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**Research Article**

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# Research on the corrugated types of the high-strength corrugated composite cardboard based on the price-performance ratio model and its corresponding evaluation

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**ABSTRACT**

*The new high-strength corrugated composite cardboard is invented recently and it carried over the tradition corrugated cardboard, which is similar to the honeycomb cardboard and has been widely used to produce various types of trays and liners, etc. The corrugated type will directly affect the cost of production, as well as the plane compressive strength. This paper analyzed the influence of different corrugated types on the cost of production and the plane compressive strength compressive strength of this plate and presented the compensation plan of material selection based on the intensity difference.*

**Keywords:** price-performance ratio model; new high-strength corrugated composite cardboard; corrugated types; plane compressive strength; cost of production;

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## INTRODUCTION

The new high-strength corrugated composite cardboard, also known as the vertical corrugated composite cardboard, is an improvement of the traditional corrugated cardboard. It is based on the traditional cardboard with two-layer single corrugated cardboards. Then cut it as required and turn 90 degrees to be vertical and glue them, forming the final vertical corrugated composite cardboard. This kind of cardboard is superior in some mechanical properties, like super plane compressive strength and bending resistance, and its function is similar to that of the honeycomb cardboard. Meanwhile, the type of cardboard, with a light weight, recoverability, environmental protection, etc., is an ideal material for green packaging. Therefore, it is widely used in the production and processing of pallets, crates and paper-heavy furniture [1-2].

## THE STRUCTURE OF THE NEW HIGH-STRENGTH CORRUGATED COMPOSITE CARDBOARD AND ITS PRODUCTION TECHNOLOGY

2.1 Structure

The high-strength corrugated composite cardboard combines the features of the ordinary corrugated cardboard and Honeycomb cardboard, light weight, high compressive strength and load-carrying capacity. However, its structure is different from both of them, as shown in Figure 1. It mainly consists of two parts, the upper-layer and lower-layer cardboards and the parallel corrugating mediums between them. As it is mainly used to make trays, the Kraft paper with great weight and high strength is often adopted as the upper-layer and lower-layer cardboards to obtain the flat pressure-bearing surface. Generally, the weight of optional cardboards is more than 200g/m$^2$, some even up to 400g/m$^2$. These parallel corrugated paper cores are based on the traditional cardboard with two-layer single corrugated cardboards. Then cut it a according to the thickness of the high-strength composite cardboard and turn 90 degrees to be vertical and glue them, forming the final three-dimensional corrugated composite cardboard, as shown in Figure 2.

**Figure 1 the structure of the new high-strength corrugated composite cardboard**

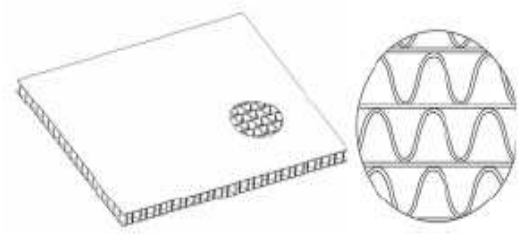

**Figure 2 the structure of the new high-strength corrugated composite cardboard**

2.2 Production process

The new high-strength corrugated composite cardboard is to adopt the traditional cardboard with two-layer single corrugated cardboards and conduct cutting and synthesis, and the common width of the online cutting with fixed width is 5-20mm. The cardboard types are similar to the traditional ones, mainly including A \ C \ B \ E. The production processes of high-strength composite cardboard generally include: production of single-sided corrugated board, online cutting with fixed width, 90 ° flip and gluing, vertical t synthesis and drying. Finally, attach the composite cardboards on the top and bottom surface of the processed vertical corrugated cardboard, as shown in Figure 3. The specific process flow is as shown in Figure 4. [2-3]

