the first stages of making the packaging to be used. To determine ultimate tensile strength, it is necessary to use a testing machine according to the criteria of the international standard ISO 2758, ISO 2759 [6]. This testing machine has the ability to determine the maximum paper strength in kPa by acting on the specimen with a hydraulic pressure. ISO 2759:2014 specifies a method for measuring the bursting strength of board submitted to increasing hydraulic pressure. It is applicable to all types of board (including corrugated and solid fibreboard) having bursting strengths within the range 350 kPa to 5500 kPa. It is also applicable to papers or boards having bursting strengths as low as 250 kPa if the paper or board is to be used to prepare a material of higher bursting strength, such as corrugated board. In such cases, the measurements will not necessarily have the accuracy or precision stated for this a prepare un material. [7] Through an elastic and circular diaphragm, the test specimen is subjected to a hydraulic pressure. When the hydraulic system is actuated, it provides a constant pressure. Thus, the pressure is recorded until the material fails. Diaphragm, circular, of natural or synthetic rubber, free from filler or loading and 0.86 mm ± 0.06 mm thick, clamped securely with its outer surface, when at rest, recessed about 3.5 mm relative to the outer plane of the diaphragm-mounting plate. The material and construction of the diaphragm shall be such that the pressure required to bulge the diaphragm 9.00 mm ± 0.2 mm outside the outer plane of the diaphragm plate is 30 kPa ± 5 kPa. Diaphragms in use shall be regularly checked and changed if the bulge-height requirement is no longer met. [8] The minimum values of Mullen burst strength in kPa are tabulated in Table 1.

Table 1

Minimum bursting strength Mullen in kPa [9]

Weight g/m^2	Minimum bursting strength Mullen $[kPa]$
115	393
125	417
200	637
300	824
400	961

The clamping system for the determination of bursting strength is drawn in figure 3.

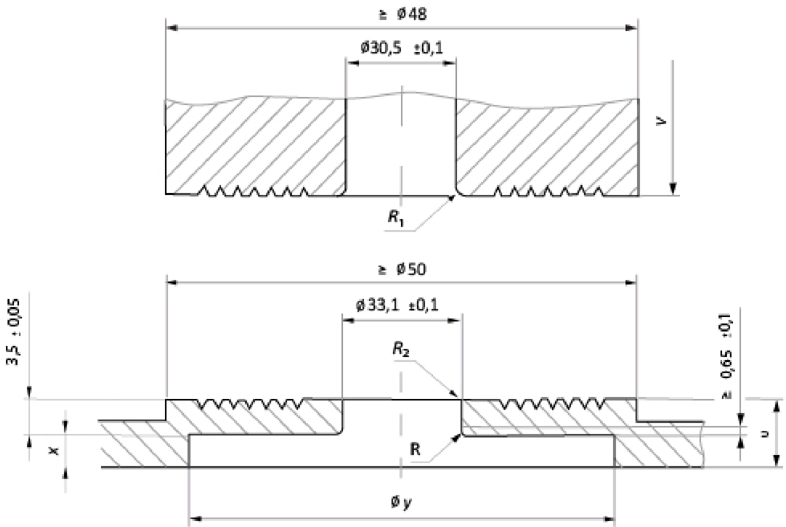

Fig. 3. Clamping system for the determination of bursting strength [10]

2.2.1. Experimental design and the method

To determine the bursting strength of the paper, we used a circular KL135 paper sample with a diameter of 100 mm and density 135 g/ m^2.
After starting the test machine, the clamping system was adjusted so that the pressure does not exceed 1200 kPa. Bring the hydraulic system to 0 and apply hydraulic pressure until the test specimen fails. It is retracted until the diaphragm is below the level of the clamping plate.

Figure 4 illustrates the way in which the test specimen is subjected to increasing hydraulic pressure. Once the specimen is prepared, hydraulic pressure is gradually applied, and the material's response is recorded in real-time. This process holds significant importance in analyzing material behavior under mechanical stress conditions, providing crucial insights for assessing structural integrity and material performance. In Figure 5, we observe the critical moment when the paper yields under the applied pressure. This image offers a visual depiction of the point where material limits are exceeded, illustrating the deformation and rupture that occur during the test. The results obtained from this stage of the study provide essential information for comprehending how materials react under extreme mechanical loads and for optimizing their performances across various industrial and technical applications.

