

Design of Different Types of Corrugated Board Packages Using Finite Element Tools

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Abstract: From a structural point of view, corrugated board would fit on the category of sandwich structures, which in sectors as aeronautics or construction are today commonly analysed using simulation tools that are based on the Finite Element Method. However, in spite of similarities to applications in other materials, FEM simulation of corrugated board is a high challenging modelling task due not only to the need of addressing properly the complex mechanical modelling of paper itself, but also because of phenomena that are directly related to the corrugated structure, as the relationships between local and global instability failure modes. The present paper, through a set of application examples, shows how different Abaqus modelling capabilities (SC8R elements, composite sections, connector elements, ...) can be applied for solving the different difficulties that arise when modelling corrugated board. The integration of these capabilities has led to the development of virtual prototypes for the two most common corrugated board packages: B1 boxes and agricultural trays. From the experience in these box types, and taking advantage from the inherent modelling simplicity of the composite layered models together to the flexibility offered by the available modelling techniques in Abaqus, these virtual prototypes have been extended as a design tool for very different types of corrugated board packages.

Keywords: Corrugated Board, Packaging, Box Compression,

1. Introduction

FE-based simulation has been increasingly used in the last decades as the main structural analysis tool in many different industrial sectors and, in combination with other numerical techniques and tools as CFD, has been also the main basis for the more recent concept of “virtual prototypes” replacing manufacturing and testing of physical components. Starting in the past from civil engineering, aeronautics and automotive industry, present applications of finite element simulation extend to any industry sector as electronics, medical equipment, packaging, and more specifically corrugated board packaging. In general terms, compression strength can be considered as the most important requirement of a package, or at least the one that is common to all package types, as during transport and storage, any box has to support without damage the weight of the rest of the supported boxes; thus, initially, corrugated board industry has considered FEM as a possible

tool for replacing the traditional application of semi-empirical expressions (Mc Kee et al. 1963) looking for both, improved accuracy in the prediction of box compression strength using numerical simulation of the package (Gilchrist et al. 1999, Rahman 1997, Urbanik et al. 2003, Biancolini et al. 2003), and extending the analysis to package types as different as possible.

The introduction process of FE in corrugated board industry has been slower than in other sectors, probably because of the very complex mechanical behaviour of both, paper itself and corrugated board, leading to models that require very specific material models or advanced FE techniques. However, and in spite of the slow start-up, applications of FEM to corrugated board industry are rapidly growing, somehow taking advantage of previous developments in advanced modelling of composites and composite sandwich structures, with relevant similarities to corrugated board. The present paper summarises the general aspects of the simulation methodology that the authors are applying for the structural analysis and design of corrugated board packages. The objective of the paper is to provide a general description of the practical capabilities of the developed simulation methodology, showing how Abaqus can be applied in the development process of corrugated board packages, but without entering into detailed descriptions of a given finite element model or simulation, nor presenting geometry and paper composition details of analysed packages.

2. GENERAL METHODOLOGY FOR FINITE ELEMENT SIMULATION OF CORRUGATED BOARD

2.1 Modelling the mechanical behaviour of paper

Resulting from the manufacturing process, paper is an orthotropic material with very different mechanical properties in each of the three principal material orientation directions (Baum et al. 1981): through thickness direction (ZD), in-plane direction parallel to rolling during processing, referred as machine direction (MD), and the in-plane direction normal to MD, referred as cross direction (CD). Apart from orthotropy, paper behaviour exhibits two additional characteristics that prevent from application of simple materials models: a) highly non linear behaviour, b) large differences between tensile and compressive responses in any of both, MD and CD. Figure 1 shows the characteristic shape of the stress-strain curves in MD and CD.

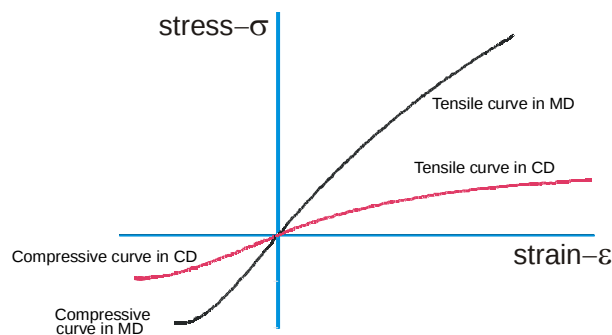


Figure 1. Characteristic stress-strain curves of paper in machine direction (MD) and cross direction (CD).

Of course, paper behaviour exhibits additional characteristics that increase additionally the level of complexity of modelling, as exhibiting significant creep, humidity dependence of mechanical properties, higroexpansion, ... In any case, it is important to remark that orthotropy, non-linearity and differences tension-compression play all an important role even in the simple case of BCT testing of a package under controlled room conditions, and because of this, mechanical modelling of paper, even for the simpler loading cases always rely on the availability of a user developed material model implementing as many as possible from the three referred characteristics plus specific features for handling other property dependences if required by specific application (Xia et al. 2002, Isaksson et al. 2004, Mäkela et al. 2003, Alfthan et al. 2005). In the examples that are next presented, an in-plane orthotropic damage model with different treatment of tension and compression and including definition of final paper failure according to the Tsai-Wu criterion (Tryding, 1994) has been applied for modelling the static response of paper in the short-term using shell elements; the model has been implemented through UMAT and VUMAT user subroutines, only shell element versions, in Abaqus/Standard and Abaqus/Explicit, while the required transverse shear stiffness values for the shells are calculated using the out-of-plane shear elastic moduli from the constituent papers. The model has been validated at paper level through validation from ECT (edge crush test) and FCT (flat crust test) experimental results (Jiménez et al. 2003, Bielsa et al. 2006).

