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A REINFORCING METHOD OF CORRUGATED FIBERBOARD BOXES

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Abstract: *A technological reinforcement method of corrugated fiberboard boxes in the area of the creases is proposed. For the same type of box three different reinforcement possibilities are subjected to the standard box compression test. The results are compared from the viewpoint of the main value and the median of the compressive strength.*
Key words: *Box Compression Test, Edgewise Compression Test, Mean value, Median, Stress Strain Diagram.*

1. INTRODUCTION

The Box Compression Test (BCT) represents along the Edgewise Compression Test (ECT) one of the main compulsory tests which must be performed on corrugated fiberboard boxes in the industrial environment.

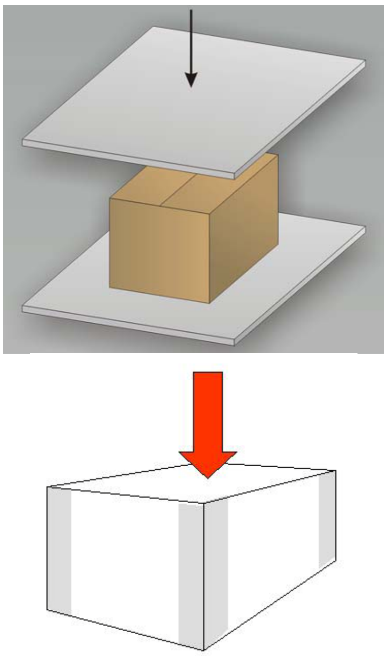

Fig. 1. BCT Principle (https://www.google.ro/?gws_rd=cr,ssl&ei=fDTmU5f2KMmJOM3rgPgK#q=3-ta3004-m2-l3-paper.pdf)

Figure 1 presents the BCT principle, consisting in the maximum load a given box can stand for a moment (60-90% occurring at 5 cm from the edges).

The test package is placed between the platens of a compression tester and either:

- in the case of a compression test, a load is applied until failure occurs or predetermined values for load or displacement are reached; or
- in the case of a stacking test, a predetermined load is applied for a predetermined time or until failure occurs.

The compression tester, motor-driven, platen-type, is capable of applying load through uniform movement of one or both platens at a relative speed of 10mm/min $\pm$ 3mm/min., dimensioned so as to extend over the whole area of that side of the test package or interposed devices with which it is in contact.

Wherever possible the test shall be carried out in the same atmospheric conditions as used for conditioning (23 g Celsius and 50% humidity) [1].

The load is applied by the relative movement of the platens at the appropriate speed, in such a way that peaks in excess of the predetermined load do not occur, until predetermined value is reached or until collapse occurs, whichever is first. If collapse occurs first, one must record the value of the load reached.

In real operating conditions, compressive strength of boxes is reduced due to the following reasons:

- the box content exercises forces that determine the wall deformation to outside
- compressive forces are acting on the boxes for long periods (weeks-months)
- during manipulation and shipping the boxes are exposed to vibrations, shocks or different strokes, also air parameters are variable, so that moisture equilibrium of the box changes relatively frequent
- during storage, compression forces are not uniformly distributed on the surface of the box

Low compression forces, are taken uniformly throughout the perimeter of the box. When load increases, a first critical point is reached (point "a", Fig. 2.). At this point the walls of the box are elastically deformed to the outside, while the corners remain unaffected [2].

Compressive forces are concentrated towards the corners of the box, which will be more affected than its sides and when the second critical point "b" is exceeded, the corners begin to crush. When reaching maximum load, the point "c" of the stress-strain diagram, sides are folded and edges are crushed [3]. Consequently, the resistance of a box is given both by the corrugated board stiffness and edgewise compressive strength.

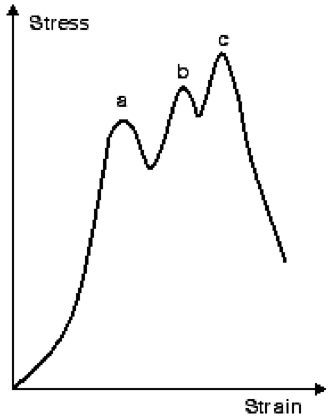

Fig. 2. Theoretical stress-strain diagram

It is worthy to note that from the practical viewpoint, the shape of critical points could greatly differ in amplitude and distance or even some of them could simply miss (see Fig. 3).

