An Overview of the Reducing Principle of Design of Corrugated Box Used in Goods Packaging

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Abstract

This study summarizes the reducing principle of design of corrugated box used in the goods packaging. Then it makes a term-by-term analysis on the selection of raw materials for paper boxes, the optimization of prism types, and the overall design of paper box, with special emphasis on the method to realize moderate packaging of goods.

Keywords: Corrugated box; Reduce; Moderate packaging

1. Introduction

Corrugated box is a container\textsuperscript{[1]} most extensively applied in goods packaging and transporting. It is made from paper, and machine-shaped from corrugated box board with hollow structure. Since 1903 when corrugated box was first accepted by legal freight classification organizations as the containers for freight transportation, the application history of corrugated box has been over more than 100 years. Because of its light weight, low cost, ease of assembly and disassembly, good sealing performance, certain cushioning and anti-vibration ability and easy recovery and waste treatment, corrugated box is widely applied in various fields.

China started to introduce and use corrugated box as the external packing box from early 1930s. At that time, 80\% of the external packing boxes in use were wooden boxes, with cartons accounting for only about 20\%. By the end of 1940 and the beginning of 1950s, the percentage of boxes in use increased to 80\%. With the development of packaging materials and machine industries, 90\% packing boxes in use nowadays are corrugated boxes\textsuperscript{[2]}. The Yangtze River Delta represented by Zhejiang, Jiangsu and Shanghai is the region which has witnessed the most rapid development of corrugated box industry in China over the past few years. According to the statistics of Paper Committee of Shanghai Packaging Technology Association, the sales volume of corrugated box industry in Shanghai in 1990 was 1 billion...
RMB. By 2002, it had increased to 6 billion RMB, and to 13 billion RMB in 2007, with an average annual increase of about 30% [3]. Apparently, China’s production capacity of corrugated box is soaring dramatically. However, with the constant rise of resource and manufacture costs, many manufacturers at home and abroad are considering increasing the income while decreasing expenditure, especially the reduction of packaging expenditure. This is not only a response to domestic and international financial crises, but also an indication of the shift in priority from cutting down the cost of the product itself to the cost of the external packaging when taking into account of products cost. It is indeed progressive.

The question is how to set the standards of over-packaging. According to the experiences of developed countries, the upper limit of volume ratio of the packaging space is controlled to be 20%; while that of the ratio of packaging fee is controlled to be 15%. The exceeding part is the wasted part. The radical solution to the high packaging cost lies in the advocacy of moderate (rational) packaging. Moderate packaging refers to this kind of packaging which is moderate and appropriate to the extent that it can completely carry the goods contained in it with proper appearance properties. And the packaging cost exceeding the upper limit is over-packaging. The reducing principle discussed in this paper purports to reduce the over-packaging. For example, an over-packaging occurs when five boxes are used instead of three boxes which are necessary; or when the box with the volume of 1.5 cubic meters is used instead of that with the volume of 1 cubic meter, resulting in a waste of space; or when low-strength corrugated box board is sufficient to withstand the load, high-strength corrugated box board is chosen instead. All the above phenomena are widespread in many manufacturing and operational enterprises. The concept of moderate packaging of goods has long been popular overseas. A bill was proposed in Connecticut, US, in 1990, compelling the implementation of “moderate packaging” in accordance with the reducing principle. Germany government proscribes over-packaging in relevant regulations, and requires the use of environmental-friendly materials. Moderate packaging is also strongly advocated in Japan, to save raw and auxiliary materials and to decrease packaging wastes. In contrast, China lags far behind in the advocacy and implementation of moderate packaging. Besides the reason of consumption and design concepts, another more important reason is the low modernization level of commercial circulation. The large number of manual work links in logistics and the frequent presence of “barbaric” transportation, loading and unloading seriously affect the promotion and implementation of moderate packaging. With the standardization and improvement of administrative mechanism of goods transportation and logistics, along with the sharp increase in raw material costs, large enterprises and manufacturers are forced to take a serious attitude towards moderate packaging. Moderate packaging of commodities requires the reasonable, appropriate and precise packaging, which means that corrugated box should be designed in accordance with reducing principle. To be specific, the content of reducing principle in the design of corrugated box comprises optimal combination of raw materials, optimal selection of prism type, optimization of overall design of box, and the cost control of packaging.

