**Investigation of Strength and Migration of Corrugated Cardboard Boxes**

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**ABSTRACT**

Corrugated cardboard is a high-performance packaging material designed to protect and present a variety of products from agricultural products to industrial products. Because of this strength of corrugated cardboards are of great importance. In this study, E flute and BC flute corrugated cardboards were prepared by using different type of paper and their strengths were investigated. For this purpose, weight, thickness measured and edge crush test (ECT) were performed. Results shows that as the paper weight increase, the strength of corrugated cardboard increase. And also, migration tests were done whether corrugated cardboard is appropriate for food contact.

**Keywords:**
Corrugated cardboard strength; ECT; PCB; Migration; Cobb test; Secondary packaging.

**INTRODUCTION**

Paper and paperboard sheet materials obtained from an interwoven lattice of cellulose fibers made of cellulosic material like wood, linen or cotton [1]. The most important application of paper and paperboard is in corrugated paperboard packages.

A corrugated cardboard consisting of a single corrugated layer sandwiched between two liner layers (Fig. 1). This product consists of a combination of the three layers stronger than each layer is individually owned. In addition to single wall, double wall and triple wall corrugated cardboards are also in current use. Double wall corrugated cardboards consist of gluing five layers of paper; one inner, one outer, one intermediate liner paper and two fluted papers and forming a double wall corrugated cardboard.

Corrugated medium part of the cardboard is called as flute (Fig. 2). Variations in flute height and number of flutes per unit of length defined as flute type (A, B, C, E) [2]. The take-up factor is a measure of the linear length of the medium per unit length of corrugated cardboard. Table 1 summarize the flute type classification.

Corrugated cardboard is the most widely used type of package for the packaging and distribution of a wide variety of commodities ranging from fruits and vegetables, consumer products, to industrial items. Corrugated cardboards have a high stiffness-weight ratio. Compared to other packaging materials, it delivers relatively high stiffness at a relatively low price [3] [4]. As a packaging material, corrugated cardboards have a lot of advantages over plastic packaging materials. Because it is a kind of environment-friendly packaging material made of reusable paper and water/starch-based glue, which are 100% recyclable, reusable and biodegradable [5].

It is equally suitable for all the different modes of storage and transport such as shipping by sea or by air. The most important feature of containers made from corrugated boards is to protect the packaged commo-
Preparation of Starch Glue

For preparation of starch glue, corn starch was used. Starch Glue is prepared according to Stein Hall Method [10] [9]. Stein Hall Method consists of two-phase concept. Primer phase is necessary to give a certain viscosity to glue and keep the viscosity constant.

For this reason, the primer phase is also called as the carrier. This means that the primer phase carries the glue. The secondary phase is the phase of the real glue formation which provides the adhesion of papers. Different resins were added the prescription to improve strengthens the starch stickiness, accelerates the drying and gives firmness. Starch glue viscosity should be stable from preparation to application.

Production of Corrugated Cardboard

Corrugated cardboards which used for the experiment were produced at Ankutsan A.Ş. production facilities. Corrugated cardboard is formed by gluing the flute layer between two flat liners with starch glue. Double-layer corrugated cardboard consist of three flat liner and two flute liner is also produced for more strength products. Corrugated cardboard manufacturing process begins with the selection of the appropriate type and amount of paper. Production side mainly consist of two parts as wet part and dry part. In the wet production side, paper softened by heat and steam preconditioners takes wave shape by passing through corrugating rolls. After this shaping, the starch-based glue is usually applied to the wave tops and adherence of the flute to pre-heated liner

| Flute Designation | Height (h) (mm) | Wavelength(λ)(mm) | Flutes number per Linear Meter | Take-up factor |
|-------------------|----------------|-------------------|-------------------------------|----------------|
| A                 | 4.0-4.8        | 8.0-9.5           | 105-125                       | 1.48-1.53      |
| B                 | 2.2-3.0        | 5.5-8.5           | 153-181                       | 1.28-1.43      |
| C                 | 3.2-4.0        | 6.8-8.0           | 125-147                       | 1.42-1.50      |
| E                 | 1.0-1.8        | 3.0-3.5           | 285-334                       | 1.22-1.29      |

Table 1. Corrugated board flute type standards.

