Journal of Korea TAPPI
Vol.41. No.5, 2009
Printed in Korea

Evaluation Methods for Flat Crush Resistance of Corrugated Fiberboard with Microflutes

Hye Jung Youn†, Hyun Seung Kwon*1 and Hak Lae Lee

(Received October 19, 2009: Accepted December 13, 2009)

ABSTRACT

Corrugated fiberboard is a widely used packaging material because of its high compressive strength and stiffness despite light weight. Corrugated fiberboards with microflutes with height ≤ 1.5 mm, such as E, F or G, have been developed. As microflutes have a different geometry from other conventional flutes, they may behave differently in testing and require a new testing method. Therefore, we evaluated the flat crush resistance of corrugated fiberboard with microflutes according to the ISO and TAPPI standard test methods. In addition, the effects of specimen area and platen compression rate were examined. The goal of this study was to identify an appropriate method for flat crush test (FCT) of corrugated fiberboard with microflutes. When a test piece with a standard area was subjected to the FCT in accordance with ISO and TAPPI methods, microflute corrugated fiberboard demonstrated a different load-displacement curve. An area of 20 cm^2 was determined to be the most appropriate for FCTof microflute corrugated fiberboard

***Keywords**: corrugated fiberboard, microflute, flat crush resistance, test method, specimen area*

1. Introduction

Corrugated fiberboard is a widely used packaging material because of its high compressive strength and stiffness despite light weight. Corrugated fiberboard is classified by the height and number per unit length of its flutes. E, F, and G corrugated fiberboards with a flute height ≤ 1.5 mm and ≥ 300 flutes per meter are called "microflute" (1).

Microflute corrugated boards were first used in 1960 as a substitute for folding carton boxes. They were able to replace folding box boards because of their many advantages, including light weight, high compressive strength, high stiffness, and high graphic quality. Since 2006, McDonald's Corp. has used F flute corrugated board for burger packaging because it reduces the weight of the paperboard containers by 30% and is environmentally-friendly due to the use of recycled fibers in the middle layer. Applications of corrugated fiberboard with microflutes have extended into various packaging fields such as electronic products, cosmetics, and liquor. Production and

• Dept. of Forest Sciences, Research Institute for Agriculture and Life Sciences, Seoul National University, Gwanak-ro 599, Gwanak-gu, Seoul, 151-921 KORE A
*1 Current address: Moorim SP Co. Ltd.
† Corresponding Author:E-mail; page94@snu.ac.kr

consumption, therefore, have been increasing in many countries in Europe, Asia and the Americas.

Though the demand for microflute has increased, international standards and test methods for microflute corrugated fiberboard have not yet been specified. Most companies that produce corrugated board with microflutes carry out quality control for edgewise and flat compressive strengths in accordance with conventional test methods. As microflutes have different geometry from other conventional flutes, it may behave differently in conventional tests. Therefore, the goal of this study was to identify appropriate test methods for corrugated fiberboard with microflutes. In particular, the flat crush resistance test (FCT) was examined as a representative property.

Flat crush resistance is the maximum force per unit area that corrugated board can resist without the corrugated layer being completely crushed (2). It relates to the final compression strength of a corrugated box during converting processes such as die cutting and printing. The load-deformation curve for the FCT has two humps for conventional corrugated board. The first hump occurs when the curvature of the flute tip disappears, and the second hump occurs when the ultimate compressive and tensile stresses are reached at the intersection of the curved and flattened portions of the flute (3). The standard FCT methods were designed for single-faced and single-wall corrugated fiberboard. According to the ISO method, the test specimen is circular and its area is not less than 50 cm^2. Areas of 64.5 cm^2 and 100 cm^2 are commonly used. The platen compression rate is 12.5 ± 2.5 mm/min (4). In the TAPPI method, the test piece has a circular (preferred) or square shape. A specimen area of 32.3 cm^2 (5 in^2) or 64.5 cm^2 (10 in^2) is preferred (5).

As noted above, microflutes are much thinner than conventional flutes. It is, therefore, necessary to determine an appropriate method for use with microflute corrugated board. We evaluated the flat crush resistance of corrugated fiberboard with microflutes in accordance with the ISO and TAPPI test methods. In addition, we examined the effects of the area of the test piece and the platen compression rate on flat crush resistance.

