PRELIMINARY COMMUNICATION
RECEIVED: 03.09.2012
ACTA GRAPHICA 211
ACCEPTED: 26.10.2012

Evaluation of Mechanical Strength of Five Layer Corrugated Cardboard Depending on Waveform Types

Authors

Ivan Budimir, Branka Lajić*, Suzana Pasanec Preprotić

[1]*University of Zagreb,*
Faculty of Graphic Arts,
Croatia
**E-mail: branka.lajic@grf.hr*

Abstract:

Due to the growing need for saving material in the production of paper packaging, its industrial production is faced with the problem of assuring quality. By controlling the cost of corrugated cardboard production, mechanical properties depend directly on flute profile. Therefore, the corrugated cardboard can be observed both from technological and environmental aspects.

For this research five-layer corrugated cardboard of different types of flute profile was used. It is assumed that the characteristic shape of the wave has a positive effect on its mechanical properties. On the other hand, it is assumed that the saving of the material can be achieved through characteristic flute profile without reducing cardboard mechanical strength. The aim of this research is to determine whether there is a direct impact of waveform type on mechanical strength. Statistical methods were used for the evaluation of expected values of corrugated cardboard estimated strength with respect to the flute profile.

Keywords:

Five Layer Corrugated Cardboard, Flute Profile, Mechanical Strength, Corrugated Cardboard

1. Introduction

Corrugated cardboard is a multi layered structure which is widely used in the packaging industry to produce various boxes. In the past few years the demand for this material has grown by hundreds of times worldwide. In addition to the package, designers around the globe are starting to make different products out of it, such as pieces of art, advertising products, furniture, shelters, accessories for storing and transportation of goods and many more. *(Arzoumanian, 2001), (Damatty & Awad, 2000), (Fornalski & Kolodziejski, 2007), (Isler, 2010).* Mathematical approach to this problem is expressed by describing physical mechanical properties of corrugated cardboard packaging based on modelling with partial differential equations with results which are numerically approximated using the method of finite elements. *(Damatty et all., 2000), (Gilchrist et all., 1999), (Pommier & Poustis, 1999), (Pommier et all., 1991), (Rahman, 1997), (Gilchrist, 1997).* The research presented in this paper is a contribution to those and similar endeavours of testing the mechanical properties of corrugated cardboard with the emphasis on numerical and experimental approach to the above-mentioned problem. *(Biancolini & Brutti, 2003),(Cavlin & Edholm, 1998), (Kirwan, 2007), (Patel et all., 1997), (Damatty, 2000), (Gilchrist, 1999), (Pommier & Poustis, 1990).* Along with the increased use of corrugated cardboard a need arises for a better understanding of its mechanical characteristics. *(Biancolini et all., 1990), (Biancolini, 2005), (Biancolini, 2005).* Five-layer corrugated cardboard consists of two sheets of fluted paper interposed between and stuck to three facings. It is made of A or B wave in combination with C or E wave. The waves differ in length (step) and wave height *(Figure 1 and Figure 2).*

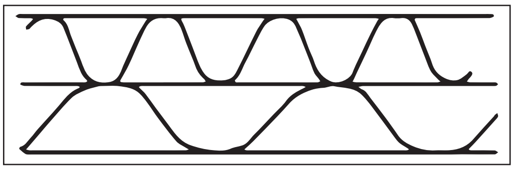

Figure 1. Five layer corrugated cardboard consisting of two sheets of fluted paper interposed between and stuck to three facings

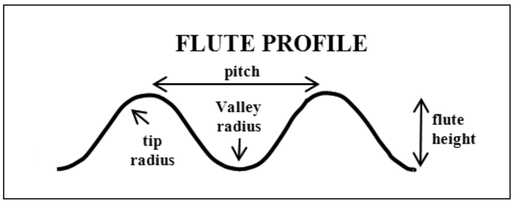

Figure 2. Flute profile

A systematization of the size of the wave was conducted according to name, marking, height, step, and number of waves *(Table 1)* according to DIN 55 468 and Container Board CEPI - European Database for Corrugated Board Life Cycle Studies 2009th.

