DESIGN AND CHARACTERIZATION OF AN ISOTROPIC RECONSTITUTED WOOD FOR ENERGY ABSORBERS

O. Roussel [1, 2] *and P. Morlier* [2]

[1] SEMAS, 33360 Latresne, France

[2] Laboratoire de Rhéologie du Bois de Bordeaux, BP10, 33610 Cestas-Gazinet, France
CNRS - INRA - Université Bordeaux I

SUMMARY

Wood has been used for years in the making of containers for transport of nuclear materials because of the good compromise offered by wood between resistance to impact and fire resistance. However wood is an anisotropic material especially when compressive strength is considered, parallel or perpendicular to the grain. The arrangement of wood inside the containers has to take into account different types of impact, especially oblique ones for which the choice of the orientation of wood elements is very difficult; for cylindrical containers with plane covers, corner zones are weak because the out of axis mechanical performances of wood is not good enough to insure a good behaviour during strong oblique shocks.

In our Laboratory of Wood Rheology we decided, in co-operation with CEA/CESTA, to design an isotropic wood based material to be especially used in the corner zones of containers; on the other hand such an isotropic material is represented by very simpler constitute laws for computer modelling of crash-tests. This material was named IWOC for Isotropic Wood Composite. IWOC was studied, in connection with its elaboration process, for quasi-static simple or multiaxial compression in the elastic-plastic domain, even with high compression ratios, then for dynamic compression tests with impact speed up to 10 ms^{-1}, with a falling mass system.

These tests show that IWOC has good properties for energy absorption, especially when it is confined by metallic or fiber casings; its static or dynamic performances are not scattered at all; its sensitivity to deformation rate, in the range which was analysed, can be correlated to the sensitivity of the different elements of this wooden composite material.

INTRODUCTION

Wood is used in the construction of containers for transport of nuclear products or wastes: confined between two metallic liners, wood plays the double role of impact limitation and fire insulation. Generally impact limiters are made of Balsa wood or Sequoia wood but the design of them tends towards using more performing and cheaper species, like Poplar wood the possibilities of which have been explored by FRANÇOIS (1992).

The containers are submitted to impact tests, especially oblique ones, at 40 ms^{-1} speed; during these tests, a great part of the energy is absorbed in the casings but the good behaviour of wood during the impact is a guarantee for the protection against fire offered by the containers. The arrangement of wood pieces in the container has to take into account oblique impacts and here is a great difficulty because wood cannot ever be oriented according to the direction of maximum strength (the longitudinal one).

Impact tests are necessary but they are time and money consuming: finite element modelling is becoming a great component of container designing, but wood is a cylindrical orthotropic material for which we cannot find easily numerical models for its behaviour in static and dynamic compression with large deformations (available models for the moment are only honeycomb and foam models, they are not actually adapted for wood): see ADALIAN and MORLIER (1998).

We considered design and characterization of an isotropic wood based material for being used in the corners, or other parts of the containers where it is difficult to arrange the orientation of solid wood and finally the isotropic nature of this material had to be associated with a simple constitutive law for large compression.

Preliminary tests were made by FRANÇOIS (1992) : he realised a cube of isotropic wood composed of 1000 elementary cubes of Poplar wood, cut along the radial, tangential and longitudinal directions, randomly joined together by a resorcinol glue; this material was then called IWOC.

This paper presents the results of a large campaign of mechanical experiments for obtaining constitutive laws for this material, in dependence of the way it was built (size of the elementary cubes, gluing process) or loaded (statically and dynamically, simple or triaxial loading).

STATIC BEHAVIOUR

The experimental campaign concerning static behaviour of IWOC revealed first that this material was isotropic as far as its elastic and plastic – up to 30% for the range of large deformations – are considered; the YOUNG modulus is slightly greater (1,270 GPa) in the direction perpendicular to the stratification-during the first manufacturing process small cubes were first glued together to constitute plates which were assembled later – than in the other directions (1,1 GPa); POISSON'S ratio is 0.2. For the following specimens, we used a 3D type of manufacturing process, described in ROUSSEL (1997), which assures a good isotropy of IWOC.

The behaviour of IWOC in pure compression is elasto-plastic with a non-linear strain hardening (Figure 1).

