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Effect of Carrying Slots on the Compressive Strength of Corrugated Board Panels

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ABSTRACT

This research is aimed at studying effects of the carrying slots on the compressive strength of corrugated board panels. Factors of interest include shape, position and size of the carrying slots. The result reveals that corrugated board with circle shape slotting shows the smallest reduction in compressive strength compared to other slotting shapes. However, perforated style shows better performance in compressive strength than the true cut slot. Furthermore, compressive strength of the board decrease as the slot position is located away from the center of the board. Also, the smaller the slot size, the higher the compressive strength. The results of this study can be applied in structural design of the corrugated boxes for suitable service environment.

Key words: corrugated board, corrugated boxes, compressive strength, carrying slots, structural design

INTRODUCTION

Corrugated boxes are the most widely used type of package for the packaging and distribution of goods ranging from fruits and vegetables, consumer products, to industrial items. Corrugated boxes are advantageous because they are practical for retail sales, require less inventory space, and are made from environmentally friendly materials. Also, corrugated cardboard can be designed for various strength applications and shapes as needed. However, the compressive strength of completed boxes depends on various design factors. These factors include board components, dimensions, designs, shipping conditions, and storage environments. Several studies (Singh, *et al*., 2004; Burgess, *et al*., 2005; Lee and Park, 2004; Sigh and Pratheepthinthong, 2000 and Fatima and Faria, 2000) also found that corrugated board lost its compressive strength when subjected to distribution hazards such as high relative humidity, excessive stacking load, long term storage, and uneven stacking patterns.

Various studies (Kellicutt, 1959; Ranger, 1960; Nyman and Gustafsson, 2000; and Lu, *et al*., 2001) have been performed on the corrugated boxes and corrugated boards' compressive strength. Some studies attempt to predict the compressive strength of boxes based on different approaches. Maltenfort (1996) indicated that there is a correlation of corrugated boxes dimensions to their compressive strength. Mckee, *et al*. (1963) introduced a formula to predict compressive strength of a single wall corrugated boxes. They indicated that the compressive strength of the box is a function of box perimeter, edge crush test (ECT) value, and the flexural stiffness of the board. This formula was further developed and became

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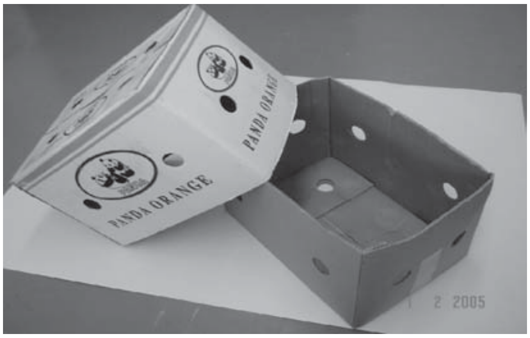
very well known among corrugated board producers as the Mckee's formula. Buchanan, *et al*. (1964) also published a formula for prediction of compressive strength based on edge crush test and bending stiffness of the corrugated board that is similar to Mckee's formula.

As mentioned previously, many factors reduce compressive strength. Among those are temperature, humidity, storage condition, dimension and style of the boxes. Kawanishi (1989) studied the compressive strength of various corrugated box styles. He also included moisture content in his formula for the prediction of compressive strength. Kutt and Mithel (1969) found that compressive strength decreased extensively when the baring area of boxes was reduced. Most corrugated boxes designed for fruit and vegetable are perforated or slotted for air ventilation and temperature balance as shown in Figure 1. Moreover, some slots are designed as handholds. Overall, the sizes and shapes of slots tends to vary by the type of product to be distributed. For example, total slotting area of the inner box should be approximately 1.07% for tomato, 2.6 % for banana, and 4 % for papaya, respectively (Thai Packaging Center, 2004). Since baring area of corrugated boxes is slotted, the prediction of compressive strength based on various formulas previously developed alone may not be accurate. Loss of compressive strength as a result of slotting should also be taken into consideration. Thus, this research aims to identify factors that lead to the loss of compressive strength as a result of different shapes, sizes, and positions of slots. In the research, panels of a corrugated board with different slotting configurations were subjected to compression testing to determine the reduction of compressive strength.



(a)

Inside Dimension (L × W × D) = 430 mm × 290 mm × 210 mm

(b)

Inside Dimension (L × W × D) = 410 mm × 230 mm × 170 mm

Figure 1 Examples of corrugated boxes for fruit and vegetable.