From the research it can be concluded that the rough wave A shows the reduced strength to pressure while the dynamic load perpendicular to the surface of the cardboard is larger. Furthermore, rough wave A shows greater strength towards bending and buckling, but only in the direction of the wave. This type of wave also exhibits a significantly higher bursting strength than the other waves (B, C, E).

Fine B wave shows good resistance to pressure and reduced strength to dynamic loads. There is a tendency of bending and buckling only in the direction of the wave, whereas its bending strength is larger vertically to the direction of the wave, which is not the case with rough waves. The mechanical properties of the middle C wave are grouped together between waves A and B. these types of waves (A, B, C) are used for the production of tertiary packaging.

Table 1. Flute types

Flute type	Flue Height [mm]	Take up factor	Flutes/m length of the corrugated board web	Glue consumption [g/m^2], Glue layer
A	4,8	1,50 – 1,55	110	4,5 – 5,0
B	2,4	1,30 – 1,35	150	5,5 – 6,0
C	3,6	1,40 – 1,45	130	5,0 – 5,5
E	1,2	1,15 – 1,25	290	6,0 – 6,5
F,G,N	0,5-0,8	1,15 – 1,25	400-550	9,0 – 11,0

Compression is much greater for small wave E as compared to other types of waves. On the other hand, this type of wave has the lowest resistance to bending and is used for making primary packaging. Mechanical properties of corrugated cardboard directly depend on the properties of wave types (A, B, C, E). The increased “fluting” is therefore directly associated with the increase of the number of waves in cardboard. Its presence in the C wave is 50% ± 5%, the B wave 30% ± 5% and E wave 15% ± 5%. The purpose of this paper is to show the influence of a combination of waveforms to the change of corrugated cardboard strength. The research has shown that a combination of waveforms achieves considerable saving in material consumption without reducing packaging quality.

2. Experiment

Three types of five-layer corrugated cardboard were produced for this research according to EN 643:2001(E) and ISO 4046. C/B and E/B waveform types were used for testing the mechanical strength of corrugated cardboard (European Organization Container Board, 1992). Testing the mechanical properties of corrugated cardboard included the measurement of surface mass, thickness, resistance to cracking-Mullen, edge crush test (ECT) and resistance to penetration (PT), according to standards ISO 536:1995, ISO 534:1988, ISO 2758:2001, ISO 3037:1994 and ISO 3036:1994. Measurements were conducted in conditional requirements according to ISO 186:2002 and ISO 187:1990. Conditions for applying the Student’s t-test for comparing arithmetic means were tested. Means were compared between groups in pairs C/B and E/B waveform types by Student’s t-test *(Creswell, 2003), (Vining & Kowalski, 2011)* on specimens made of different materials. Based on test results it can be concluded that E/B waveform type in five-layer corrugated cardboard has certain advantages in comparison with C/B waveform type. The specification of cardboard samples with respect to the waveform type is shown in *Table 2.* In order to achieve objective results of corrugated cardboard strength, laboratory measurements of different types of paper in the development of flat layers are obligatory: testliner, white testliner and Common wrapping are mandatory.

Wellenstoff was used to create layers of corrugated cardboard. Measurements of surface mass and resistance to cracking by Mullen for flat layer, as well as the surface mass and resistance to pressure (CMT) for corrugated layer were conducted according to standards ISO 536:1995, ISO 7263:1994 and ISO 7263:1994. Measurements of materials were carried out in conditional requirements according to ISO 186:2002 and ISO 187:1990. Five layer corrugated cardboard marked T2Š-C/B is made out of testliner (130 g/m^2), (top surface) and two layers of Common wrapping (100 g/m^2), (middle and back side) for a flat layer. Wellenstoff (115 g/m^2 to 100 g/m^2) is used for making different types of C/B waveforms. The components for the cardboard marked T2Š- E/B are the same as the above, except for the use of E/B waveform type. Sample marked 2TŠ-C/B is made of two-layered testliner (130 g/m^2) and Common wrapping layer (100 g/m^2) in combination with C/B waveforms. The same goes for the sample marked 2TŠ-E/B in combination with E/B waveforms. Components for cardboard-marked BTŠ-C/B and BTŠ-E/B are white testliner (135 g/m^2), testliner (130 g/m^2) and Common wrapping (100 g/m^2) in combination of C/B and E/B waveforms.

