A New Design of Carton Compression Experiment for Undergraduate Students*

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Abstract: A new design of carton compression experiment for the lab course of packaging materials was developed for the undergraduate students to study the influence of dimensions including perimeter, length-width ratio and height of cartons on their compression strengths. The students are divided into groups. Each group designs an experiment to study the influence of one dimension factor. All the testing should be finished in two credit hours and the groups take turns to use the instruments. They are asked to operate the instruments independently with the guide of operation manuals. Determined values were compared with calculated values derived from Kellicutt formula. Detailed analysis of the influence should be made. The students are asked to purchase the desired cartons directly from the carton plant, which makes them to get familiar with real-life carton market. A pretest showed that this design was feasible. By doing this experiment, the students can fully explore their social and academic abilities. Thus this new design is meaningful.

Keywords: carton compression experiment; compression strength; Kellicutt formula; dimensions of carton

1. Introduction

The lab course of packaging materials is offered to third-year college students majoring in packaging engineering. In some colleges in China, there are three experiments in the syllabus [1]. One is the comprehensive experiment studying the properties of packaging paper and paperboard, which include the determination of their thickness, folding strength, tear, ring crush test and bursting strength etc. Another is the comprehensive experiment studying the properties of corrugated paperboards and cartons. The last one is the comprehensive experiment studying the properties of flexible plastic packaging material. In this study, a new design of carton compression experiment was developed to investigate the influence of dimensions of the corrugated cartons on cartons' compression strength and compare the determined value with the calculated value obtained from the empirical Kellicutt formula. As it is widely known, there are several factors influencing the compression strength. The major factors include the quality of raw materials, grade and flute structure of corrugated fiberboard, moisture content of the corrugated board while the minor factors include dimensions and construction of the cartons, inner supports and printing & open. However the influence of dimensions are not well studied, herein they are chosen as the parameters of study which include perimeter, height and length-width or base ratio. The students are responsible for the selection of dimensions. Also they order the cartons from a carton plant by themselves. This way they can get to know the real carton market. What's more, they learn to use the relevant instruments by following the guidance of the operation manuals which were given to them in advance. After finishing the experiments, they can not only have a vivid understanding of the influence of dimensions after the analysis of the experimental results but also develop their ability to design and conduct the experiment independently. Also this experiment can prepare them for the following course of design of carton structure. The feasibility of this design was tested with a positive feedback.

2. Design of Experiment

Students are divided into three groups. They are given the experiment guidebook in advance, which includes the outline of the experiment and the operation manuals of the instruments. Each group studies one of the three parameters and selects three sizes. For each size, three specimens are needed. Therefore 27 cartons should be bought altogether from one carton plant. At the same time the linerboard and the corrugating medium of the corrugated carton's board should also be bought. One day before the experiment, the purchased cartons should be put by the lab technician in the constant temperature and humidity chamber for 24 h treatment in 23℃ with humidity of 50%. The box compression tester is used to test the compression strength. The universal testing machine is used to obtain the cross direction ring crush test of the above base paper for the calculation of compression strength using Kellicutt formula. Since these two instruments are easy to operate, the students conduct the experiment by themselves and the teacher is ready to help. This way the students can develop their initiative better. One group does the ring crush test first. Another one seals the cartons and does the carton compression test. The

*** Contract/grant sponsor: Project 50775100 supported by National Natural Science Foundation of China, and project 2009BADB9B04-01 supported by National Key Technology R & D Program of China.**

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third one just seals the cartons. Afterwards they alternate the tasks until finish the whole experiment within the two credit hours. In their reports, students should include the experimental results and their own analysis. At the same time, they should provide a solution to the question of how to improve the compression strength of cartons considering the influencing factors. The students are supposed to upload their reports to internet to share with each other. This way they can get a deep understanding.