MATERIALS AND METHODS

Test samples

Test sample is a C flute corrugated board made from Kraft paper with a basis weight of 150 g/m^2 for both an inner and an outer liners. A corrugated medium has a basis weight of 125 g/m^2. The corrugated board was cut into a panel of 225 × 150 mm. Each of the board panel is slotted at the center of the board for one slotting shape. Seven different slotting shapes were subjected to compression testing as shown in Figure 2. Shapes of the slots are selected from slotting styles commonly found in the marketplace for corrugated boxes of fruit and vegetable. For further investigation, total slotting areas of each sample are designed to be 1%, 2%, 3% and 4% of the

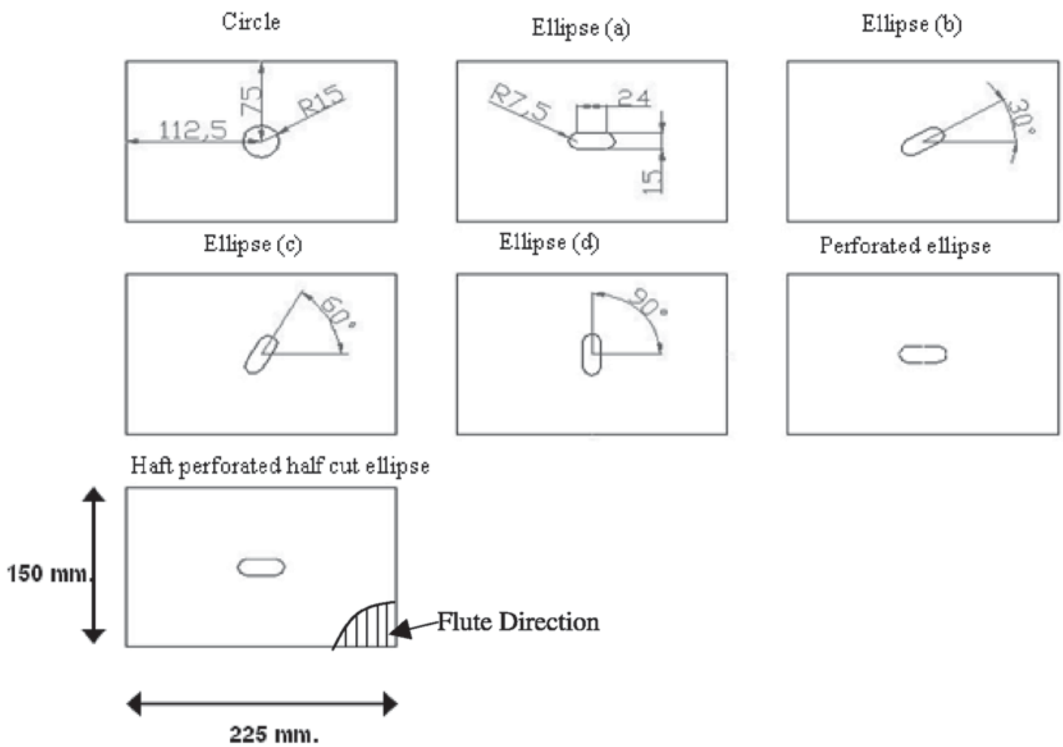


Figure 2 Test samples for different slotting shapes.

board panel. In addition, to test the effect of slotting positions on the loss of compressive strength, a slot was cut at different positions on the board panel for each slotting size of a particular shape as shown in Figure 3. The control corrugated board panel is the one without any slotting. All samples are conditioned under a standard atmosphere at temperature 27±1°C with 65±2% relative humidity. The average moisture content of the corrugated board sample before the test was measured and is approximately 7.5-8.0%.

Compression test

Static compression test procedure which is modified from TAPPI T811 (edgewise compressive strength of corrugated fiberboard (short column test)) was conducted for each sample using a compression machine (Testometric-micro 350 made in UK by Shirley Developments, with 10-kg load cell). Two wooden plates with smooth surfaces are attached to the upper and the lower compression jaws of the machine to evenly distribute the compression load on the corrugated board panel. Each wooden plate weighed 221 g. The test speed was set for 12 mm./min. The test configuration is shown in Figure 4.

Statistical analysis

Data analysis was performed using analysis of variance (SPSS statistical software version 10.0). Significant differences were further examined with Duncan's multiple range test (DMRT) at 5 percent level.