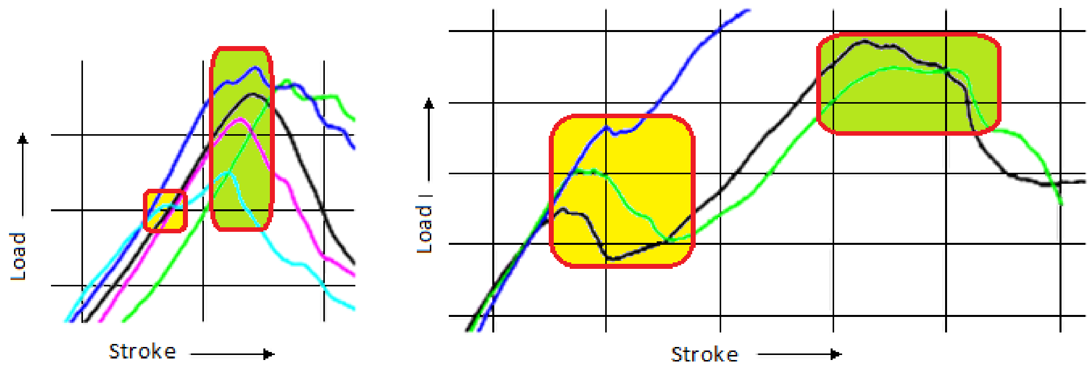

Fig. 3. Comparison between the buckling areas of two different compression tests

The larger the buckling area in a box compression test, the risk of damages is more pronounced, while in these types of areas the compression of the package is more significant. At the same time one can observe that from the post buckling point until the point of irreversible compression, the slopes of the curves are lower than on the area of elasticity, which determines an extra compression of the package even for smaller efforts. That is why, in the design process of packages, extra measures must be taken in order to mitigate the buckling, because the phenomenon is more acute after stacking, in manipulation and/or transport processes.

The values of compressive strength of boxes can be determined by calculation, if one knows [4, 5]:

- the Edgewise Compression Strength, obtained after tests ECT [kN/m]
- the corrugated board stiffness S_b, on machine direction (S_{bMD}) and on cross-machine direction (S_{bCD}) [Nm]
- the perimeter of the box, Z [m]

These parameters compose the McKee's well-known equation which has the general form:

$$BCT = k_1 \cdot ECT^{b} \cdot Sb^{1-b} Z^{2b-1} \,[\mathrm{N}]$$

For the particular case of corrugated board boxes, McKee's formula becomes:

$$BCT = k_1 \cdot ECT^{0.75} \cdot Sb^{10.25} Z^{0.5} \,[\mathrm{N}]$$

where:

$$Sb = \sqrt{Sb_{MD} \cdot Sb_{CD}} \,[\mathrm{N \cdot m}]$$

A simplified practical form of McKee's formula, applicable to corrugated paperboard is:

$$BCT = k_2 \cdot ECT \cdot T^{0.5} \cdot Z^{0.5} \,[\mathrm{N}]$$

Tests were carried out using the MESSPHYSIK ALPHA 50 BCT tester, presented in Fig.4.

Test parameters are:

BN_0 ....Batch number
F_{max} ....Maximum load
"M ....Strain at compressive strength
FB ....Breaking load
t ....Test duration
sF_{max} ....Stroke at F_{max}
sB ....Stroke at break

The test reports give several statistic results [6-7]. The mean value is in this case the arithmetic mean, which for a data set represents the sum of the observations divided by number of observations.

In probability theory and statistics, the median is described as the number separating the higher half of a population from the lower half. If there is an even number of observations, the median is not unique, so one often takes the mean of the two middle values. In our case, the median is the geometric mean of the two middle values. The median is less sensitive to extreme scores than the mean and this makes it a better measure than the mean value income, especially for highly skewed distributions.

The range is the length of the smallest interval which contains all the data. It is calculated by subtracting the smallest observation from the greatest and provides an indication of statistical dispersion.

