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Shear Test of Corrugated Board

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Abstract. Mechanical strength in the packaging industry poses a significant challenge for manufacturers, particularly in the case of corrugated cardboard boxes with their various designs and layers. In this context, this study focuses on evaluating the effects of tangential stresses on corrugated cardboard and its components. Using a specialized testing mechanism, controlled tangential forces are applied to cardboard samples, allowing for a deeper understanding of the material's behavior under different conditions. This empirical approach enables the identification of key variables influencing stress distribution and potential yield points in corrugated cardboard material. The findings contribute to the development of more efficient and reliable packaging solutions, thereby supporting the sustainability and economic viability of the packaging industry.
Keywords: *mechanical strength, corrugated cardboard, tangential stresses, stress distribution.*

1. Introduction

In the packaging industry, mechanical strength is a challenge that manufacturers are keen to pursue. This is especially important in the case of corrugated cardboard boxes, with their different designs, layers etc. Even for a simple, single-layer corrugated board design, the question arises as to its mechanical strength as a wall of a box of a conventional geometrical shape (in space). Even if the load is assumed to be uni-axial on this box (packaging), due to the position of the walls in relation to this load, they will be stressed in different directions. Furthermore, it is very important that in this complex state of stress of a carton wall of the packaging, we also take into account the effects that are additionally created, such as torsional stress. In all this complex stress, the transverse stress is also taken into account, as can be seen in the model in Fig.1.[1]

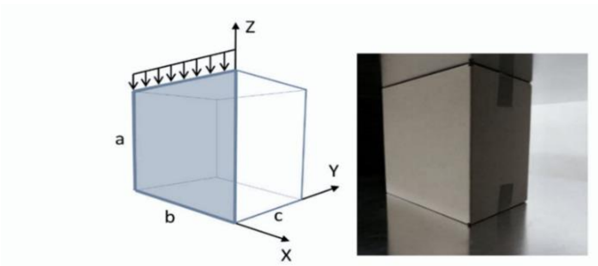

Fig.1 Model of cardboard package under load
(After Garbowski T., Gajewski T., Grabski J.K., The Role of Buckling in the Estimation of Compressive Strength of Corrugated Cardboard Boxes, *Materials* 2020, *13*(20), 4578; https://doi.org/10.3390/ma13204578, 1-15. [1])

There have been numerous studies on the transverse stress behavior of corrugated box walls. The most common case is the study of the behavior of a box wall under compressive stress of the box. Under the compressive load the box walls will deform out of the plane (of the initial position in the absence of stress), and different stress effects will also occur even within the sandwich structure of the wall. Thus, the outer parts of the wall, the liners, will move relative to each other and thus a shearing situation of the corrugated board occurs. The effect of this stress, the deformation of the wall structure, is directly related to the transverse shear stiffness of this complex structure. However, this stress cannot be measured in the usual way by standardized tests, as is the case with tests measuring compressive or bending stiffness. But the effects of this type of stress are still very important. Popil and others [2] show the following:
"A typical 10 % loss of caliper from board crushing which arises from the press feed roll results in a 20% reduction in flexural rigidity and a corresponding 65% loss in transverse shear rigidity. A loss in shear rigidity of this magnitude will affect the stacking strength more so than predicted from only the combined loss of flexural rigidity or caliper and ECT" [2] (R.Popil, D.W.Coffin, C.C.Haberger, Transverse shear measurement for corrugated board and its significance, July 2008, *Appita Journal* 61(4):307-312)
Another important problem that arises in studies of the behavior of corrugated structure is that of the realization of the bonding of the component parts of the corrugated structure, i.e. the liner (bottom and top) and the central part of this sandwich, the flutter, the corrugation. The lamination is made by gluing and damage to the lamination can be achieved in two ways: by peeling off the glue or by delaminating the paper component.[3]
Another noteworthy study by N. Talbi, A. Batti, R. Ayad, and Y.Q. Guo delved into the behavior of corrugated cardboard under translation forces and torsional moments. They meticulously analyzed both laminate and sandwich plate theories, proposing significant enhancements. Subsequently, their developed model was integrated into a 3-node shell element for linear and buckling analyses. The outcomes were then juxtaposed against 3D simulations and experiments, showcasing the effectiveness and precision of the homogenization model.[4]. Another work related to corrugated cardboard structure is that of T. Pereira and colleagues. Their study focuses on analyzing and improving the production process in an industrial company, employing methods such as the PDCA cycle. Their results demonstrate a significant reduction in waste and starch glue consumption, bringing considerable benefits in process efficiency and quality.[5]

