

Analysis of mechanical properties of vented corrugated container for fresh horticultural produce by finite element method

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Abstract

Corrugated containers are used to transport horticultural fresh produce through the cold chain environment that requires these boxes to have venting to maintain an air flow channel between the surroundings and the inside of the containers. Ventilated packages should be designed in such a way that they can provide a uniform airflow distribution and consequently uniform produce cooling. Total opening area and opening size and position show significant effect on pressure drop, air distribution uniformity and cooling efficiency. The presence of ventilation holes causes a loss of material in the box. As a result the compression strength required for shipping and stacking is compromised and can result in damage to contents. Strength of corrugated board containers is crucial for preserving the content, while an optimization of corrugated board containers is essential to save money and resources. Vibration and shocks acting on pallets during transportation are transferred to the corrugated boxes and considerably reduce the integrity and life time of the boxes.

This study was initiated to understand the loss in mechanical behaviour of corrugated containers as a function of size, shape and location of ventilation holes used for extending shelf life for fresh produce with good air flow. Model was used to study the effect of total opening area and opening size and position on mechanical properties. The von-Mises stress increased with ventilated opening. It also introduces the methodology of a packaging design project and discusses results of its application for design and optimization of packages, based on finite element model (FEM). The scope of this study focuses on presenting alternative corrugated packaging designs considering the proper ventilation for fresh produce industry.

Keywords: FEM, Compression, Vents, Horticultural produce, Corrugated container

1. Introduction

Global marketing of fresh produce widely adopts the ventilated packaging; one of the most important technological innovations with a minimal amount of internal packaging material to promote rapid, uniform and efficient cooling process of horticultural produce (Castro et al., 2005; Thompson et al., 2010). Ventilation holes in the container maintain an air flow channel between the surroundings and the inside of the containers. This results in reinforcement of the preservation function of the containers (Han and Park, 2007). Vents also allow the heat built up by respiration to escape. Ventilated packages should be designed in such a way that they can provide a uniform airflow distribution and consequently uniform produce cooling (Pathare et al. 2012). The package must have enough openings to provide uniform airflow through the entire mass of produce while providing suitable mechanical resistance (Castro (de) et al., 2004a; Vigneault and Goyette, 2002; Vigneault and Castro (de), 2005). A proper package vent design must include not only the total vent area (Brosnan and Sun, 2001; Castro (de) et al., 2004b; Smale et al., 2003; Stanley, 1989), but also the size and the position of each individual opening to enhance the efficiency of forced air precooling system

while still offering an adequate mechanical support for the produce (Émond & Vigneault, 1998).

The types of packaging used to package fresh horticultural produce are wood crates, corrugated shipping cartons polymeric films pouches, bags, baskets, crates, and trays; paper sheets, pouches, etc (Pascall, 2010). Corrugated board is manufactured in many different styles and weights. Because of its relatively low cost and versatility, it is the dominant produce container material and will probably remain so in the near future. Boxes have to withstand significant compression loading conditions during carriage and storage. In order to evaluate their structural performance, the box compression test is the most currently performed experiment (Viguié et al., 2011). Therefore, the strength of corrugated board containers is crucial for preserving the content, while an optimization of corrugated board containers is essential to save money and resources (Biancolini and Brutti, 2003).

The vent hole design of most packaging systems is based on a rule of thumb, which is more arbitrary than scientific (Talbot, 1988). Singh et al. (2008) initiated to understand the loss of compression strength in corrugated containers as a function of size, shape and location of ventilation and hand holes. They found a linear relationship between the loss of strength and the total area of the holes made for venting or handling. Recently to model the structural behaviour of corrugated board packages, several finite elements models were developed (Biancolini and Brutti, 2003). FEM is used to buckling analysis of corrugated boxes, box compressive strength and the relationship of the critical buckling load. The present study evaluated the effect of different ventilation opening on corrugated container strength by using FEM.