RESULTS AND DISCUSSION

Shapes and sizes of the slots and loss of compressive strength

Compressive strength of the corrugated board is reduced when the board is slotted. This

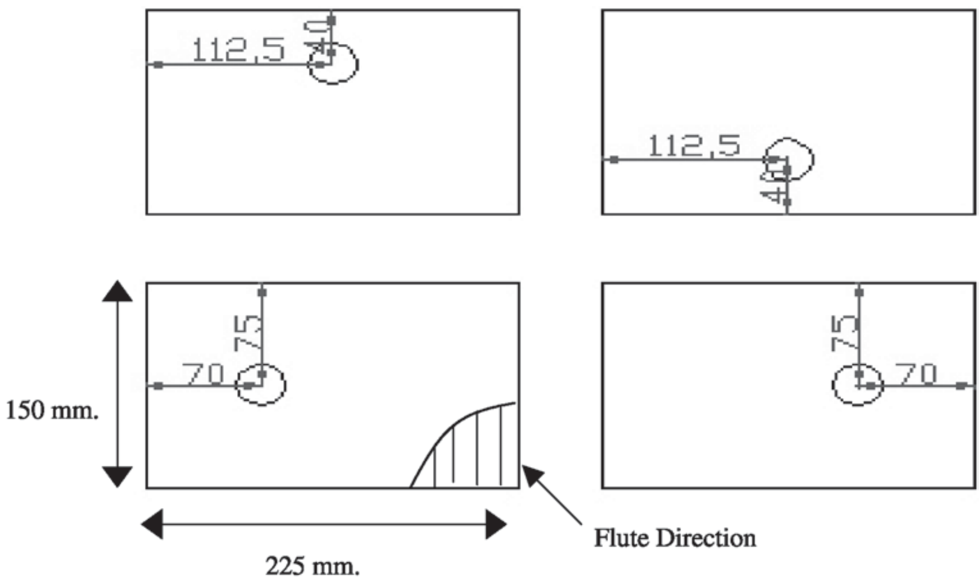


Figure 3 Test samples for different slotting positions.

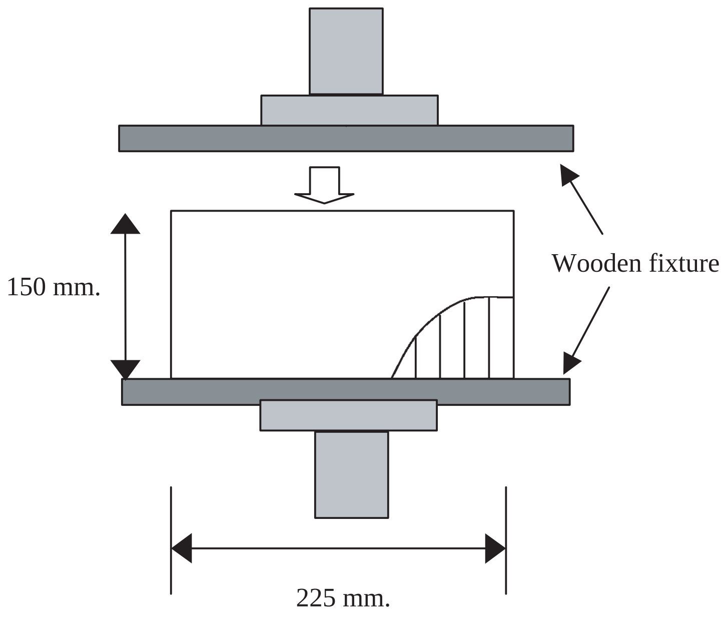


Figure 4 The test configuration.

is due to the reduction of the load baring area of the corrugated board. The result of compression test for a particular slotting shape is displayed in Figure 5. Shapes and sizes of slots significantly effect compressive strength of the corrugated board panels ($p \leq 0.05$). A perforated ellipse shape showed the lowest reduction of compressive strength followed by circle, ellipse (d), and ellipse (a) respectively. For a particular slotting area, more reduction of compressive strength can be observed