Fig. 4. Placement of the specimen

Fig. 5. The breaking moment of the specimen

Read the indicated burst pressure to the nearest kilopascal and release the clamp. The refractive index x, expressed in $\boldsymbol{kPa \cdot m^2/g}$, can be calculated using the formula:

$$\mathbf{X} = \frac{\mathbf{p}}{\boldsymbol{g}} \tag{2}$$

where:

– p average bursting strength in kilopascals;

– g paper weight in grams per meter square metre, in according with ISO 536. [11]

2.2.2. Discussions

The results that we obtained are represented in Table 2.

Table 2

No.	P [kPa]	Series n = 9	P [kPa]	X [kPa · m²/g]
1	704	x	610	4.52
2	600	s	19	0.144
3	583	v	3.18	3.18
4	646	min	583	4.32
No.	P [kPa]	Series n = 9	P [kPa]	X [kPa · m²/g]
5	620	max	646	4.79
6	599			
7	607			
8	622			
9	623			
10	592			

This collection of experimental data is succinctly presented in Fig. 6, where the analysis of the material's tensile strength reveals a directly proportional correlation between the applied stress level and the obtained response, up to the milestone of 610 kPa. In an effort to detail the material's behavior under different loads, it is observed that its integrity exhibits a significant decrease after surpassing this threshold, reaching approximately 220 kPa. It is noteworthy that the captivating observation lies in the fact that the materials fibers to some extent attempt to recover after the point of rupture, offering a minor resistance.

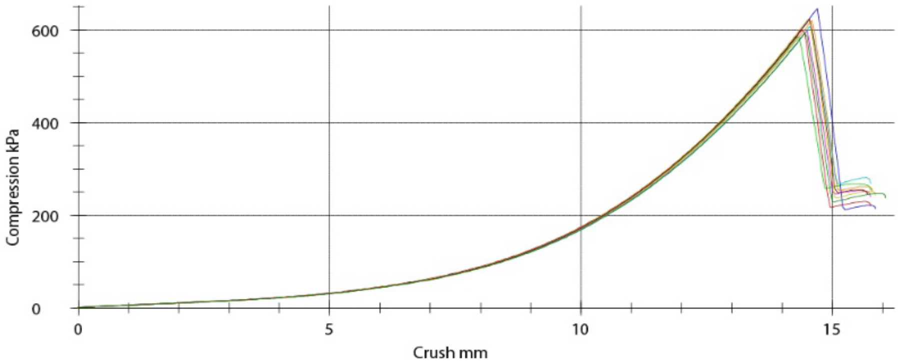

Fig. 6. Graphical representation of the determination of breaking strength

This substantial progression is comprehensively documented in the adjacent table, providing a clear insight into how the material behaves under various loading conditions.

Based on this data, the Refractive Index X was calculated to have an average value of 4.52 $kPa \cdot m^2/g$. Additionally, a standard deviation of 0.144 $kPa \cdot m^2/g$ was calculated, and a coefficient of variation of 3.18 $kPa \cdot m^2/g$ was determined. These measurements provide a detailed understanding of data variability and its consistency within the test series. In conclusion, this study highlights the material's behavior in a comprehensive manner, offering valuable insights for further knowledge development in this field.

2.3. Box Compression Test

The stacking strength of a corrugated box is determined by its degree of deformation following the compression test (BCT).

This test is established by ISO 12048 [12] having clear specifications both how to perform the test and specifications of the test machine. If the inner packaging is designed to take a proportion of the weight, then this should also be included during the test.