Fig. 4. The BCT machine

2. EXPERIMENTAL RESULTS

One of the main issues of corrugated fiberboard packaging is the compression strength. That is why the company Tesa has developed a series of tapes used for reinforcing corrugated fiberboard packages. http://www.tesa.com/. The company further developed a practical technology using the reinforcing tapes for corrugated fiberboard packages. From Fig. 5 on can notice that the tape is applied cross machine direction (CMD). http://winterhalder.de/en/media/selbstklebebaender/en/tesa-reinforcement.pdf

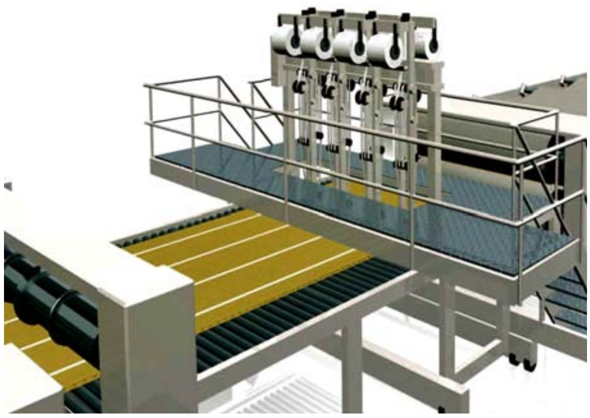

Fig. 5. Industrial equipment for applying the reinforcing tapes

On the other hand from the industry practice it is well known that the higher degree risky creases are those placed on machine direction (MD); these creases are situated along the slots as it can be seen in Figure 6.

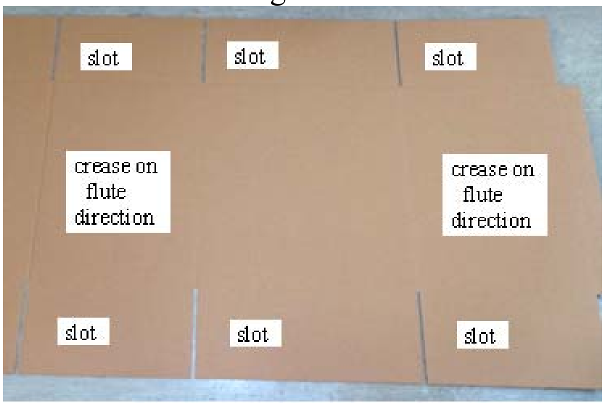

Fig. 6. A FEFCO 201 package

These types of packages are manufactured in the Flexo-Folder-Gluer machines, which could be easily transformed by introducing one creases reinforcement unit, based the same principle used in the slots and creases unit.

Starting from these premises, compression strengths for a FEFCO type package will be studied in three different cases, namely: no reinforced package, reinforced package using adhesive type of Kraft paper and gummed paper tape.

The package under test is a FEFCO 201 one, 321E flute, having the dimensions 250x200x100 mm (Fig. 7).

Fig. 7. The package under test

The test report of the non reinforced package is presented in Fig. 8, and the corresponding graphs are depicted in Figure 9 for a batch of five similar boxes. The summary table (i.e. Table 1) depicts two results of the test report of the package in the two different conditions; the first one for the reinforcement using adhesive type of Kraft paper and the second one using the reinforcement using gummed paper tape.

Figure 10 presents the histogram corresponding to the three situations which turns to the conclusion that the best compression strengths is obtained for the gummed paper tape.

Testing machine...................ALPHA50
Pretension............................50 N
Platen distance.....................300 mm
Test speed 1........................0 % - ›12.50 mm/min

Directory...proiect
Parameter set..DEFAULT

Legend

BNo.......................Batch number
Fmax....................Maximum load
"M.........................Strain at compressive strength
FB.........................Breaking load
t............................Test duration
sFmax..................Stroke at Fmax
sB..........................Stroke at break
Date......................Tested on
Comment.............Comment