Table 2. Systematization of five-layer corrugated cardboard

Ordering code sample	Type of waveform (flute profile)
T2Š	C/B
T2Š	E/B
2TŠ	C/B
2TŠ	E/B
BTŠ	C/B
BTŠ	E/B

3. Results and Discussion

In the first part of the research the analysis of the basic parameters and mechanical properties of different components of five-layer corrugated cardboard was conducted, including only a combination of two types of waveforms: C/B and E/B.

In the second part of the research, the same components of different types of waveforms were compared to each other with the aim of evaluating the mechanical strength of five-layer corrugated cardboard. *Tables 3a-f* show the basic descriptive statistics, which include mean, 95-percent confidence intervals, median, minimum, maximum, variance and standard deviation of measured data obtained by instrumental analysis of all tested parameters of sub-types of five layer corrugated cardboard.

Furthermore, distribution normality of all observed variables has been established by Shapiro-Wilk test *(Tables 4a-f)*. This way the conditions for the application of Student's t-test for comparing the arithmetic means were to be checked. Student's t-test for comparing arithmetic means was conducted in order to determine which type of corrugated cardboard had the best properties. Statistical analysis was made in the package Statistica 7.0.

Lower 5% Critical Values for Shapiro-Wilk Test Statistic W, for n=10 and p= 0.05 is W_o=0.8420. It has been shown by Shapiro-Wilk test that *(Table 4a-f)* all measured samples were compatible with normal distribution because statistics is W_o=0.8420 in all cases but one, which can be disregarded. It is possible to implement the Student's t-test for arithmetic means, given that the number of measurements is n = 10 < 30th. Student's t-test for variables in independent samples showed the statistical significance of differences of results of arithmetic mean. Results of weight, thickness, resistance to cracking by Mullen and resistance to penetration (PT test) of sample pairs of components of corrugated cardboard were compared: T2Š C/B and T2Š E/B *(Table 5)*, 2TŠ C/B and 2TŠ E/B *(Table 6)* and BTŠ C/B and BTŠ E/B *(Table 7)*.

The following hypothesis is tested for the given pairs of samples:

H_o*: *there is no statistically significant difference between the corresponding mean values

Versus the alternative hypothesis:

H_a*: *the difference between corresponding mean values is statistically significant

The used statistical test is of the form:

$$t = \frac{\left|\overline{X}_1 - \overline{X}_2\right|}{\sqrt{\frac{S_{d1}^2 - S_{d2}^2}{N-1}}} \qquad (1)$$

Where $\overline{X}_1$ and $\overline{X}_2$ are the arithmetic means of the compared samples and S_{d1} and S_{d2} are their deviations.

Statistically significant are different weights and thicknesses of 2TŠ C/B and 2TŠ E/B, and both were higher in sample 2TŠ C/B as compared to sample 2TŠ E/B. Mullen and ECT were also significantly different, Mullen and ECT were higher in sample 2TŠ E/B. There were no statistically significant differences in PT J.

Weight and thickness of 2TŠ C/B and 2TŠ E/B samples were significantly different and both were higher in sample 2TŠ C/B as compared to sample 2TŠ E/B. Mullen and ECT parameters also show statistically significant difference, the Mullen parameter was greater for 2TŠ E/B sample, while ECT increased in the sample 2TŠ E/B. There were no statistically significant differences in parameter PT J.

Weight and thickness of BTŠ C/B and BTŠ E/B samples were significantly different and both were higher in sample BTŠ C/B as compared to sample BTŠ E/B. Parameters Mullen, ECT and PTJ were also statistically significantly different and all three values were higher for BTŠ E/B sample than for BTŠ C/B sample. It is possible to display the received results graphically by corresponding histograms *(Figures 3a-e)*.