Figure 2 summarises as example the validation of the paper material model by simulating in Abaqus/Explicit a FCT test of a single flute board by means of a single wave model in which symmetry boundary conditions are applied in all the edges given the large dimensions of the FCT sample (100 mm x 25 mm) when compared to the single wave. Results show how three experimental load peaks can be identified along the test with deviations around to 10%. As already expected when designing these validation tests, the differences in displacement prediction are higher because of different reasons, including among these the simplifications in the modelling of the adhesive and of the out-of-plane behaviour of the paper

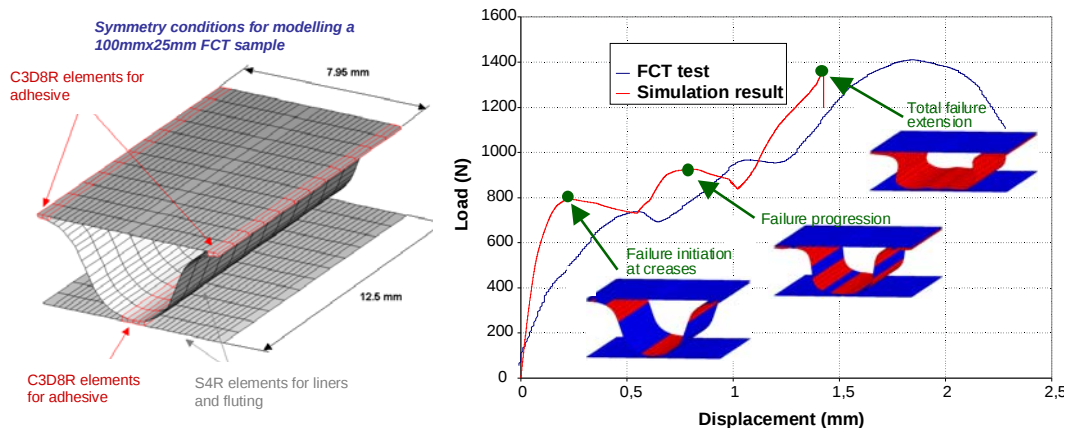


Figure 2. Comparison of simulation and experimental results for FCT simulation of single flute paperboard.

As it will be presented in forthcoming parts of the paper, carrying trays for agricultural products present, in addition to BCT qualification, another key requirement in terms of the so called “bottom sag” under sustained load or creep. This requirement is established in terms of displacement instead of strength, as the limit structural condition is determined by the possibility of the bottom of a given tray touching and damaging the fruits or vegetables that are packaged in the box underneath. In order to cover creep, the material model of paper has been modified for considering viscoelastic strains under sustained loads. The selected model is based on Coffin equation for paper creep (Coffin, 2005) that considers potential and logarithmic behaviour (see equation 1) and fulfils the needed conditions leading to the possibility of creating master curves for paper through a logarithmic time shift in stress values (Brezinski, 1956). Coffin equation for the creep modulus, J , is shown in Equation 1.

$$J = \frac{\varepsilon(t)}{\sigma_0} = \frac{1}{E} \left[1 + A(1 - e^{-at^\alpha}) + B \ln(bt + 1) \right] \quad 1$$

The first term represents primary creep, which is considered a delayed response where A is the inverse of elastic modulus of the delayed response, a is a time scale factor and α is the exponent of the potential behaviour observed for short times. The second term represents secondary creep and is based on Brezinski’s observation that long term creep is a lineal function of logarithm of time. B is a creep flow parameter and b is a time scale factor. Figure 3 shows results from simulation of patch tests with a single shell for tensile creep at different percentage of tensile failure stress, together to results of the experimental creep tests that were used for determining the parameters of the corresponding creep equation; results correspond to a recycled paper to be used as linerboard.

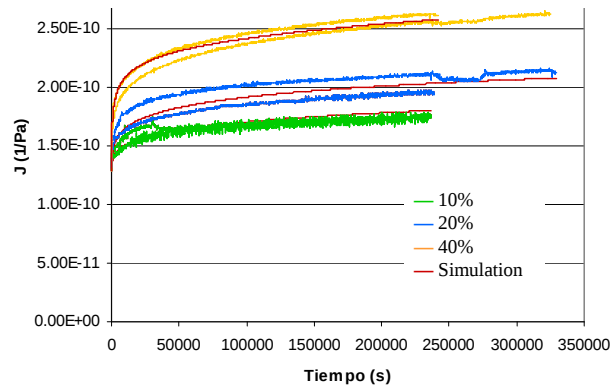


Figure 3. Results of creep characterisation of a sample paper and validation of user creep model for paper through tensile patch test

The modelling methodology that is proposed by the authors for BCT simulations and analysis of box bottom sag (including creep) is based on Abaqus/Standard simulations, mainly because of higher computational efficiency for most of the analysed cases. In any case, during the initial stages of the methodology development, Abaqus/Explicit was also used from time to time for very specific simulations, as an easier way to extend analysis beyond specific instabilities as those in the FCT example that has been previously presented (Figure 2).

