Determination of material and structural properties of corrugated board in manufacturing and processing

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Abstract

Corrugated cardboard is a material commonly used in packaging for various types of products. Nowadays, a lot of products are transported in such packaging directly to customers, bypassing the store display. This makes the optimization of the packaging design, but also the composition of corrugated board itself, a key issue for companies producing corrugated cardboard packaging.

Corrugated board as a material is difficult to reliably model because its properties largely depend on environmental conditions (temperature and relative humidity) [1], and also because, to a large extent, the final load-bearing capacity depends on the production process [2]. Although the production parameters can be set and controlled very precisely, in general, their direct impact on the load-bearing capacity is not known. Manufacturing processes, such as cutting or printing, can significantly reduce the load-bearing capacity of the board and result in properties that are actually lower than the intended product specification. Therefore, in the long term, the current research is aimed at building a procedure that will enable the determination of the properties of cardboard on the basis of its composition, i.e. the geometry of the layers (paper thicknesses and shape of the wavy layers) and the mechanical parameters of the papers, as well as the production processes it has undergone.

In this paper, we present several issues that have to be tackled toward the achievement of the above aim. The first is to verify the accuracy of simplified cardboard modeling using effective shell model, which is required to efficiently model the corrugated board, instead of full three-dimensional modelling, which is very costly. In the reduced approach, the Finite Element Method (FEM) and numerical homogenization [3,4] were used, which made it possible to significantly limit the number of FEM unknowns, compared to a full three-dimensional model of corrugated cardboard. During the verification, four mechanical tests of corrugated cardboard were considered, for comparison of the results (simplified model vs. three-dimensional model): 4-point bending, edge crush, shear and torsion test. Three different papers were used for testing, on the basis of which 27 different cardboards were created. The average errors between the simplified and full models ranged from 0.8% to 6.6% for all boards.

The second issue is to create an Artificial Neural Network (ANN) that will enable the calculation of effective material parameters of corrugated cardboard based on the geometry of the layers and the mechanical parameters of the papers. For this purpose, 24 paper parameter sets (e.g. grammage, paper thickness, short-span compression strengths, and tension strengths) were used as inputs to the ANN, and 8 effective mechanical cardboard parameters were used as outputs. ANN cases were generated using 18 different papers, resulting in 5832 cases of cardboard. This database was divided into 4957 training cases and 875 testing cases. Finally, the dataset showed very good agreement, i.e. the root mean square error was smaller than 0.005 (0.5%) for testing cases for each effective material parameter of the homogenized board.

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