Figure 3. Illustration of board styles and layers (a) E flute Single Wall (b) BC Flute Double Wall

MATERIALS AND METHODS

Starch and NaOH were purchased from Tate & Lyle Inc., Koruma Klor Alkali San. ve Tic. Inc., respectively. Borax (Na₂B₄O₇•10H₂O) purchased from MTA. Starch Glue prepared according to Stein Hall Method [9]. Different type of papers, Kraft (KR), Neutral Sulfite Semi-Chemical (NC), White Kraft (WKR), White Test Liner (WTL) and Fluting (FL) used for corrugated cardboard production. Kraft papers purchased from International Paper Company. VinciLiner (WKR) and NSSC papers purchased from Reno De Medici Group, in Italy.

In this study we prepared ten different corrugated cardboard for making fresh fruit-vegetable box and pizza box. Then we analyzed the boxes’ strength, water absorptivity and conformity with food contact.
paper by pressing is ensured. In the dry production side, after the laminated cardboard sheet is removed from the wet part, the edges are trimmed and sized for the planned box production. Blunt blades pressed on the corrugated cardboard for facilitate box folding. Then the products are stacked on top. In this study, 10 corrugated cardboard samples were prepared with different paper combinations. Two of them are E wave single wall corrugated cardboards used in the production of pizza boxes and are named EF@WTL120 and EF@WTL125. The other eight are BC wave double wall corrugated cardboards used in the production of fresh fruit and vegetable (FFV) boxes. The paper types and properties used in the preparation of these 10 samples and the names given to the samples are given in Table-2. The nomenclature of the samples was made as "flute type@ changing paper".

Chemical Analysis

Polychlorobiphenyls (PCBs) analysis of samples were done in Intertek Laboratories according to TS EN ISO 15318 [11] by using ISQ-GC/MS technique. Trace Element analysis of samples was done in Intertek Laboratories and according to NMKL 186 [12] by using ICAP Q ICP-MS technique.

Formaldehyde, chlorine and Pentachloro Phenol (PCP) analysis also was made in Intertek Laboratories according to EN 1541: 2001 [13], TS ISO 5647, Mohr Method and 35 LMBG B 82.02-8 standards, respectively.

Strength Test

ECT Test

Edge crush test (ECT) gives information about the strength of corrugated board on vertically positioned corrugations. During these tests it is important that the force applied to the sample is exactly perpendicular. Edge Crush Test (ECT) is carried out according to DIN EN ISO 3037:2013 [14].

Edge Crush Test (ECT) is a true performance test and is directly related to the stacking strength of a carton. ECT is a measure of the edgewise compressive strength of corrugated board. ECT values are of great importance in estimating the quality of corrugated cardboard.

Cobb Tests

The Cobb test is used to determine the water absorptivity of paper, cardboard and corrugated cardboard. Cobb Test is carried out according to the TAPPIT441 standard [16]. The sample is weighed dry and placed under a cylinder with an inner diameter of about 100 cm². The cylinder is filled with approximately 100 ml of water. The water is drained after a certain waiting period. The excess water on the sample is wiped with a blotter. The sample is weighed and the amount of water sucked by 1 m² of the material is calculated (1).

\[
Weight \ of \ water \ (\frac{g}{m^2}) = \frac{m_2 - m_1}{F} \times F
\]

where \( m_2 \) is final weight and \( m_1 \) is dry weight of samples.

RESULTS AND DISCUSSION

Strength Tests

ECT test was performed for investigation of paper type and weight effect on corrugated cardboards’ strength. In Table 1, when the weight has increased 5 gram of outer