Table 3a: Descriptive statistics for sample marked T2Š- C/B

	Valid N	Mean	Confidence -95	Confidence +95	Median	Min.	Max	Var.	Std.Dev.
ISO 536	10	668	666,88	669,12	668,00	666	670	2,44	1,56
ISO 534	10	6,45	6,44	6,46	6,45	6,43	6,47	0,000156	0,01
ISO 2758	10	750	748,69	751,31	750	747	753	3,33	1,83
ISO 3037	10	6,00	5,89	6,11	6,00	5,80	6,20	0,02	0,15
ISO 3036	10	6,50	6,39	6,61	6,50	6,30	6,70	0,02	0,15

Table 3b: Descriptive statistics for sample marked T2Š- E/B

	Valid N	Mean	Confidence -95	Confidence +95	Median	Min.	Max	Var.	Std.Dev.
ISO 536	10	660	658,74	661,26	660	657	662	3,31	1,76
ISO 534	10	4,05	4,04	4,06	4,05	4,04	4,07	0,0001	0,01
ISO 2758	10	900	898,93	901,07	900	898	902	2,22	1,49
ISO 3037	10	7	6,91	7,09	7	6,80	7,20	0,015	0,12
ISO 3036	10	6,40	6,30	6,50	6,40	6,20	6,60	0,02	0,14

Table 3c: Descriptive statistics for sample marked 2TŠ-C/B

	Valid N	Mean	Confidence -95	Confidence +95	Median	Min.	Max	Var.	Std.Dev.
ISO 536	10	698	697,17	698,83	698	696	700	1,33	1,15
ISO 534	10	6,45	6,44	4,46	6,45	6,43	6,47	0,0002	0,015
ISO 2758	10	800	798,88	801,12	800	798	803	2,44	1,56
ISO 3037	10	6,80	6,70	6,90	6,80	6,60	7	0,017	0,13
ISO 3036	10	7	6,89	7,11	7	6,70	7,20	0,024	0,16

Table 3d: Descriptive statistics for sample marked 2TŠ-E/B

	Valid N	Mean	Confidence -95	Confidence +95	Median	Min.	Max	Var.	Std.Dev.
ISO 536	10	690	689,05	690,95	690	688	692	1,78	1,33
ISO 534	10	4,05	4,04	4,06	4,05	4,03	4,07	0,0001	0,01
ISO 2758	10	900	898,88	901,12	900,50	897	902	2,44	1,56
ISO 3037	10	6,60	6,52	6,68	6,60	6,40	6,70	0,01	0,11
ISO 3036	10	7	6,89	7,11	7	6,70	7,20	0,02	0,16

Table 3e: Descriptive statistics for sample marked BTŠ-C/B

	Valid N	Mean	Confidence -95	Confidence +95	Median	Min.	Max	Var.	Std.Dev.
ISO 536	10	703	701,99	704,01	702,50	701	705	2	1,41
ISO 534	10	6,45	6,44	6,46	6,45	6,43	6,47	0,0002	0,015
ISO 2758	10	800	798,88	801,12	800	798	802	2,44	1,56
ISO 3037	10	6,75	6,70	6,80	6,75	6,65	6,85	0,006	0,075
ISO 3036	10	5,50	5,42	5,58	5,50	5,40	5,70	0,0013	0,12

Table 3f: Descriptive statistics for sample marked BTŠ-E/B

	Valid N	Mean	Confidence -95	Confidence +95	Median	Min.	Max	Var.	Std.Dev.
ISO 536	10	695	694,05	695,95	695	693	697	1,78	1,33
ISO 534	10	4,05	4,04	4,06	4,05	4,03	4,07	0,00013	0,012
ISO 2758	10	900	898,88	901,12	900,50	897	902	2,44	1,56
ISO 3037	10	7	6,91	7,09	7	6,80	7,20	0,016	0,12
ISO 3036	10	7	6,91		7	6,80	7,20	0,016	0,12

Table 4a. S-West test for sample 2TŠ-C/B with Lower 5% Critical Values
W_0=0.8420

