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포장재료의 완충특성 분석-골판지를 중심으로

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Cushioning Properties Analysis for Packaging Materials -corrugated fiberboard

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Abstract

From the maximum acceleration-static stress curve and the cushion factor-dynamic stress curve which were derived from the dynamic compression test, the shock-absorbing characteristics according to the flute-type and equilibrating environmental condition were analyzed. In addition, restoring performance of flutes were analyzed by the shock pulse and hysteresis. It showed that the cushioning performance under high stress level made satisfactory progress in the order of DM, DW and SW. Also, under the equal condition, restoring performance in corrugated fiberboard tested is better in the order of DM, DW and SW. Restoring performance of corrugated fiberboard is more closely related to structural formation in flute rather than basic weight of flute and corrugated fiberboard.

Key words: corrugated fiberboard, dynamic cushioning properties, cushion curve, cushion packaging design, restoring performance, shock pulse

Introduction

There has been a growing interest in the use of environmentally-friendly paper packaging materials, such as corrugated fiberboard and pulp mold instead of plastics (EPS, EPE, EPU, etc) which were mainly used for package cushioning materials, due in part to the concern over pollution. The most important thing for packaging design of products is the physical properties of the cushioning materials. There have been a lot of problems according to the application of materials and data produced and supplied by industrially advanced nations without analysis or verification of the materials. Therefore, it is urgent to collect and to establish object data after detailed analysis of the characteristics for cushioning materials produced in Korea.

Corrugated fiberboards, not only as materials of packaging containers, but also as package cushioning materials are expected to grow in the usage. Corrugated fiberboard is a kind of structure which has its mechanical properties depending on the flute-type and the paper composition. In order to improve its compression strength and cushioning properties, strengthening the corrugating medium itself is required, however it is more important and effective economically to improve these properties by varying the optimal design of flute structure.

The shock-absorbing properties of cushioning materials are usually presented in cushion curves such as maximum acceleration-static stress and cushion factor-dynamic stress, for several conditions (drop heights, material thickness, etc.) (Kawazi, 1969; Marcondes, 1992; Paine, 1990).

Several attempts have been made to model cushion curves mathematically. Burgess (1990) suggested a method to consolidate cushion curves for a material, and applied the method for expanded polypropylene. Asvanit (1988) used a curve fitting approach to describe behaviors

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of the kraft honeycomb under impacts. Marcondes *et al.* (1990) used a high-speed filming technique to closely observe the dynamic deflection of expanded polyethylene and fitted a 5th order polynomial to the acceleration versus time history.

Crofts (1989) studied the effect of simulated handling (drops) on the compressive strength of corrugated fiberboard boxes and found that the compressive strength was decreased as the drop height increased and that compressive strength decreased as package weight increased.

The effects of moisture content on the performance of corrugated fiberboard boxes have been extensively studied with respect to compressive strength (Peleg, 1981; Park *et al.*, 1994), but little has been done in the effects of moisture content on the cushioning properties.

The objective of this study was to demonstrate that the flute-type and the equilibrating enviromental conditions of corrugated fiberboards alter its cushioning properties and restoring performance.

Materials and Methods

Experimental design and materials

Samples used in analysis of cushioning properties and restoring performance for flute-type and equilibrating enviromental conditions of corrugated fiberboard were 2 kinds of single-wall (SW), 4 kinds of double-wall (DW), and 1 kind of dual-layer medium corrugated fiberboard (Table 1). Table 2 shows the physical dimensions of flutes for the corrugated fiberboards tested.

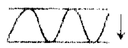
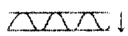
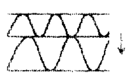
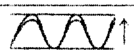
Cushioning properties of corrugated fiberboard can easily be analyzed by maximum acceleration-static stress curve and cushion factor-dynamic stress curve which are derived from the estimation of acceleration by the free-falling of drop-weight. Therefore, the dynamic cushioning tester, which was designed by Park *et al.* (1998), were used in this study.