A very important thing is that everything we do now with ease, that is, with the help of testing machines, has deep roots in the studies developed by McKee, with the help of calculations based on McKee's theory of compressive strength, the design of corrugated packaging enjoyed of good results, which culminated in more ambitious developments with the advancement of Computer Numerical Calculations, thus making possible advanced predictions using Finite Element Analysis (FEA). FEA has been considered as a possible tool to replace the tedious and time-consuming experimental analysis of package strength. [13]

The ISO 12048 standard requires a compression strength test (Fig. 7) method for packages to be transported or stored in organized stacks for a well-established distribution chain. Through these tests, the resistance parameters are established following the reports made by the test machine. When a product requires packaging, manufacturers offer a corrugated cardboard box with optimal resistance results following the BCT test, with the option to test the box without the product or with the product included in the box only if the product, through ergonomics and design, is able to take a percentage of the weight, as for example the shampoo, the main packaging can take over a percentage of the applied load because the structure of the polymer material from which it is made can support the weight of the stack without major problems, in other words we can make a box with a lower efficiency because in in this case the box has the role of keeping the packaged product thus forming a compact structure.

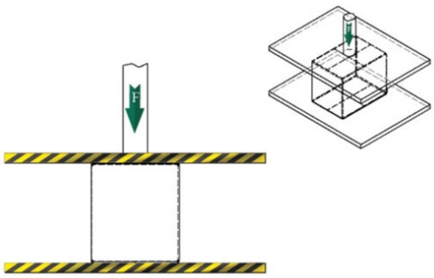

Fig. 7. The principle of compressive strength testing

2.3.1. BCT test principle

The test stand for determining the BCT reaches a force of 30 $\boldsymbol{kN}$. Conditioning the box at a temperature of 23°C and 50% relative humidity is strictly required according to ISO 178, and the box must be prepared for determination by applying adhesive tape, thus making an empty and sealed box. "For packages made up of several parts that each contribute to the total strength (i.e., full telescoping boxes, packages with internal accessories, etc.), it may be useful to determine the strength of its components separately according to this procedure and then compare the strength. of the packaging to the sum of the resistances of its components".[14]

2.3.2. Experimental design and BCT procedure

In order to determine the compressive strength or the stacking capacity of a folding corrugated box, we used a CO5 34.1 CB corrugated box with a protective liner of KL135 followed by an FT112 type corrugation and for the central liner used a 115 g paper, i.e. a TL115, followed by the FT112 wave with a weight of 112 g, and for the lower liner a KT135 paper was used.

As can be seen in Fig. 8, four types of paper are used for one CO5 carton. The upper liner is a protective paper with 135 g and lends itself to the printing process, instead the corrugated paper is a paper with a grammage of 112 g, having an important role due to the profile and the possibility of production with high efficiency. To assemble by gluing the upper wave and the lower wave, a paper with a weight of 115g is used, and for the lower liner, the properties of the upper one is given up because, unlike the upper one, the lower liner is more protected from external factors, and for efficiency costs, materials with different properties are used.

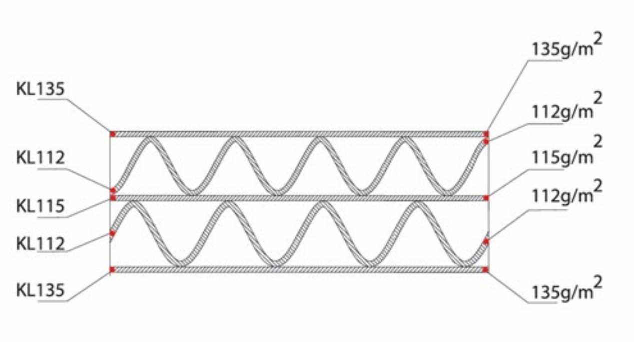

Fig. 8. Corrugated cardboard CO5 34.1 CB

Choosing the type of paper is an important stage in the production of corrugated cardboard, thus different types of corrugated cardboard are made with paper liner and different properties until the right corrugated cardboard is determined for the product we are going to package. The overall dimensions of the box tested for the determination of compressive strength were as follows: 390x270x300 mm, and the testing was carried out on a Zwick Roel Z030 crushing and stacking test stand.

Fig. 8. The compression tester, powered, plate type [15]

Fig. 9. The BCT test.

