Encapsulated OSB Energy Absorption Potential: A preliminary analysis

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ABSTRACT

The transport of radioactive substances is, in many ways, necessary in the context of the nuclear fuel cycle that aims to generate energy or radioisotopes. In the event of a possible accident, the shock-absorbing parts reduce the mechanical stresses on the other components of the transport packaging, since a large part of the kinetic energy is absorbed by the shock absorber. To standardize the design of the research reactor spent fuel assembly transport devices by numerical analysis, a set of dynamic simulations of a benchmark was conducted to representatively capture the phenomena found in the drop tests used in project qualifications. This study aims to present a comparison of different ways of applying wood and wood composites as a useful and accessible impact-absorbing material. The necessary numerical modelling characteristics are validated and the phenomena present in non-isotropic materials are discussed. This study demonstrates the application of material models where energy absorption is the main structural function. In this case, the orientation of the wood fibers became sensitive with an approximate difference of 10\% more in the impact absorption potential, without considerable variation in the duration interval of the maximum deceleration.

Keywords: Shock absorbers, Wood, Cellular solids, Finite elements method, Ls-dyna.
1. INTRODUCTION

The transport of radioactive substances is, in many ways, necessary in the context of the nuclear fuel cycle that aims to generate energy or radioisotopes. The research reactors spent fuel packages used for transporting and storing are equipped with bolted or welded locking systems and are mainly, supplied with shock-absorbing parts. In the event of a possible accident, the shock-absorbing parts reduce the mechanical stresses on the other components of the transport packaging, since a large part of the kinetic energy is absorbed by them, which, compared to the container and the impact body, is more resilient [1].

The container must provide shielding to protect workers, the public, and the environment from the effects of radiation, to prevent an unwanted chain reaction, heat damage, and also protect against dispersion of the contents. To standardize the design of this type of transportation devices by numerical analysis, a set of dynamic simulations was conducted to representatively capture the phenomena found in the drop tests used in project qualification [1].

This study aims to present a comparison of different ways of applying wood and wood composites as a useful and accessible impact-absorbing material. The necessary numerical modelling characteristics are validated and the phenomena present in non-isotropic materials are discussed in the numerical simulations of a drop test benchmark described in [2].

2. METHODOLOGY

To start interpreting the phenomena and characteristics of wood and wood composites, it is first necessary to define what cellular solids are. They are composed of an interconnected network of supports or solid shells that forms the edges and faces of cells. Typically, as is in one of three different formations, as shown in Fig. 1. The simplest, Fig.1(a), is formed by a two-dimensional array of polygons that groups together to fill a flat area with hexagonal cell materials such as honeycombs. Most commonly, cells are made up of polyhedral that cluster in three dimensions to fill space; also called three-dimensional cellular materials foams. If the solid from which the foam is made is contained only at the edges of the cells (so that the cells connect through open faces), the
foam is said to be an open-cell, Fig. 1(b). If the faces are also solid, such that each cell is sealed off from its neighbors, it is said to be a closed-cell, Fig. 1(c); and, of course, some foams are partially open and partially closed [3].

Figure 1: Main cellular solid formations - 1(a) polygons; 1(b) solid faces; 1(c) open and closed foams
Source: [3]

The control of the different properties of wood and wood composites is such that it is hard to establish a material model and the respective constitutive equations to cover each variation, species, formation, characteristic or origin. However, it is possible to propose a progression in adding different complexities allowing studying their effects at each step.

Fig. 2 tries to summarize this procedure, so that the most recommended step is chosen for a given application, considering the properties of the Material (elasticity, viscoelasticity, plasticity, humidity, temperature), the Anisotropy (longitudinal, radial, and tangential), the Structure (Polar Orthotropic, Grain Direction, Density, Cell Structure, Knots) and Heterogeneity (Earlywood, Latewood, Fibers, Ray Cells, Heartwood, Knots).
The most direct wood factors to be considered in numerical modeling are: (i) Fiber Position – Axial to radial/tangential curves can vary widely, by a factor of up to 10, depending on species. However, statistically, when a lower percentage of Latewood, the greater the resistance in the radial component, in a higher percentage it presents greater resistance in the tangential direction; (ii) Density – density variation, densification; (iii) Temperature – The effect of temperature is due to the variation of intermolecular forces of attraction (hydrogen bridges), which are weakened by the frequency of atomic or molecular oscillations caused by temperature. The magnitude of influence is additionally a function of the shape of the sample with which the characteristics are determined (-20°C to 60°C – 40%; -20°C to 150°C – 55% of the Modulus of Elasticity); (iv) Moisture – Wood should be understood as a partially porous, hygroscopic (absorbs moisture from the air) and capillary substance. The proportion of cavities on average is 50 to 60% of the volume. Wood can acquire and store water through capillary absorption and transport processes, better seen in Fig. 3.
The Oriented Strand Board (OSB) is a wood composite made from fine wood flakes primarily from commercially grown trees. The predominant orientation of the flakes gives it relatively higher mechanical properties in the direction of the flakes (the longitudinal direction of a board) than in the transverse direction. OSB is therefore an orthotropic material [5].

