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Strength Parameters of Corrugated Cardboard and Corrugated Cardboard Joints

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ABSTRACT

The aim of the article is to determine the strength parameters of corrugated cardboard as well as adhesive and embossed joints of the corrugated cardboard, which is used to produce textured unit packaging in the form of boxes. The strength parameters of the unit packages and the materials from which they are made are important data helpful in selecting the unit packages for packaging the products of a specific mass. The subject of the research were two types of corrugated cardboard: three-layer –single board style made of low wave marked B flute, for which the average wave height is 2–3 mm and five-layer cardboard double wall (in two flute configurations: B+B and B+C, where B flute is a low wave, and flute marked C is a medium wave, for which the average wave height is from 3–4 mm), from which unit packaging was made in the form of boxes. These cardboard boxes were joined with an adhesive (by making the adhesive joints) and embossed joints were made in the corners of the box (where the individual sides of the box were folded). The tensile strength (in accordance with PN-EN ISO 1924-2) was analyzed, both of the material itself in two directions (transverse and longitudinal to the direction of the arrangement of the paper layers), as well as of the adhesive and the shaped (embossed) joints. Based on the strength tests, it was noticed that the corrugated cardboard samples subjected to a force transverse to the direction of the paper layer arrangement have a greater failure force, and this applies to the three analyzed types of the corrugated cardboard although the difference is greater occurs in the case of the three-layer cardboard(approx. 25%). Based on the results, it can be concluded that both the types of the corrugated cardboard and the type of the joints affect the strength parameters of the unit packaging. Based on the test results, it was noted that the direction of the paper layer arrangement has no effect on the initiating of the failure force, and the value of the initiating of the failure force in the case of three-layer corrugated cardboard samples is approximately 72–74%, while for five-layer corrugated cardboard it is approximately 80–82%.

Keywords: corrugated cardboard, adhesive joint, embossed joint, mechanical properties.

INTRODUCTION

The corrugated cardboard is a paper product in the form of a laminate, consisting of corrugated and flat layers bonded together [1–3]. Thanks to this structure, it has a spatial structure, giving it good shock-absorbing and strength properties at a low specific weight. However, its biggest disadvantage is its low resistance to moisture, which significantly reduces the strength properties of the cardboard. It should be mentioned that humidity adds cushioning properties, cardboard does not crack, has the ability to stretch, and loses stiffness. Absolute humidity of corrugated cardboard should be between 6 and 9%. Relative humidity should be maintained at 60%.

The constantly increasing range of applications and range of cardboard products has resulted in the creation of new types of the corrugated cardboard [4, 5]. In the first stage, the number of layers was increased; producing five- and seven-layer cardboard, and then technologies for producing four- and six-layer cardboard were developed. Cardboard with a crossed flute and a snake flute are also available [1, 6, 7] (Table 1).

The largest groups of products made of corrugated cardboard are boxes of various shapes and sizes, and due to the flexibility of the corrugated layers, corrugated cardboard packaging has good shock-absorbing properties. Fehér et al. [2] underlined that **"**corrugated cardboard boxes are generally used in modern supply chains for the handling, storage, and distribution of numerous goods" and "These packages require suitable strength to maintain adequate protection within the package". Mrówczyński et al. [8] show that various properties of materials attract the attention of packaging manufacturers, including the important construction of packaging.

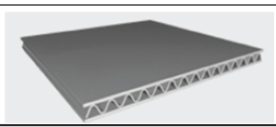
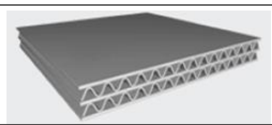
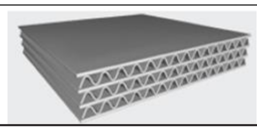
The cardboard boxes can be folded stapled or bonded [9–13]. Folding and bonding the corrugated cardboard boxes is a very important stage of packaging production. Beex and Peerlings point out [13] that fold lines in boxes must be precisely made and visually interesting. However, the quality of the folds depends on two processing processes: the generation of the fold line (creasing) and the subsequent folding. In turn precise bonding ensures durability, stability and maintaining the appropriate form of the packaging. This is important from an aesthetic point of view and is necessary to protect the contents. This stage affects the functionality and durability of box packaging. The bonding cartons involve pre-forming the packages, applying adhesive in appropriate places and assembling the packages [7]. The cold or the hot adhesives are used for bonding [14–16], depending on the raw material used and its specific type of packaging surface finish. In the case of cold bonding, water- or solvent-based adhesives are used [17–19]. The bonding method offers the advantages over stapling or using adhesive tapes, including: in the form of visual benefits (no visible elements used for joining), as well as the possibility of a high degree of automation in the production of such corrugated textured packaging.