2. Materials and Methods

2.1 Materials

G flute corrugated fiberboard (“C” Co., Japan) and F flute corrugated fiberboard (“J” Co., Korea) were used for the flat crush test (FCT). Table 1 shows the properties of the corrugated fiberboards. Sampling was carried out in accordance with ISO 186: 2002(E). The samples were preconditioned at 23°C and 50% RH in accordance with ISO 187.

Table 1. Properties of the materials

	G flute	F flute
Basis weight (g/m^2)	463	225
Thickness (mm)	0.93	0.88
Flutes per meter	587	397

2.2 Evaluation of flat crush resistance

Circular test pieces were cut with a guided circular knife. The flat crush resistance test was carried out using a crush tester (L&W Co., Sweden) and a universal strength tester (Zwick Roell, Germany). The test was conducted on 10 test pieces. The maximum flat crush resistance and load-deformation curve were obtained on the basis of the test results. The specimen area and platen compression rate were varied in this study.

2.2.1 Conventional FCT

An FCT of corrugated fiberboard with A flute was carried out as a control experiment. The areas of the test piece were 32.3 cm^2 and 64.5 cm^2 in accordance with the ISO and TAPPI standard test methods. The same experiment was performed on corrugated fiberboard with G flutes. The platen compression rate was held at 12.5 mm/min.

2.2.2 FCT of microflute corrugated fiberboard

To determine the appropriate test method, we evaluated the effects of specimen area and platen compression rate. Tests were performed on test pieces with an area of 10.0, 20.0, 32.3 and 64.5 cm^2. For these tests, the platen compression rate was held at 12.5 ± 2.5 mm/min. We also evaluated various platen compression rates of 1, 7.5, 12.5, and 17.5 mm/min.

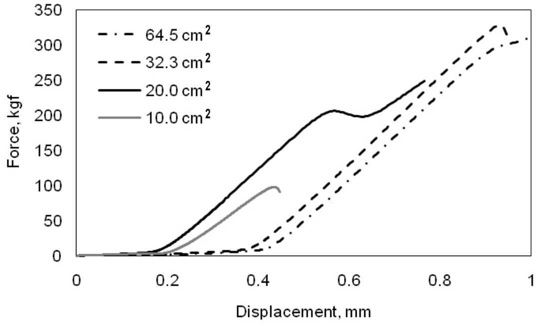

Fig. 2. Load-displacement curves for G flute corrugated boards.

3. Results and Discussion

3.1 Effect of the specimen area

Single-wall corrugated fiberboard shows a characteristic load-deformation curve during the FCT, and the maximum force sustained by the test piece before collapsing is generally recorded. Fig. 1 depicts FCT curves for A flute with sample areas of 64.5 cm^2 and 32.3 cm^2. The A type flute corrugated board had a typical FCT curve with humps indicating the collapse of the fluting medium. On the other hand, the G flute corrugated board with an area of 64.5 cm^2 showed a linear pattern without any humps in the FCT curve (Fig. 2). When the tests were carried out with these areas, the maximum force occurred at a displacement of about 0.9 mm, which corresponds to the thickness of the corrugated fiberboard. In other words, the microflutes were completely destroyed or collapsed by forces perpendicular to the surface. Thus, the G flute corrugated board was damaged by too high compression force because of the thin thickness and the weakness of microflutes. Consequently, the area of the test piece recommended in the ISO and TAPPI methods is not appropriate and a new FCT method is required to determine accurate flat crush resistance of corrugated fiberboard with microflutes. Therefore, we varied the area of the test piece in this study. When the area of test piece of G flute corrugated fiberboard was decreased, the curve showed a stagnation stage or hump. The hump appeared at a displacement of 0.6 mm and 0.4 mm for 10.0 cm^2 and 20.0 cm^2, respectively. This displacement corresponded to half the initial thickness of the corrugated board. The maximum force

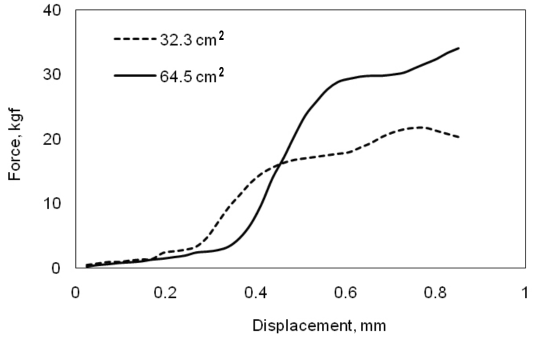

Fig. 1. FCT curves for A flute corrugated boards.

