Impact simulations on home appliances to optimize packaging protection: a case study on a refrigerator

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Abstract

Numerical simulations were used to investigate the impact behavior of complex products such as home appliances. LS-DYNA® is a powerful tool for performing repeat analysis of large assembled parts of the final product, including the packaging. The main goal of the simulations was to verify the performance and suitability of the packaging and its interaction with the structure in case of damage occurring during transportation or delivery. The studies were carried out to guarantee the integrity of the product from factory to customer and therefore to reduce customers service calls.

In particular, impact simulations on a refrigerator and its packaging were performed using LS-DYNA®. The FE model reproduced the testing conditions defined by internal Electrolux regulations. A rear edge drop test was studied and results used to improve current parts.

The paper presents the methodology developed to speed up the product development and to reduce the time to market (TTM). Comparison between the experimental and numerical results are also explored.

Keywords: Home appliances, Drop Testing, Refrigerator, modeFRONTIER, Packaging

1 Introduction

Effective goods packaging is mandatory for Electrolux in order to reduce accidental transportation damage and therefore guarantee the integrity of the product from factory to customer.

To evaluate potential problems, the company has established a rigorous packaging testing procedure, reproducing the stresses / impacts occurring during transportation, handling and product storage. After testing, a score ranging from 0 to 4 is given to the packaging performances according to the structural integrity of the product; 0 implies that the main functions of the product are compromised, while 4 means that the product is fully intact. The testing procedure encompasses clamping tests, stacking tests, vibration tests, inclined plane impacts, drop tests, walking test and others.

In the last few years (2012-2014), a new range of bottom freezer free standing appliances has been developed in different sizes and sub ranges, so called : ZEF (mass range), CANNES (premium range), CREIL (ZEF with double compressor) and all of these have been subjected to internal packaging tests. A design constraint has been to develop identical packaging for this new family of products.

After the first tests on the ZEF range (the first one going into production), unacceptable deformations on the side panels as well as rear compressor crossbeam were found causing a low score in internal testing (score 1). This score is not acceptable since it means that the packaging does not guarantee the integrity of the product in case of inappropriate handling.

In light of these internal testing results prior to production, Electrolux involved EnginSoft to develop a numerical methodology to simulate the experimental packaging tests. The study focused on the most critical test impact in the packaging regulation, which was identified as the rear edge drop test.

LS-DYNA® has been proved to be a powerful tool for several reasons:

- reliability of results
- scalability
- robust contact algorithms
- several material models already implemented in the code (for plastic and foam parts)

The numerical results were used to develop the packaging to meet the requirements of the internal tests for all product ranges. The paper presents the numerical methodology developed to improve and optimize the packaging.

2 Methodology and workflow

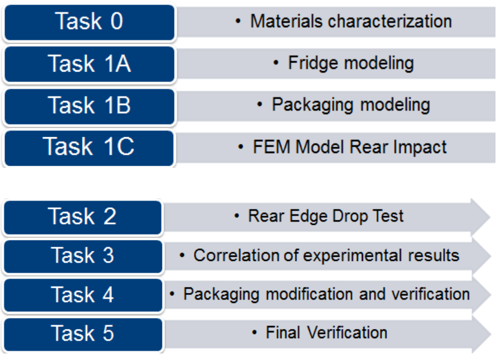

Fig.1: Overview of the work flow to numerically investigate the impact behavior of the refrigerator

The methodology shown in figure 1 allowed Enginsoft to work simultaneously on different tasks to achieve efficient results. Whilst the material characterization was carried out, other engineers were able to independently produce the CAD of the refrigerator and packaging to develop the corresponding FEA models. Once the tasks 0 to 1B were completed, the refrigerator and packaging were assembled and all initial conditions and constraints applied.

The FE model for task 1C was optimize to the specific impact, therefore, a detailed mesh of the front door was not required since the focus of the study was the rear compressor crossbeam and side panels.

2.1 Materials characterization

A refrigerator is a complex product in terms of material characterization since it comprises of many types of materials such as steel, thermoplastics, foams and rubber components.

The steel panels and thermoplastic materials were characterized with *MAT_24 (Piecewise linear plasticity) available in LS-DYNA®, while packaging and cabinet foams were modeled with *MAT_083 (Fu Chang Foam). The compressor support pads, made of rubber, were modeled with *MAT_181 (Simplified Rubber Foam).

Experimental laboratory test results were used to develop the materials using the modeFRONTIER Integration and Design Optimization software. Tensile tests on steels and compression test on EPS samples were used to calibrate the material models.