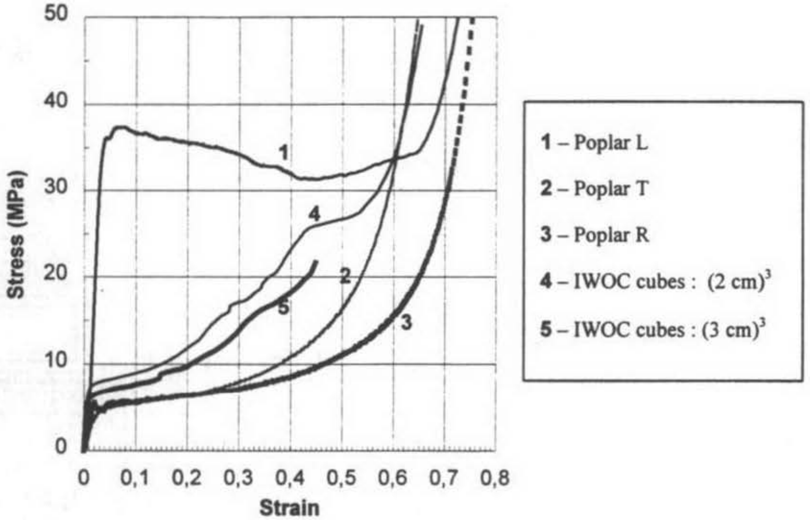


Figure 1 : stress-strain curve of Poplar wood (directions R, T, L) and IWOC (2 sizes of elementary cubes) in pure compression.

At different stages of compression, we have calculated the energy W absorbed in a unit volume of material (Figure 2) : at high level of compression, more than 0.4, W for IWOC is equivalent to the mean value of W for basic material (Poplar) in the three directions R (radial), T (tangential) and L (longitudinal).

ε	W_L	W_R	W_T	$\frac{W_L + W_R + W_T}{3}$	W_I	W_{II}
0,1	2,9	0,5	0,4	1,3	0,8	0,7
0,2	6,5	1,1	1	2,9	1,9	1,6
0,3	10	1,8	1,7	4,5	3,3	2,7
0,35	11,7	2,1	2,1	5,3	4,1	3,5
0,4	13,3	2,6	2,7	6,2	5,2	4,4
0,45	14,9	3	3,2	7	6,5	5,3
0,5	16,5	3,5	4	8	7,4	
0,6	19,9	4,8	6,2	10,3	10,9	
0,7	23,5	6,9	11,7	14		
0,8	32,2	12,2				

Figure 2 : absorbed energy W (MJ/m^3) for different compression deformations (ε) :
W_L, W_R, W_T is relative to Poplar wood, W_I, W_{II} to IWOC with two sizes of elementary cubes : $(2\ cm)^3$ for I and $(3\ cm)^3$ for II.

IWOC material becomes homogeneous as soon as the elementary volume consists of a number of elementary cubes randomly joined which is greater than 5^3, but apparent stiffness, elastic limit and strain-hardening are greatly influenced by the size of the elementary cubes (see Figure 1) and by the gluing process.

This is especially revealed by triaxial tests ; let q be the deviatoric stress, p_c the confining pressure (Figure 3) :

$$\sigma_2 = \sigma_3 = p_c \quad \text{and } \sigma_1 = p_c + q \qquad \text{are the principal stresses .}$$

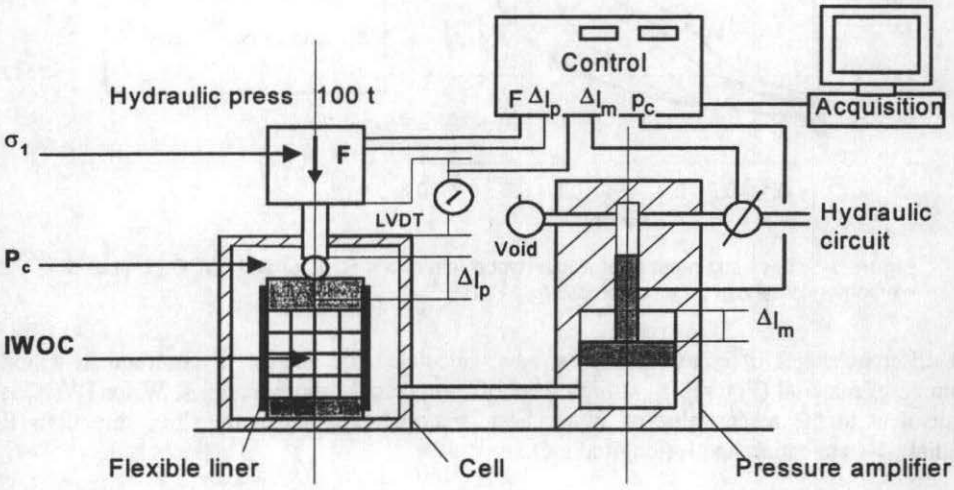
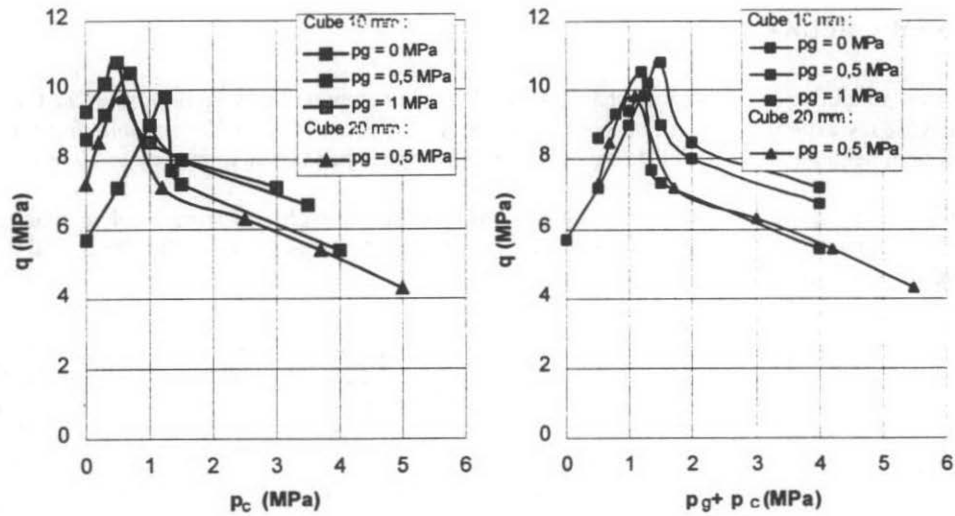