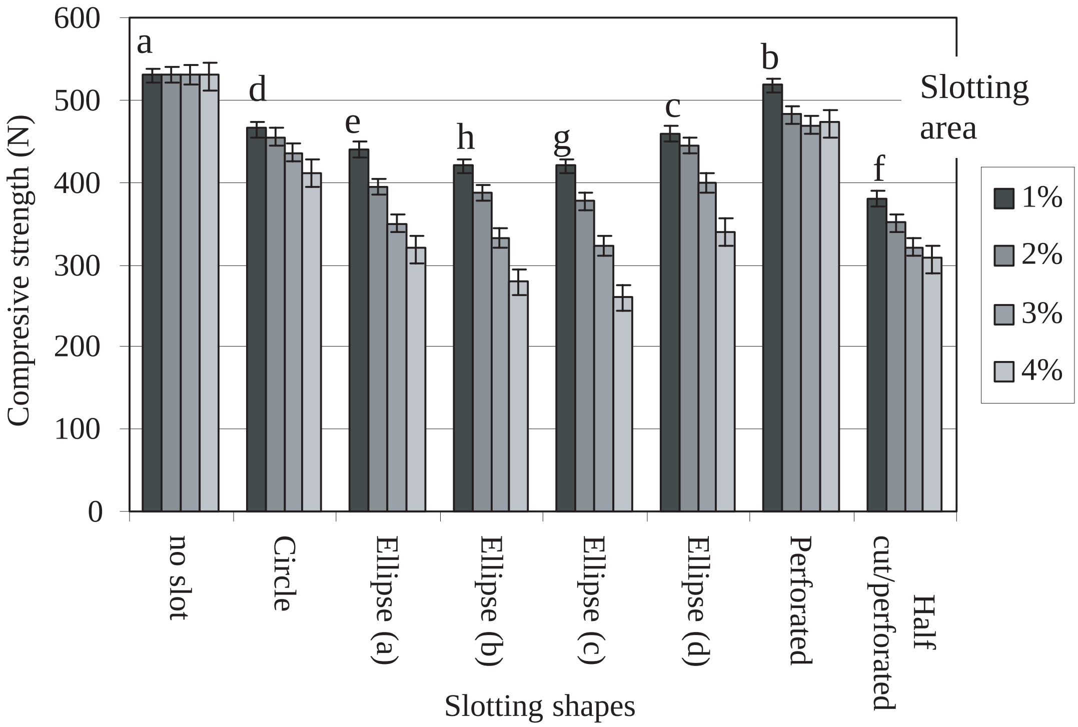


Figure 5 Compressive strength of corrugated board panels with different slot styles. Same letter above the bar of 1% slotting area are not significant different at 0.05 level by Duncan's multiple range test. Same statistical results as 1 % slotting area are observed for 2%, 3% and 4% slotting area. Significant differences are observed at 0.05 level by Duncan's multiple range test for all values of bars in the same group except for no slot group which all values of bar are not significant different.

for a half cut haft perforated ellipse, ellipse (b), and ellipse(c). Since perforated style is not a completely cut slot, thus, the board panel can withstand more compressive load compared to other cut slots. Half cut half perforated ellipse slot style shows more reduction of compressive strength than the perforated ellipse style. For half cut half perforated ellipse slot style, the corrugated flutes were completely cut at the lower half of the ellipse shape; therefore, the compressive strength of the corrugated board could not be maintained compared to the perforated style. Comparing among the ellipse styles, ellipse (d) showed the lowest reduction in compressive strength. During the compression test, columns of corrugated flutes helped sustain the compressive load. For ellipse (d) fewer flute columns were cut across the corrugated board panel compared to other ellipse styles of equal slotting area. As a result, ellipses (a) as well as other ellipse slotting styles showed more reduction in compressive strength than did the ellipse (d). For each slotting shape, compressive strength is significantly reduced when the slotting area was increased ($p \leq 0.05$). This result confirms the study of Kutt and Mithel (1969) which indicated that compressive strength was decreased extensively when the baring area of boxes was reduced.