2. Methodology for Finite element analysis of corrugated container

The corrugated container has orthotropic property with very different mechanical properties in each of three principal material orientation directions; through thickness direction (ZD), in plane direction parallel to rolling during processing, referred as machine direction (MD), and in plane direction normal to MD, referred as cross direction (CD). ANSYS 13.0 was used for FEA of corrugated container design. Material properties of the package are model input parameters. Results of the stress analysis by FEA were used to determine the appropriate location and the shapes of the ventilation holes. Corrugated container has dimensions of 410 x 300 x 250mm. The surface area occupied by the ventilations was approximately 2 – 6% of the total surface area of the side faces of the container. A graphical presentation of the FE models without ventilation is of the sample is presented in Figure 1. Boundary and load conditions were determined to simulate the actual box use conditions as closely as possible. To simulate the top-to-bottom compression situation and obtain better simulation results for the side panels of the box structure, a constant displacement of 4% of the depth of the box structure, e.g. 10mm for 250mm depth, was applied to the top edges of the structure.

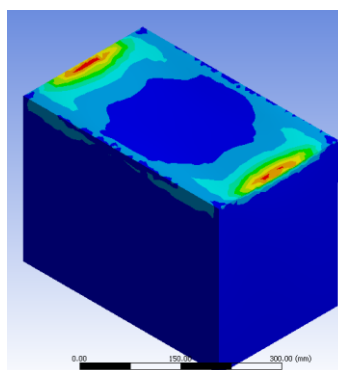


FIGURE1: Stress distribution of corrugated container.

3. Simulation results

The stress on the corrugated container with ventilation openings (#1 – 2%, #2 – 4%, #3 – 5% and #4 – 6%) was analysed as explained in Figure 2. Maximum stress was produced at the top corners of the boxes and the diagonal lines connecting the corners generally represented stress concentration. The ventilated opening demonstrated the maximum stress of 24.34, 24.43, 24.83 and 24.96 MPa respectively. Highest ventilated opening (6%) showed the maximum stress. The dependence of maximum stress on the location of with ventilated openings boxes showed the highest compression strength requirement. Top and corners of the ventilated openings of the container also experienced von-Mises stress. The result showed that the container with smaller ventilated openings would experience smaller stress than container having larger opening near top and corners of ventilated openings. The stress was produced at top and towards corner of ventilated opening and the connecting lines represents stress concentration.