The procedure is as follows:

The package is placed on the lower plate of the compression stand, the test stand is turned on, after starting the stand begins to move the upper plate towards its base where the lower plate serving as a support for the tested box is located (Fig. 9). The force applied to the box continues and the stand records the behavior of the corrugated box. The behavior of the box is interpreted numerically and the results are recorded in a report according to the DIN EN ISO 12048 standard, thus the maximum resistance of the packaging in Newtons is observed (Fig. 10).

After interpreting the results, the designers determine the load capacity of the box or it is proposed to change the type of corrugated cardboard, often corrugated cardboard is made according to the needs of the product.

Applying the well-known McKee equation, which has the general form:

$$\mathrm{BCT} = \mathrm{K_1} \cdot \mathrm{ECT^b} \cdot \mathrm{Sb^{1-b}} \cdot \mathrm{Z^{2b-1}} [\mathrm{N}] \quad (3)$$

Where:

ECT – edge compressive strength of corrugated board [kN/m]

Sb - the stiffness of the corrugated board, in the direction of the machine test and in the transverse direction (Sb_{MD}, respectiv Sb_{CD}) [Nm]

Z - perimeter of the box [m]

K_1 – constant

$b = 0.75$ for corrugated board.

3. Results

Considering the properties of corrugated board, namely that it is an orthotropic and inhomogeneous material, several tests are made in the laboratory for the tested packaging, for a more precise determination of the mechanical strength parameters of the used corrugated board assortment, we subjected 7 boxes in compression, the material conditioned according to the ISO 178 [16] standard. But even if we carry out several tests and get as close as possible to the actual properties, the ideal would be a test of the packaging under conditions of use, that is, to expose the packaging to the temperature change in a stack over a period of time according to the laboratory test results and thus we can determine the dispersion of the laboratory results with the exact behavior of the packaging in the cargo warehouses.

The creation of customizable cardboard does not exclude materials, adhesives and standardized processes. In practice, another carton is made with standard materials, with a different structure or paper weight.

Through the analysis of the graphical representation (Fig. 11) concerning the compression behavior evaluation of corrugated cardboard boxes, a significant observation emerges: in the initial part of the curve, where forces reach a maximum of 400 N, a direct proportional relationship is observed, followed by plastic deformation in the range between 400 and 4000 N.

Table 2

Test results:		Statistics:	
Nr.	$\mathbf{F_{max}}$ [N]	**Series n= 10**	$\mathbf{F_{max}}$ [N]
1	4250	x	4510
2	4080	s	362
3	4950	ν	8.03
4	4340	min	4080
Test results:		Statistics:	
5	4240	max	4950
6	4770		
7	4340		
8	4950		
9	4250		
10	4930		

Simultaneously, a careful examination of the data provided by Table 3 highlights a distinct pattern: the load range between 4080 and 4950 N delineates the minimum and maximum values for the compression resistance manifested by the scrutinized box. The average compression resistance, around the value of 4510 N, corresponds to an equivalent force of approximately 460 Kgf, accompanied by a standard deviation of 362 N.

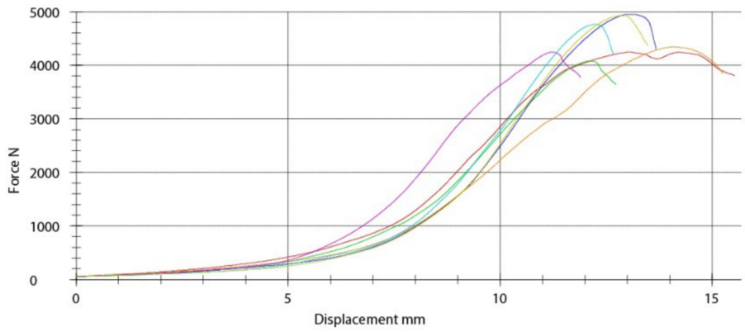

Fig. 10. Graphical representation for the compression determination of corrugated cardboard boxes.

In light of these meticulous observations, a clear conclusion can be drawn: the investigated box, characterized by dimensions of 390x270x300 mm and crafted from a type of corrugated cardboard known as CB, with the specification CO 5, undeniably demonstrates the capacity to withstand the cumulative load imposed by a stack comprising 6 + 1 units. As for the upper limit of the packaged product's weight, it can reach approximately ≃ 76.5 kgf.