Test No	BNo	Fmax kN	"M %	FB kN	t s	sFmax mm	sB mm	Date	Comment
22	5	1.020	-31.03	0.637	66480	5.399	13.85	2014-08-05	
23	5	0.926	-27.28	0.565	6540	4.799	8.698	2014-08-05	
24	5	0.714	-24.45	0.524	50100	4.542	10.44	2014-08-05	
25	5	1.332	-27.97	0.831	47280	5.129	9.850	2014-08-05	
26	5	1.006	-31.57	0.496	88040	5.554	18.34	2014-08-05	

	Fmax kN	"M %	FB kN	t s	sFmax mm	sB mm
Mean:	1.000	-28.46	0.611	51688	5.085	12.24
Median:	1.006	-27.97	0.565	50100	5.129	10.44
Minimum:	0.714	-31.57	0.496	6540	4.542	8.698
Maximum:	1.332	-24.45	0.831	88040	5.554	18.34
Range:	0.618	7.120	0.335	81500	1.012	9.642
Std.dev.:	0.222	2.915	0.134	30002	0.417	3.915
Values:	5	5	5	5	5	5

Fig. 8. Test report of the non reinforced package

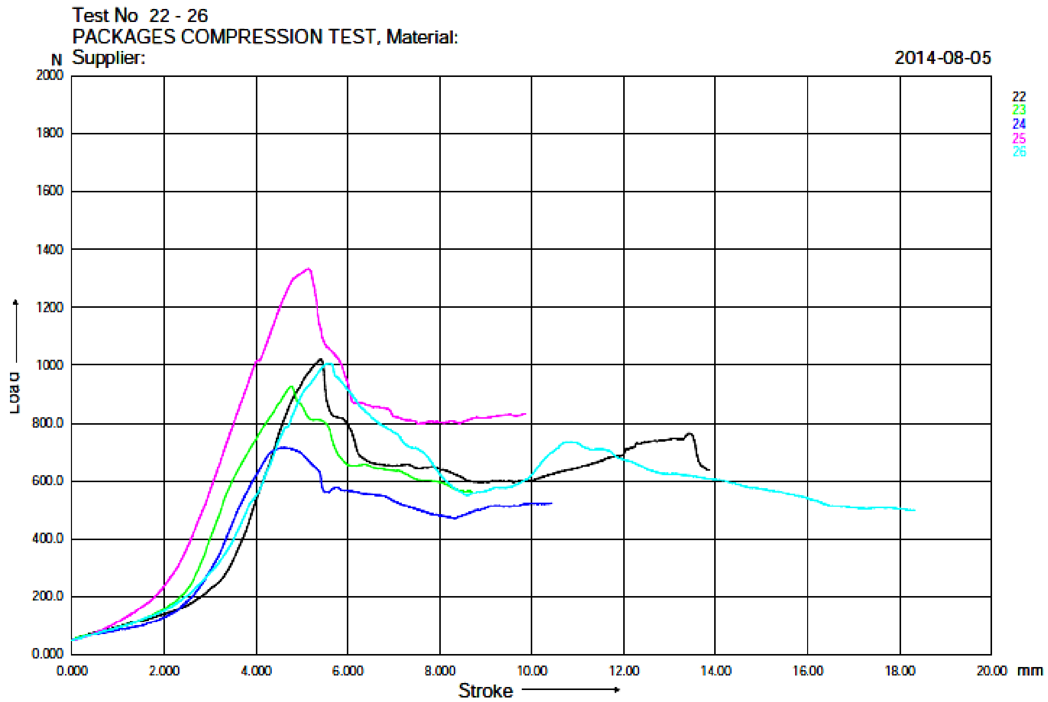

Fig. 9. Graphs corresponding to the compression test of the non reinforced package

Table 1

Summary table of the compression tests

	Package	**Mean value (kN)**	**Median (kN)**	**Minimum value (kN)**	**Maximum value (kN)**
A	Non reinforced	1,000	1,006	0,714	1,332
B	Reinforced using Kraft paper	1,152	1,121	0,901	1,380
C	Reinforced using gummed paper	1,248	1,302	0,898	1,477

