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A SUMMARY OF THE REDUCING PRINCIPLE IN THE DESIGN OF CORRUGATED BOXES FOR GOODS PACKAGING

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Abstract

This research provides an overview of the design principles aimed at minimizing the environmental impact of corrugated boxes employed in product packaging. It subsequently conducts a detailed analysis of various factors, including the selection of raw materials for paper boxes, the optimization of prism types, and the comprehensive design of paper boxes. Notably, it places a special emphasis on methods to achieve sustainable packaging practices for goods.

Keywords: Corrugated box, Reduce, Moderate packaging

INTRODUCTION

The corrugated box serves as the most widely utilized container for goods packaging and transportation, crafted from paper and machine-shaped from corrugated box board with a hollow structure. Since its acceptance by legal freight classification organizations in 1903, marking it as a suitable container for freight transportation, the history of corrugated box application spans over a century. Its popularity is attributed to its lightweight nature, cost-effectiveness, ease of assembly and disassembly, effective sealing, cushioning, anti-vibration properties, and straightforward recovery and waste treatment.

In the early 1930s, China embraced the use of corrugated boxes as external packing, transitioning from the predominant use of wooden boxes to a shift where cartons accounted for around 80% of external packing boxes. By the 1950s, with advancements in packaging materials and machinery industries, corrugated boxes constituted approximately 90% of the packing boxes in use. Notably, the Yangtze River Delta, led by Zhejiang, Jiangsu, and Shanghai, witnessed rapid development in the corrugated box industry over recent years.

Statistics from the Paper Committee of the Shanghai Packaging Technology Association reveal significant growth in the sales volume of the corrugated box industry in Shanghai, increasing from 1 billion RMB in 1990 to 13 billion RMB in 2007, with an average annual increase of about 30%. This surge in production capacity raises concerns about the associated resource and manufacturing costs, prompting manufacturers worldwide to consider strategies for increasing income while reducing expenditure, particularly in packaging costs.

The challenge lies in establishing standards for preventing over-packaging. Drawing on the experiences of developed countries, the upper limits for the volume ratio of packaging space and the ratio of packaging fees are set at 20% and 15%, respectively, with any excess considered wasteful. The solution lies in advocating for moderate (rational) packaging, defined as packaging that is appropriate and proportionate to effectively contain the goods with the correct appearance properties. The focus of this paper's reducing principle is on minimizing over-packaging instances.

For instance, over-packaging occurs when five boxes are used instead of the necessary three, or when a box with a volume of 1.5 cubic meters is used instead of one with a volume of 1 cubic meter, resulting in wasted space. Similarly, opting for high-strength corrugated box board when low-strength would suffice contributes to over-packaging. These occurrences are widespread in many manufacturing and operational enterprises.

The concept of moderate packaging has gained popularity overseas, with examples such as a bill proposed in Connecticut in 1990 advocating for "moderate packaging" based on the reducing principle. Germany mandates against over-packaging and emphasizes the use of environmentally friendly materials, while Japan strongly promotes moderate packaging to conserve raw materials and reduce packaging waste. In contrast, China lags behind in the advocacy and implementation of moderate packaging, partly due to consumption and design concepts and, more significantly, the low modernization level of commercial circulation.

Manual labor in logistics and the prevalence of "barbaric" transportation, loading, and unloading hinder the widespread adoption of moderate packaging in China. Nevertheless, with the standardization and improvement of administrative mechanisms in goods transportation and logistics, coupled with rising raw material costs, large enterprises and manufacturers are compelled to adopt a serious attitude towards moderate packaging. The essence of moderate packaging necessitates reasonable, appropriate, and precise corrugated box design, encompassing the optimal combination of raw materials, selection of prism type, overall box design optimization, and meticulous packaging cost control.

OPTIMAL COMBINATION OF RAW MATERIALS

The Principle of “Light Weight”

The reduction in the weight of corrugated boxes can be achieved through careful selection and application of base paper, representing a crucial step in achieving moderate packaging. This principle necessitates the choice of base paper characterized by low gram weight, high strength, and weight reduction, primarily used in packaging large electrical household appliances and equipment. Substantially reducing the overall weight of the freight enhances the convenience of handling and transportation. The currently advocated "light-weight base paper" has a significantly lower gram weight per unit area compared to normal base paper, while maintaining strength comparable to that of standard base paper.

Consequently, this type of "light-weight base paper" is destined to become the preferred choice in the future. In the 1950s, due to the underdeveloped state of China's paper-making industry, the average gram weight of boxes ranged between 320g to 360g, and the base paper used for manufacturing export boxes and domestic sale boxes was of poor quality [4]. Various opinions exist regarding the selection of "light-weight" base paper. According to one viewpoint, the ratio of base paper should be as low as possible, while another perspective suggests explicit requirements for the selection of "light-weight base paper," with at least one of the following three conditions being met: processed by special techniques, manufactured by independent equipment, or a gram weight of less than 150g. A more widely accepted opinion proposes a base paper ratio ranging between 100-180g/m2, with indicators such as ring pressure and breaking length complying with certain standards [5]. Regarding the application of base paper domestically, a segment of the electrical household appliances industry has transitioned from using 5 layers of corrugated cardboard to 3 layers. High-strength, light-weight base paper is employed for the outer and inner layers of corrugated cardboard, while the middle layer uses high-strength corrugated cardboard. This approach has significantly reduced the quantity of boxes consumed while maintaining equal strength.