Due to the fact that, in addition to the number of the layers, the strength of corrugated cardboards is also determined by the type of wave (or fluting, i.e. the height of the corrugated layer), samples made of the corrugated cardboard with different numbers of layers and different flutes (waves) were used for the tests. In this article, two types of corrugated cardboard were used for research: three-layer and five-layer due to the widespread use of them. Three-layer corrugated cardboard consists of one corrugated layer and two flat layers (single wall) and is produced in the form of sheets [1, 20]. This is the most popular type of the corrugated cardboard and has many applications. It is most often used to produce packaging in the form of collective boxes, inserts and unit packaging. Five-layer corrugated cardboard consists of two corrugated layers and three flat layers (double wall) and is produced in the form of sheets. This type of the corrugated cardboard is most often used to produce large collective or unit packaging intended for packaging heavy or large products [21]. Sometimes five-layer corrugated cardboard is used as a construction material for the production of the cardboard pallets, displays, and in special cases even for interior finishing or furniture production. This type of cardboard can come in various configurations of flute type and height [1, 6]. There are flutes marked A, B, C, E, F, G, N, W, D and K and their configurations, which differ in both flute height and flute coefficient [1].

The mentioned cardboard was used to make boxes in which the corrugated cardboard was joined using adhesive. The adhesive joints were subjected to strength tests. The boxes also had shaped joints in the form of embossing on the corners of the box, for which their strength parameters were also determined in the form of maximum force, maximum stress, maximum deformation and the force at which the material broke.

Knowledge of the strength parameters of both the material from which the box is made and the joints present in the packaging allows for a rational selection of the weight of items packed in such a box. This also constitutes valuable information in the transport and storage process during handling and

Table 1. Examples of corrugated cardboard [1, 6, 7]

	Three-layer	Five-layer	Seven-layer
Type of cardboard			

reloading activities. Grabowski et al. [22] emphasize that conducting experimental work allows the design and development of corrugated cardboard or corrugated board boxes to ensure their appropriate mechanical strength. Although it should be remembered that the strength of the packaging itself is determined in accordance with the relevant standards. The issues of testing the mechanical properties of both materials – the corrugated cardboard, used to produce boxes, and the boxes themselves were presented, among others, in the works [23–24].

METHODS AND EXPERIMENTAL

Corrugated cardboard

The basic geometric parameters characterizing corrugated board are board thickness (H), wave height (h), pitch (t) and corrugation coefficient (λ) – Figure 1 [1].

The strength tests used samples made of the three-layer corrugated cardboard (single wall) and five-layer corrugated cardboard (double wall in two configurations), the characteristics of which is presented in Table 2 and Figure 2. Three-layer corrugated cardboard consists of one corrugated layer and two flat layers. In the case of three-layer cardboard, a type B flute was used (low flute with a rounded cross-section) with a height of 2.5 mm to 3.0 mm and a corrugation coefficient of 1.36 (Figure 2a). The corrugation (fluting) coefficient expresses the ratio of the length of the corrugated layer before fluting to the length after fluting [1]. Five-layer corrugated cardboard (Figure 2b) consists of two corrugated layers and three flat layers. In the case of five-layer cardboard, two flute patterns were used:

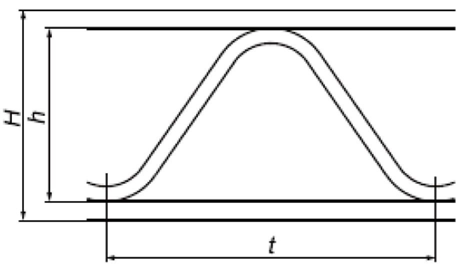


Figure 1. Geometric parameters of the cardboard cross-section: H – board thickness, h – wave height, t – pitch [1]

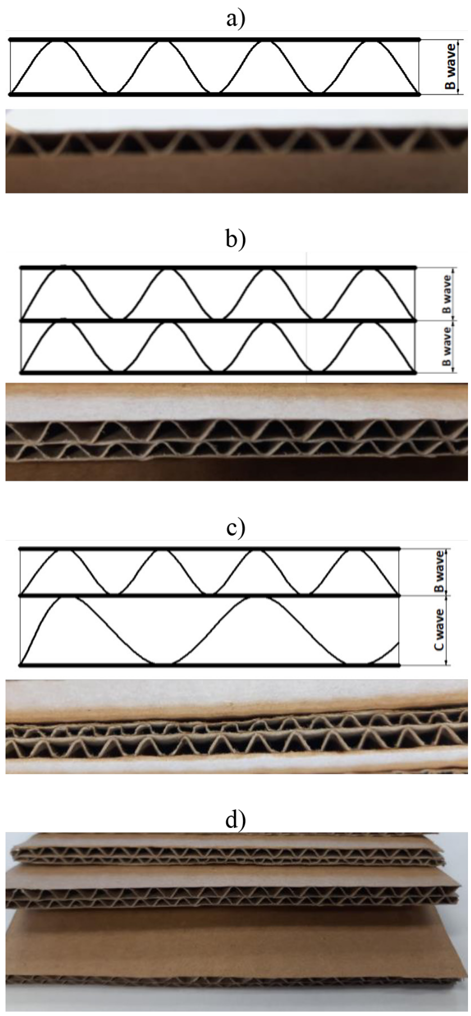


Figure 2. Scheme and view of the type of the corrugated cardboard: a) B flute, b) B+B flutes system, c) B+C flutes system, d) set of three type of corrugated cardboards

Table 2. Characteristics of corrugated cardboard samples

Type of cardboard	Characteristics		
	Board style	Flute type	Flute height (h)*
Three-layer	Single wall	B	from 2.5 mm to 3.0 mm
Five-layer	Double wall	B+B	from 2.5 mm to 3.0 mm + from 2.5 mm to 3.0 mm
		B+C	from 2.5 mm to 3.0 mm + flute height from 3.0 mm to 3.7 mm
*The average wave height (h) corresponds to the distance between the inner surfaces of the covering layers adjacent to the wave.			

1. B+B system: type B flute (low flute) with a height of 2.5 mm to 3.0 mm and a corrugation coefficient of 1.36 (Figure 2b),
2. B+C system: type B flute (low flute) with a height of 2.5 mm to 3.0 mm and a corrugation coefficient of 1.36 and type C flute (medium flute with a rounded cross-section) with a height of 3.0 mm up to 3.7 mm and a corrugation coefficient of 1.45 (Figure 2c).

C flute allows you to obtain cardboard with good stiffness and high strength properties. C flute cardboard is most often used for the production of boxes and is suitable for producing cutouts using rotary die-cutters. Cardboard with B flute has slightly worse strength properties than cardboard with e.g. C flute, but it is also used for the production of small collective packaging. Due to the smaller thickness of B flute cardboard s, packaging made of them takes up less space during storage and transport than C flute cardboards. B flute cardboards have good printing properties.

The conditions for the conditioning the corrugated cardboard samples and during the tests were as follows: relative humidity was 46% and the temperature was 20 °C, which was in line with the recommended conditions for this type of material [25]. In addition, it was ensured that the samples were not exposed to sunlight.