Table 1. Dimensions of boxes and their respective determined and calculated compression strengths

Group	Dimensions (cm)			Z^d (cm)	L/W	P_{det} (N)		P_{cal} (N)
	L^a	W^b	H^c			n^e=3	n=5	
1	36	24	40	120	1.5	2064	2048	1431
	45	30	40	150	1.5	2699	2701	1542
	54	36	40	180	1.5	1772	1804	1638
2	45	30	30	150	1.5	1771	1770	1542
	45	30	40	150	1.5	2699	2701	1542
	45	30	50	150	1.5	1581	1519	1542
3	30	30	30	120	1	1645	1683	1431
	36	24	30	120	1.5	1855	1830	1431
	40	20	30	120	2	1836	1771	1431

a, length; b, width; c, height; d, perimeter; e, number of replicate tests.
Pdet, determined compression strength; Pcal, calculated compression strength.

3. Pretest

3.1. Materials

Three groups of cartons of 0201 type were bought from Guangzhou Furong carton plant. First group consists of cartons with identical height and base ratio but various perimeters. Second group consists of cartons with identical perimeter and base ratio but various heights. Third group consists of cartons with identical perimeter and height but various base ratios. Details were shown in Table 1. A small number of test liners and high-strength corrugating media were bought as well, of which this B-flute corrugated board is made. The paper weights of the above two materials are 160g/m^2 and 105g/m^2 respectively.

3.2. Procedure

Top and bottom sides of conditioned cartons were sealed with tape before they were subjected to the box compression test (BCT) using a RS-8401box compression tester. According to Chinese standard GB/T 4857.4-92, at least three specimens were compressed between two platens until maximum load was reached at a constant speed of 10mm/min. Load vs. displacement curves were recorded.

For each size, five replicas were tested. Ring crush test was performed on a CMT8202 universal testing machine according to Chinese standard GB/T 2679.8-1995. The specimen has the length of 152 mm and the width of 12.7 mm. Ten replicas for each base paper were tested.

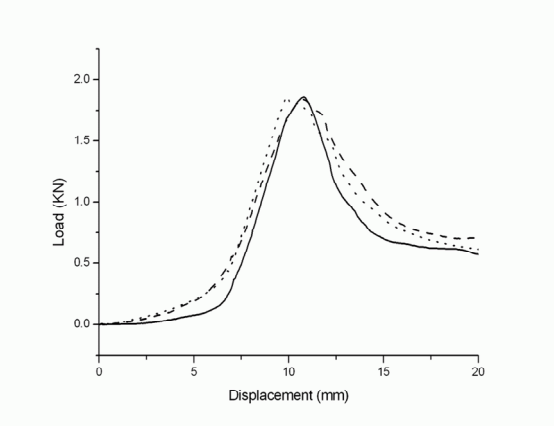

Figure 1. Load vs. displacement curves for three boxes with length of 360 mm, width of 240 mm and height of 300 mm respectively.

3.3. Results and Discussion

The average compression strength value of three replicate tests was similar to that of five replicate tests. The curves of three replicate tests for one size were shown in Fig. 1. In order to save the cost and avoid the crush of the paperboards in the constant temperature and humidity chamber, three specimens were chosen for each size. Calculation of compression strength was attempted using Kellicutt formula [2]:

$$P = P_x \left\{ \frac{(ax_2)^2}{(Z/4)^2} \right\}^{\frac{1}{3}} ZJ \qquad (1)$$

Where P is defined as compression strength of corrugated carton (N), ax_2 is flute constant, J is defined as box coefficient, Z is box perimeter (cm), P_x is comprehensive ring crush value of base paper (N/cm), which is defined as:

$$P_x = \frac{\sum R_1 + \sum R_m \cdot \gamma}{100} \qquad (2)$$

Where R_1 is defined as the ring crush test of linerboard or(N/m), R_m is the ring crush test of the corrugating medium (N/m), and γ is the shrinkage of flute. For single-wall B-flute, equation (2) can be written as:

$$P_x = \frac{2R_1 + R_m \cdot \gamma}{100} \qquad (3)$$

Here ax_2 is 5, J is 1.26 and γ is 1.361. R_1 and R_m were determined to be 1030.33 and 782.68 N/m respectively.