High-Strength Corrugated Honeycomb Composite Board

High-strength corrugated honeycomb composite board is categorized into two types: laminated board of corrugated cardboard and honeycomb board, and composite board of corrugated honeycomb board [6]. The manufacturing process for the laminated board involves arranging several pieces of continuous corrugated core papers, cut to a specific width, in a parallel and vertical manner. Subsequently, waveform dislocation sticking is performed to create a structure similar to honeycomb (though not a perfect hexagon), which is then affixed to outer tissue and inner tissue. The corrugated core paper layer and flat paper layer run parallel to each other and are bonded together, with the prism perpendicular to the outer layer. In the case of corrugated honeycomb composite boards composed of more than two layers, the orientations of adjacent corrugated cardboard layers can be deviated from each other at a certain included angle [7].

Due to the "half-hardened" nature of the corrugated core, this high-strength corrugated cardboard exhibits superior stiffness compared to honeycomb board, although its transverse stiffness is slightly lower. The resulting board boasts a firm overall structure, with high strength in various directions and balanced performance. Notably, its load-bearing capacity, pressure resistance, anti-rupture strength, and cushioning performance have been significantly enhanced, making it an excellent substitute for wood. The primary technical performance indicator for this high-strength corrugated composite box is its compressive strength: when subjected to a pressure of 10,560N, the residual deformation is 17.6mm [8]. Upon replacing a wooden box, this high-strength corrugated composite box not only improves in appearance and printing but, more importantly, meets environmental protection requirements at a significantly reduced cost.

Intensified Sandwich Corrugated Cardboard

The enhanced sandwich corrugated paper is referred to as "corrugated cardboards of corrugation." Typically, two, three, or five layers of corrugated cardboard serve as the outer and inner paper (board). In between, specifically arranged corrugated cardboard or corrugated paper-tube forms a wave-type sandwich layer [9]. A well-thought-out structural design imparts high strength to the intensified sandwich corrugated board. Testing reveals that the total thickness of the board is 3.2cm (adjustable as needed), and the corrugation density of the sandwich layer is 38-40 prism/m. The outer layer consists of five layers of ordinary corrugated cardboard (C prism B prism) with a ratio of 780g/m2, while the inner layers consist of three layers of ordinary corrugated cardboard (C Prism) with a ratio of 470g/m2. The sandwich layer comprises three layers of ordinary corrugated cardboard (B prisma) with a ratio of 680g/m2, resulting in a total ratio of 1900-2000g/m2 [10].

The concept of "corrugated cardboard of corrugation" applies the mechanical principle of multi-azimuth support. Constructed from high-strength corrugated cardboard deformed and arranged using special techniques, it forms an optimal mechanical structure. This type of material is suitable for manufacturing six-sided packing boxes, creating a robust tubular matrix. Its superiority lies in its ability to prevent damage to items contained in the box, especially when packaging large-volume, heavier, fragile, and pressure-sensitive items. Additionally, due to its compact structure, seamless nature, absence of nails, foldability, and formability, the overall packaging cost can be reduced by approximately 30%, improving both appearance and integrity. Hence, this structure is highly applicable for packaging and transporting large electrical household appliances and electromechanical equipment.

Four-Layer Corrugated Cardboard (Also Called Double-Arch Composite Corrugated Cardboard)

The four-layer composite corrugated cardboard is also known as double-core superimposed corrugated cardboard, double-arch corrugated cardboard, or UPS resulting force corrugated cardboard. Typically, it is created by applying adhesive with special properties to two layers of corrugated base paper, allowing the adhesive to permeate the cardboard fibers. This process modifies the paper's softness, bringing the two layers of corrugated base paper together. The corrugation is then rolled under heating conditions and adhered to an outer layer to produce a sturdy and rigid four-layer corrugated cardboard. The corrugated core's structure is the double arch "honeycomb" structure, formed by adhering double-layer core papers and then shaping them with a corrugation roller. The two arches of the four-layer corrugated cardboard adopt the shape of ordinary corrugation—U-shaped or V-shaped corrugation, categorized as 2A, 2B, and 2C types [11].

The research, development, and application of four-layer corrugated cardboard have been widespread in Japan, Europe, and America. In China, its adoption has been limited, with only a small number of corrugated cardboard manufacturers introducing the manufacturing and processing techniques for four-layer corrugated cardboard. However, widespread promotion and application have not yet been achieved.