Important variables in the dynamic compression test are the range of drop height and drop-weight variation. Establishing standards which was regarding the two variables, following points were considered;

(1) to select the range of drop-weight variations including the inflexing point of maximum acceleration-static stress curve for the corrugated fiberboard by each drop height throughout the several preliminary experiments.

(2) to consider the weight (approx. 5~30 kg.) of pro-

Table 1. Paper composition and basic weight of the corrugated fiberboard tested

Kinds	Symbol	Flute-type	Paper composition	Basic weight, g/m²	Remarks
Single-wall (SW)	SWA	A/F	SK180/K180/K180	646.2	
	SWB	B/F	KA180/K180/K180	603.0	
Double-wall (DW)	DW1	AB/F	SK210/B150/K180/B150/K180	1,011.0	
	DW2		SK180/S120/S120/S120/K180	832.8	
	DW3		KA210/AS210/S125/AS250/KA210	1,226.0	
	DW4		SC240/AS250/AS180/AS250/KA240	1,395.0	
Dual-layer[1] (DM)	DM	AA'/F[2]	SK180/K180/K180/K180	907.2	

[1]dual-layer medium corrugated fiberboard.
[2]A': lower flute medium of dual-layer medium corrugated fiberboard. It is a modified A-flute that its pitch is same as the A-flute but differs in flute height.

Table 2. Physical dimensions of flute for the corrugated fiberboard tested

Flute type	Flute height, mm		Wave length of flute, mm		Flute no. per 30 cm		Take-up factor	
	Standard	Actual	Standard	Actual	Standard	Actual	Standard	Actual
A/F	4.6~4.8	4.90	8.33~9.38	8.547	34±2	35.1	1.6	1.560
B/F	2.5~2.7	2.47	5.77~6.25	6.479	50±2	46.3	1.4	1.319
A'/F	—	4.20	—	8.547	—	35.1	—	1.450

ducts that are packed with corrugated fiberboard boxes.

(3) to consider handling height in human engineering perspective when dealing with corrugated fiberboard box.

Experimental methods

Corrugated fiberboard were conditioned for 24 hours at three different relative humidity (50, 70, and 90%) at 23℃ using constant temperature and humidity chamber prior to experiment, respectively (ASTM D685).

Drop heights were 30, 60, and 90 cm and weight of the drop-weight were cumulatively increased to 9~11 level. A specimen was round shape (9.06 cm in diameter, 64.5 cm^2 in area), and the shape made the contact condition equal between a specimen and the impact plate amongst the replicating tests (TAPPI T808).

Theoretical Background

The ratio between absorbed energy per unit thickness of cushioning material and the force transmitted to the product, in other words force exerted on the cushioning material, is called cushion efficiency. If the cushion efficiency is higher at same condition, less amount of material is required in cushion packaging design of products. A coefficient developed to apply cushion efficiency into packaging design is cushion factor. Cushion factor is directly calculated from the ratio of dynamic stress to absorbed energy per unit volume of cushioning material.

In dynamic compression test, cushion factor (C) can be calculated by applying Newton's law of motion and energy balance equation to impact between drop-weight and specimen (Eq.(1)~Eq.(4)).

$$W(H + D_m) = ATe \rightarrow e = \frac{W(H + D_m)}{AT} \qquad (1)$$

$$\Sigma F = ma \rightarrow F_t - W = ma = WG \rightarrow F_t = (G + 1)W,\ N \qquad (2)$$

$$\sigma = \frac{F_t}{A} = \frac{(G + 1)W}{A} \rightarrow \sigma_m = \frac{W}{A}(G_m + 1),\ Pa \qquad (3)$$

$$C = \frac{\sigma_m}{e} = \frac{T}{H + D_m}(G_m + 1) \fallingdotseq \frac{G_m}{H}T \qquad (4)$$

In Eq.(1) to (4), W is the weight of drop-weight (N), H is the drop height (m), D_m is maximum dynamic deflection of specimen (m), A is the area of specimen (m^2), T is the thickness of specimen (m), is the amount of absorbed energy per unit volume of specimen (J/m^3), and σ_m is dynamic stress (Pa).