2. Optimal combination of raw materials

2.1. The principle of “light weight”

Weight lightening of corrugated box can be realized through the selection and application of base paper, which is an important measure to achieve moderate packaging. This principle demands the selection of base paper characterized by low gram weight, high strength and weight lightening, which is mainly applied in the packaging of some large electrical household appliances and equipments. By considerably reducing the overall weight of the freight, it makes the handling and transportation more convenient. “Light-weight base paper” advocated currently has significantly lower gram weight of unit area of base paper than that of normal base paper, while its strength is comparable to that of normal base paper.
Therefore, this type of “light-weight base paper” will inevitably become the superior choice in the future. In 1950s, due to the backward development of China’s paper making, the gram weight of box averaged between 320g to 360g, and the base paper used for the manufacture of export boxes and domestic sale boxes was of poor quality [4]. There are several opinions concerning the selection of “light-weight” base paper. According to one opinion, the ration of base paper should be as low as possible; while according to another opinion, there should be explicit requirements on the selection of “light-weight base paper”, and at least one of the following three requirements, namely, processed by special techniques, manufactured by independent equipments, with gram weight of less than 150g, should be satisfied. There is a more widespread opinion: the ration of base paper should range between 100-180g/m²; indicators, such as ring pressure and breaking length should comply with certain standards [5]. And, as to the aspects of base paper application in domestic, part of the electrical household appliances industry has adopted 3 layers of corrugated cardboard to replace 5 layer of corrugated cardboard previously used. For the outer and inner layer of corrugated cardboard, high-strength light-weight base paper is adopted, while for the middle layer, the high-strength corrugated cardboard. In this way, the consumption quantity of boxes was reduced tremendously, but with equal strength.

2.2. High-strength corrugated honeycomb composite board

High-strength corrugated honeycomb composite board in divided into two types, namely, laminated board of corrugated cardboard and honeycomb board, and composite board of corrugated honeycomb board [6]. The laminated board of corrugated cardboard and honeycomb board is manufactured by arranging several pieces of continuous corrugated core papers cut into certain width in a parallel and vertical manner. Then waveform dislocation sticking is performed to form a structure similar to honeycomb (not a perfect hexagon), which is then glued to outer tissue and inner tissue. The corrugated core paper layer and flat paper layer are parallel to each other and glued together, with the prism perpendicular to the outer layer. For the corrugated honeycomb composite board glued together of more than two layers, the arrangement orientations of adjacent corrugated cardboard layers can be deviated from each other with a certain included angle [7]. Since the corrugated core is “half-hardened”, this type of high-strength corrugated cardboard has superior stiffness than honeycomb board, but its transverse stiffness is slightly lower than honeycomb. The board manufactured by this method is firm in overall structure, with high strength along various directions and balanced performance. Its load bearing capacity, pressure resistance, anti-rupture strength and cushioning performance have been significantly improved. Therefore, it proves to be an excellent substitute material for wood. The compressive strength as principle technical performance indictor of this high-strength corrugated composite box is as follows: when the pressure is 10560N, residual deformation ≤17.6mm [8]. When this high strength corrugated composite box replaces wooden box, not only its appearance and printing has been improved, but more importantly, it satisfies the environmental protection requirement, at a remarkably reduced cost.

