Numerical modelling of Wood behaviour under large deformation

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Abstract

In the field of materials capable to absorb the energy from impacts, wood appears to be a reasonable option because of its capacity to deform until large values depending on the spice of wood. The present work deals with the elaboration of a material law within Ls-dyna software which will be able to reproduce the behaviour of wood under quasi-static compressive loads until large deformation, as observed physically in real experimental tests. A second task of the present investigation was to carry out a literature survey to study different constitutive material laws proposed by other researchers over the world. The results have been obtained with different models available in Ls-dyna (MAT024, MAT026, MAT063, MAT126 and MAT105) based on elastic and/or elasto-plastic behaviour, both isotropic and orthotropic, show that is possible to simulate adequately the wood behaviour under quasi-static compressive loads until large deformations.

1 Introduction

Cellular materials have an important plastic deformation dissipation to a load level almost constant in a large range of deformations, they are very used as impact absorbers. Among these materials, wood which can be deformed during an impact until 60% or 80% depending on the spice can be found. Mechanical properties of wood are characterized for a very high variability [4]. This variability results from the differences observed on a macroscopic level but also on its microscopic structure. The development of investigation in this field is emerging in the actual context, as well as in the future one, due to environmental concern and sustainable development, above all in building field. In terms of mechanical behaviour, wood is a cellular complex material: orthotropic, highly anisotropic and has a brittle behaviour in transverse tension, shear and tensile longitudinal [5] Concerning the study of wood under impact/ dynamic loads, work remains at the experimental stage. The problem related to the influence of strain rate on the mechanical behaviour to treat rapid stress, such as shock or crash, has been studied relatively little in literature. So this work wants to extend and complement the literature by providing a complete study about modelling wood behaviour with all the particularities of wood as a material. As said before wood is an orthotropic and highly anisotropic material. This fact makes finding a material model that covers all this aspects necessary.

To accomplish the objectives sets, some studies has taken as reference, such as [5] and [6] to understand all the particularities that wood has and that have to be present when finding which equations will represent better the real behaviour. Some important studies like [9] and [11] are an important theorical basis for solve wood problems using finite elements methods.

The procedure followed to evaluated the different material models that the software offers and allows to represent the behaviour of wood under large deformation with high accuracy is divided into experimental tests carried out to obtain good experimental results which we can use to compare with the simulations carried out with LS-Dyna software.

2 Experimental tests on pin wood under compressive loading

The next experiments were carried on by Dong TRAN (LERMAB, 2013) using pine wood of French production. All the samples had similar characteristics, densities between 385 kg/m3 and 420 kg/m3 and a moisture content around 12%. According to EN 338 the samples were graded C30 which means a 30 N/mm2 bending resistance.

Two different orientation have been considered in this experiments: longitudinal direction and radial direction. The different samples have been tested in a standard Instron© Machine with a compression load equivalent to a 3mm/minute displacement.

The experimental curves obtained from the results of the experiment were determinate using stress-displacement curves and the next relationships:

$$\sigma_c = \frac{F}{A} \tag{1}$$

With equation (1) σ_c can be obtained dividing the load applied (in N) and the surface where is applied (mm^2). Equation (2) is the relationship used to calculate engineering strain dividing the relative displacement (ΔL) and the original length of the sample.

$$\epsilon = \frac{\Delta F}{L_0} \tag{2}$$

2.1 Compression at Longitudinal direction

As it can be observed in the experimental curves obtained, in compression at longitudinal direction after the first elastic region there is a characteristic load drop and after there is a plastic region with softening. According to literature [5], the typical complex mechanisms of deformation in this area after the load drop are telescoping and buckling mechanisms or localized shearing. In cellular solids terms wood behaviour to compression at longitudinal direction (load parallel to the grain) can be described as intermediate between a rigid-plastic and a brittle cellular material.
In this case, ten different samples were tested:

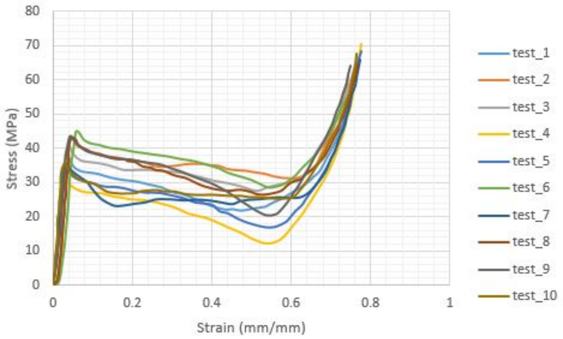

Figure 1: Stress-Strain experimental curves for compression at longitudinal direction

Values obtained from the different samples are used to calculate a mean for σ. This value, 38.862 MPa is the one used in the numerical simulations.

