

# Comparison Studies on Strength Properties of Corrugated and Honeycomb Composite Paperboards

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**ABSTRACT:** In order to improve on the compressive loading capability and package cushioning properties of honeycomb paperboard, the novel structure of corrugated and honeycomb composite paperboard is put forward in this article. It consists of honeycomb paperboard and corrugated paperboard, the honeycomb paperboard is the fundamental structure, and the single-wall corrugated paperboard is adhered on the liner (or facing sheet) of honeycomb paperboard with thickness smaller than or equal to 20mm. The aim of this paper is to evaluate on strength properties of the novel structure of corrugated and honeycomb composite paperboard by a series of experimental studies, and analyze the flat crush resistance, edgewise crush resistance, bursting strength and puncture resistance between the novel structure of paperboard and honeycomb paperboard by comparison. The experimental results show as follows: (1) For the honeycomb paperboard with thickness 10mm, the flat crush resistance of corrugated and honeycomb composite paperboard all reduce, yet for the honeycomb paperboard with thickness 15mm or 20mm, the flat crush resistances corrugated and honeycomb composite paperboard all raise on the whole. (2) For the same thickness honeycomb paperboard, the edgewise crush resistance of corrugated and honeycomb composite paperboard obviously increases than the honeycomb paperboard, moreover the double-face corrugated-honeycomb composite paperboard is best. (3) For the same thickness honeycomb paperboard, the bursting strength and puncture resistance of corrugated and honeycomb composite paperboard obviously increases than the honeycomb paperboard. So, the corrugated and honeycomb composite paperboard holds excellent strength properties such as flat crush resistance, edgewise crush resistance, bursting strength and puncture resistance on the whole, and it possesses an attractive prospective in transportation packaging of goods. All research work provides basic data and instruction for the design and application of the novel structure of corrugated and honeycomb composite paperboard in protective packaging.

**Keywords:** Corrugated and Honeycomb Composite Paperboard, Flat Crush Resistance, Edgewise crush Resistance, Bursting Strength, Puncture Resistance

## 1. Introduction

Paperboard structural material is a kind of environmental-friendly packaging material made of reusable paper and water-based glue, which are 100% recyclable, reusable and fully biodegradable. So, it can settle the important strategic issue of the environment pressure, particular in relation to concerns over the amount of packaging waste, and has economic and environmental advantages over plastic foams<sup>[1-2]</sup>. It belongs to a kind of inexpensive packaging material with corrugated or honeycomb sandwich structure, holds lightweight, high strength-to-weight and stiffness-to-weight ratios<sup>[3]</sup>. Paperboard packaging material may be made into package boxes, pads and pallets for transport packaging and storage of goods, such as corrugated paperboards, X-PLY corrugated paperboard, honeycomb paperboard. For corrugated paperboard, the compressive strength, crush strength, bending deflection and flexural stiffness, creep property and recoverability, and the mechanical behaviors such as buckling, transverse shear, elasticity, stability, collapse and ultimate failure were investigated by Hahn, Lee, Urbanik, Guo, Nordstrand, Aboura, Talbi

*et al.*<sup>[4-10]</sup>. The mechanical properties such as flat and edgewise crush resistance, bursting strength and puncture resistance of X-PLY corrugated paperboards were studied by Guo *et al.*<sup>[11]</sup>. For honeycomb paperboard, the compressive strength and deformation rule, out-of-plane buckling criterions, shock absorption characteristics and vibration transmissibility, energy absorption diagrams were researched by Guo, Lu, Wang *et al.*<sup>[12-15]</sup>. The corrugated sandwich structure with a series of connected arch cells holds favorable compressive loading capability and package cushioning properties for shock and vibration, yet the honeycomb sandwich structure with a series of connected regular hexagonal cells has better compressive loading capability than the corrugated sandwich structure with the same thickness. In order to improve on the compressive loading capability and package cushioning properties of honeycomb paperboard, the novel structure of corrugated and honeycomb composite paperboard is put forward in this article. The novel structure of sandwich paperboard consists of honeycomb paperboard and corrugated paperboard, the honeycomb paperboard is the fundamental structure, and the single-wall corrugated paperboard is adhered on the