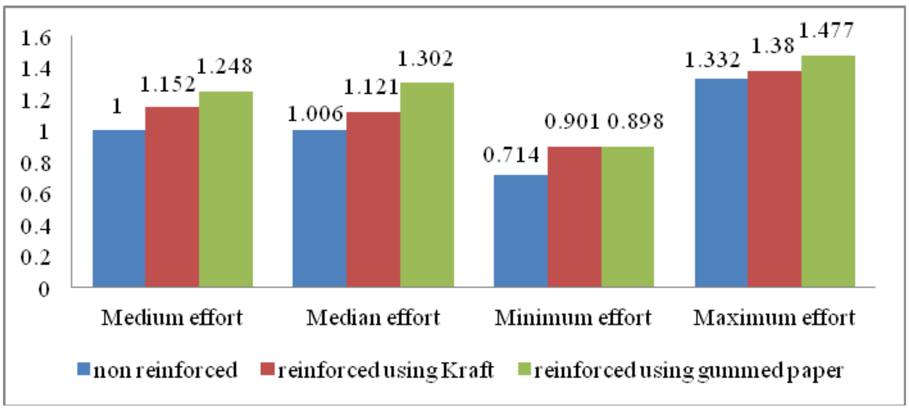

Fig. 10. Comparative histogram corresponding to the compression tests in the three situations

The relative growth of the compression strengths versus the non reinforced package in the terms of the medium effort is for the reinforcement using Kraft adhesive paper:

$$G_{rmediu}\% = \frac{|F_{medieB} - F_{medA}|}{F_{medA}} \cdot 100\% = \frac{|1,152 - 1,00|}{1,00} \cdot 100\% = 15\%$$

Similar, for the reinforced gummed adhesive paper,

$$G_{rmediu}\% = \frac{|F_{medieC} - F_{medA}|}{F_{medA}} \cdot 100\% = 24,8\%$$

In terms of the median the reinforcement using Kraft adhesive paper:

$$G_{rmedian}\% = \frac{|F_{medianB} - F_{medianA}|}{F_{medianA}} \cdot 100\% = 11.4\%$$

and for the gummed adhesive paper:

$$G_{rmedian}\% = \frac{|F_{medianC} - F_{medianA}|}{F_{medianA}} \cdot 100\% = 29{,}5\%$$

CONCLUSIONS

The presented method is quite simple to be implemented as additional units in Flexo-Folder-Gluer machines and the performed reinforcement greatly improve the compressive strength of corrugated fiberboard boxes in terms of the mean value of the effort which is greater with almost 25%, and in terms of the median value of the compression effort almost 30%.

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REFERENCES

[1] Modzelewska, I., "Climatic conditions vs. hygrostability and strength properties of corrugated board", *Folia Forestalia Polonica*, Wyd. AR Poznan, 37, 2006, pp. 33-45.

[2] Isaksson, P., Hagglund, R., "A mechanical model of damage and delamination in corrugated board during folding", *Engineering Fracture Mechanics*, 72, 2005, pp. 2299–2315

[3] Harrysson, A., Ristinmaa, M., "Large strain elasto-plastic model of paper and corrugated board" *International Journal of Solids and Structures*, 45, 2008, pp. 3334–3352

[4] Luo, S., et al., "The Bending Stiffness of Corrugated Board", *AMD*-Vol. 145/MD-Vol. 36, *Mechanics of Cellulosic Materials* 1992, pp. 15-26.

[5] Ryan, T., *Modern Engineering Statistics*, John Willey &Sons Inc., 2007.

[6] Antoniou, A., Wu-Seng, L., *Practical optimization*, Springer Science+Business Media, 2007.

[7] Neidoni N., Boloş V., Buzdugan MI, Experimental Optimization of Perforations for Corrugated Board Boxes , The 4th edition of the InterEng Conference, "Petru Maior" University of Tîrgu Mureş, Romania, 2009

PROPUNERE TEHNOLOGICĂ PENTRU RANFORSAREA CUTIILOR DE CARTON ONDULAT

Rezumat: Lucrarea prezintă o propunere tehnologică de ranforsare pe linia de fabricaţie flexografică a cutiilor de carton ondulat. Sunt prezentate două variante de ranforsări, una dintre acestea determinând creşterea rezistenţei la compresiune cu până la 30% în raport cu varianta neranforsată.

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