2.2 Compression at Radial direction

For compression at radial tangential direction, 5 different samples were used, and the experimental curves obtained are shown in Figure 2. As it can be observed the curve can be divided in two parts, the first part with elastic behaviour and the second part with a plastic behaviour with hardening [4]. The deformation starts in the earlywood zone of and annual ring which is deformed in an approximately uniform way, and after, the latewood cells are collapsed and densification is the reason why the stress-strain curves increase [5].

In this case, the mean obtained is 3.162 MPa.

3 Simulation results

In this section, the results from the different simulations carried out are presented.

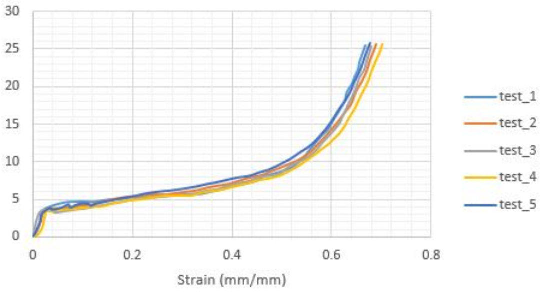

Figure 2: Stress-Strain experimental curves for compression at radial direction

Although different models offered by Ls-Dyna has been tested, we have group the results depending if the model includes damage criterion or not. So the results presented below correspond to a logical approximation to the material model that fits better the experimental curves. We have start with the simpler material models that we thought that could represent the mechanical behaviour of wood evolving step by step to material models more complex ending by using Damage models. Further information about the material models used can be found in [1], [2] and [3]. For more detailed information on how finite elements are applied on wood read [9] and [10].

3.1 Quasi-static loads. Implicit

Cubes under compressive loads have been modelled only using a quarter of the sample and applying appropriate symmetry conditions. Different 3D models have been implemented to simulate the behaviour of wood under compressive loads. The numerical simulations have been carried out by controlled velocity on the nodes of the quarter's top surface while the nodes in the base's surface have a displacement in y-direction constrained. Implicit nonlinear calculation with 100 steps and increment versus total displacement as convergence norm have been done.

Due to numerical solutions have an important dependence on the quality of the mesh three different meshes have been done with 16, 128 and 250 quadratic elements to observed how the solution converge, and get good results.

At the time of calculation, the element formulation option has been set as fully integrated solid (ELFORM=2), except for MAT126 (ELFORM=0), which assumes that pressure is constant throughout the element to avoid pressure locking during nearly incompressible flow [2].

3.1.1 MAT024

The first Model implemented has been done with MAT024 which is an elasto-plastic material, isotropic and with VON MISES flow criterion material model. In both longitudinal and radial direction the mechanical behaviour has been defined using Effective plastic strain (EPS) and Effective strain (ES) values.

It can be observed that however the numerical curve gives a good approach, the numerical deformed shape is not realistic due to differences in failure and in the increment in length in radial and tangential direction. Also we see that the mesh has very little influence in this simulation since the numerical results has no significant difference between them.

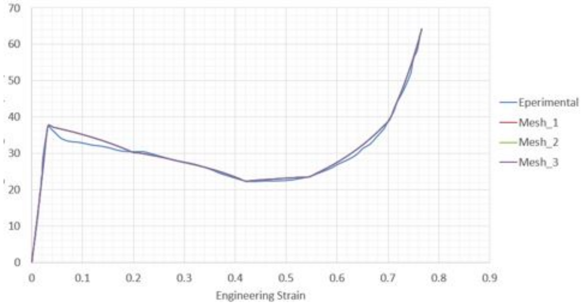

Figure 3: MAT024: Stress-Strain simulation. Compression at longitudinal direction

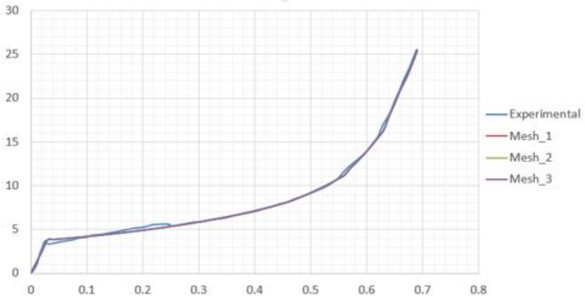

Figure 4: MAT024: Stress-Strain simulation. Compression at radial direction

Also note, that due to this model is anisotropic information on other directions do not appear in the simulation. As seen, we need to simulate both directions separetly.