2.2 Simplified laminated composite models

Modelling of the corrugated structure using 3D shells for liners and fluting, as in the example shown in Figure 4, is not realistic when thinking of virtual prototyping for efficient material selection or analysis of geometry variations. Efficiency problems of 3D shell-based modelling of corrugated shape are not only related to computation times for the whole package but also to modelling details of complex package areas as corners and flaps; in addition, it must be noticed that strength analysis of paperboard requires non-linear FEM analysis due to the importance of instabilities, so requiring some computational effort. Thus, detailed FEM models of corrugated board structures, like the ones that are shown in Figure 4, are useful for estimating some corrugated board properties that are difficult to be measured experimentally, but are not yet realistic for the modelling and simulation of the whole package when thinking of a large variety of package types. It is important to remark here that simulation difficulties are not only related to computational effort but also to the complexity of geometrical modelling.

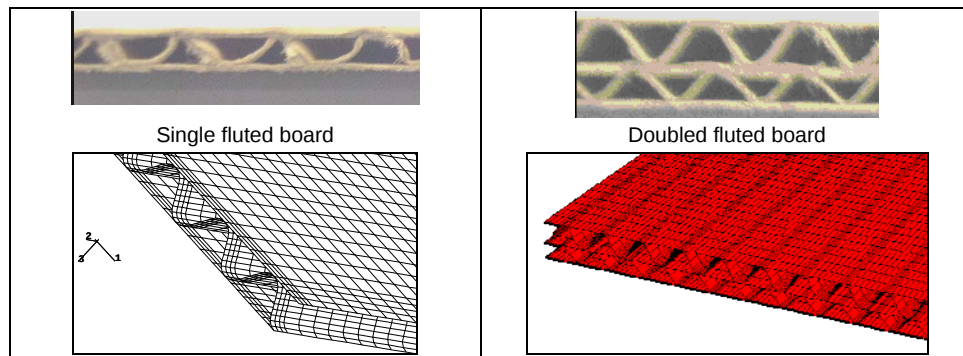


Figure 4. Pictures of single flute and double flute corrugated board and corresponding 3D-shells models with detailed flute geometry

For modelling purposes, corrugated board can be simplified to a laminated structure with alternative “thin” layers of non-corrugated liners, and “thick” layer consisting of a corrugated paper flute. Hence, corrugated board is defined structurally as a sandwich structure with a non-continuous core, like other well-known sandwich structures as composite sandwich panels with honeycomb cores. Thus, a first step for simulation is translating the actual corrugated core geometry to a set of equivalent mechanical properties to be associated to a continuum core, therefore allowing simulation through any of the different techniques that are used for sandwich structures (with technique selection depending mainly on sandwich thickness): layered solids, layered thick shells, layered continuum shells, or combinations of previous approaches. Several methods can be found in literature for minimising the errors in the in-plane and flexural behaviours that are related to the simplifications for establishing the equivalent flue properties (Luo et al. 1992), as well as for estimating transverse shear equivalent properties (Nordstrand et al. 1997) for the equivalent structure. In the examples in this paper, estimation of transverse shear stiffness is performed from simulations of detailed corrugated geometry models as in Figure 4, as modelling of a flat panel for determination of equivalent properties is easy to be parameterised and automated, even if not suitable for the modelling of the final package.

Once an equivalent material for a continuous core is considered, the most cost-effective element type for corrugated board is usually a S4R thick-shell with proper accounting for transverse shear stiffness. Of course, other approaches exist for modelling corrugated board, as using solid elements for the core or using layered solid elements (C38R for instance) instead of layered shells, but some modelling issues, as keeping suitable aspect ratios in the solid elements or reaching to the required number of through thickness solids for proper accounting of transverse shear, require usually quite large computational models. However, as it is later presented when discussing bottom sag, such approaches are sometimes required to improve modelling results.

Next, Figure 5 shows an example of the CD stresses in a liner for a non-linear buckling analysis of a corrugated board panel. Results on the left correspond to a detailed FE model with modelling of flute geometry using S4R elements, while results on the right have been obtained from a simplified composite shell model, using a single layer of S4R with a *COMPOSITE section definition, using equivalent core properties. It is required to remark that detailed modelling of the corrugated medium implies some restriction for the mesh size in the liners, so in the example of Figure 5 it is also interesting to note the much coarser mesh size while maintaining the significant stress values (compressive ones) below a 6% difference with regard to the detailed model, which is a quite low value considering non-linear buckling analysis.

