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Strain rate effects on the compressive response of wood and energy absorption capabilities – Part B: Experimental investigation under rigid lateral confinement

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A B S T R A C T

The compressive properties of spruce and beech wood species at a large range of strain rates – from 0.001 to 600 s^{-1} – under rigid lateral confinement have been investigated, using an original experimental device especially developed for the purpose. The work is motivated by the need to explore the dynamic behavior of wood up to large strains close to 70%. Three experimental apparatus have been used to obtain the compressive responses: the quasi-static tests have been performed using a Sintech 20D test system, the compressive responses at intermediate strain rates have been obtained with an Instron VHS65/20 apparatus and the dynamic tests have been conducted using a Split Hopkinson Pressure Bars (SHPB) system. The strain rate sensitivity of wood is clearly visible on the crushing strength with an increase between 80 and 155% but also on the plastic like behavior. In addition, the entire responses exhibit an elastic-plastic like behavior whereas an elastic brittle behavior could be observed, in the previous Part A which was focused on the compression configuration without lateral confinement. Even if no significant effect of the rigid lateral confinement is observed on the apparent Young modulus and the crushing strength values for both species, the wood energy absorption capability is better when longitudinal failure mechanisms are restricted thanks to the rigid lateral confinement.

1. Introduction

Wood is a natural cellular material [1] which is extensively used as protective material for impact loadings [2]. It is used as core material in sandwich structures [3,4], as a guardrail on roads [5] or as energy-absorbing material in impact limiters of transport packages for radioactive material [6,7]. In this way, investigations on the dynamic properties of wood are of primary importance in the context of high strain rate loadings and they clearly indicate the strain rate sensitivity of wood material [8,9]. Nevertheless, for the latter use, the structures consist in a metallic capsule divided into several compartments which are filled with wood blocks. It appears that wood properties depend on lateral restrictions, especially under dynamic loadings in the longitudinal direction [7]. It is essential to deeply understand the wood behavior for general stress states since complete data set of material properties is imperative for performing efficient and accurate numerical simulations of wood under impact loading.

In the previous paper, Part A [9], it was found that in general wood exhibits strain-rate dependent behavior in its three orthotropic directions. However, in compression parallel to the grain brittle failure mechanism occurs beyond the pic load leading to the loss of the plateau stress, and in turn this leads to significant reduction of energy absorption capability. This is the main reason why in practice the wood blocks dedicated to energy absorption are generally filled in metallic jackets to prevent splintering and premature failure mechanisms in the longitudinal direction.

In the present study, it is proposed to extend the previous work on unconfined specimens [9] to laterally rigid confinement conditions, assuming that the behavior of real structural parts in the context of impact limiters is bounded between these two extreme behavior limits.

Similarly to the Part A, experiments were conducted at quasi-static, intermediate and dynamic regimes with rigid confinement devices to evaluate the effect of strain rate combined with the lateral confinement on the compressive properties of wood within the three material directions. Consequently, the paper presents and compares at various strain rates, from 0.001 to 600 s^{-1}, the compressive response of wood

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specimens within a rigid lateral confinement against the corresponding unconfined specimens. In addition, the main parameters involved in the compressive stress–strain relationship as well as the deformation and failure modes are compared and discussed.

2. Material and method

2.1. Wood material

As in the previous work by the authors [9], spruce and beech are the investigated wood species. This choice is justified, in the one hand, by the difference in specific density (around 0.38 and 0.71 for spruce and beech respectively at a moisture content of 10 ± 1%), which is closely related to the mechanical properties, and on the other hand, by the difference of the microstructure of the both species [9]. The geometries of the wood samples have been prepared by taking into consideration the different apparatus, the length-to-diameter ratio of the specimens and also the dimensions of cells [10] to be in accordance with the Representative Elementary Volume (REV) requirements. Thus, a tracheid is 2–4 mm long with a ratio (length/diameter) of 100:1, the fiber is 1–2 mm long with a similar ratio of 100:1, while the length of a vessel is 0.2–1.2 mm and its diameter up/around 0.5 mm. Considering, as unit cell, tracheids for spruce and fibers for beech, it can be determined a REV for each direction. It is recommended [11] to consider at least 6 or 7 unit cells in each material direction to respect the REV and thus to prevent the size effect. Consequently, minimal lengths can be estimated and they are ranged, for the longitudinal direction, between 24–28 mm and 12–14 mm for softwoods and hardwoods, respectively. Along the transverse directions, minimal lengths of 0.3 mm and 0.15 mm are respectively obtained for spruce and beech.