As the dynamic stress (G-factor × static stress) of a product corresponding to optimal cushion factor is determined from cushion factor-dynamic stress curve, a material whose value of dynamic stress is most optimal, can be selected from cushion factor-dynamic stress curves of many materials. From this method, the most efficient way of cushioning can be achieved (Hanlon, 1984: Jönson, 1993: Paine, 1990).

The further right the inflexion point which indicates the minimum magnitude of cushion factor is located, the better cushioning material for heavy product, and the more flat the area near the inflexion point is, the broader the range of stress for which the material can be used.

Compressive strength (column & flat crush strength) and cushioning properties of a corrugated fiberboard changes depending on the flute-type and physical properties of corrugating medium. Thus, restoring performance of flute against external force determines the resilience of the corrugated fiberboard.

Restoring performance of a corrugated fiberboard can be more easily analysed from energy relationship in loading-unloading cycle in which the flat side of corrugated fiberboard is strained to a certain degree at a constant loading rate, and unloaded the force at the same rate.

The area *oab* in Fig. 1 represents the loading energy exerted on corrugated fiberboard and the area *abc* represents the recovering energy in unloading. As the degree of compression for thickness of corrugated fiberboard increases, loading-unloading cycle resembles the Fig. 1-(B) more closely, and the stronger the restoring

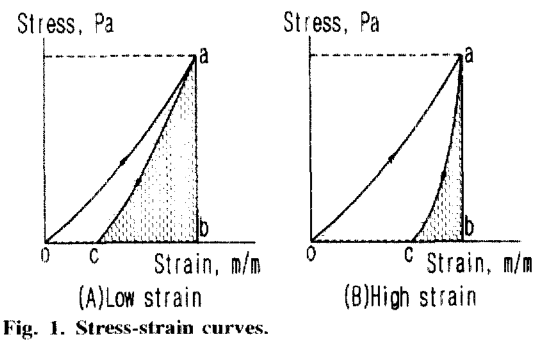


Fig. 1. Stress-strain curves.

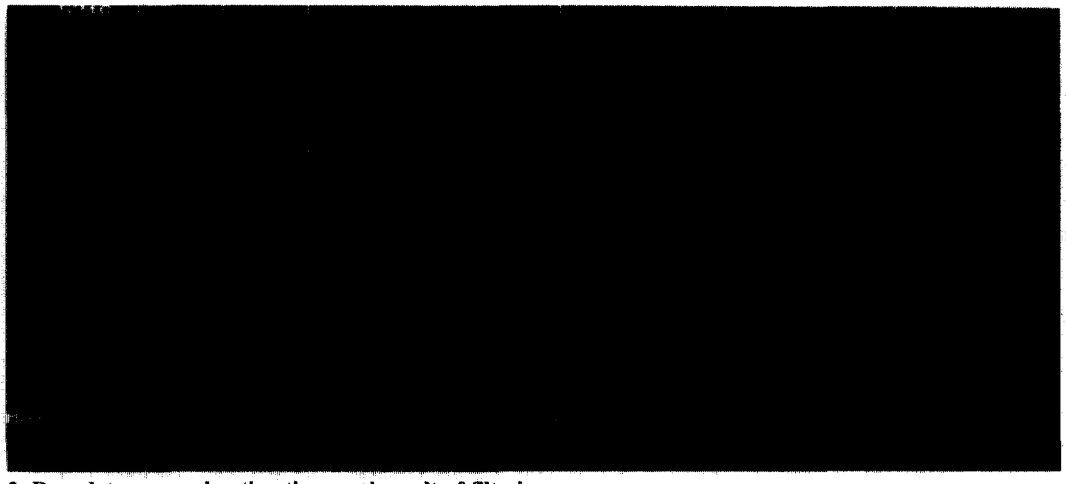


Fig. 2. Raw data on acceleration-time, and result of filtering

performance and elasticity of corrugated fiberboard, the more it resembles Fig. 1-(A). Therefore, restoring performance of a corrugated fiberboard can be analysed from the ratio of area *oac* to area *oab*, this is called hysteresis loss, in loading-unloading cycle.