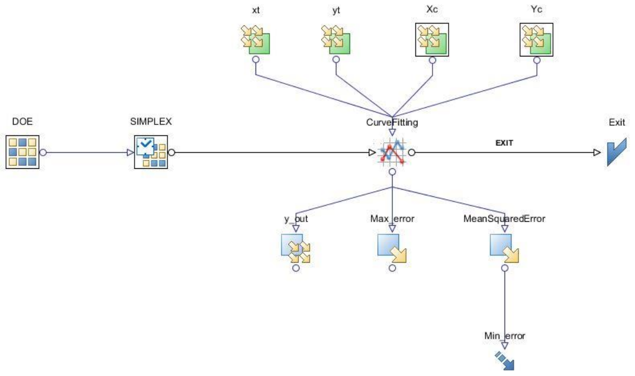

Fig.2: Example of modeFRONTIER workflow used to perform the material calibration

2.2 Refrigerator Modeling

Refrigerators are mainly constructed of an external cabinet and door, the inner cabinet and the injected insulation foam (polyurethane) which bonds both cabinets together.
Simplification of the refrigerator geometry (see figure 3) was performed to reduce the number of elements in the model and to improve mesh quality. Parts with negligible influence on the structural behavior were also simplified (see figure 4) while keeping the mass of the original components. For some components such as drawers and electronic components etc, an equivalent mass was applied to the external cabinet.

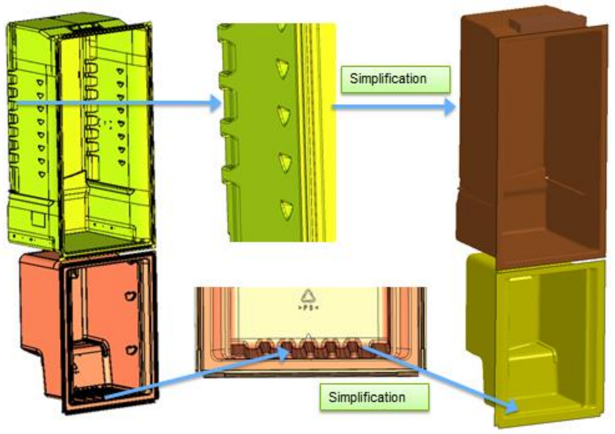

Fig.3: Example of geometry simplification on the internal food compartments

Fig.4: Example of geometry simplification on the evaporator fan system and the condenser coils

The refrigerator model consisted of 3.9 million solid elements and 1 million shell elements. Most of the solid elements correspond to the insulation foams. They were modeled with 1 point integration tetrahedron elements (ELFORM=10) with an average mesh size of 4 mm. Shell elements corresponding to the outer and inner cabinets are under-integrated Belytschko-Tsay shell elements

(ELFORM=2) [1]. Cabinets were bonded to the insulation foams by means of a tied contact formulation (*CONTACT_TIED_NODES_TO_SURFACE).

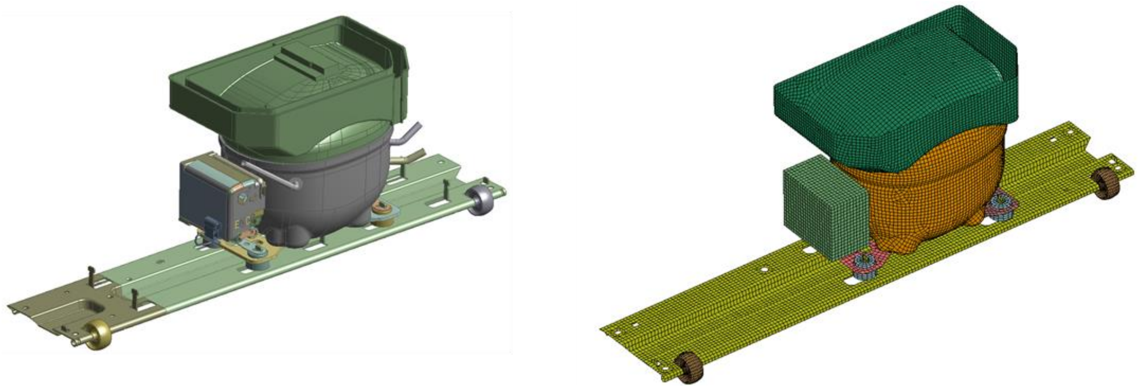

Fig.5: Overview of the rear crossbeam with the compressor. Left. CAD. Right. FEM Model

2.3 Packaging Modeling

The packaging shape is crucial to avoid accidental damage during the transportation of the refrigerator. Therefore, all packaging components were carefully meshed with special attention to the packaging base, which is the key component driving simulation results on the rear edge drop tests.