3.1.2 MAT063

This finite element model is based in MAT063. It is also an isotropic material but in this case a multiplanar flow condition according to JOHANSON is used. Flowing occurs only as a function of the maximum amount of the principal stress [6].

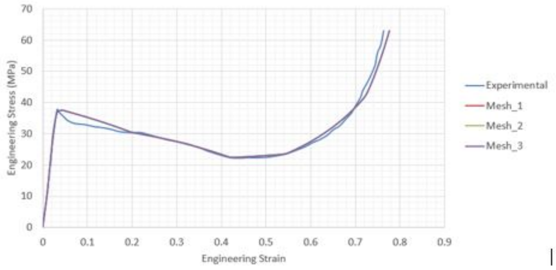

Figure 5: MAT063: Stress-Strain simulation. Compression at longitudinal direction

Figure 5 shows the comparison between the experimental results and the simulation results. As it can be observed, one can get good results using material 063 but the error between experimental and simulation results is bigger than in material 024 especially when densification phenomenon appears.

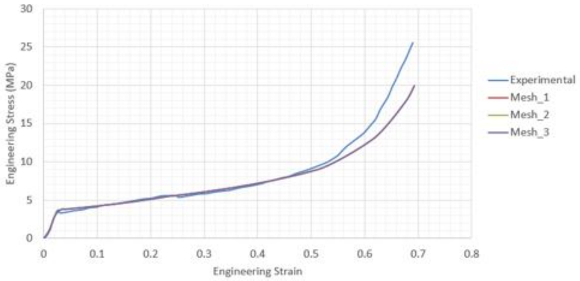

Figure 6: MAT063: Stress-Strain simulation. Compression at radial direction

On the results shown in Figure 6 one can notice that the error is more important than in longitudinal direction. However, the behaviour can be well represented with small displacement and until a 45% of strain.

3.1.3 MAT026

This model is based on honeycomb models, it is an orthotropic model which uses flow conditions according to JOHANSON [1].
Material 026 needs the properties of the fully compacted honeycomb material. In the literature some different values were found for wood [5]. In the following points this values are exposed and numerically simulated.

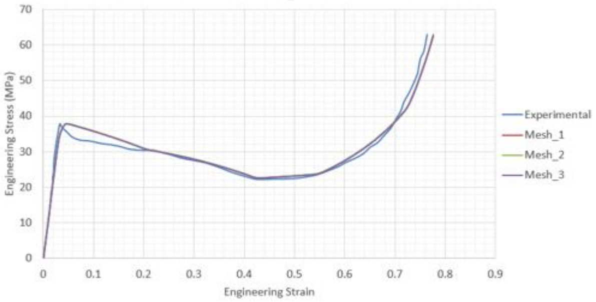

Figure 7: MAT026: Stress-Strain simulation. Compression at longitudinal direction

In Figure 7 it can be observed that the results with material 026 model are good, although small errors with sigma y and at the end of the curve can be noticed. It is important to remark that the softening is quite well represented by this model.

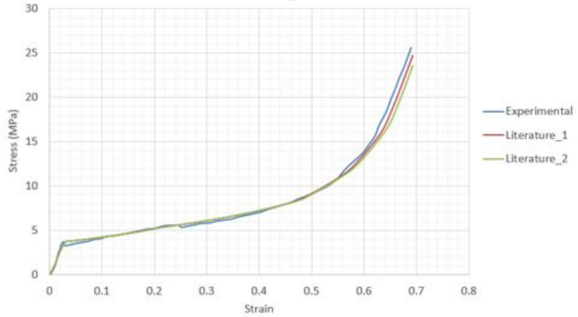

Figure 8: MAT026: Stress-Strain simulation. Compression at radial direction

As expected, this model gives good results for radial direction. Just with a small error in sigma y and at the end of the curve as the model in longitudinal direction.

3.1.4 MAT126

This model is based on honeycomb models, it is an orthotropic model which uses flow conditions according to JOHANSON [1]. The difference with material 026, is the used of differing expansion dimensions. Values for fully compacted parameters for both longitudinal and radial direction are based on the model defined with material 026.
Next graphic shows how the numerical results obtained are. One can observe that the model gives good results, also for the softening part. Also that there is no noticeable difference with the meshes used.