Results and Discussion

Cushioning properties

Fig. 2 represents the acceleration occurred during a short shock duration between drop-weight and specimen. However, among a number of shock pulse, the first pulse is the most concerned, and therefore it is enlarged by using analysing software (Fig. 3).

The area under the shock pulse which represents the velocity change, magnitude of peak acceleration, and the shock duration are the important elements that determine cushioning properties of the material. The distorted shape of the right side of the peak acceleration in the pulse was observed mostly at the higher relative humidity, and the bell shaped form was observed at the lower relative humidity. Amongst the tested corrugated fiberboard, DM was nearly similar with pulse (B) than SW or DW under the same condition.

(A)

(B)

Fig. 3. The shape of the first shock pulse.

Maximum acceleration against varying static stress which were derived from raw data of acceleration-time, is displayed in Fig. 4 through 6. Cushioning materials serve the purpose of limiting the shock, which a product was experienced, below the product's fragility (G-factor). Cushioning material works the best performance at the inflexion point which indicates the minimum magnitude of acceleration on maximum acceleration-static stress curve. The further right the inflexion point is located, the better cushioning material for heavy product, and the higher the inflexion point is

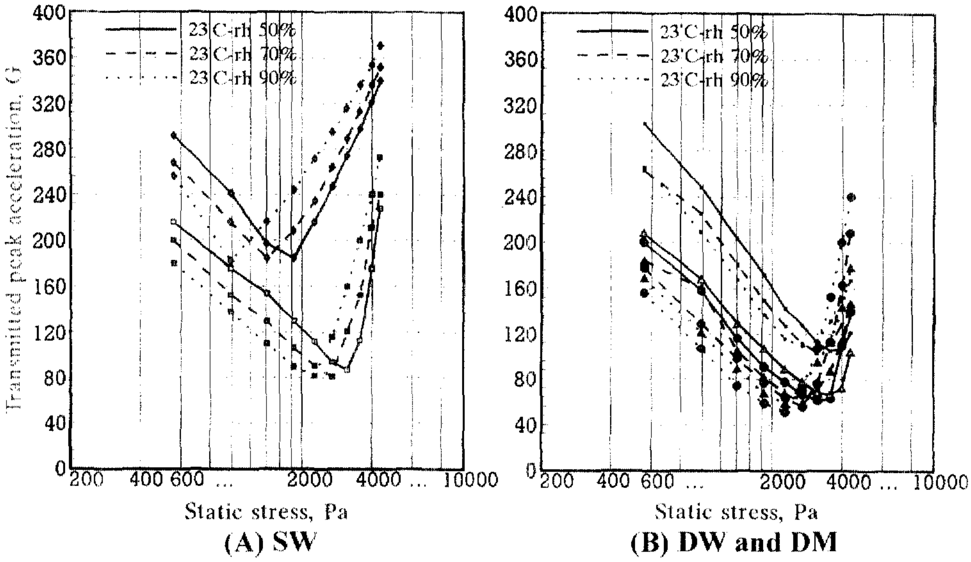


Fig. 4. Maximum acceleration-static stress curves (drop height 30 cm). ■—■: SWA, ◆—◆: SWB, ▲—▲: DW1, ●—●: DW2, ▪—▪: DM

located, the better cushioning material for products with higher fragility (Jönson, 1993; Paine, 1990; Takahashi, 1969).

As it is seen in the Fig. 4 through 6, the location of inflexion points are located further right in the order of DM, DW and SW. The higher the equilibrating relative humidity is, the further left the inflexion point is located. It can be assumed that the value of static stress lossing the cushioning performance due to the high moisture content of the corrugated fiberboard by high relative humidity was relatively low.

The value of acceleration was generally low according to the increment of the equilibrating relative humidity at the static stress of below the inflexion point. On the other hand, it was high according to the increment of the equilibrating relative humidity at the static stress over the inflexion point. This phenomenon could be assumed that the high value of acceleration could be caused by the high impulse delivered through the corrugated fiberboard in consequence of it's own rigidity according as the decrement of the equilibrating relative humidity under the low static stress, and under the high static stress, the high value of acceleration may be caused by the high impulse delivered through the corrugated fiberboard which lost it's rigidity when the flutes of corrugated fiberboard buckled at same time as collision according as the increment of the equilibrating relative humidity (Marcondes, 1992).