Joints

There were two types of joints in boxes made of the two types of the cardboard analyzed: (i) adhesive joints, and (ii) form-fit (embossed) joints (in the form of embossing on the corner of the box). PVAc-based dispersion adhesive (FOLCO LIT, Follmann GmbH & Co. KG, Germany) was used to bonding the walls of the box.

Strength tests

Strength tests were carried out both for the material itself, which was three-layer corrugated cardboard (B) and two varieties of five-layer corrugated cardboard (B+B and B+C system), as well as for the adhesive and embossed joints of three-layer corrugated cardboard (B) and five-layer corrugated cardboard (B+B).

The strength of the packaging material (corrugated cardboard) was analyzed in two directions (transverse and longitudinal to the direction of arrangement of the paper layers) (Figure 3).

The dimensions of the corrugated cardboard samples and joints samples were presented in Table 3 and additionally, the standard deviation of the individual results was given. For the strength tests, 6 samples were made for each type of the corrugated cardboard and 36 cardboard samples were subjected to the strength tests. The scheme and a view (example) of the adhesive joints of the corrugated cardboards were shown in Figure 4.

The adhesive joints (Figure 4b) have 10±0.12 mm overlap length (lad) and 0.5 mm adhesive thickness (tad). The remaining cardboard dimensions depending on the sample variant are presented in Table 3. For strength tests, 6 samples were made for each type of the joints (24 joints in total). The adhesive surface in the case of adhesive joints of three-layer corrugated cardboard was 260 mm^2, and in the case of faive-layer corrugated cardboard it was 240 mm^2 (flute configuration B+B) and 250 mm^2 (flute configuration B+C).

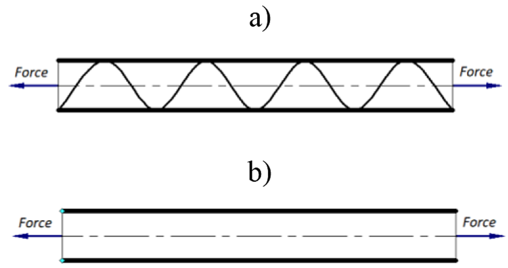


Figure 3. Scheme of force application in the case of testing the tensile strength of cardboard samples (B flute, three-layer) in the direction: a) transversely to the arrangement of paper layers, b) longitudinally to the arrangement of paper layers

Table 3. Dimensions of corrugated cardboard samples

Type of cardboard	Dimensions of corrugated cardboard samples [mm]			
	Flute type	Thickness (t)	Width (w)	Length (L)
Three-layer	B	3±0.02	26 ±0.4	100±2.1
Five-layer	B+B	6.5±0.02	24 ±0.8	100±1.4
	B+C	7.0±0.03	25 ±0.3	100±1.3

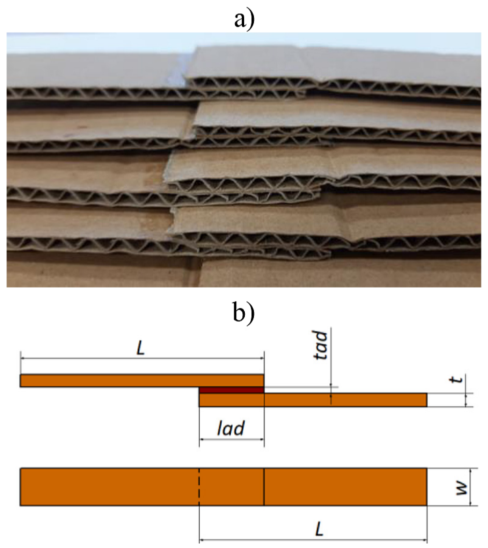


Figure 4. The three-layer corrugated cardboard (B flute) cardboard adhesive joints samples: a) view of several joints, b) parametric scheme

Tensile strength tests were carried out in accordance with the PN-EN ISO 1924-2 standard, on the Shimadzu EZ Test EZ-LX testing machine. The speed of the tensile force was 5 mm/min.