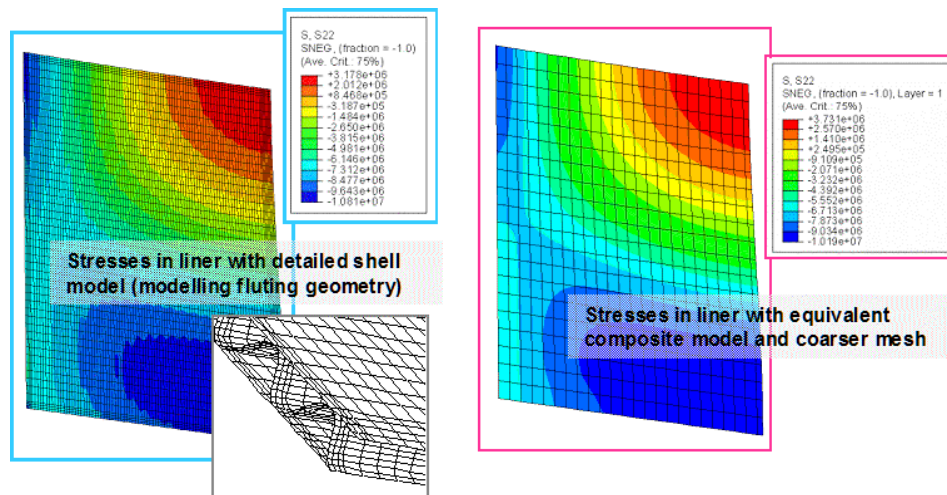


Figure 5. Comparison of CD stresses between detailed model including corrugated flute geometry and equivalent composite model.

In spite of its simplicity, the application of simplified composite models gives rise to an added problem when thinking of failure prediction: a detailed model with flute geometry, as the one in the left part of Figure 5, could be directly applied for prediction of local instabilities in the case that the mesh size is properly selected (see Figure 6), but analysis of local buckling in a simplified model without considering corrugation shape is not so simple.

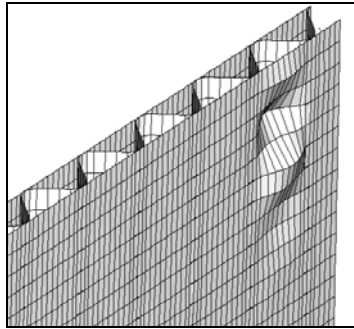


Figure 6. Detailed FE model for local buckling prediction.

As already mentioned, the Tsai-Wu failure criterion is possibly the most usual for paper strength analysis. Nevertheless, when paper is used as part of corrugated paperboard, the failure criterion has to take into account also local buckling as a possible failure mode for the liners, at loads significantly lower than those for strength failure. The alternative way for considering local buckling in simplified models that is followed by the authors consists of combining the Tsai-Wu strength criterion with an additional criterion related to local instability. This approach requires for each different corrugated board specific determination of such instability criterion either by analytical or numerical tools (Nyamn et al 1999, Biancolini et al. 2003), as this depends on the specific geometry of the supporting corrugation wave. The development and validation of the proposed simulation methodology has been supported by a large experimental program, not only at package level, but also in previous development stages through in-plane compression tests of rectangular corrugated boards using lateral supports for preventing global buckling at low loads.

2.3 Selection of element type

As already mentioned, equivalent composite models are not limited to layered shells but can include combinations of different elements, as for instance, shells for liners with solids for the core, or even layered solid without shells. Like in any FE simulation, the selection of the right element is critical. As an example of the relevance of element selection, a numerical and experimental study for the selection of the most adequate element type for modelling bending in corrugated board panels was carried by the authors (Jiménez et al. 2004). Bottom sag analysis of box bottom requires simulation of bending, and therefore, transverse shear stiffness may play an important role. Not all the element types that can be used for modelling an equivalent laminate consider transverse shear behaviour with the same accuracy, neither all of them are able to take into account possible thinning of corrugated board. The results of the study indicated that a very simple model of composite linear thick shells with reduced integration (S4R) using simplified continuum-equivalent properties for the fluting is the most efficient solution for single flute corrugated board; however, when double fluted boards are of interest, as it is usually the case in carrying trays, importance of shear transverse stiffness and thinning of paperboard increase significantly, being highly recommended the using of at least four layers of composite reduced integration continuum shells (SC8R). Figure 7, from the referred study, illustrates the difference between a single flute board and a double flute one. The first graph shows how the composite shells capture corrugated board stiffness very accurately in a single flute board, the second one

shows how the same elements behaves too stiff when a double flute is analysed, finally, the third one shows how using four layers of composite continuum shells (SC8R) solves the problem.

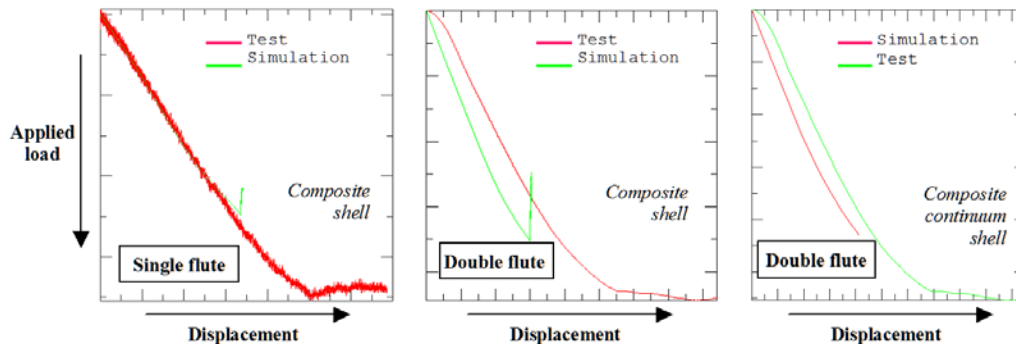


Figure 7. Comparison of flexural stiffness prediction capabilities for different types of equivalent composite models.