Figure 3 : principle of the triaxial test, performed in L.M.S., Ecole Polytechnique

Figure 4 (a) shows that the q value at elastic limit is first increasing with p_c (behaviour of a material with internal friction like a soil) then decreasing (behaviour of a cellular material, or a foam) with a slope of the (q, p_c) curve (–1) indicating that the sum $p_c + q = \sigma_1$ is constant (we encounter there the behaviour described in FRANÇOIS and MORLIER (1993) and the so called "box-like criterion") ; but the curve depends on the size of elementary cubes and on the gluing pressure p_g.

If the q value is plotted versus the sum $p_g + p_c$ like on Figure 4 (b), a unique critical value of ($p_g + p_c$), called prestress pressure, is evidenced : 1.2 MPa.

A gluing pressure of 1.2 MPa allows to optimize the material as an impact absorber, whatever the size of the elementary cubes are ; on the other hand, and for a given gluing pressure, the small size elementary cubes produce the best mechanical performances.



(a) (b)

Figure 4 : Evolution of the deviatoric elastic limit:
(a) versus confining pressure p_c for different gluing pressures p_g
(b) versus p_g+p_g

Lateral reinforcement, with a metallic casing or glued composite materials, is a way to improve mechanical performances of IWOC as impact absorber, but (Figure 5) metallic liners can have a negative influence in term of energy absorbed per unit mass.

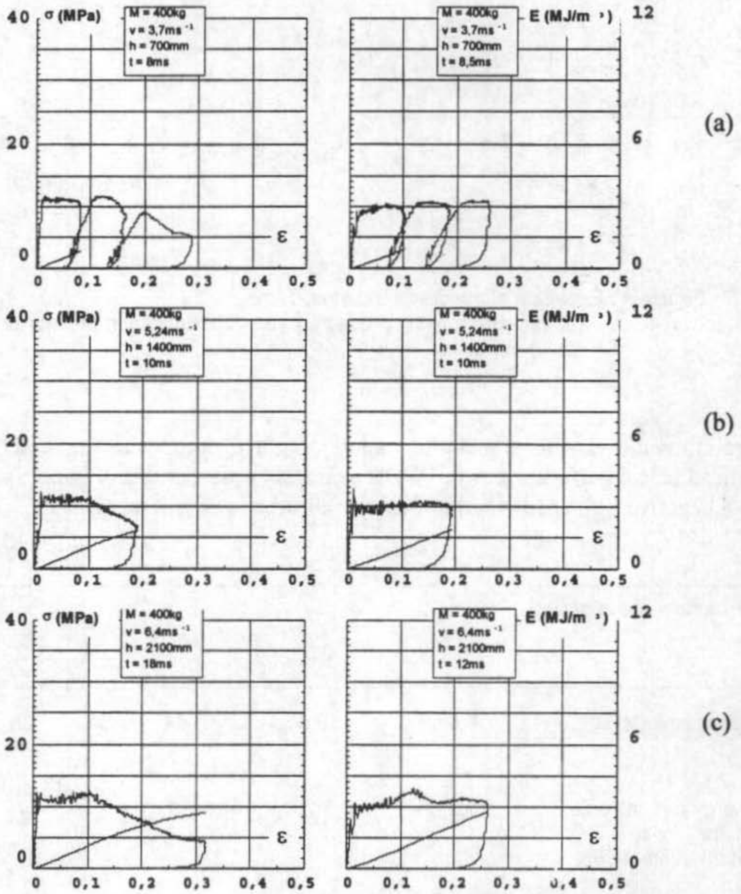
Thickness of the casing	0	0,5	1	2
Elastic limit (MPa)	6,5	10,5	14	25
Energy per unit volum (MJ/m^3) for a deformation of 35%	3,5	5,2	6	7
Energy per unit mass (MJ/kg) for a deformation of 35%	8,1	9,6	9,5	8,3

Figure 5 : Energy absorbed per unit volume or unit mass according to the thickness of a metallic casing (size of elementary cubes : $(3\ cm)^3$).