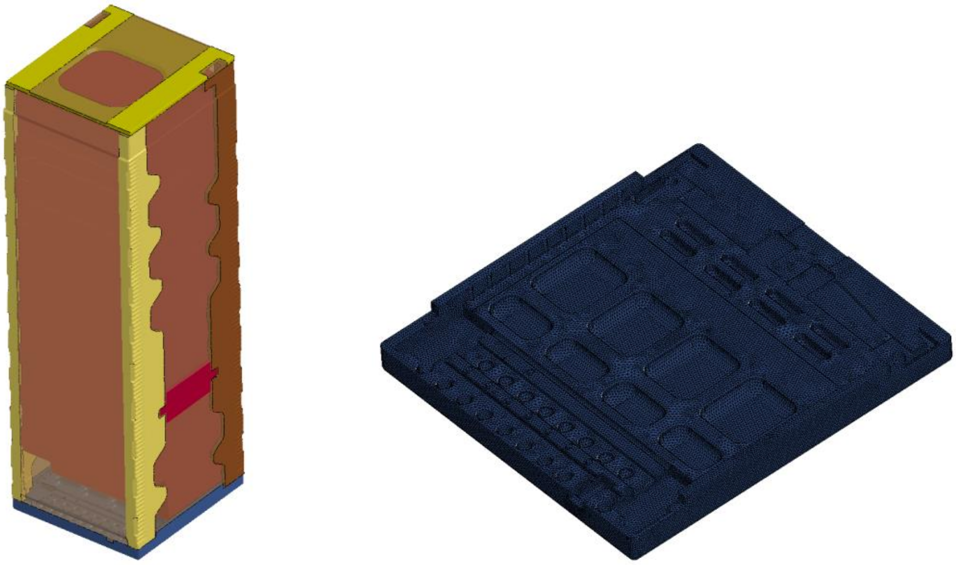

Fig.6: Overview of the meshed packaging. Left: complete packaging. Right: packaging base

The packaging was modeled with 1 point integration tetrahedron elements, which yielded to 3.3 million elements. In order to keep all packaging components together with the refrigerator, it was necessary to model the shrink LDPE. For this reason, 4 node fully integrated membrane shell elements (ELFORM=9) were used.

Once the refrigerator and the packaging FEM models were completed, the model was assembled and initial conditions applied. A powerful LS-DYNA® feature is the contact treatment between all parts; whereby the interactions were successfully handled with only one contact definition (*CONTACT_AUTOMATIC_GENERAL).

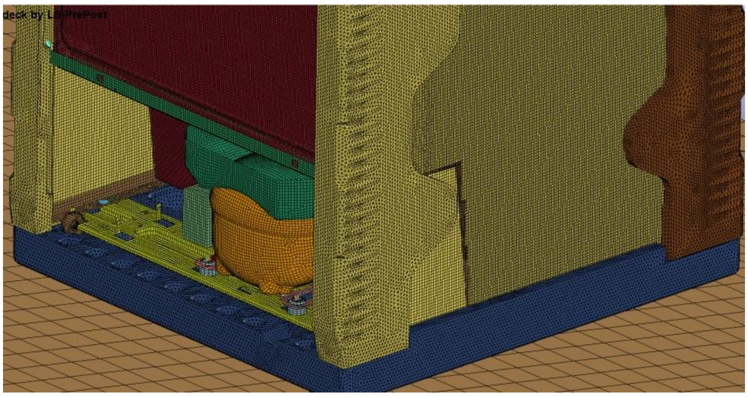

Fig.7: Overview of the rear side of the refrigerator with the packaging

3 Brief Test Description

The internal test procedure foresees several free fall tests to validate the quality of the packaging. In the numerical investigation, the rear edge impact was explored since it was identified as the most critical one.

The simulated test is a free fall edge impact at 10 degrees with respect to the floor. The falling height is set up to 250 mm, which corresponds to an impact speed of 2.21 m/s.

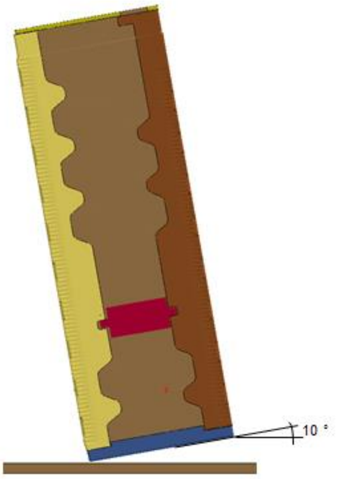

Fig.8: Overview of the fridge free fall

The experimental and numerical mass of the model were in agreement; the measured mass for the refrigerator ZEF corresponded to 75.8 Kg, while the numerical model computed 75.5 Kg.