3.1. Short Span Compression (SCT)

The ISO 9895:2008 or Tappi 826 standards provide the method for determining the compressive strength in the Machine Direction (MD) and in the cross directions of paper and board Cross Machine Direction (CD) using a short duration compression tester.

So, we are discussing two main directions that we use whenever we determine the strength of corrugated board. To define the directional properties, we need the thickness direction (ZD) of the material (Fig. 12).

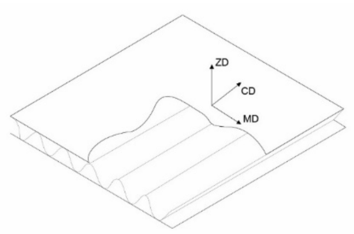

Fig. 11. The main directions of a corrugated board.

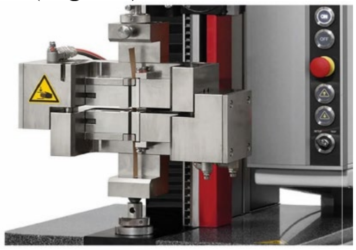

Fig. 12. Short Time Compression Tester. [17]

To produce corrugated cardboard boxes, this method is the most suitable, as it meets all the requirements set by the international standard ISO 9895. Short-term compression testing machines have been developed for the paper and corrugated industry to determine (SCT), this test is performed on paper with a weight between 100 and 400 g/m^2, we can see such an example in the figure Fig.13.

3.1.1. SCT test principle

This standard requires a compression test, provided with two clamps, for holding a test specimen with a width of 15 mm. Each clamp must include a stationary jaw (S1, S2) and a movable jaw (M1, M2). The quality and dimensions of the clamps (C1 and C2) are established for the test by the norms of the ISO 9895 standard. They must be 30 mm long and have a high friction surface, also the clamps must be capable of holding the test piece (T) in position with a constant clamping force of 2 300 ± 500 N. The design the clamps must be made so that through the manufacturing process the clamps have a sufficiently adherent surface for a firm grip of the test piece over its entire width (Fig.14).

The stationary jaws must be in the same plane and on the same side of the test piece. The gripping surfaces of the movable jaws must be flush and parallel with those of the stationary jaws.

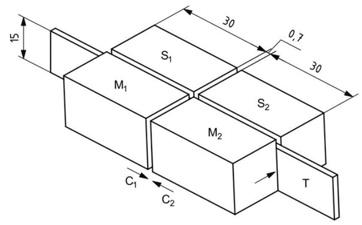

Fig. 13. Clamp arrangement. [18]

The clamping device for testing has two clamps in its composition, and each clamp has a fixed and a movable jaw, where the specimen with a side of 15 mm is fixed. These clamps are 30 mm long and have contact surfaces with a high coefficient of adhesion, being able to hold the specimen in position with a constant force of 2300 N ± 500 N.

C_1 and C_2 are the clamping clamps, and after fixing the specimen between the movable jaws M_1 and M_2, the specimen is subjected to compression in the direction of the fixed jaws S_1 and S_2, and the indicated maximum compression value is read.

The preparation of the clamping system is very important because the clamps must tighten the specimen sufficiently during the test, therefore the clamps are adjusted with a clearance of 0.7 mm ± 0.05 mm.

To determine the short-term compressive strength, it is necessary to carry out tests in both the machine direction and the transverse direction. The compressive strength, SCT, is the compressive force, F, divided by the width of the test piece [19].

So, we will have, according to international standards, a ribbon-shaped tube with a minimum length of 70 mm and a width of 15 mm+/-0.1 mm. So, we will write SCT = F/0.015, $[N/m]$, remember that:

$$\mathrm{SCTindex} = \mathrm{SCT/Q}, \quad [\mathrm{Nm/g}] \tag{4}$$

Where :

– SCTindex - compression index, SCTindex represents the value SCT divided by weight, Q $\left[\frac{\mathrm{g}}{\mathrm{m}^2}\right]$.