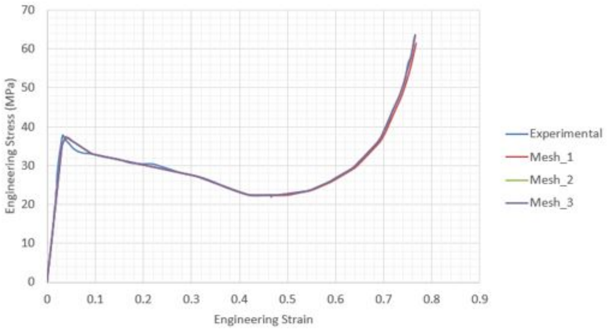

Figure 9: MAT126: Stress-Strain simulation. Compression at longitudinal direction

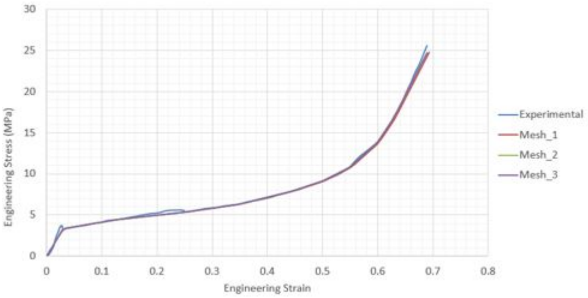

Figure 10: MAT126: Stress-Strain simulation. Compression at radial direction

3.2 Quasi-static loads. Damage

Also a little intrusion to material model using damage criterion has been done. The results that follows are the first approach to Damage material models and not only get good numerical results in the elastic and in the beginning of the plastic state but also when wood collapse.

3.2.1 MAT105 / MAT_DAMAGE-2

This model is based on MAT105 which is an elastic viscoplastic material model combined with continuum damage mechanics.

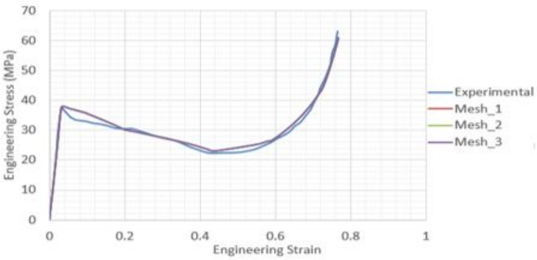

Figure 11: MAT105: Stress-Strain simulation. Compression at longitudinal direction

To reduce this error, LCSS curve is used instead the eight points available in CARD 4 and CARD 5:

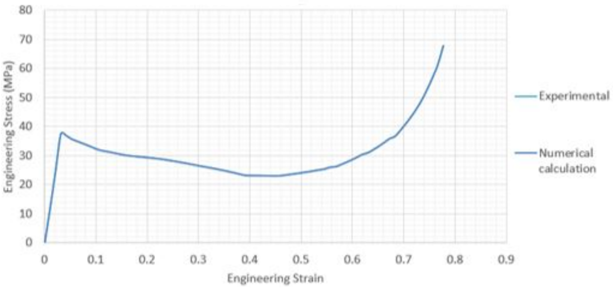

Figure 12: MAT105: Stress-Strain simulation. Compression at longitudinal direction with LCSS curve.

As Figure 13 shows, using LCSS instead of EPS-ES parameters the results improve significantly. That means that is possible to reproduce some experimental already obtained.

4 CONCLUSIONS

The results from the numerical simulations show that is possible to represent with good results wood's behaviour in longitudinal and radial with an elasto-plastic model without damage and without taking into account failure criterions, also with an isotropic material as MAT024. Taking into account damage, with material MAT105, it can be observed that with a material elasto-plastic with damage the behaviour of wood under large deformation can be satisfactorily represented, but due to in MAT105 the elasto-plastic behaviour is defined in the same way as in MAT024 it can be observed that the deformed shape is not realistic, like in materials based on honeycombs. In conclusion, material model MAT126 (Material modified honey comb) give us the best results for both Stress versus Strain curves and for the deformed shape.