3. Application to papers selection in B1 boxes and agricultural trays

3.1 Simulation of BCT test

The BCT (box compression test) value is the most usual property for qualifying package performance in corrugated board packages. It consists of the maximum achieved load level under quasi-static compression of the package between two rigid plates in a universal testing machine under controlled temperature and humidity room conditions. Regarding package functionality, the BCT value refers to the package capability to withstand the weight of the rest of the stack over it. Figure 8 shows an image of a finite element model for simulating the BCT test of a B1-type box, also referred as american box; it includes the final damaged areas together to a picture of a tested sample, showing very good correlation in terms of predicting failure mode.

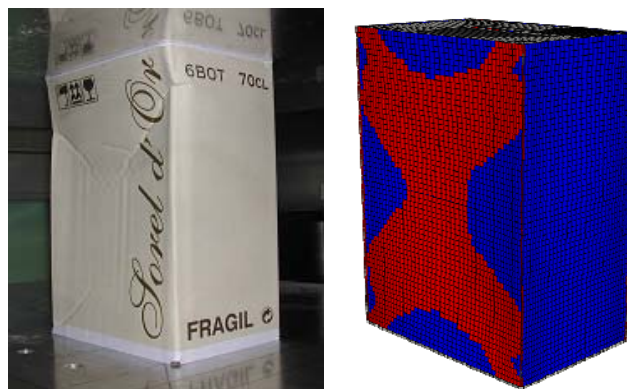


Figure 8. Comparison of BCT simulation with experiment.

The finite element model for the simulation in Figure 8 consists of S4R elements with layered composite definition for the corresponding *SHELL SECTION and definition of connector elements (type=CONN3D2) for the corner lines. The section behaviour of these connector has been defined after experimental characterisation of the torque/angle behaviour of the folded lines for the corresponding boards, following recommendations from studies on other paperboard packages (Beldie et al. 2001). JOIN and REVOLUTE behaviours in the connector section definition, in combination with the NONLINEAR option in *CONNECTOR ELASTICITY, are applied when it is required to define non-linear behaviour.

For the examples presented in the paper, connector elements are always selected instead of other means to accomplish the connection as multipoint constraints. Model sizes are not too big and therefore the higher efficiency of multi-point constraints is not a key factor, while connector elements combine very high versatility in connection behaviour with easy definition and they allow very easy modification of connector type and behaviour details during the initial stages of model development and validation.

The larger complexity of the BCT model for a B1 box is the definition of the contacts between box flaps and between these and compression plates (Figure 9 shows an example of a magnified global buckling behaviour of the top part of a box, with some flaps removed for displaying purposes). Analysis involves combination of local material failure with global instability, therefore non-linear geometric analysis is required. Because of the relevance of the global buckling behaviour when analysing BCT, it is important to account for geometric imperfections of the box; in the examples in this paper, this was accomplished by using the option *IMPERFECTION with mode shapes from a previous eigenvalue buckling modes estimation using *BUCKLE.

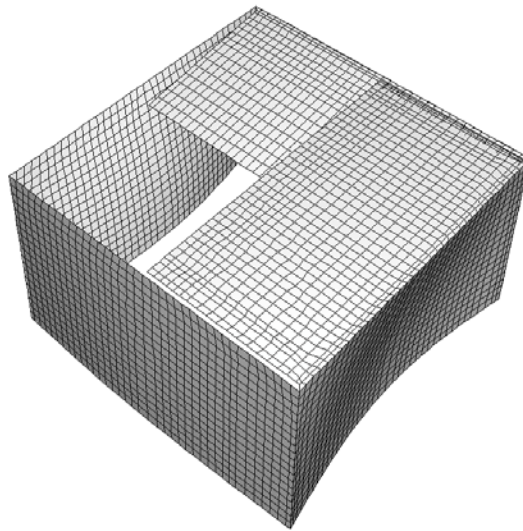


Figure 9. Finite element model of B1 box (two of the top flaps are removed for displaying purposes) with magnified deformation to show global buckling.

While it is usual that B1 boxes allow symmetry modelling in height (as the model in Figure 9, only for the top half of the box), carrying trays as AGRIPLAT and PLAFORM types for agricultural products allow one-quarter symmetry models (see Figure 10). However, modelling of the corner areas adds certain complexity to the modelling tasks, requiring also to keep good control of material orientation definitions. Modelling of glue lines in corner areas and flaps can be also carried out by using connector elements.