2.3. Intensified sandwich corrugated cardboard

Intensified sandwich corrugate paper is called “corrugated cardboards of corrugation”. Generally, two, three or five layers of corrugated cardboard are used as outer paper and inner paper (board), between which corrugated cardboard or corrugated paper-tube specially arranged is sandwiched to form wave-type sandwich layer [9]. Reasonable structural design endows the intensified sandwich corrugated board with high strength. It is measured through testing that the total thickness of the board is 3.2cm (adjustable at will); corrugation density of sandwich layer is 38-40 prism/m; there are five layers of ordinary corrugated cardboard (C prism B prism) as outer layer(ration 780g/m2); three layers of ordinary corrugated
“Corrugated cardboard of corrugation” is an application of the mechanical principle of multi-azimuth support. It is made of high strength corrugated cardboard, which is deformed and arranged by special technique to form optimal mechanical structure. It can be applied in the manufacture of the packing box of six facades, by forming strong tubular matrix. Its superiority is mainly manifested in its ability to prevent damages to the objects contained in the box, especially for the packaging of large-volume, heavier, fragile and pressure susceptibility items. Moreover, because of its compact structure, seamless, absence of nails, foldability and forming ability, the overall packaging cost can be reduced by about 30%, and its appearance and integrity are also improved. Therefore, this kind of structure is very applicable for the packaging and transportation of large electrical household appliances and electromechanical equipments.

2.4. Four-layer corrugated cardboard (also called double-arch composite corrugated cardboard)

Four-layer composite corrugated cardboard is also called double-core superimposed corrugated cardboard, double-arch corrugated cardboard or UPS resulting force corrugated cardboard. It is generally made by smearing the adhesive with special performance on two layers of corrugated base paper, so that adhesive can filter into the cardboard fibers. Thus, the softness of paper can be modified, and the two layers of corrugated base paper are combined together. The corrugation is rolled under heating conditions; then it is adhered to outer layer to form firm and stiff four layer corrugated cardboard. The structure of its corrugated core is the double arch “honeycomb” structure which is made by adhering double-layer core papers and then formed by corrugation roller. The two archs of four-layer corrugated cardboard adopts the shape of ordinary corrugation—U-shaped or V-shaped corrugation, which can be divided into 2A, 2B and 2C type [11].

The research, development and application of four-layer corrugated cardboard have been very widespread in Japan, Europe and America. Due to its late start in China, only a small number of corrugation cardboard manufactures have introduced the manufacture and processing technique of four-layer corrugated cardboard. However, its promotion and application have not been realized yet.

2.5. Network-structured corrugated cardboard

The inner layer of network-structured corrugated cardboard is made of corrugated paper. The adjacent corrugations are perpendicular to each other or at certain angle, and the lattice network is formed by adhering the prisms at the intersection points between corrugations. The layer number is determined according to specific need, and the network-structured corrugated cardboard and its products are obtained by covering it with cardboard. In contrast, the corrugated cardboard and its products of conventional structure have good performance in bearing the load along the direction of prisms. However, its load bearing capacity along other directions is relatively poor. By modifying the original structure of corrugated cardboard, the good load bearing capacity along the prism direction is fully utilized. Its impact resistance and flexibility, as well as its overall load bearing capacity, i.e. anti-puncture capacity, impact resistance, ring pressure resistance, and edge crush strength, can be improved by increasing its thickness. Since corrugated paper is used to replace the original sandwich paper, the weight is reduced while its thickness is increased. Therefore, anti-puncture capacity, pressure resistance, ring pressure resistance, edge crush strength and flexibility are improved. If applied to the design of five-layer corrugated cardboard, this method can save 296g of paper per square meter of cardboard, with a 13% reduction in cost. Moreover, the cost and freight charges are lowered, and labor intensity of transport workers is also lessened.
3. Prism type optimization

Prism type optimization refers to diversified design by designers based on their working experience and suitable engineering principles of the corrugation shape, with the purpose of strengthening its properties, such as pressure resistance and bursting strength. By this means, less consumption quantity of new corrugated cardboard will be needed to support the box, so that corrugation optimization is achieved on the same level. The tooth profile of corrugated box is divided into U type, V type and UV type. Its prism type can be divided into heavy type (D type, K type), ordinary type (A type, C type, B type, E type) and miniature type (F type, G type, N type, O type) [12].