4 Rear Edge Impact

4.1 Results and discussion

Experimentally, two kinds of problems were identified in the refrigerator structure after the free fall impact. The compressor crossbeam excessively bent during the impact, which in turn caused unacceptable large permanent deformations on the side panels.

The goal of the simulation was to replicate the observed experimental damage (plastic deformations) on the refrigerator and therefore to understand, during the impact, the interaction between the model parts. The impact dynamics knowledge is fundamental to improve the packaging design.

The necessary clock time to simulate 40 ms of impact event was about 20 hours using 24 CPU's (Intel® Xeon® Processor X5670 – 2.93 Ghz). The work was carried out with LS-DYNA® 7.0.0 MPP single precision solver.

The capability to simulate complex impact interactions by LS-DYNA® was proven since the simulation results were able to realistically replicate the experimental tests without any "reverse engineering" model calibration tricks. The main correlation results are depicted in the following figure 9.

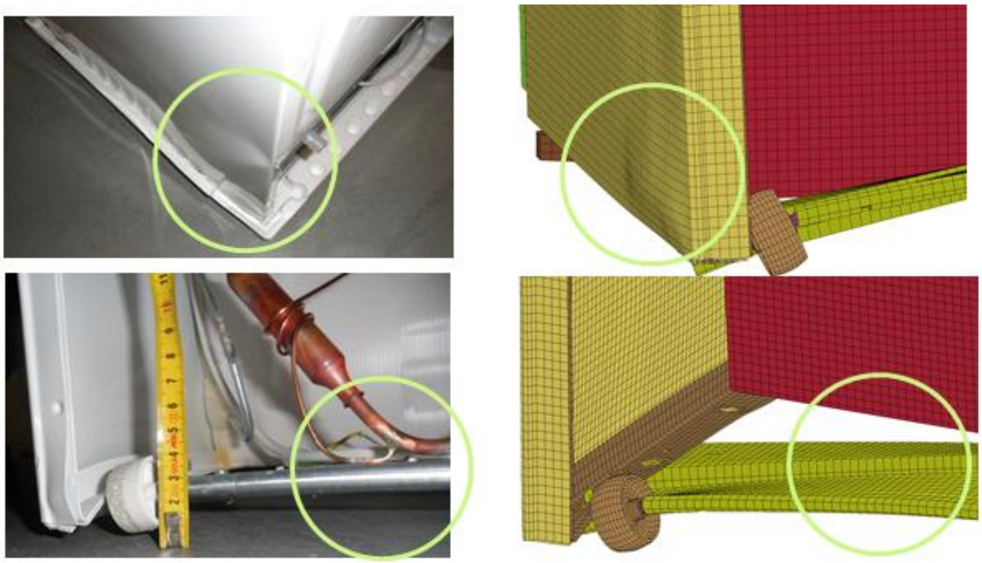

Fig.9: Experimental vs numerical results for the rear edge impact.

The key point is that the simulations were able to completely investigate the impact sequence and to expose that the crossbeam bending and side panel deformations occur due to the reaction force from packaging base (see figure 10).

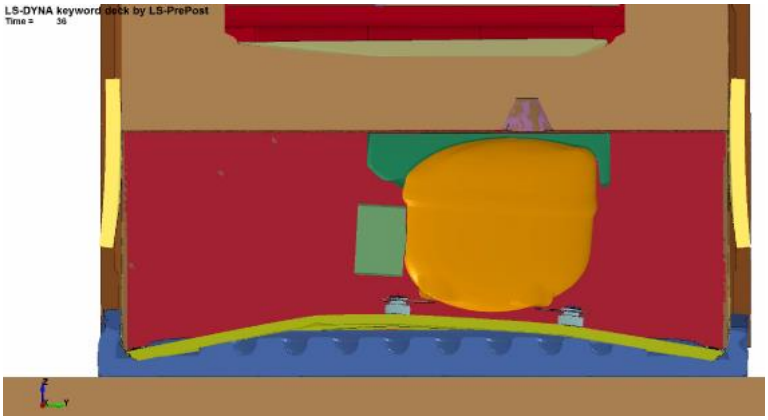

Fig.10: Cross section rear edge impact.

Therefore, once the behavior was understood, the design efforts were concentrated on modifying the packaging base to reduce impact forces transmitted to the structure. Packaging changes and subsequent meshing were produced directly by means of LS-Prepost (without CAD geometry).