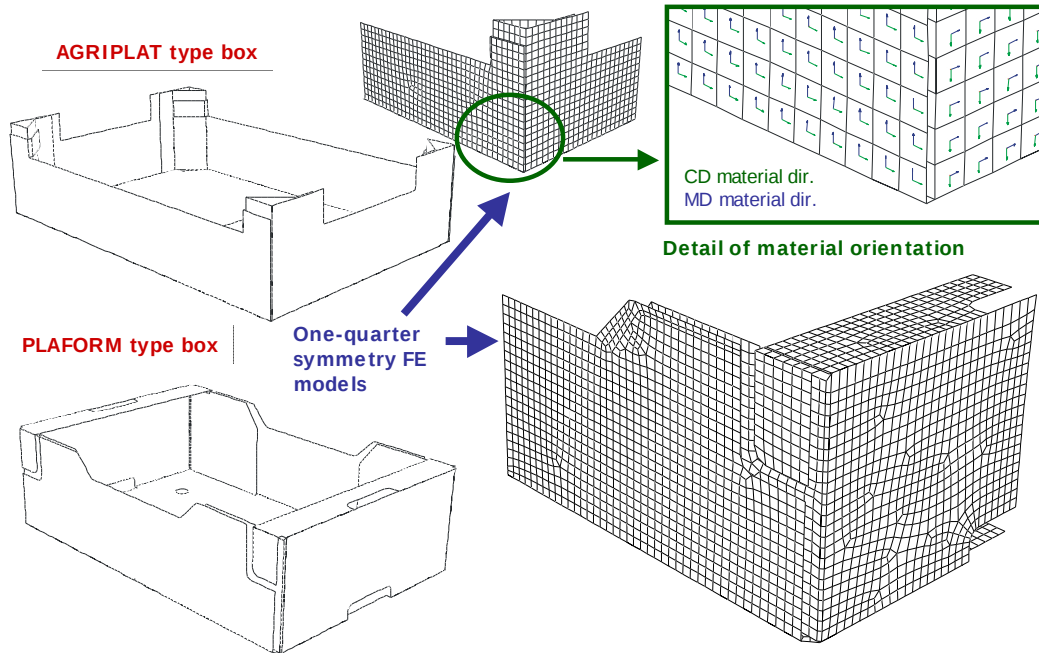


Figure 10. FE models of carrying trays for agricultural products, including an example material orientation definition details

Figure 11 illustrates how the FE simulation of a PLAFORM type carrying tray is used for analysing which is the effect in BCT value and failure mode of using two possible considerations for including a carrying hole in the tray lateral side, the first option considers such hole as additional to the venting hole in the bottom line, while the second one just enlarges the venting hole to the required size for placing easily the hand. Figure 11 illustrates also how the simulations have been validated experimentally, not only in terms of BCT load value, but also in terms of damaged areas and failure mode.

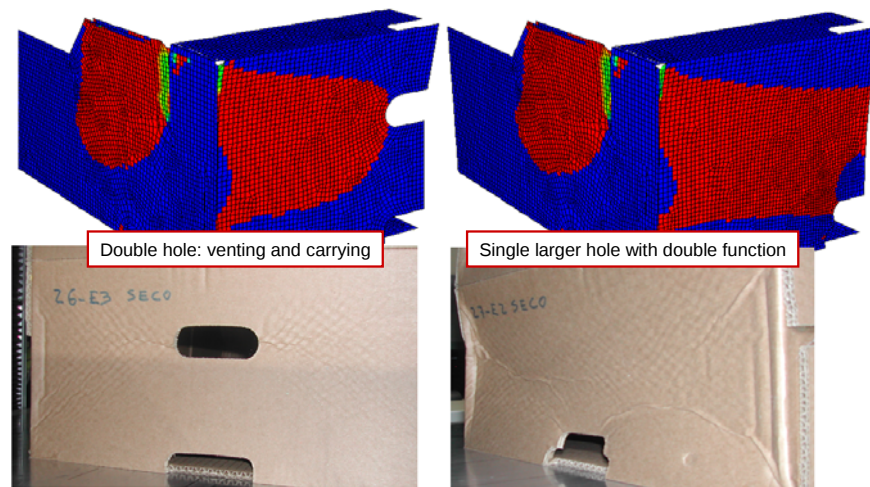


Figure 11. Validation of prediction of global failure areas in PLAFORM type box with different geometry for venting and carrying holes

Simulations following the proposed methodology present an error with regard to experimental BCT values that is usually below 10% in terms of maximum load, which can be considered a very low error if the complexity of material behaviour and failure mode (combining local buckling and strength failure) is put together to other simulation details as torque-angle behavior of folded lines, definition of glue lines, or non-linear analysis involving global buckling. Validation of all model details for different packages has required a large experimental effort with monitoring of many different variables during the test, as out-of-plane displacement of package faces or application of high speed cameras for identifying onset of local buckling. Figure 12 shows an example of the experimental set-up during the initial testing program for model development of agricultural trays.