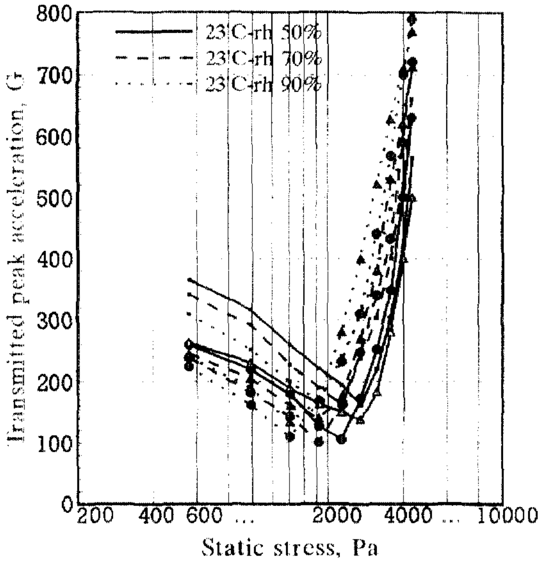


Fig. 5. Maximum acceleration-static stress curves (drop height 60 cm). ▲—▲: DW1, ●—●: DW2, ▪—▪: DM

As it is seen in the Fig. 7 through 9, the location of inflexion points are located further right in order of DM→SWB→DW1, SWB→DW2. Also, DM in corrugated fiberboard tested, has more flat curve near the inflexion point.

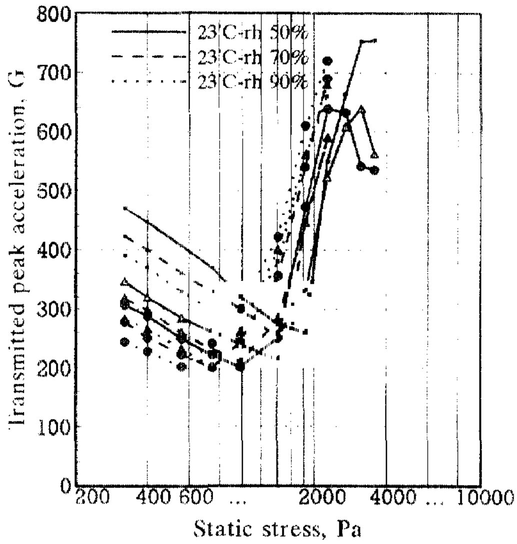


Fig. 6. Maximum acceleration-static stress curves (drop height 90 cm). ▲—▲: DW1, ●—●: DW2, ▪—▪: DM

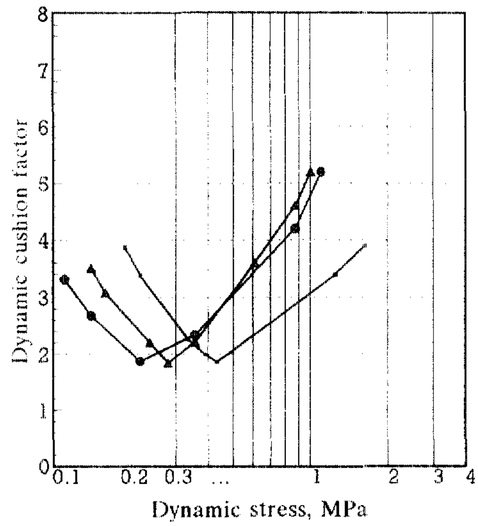


Fig 8. Cushion factor-dynamic stress curves (drop height 60 cm, 23°C-rh 50%). ▲—▲: DW1, ●—●: DW2, ▪—▪: DM