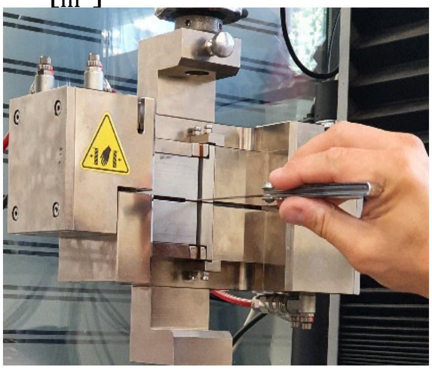

Fig. 14. Measuring Clamps.

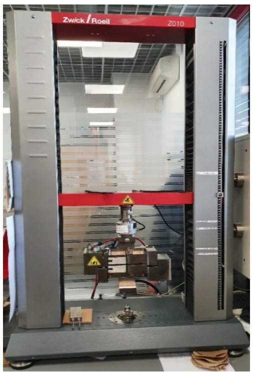

Fig. 15. Test stand with the module for determining compression-elongation tests.

In the laboratory we carried out short-term compression tests (SCT), practically we managed to determine the compressive strength of the paper used to make the corrugated cardboard sandwich structure.

A very short length of paper is used in this test mode on the multifunction stand. The test focuses more on load-bearing fiber length than traditional test methods (ring crush test, wave crush test or linear crush test).

The test pieces are cut according to the requirements of the ISO 9895 [20] standard, i.e. with optimal parallelism with the strip cutter.

3.1.2. Experimental design and SCT procedure

We used a KL 135 g ribbon-shaped test piece 170 x15 x 0,2mm and 20 tests were carried out according to the international standard ISO 9895 (Fig.17).

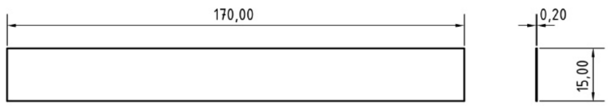

Fig. 16. Test specimen for compression determination.

This test, like any other tests that depend on the compressive strength, is very sensitive to changes in the humidity of the specimen. Handle the specimens with care and never touch the compression area with bare hands. The samples are kept away from moisture, heat, direct lighting, drafts and other conditions that can change the moisture content. The tightening clamps must not be subjected to heat from lamps, motors, etc. Compressive strength is best measured on a small surface of 0.7mm +/-15mm. In order to eliminate the influence of variations in characteristics on the surface of the paper, at least 20 determinations are recommended. [21]

The compression index can be calculated with the calculation relation:

$$X = \frac{F}{15} \quad (5)$$

where:

- X is the compressive strength expressed in [kN/m];
- F is the compressive strength expressed in [N];
- 15 is the width of the specimen expressed in [mm].

Many times, it is necessary to determine the compression index as well, it is determined with the relationship:

$$Y = \frac{1000\overline{X}}{\rho_A} \quad (6)$$

where:

- Y is compression index expressed in $[Nm/g]$;
- $\overline{X}$ is the average resistance value expressed in $[kN/m]$;
- ρ_A is the grammage expressed in $[g/m^2]$.

3.1.3. Results

In the graphical representation of Fig.18, the analysis of Short Span Compression (SCT) for determining compressive strength is highlighted. The linear curve portrays the consistent nature of the material's behavior under pressure. The minimum and maximum resistance values, reaching 2.3 kN/m and 2.65 kN/m respectively, along with an average of 2.47 kN/m, underscore a coherent range of performance regarding compressive strength.

Within Table 4, noteworthy parameters come to the forefront, such as the Standard Deviation, registering a value of 0.113 kN/m. This metric quantifies data dispersion relative to the mean, thereby affording an intricate understanding of the degree of variability within this dataset. Concurrently, the Coefficient of Variation, measuring at 4.6 kN/m, provides a comparative gauge of this dispersion within the dataset. Through meticulous analysis of these parameters, a comprehensive insight into the stability and consistency of the data garnered during the assessment of compressive strength is unveiled.