RESULTS

Strength parameters of corrugated cardboard

The strength parameters (and standard deviation of these parametrs) of the corrugated cardboard taken transversely and longitudinally to the direction of the paper layer arrangement for three-layer corrugated cardboard (flute B) and five-layer corrugated cardboard (systems: B+B and B+C) were presented in Figures 5, 6 and 7). Based on strength tests, it was noticed that the corrugated cardboard samples subjected to a force transverse to the direction of the paper layer arrangement have a greater failure force (Figure 5) and this applies to the three analyzed types of the corrugated cardboard (flute type B, B+B and B+C), although the difference is greater in the case of three-layer corrugated cardboard (approx. 25%).

The difference in the value of the failure force between samples with different flute arrangement and application of the failure force (direction of the force in relation to the direction of the paper layers arrangement) in the case of five-layer corrugated cardboard (B+B system and B+C system) is approximately 17%. Similar relationships were observed in the case of the obtained values of maximum stresses (Figure 6) accompanying the destruction of the cardboard samples. In the case of the elongation results (Figure 7), much greater elongations were observed in the case of the samples with a longitudinal orientation of the paper layers.

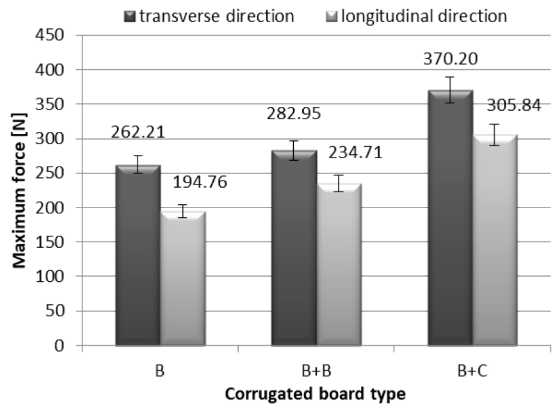


Figure 5. Maximum failure force of corrugated cardboard

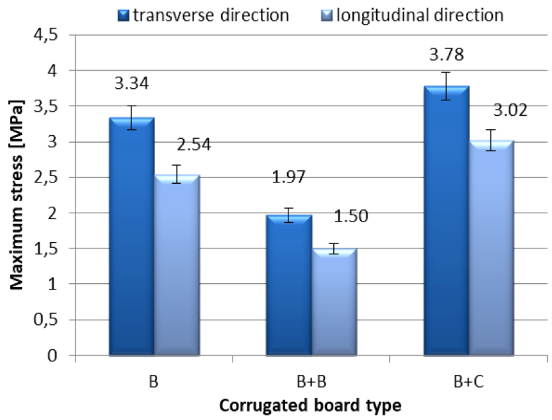


Figure 6. Maximum stress of corrugated cardboard

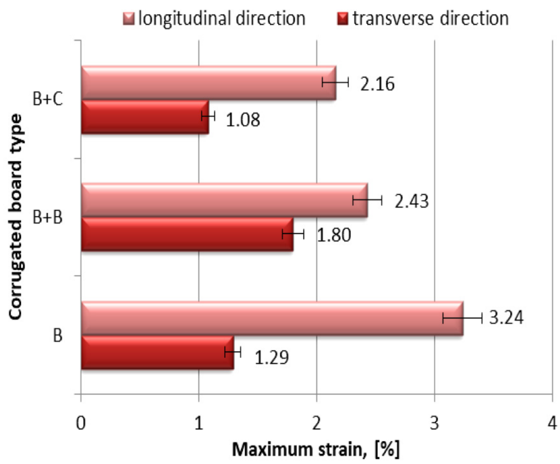


Figure 7. Maximum strain of corrugated cardboard

Strength parameters of corrugated cardboard joints

The strength results of the corrugated cardboard joints (and standard deviation of these parameters) are reported in Figures. 8, 9 and 10. The corrugated cardboard samples in the joints were made transversely to the direction of arrangement of the paper layers. The samples of three-layer (B flute) and five-layer (system: B+B) corrugated cardboard joints were tested. Based on the strength tests of the corrugated cardboard joints, it can be noticed that:

a) the adhesive joints are characterized by higher maximum force (Figure 8) and maximum stress (Figure 9) compared to embossed joints. And this result applies to the joints of both three-layer cardboard (B) and five-layer cardboard (B+B system),
b) the adhesive joints of three-layer cardboard (B) are characterized by higher values of maximum force (by 22%) and maximum stresses (by 68%) than those of five-layer corrugated cardboard (B+B system),
c) the embossed joints of five-layer cardboard (B+B system) obtained a higher maximum force than embossed joints of three-layer corrugated cardboard (B) by approximately 7%.
d) greater differences in strength results were obtained for three-layer corrugated cardboard joints (B),
e) in the case of three-layer corrugated cardboard joints (B), embossed joints have a greater maximum strain by about 12%, and in the case of five-layer cardboard (B+B system) – the adhesive joints (the difference is about 50%).

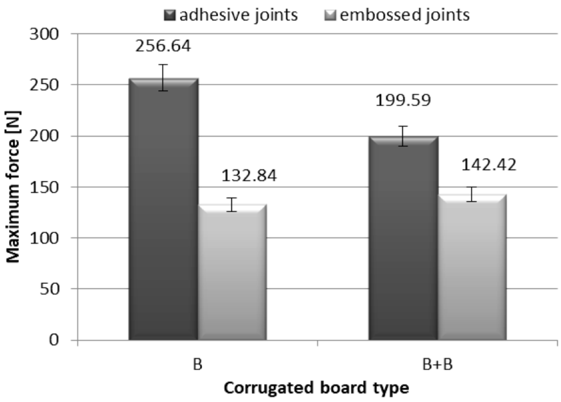


Figure 8. Maximum failure force of corrugated cardboard joints

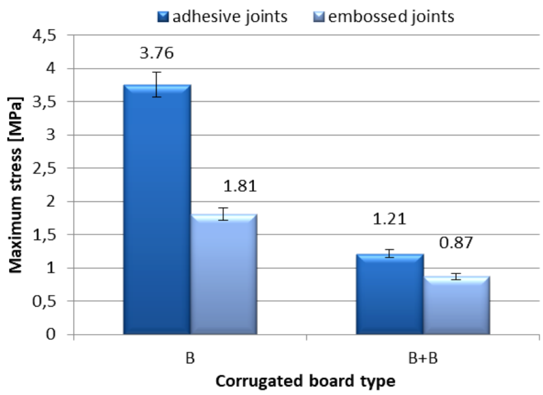


Figure 9. Maximum stress of corrugated cardboard joints

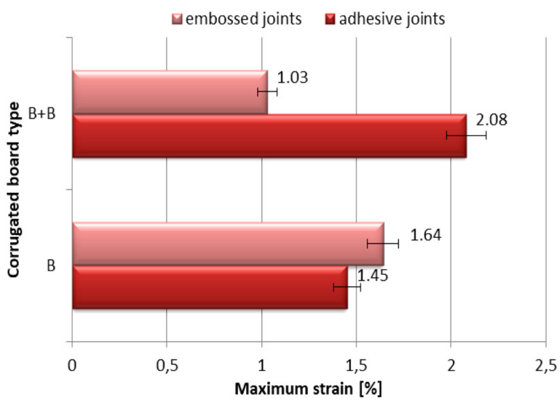


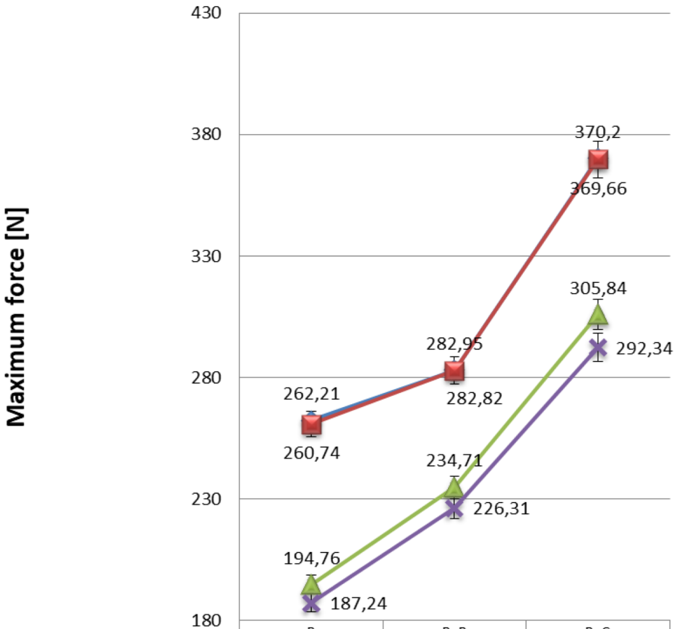
Figure 10. Maximum strain force of corrugated cardboard joints