The results obtained from Kellicutt formula were lower than the actual values which was consistent with the literature [3]. For group one, it could be seen in Fig. 2 that within the range between 120 and 180 cm the determined

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compression strength first increase and then decrease. The extent of the change is about 37%. It is probably because

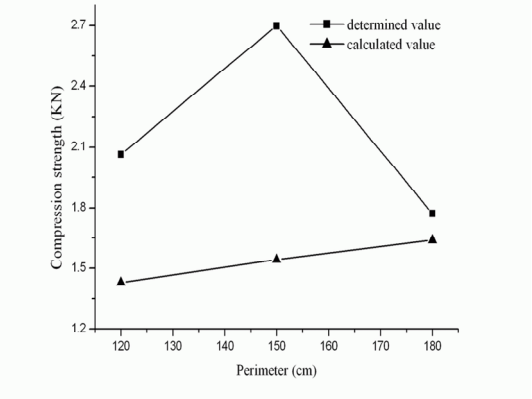

Figure 2. Influence of perimeter on compression strength of boxes with height of 40 cm and base ratio of 1.5.

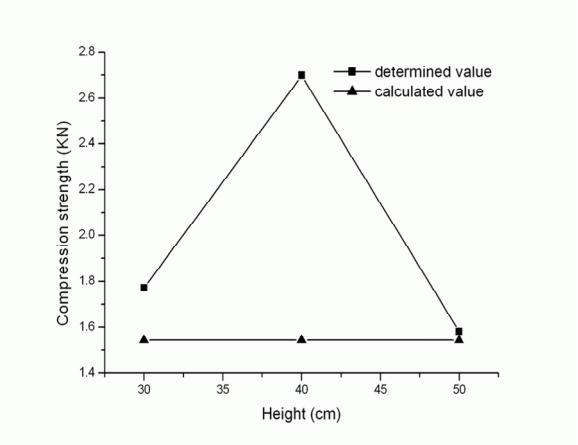

Figure 3. Influence of height on compression strength

the instability increases with the increase of the perimeter when the perimeter is larger than a value [4]. For group two, it could be seen in Fig. 3 that within the range between 30 and 50 cm, the determined compression strength also first increase and then decrease. The extent of the change is about 45%. For group three, it could be seen in Fig. 4 that within the range between 1 and 2, the change trend is the same to those of the previous groups. However the extent of the change is smaller. According to Kellicutt formula, there is a linear relationship between the perimeter and the compression strength with a positive slope. With the same perimeter, despite of the different height or base ratio, the compression strength should be the same. It is obvious that Kellicutt formula can not represent the real situation of Chinese cartons. Therefore people have tried to modify it [4].

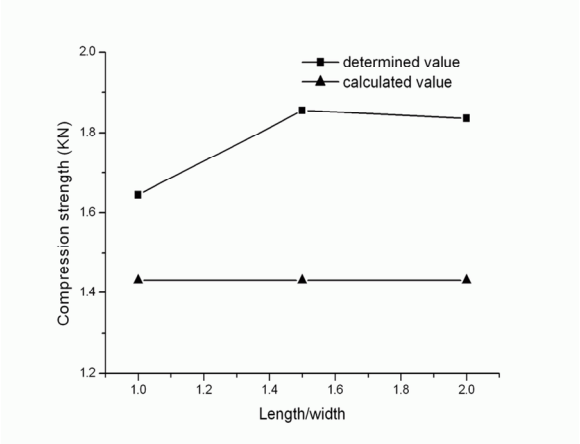

Figure 4. Influence of base ratio on compression strength of boxes with height of 30 cm and perimeter of

3.4. Challenges

Since the need for cartons of each size is small, the carton plants offer the price much higher than that of larger number of cartons. In this case the students can consult the manufacturers to get the sizes of the stocked cartons to find the suitable ones for the experiments. If there are no enough sizes, they can design the sizes and make order from the plant. Thus the cost can be dramatically reduced. Because there are only two credit hours for this lab course, the students should study carefully the experiment guidebook, especially the operational manuals of instruments.

4. Conclusion

A new design of carton compression experiment is developed. According to the feasibility study, it is obvious that it is feasible and meaningful. It can explore the students' abilities and let them realize the difference between the theory and the reality. It makes the students deeply understand the influence of dimensions on compression strength.

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