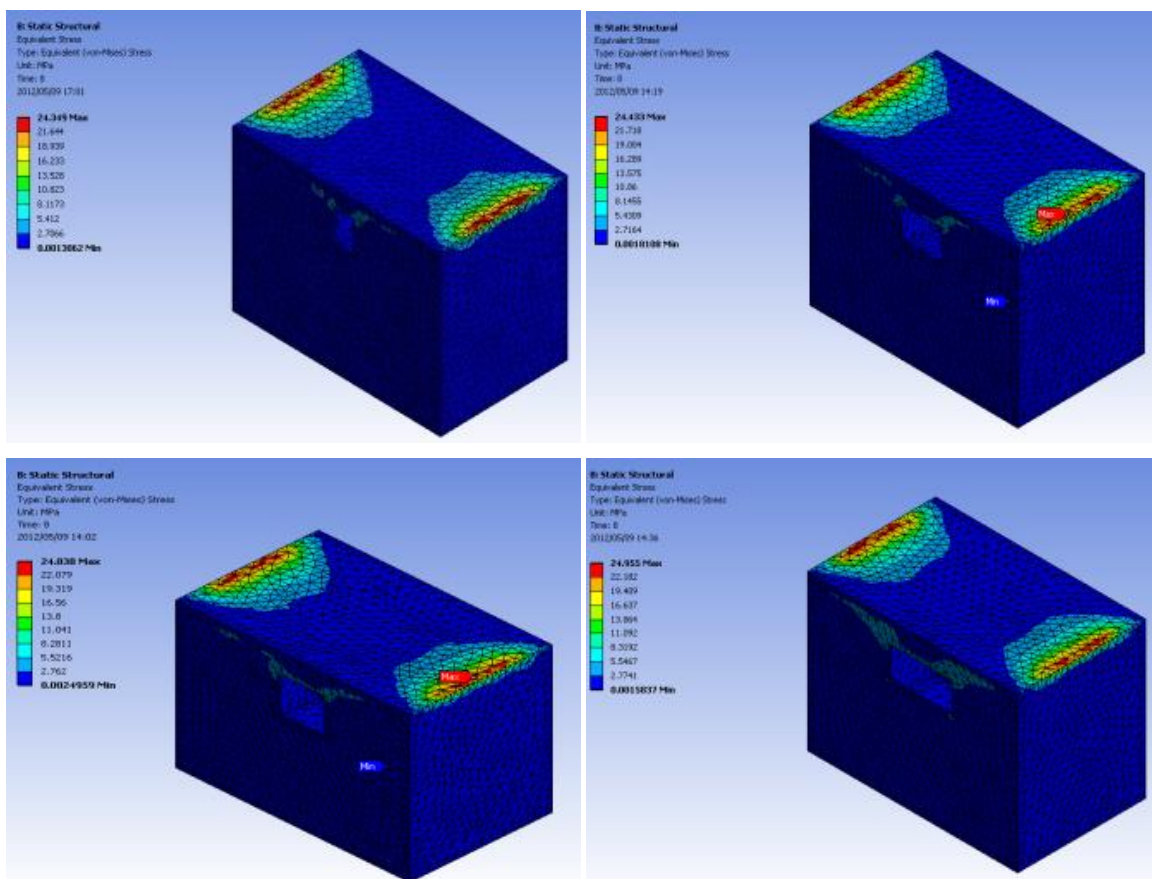


FIGURE 2: FEA models for various ventilated openings (2%, 4%, 5% and 6%).

Figure 3 shows that stress increased with ventilated opening. A linear relationship exists between stress demonstrated and ventilated openings. When ventilated opening increases from 2 % to 4% , the stress increased by 0.09MPa which is lower than 0.53 MPa when ventilated opening increased to 6% from 4%. The container having less ventilated openings is structurally stronger than other cases. Singh et al. (2008) also reported the linear relationship between loss of strength and vent holes for corrugated container. The maximum stress area should be used for appropriate structurally strong corrugated container design.