DISCUSSIONS

Analyzing the results of the strength tests of corrugated cardboard, it was noticed that the corrugated cardboard samples subjected to the action of a force transverse to the direction of the paper layers have a greater failure force than the force directed along the direction of the paper layers. In the case of three-layer corrugated cardboard this difference is 25%, and in the case of five-layer corrugated cardboard in the B+B flute system and the B+C flute system this difference is 17%.

A comparison of the maximum force at which failure occurred and the force initiating failure of the corrugated cardboard is presented in Figure 11. On the basis of the results presented in Figure 11, it can be observed that smaller differences in values were observed in the case of maximum failure forces, and larger ones in the case of forces initiating failure.

The force initiating failure for three-layer corrugated cardboard samples (B) in the transverse direction is approximately 74% of the maximum force value, and in the longitudinal direction



	B	B+B	B+C
Max - transverse direction	262,21	282,95	370,2
Max - longitudinal direction	260,74	282,82	369,66
Init - transverse direction	194,76	234,71	305,84
Init - longitudinal direction	187,24	226,31	292,34

Figure 11. Comparison of the maximum force and the force initiating failure of the corrugated cardboard

- approximately 72%. Therefore, it can be assumed that the direction of arrangement of paper layers has no influence on the beginning of the failure.

The force initiating failure for five-layer cardboard samples (both B+B system and B+C system) in the transverse direction is approximately 82% of the maximum force value, and in the longitudinal direction approximately 80%. Therefore, it can be assumed that the direction of arrangement of paper layers has no influence on the beginning of the failure and no differences were noticed in the types of layers (B or C) in the structure of the corrugated cardboard. Fehér et al. [2] presented research that aimed at the performance of CCBs by considering the effects of different sidewall cutout configurations. The compressive strength of different dimensions of CCB with B flute was analyzed. It was noted, among others, that the geometric size of the boxes varied over a wider range, but for the 400 mm boxes with the best BCT results.

PVAc-based dispersion adhesive was used in the tests. The literature [10, 17] presents various aspects of the use of this type of the adhesive for bonding wooden and wood-based materials (e.g. different kind of cardboards). The use of a different type of the adhesive would perhaps contribute to obtaining slightly different relationships between the strength results of the analyzed joints. Beex and Peerlings [13] also presented the issues of processing cardboard into packaging through simple operations such as cutting, folding and bonding, and pointed out various difficulties related to the correctness of the production and aesthetics of the box using the folding process. With regard to the type of the joined materials (different type of paperboards), Rudawska and Gola [12] also presented research results indicating that the type of the packing material has an impact on the adhesive joints strength.

CONCLUSIONS

Based on the results of the experimental studies, it was noted that:

- the type of corrugated cardboard (the number of layers and the type of layers in five-layer boards) affects the strength results of the packaging material itself and the joints made from it,
- the corrugated cardboard samples subjected to a force transverse to the direction of the paper layers have a higher failure force,
- the direction of the paper layers in the tested three-layer and five-layer corrugated cardboard samples has no effect on the onset of damage,
- the adhesive joints of the corrugated cardboard are characterized by a higher maximum failure

force compared to the embossed joints of the analyzed corrugated boards.

Based on the research, it can be concluded that both the type of the corrugated cardboard and the type of the joints affect the strength of the unit packaging.

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