liner (or facing sheet) of honeycomb paperboard. The novel structure of sandwich paperboard may be made into more heavily loaded package boxes, pads and pallets for transport packaging and storage of goods. So, the main aims of this study are as follows: firstly, evaluate the strength properties (E.g. flat crush resistance, edgewise crush resistance, bursting strength and puncture resistance) of corrugated and honeycomb composite paperboards by experimental studies. Secondly, compare and analyze the strength properties between honeycomb paperboards with different thickness, and the corrugated and honeycomb composite paperboards. The research work would provide instruction for the design and application of the corrugated and honeycomb composite paperboards in protective packaging.

## 2. Test materials and Methods

Test material is the novel structure of corrugated and honeycomb composite paperboard (Fig.1), the honeycomb paperboard is the fundamental structure, the single-wall corrugated paperboard is adhered on the liner (or facing sheet) of honeycomb paperboard with thickness smaller than or equal 20mm. In this paper, two

kinds of corrugated and honeycomb composite paperboards are studied by comparison. One is the single-face corrugated-honeycomb composite paperboard (Fig.1(a)), one single-wall corrugated paperboard is pasted on among of facing sheets of honeycomb paperboard. The other one is the double-face corrugated-honeycomb composite paperboard (Fig.1(b)), and two single-wall corrugated paperboards are respectively adhere on the facing sheets of honeycomb paperboard. The flute of single-wall corrugated paperboard has two cases such as flute A and flute B, the thickness of honeycomb paperboard has three cases such as 10mm, 15mm and 20mm, so the combination of corrugated and honeycomb composite paperboards has nine kinds, its for short and meaning of combination type are written in Table.1. The honeycomb core has regular hexagonal cells with the diameter of inscribed circle 12mm, the facing sheets are kraft linerboard paper with grammage of 300g/m<sup>2</sup>, and the inner sheets are reusable paper with grammage of 110g/m<sup>2</sup>. The face sheets of corrugated paperboard are kraft linerboard with grammage of 200g/m<sup>2</sup>, the corrugated core is corrugated paper with grammage of 175g/m<sup>2</sup>.

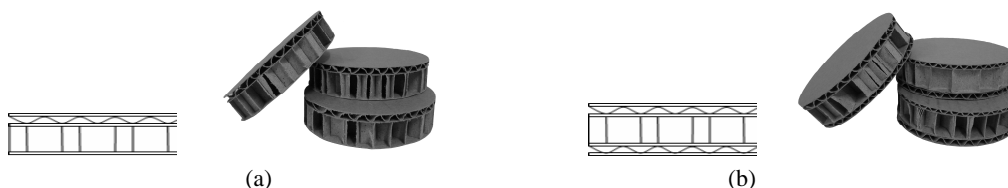


Fig.1 Structures of corrugated and honeycomb composite paperboard

Table.1 Combination types of corrugated and honeycomb composite paperboard

For short	Meaning of combination type
10mm (or 15mm, 20mm)	Honeycomb paperboard with thickness 10mm or 15mm, 20mm
10mmA (or B)	Honeycomb paperboard with thickness 10mm and single-wall corrugated paperboard with flute A or B (Fig.1(a))
10mmAB	Honeycomb paperboard with thickness 10mm and two single-wall corrugated paperboard (Fig.1(b))
15mmA (or B)	Honeycomb paperboard with thickness 15mm and single-wall corrugated paperboard with flute A or B (Fig.1(a))
15mmAB	Honeycomb paperboard with thickness 15mm and two single-wall corrugated paperboard (Fig.1(b))
20mmA (or B)	Honeycomb paperboard with thickness 20mm and single-wall corrugated paperboard with flute A or B (Fig.1(a))
20mmAB	Honeycomb paperboard with thickness 20mm and two single-wall corrugated paperboard (Fig.1(b))