5 BIBLIOGRAPHY

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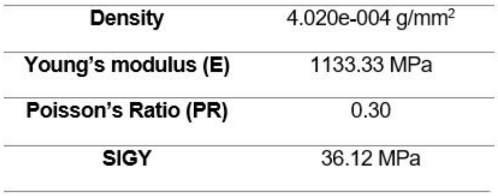
6 APENDIX

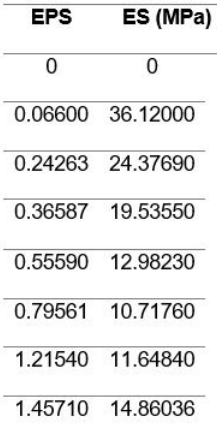
6.1 MAT024

The value for the mechanical properties and for parameters used in longitudinal simulation are summarised in the next tables:



Density	4.020e-004 g/mm^2
Young's modulus (E)	1133.33 MPa
Poisson's Ratio (PR)	0.30
SIGY	36.12 MPa

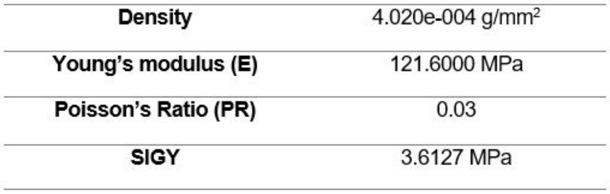
Figure 13: Mechanical properties MAT024. Longitudinal direction.



EPS	ES (MPa)
0	0
0.06600	36.12000
0.24263	24.37690
0.36587	19.53550
0.55590	12.98230
0.79561	10.71760
1.21540	11.64840
1.45710	14.86036

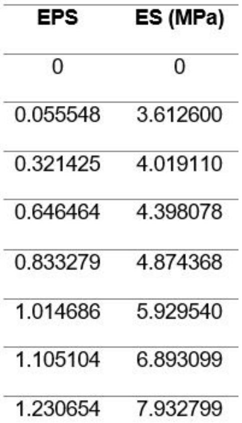
Figure 14: Effective plastic strain vs. effective stress values. Longitudinal direction.

And for radial direction:



Density	4.020e-004 g/mm^2
Young's modulus (E)	121.6000 MPa
Poisson's Ratio (PR)	0.03
SIGY	3.6127 MPa

Figure 15: Mechanical properties MAT024. Radial direction.



EPS	ES (MPa)
0	0
0.055548	3.612600
0.321425	4.019110
0.646464	4.398078
0.833279	4.874368
1.014686	5.929540
1.105104	6.893099
1.230654	7.932799

Figure 16: Effective plastic strain vs. effective stress values. Radial direction.

6.2 MAT063

The mechanical properties used in this model are all from the samples and experimental data of compression in longitudinal direction. The next tables show the values used:

Density	4.020e-004 g/mm^2
Young's modulus (E)	1133.33 MPa
Poisson's Ratio (PR)	0.0

Figure 17: Mechanical properties MAT063. Longitudinal direction.

The curve that represents the material behaviour is shown in the figure below and is the relationship between True Stress and Gamma. Gamma is defined as:

$$\gamma = 1 - V_{rel} = 1 - \frac{V_{initial} - \Delta V}{V_{initial}}$$

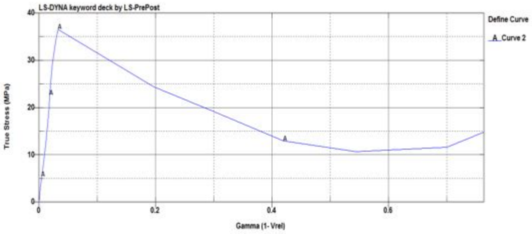


Figure 18: Stress vs. Gamma (1-Relative volume) curve. Longitudinal direction.

And for radial direction:

Density	4.020e-004 g/mm^2
Young's modulus (E)	130.618 MPa
Poisson's Ratio (PR)	0.0

Figure 19: Mechanical properties MAT063. Radial direction.

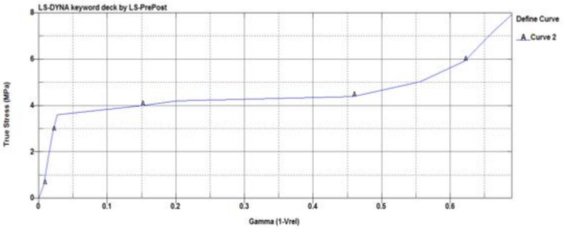
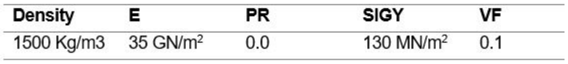


Figure 20: Stress vs. Gamma (1-Relative volume) curve. Radial direction.