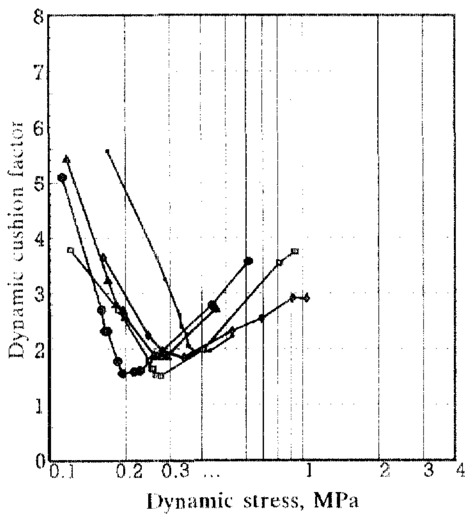


Fig 7. Cushion factor-dynamic stress curves (drop height 30 cm, 23°C-rh 50%). ■—■: SWA, ◆—◆: SWB, ▲—▲: DW1, ●—●: DW2, ▪—▪: DM

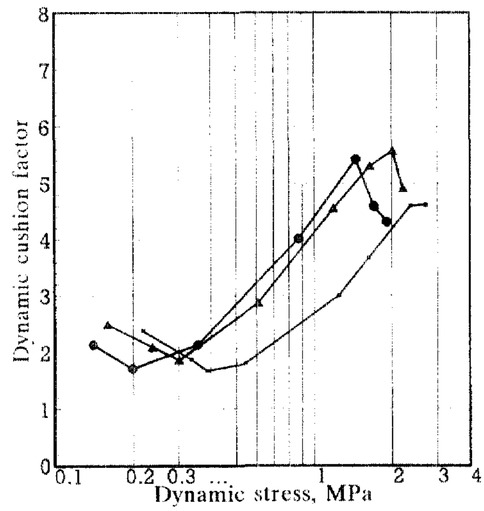


Fig. 9. Cushion factor-dynamic stress curves (drop height 90 cm, 23°C-rh 50%). ▲—▲: DW1, ●—●: DW2, ▪—▪: DM

Corrugated fiberboard shows various cushioning performance according to its stack style and number. Packaging material of stacked corrugated fiberboard is used wide as cushioning material today (honey cushion, corrupad, etc.).

Fig. 10 is the maximum acceleration-static stress curve when SWA and SWB are stacked three, five, and seven times over and DM is stacked two, three, and four times over. Although DM is stacked one to three fold less than SWA and SWB, the minimum value of acceleration is smaller in the order of SWA, DM and SWB.

Restoring performance

The results of loading and unloading each corrugated fiberboard to the degree of 50% and 70% of its total thickness with a loading rate of 12.7mm/min (ASTM D 2808: TAPPI T808) are shown in Fig. 11-(A) and (B).

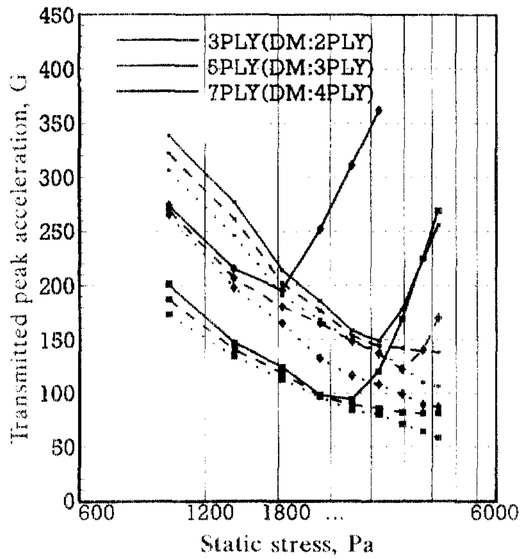


Fig. 10. Maximum acceleration-static stress curves for differently stacked corrugated fi-berboard. ▪—▪: DM, ■—■: SWA, ◆—◆: SWB