For a series of experiment studies on the strength properties of corrugated and honeycomb composite paperboards, four kinds of test methods would be respectively adopted as follows: ASTM D 1225 “Standard test method for flat crush resistance of corrugated fiber-

board”, ISO 3037 “Corrugated fiberboard -determination of edgewise crush resistance”, ASTM D 2738 “Standard test method for bursting strength of corrugated and solid fiberboard”, and ASTM D 781 “Standard test method for puncture stiffness of paper-

board, corrugated and solid fiberboard". The testing apparatus has the compression tester, the bursting strength apparatus, and the puncture resistance apparatus. Before each of tests, all the test specimens should be preconditioned to equilibrium in air uniformly maintained for at least 24 hours at the ambient temperature 25°C and relative humidity 60%.

### 3. Experimental Results Discussion

#### 3.1. Flat Crush Resistance Analysis

The compressive strength reflects the strength of paperboard packaging material at compression loads. It includes two kinds such as flat crush resistance, edgewise crush resistance. The flat crush resistance expresses the maximum compressive loading capacity of unit area along the plane of paperboard packaging material. According to the test method ASTM D 1225, a series of experimental studies on honeycomb paperboards, corrugated and honeycomb composite paperboards are respectively made. During testing, put the test specimen on the bottom platen, and gradually exert the static compression load on the test specimen by top platen with the speed of 12.5mm/min until the test specimen would be crushed. The maximum of compressive load per unit area of test specimen is the flat crush resistance. The flat crush resistance of honeycomb paperboards with different thickness, corrugated and honeycomb composite paperboards are calculated and given in Ta-

ble.2. By comparison and analysis on the experimental results, some conclusions may be provided follows:

- (1) For the honeycomb paperboards with different thickness, the flat crush resistance of 10mm honeycomb paperboard is the largest, and the flat crush resistance evidently decreases with the increment of thickness. The flat crush resistance of 15mm honeycomb paperboard reduces 26.57% than 10mm honeycomb paperboard, and that of 20mm honeycomb paperboard decreases 50.87% than 10mm honeycomb paperboard.
- (2) For the honeycomb paperboards with thickness 10mm, the flat crush resistance of corrugated and honeycomb composite paperboard all reduce. The flat crush resistances of "10mmA", "10mmB" and "10mmAB" reduce 31.68%, 49.14% and 44.72% than the honeycomb paperboard with thickness 10mm, respectively.
- (3) For the honeycomb paperboards with thickness 15mm or 20mm, the flat crush resistances corrugated and honeycomb composite paperboard all raise on the whole. For example, the flat crush resistances of "15mmA", "15mmB" and "15mmAB" increase 0.99%, -4.96% and 4.93% than the 15mm honeycomb paperboard. The flat crush resistances of "20mmA", "20mmB", "20mmAB" enhance 8.05%, 17.48% and 5.89% than the 20mm honeycomb paperboard, respectively.

**Table.2 Experimental results of flat crush resistance**

Combination type	Average value, kPa	Raising rate, %	Combination type	Average value, kPa	Raising rate, %
10mm	190.30		15mmB	132.80	-4.96
10mmA	130.02	-31.68	15mmAB	146.62	4.93
10mmB	96.79	-49.14	20mm	93.50	
10mmAB	105.19	-44.72	20mmA	101.03	8.05
15mm	139.73		20mmB	109.84	17.48
15mmA	141.11	0.99	20mmAB	99.01	5.89