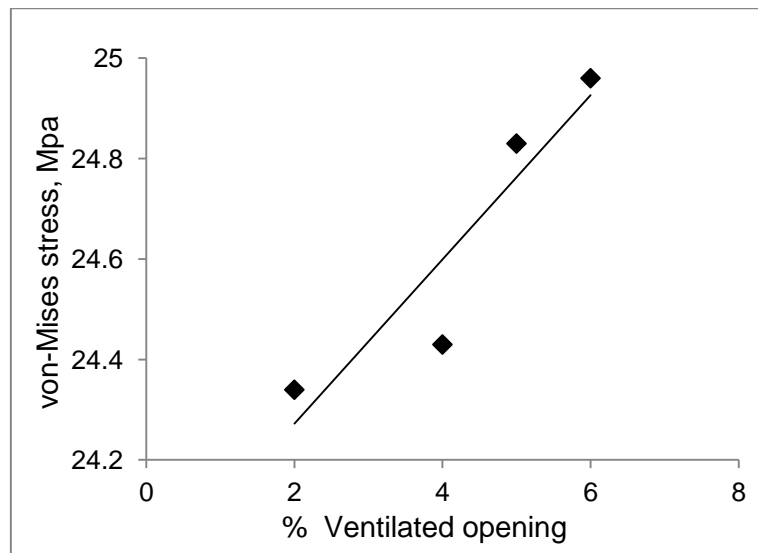


FIGURE 3: Maximum von-Mises stress demonstration due to ventilated opening

4. Conclusion

Finite element analysis method is fast and efficient, cost-saving calculations visually, designers will be able to grasp the performance parameters in the product development stage. Know the constitutive relation of the corrugated material; we can easily build models of different structural shapes, further analysis of the compressive strength of the carton height, aspect ratio, number of openings, size, shape, location, relationship, and so on. Improve the modelling accuracy, reasonable boundary conditions, and precise determination of the raw material constitutive relations; we can further improve the computational accuracy. Linear relationship found between the stress and ventilated opening of corrugated container. For future studies laboratory compression and drop test performance of corrugated container with different shape and sizes of ventilation opening were analysed using FEM modelling for optimise the container design. Future research efforts should be directed towards the balancing the needs for adequate resistance to mechanical strength and proving optimum ventilation for airflow to maintain the cold chain is a primary challenge in the design and development packaging in the fresh food industry.

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Reference list

- Biancolini M., & Brutti C. (2003). Numerical and experimental investigation of the strength of corrugated board packages. *Packaging technology and science*, 16(2), 47-60.
- Brosnan T., & Sun D. (2001). Precooling techniques and applications for horticultural products - a review. *International Journal of Refrigeration*, 24(2), 154-170.
- Castro (de) L.R., Vigneault C., & Cortez L.A.B. (2004a). Effect of container opening area on air distribution during precooling of horticultural produce. *Transactions of the ASAE*, 47(6), 2033–2038.

- Castro (de) L.R., Vigneault C., & Cortez L. (2004b). Container opening design for horticultural produce cooling efficiency. *Journal of Food, Agriculture and Environment*, 2(1), 135-140.
- Castro (de) LR, Vigneault C & Cortez LAB (2005) Effect of container openings and airflow on energy required for forced air cooling of horticultural produce. *Canadian Biosystems Engineering*, (47)3,1-3.9.
- Émond, J.P., & Vigneault, C. (1998). Reusable container for the preservation of fresh fruits and vegetables. United States Patent No. 5,727,711. Washington, DC: United States Patent Office.
- Han J., & Park J.M. (2007). Finite element analysis of vent/hand hole designs for corrugated fibreboard boxes. *Packaging Technology and Science*, 20(1), 39-47.
- Pathare P.B., Opara U.L., Vigneault C, Delele M. A., & Al-said F A (2012) Design of packaging vents for cooling fresh horticultural produce. *Food and Bioprocess Technology* (In press).
- Pascall M.A. (2010). Packaging for Fresh Vegetables and Vegetable Products. *Handbook of Vegetables and Vegetable Processing*, 405-422.
- Singh J., Olsen E., Singh S., Manley J., & Wallace F. (2008). The effect of ventilation and hand Holes on loss of compression strength in corrugated boxes. *Journal of Applied Packaging Research*, 2(4), 227-238.
- Smale N., Tanner D., Amos N., & Cleland D. (2003). Airflow properties of packaged horticultural produce-a practical study. In *International Conference: Postharvest Unlimited 599*, ISHS.
- Stanley R. (1989). The influence of temperature and packaging material on the post harvest quality of iceberg lettuce. *Acta Hort*, 244, 171-180.
- Talbot M (1988) An approach to better design of pressure-cooled produce containers. In *Proceedings of the Florida State Horticultural Society* 101, 165-175.
- Thompson, J.F., Mejia, D.C., & Singh, R.P (2010). Energy Use of Commercial Forced-Air Coolers for Fruit. *Applied Engineering in Agriculture*, 26(5): 919-924.
- Vigneault C., & Goyette B. (2002). Design of plastic container opening to optimize forced-air precooling of fruits and vegetables. *Applied Engineering in Agriculture*, 18(1), 73-76.
- Vigneault C., & Castro (de) L.R. (2005). Produce-simulator property evaluation for indirect airflow distribution measurement through horticultural crop package. *Journal of Food, Agriculture & Environment*, 3(2), 67-72.
- Viguié J., Dumont P.J.J., Orgéas L., Vacher P., Desloges I., & Mauret E. (2011). Surface stress and strain fields on compressed panels of corrugated board boxes. An experimental analysis by using Digital Image Stereocorrelation. *Composite Structures*, 93(11), 2861-2873.