| Sample Name   | Flute Type | Paper Type and Weight (g/m²) |
|---------------|------------|-----------------------------|
| EF@WTL120     | E          | WTL 120 FL 80 WTL 120       |
| EF@WTL125     | E          | WTL 125 FL 80 WTL 120       |
| BC@NC150      | BC         | KR 175 NC 150 KR 170 NC 160 KR 170 |
| BC@NC160      | BC         | KR 175 NC 160 KR 170 NC 160 KR 170 |
| BC@FL100-FL75 | BC         | KR 100 FL 80 FL 75 FL 100 KR 100 |
| BC@FL100-FL80 | BC         | KR 100 FL 100 FL 80 FL 100 KR 100 |
| BC@NC164-KR185| BC         | WKR 225 NC 164 KR 140 NC 170 KR 185 |
| BC@NC127-KR189| BC         | WKR 225 NC 127 KR 140 NC 150 KR 189 |
| BC@KR135      | BC         | WKR 180 NC 160 KR 135 NC 160 KR 170 |
| BC@KR170      | BC         | WKR 180 NC 160 KR 170 NC 160 KR 170 |
liner paper of E flute corrugated cardboard, strength enhanced % 15.6. Increasing weight of liner or flute paper led to the enhancement of the CCs strength, which was clear from Table 3, ascending between 7, 77% to 18,50%. As seen in Fig. 4, when the enhancement in ECT values of the CCs is examined the most significant increase in strength was observed in BC@NC160 and BC@NC127-KR189. When the weight of B flute paper of BC@NC150 was increased by 10 g, the strength enhancement was 18.50% with the highest increase. On the other hand, when the weight of the B flute paper (NC) of BC@NC164-KR185 was decreased from 164 to 127 and the weight of inner liner paper (KR) was increased from 185 to 189, there was an enhancement of 18.11%. When the weight of the intermediate liner paper (KR) of BC@KR135 was increased from 135 to 170 (BC@KR170), there was a 7.77% increase in strength. On the other hand, when the weight of both the intermediate liner paper and the B flute paper of BC@FL80-FL75 was increased (BC@FL100-FL80), there was an enhancement of 14.35%. Obviously, when the weight of the inner and outer liner papers of corrugated board is increased, there is a significant enhancement in strength. However, increasing the weight of the liner and flute papers has little effect on increasing the strength.

Cobb Tests

Cobb test were performed for determination of water absorptivity of corrugated cardboard samples. Due to their hygroscopic nature, paper and cardboard tend to hold moisture and water from the surrounding environment. The Cobb test is important because it determines the resistance of paper to water penetration and the amount of water absorbed. A high Cobb value indicates that the material is prone to absorb moisture, while a low value indicates that it is resistant to water penetration and humidity.

Table 3. Effect of the paper type and weight on strength of E flute and BC corrugated cardboard.

| Sample name   | ECT (kN/m) | Increase of Strength % |
|---------------|------------|------------------------|
| EF@WTL120     | 3.2        |                        |
| EF@WTL125     | 3.7        | 15.6                   |
| BC@NC150      | 11.61      |                        |
| BC@NC160      | 13.76      | 18.50                  |
| BC@FL100-FL80 | 4.11       |                        |
| BC@FL80-FL75  | 4.70       | 14.35                  |
| BC@NC164-KR185| 12.20      |                        |
| BC@NC127-KR189| 14.41      | 18.11                  |
| BC@KR135      | 12.60      |                        |
| BC@KR170      | 13.58      | 7.77                   |

Table 4. Effect of the paper type and weight on strength of E flute and BC corrugated cardboard.

| Cobb test number | m1 (g) | m2 (g) | Absorbed Water(g) | Cobb (g/m²) |
|------------------|--------|--------|--------------------|-------------|
| 1                | 12.17  | 11.35  | 1.035              | 66.02       |
| 2                | 12.195 | 11.080 | 1.115              | 71.02       |
| 3                | 12.055 | 11.085 | 0.970              | 62.02       |
| Average          |        |        |                    | 66.35       |
PCB content of corrugated cardboard-analyzed according to TS EN ISO 15318 by ISQ-GC/MS analysis technique in order to determine whether the corrugated cardboard BC@NC127-KR189 appropriate for food contact. As shown in Table 4 corrugated cardboard BC@NC127-KR189 has no PCB_18, PCB_28, PCB_52, PCB_101, PCB_138 and 0, 01 mg/kg PCB_153, PCB_180.

Pentachloro Phenol is not detected in sample BC@NC127-KR189 (Table 5). Overall migration from food packaging materials is one of the fundamental requirements according to TS EN 1186 13. Overall migration covers all kind of substances which are transferred from food packaging to food irrespective of the nature and the toxicological profile of the substance. Migration test results given in the Table 6. Overall migration from paper based food packaging materials is limited to 10 mg/dm² and sample BC@NC127-KR189’s overall migration test result is 1,9 mg/dm², below 10 mg/dm².