	N	W	$W>W_0$=0.8420
ISO 536	10	0.8707	Normal
ISO 534	10	0.9395	Normal
ISO 2758	10	0.9838	Normal
ISO 3037	10	0.9180	Normal
ISO 3036	10	0.9180	Normal

Table 4b. S-W test for sample 2TŠ-E/B with Lower 5% Critical Values
W_0=0.8420

	N	W	$W>W_0$=0.8420
ISO 536	10	0.9191	Normal
ISO 534	10	0.8587	Normal
ISO 2758	10	0.9180	Normal
ISO 3037	10	0.9395	Normal
ISO 3036	10	0.9068	Normal

Table 4c. S-W test for sample 2TŠ-E/B with Lower 5% Critical Values
W_o=0.8420

	N	W	$W>W_0$=0.8420
ISO 536	10	0.9531	Normal
ISO 534	10	0.9180	Normal
ISO 2758	10	0.9326	Normal
ISO 3037	10	0.9184	Normal
ISO 3036	10	0.9326	Normal

Table 4d. S-W test for sample 2TŠ-E/B with Lower 5% Critical Values
W0=0.8420

	N	W	$W>W_0$=0.8420
ISO 536	10	0.9184	Normal
ISO 534	10	0.9531	Normal
ISO 2758	10	0.8990	Normal
ISO 3037	10	0.8587	Normal
ISO 3036	10	0.9326	Normal

Table 4e. S-W test for sample 2TŠ-E/B with Lower 5% Critical Values
W0=0.8420

	N	W	$W>W_0$=0.8420
ISO 536	10	0.8870	Normal
ISO 534	10	0.9180	Normal
ISO 2758	10	0.8707	Normal
ISO 3037	10	0.9180	Normal
ISO 3036	10	0.7729	Not normal

Table 4f. S-W test for sample 2TŠ-E/B with Lower 5% Critical Values
W0=0.8420

	N	W	$W>W_0$=0.8420
ISO 536	10	0.9184	Normal
ISO 534	10	0.9531	Normal
ISO 2758	10	0.8990	Normal
ISO 3037	10	0.9395	Normal
ISO 3036	10	0.9395	Normal

Table 5. T-test for independent samples compared the mean Components of the Cardboard T2Š C/B and T2Š E/B

Comparison of the values of samples T2Š C/B vs. T2Š E/B	Mean T2Š C/B	Mean T2Š E/B	t-value	df	p
ISO 536	668	660	10,73	18	0,000000
ISO 534	6,45	4,05	464,76	18	0,000000
ISO 2758	750	900	-201,25	18	0,000000
ISO 3037	6	7	-16,27	18	0,000000
ISO 3036	6,50	6,40	1,54	18	0,141207

Table 6. T-test for independent samples compared the mean Components of the Cardboard 2TŠ C/B and 2TŠ E/B

Comparison of the values of samples 2TŠ C/B vs. 2TŠ E/B	Mean 2TŠ C/B	Mean 2TŠ E/B	t-value	df	p
ISO 536	668	690	14,34	18	0,000000
ISO 534	6,45	4,05	402,49	18	0,000000
ISO 2758	800	900	-143,02	18	0,000000
ISO 3037	6,80	6	3,72	18	0,001564
ISO 3036	7	7	0,00	18	0,00000

Table 7. T-test for independent samples compared the mean Components for the cardboard BTŠ C/B and BTŠ E/B

Comparison of the values of samples BTŠ B/C vs. BTŠ E/B	Mean BTŠ C/B	Mean BTŠ E/B	t-value	df	p
ISO 536	703,00	695,00	1302	18	0,000000
ISO 534	6,45	4,05	402,49	18	0,000000
ISO 2758	800,00	900,00	-143,02	18	0,000000
ISO 3037	6,75	7,00	-5,44	18	0,000036
ISO 3036	5,50	7,00	-27,91	18	0,00000

4. Conclusion

The results of statistical analysis show that the production of five-layer corrugated cardboard for E/B waveform type is environmentally friendlier as the C/B waveform type. Corrugated cardboard of smaller weight and thickness is of the same or higher quality considering the parameters of mechanical properties (Mullen, ECT and PT). By reducing the thickness of cardboard, its transportation costs are reduced up to 20 percent. Furthermore, the production of five-layer corrugated cardboard waveform E/B results in a 3 percent total saving of material in comparison with the production of five-layer corrugated cardboard C/B waveform.