Several simulations were carried out to configure a suitable packaging base that would avoid crossbeam and side panels' deformation. Essentially, the strategy was to remove the EPS material in the central crossbeam area and add two EPS supports on the sides. This decision proved to be desirable; achieving a significant improvement in terms of crossbeam bending and side panel deformation. The following figure 11, presents the impact behavior of the initial and improved packaging base for the double compressor configuration.

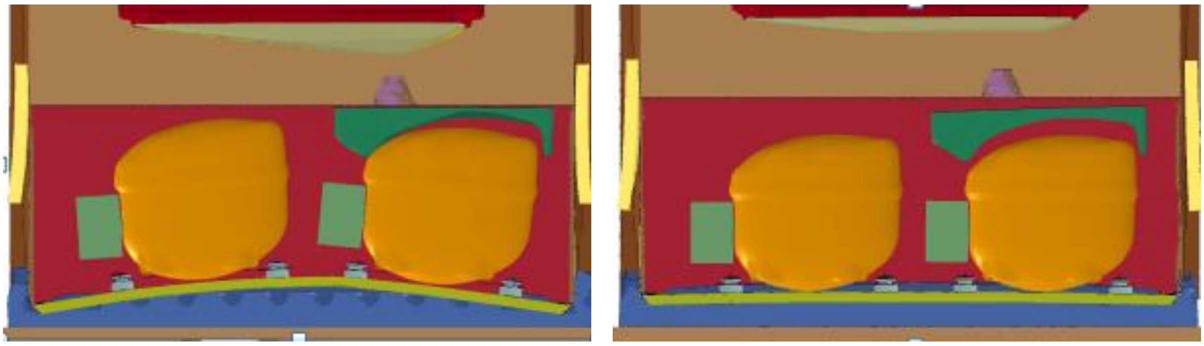

Fig.11: Cross section rear edge impact. CREIL: Double Compressor Configuration

Fig.12: Initial vs New Packaging Base

Once the feasibility of the design was approved by Electrolux, a new campaign of experimental testing was performed on the final packaging design to validate the packaging base.

As predicted in LS-DYNA®, the experimental results showed a crucial improvement in terms of side panel and crossbeam deformation. A comparison of the experimental deformations after the impact test is shown in the following figures 13-14.

Fig.13: Experimental results on side panels. Old vs New Packaging

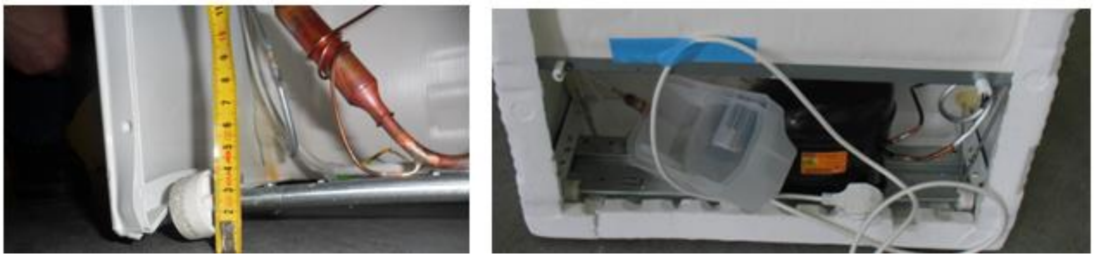

Fig.14: Experimental results on crossbeam. Old vs New Packaging

The key result was that the packaging concept was validated since the score was improved from 1 to 3 (out of 4) by modifying the packaging base alone. Although the crossbeam bending was reduced, some residual side panel deformations were still present and therefore the maximum score of 4 out of 4 was not reached. After the presented study, further work was done to achieve the full score.

5 Conclusion

The goal of the project was to numerically study the impact behavior of ZEF refrigerator according to Electrolux's standards. Experimental tests showed that current packaging was not able to adequately manage loads generated by the impact. In fact, the internal testing score was 1 out of 4 (4 means "product fully intact").

EnginSoft worked with Electrolux choosing LS-DYNA® as the software tool to investigate the impact in order to understand the rear edge impact sequence. It was discovered that the packaging base was the key component that compromised the integrity of the refrigerator.

A new design solving the structural problems was defined after several runs. The reliability of the simulation results was confirmed by experimental tests. As a result, the packaging was validated and the score increased from 1 to 3 (out of 4) by only modifying a packaging part.

References

[1] LS-DYNA® Theory Manual, March 2006, John O. Hallquist, LSTC.