The results of the work carried out in [2] demonstrate that OSB is an orthotropic material with its strongest properties in the direction of wire orientation. OSB is stronger in compression. In traction, OSB behaves linearly to near failure, while in compression it exhibits plasticity. In elastic-plastic behavior in compression, it exhibits a stress-strain curve similar to a parabola. There is little difference in the OSB’s modulus of elasticity in tension and compression, which allows a single value to be used in both cases. Thus, it was proposed through Benchmark 3 of [2], once the methodology and phenomena were validated through a solid model, to quantitatively predict the difference in the orientation of the flakes, or here also called fibers. The fibers were studied in two orientations, parallel and perpendicular to the compression.

Considering that the numerical simulations are performed with LS-DYNA [6], a computer code based on the finite element method, its material model 24 (MAT024 – MAT PIECEWISE_LINEAR PLASTICITY) is widely used in the simulation of shock-type events as an isotropic material model with the VON MISES stress flow criterion [7]. Figure 4 shows finite element models considering the fibers orientation.
3. RESULTS AND DISCUSSION

Benchmark 03, which is proposed by OAPIL [2], was modeled to represent the combination of a wooden cylinder encapsulated by a steel plate, resisting axial compression resulting from a free-fall impact of 9m. The goal is the assessment of the joint conformation of the two different materials and the performance of the interaction between them. Table 1 and Fig. 5 illustrate some geometric and materials data.

<table>
<thead>
<tr>
<th>Impacting Mass</th>
<th>Material A - Liner</th>
<th>Mild steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Material type</td>
<td>Rigid</td>
<td></td>
</tr>
<tr>
<td>- Diameter</td>
<td>D 150 mm</td>
<td>E 210 000 N/mm²</td>
</tr>
<tr>
<td>- Mass</td>
<td>M 100 kg</td>
<td>nu 0.3</td>
</tr>
<tr>
<td>- Impact velocity</td>
<td>v 13.41 m/s</td>
<td>SigY 200 N/mm²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wooden Impact Limiter</th>
<th>Material B</th>
<th>Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Overall Height</td>
<td>H 50 mm</td>
<td>Perfectly Plastic</td>
</tr>
<tr>
<td>- Overall Diameter</td>
<td>D 100 mm</td>
<td>rho 500 kg/m²</td>
</tr>
<tr>
<td>- Liner thickness</td>
<td>s 1 mm</td>
<td>SigY 17 N/mm²</td>
</tr>
</tbody>
</table>

In the study, all contacts are defined as friction and a friction coefficient set is 0.2 (Coulomb Coefficient), being Wood-Steel, Wood-Impactor, and Wood-Rigid Surface. To configure the 9m
high free-fall motion, the final speed, or impact speed, was determined as 13.41 m/s. Considering this speed, the period of observation of the behavior of the structure was estimated to be 5 ms from the initial contact of the Impactor in wood. Impactor vertical displacement, Impact Force over time, and Maximum Wood Compression were defined as results of interest for analysis over time. Some benchmark details are illustrated in Fig. 5.

Figure 5: Benchmark details.
Source: [2]

Three different approaches are proposed: the first and closest to the original study, in the 3D environment with two symmetry planes (1/4) with Liner modeled as shell elements; the second of the same dimensions as the first, but with the Liner as solid elements; the third in a 2D axisymmetric environment that took two forms: one as a reproduction of the two previous cases (continuous medium) and another with the detailing of the fibers (wood/OSB) of the impact absorber (this one in two conditions, with fibers parallel and perpendicular to the loading).

However, recommended values of Poisson and Modulus of Elasticity, both necessary to characterize the material in the ANSYS Workbench LS-DYNA [4], were not identified in [2]. Therefore, in the different simulations presented, observing the due representation of a perfectly plastic behavior idealized for the wood, MAT024 was applied with the properties described in Table 1.
3.1. Liner modelled using shell elements

Considered as the control analysis, special attention was given to the contacts involved and to the mesh optimization studies were carried out, to represent with greater accuracy, the modelling of the original study. Some model details can be observed in Fig. 6.