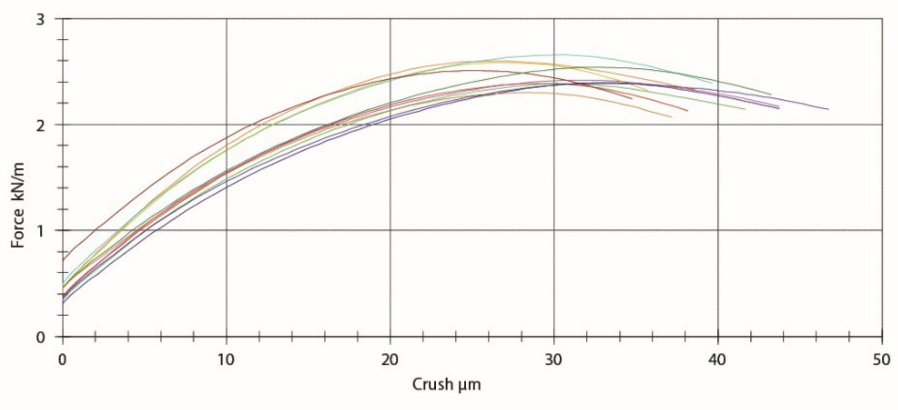

Fig. 17. Graphic representation for the determination of compressive strength.

This detailed analysis of behavior under compression underscores the significance of SCT parameters in comprehending mechanical properties of materials. These indicators, coupled with graphical analyses, facilitate a deeper understanding of how the material responds under pressure and can contribute to the development of high-performing materials across a wide spectrum of technical and industrial applications.

Table 3

Test results:				Statistics:	
Nr.	F_{max} [kN/m]	Nr.	F_{max} [kN/m]	Series n = 20	F_{max} [kN/m]
1	2.39	11	2.39	x	2.47
2	2.38	12	2.50	s	0.113
3	2.55	13	2.45	ν	4.60
4	2.39	14	2.39	min	2.30
5	2.60	15	2.63	max	2.65
6	2.42	16	2.58		

7	2.65	17	2.46		
8	2.30	18	2.54		
9	2.58	19	2.39		
10	2.51	20	2.30		

3.2. Edgewise Compression Test (ECT)

This standard only refers to the strength test of corrugated cardboard, respectively to "Determination of the crushing strength on the edge (unwaxed edge method)" - in fact it is about testing the crushing strength of the cardboard sample placed according to the figure, with the load applied on the edge of the cardboard sample. In other words, the ISO 3037 Standard establishes methods for determining the edge crushing resistance of paper and corrugated board, using a crushing test stand. The Edge Crush Test (ECT) is the test for determining the edge crush resistance of corrugated cardboard packaging. In the present situation the test is applied on the vertical axis of the specimen.

3.2.1. Experimental design and procedure in ECT

The tests were carried out on a Zwick Roel Z010 tester (Fig.19), and we used CO5 type corrugated cardboard samples, with type B corrugations and a weight of $328\frac{g}{m^2}$.

The test piece is placed in the compression cups of the test device with the corrugations perpendicular to the cups and a force is applied until the test piece is crushed in the area of the action of the force, thus the maximum force that the test piece can withstand is recorded and, after ten tests, calculate the stacking strength on the cant. For better lateral rigidity of the test piece, compressions plates or guide bars are used on one side and the other of the test piece, which are intended to ensure reproducible test values. An important factor is that when the guide bars are in position, the indicator needle should indicate the value 0.

After stabilizing the specimen, turn on the device and apply a crushing force until the load reaches 50 N.

The weight of the guide bars supported by the bottom plate slightly distorts the force reading. The force applied at the moment of crushing is noted with an approximation of 1 N. If the force is calculated from the measurement of a deformation, the deformation shall be noted to the nearest 0.01 mm. Repeat the test on the remaining specimens and calculate the mean peak force and standard deviation [22].

The tests are repeated on the remaining specimens, after which the mean maximum force and standard deviation are calculated.

According to FETCO the speed with which the plates approach each other must be 12.5 $[mm/min]$± 2.5 $[mm/min]$.