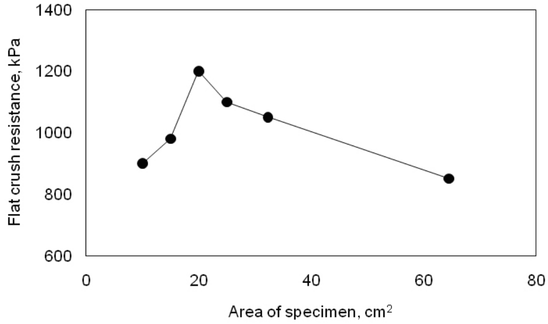

Fig. 3. Flat crush resistance of G flute test pieces depending on specimen area.

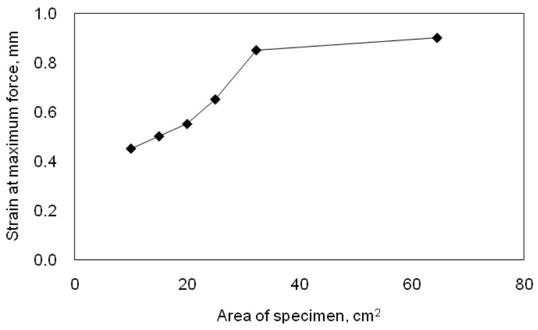

Fig. 4. Effect of specimen area on strain at maximum force (G flute).

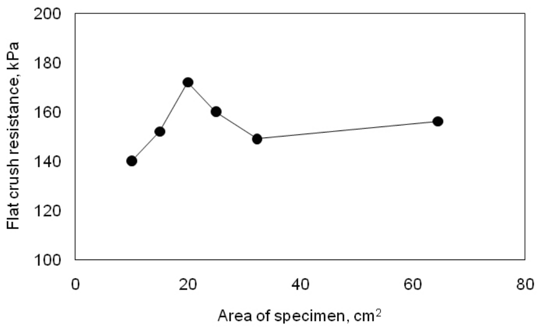

Fig. 6. Flat crush resistance of F flute test pieces depending on specimen area.

before collapsing could be determined at this point.

Fig. 3 shows the flat crush resistance of G flute corrugated board depending on the area of the test piece. In general, smaller test pieces had smaller flat crush resistances. Fig. 4 shows the effect of specimen area on the strain at maximum force for G flute corrugated board. The test piece of 20 cm^2 was crushed at half the initial thickness with maximum flat crush resistance. Consequently, a smaller test piece with an area of 10 cm^2 or 20 cm^2 appears to give a reasonable result in the FCT for microflute corrugated fiberboard. These results were more pronounced for the FCT of F flute corrugated fiberboard.

Fig. 5 depicts load-deformation curves for the FCT of F flute corrugated fiberboard. The test piece with an area of 10 cm^2 had two humps that were more clearly distinguishable than the other test piece with a larger area. The second hump appeared at a displacement of 0.4 mm, which was nearly half the thickness of the microflute corrugated board. Fig. 6 shows the flat crush resistance of F flute corrugated board depending on the area of the test piece. Generally, smaller test samples had smaller flat crush resistances. Fig. 7 shows the effect of specimen area on the strain at maximum force for F flute corrugated board. The 20-cm^2 test sample collapsed at half the initial thickness with maximum flat crush resistance. These results suggest that a smaller test piece with an area of 20 cm^2 could be recommended for FCT of microflute corrugated fiberboard.