The contacts, all with a friction coefficient of 0.2, were configured with an Offset close to 0.2mm and a Viscous Damping Coefficient of 10. It was not necessary to specify stiffness values. The default values of Soft Constraint Scale Factor (0.1) and Depth (1) were kept [6]. In Fig. 8, one may identify through the contacts Wood, Liner L and Liner S the respective force magnitude and the main reference from [2].

Figure 6: Benchmark details – control analysis.
Source: Authors

Figure 7: Impact force vs time.
Source: [2] and authors
After reproducing the behavior of the impact force overtime, the variation of this force was evaluated for the different combinations of v-E, respectively Poissons ratio and Modulus of elasticity. The maximum displacements found showed no significant variation for the v-E variations (Fig. 8). The vertical displacement and the speed of the Impactor vs Time were evaluated as well (Fig. 9). The original study responses are on left and the present study responses, on right.

Figure 8: Maximum displacements.
Source: Authors

Figure 9: Impactor displacement and speed vs time.
Source: [8] (left) and authors (right)
In the impact force vs time graph, the forces exerted by the contacts modeled on the Impactor were presented, but it is also possible to extract the force acting on the rigid body through its acceleration in time. Applying the Result Tracker, with nodal selection, to any node of the body we can evaluate the behavior of the acting acceleration and correcting the mass for a 100 kg body, the relation between impactor force and time is reached in Fig. 10.

![Impact Force vs Time](image)

**Figure 10:** Impactor force vs time.
Source: Authors

Therefore, it is possible to identify the phenomenon presented with better correlation, without possible deviations in the behavior of the contacts. Thus, observing the combinations (v-E) previously defined, Figure 11 shows the small variation in Force (<1%), compared to the maximum value, when the Poisson and Modulus of Elasticity are varied.

![Impact Force Comparison](image)

**Figure 11:** Impactor force comparison.
Source: Authors
3.2. Axisymmetric analysis

As suggested by the original study author, it is possible to perform this calculation in the 2D environment, using axisymmetric. In the present study, three types of modeling were explored: continuous medium; 1 mm fibers in two different orientations: only parallel to the load and only perpendicular. The required outputs were explored to confirm the Benchmark reproduction in a comparative way between the three different analyses. For the case without fibers, the contacts followed the definitions of the other analyses, for the cases in which the fibers were modeled, the coefficient of friction between them was considered to be 0.5. Fig. 12 illustrates the geometric and mathematics models, for the three analyses.

![Geometric and mathematics models](image)

**Figure 12:** Geometric and mathematics models. Source: Authors

3.2.1. No fibers case

The axisymmetric analysis was performed, as described in Figure 13. The v-E combination set in the analysis is in Table 1. The maximum horizontal and vertical displacements are shown in Fig. 13. Finally, Fig. 14 illustrates the variation of the impact force for each v-E set.
Table 2: v-E combination.

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<th>v</th>
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Figure 13: Maximum displacements.
Source: Authors
3.2.1. Fibers consideration

The axisymmetric analysis was performed, as described in Figure 12, using an isotropic material. The definition of friction at 50% between the fibers was used, imposing a behavior close to an orthotropic one, so the compression on fibers effect would be better simulated. Two orientations, perpendicular to the direction of compression and parallel to it, were modeled.

The $v$-$E$ combination set in the analysis is in Table 4. The deformation line, for both fiber orientations, is observed in Figure 15. Finally, Figure 16 illustrates the variation of the impact force for each $v$-$E$ set, for horizontal (left) and vertical (right) fiber orientation.

Table 4: $v$-$E$ combination.

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Figure 14: Variation of the impact force.
Source: Authors

Figure 15: Deformation line.
At this point, it was possible to comparatively notice the difference in the fiber deformation process and when the development of force in time in both cases was analyzed, it is possible to infer the influence of fiber torsion on the energy absorption potential.

Through this study, it is possible to comparatively notice the difference in the fiber deformation process and when observing the development of strength over time in both cases, one can infer the influence of the fiber’s torsion on the energy absorption potential, increasing the absorption capacity by approximately 10%.

4. CONCLUSION

In summary, it was possible to study advanced definitions of materials and reproduce the study developed in 1998. Objectively, it was demonstrated the application of material models where energy absorption is the main structural function. In this case, the orientation of the wood fiber became sensitive with an approximate difference of 10% more in the impact absorption potential, without considerable variation in the duration interval of the maximum deceleration. The next steps are: to explore greater bibliography on rigid polyurethane foams, apply this methodology and comparatively display the results. Once this step is completed, it is expected to apply in a satisfactorily calibrated model of numerical simulations of packaging for transporting research reactor spent fuel elements.
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REFERENCES