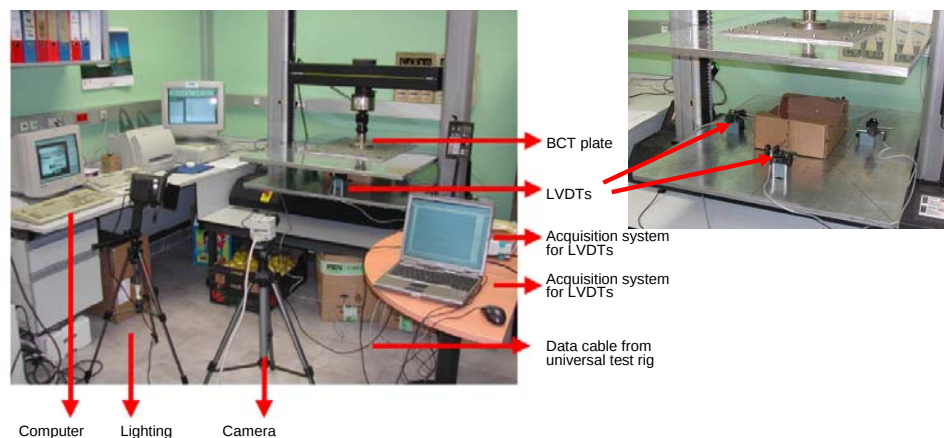


Figure 12. Experimental set-up for detailed BCT analysis to provide data for FE model development and validation

3.2 Simulation of bottom sag in agricultural trays

The bottom sag of agriculture carrying trays can be studied with the presented composite models since they reproduce flexural rigidity of corrugated board accurately in the loading range of interest (Jiménez et al. 2004). The strength requirements from BCT are increased now with stiffness ones; the objective in the design is to avoid excessive displacements that would cause the tray bottom to contact with the products in the box below (what happens at load levels well below ultimate bottom sag strength), so requiring consideration of creep displacements after initial load application.

In the example corresponding to the simulation in Figure 13, the tests were performed on a PLAFORM® carrying try, measuring the displacement in the centre of the bottom. The load was applied by means of bags filled with of golf balls so that load is distributed in the box bottom. Simulation consisted of one unique step using the procedure *STATIC and specifying the real duration of the test. Load application in time was controlled by means of an *AMPLITUDE procedure. The material model included the Coffin model for paper creep already commented in previous points of this paper. Comparison of simulation results to experimental ones for the creep displacement shows a good approximation to prediction of creep displacements. Although it exists a difference in the total predicted displacement value, this is related to the large initial compliance showed during the experimental process of loading application, because of the trays not being perfectly flat, and so with uneven support along test rig.

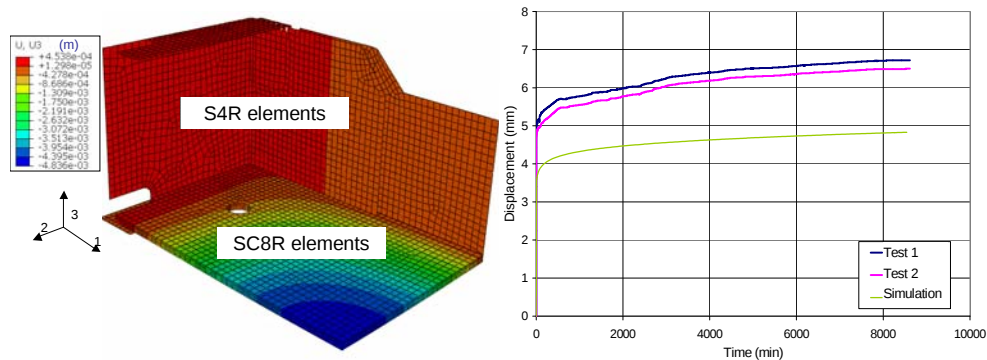


Figure 13. Simulation of bottom sag in agricultural creep and comparison to experimental results in terms of displacement increase in time

4. Examples of application to other package designs

FEM simulation of corrugated board is not limited to B1 boxes or agricultural tries. Using simplified-composite linear 3D shells is usually sufficient for most types of analysis, and because of this, modelling of almost any package becomes a relatively straight task. Figure 14 shows simulation and test results corresponding to a corrugated ring that is used as reinforcement in the packaging of washing powder. FE results show a very good prediction of the failure mode.

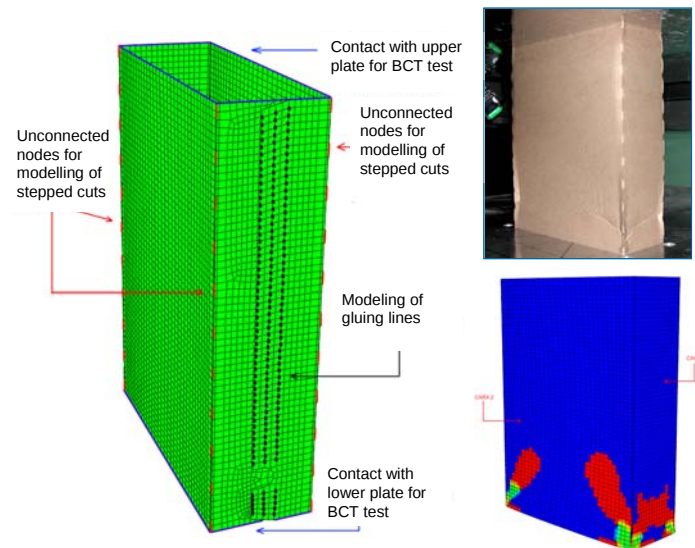


Figure 14. Simulation of BCT of corrugated inner ring for reinforcement of washing powder packaging

Evolution of markets and packaging personalisation generates continuously new package types, for which corrugated board remains as a cost-effective and environmentally friendly solution. One of the new corrugated board package types of highest commercial interest is the ready-to-sell one. Using of stepped cut along box faces facilitates removal of the top half of the package; therefore, the same package can be used first for transport and later for showing the product in the store shelves, just using quick removal of top part of the package without the need of taking out one by one the products inside. Figure 15 shows how an Abaqus models that has developed for analysing how the presence of stepped cuts modifies failure mode in comparison to the uncut package. Modelling of the stepped cuts is carried out using unconnected nodes in combination to connector elements for taking into account contact along cut line. The model has been applied for analysing the influence of different designs of the stepped-cuts in the final BCT performance, as the objective is to keep this in the highest possible value while assuring easy opening of the box without tearing outside provided cut lines.