Trace Metal Analysis

Heavy metal analysis was done in three replicates according to NMKL 186 [20] in Intertek laboratories by using ICAP Q ICP-MS technique. This method describes the detection of trace elements such as arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) at low concentrations in each food. As shown in Table 7 BC@NC127-KR189 contain 15,8403 ppm 48Ti, 0,0273 ppm 75As, 0,019 ppm111 Cd, 0,018 ppm 202Hg and 0,7429 ppm 208Pb.

Restrictions on the trace element content of paper based materials that come into contact with food are determined by the Turkish Food Codex [21]. Lead, chloride and titanium dioxide content of BC@NC127-KR189 below the limitation according to relevant standards (Table 7 and Table 8).

Table 5. PCBs ingredient of corrugated cardboard BC@NC127-KR189

| RT (min) | Component Name | Amount mg/kg |
|---------|----------------|--------------|
| 10.84   | PCB_18         | 0,00         |
| 11.65   | PCB_28         | 0,00         |
| 12.30   | PCB_52         | 0,00         |
| 14.25   | PCB_101        | 0,00         |
| 16.48   | PCB_138        | 0,00         |
| 17.27   | PCB_153        | 0,01         |
| 19.26   | PCB_180        | 0,01         |

Table 6. Interpretation of migration test results according to relevant standards

| Analyses name                  | Method                | LOQ         | Results mg/kg | Requirement | Interpretation |
|--------------------------------|-----------------------|--------------|---------------|-------------|---------------|
| Determination of Overall Migration* | TS EN 1186 13       | 1 mg/dm²   | 1,9 mg/dm²   | ≤10 mg/dm² | Pass          |
| Polichlorbiphenyl (PCB)        | TS EN ISO 15318      | 0,5 mg/kg   | Not Detected  | ≤ 2 mg/kg  | Pass          |
| Formaldehyde                   | EN 1541: 2001        | 5 mg/kg     | <5 mg/kg     | ≤ 15 mg/kg | Pass          |
| Pentachloro Phenol (PCP)       | 35 LMBG B 82.02-8    | 0,1 g/kg    | Not Detected  | ≤ 0,15 mg/kg | Pass          |

Table 7. Trace element concentration of BC@NC127-KR189

| Analyses name | 48Ti | 75As | 111Cd | 202Hg | 208Pb |
|---------------|------|------|------|------|------|
| Concentration (ppm) | 16,1670 | 0,0280 | 0.019 | 0,018 | 0,7510 |
| Concentration average (ppm) | 15,6960 | 0,0270 | 0,019 | 0,018 | 0,7420 |
| Concentration average (ppm) | 15,6590 | 0,0270 | 0,019 | 0,018 | 0,7360 |
| Concentration average (ppm) | 15,8403 | 0,0273 | 0,019 | 0,018 | 0,7429 |

Table 8. Interpretation of trace metal migration results according to relevant standards.

| Analyses | LOQ mg/kg | Results mg/kg | Requirement | Method |
|----------|-----------|---------------|-------------|--------|
| Hg content | 0.01 % | 0.02 | - | NMKL 186 |
| Cl content | 0.02 % | N/A | <= 0.2 % | TS ISO 5647, Mohr Method |
| Cd content | 0.01 % | 0.02 | - | NMKL 186 |
| Pb content | 0.05 % | 0.74 | <= 20 mg/kg | NMKL 186 |
CONCLUSION

Corrugated cardboard boxes are often used as secondary packaging (carrying box), so the strength of boxes is highly important. In this study, the effect of the paper types and weight used in making corrugated cardboard on the box strength was examined. It can be said that generally increasing the paper quality and weight increases the strength of the box. While inner and outer liner papers of CCs have a significant effect on strength, the intermediate liner and flute papers have a minimal effect.

In addition to high strength, it is extremely important that there is no migration from boxes to foods boxes that are in direct contact with food, such as a pizza boxes and fresh fruit and vegetable boxes. We also applied the migration test to the boxes. The results of the analysis show that the corrugated cardboard boxes are suitable for food contact.