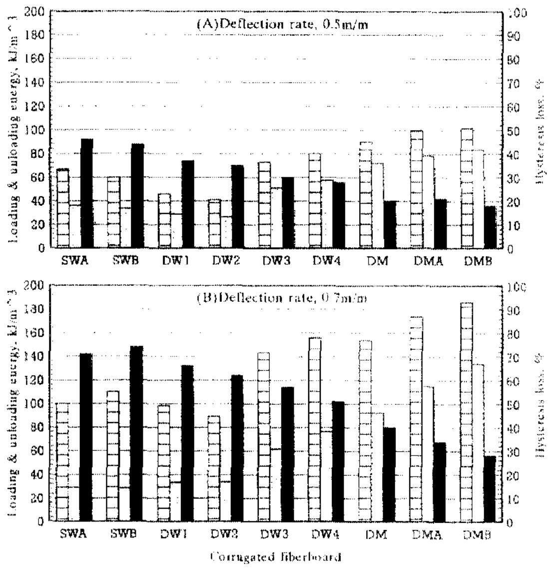


Fig. 11. Loading and unloading energy according to flute-type of corrugated fiberboard

Table 3. Relationship between restoring performance and basic weight of flute and corrugated fiberboard

Kinds	Symbol	BW-CF[1], g/m²	BW-F[2], g/m²	BW-CF /BW-F[3]	Deflection, 50%			Deflection, 70%		
					Loading Energy	Unloading Energy	Hysteresis Loss	Loading Energy	Unloading Energy	Hysteresis Loss
Single-wall (SW)	SWA	646.2	286.2	44.3	67.1	36.2	46^{a}	100.0	29.0	71^{a}
	SWB	603.0	243.0	40.3	60.2	33.6	44^{a}	110.0	28.6	74^{a}
Double-wall (DW)	DW1	1,011.0	441.0	43.6	46.4	29.0	37^{b}	98.4	33.5	66^{b}
	DW2	832.8	352.8	42.4	41.2	26.7	35^{b}	89.4	34.0	62^{b}
	DW3	1,226.0	681.0	55.5	73.2	51.1	30^{c}	143.4	61.7	57^{c}
	DW4	1,395.0	735.0	52.7	80.1	57.6	28^{c}	156.1	76.1	51^{d}
Dual-layer (DM)	DM	907.2	547.2	60.3	90.0	72.0	20^{d}	154.2	92.4	40^{e}

[1]basic weight of corrugated fiberboard
[2]basic weight of flute
[3]the ratio of BW-F to BW-CF. Means in a column followed by the same letter are not significantly different (5% significant level) by Duncan's multiple range test.

respectively. Among the corrugated fiberboard tested, loading energy decreases in the order of DM, DW4, DW3 →SWA, SWB→DW1→DW2. Hysteresis loss, which indicates degree of restoring performance of corrugated fiberboard, decreases in the order of SWA, SWB→DW1, DW2→DW3, DW4→DM. Thus, under the equal condition, restoring performance is better in the order of DM→DW3, DW4→DW1, DW2→SWA, SWB. The difference in restoring performance between corrugated fiberboard tested, increases as the degree of compression increases.

Table 3 illustrates the analysis on the relationship between restoring performance and basic weight of flute and corrugated fiberboard. According to the results, restoring performance of corrugated fiberboard is more closely related to structural formation in flute rather than basic weight of flute and corrugated fiberboard.

Conclusions

In order to prepare and to promote the demands of environmentally-friendly paper packaging materials, Establishment of object data after detailed analysis of overall properties of packaging materials is urgent. Especially information on the verious quality characteristics for the corrugated fiberboard due to the variety of uses.

This study is to demonstrate that the flute-type and the equilibrating enviromental condition of corrugated fiberboards alter its cushioning properties and restoring performance.

The results of this study may be summarized as follows;

1. As a result of analysis on cushioning properties of corrugated fiberboards which are obtained from maximum acceleration-static stress curve and cushion factor-dynamic stress curve derived from the dynamic compression test. it showed that the cushioning performance under high stress level made satisfactory progress in the order of DM, DW and SW.

2. The lower the relative humidity increases, the further left the inflexion point is located. The value of acceleration was generally low according to the increment of the equilibrating relative humidity at the static stress below the inflexion point. On the other hand, it was high according to the increment of the equilibrating relative humidity at the static stress over the inflexion point.

3. Under the equal condition, restoring performance of corrugated fiberboard tested is better in the order of DM, DW and SW. Also, restoring performance of corrugated fiberboard is more closely related to structural formation in flute rather than basic weight of flute and corrugated fiberboard.

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