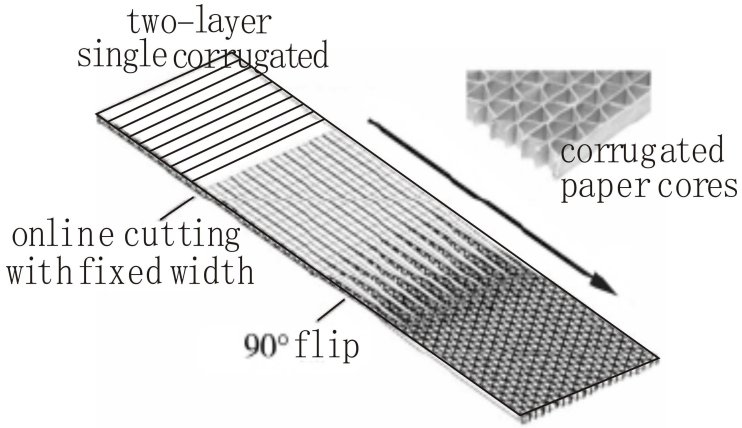


**Figure 3 schematic diagram of he high-strength corrugated composite cardboard**

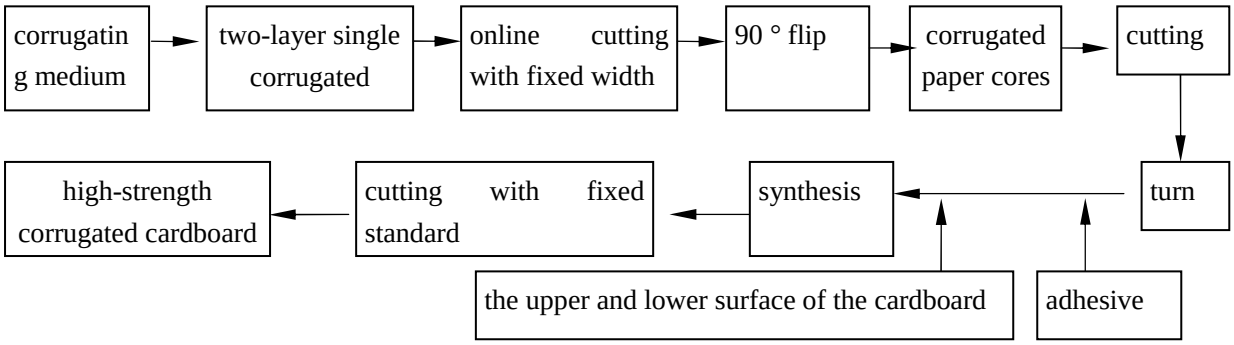


**Figure 4 the process flow of the high-strength corrugated composite cardboard**

**INFLUENCES OF CORRUGATED TYPES ON PRODUCTION COSTS OF CARDBOARDS**

3.1 Common domestic corrugated types and related technical parameters

National Standard GB / T 6544-2008 corrugated cardboard provides five corrugated types-A, C, B, E, and F and corresponding technical parameters, the first four of which are more commonly used in the country, specifically as shown in Table 1 [5].

**Table 1 Basic technical parameters of four commonly used corrugated types**

| Corrugated types | Corrugated height（*h*/mm） | Corrugated number（per/30cm） | -Corrugated width（T/mm） | Common corrugated coefficient（$\gamma$） |
|---|---|---|---|---|
| A | 4.5～5.0 | 34±3 | 8.0～9.5 | 1.53 |
| C | 3.5～4.0 | 41±3 | 6.8～7.9 | 1.46 |
| B | 2.5～3.0 | 50±4 | 5.5～6.5 | 1.37 |
| E | 1.1～2.0 | 93±6 | 3.0～3.5 | 1.15 |

3.2 Influences of corrugated types on production costs of cardboards

The production costs of cardboards generally include the base papers, adhesives and production and processing costs. In order to simplify the discussion here, we only discuss the influences of the costs of papers.

1) Understanding of the formula of production costs of base papers

The corrugated height varies greatly when different corrugated types are selected to process and produce single-sided corrugated boards, and it also consumes different base papers. In order to facilitate the statistics and calculations of material costs of such base papers, we take the composite board with one meter of length and width as an example in deducing the formula to calculate the paper costs per square meter, which should be the total price of surface paper, internal paper and corrugated core paper as well as the sandwich paper. In the general production process, as both the corrugated core papers and the sandwich papers are made from the same high-strength corrugated papers, the price of such cardboard per square meter can be expressed as formula (1).

$$P = (1+\gamma)P_3/100D + P_1 + P_2 \quad (1)$$

In the formula, P represents the base paper costs of new high-strength corrugated composite board, $P_1$ stands for the costs of surface paper, $P_2$ refers to the costs of internal paper, $P_3$ signifies the costs of corrugated paper and sandwich paper, D denotes single-sided corrugated height, including the height and thickness of corrugated paper, whose upper or lower limit can be unified in the calculation process, and $\gamma$ means the pressure coefficient of different types of corrugated boards.