2.2. Experimental procedure

2.2.1. Low strain rate set-up

A screw driven testing machine of type Sintech 20D (Fig. 1(a)) is used to perform the quasi-static tests. Force levels up to 100 kN are allowed and a maximal speed of 100 mm.min^{-1} can be used. The rigid confinement is ensured by a rigid steel hollow cylinder and two pistons crush the sample positioned inside the hollow cylinder (Fig. 1(b) and (c)). For these tests, two configurations of hollow cylinder are used depending on the loading direction of the tested specimen. For the longitudinal direction, the inner diameter is 20 mm and the outside diameter is 40 mm while for the transversal directions (radial and tangential) the inner and outer diameters are 35 mm and 55 mm respectively. A set of two 70 kN piezoelectric load cells (Kistler 9343a (Fig. 2)) with a threshold close to 0.02 N are chosen to measure the current forces. The first one is fixed on the rigid frame of the testing machine while the second one is mounted on the mobile traverse. The displacement and thus the specimen crushing versus time is obtained using an electro-optical extensometer (Rudolph XR200 (Fig. 2)) with a 200 kHz bandwidth allowing to track a set of two focal points up to high speed, and a 50 mm lens with a resolution of 50 µm. It can be indicated that the set of signals is recorded using an eight-channel oscilloscope (Yokogawa DL750-10 MHz).

Table 1
Dimensions of the specimens (in mm).

Species	Direction	Strain Rate regime	Diameter size	Height
Spruce	Longitudinal	Quasi static	20	25
		Intermediate	16	20
		Dynamic	20	25
	Transversal	Quasi static	35	20
		Intermediate	20	10
		Dynamic	35	20
Beech	Longitudinal	Quasi static	20	20
		Intermediate	10	10
		Dynamic	20	20
	Transversal	Quasi static	35	20
		Intermediate	20	10
		Dynamic	35	20

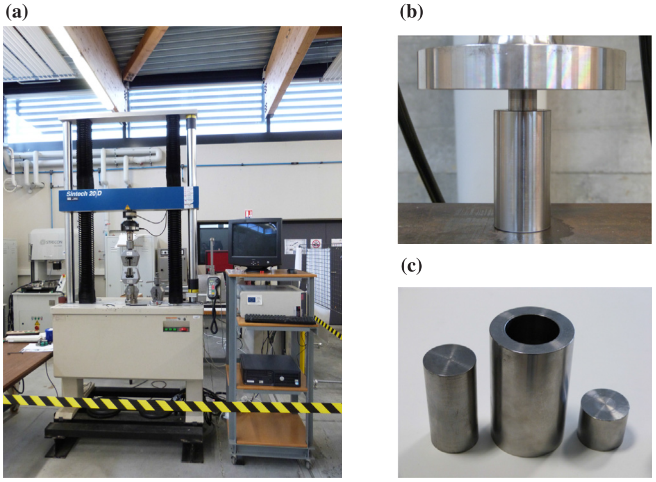

Fig. 1. (a) Quasi-static testing machine Sintech 20D, (b) Compression configuration, (c) Rigid confinement device with pistons.

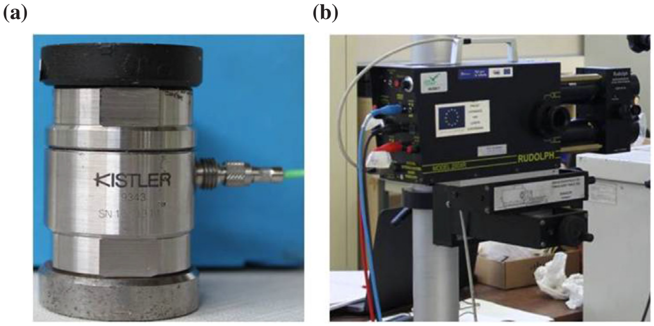

Fig. 2. (a) Piezoelectric load cell (Kistler 9343a) – (b) Electro-optic extensometer (Rudolph XR200).

2.2.2. Intermediate strain rate set-up

A dynamic testing machine (Instron VHS65/20 (Fig. 3(a)) with loading capacities up to 70 kN and a speed loading ranged from 1 mm.s^{-1} to 20 m.s^{-1} is employed. To ensure a test in closed loop conditions at moderate velocity, it was necessary to limit the maximum force to 10–12 kN by reducing the cross sections of samples. The confinement device (Fig. 3(c)) dedicated to the test machine is quite complex in order to allow to the rising rod to reach the imposed speed, without inertial effects and to ensure the test under safety conditions. A dedicated facility (Fig. 3(b)) is required under compression loadings to avoid the global buckling of the moving rod. It was decided to conserve the measurement conditions of quasi-static strain rate hence both 70 kN load cells mentioned previously are used. The first one is fixed on the rising rod and the second one is mounted on the rigid frame. In this way, both load cells are placed on each side of the tested specimen and it is thus possible to check the balance of forces during the compression test. The displacement is measured with the same electro-optic extensometer as in quasi-static. However, it is a 25 mm lens with a resolution of 25 µm which is used due to the reduced sizes of samples under intermediate regime.

2.2.3. High strain rate set-up – Hopkinson bars apparatus

A SHPB system modified with an original confinement device,