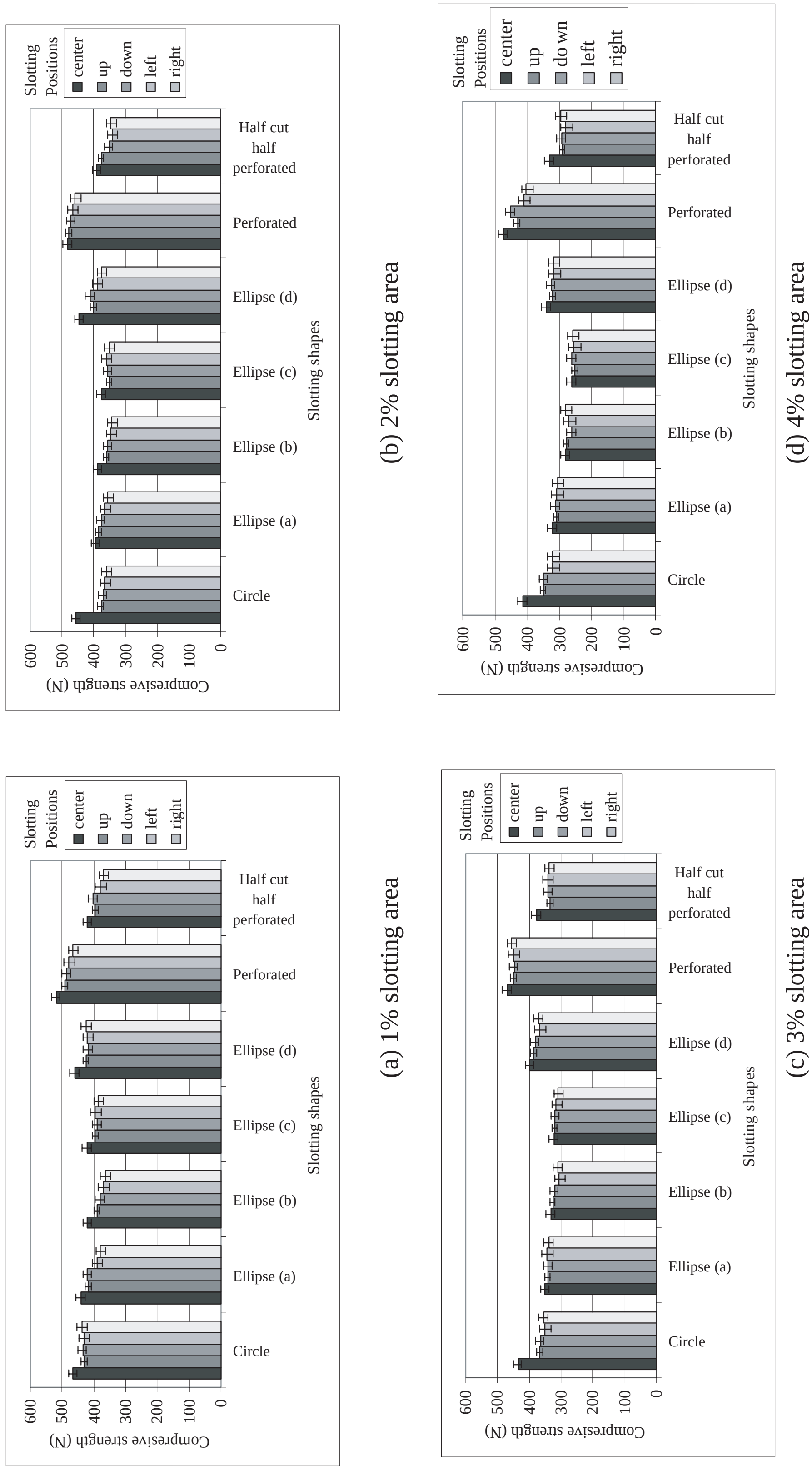


Figure 6 Compressive strength of corrugated board panels at different slotting positions.

Slotting positions and loss of compressive strength

The position of slots significantly affects the compressive strength ($p \leq 0.05$). All slotting shapes cut at the center of the corrugated board panel show less reduction in compressive strength compared to other cutting positions moved up, down, left, or right of the center of the panel (Figure 6). Moreover, slotting at the up and down positions seems to show slightly better compression performance compared with the left and right positions. According to the results, unbalanced load baring area on the left and the right side of the corrugated board panel might induce more reduction in compressive strength. However, more studies are needed to investigate this phenomenon in order to better confirm the results. For all test samples, regardless of shapes, sizes, and positions, fail area after subjected to the compression test was located across the board at the same position as the slot.

CONCLUSION

Shapes and sizes of the slots significantly affect compressive strength of corrugated board panel ($P<0.05$). Perforated style shows less reduction of compressive strength compared to other true cut slots of all shapes. Among various shapes, circles were found to show the lowest reduction in compressive strength. In addition, the slot position located closer to the center of the corrugated board panel cause less reduction of compressive strength.

Since more cutting area indicates more loss of compressive strength, thus, slotting area should be minimized as much as possible in order to maintain compression properties of the board. Reduction of compressive strength as a result of slotting found in this research can be applied with various established formulas to predict the overall box compressive strength. However, more research is required to further explore more complex configurations such as corrugated boards with multiple slotting patterns at different positions or stacking performance of slotted corrugated containers.

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