2) Case computing

Common surface paper and internal paper of high-strength corrugated composite cardboard are 200g/$m^2$ kraft papers, with the as the price of 3,500 Yuan / ton, while sandwich paper and corrugated paper use 110g/m2 high-strength corrugated cardboard, priced at 2500 Yuan / ton. In the following, combining table one and formula One, we can calculate the costs of base papers of different high-strength corrugated composite cardboards, with the results shown in Table 2.

**Table 2 Base paper costs of different types of composite board**

| Corrugated types | Corrugated height *h*/mm (Universal use of the upper limit) | Corrugated coefficient ($\gamma$) (Universal use of commonly used parameters) | Costs of base papers (Yuan) |
|---|---|---|---|
| A | 5.0 | 1.53 | （1+1.53）*0.275/0.5+0.7+0.7=2.79 |
| C | 4.0 | 1.46 | （1+1.46）*0.275/0.4+0.7+0.7=3.09 |
| B | 3.0 | 1.37 | （1+1.37）*0.275/0.3+0.7+0.7=3.57 |
| E | 2.0 | 1.15 | （1+1.15）*0.275/0.2+0.7+0.7=4.36 |

**INFLUENCE OF THE CORRUGATED TYPES ON PLANE COMPRESSIVE STRENGTH OF THE CARDBOARD**

The high-strength corrugated composite board has been widely used in the production of trays and other products due to its special structure; therefore, in all of its performance indicators, the plane compressive strength is especially important. Thus, this paper analyzes the plane compressive strength of different corrugated cardboards processed by the same raw materials [6-11] .

4.1Experiment

1）Experimental equipment

Test of the four kinds of high-strength corrugated composite cardboard, PN-CT50KA compression resistance tester, sampling, etc.

2）Experimental environment
The standard environment, temperature of 23 ℃ ± 2 ℃, relative humidity of 45% to 55%.

3)Test process and data select four different types of high-strength corrugated composite cardboard to prepare 10*10cm specimen. Select 5 of them randomly as the test samples, and then test the plane compressive strength after the process in a standard environment for 24 hours.

**Table 3 the plane compressive strength of 4 different types of corrugated cardboards**

| corrugated types | thickness of the cardboard（cm） | the plane compressive strength of the cardboard/ the average compressive strength（Kpa） | |
|---|---|---|---|
| A | 1.0 | 572、566、578、590、555 | 572.2 |
| C | 1.0 | 595、599、614、622、631 | 612.3 |
| B | 1.0 | 687、669、642、655、666 | 663.8 |
| E | 1.0 | 744、736、751、737、723 | 738.1 |

4.2 Evaluation of price-performance ratio
1) Introduction of price-performance ratio model
In VE (Value Engineering), the "value" is defined as the ratio of the functions of an object and the total cost to access to these functions:

$$v = f / c \quad (2)$$

Where: $v$ means value; $f$ means function; $c$ means cost.

Here the price-performance ratio of the high-strength corrugated composite cardboard is similar to the “value” in VE. Therefore, the former one can be expressed as:

$$V = P / C \quad (3)$$

Where: V is the price-performance ratio of the high-strength corrugated composite cardboard (N /yuan); P is the plane compressive strength of the high-strength corrugated composite board; C is the production costs of the raw material of this kind of cardboard per square (yuan).

2) Calculation of the price-performance ratio
Combined with the data in Table 2 and Table 3, formula 3 can be used to calculate the price-performance ratio V, as shown in Table 4.

**Table 4 the cost ratio, plane compressive strength and the price-performance ratio of plane compressive strength and raw material cost of different corrugated cardboards**

| corrugated types | cost ratio | plane compressive strength ratio | the price-performance ratio of plane compressive strength and raw material cost of different corrugated cardboards |
|---|---|---|---|
| A | A/A=1 | A/A= 1 | 1 |
| C | C/A=1．11 | C/A=1.07 | 0.96 |
| B | B/A=1．28 | B/A=1.16 | 0.91 |
| E | E/A=1．56 | E/A=1.29 | 0.83 |

Convert the data in Table 4 to the corresponding graph, as in Figure 5.