2. The model

In this paper the authors have focused on the study of the effects of tangential stresses for a simplified model, in which the buckling effect is not taken into account. The model is shown in Fig.2
Over the years, several types of tests have been used to obtain compartmental parameters. Typically, X and Y represent the material directions in the plane of the paper component and Z represents the thickness direction. Therefore, when talking about out-of-plane components, we must first determine the principal stresses and the relationship between specific strains and these stresses.

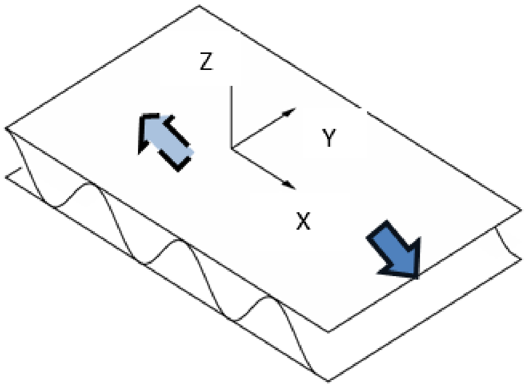

Fig.2 Shear stress model of single-wave corrugated board

The specific stress-strain relationship is:

$$\begin{Bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\\ \tau_{23}\\ \tau_{31}\end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & 0 & 0 & 0\\ D_{21} & D_{22} & 0 & 0 & 0\\ 0 & 0 & D_{66} & 0 & 0\\ 0 & 0 & 0 & D_{44} & 0\\ 0 & 0 & 0 & 0 & D_{55}\end{bmatrix}\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\\ \gamma_{23}\\ \gamma_{31}\end{Bmatrix} \qquad (1)$$

where

$$D_{11} = \frac{E_1}{1-\nu_{21}\nu_{12}} \qquad D_{12} = \frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}}$$
$$D_{21} = \frac{\nu_{12}E_1}{1-\nu_{21}\nu_{12}} \qquad D_{22} = \frac{E_2}{1-\nu_{21}\nu_{12}}$$
$$D_{66} = G_{12}$$
$$D_{44} = G_{23}$$
$$D_{55} = G_{13}$$
$$(2)$$

and, important,

$$D_{66} = \frac{1}{2} G_{xy}\, th^2$$

where G_{xy} is the in-plane shear stiffness of the liners, t is the thickness of the liner, and h is the thickness of the board.

The relation of D_{66} can be interpreted as a simplification in which only the dominant term is retained in the behaviour expression of the complex structure with liner and fluting, the contribution of the fluting, sandwich interior being considered negligible.

3. The experiment

The research presented in the paper focuses the development and validation of a testing mechanism designed to measure tangential/shear stresses, providing a detailed understanding of the material's performance under real-world conditions for corrugated cardboard boxes. In the context of this scientific research, the sample of the test is shown in Fig.3. Standard cardboard specimens are 70x20x3 mm dimensions.

In order to carry out the test to highlight the state of tangential stresses in the outer parts of the corrugated board, i.e. in the liner, and to be able to accurately process complex stress patterns, a specialized clamping mechanism was designed to exert controlled tangential forces on the board. This fixture, coupled with a data acquisition system, is represented by the CETR-UMT 2 microtribometer, which is part of the Tribology Laboratory in the Department of Machine Elements and Tribology, and allows the detection and analysis of stress distribution and deformation behavior under various simulated conditions.

The methodology facilitates an investigation of the relationship between the geometry of the corrugated structure and its stress responses, thus revealing the mechanical properties and resistance of the material to tangential forces. During the test, the lower plate of the system moves along the X-axis at a constant velocity of 0.50 mm/s, while the upper assembly exerts a perpendicular force, hence in the Z-direction, constant. In Fig.4 is presented the set-up of the sample.