Fig. 8 shows the change in thickness of the test piece before and after the FCT. The thickness of the test piece was generally reduced by crush testing and had recovered by 50% 3 hrs after the test. The test piece of

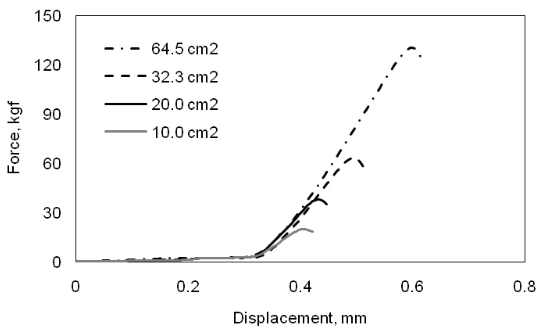

Fig. 5. Load-displacement curves for F flute corrugated boards.

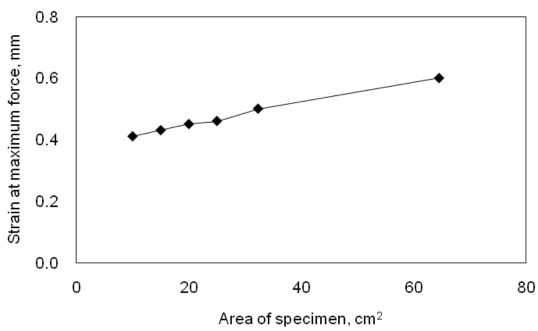

Fig. 7. Effect of specimen area on strain at maximum force (F flute).

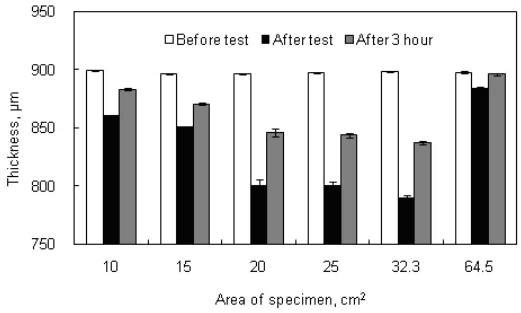

Fig. 8. Thickness of F flute corrugated board after flat crush testing.

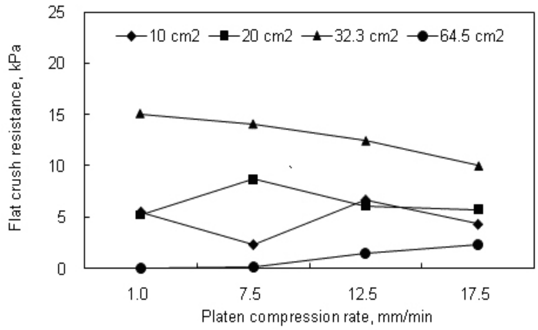

Fig. 10. COV of the flat crush resistance of G flute test pieces at various platen compression rates.

64.5 cm^2 had the smallest reduction in thickness.

3.2 Effect of the platen compression rate

In accordance with the ISO and TAPPI test methods, the platen compression rate was adjusted to 12.5 ± 2.5 mm/min. We then examined the effect of the platen compression rate on the FCT results. Fig. 9 shows the flat crush resistances of G flute corrugated fiberboard depending on the specimen area and the platen compression rate. Generally, the platen compression rate had little influence on flat crush resistance. For a sample area of 32.3 cm^2, the resistance increased slightly with increasing platen compression rate. The coefficient of variation (COV) was the smallest for 64.5 cm^2, and was around 6% for 10.0 cm^2 and 20.0 cm^2 (Fig. 10). The COV of the test piece with an area of 32.3 cm^2 was very high and decreased with increasing platen compression rate.

3.3 Repeatability of flat crush resistance measurements

The repeatability of flat crush resistance measurements for microflute corrugated fiberboard was evaluated. The test material was F flute corrugated board. Tests were performed on test pieces with areas of 10.0, 20.0, 32.3, and 64.5 cm^2. Three different laboratories have tested flat crush resistance. The results of the FCT and standard deviations from the three laboratories are shown in Fig. 11. Tables 2 and 3 summarize the average values and COV of 10 measurements. The 20-cm^2 test piece had the highest flat crush resistance and lowest standard deviation. The repeatability of the

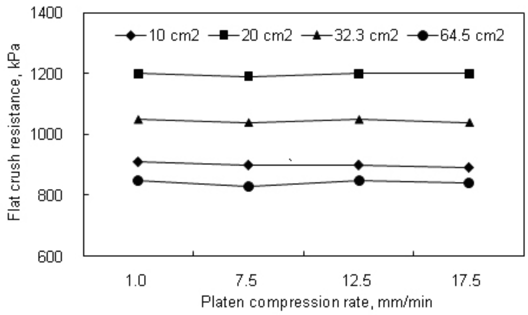

Fig. 9. Flat crush resistance of G flute test pieces at various platen compression rates.