Network-Structured Corrugated Cardboard

The inner layer of network-structured corrugated cardboard consists of corrugated paper. The adjacent corrugations are oriented perpendicular to each other or at certain angles, forming a lattice network by adhering the prisms at the intersection points between corrugations. The layer count is determined based on specific requirements, and network-structured corrugated cardboard and its products are obtained by covering it with cardboard. In contrast, conventional structured corrugated cardboard and its products excel in load-bearing performance along the direction of prisms. However, their load-bearing capacity along other directions is relatively weak. By modifying the original corrugated cardboard structure, the strong load-bearing capacity along the prism direction is fully harnessed. Increasing its thickness enhances impact resistance, flexibility, and overall load-bearing capacity, encompassing anti-puncture capacity, impact resistance, ring pressure resistance, and edge crush strength.

The use of corrugated paper to replace the original sandwich paper reduces weight while increasing thickness. Consequently, anti-puncture capacity, pressure resistance, ring pressure resistance, edge crush strength, and flexibility are all improved. When applied to the design of five-layer corrugated cardboard, this method can save 296g of paper per square meter of cardboard, resulting in a 13% reduction in cost. Additionally, both cost and freight charges are lowered, and the labor intensity of transport workers is lessened.

PRISM TYPE OPTIMIZATION

Prism type optimization involves diverse designs by designers based on their practical experience and relevant engineering principles of corrugation shape. The aim is to enhance properties such as pressure resistance and bursting strength. This approach leads to the use of fewer quantities of new corrugated cardboard to support the box, achieving optimization at the same level. The tooth profile of a corrugated box is categorized into U type, V type, and UV type, while its prism type can be further classified 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].

In recent years, progress has been made in the research of corrugation structure, placing increased emphasis on the optimal selection of corrugation structure within the reducing principle in corrugated packaging design. The growing use of minute corrugated packaging is attributed to its lower cost, offering nearly a 20% reduction compared to solid corrugated cardboard. In comparison to large prisma type packaging, such as B prisma, the corrugated height of minute corrugated packaging is relatively lower, with more prisms per unit area. Additionally, its prism type is denser, resulting in a firmer structure. Consequently, its advantages in bearing strength and cushioning capacity under parallel pressure conditions are more significant when using identical base paper under equal pressure [13]. As a result, more enterprises and manufacturers are opting for minute corrugated boxes.

OPTIMIZATION OF OVERALL DESIGN OF CORRUGATED BOX

Design optimization involves designers making adjustments according to the theory to meet specific properties. The goal is to achieve various configurations that adhere to new standards..

Forming Process

The quality of corrugated boxes is significantly influenced by the forming process, which includes groove, slotting, printing, and gluing operations that require optimization during actual production. Firstly, the strength of a corrugated box is closely tied to the width and depth of the press mark line on the cardboard. Excessive width and depth may lead to inner paper rupture, while insufficient dimensions can result in a corrugated box that is not foldable. Therefore, a thorough investigation into the groove process of corrugated cardboard is necessary to determine the optimal operational parameters. Secondly, the printing process is another factor affecting the load-bearing strength of corrugated boxes. Research indicates that as printing pressure increases, corrugated cardboard experiences contraction and deformation, leading to a decline in compressive strength until the box is crushed. Hence, it is essential to use the smallest printing pressure possible while maintaining satisfactory printing appearance. Thirdly, the optimization of the slotting and gluing processes requires exploration. The compressive strength of corrugated boxes significantly decreases with the deepening of the slotting, and insufficient adhesive can result in weak cohesion. Inadequate bonding may lead to adhesive failure under pressure, resulting in crushing and a decline in compressive strength. Conversely, excessive adhesive may cause glue overflow, affecting the appearance of the products or causing cohesion between corrugated boxes, leading to a waste of production cost [14].

Optimization of Size and Proportion

To ensure moderate packaging, optimization of the arrangement number and orientation of packaged commodities, as well as the internal and external size of the corrugated box, can be carried out during transportation [15][16]. In practical applications, various types of cushioning pads are often placed inside the corrugated box to prevent damage to the packaged commodity. This practice can result in the volume of the packaged commodity being larger than that of the commodity itself, sometimes by 5-10 times. This leads to significant waste and a several-fold increase in the consumption quantity of corrugated cardboard. Therefore, there is ample opportunity to reduce the size of the corrugated box in line with the reducing principle of corrugated boxes [17].

Palletized Corrugated Packaging

The logistics industry has fully embraced the use of pallets, which includes wooden, plastic, and metal pallets. This widespread adoption has made handling, loading, unloading, stacking, and classification significantly more convenient. In recent years, the introduction of paper pallets has seamlessly connected logistics packaging with retail packaging. The utilization of corrugated pallets, designed to protect the bottom and facades of commodities, facilitates easier stacking. The remaining portion is typically wrapped with plastic thin films or other packaging methods, leading to a reduction in the consumption quantity of corrugated cardboard by 60% or more. Pallets, with their visibility and air permeability, find extensive applications in the integrated packaging of carbonated soft drinks, mineral water, beer, and various soft drinks [17].

In summary, the discussed reduction measures are typically implemented in combination by enterprises. This integrated approach enables the implementation of reduction design for corrugated boxes, marking the initial step toward achieving moderate packaging. Given its cost-saving and environmentally friendly attributes, the reduction principle in packaging design warrants further in-depth research in future commodity packaging. Undoubtedly, it will make a valuable contribution to the effective utilization of natural resources.

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