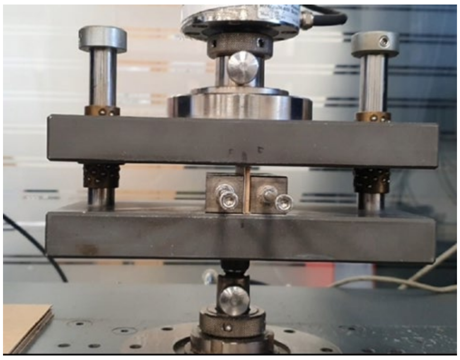

Fig. 18. Test device for determining edge crushing strength.

The determination of the crushing strength on the edge is calculated with the formula:

$$R = \frac{F}{L} \tag{7}$$

where: R- edge crushing strength [kN/m]; F- maximum load [N];
- L- the length of the test piece [mm].

3.2.2. Results

To evaluate the edge crush resistance of corrugated cardboard type B, we conducted the Edge Crush Test (ECT) using the Zwick Roell Z010 testing machine. During the test, a constant force of 10N was applied to a specific assortment of corrugated cardboard type B at a controlled speed of 12.5 mm/min. In Fig. 20, depicting the graphical representation of edge stacking resistance, a linear trend is noticeable around the value of 3 kN/m. Subsequently, we observe the initiation of plastic deformation, which gradually progresses and reaches a maximum value of 5.19 kN/m.

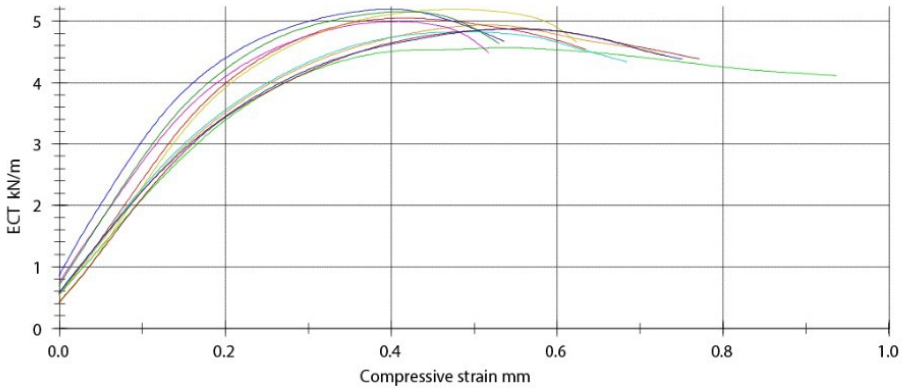

Fig. 19. Graphical representation for determining edge stacking strength.

In Table 5, we can observe that the average strength of the tested sample stands at 4.97 kN/m. Additionally, the data dispersion in relation to the mean is indicated by a standard deviation of 0.195 kN/m, while the coefficient of variation records at 3.93 kN/m. These aspects provide a clear understanding of the degree of variation and consistency within the results obtained in this study.

Table 4

Test results:		Statistics:	
Nr.	F_{max} [kN/m]	Series n = 10	F_{max} [kN/m]
1	5.05	x	4.97
2	4.57	s	0.195
3	5.19	ν	3.93
4	4.94	min	4.57
5	4.99	max	5.19
6	4.82		
7	5.19		
8	4.87		
9	5.16		
10	4.87		

This comprehensive analysis reveals significant insights into the response of corrugated cardboard type B to mechanical stresses. The data and conclusions derived not only enhance our comprehension of the material's behavior but also inform future directions for its development and optimization in various technical and industrial applications.

4. Conclusions

The paper summarizes how to apply it in the laboratory on different tests dedicated to the study of the strength and behavior of corrugated cardboard. The tests carried out make possible a better understanding of the behavior of the material with a complexity both in specialized studies and in the laboratory. Thus, we highlighted the most used testing methods for making everyday packaging. These tests are established in accordance with European standards and are fully performed by the testing machines. It was found that in the absence of a specialized laboratory, a numerical analysis can be performed through simplified homogenization in the preliminary stages, but for a factory with a large production volume, such a laboratory is strictly necessary. So, we conclude, that for making corrugated cardboard, a test and verification laboratory is the most suitable for decision-making in the packaging prototyping department with an enormous contribution in choosing the type of cardboard used for each individual product.

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