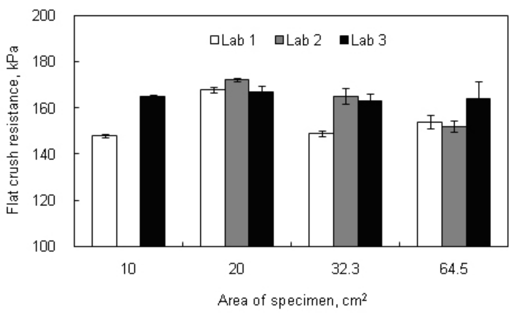

Fig. 11. Results of the FCT from three different laboratories.

Table 2. Average FCT results for the three laboratories

Lab	Average FCT value, kPa			
	10 cm^2	20 cm^2	32.3 cm^2	64.5 cm^2
Lab 1	148	168	149	154
Lab 2	N.D.	172	165	152
Lab 3	165	167	163	164

Table 3. Coefficients of variation for the three laboratories

Lab	COV, %			
	10 cm^2	20 cm^2	32.3 cm^2	64.5 cm^2
Lab 1	5.4	6.8	8.7	19.5
Lab 2	N.D.	4.3	20.2	15.3
Lab 3	4.9	16.1	18.5	46.5

Table 4. Repeatability of FCT results

Specimen area	COV, %
10 cm^2	7
20 cm^2	6
32.3 cm^2	5
64.5 cm^2	4

FCT results is reported in Table 4, and Table 5 shows the number of tests required to obtain a significant FCT value. The 20-cm^2 test piece showed good repeatability and reproducibility. These results clearly show that 20 cm^2 is the most appropriate test specimen area for FCT testing of microflute corrugated fiberboard.

4. Conclusions

To determine an appropriate FCT method for single-wall corrugated fiberboard with microflutes, we investigated the effects of specimen area and platen compression rate. The load-displacement curve and the maximum force were obtained. When a test piece with a standard area was tested in accordance with the ISO and TAPPI methods, the microflute corrugated fiberboard had a different load-displacement curve in the FCT. When a test piece with a smaller area was

Table 5. Number of tests required to obtain a significant FCT value

Lab	Test number			
	10 cm^2	20 cm^2	32.3 cm^2	64.5 cm^2
Lab 1	10/13	10/10	10/13	10/12
Lab 2	-	10/11	10/16	10/20
Lab 3	10/11	10/10	10/12	10/11

used, a typical curve showing the first and second collapses was obtained. These results suggest that a smaller test piece with an area of 10.0 cm^2 or 20.0 cm^2 could be recommended for FCT of microflute corrugated fiberboards. The platen compression rate had little influence on the FCT results when test pieces with area of 10.0 cm^2 or 20.0 cm^2 were used. The test sample with an area of 20 cm^2 had higher flat crush resistance, a lower standard deviation, and better reproducibility than the 10-cm^2 test piece. These results demonstrate that an area of 20 cm^2 is the most appropriate for flat crush testing of microflute corrugated fiberboard.

Acknowledgement

This work was supported by Ministry of Commerce, Industry and Energy.

Literature Cited

1. Hartikainen, K., Corrugated board manufacturing, In Paper and Paperboard Converting, Savolainen, A. (Ed.), Papermaking Science and Technology series vol. 12, Fapet Oy, Finland, p. 244 (1988).
2. Markström, H., Testing Methods and Instruments for Corrugated Board, Lorentzen & Wettre, Sweden, pp.41-45(1999).
3. Liu, J. Y., Flat-crush failure mechanism of corrugated fibreboard, Journal of Applied Mechanics 53:602 (1986).
4. ISO 3035-1982(E), Single-faced and single-wall corrugated fiberboard- Determination of flat crush resistance, ISO.
5. TAPPI T 825 om-96, Flat crush test of corrugated board (rigid support method), TAPPI Press.