#### 3.2. Edgewise Crush Resistance Analysis

The edgewise crush resistance describes the maximum compressive loading capacity of unit length along the corrugated core or honeycomb core. According to the test method ISO 3037, a series of experimental studies on honeycomb paperboards, corrugated and honeycomb composite paperboards are respectively made. During the test, put the rectangular test specimens between top and bottom platens, with two metallic clamp blocks to make sure that the test specimens are perpendicular to the platens. The static compression load is gradually exerted on the test specimen by top platen with the speed of 12.5mm/min until the test specimens would be crushed. The maximum of compressive load per unit

length of test specimen is the edgewise crush resistance. The edgewise crush resistance of honeycomb paperboards with different thickness, corrugated and honeycomb composite paperboards are calculated and provided in Table 3. By comparison and analysis on the experimental results, some conclusions may be made as follows:

- (1) For the honeycomb paperboards with different thickness, the edgewise crush resistance of 15mm honeycomb paperboard is the largest. The edgewise crush resistance of 15mm honeycomb paperboard raises 26.68% than 10mm honeycomb paperboard, and that of 20mm honeycomb paperboard decreases 16.72% than 10mm honeycomb paperboard.
- (2) For the same thickness honeycomb paperboard, the

edgewise crush resistance of corrugated and honeycomb composite paperboard obviously increases than the honeycomb paperboard, moreover the double-face corrugated-honeycomb composite paperboard is best. For example, the edgewise crush resistances of “10mmA”, “10mmB” and “10mmAB” respectively raise 128.21%, 227.42% and 300.57% than 10mm honeycomb paperboard. The edgewise

crush resistances of “15mmA”, “15mmB” and “15mmAB” respectively improve 65.67%, 124.59% and 187.43% than 15mm honeycomb paperboard. The edgewise crush resistances of “20mmA”, “20mmB” and “20mmAB” increase 83.89%, 159.22% and 286.56% than 20mm honeycomb paperboard, respectively.

**Table.3 Experimental results of edgewise crush resistance**

Combination type	Average value, N/cm	Raising rate, %	Combination type	Average value, N/cm	Raising rate, %
10mm	22.79		15mmB	64.84	124.59
10mmA	52.01	128.21	15mmAB	82.98	187.43
10mmB	74.62	227.42	20mm	18.98	
10mmAB	91.29	300.57	20mmA	34.92	83.98
15mm	28.87		20mmB	49.20	159.22
15mmA	47.83	65.67	20mmAB	73.37	286.56

### 3.3. Bursting Strength Analysis

The bursting strength belongs to a kind of static strength, which expresses the maximum loading capability of unit area along the plane of corrugated paperboard while extrusion with a bouffant rubber half-ball. It is a comprehensive description of tensile breaking strength and tensile rate for paperboard packaging materials. According to the test method ASTM D 2738, a series of experimental studies on honeycomb paperboards, corrugated and honeycomb composite paperboards are respectively made. During testing, put the test specimens

between top and bottom clamp platens to make sure that the test specimen would not slip on the bottom platen. The compressive load is equably exerted on the half-ball rubber film by hydraulic oil of cylinder, and the half-ball rubber film upward acts on the test specimen until the test specimen would be ruptured. The maximum of compressive load per unit area of test specimen is the bursting strength. The bursting strength of honeycomb paperboards with different thickness, corrugated and honeycomb composite paperboards are calculated and shown in Table.4.

**Table.4 Experimental results of bursting strength**

Combination type	Average value, kPa	Raising rate, %	Combination type	Average value, kPa	Raising rate, %
10mm	430.06		15mm	817.95	
10mmA	790.0	83.70	15mmA	1200.2	46.73
10mmB	1027.2	138.85	15mmB	1312.85	60.50
10mmAB	1396.9	224.82			

By comparison and analysis on the experimental results, some conclusions may be made as follows: the bursting strength of 15mm honeycomb paperboard is 90.19% more than 10mm honeycomb paperboard. For the same thickness honeycomb paperboard, the bursting strength of corrugated and honeycomb composite paperboard obviously increases than the honeycomb paperboard. For example, the bursting strengths of “10mmA”, “10mmB” and “10mmAB” enhance 83.70%, 138.85% and 224.82% than 10mm honeycomb paperboard, respectively. The bursting strength of “15mmA” and “15mmB” raise 46.73% and 60.50% than 15mm honeycomb paperboard.