References

Arzoumanian, M.M., 2001. Copression-based linerboard: Whats really changed? Officiall Board Markets, 77, p.16.

Biancolini, M.E., 2005. Evaluation of equivalent stiffness properties of corrugated board. Composite Structures 69(3), p.322-328.

Biancolini, M.E., 2000. Online quality control of corrugated board panel by image processing.International Journal of Computer Applications in Technology, 23(2-4), p.157-165.

ISO 536 (a)

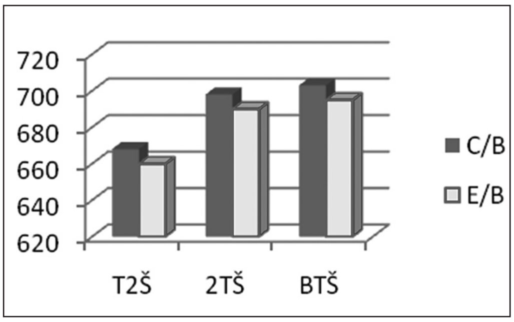

Figure 3a. Graphic display showing the comparison of measured values of the surface mass of different components of corrugated cardboard with respect to waveform type

ISO 534 (b)

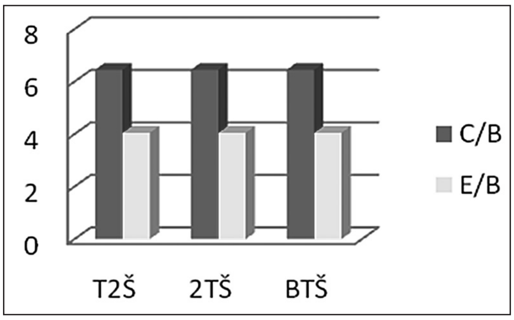

Figure 3b. Graphic display showing the comparison of measured values of the thickness of different components of corrugated cardboard with respect to waveform type

ISO 2758 (c)

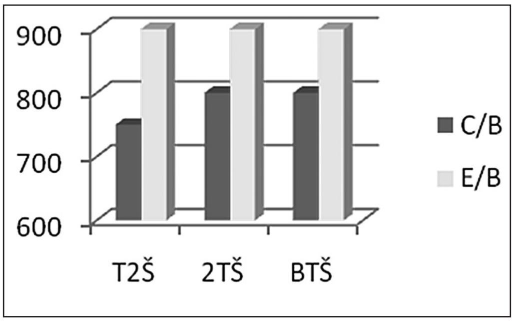

Figure 3c. Graphic display showing the comparison of measured values of the cracking-Mullen parameter and different components of corrugated cardboard with respect to waveform type

ISO 3037 (d)

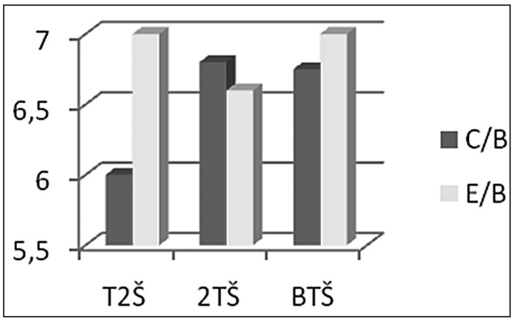

Figure 3d. Graphic display showing the comparison of measured values of the tensile force edge action parameter and different components of corrugated cardboard with respect to waveform type

ISO 3036 (e)