The force applied on the specimen is F=(10:100) N. This set-up allows the precise determination and recording of the tangential stresses to which the CO3 corrugated cardboard specimen is subjected. Through these experimental procedures, the research identifies the key variables influencing the stress distribution and potential yield points in the paperboard material. Insights gained from the empirical data allow a deeper understanding of the mechanical properties of corrugated board. The aim of this study is to investigate the identification of more efficient and reliable packaging solutions. In conclusion, this study's approach to quantifying tangential stresses in corrugated board can be used to evolve the technical design of packaging materials. By improving the reliability of carboard boxes, this research not only increases logistical efficiency, but also significantly reduces the risk of product damage during transport, ultimately supporting the sustainability and economic viability of the packaging sector.

In Fig.5 is shown the test by the CETR-UMT 2 microtribometer.

Fig.3. The sample of carboard CO3

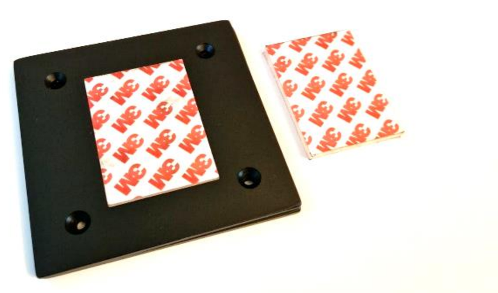

Fig.4. The set-up of the sample.
Mounting the glued sample

The test was performed for various normal and tangential loads. Five tests were performed, and the results are shown in Fig.6. First of all,

it is observed that the tangential force tends to increase in a first step, which is due to the material elasticity of the composite material made of linners and flutting. Then, when a depletion of the elasticity resource is yield strength increases and the deformation, due to the decrease of the force amount, will also decrease

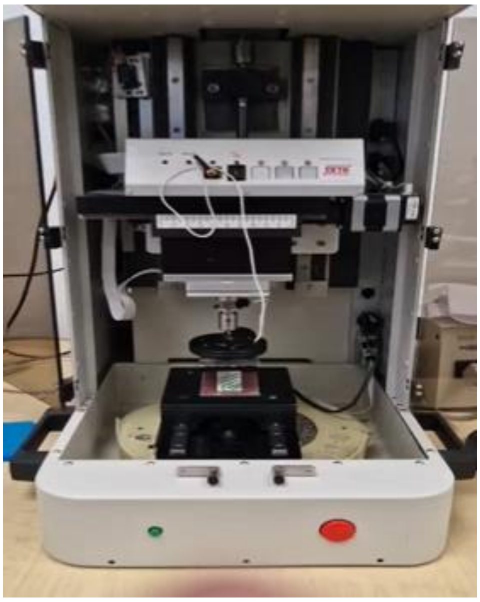

Fig.5 The CETR-UMT2 set-up

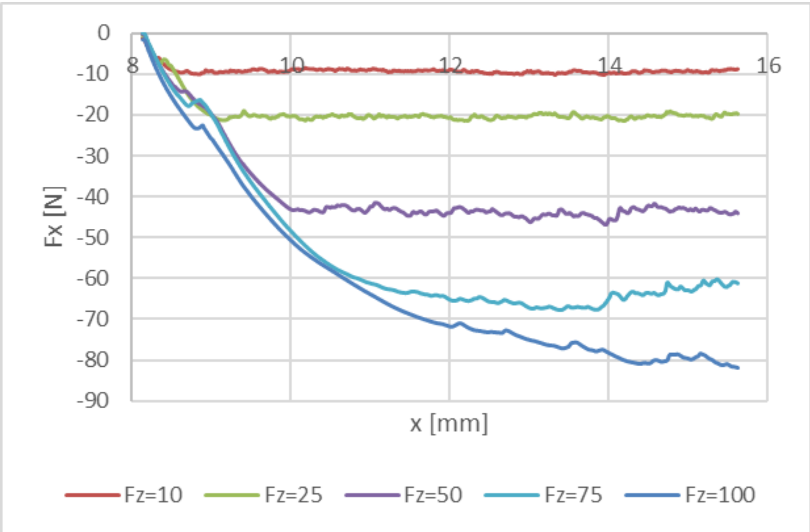

Fig.6 Test results

4. Conclusion

As a general conclusion Liners, Fluting and mechanical properties have been analyzed since they are considered in adhesive join. A more in-depth experimental study is needed to confirm the comportment of the structure, especially concerning the hypoelasticity of the structure.

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