Over the recent years, achievements have been made in the research of corrugation structure. More and more attention has been drawn to optimal selection of corrugation structure in the reducing principle in the design of corrugated packaging. The constant increase in the consumption of minute corrugated packaging is due to its lower cost with a reduction of nearly 20% compared with solid corrugated cardboard; compared with large prisma type packaging, such as B prisma, the corrugated height of minute corrugated packaging is relatively lower, with more prisms per unit area. Moreover, its prism type is denser, with firmer structure. Therefore, its advantages in bearing strength and cushioning capacity with respect to parallel pressure are more significant under the conditions of using identical base paper under equal pressure [13]. Therefore, more and more enterprises and manufacturers begin to choose minute corrugated box.

4. Optimization of overall design of corrugated box

Design optimization refers to the optimization made by designers according to the theory of meeting specific properties, so that different configuration complying with new standards will be obtained.

4.1. Forming process

The forming process of corrugated boxes has significant impact on the quality of corrugated box. Groove, slotting, printing, and gluing all need to be optimized in actual operation. First, the strength of corrugated box is associated with the width and depth of press mark line of cardboard. Excessive width and depth of press mark will lead to the rupture of inner paper; while insufficient width and depth lead to the non-foldability of the corrugated box. Therefore, investigation has to be made into the groove process of corrugated cardboard, so as to determine the optimal operational parameters. Second, the printing process is another factor affecting the load bearing strength of corrugated box. Research shows that with the increase of printing pressure, the contraction and deformation will occur to corrugated cardboard; its compressive strength declines until the crush of the corrugated box. It is thus necessary to adopt the smallest printing pressure possible while ensuring good printing appearance. Third, the slotting and gluing process optimization also need exploration, since the compressive strength of corrugated box dramatically decreases with the deepening of the slotting; inadequate dosage of adhesive leads to the weak cohesion. As a result, adhesive failure is very likely to happen under pressure, leading to crushing and the decline of compressive strength. On the other hand, excessive dosage will bring about glue overflow, which affects the appearance of the products; or, it will result in cohesion between corrugated boxes, with a waste of production cost [14].

4.2. Optimization of size and proportion
To ensure moderate packaging, the arrangement number and arrangement orientation of the packaged commodities, as well as the internal and external size of the corrugated box can be optimized during the transportation \[15\][16]. In actual practice, various kinds of cushioning pads are placed inside the corrugated box to prevent the packaged commodity from being damaged. By this means, the volume of commodity after packaging is usually larger than that of the commodity itself, sometimes by 5-10 times. In this case, prodigious waste is incurred with a several-fold increase in consumption quantity of corrugated cardboard. Therefore, much can be done in reducing the size of corrugated box in accordance with the reducing principle of corrugated box\[17\].

4.3. Palletized corrugated packaging

The use of pallets in logistics has already reached maturity, including wooden pallets, plastic pallets, and metal pallets. The application of pallets makes the handling, loading and unloading, stacking and classification much more convenient. Over the recent years, the emergence of paper pallet has facilitated the seamless linkage of logistics packaging and retail packaging. The use of corrugated pallets, by protecting the bottom and facades of the commodity, makes the packaged commodities easier to be stacked. The remaining part is wrapped by plastic thin films or other packing methods. By this means, the consumption quantity of corrugated cardboard can be reduced by 60% or more. With its visibility and air permeability, pallets are extensively applied in the integrated packaging of carbonated soft drinks, mineral water, beer and other kinds of soft drinks \[17\].

To sum up, the reduction measures discussed above are not applied solely, but in combination by enterprises. In this way, the reduction design of corrugated boxess is implemented, which provides the first step to achieve moderate packaging. Due to its characteristics of being cost-saving and environmentally friendly, the reduction principle in packaging design deserves more thorough research in future commodity packaging. Moreover, it will definitely make its own contribution to the effective utilization of natural resources.

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