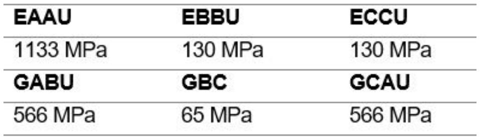
6.3 MAT026

The next two table show different values for fully compacted wood. This values come from the literature (Gibson L.J. and Ashby M.F).



Density	E	PR	SIGY	VF
1500 Kg/m3	35 GN/m^2	0.0	130 MN/m^2	0.1

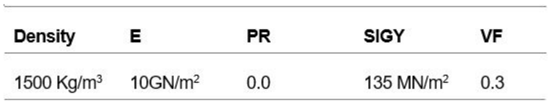
Figure 21: Mechanical properties MAT026. Longitudinal direction.



EAAU	EBBU	ECCU
1133 MPa	130 MPa	130 MPa
GABU	**GBC**	**GCAU**
566 MPa	65 MPa	566 MPa

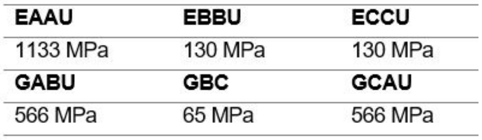
Figure 22: Material model values for uncompact parameters. Longitudinal direction.

And for radial direction:



Density	E	PR	SIGY	VF
1500 Kg/m^3	10GN/m^2	0.0	135 MN/m^2	0.3

Figure 23: Mechanical properties MAT026. Radial direction.

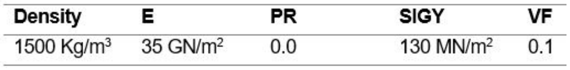


EAAU	EBBU	ECCU
1133 MPa	130 MPa	130 MPa
GABU	**GBC**	**GCAU**
566 MPa	65 MPa	566 MPa

Figure 24: Material model values for uncompact parameters. Radial direction.

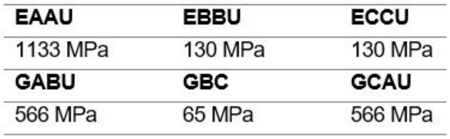
6.4 MAT126

The value for the mechanical properties and for parameters used in longitudinal simulation are summarised in the next tables:



Density	E	PR	SIGY	VF
1500 Kg/m^3	35 GN/m^2	0.0	130 MN/m^2	0.1

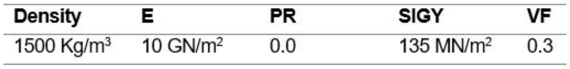
Figure 25: Mechanical properties MAT126. Longitudinal direction.



EAAU	EBBU	ECCU
1133 MPa	130 MPa	130 MPa
GABU	**GBC**	**GCAU**
566 MPa	65 MPa	566 MPa

Figure 26: Material model values for uncompact parameters. Longitudinal direction.

And for radial direction:



Density	E	PR	SIGY	VF
1500 Kg/m^3	10 GN/m^2	0.0	135 MN/m^2	0.3

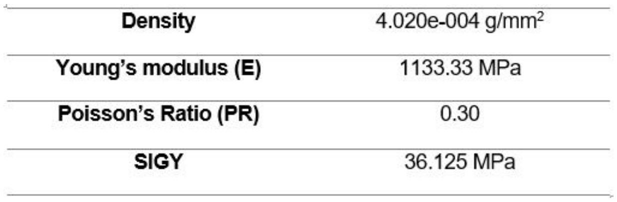
Figure 27: Mechanical properties MAT126. Radial direction.

EAAU	EBBU	ECCU
1133 MPa	130 MPa	130 MPa
GABU	**GBC**	**GCAU**
566 MPa	65 MPa	566 MPa

Figure 28: Material model values for uncompact parameters. Radial direction.

6.5 MAT105

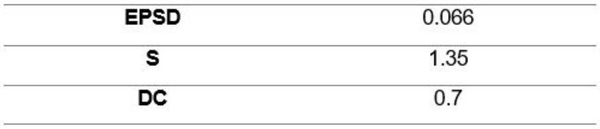
The elastoplastic behaviour is defined in the same way as in MAT024, the same curves and the same values have been used.



Density	4.020e-004 g/mm^2
Young's modulus (E)	1133.33 MPa
Poisson's Ratio (PR)	0.30
SIGY	36.125 MPa

Figure 29: Mechanical properties MAT105.

The next table shows the damage parameters used in this model:



EPSD	0.066
S	1.35
DC	0.7

Figure 30: Damage parameters MAT105.

The effective plastic strain has been defined as explained in MAT024