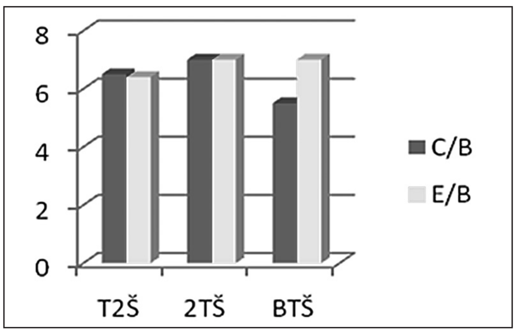

Figure 3e: Graphic display showing the comparison of measured values of the penetration parameter and different components of corrugated cardboard with respect to waveform type

Biancolini, M.E., Brutti, C. et al., 2000. Corrugated board containers design methods.International Journal of Computational Materials Science and Surface Engineering, 3(2-3), p.143-163.

Biancolini, M.E., Brutti, C.,2003. Numerical and experimental investigation of the strength of corrugated board packages. Packaging Technology and Science, 16(2), p.47-60.

Cavlin, S.I., Edholm, B.,1998. Converting cracks in corrugated bord: Effect of liner and fluting properties. Packaging Technology and Science, 1(1), p.25-34.

Creswell, J., 2003. Research Design: Qualitative, Quantitative and Mixed Methods Approaches. Thousand Oaks, Sage Publications, California.

El Damatty A.A., Mikhael, A., et al., 2000. Finite element modelling and analysis of a cardboard shelter. Thin-Walled Structures, 38, p.145-165.

El Damatty, A.A., Awad, A,A., 2000. Finite Element modeling and analysis of a cardboard shelter.Thin Walled Structure, 38(2), p145-165.

El Damatty A.A., Mikhael A. et al., 2000. Finite element modelling and analysis of a cardboard shelter. Thin-Walled Structures, 38, p.145-165.

Fornalski, Z., Kolodziejski, R., 2007. Corrugated board packaging more and more „valuable“ Opakowania z tektuty falistej coraz „cenniejsze“).Przeglad Papierniczy 63(8), p.450-452.

Gilchrist A.C., Suhling J.C. et al., 1999. Nonlinear finite element modeling of corrugated cardboard.Mechanical Cellulosic Maerialt, 85, p.101–107.

Gilchrist, A.C., Suhling, J. C. et al., 1999. Nonlinear finite element modeling of corrugated bord. Mechanics of Cellulose Materials-ASME AMD 231/MD 85, p.101-106.

Gilchrist, A.C, Suhling, J.C. et al., 1999. Nonlinear finite element modeling of corrugated cardboard. Mechanical Cellulosic Maerialt, 85, p.101–107.

Isler, W., 2010. Latest developments in the paper industry.International Paperworld IPW 10-11, p.32-34.

Kirwan, K.J., 2007. Corrugated Fibreboard Packaging. Paper and Paperboard Packaging Technology, p.317-372.

Patel, P., Nordstrand, T.M et al., 1997. Local buckling and collapse of corrugated cardboard under biaxial stress.Composite Structures, 39, p.93–110.

Pommier, J.C., Poustis, J., 1990. Bending Stiffness of Corrugated Board Prediction Using the Finite Element Method.Mechanics of Wood and Paper Materials, 112, p.67-70.

Pommier, J.C., Poustis, J., 1990. Bending Stiffness of Corrugated Board Prediction: Using the Finite Element Method Mechanics of Wood and Paper Materials. ASME AMD 112, R.W. Perkins.

Pommier, J.C., Poustis, J. et. al., 1991. Determination of the critical load of a Corrugated Box Subjected to Vertical Compression by Finite Element Method. Proceedings of the 1991 International Paper Physics Conference, p.437-447.

Rahman, A., 1997. Finite element buckling analysis of corrugated fiberboard panels. Proceedings of the 1997 joint ASME/ASCE/SES summer meeting entitled mechanics of cellulosic materials, p.87-92.

Richard L., Scheaffer, M.S. et all., 2011. Probability and Statistic for Engineers, Cengage Learning, Canada.

Soong, T.T., 2004. Fundamentals of Probability and Statistics for Engineers, John Wiley Sons, Chicsghester.

Vining, G.; Kowalski, S., 2011. Statistical Methods for Engineers, Cengage Learning, Boston.