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References

1. T. Fadiji, T. Berry, C. J. Coetzee and L. Opara, "Investigating the Mechanical Properties of Paperboard Packaging Material for Handling Fresh Produce Under Different Environmental Conditions: Experimental Analysis and Finite Element Modelling," Journal of Applied Packaging Research, vol. 9, no. 2, pp. 20-34, 2017.
2. L. L. Zhao, Evaluation of the Performance of Corrugated Shipping Containers: Virgin Versus Recycled Boards, 1993.
3. B. Steenberg, J. Kubat and L. Rudstrom, Competition In Rigid Packaging Materials, STOCKHOLM: ARBOR PUBLISHING AB, 1970.
4. N. Chibani, H. Djidjelli and A. Dufresne, "Study of effect of old corrugated cardboard in properties of polypropylene composites: Study of mechanical properties, thermal behavior, and morphological properties," JOURNAL OF VINYL & ADDITIVE TECHNOLOGY, pp. 231-238, 2016.
5. R. Coles, D. McDowell and M. J. Kirwan, Food Packaging Technology, CRC Press, 2003.
6. D. V. Hung , Y. Nakano , F. Tanaka, D. Hamanaka and T. Uchino, "Preserving the strength of corrugated cardboard under high humidity," Composites Science and Technology, vol. 70, p. 2123–2127, 2010.
7. M. Vishnuvarthan and N. Rajeswari, "Additives for enhancing the drying properties of," Alexandria Engineering Journal, vol. 52, p. 137–140., 2013.
8. R. P. A. T. C. O. T. EUROPEAN, on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC, 2004.
9. D. Vandervele, "High dry substance stein hall adhesives and method for preparing high dry substance stein hall adhesives". Patent CA2470618 C, 29 09. 2009.
10. F. O. Ware and W. . S. McDonald, "Process for the production of corrugated paperboard adhesive". Patent US4343654 A, 10 8 1982.
11. International Organization for Standardization, Pulp, paper and board -- Determination of 7 specified polychlorinated biphenyls (PCB), TS EN ISO 15318, 1999.
12. Trace elements - As, Cd, Hg, Pb and other elements. Determination by ICP-MS after pressure digestion. (NMKL 186), 2007.
13. Paper and board intended to come into contact with foodstuffs. Determination of formaldehyde in an aqueous extract, EN 1541, BSI, 2001.
14. EUROPEAN COMMITTEE FOR STANDARDIZATION, Corrugated fibreboard - Determination of edgewise crush resistance (unwaxed edge method) (ISO 3037:2013), 2013.
15. M. E. Biancolini and C. Brutt, "Numerical and Experimental Investigation of the Strength of Corrugated Board Packages," PACKAGING TECHNOLOGY AND SCIENCE, vol. 16, pp. 47-60, 2003.
16. Technical Association of the Pulp and Paper Industry, Water Absorptiveness of Sized (Non-bibulous) Paper, Paperboard, and Corrugated Fiberboard (Cobb Test), 2013.
17. J. J. Parnell, J. Park, V. Denec, T. Tsoi, S. Hashsham and J. Quensen, "Coping with Polychlorinated Biphenyl(PCB)Toxicity: Physiological and Genome-Wide Responses of Burkholderia xenovorans LB400 to PCB-Mediated Stress," Applied and Environmental Microbiology, vol. 72, no. 10, p. 6607–6614, 2006.
18. K. Ballschmider and M. Zell, "Analysis of Polychlorinated Biphenyls (PCB) by Glass Capillary Gas Chromatography," Fresenius' Zeitschrift für Analytische Chemie, no. 302, pp. 20-31, 1980.
19. World Health Organization, "Polychlorinated biphenyls(PCBs)," in Air Quality Guidelines For Europe-Second Edition, Denmark, WHO Regional Publications, 2000, pp. 97-101.
20. "www.nmkl.org," [Online]. Available: http://www.nmkl.org/index.php/en/webshop/item/tungmetaller-as-cd-hg-og-pb-bestemmelse-med-icp-ms-etter-syreopslutning-under-trykk-nmkl-186-2007. [Accessed 22 8 2017].
21. "resmigazete.gov.tr," 19 12 2011. [Online]. Available: http://www.resmigazete.gov.tr/eskiler/2011/12/20111222M3-9.htm. [Accessed 22 8 2017].
22. EUROPEAN COMMITTEE FOR STANDARDIZATION, Paper and board - Determination of water absorptiveness – Cobb Method, Turkish Standards Institute, 2014.