DYNAMIC BEHAVIOUR

Tests for obtaining the dynamic behaviour of IWOC in compression were performed at the CEA-CESTA experimental unit on a test-machine MTS : a mass (90 to 700 kg) falls from a maximum height of 4.5m, that is to say with a possible speed just before impact up to 10 ms^{-1}.

The Figure 6 represents the response of the IWOC material, with two sizes of elementary cubes to impacts, or re-impacts when the energy level is the weakest (a) : the stress-strain curve and the energy-strain curve are represented.



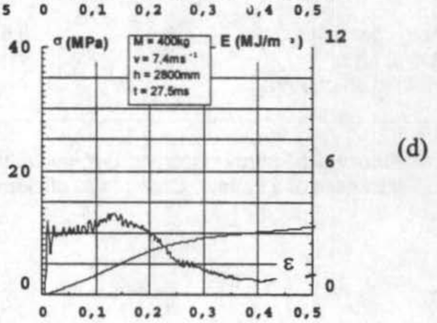


Figure 6 : dynamic behaviour of IWOC with small energy level. Left and right column are concerning two sizes of elementary cubes [resp. $(2\ cm)^3$ and $(3\ cm)^3$]

The main results of this part are the following :

- The elastic limit in dynamic compression is 1.45 times the elastic limit in static conditions for the tests having the smallest energy level - (a) on Figure 6 - and generally speaking is sensitive to strain rate. The mechanical performances are better during impacts than in static conditions; however, for an equal impact energy, the initial instability is more pronounced with a high speed of impact (see Figure 7).

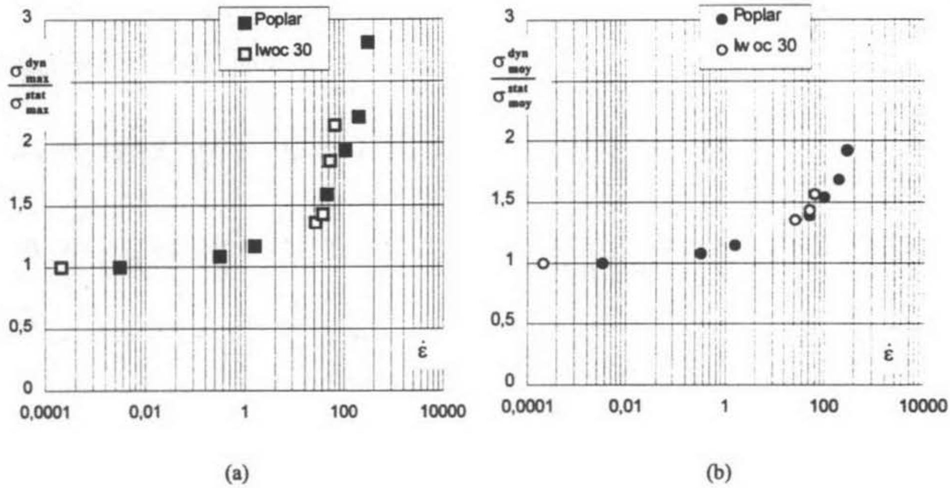


Figure 7 : evolution of the peak stress (a) and mean stress (b) for dynamic compression tests compared to static conditions, versus mean strain rate $\dot{\varepsilon}$.

- The size of the elementary cubes has still an influence on the dynamic mechanical performance of IWOC.

- IWOC reinforcement by a lateral composite material is a good way to increase the mechanical performance with a small extra-weight, if the deformation is not greater than 25%.

- IWOC reinforcement by a metallic casing, if its thickness is small, is a good way to stabilize the deformation process during impact and the compression can be as high as 50% ; nevertheless, the metallic casing induces an instability at the beginning of the deformation which can be a disavantage for energy absorption.

In conclusion to this part, we can notice the excellent reproducibility of the test results. When the compression process is stabilized by a metallic casing, IWOC behaviour is reliable : IWOC is able to store 10 MJ/m^3 at a deformation of 50% and for an impact speed of 10 ms^{-1}.

CONCLUSION

We developed a composite material which is a random assembly by gluing of small cubes of Poplar wood I.214. This material is sensitive to hydrostatic pressures and, consequently, to the stiffness of lateral confining systems. Its dynamic and static performances for energy absorption are reliable and interesting (0 to 10 MJ/m^3), when compared to the performances of other, anisotropic, wood based materials.

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