4.3 Analysis of experimental results
According to the data in table 3 and the corresponding curve in figure 4, the plane compressive strength and the price-performance ratio of the raw paper of four common corrugated types vary greatly with the changes of the size of corrugated cardboard. In the experiment, A-type is regarded as the basic reference standard, the cost ratio of the raw paper of C, B, E corrugated cardboard is respectively 1.11, 1.28, 1.56, the plane compressive strength is respectively 1.07, 1.16, 1.29, the price-performance ratio of plane compressive strength and raw material cost of different corrugated cardboards is respectively 0.96,0.91,0.83.

The comparison of the data shows that: the price-performance ratio of A-type is the highest, while that of the E-type is the lowest. Therefore, if the customer does not explicitly specify the corrugated type, manufacturers should choose A-type to achieve the highest price-performance ratio.

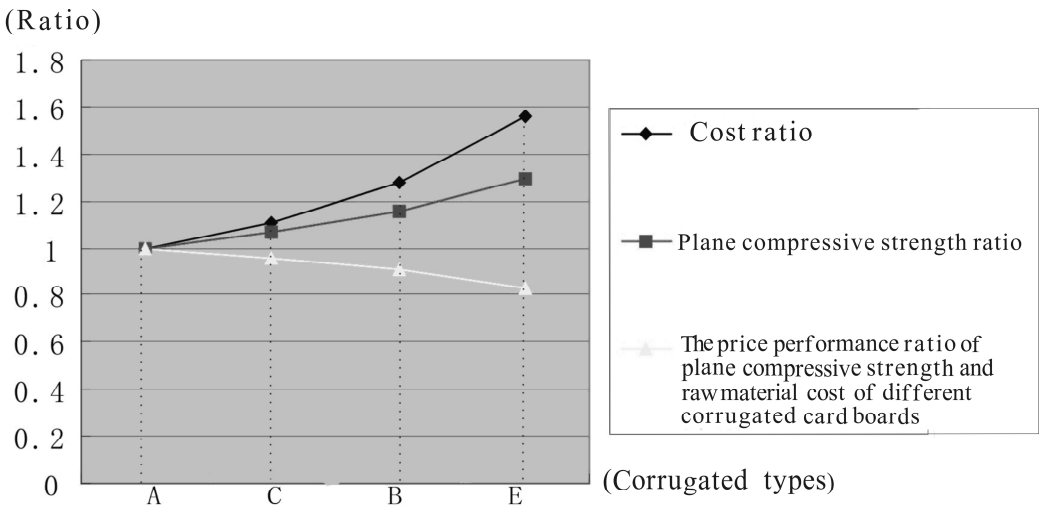


**Figure 5 the price-performance ratio of plane compressive strength and raw material cost of different corrugated cardboards**

4.4 Compensation plan for the strength

The above experiments indicate that A-type corrugated cardboard has the highest price-performance ratio. But if the customers clearly put forward their requirements for the plane compressive strength or other physical mechanical performance of the cardboard, it is necessary to combine with the specific experimental data and do some improvement. In these experiments, A-type corrugated board has the lowest plan compressive strength, so to improve its compressive strength to compete with other requires the compensation design for the strength in the preparation of paper ingredients. Enterprises could conduct experiments according to different materials in the production process and get the feasible information in order to establish a database for reference.

In fact, in addition to what has discussed above, other production techniques could also be used to improve the plane compressive strength. For example, a packaging enterprise in Zhejiang Province has developed a technique to improve the strength of the corrugated cardboard by using the fine stuff to fill the void. A manufacturer could improve the filling pattern, filling material to increase the compressive strength of the cardboard without breaking the intellectual property.

## CONCLUSION

The new high-strength corrugated composite cardboard demonstrates superior plane compressive strength, which is widely used in various types of trays and liners, etc. During the production and processing of composite board, it can be found through experimental comparisons that the corrugated types have great impact on the plane compressive strength of the composite cardboard and the production and processing costs of base papers. The comparison and analysis of experimental data show that the plane compressive strength of corrugated board and costs of base papers have different performance price ratios with the change of corrugated size when the same base papers are selected for producing and processing high-strength composite cardboard. A comes first, followed by C and B, with E ranking the lowest.

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