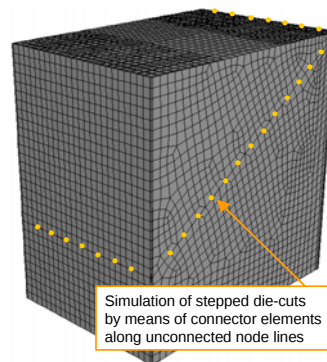


Figure 15. FE model of ready-to-sell box for analysis influence of stepped-cuts design on BCT performance

5. Conclusions

Because of their broad range of simulation procedures and element types, together to the large possibilities offered by user subroutines, Abaqus provides the required framework for the development of a virtual prototyping framework for the corrugated board industry. Presented results show that Abaqus application offers possibilities ranging from selection of constituent papers or flute geometry, to detailed design of package geometry for a set of given performance requirements.

Although it has not been referred in the present paper, FEM in general, and particularly Abaqus thanks to its advanced features, offers to the paperboard industry other possible applications as analysis of board manipulation processes for package production, or even prediction of macroscopic paper performance from microstructure details resulting from manufacturing process.

6. References

1. J. Alfthan, P. Gudmundson. "Linear constitutive model for mechano-sorptive creep in paper". International Journal of Solids and Structures, 42, 2005.
2. L. Beldie; G. Sandberg; L. Sandberg, "Paperboard packages exposed to static loads-finite element modelling and experiments" Packaging technology & science, vol. 14, 2001.
3. Brezinski, J. P. "The creep properties of paper". Tappi Journal 39(2), 1956.
4. G.A. Baum, D.C., Brennan and CC .Habeger, Orthotropic elastic constants of paper, Tappi Journal, Vol. 64, 1981.

5. M. E. Biancolini and C. Brutti, "Numerical and experimental investigation of the strength of corrugated board packages", *Packaging Technology and Science*, Vol. 16(2), March 2003.
6. J.M. Bielsa, R. Rodriguez, L. Vila, M. A. Jiménez, "Parametrized finite element analysis of tribological instabilities on polymer-metal sliding contacts", III ECCM, Lisbon 2006.
7. Coffin, D. W., "The creep response of paper", 13th Fundamental Research Symposium, Cambridge, 2005
8. A.C. Gilchrist, J.C. Suhling, T.J. Urbanik. "Nonlinear finite element modeling of corrugated board". *Mechanics of Cellulosic Materials*, 1999, AMD-Vol. 231/MD-Vol. 85, 1999.
9. P. Isaksson, R. Hägglund, P. Gradina. "Continuum damage mechanics applied to paper". *International Journal of Solids and Structures*, 41, 2004.
10. M.A. Jiménez, I. Conde, E. Liarte, E. Mozas. "Modelling of bending in a corrugated board", *International Paper Physics Seminar*, Trondheim 2004
11. M.A. Jiménez, E. Liarte. "Simulation of the Edge Crush Test of corrugated paperboard using Abaqus", *Abaqus World Users Conference 2003*, Munich.
12. P. Mäkelä, S. Östlund. "Orthotropic elastic-plastic material model for paper materials". *International Journal of Solids and Structures*, 40, 2003.
13. R.C. Mc Kee, J.W. Gander, J.R. Wachuta. "Compression Strength Formula for Corrugated Board". *Paperboard Packaging*, Aug 1963
14. T. Nordstrand, L.A. Carlsson, *Evaluation of Transverse Shear Stiffness of Structural Core Sandwich Plates*, *Composite Structures*, Vol. 37, 1997.
15. U. Nyman, P.J. Gustafsson, "Local buckling of corrugated board facings, *Proceedings of the European Conference on Computational Mechanics*", Munich 1999.
16. S. Luo, J. C. Suhling, *The bending stiffness of corrugated board*, *Mechanics of Cellulosic Materials* AMD-Vol. 145/MD-Vol. 36, 1992.
17. A.A. Rahman. "Finite Element Buckling Analysis of Corrugated Fiberboard Panels". *ASME Symposium on Cellulosic Materials*, AMD-Vol.221, 1997, Evanston.
18. J. Tryding, *A modification of the Tsai-Wu failure criterion for the biaxial strength of paper*, *Tappi Journal*, Vol. 77, 1994
19. T.J. Urbanik, E.P. Saliklis. "Finite element corroboration of buckling phenomena observed in corrugated boxes". *Wood and Fiber Science*, 35(3), 2003.
20. Q.S. Xia, M.C. Boyce, D.M. Parks. "A Constitutive Model for the Anisotropic Elastic-Plastic Deformation of Paper and Paperboard". *Int. Journal of Solids and Structures*, 39, 2002.

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