### 3.4. Puncture Resistance Analysis

The puncture resistance reflects the dynamic loading

capability while piercing through paperboard packaging materials with a cone-shaped object, and includes the initial potential energy of the cone-shaped object and puncture energy needed to tear the test specimen into a hole. The total energy loss of the cone-shaped object is taken as the puncture resistance of test specimen. According to the test method ASTM D 781, a series of experimental studies on honeycomb paperboards, corrugated and honeycomb composite paperboards are respectively made. During the test, put the test specimen between top and bottom clamp platens with an equilateral triangle hole in the center. After releasing the cone-shaped punch block, it would punch through the test specimen. The puncture resistance of honeycomb paperboards with different thickness, corrugated and honeycomb composite paperboards are calculated and



shown in Table.5. By comparison and analysis on the experimental results, some conclusions may be made as follows: the puncture resistance of 15mm honeycomb paperboard is 27.93% more than 10mm honeycomb paperboard. For the same thickness honeycomb paperboard, the puncture resistance of corrugated and honeycomb composite paperboard obviously increases than

the honeycomb paperboard. For example, the puncture resistances of “10mmA”, “10mmB” and “10mmAB” respectively increase 70.89%, 108.69% and 223.47% than 10mm honeycomb paperboard. The puncture resistances of “15mmA”, “15mmB” and “15mmAB” raise 88.62%, 89.17% and 270.64% than 15mm honeycomb paperboard, respectively.

**Table.5 Experimental results of puncture resistance**

Combination type	Average value, J	Raising rate, %	Combination type	Average value, J	Raising rate, %
10mm	4.26		15mm	5.45	
10mmA	7.28	70.89	15mmA	10.28	88.62
10mmB	8.89	108.69	15mmB	10.31	89.17
10mmAB	13.78	223.47	15mmAB	20.20	270.64

### 3.5. Discussion

The experimental results of corrugated and honeycomb composite paperboards, and honeycomb paperboards with different thickness smaller than or equal 20mm has proved that, the single-face or double-face corrugated and honeycomb composite paperboard holds excellent strength properties such as flat crush resistance, edgewise crush resistance, bursting strength and puncture resistance on the whole. Moreover usual corrugated paperboard has favorable package cushioning properties for shock and vibration <sup>[1]</sup>. So the novel structure of corrugated and honeycomb composite paperboard may improve on the compressive loading capability and package cushioning properties of honeycomb paperboard, and possesses an attractive prospective in transportation packaging of goods.

### 4. Conclusions

The novel structure of corrugated and honeycomb composite paperboard is put forward, and the characterization of strength properties such as flat crush resistance, edgewise crush resistance, bursting strength and puncture resistance are evaluated by comparison. The experimental results show as follows:

1) For the honeycomb paperboard with thickness 10mm, the flat crush resistance of corrugated and honeycomb composite paperboard all reduce, yet for the honeycomb paperboard with thickness 15mm or 20mm, the flat crush resistances corrugated and honeycomb composite paperboard all raise on the whole.

2) For the same thickness honeycomb paperboard, the edgewise crush resistance of corrugated and honeycomb composite paperboard obviously increases than the honeycomb paperboard, moreover the double-face corrugated-honeycomb composite paperboard is best.

3) For the same thickness honeycomb paperboard, the bursting strength and puncture resistance of corrugated and honeycomb composite paperboard obviously in-

creases than the honeycomb paperboard. So, the corrugated and honeycomb composite paperboard holds excellent strength properties such as flat crush resistance, edgewise crush resistance, bursting strength and puncture resistance on the whole, and it possesses an attractive prospective in transportation packaging of goods.

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