Acoustic emission of poplar wood subjected to compressive loading

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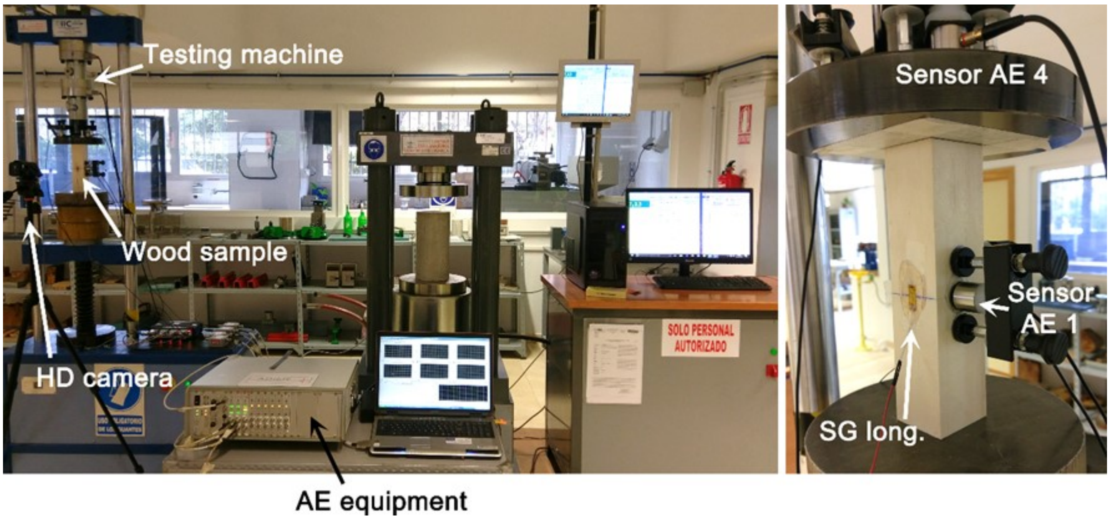
1 Purpose

To enable an increased use of wood products for construction there is a need to include products based not only on softwoods. Poplar-based products are an excellent and promising tool allowing to develop sustainable strategies, as fast-growing species reduce pressure on natural forests. In this direction, this paper presents a relationship between mechanical properties under compressive loading (strength, modulus of elasticity parallel to grain, and Poisson ratio) of one of the most commonly planted clones, I-214, and the spectral response of the acoustic emission signals and the process of fracture observed visually and microscopically.

2 Material and Methods

To characterise the mechanical behaviour of Populus x euramericana (Dode) Guinier "I-214", 90 samples (nominal area A=50x50 mm2, and length L=200 mm) of clear wood were monotonically loaded parallel to grain on a universal testing machine, with a constant displacement speed equal to 0.6 mm/min. Four randomly selected samples were instrumented with four AE sensors each, located as shown in Figure below. For comparison reasons, two types of sensors were used: multiresonant VS45-H (shortly named as MR), and broadband FC 2045S sensors (named as BW). During each test, the acoustic emission was recorded with the four sensors using an ANSY-5 equipment from Vallen Systeme. For each recorded signal, the peak amplitude in dBAE (A), the duration (Dur), and the following features were obtained: 1) Fmax: Frequency at which its spectrum reaches the maximum value; 2) Spectral ratio at two different frequency ranges (low frequencies: [50-250 kHz] and high frequencies: [250-500] kHz); 3) Ratio of spectral energy, representing the proportion of spectral energy between the considered high and low frequency bands.



3 Results

Results from multiresonant and broadband sensors show that multiresonant sensors can detect the mechanism of low frequency damage at the beginning of the load, but broadband sensors outperform at detecting the onset of the fibre buckling and the appearance macrocracks.

4. Conclusions

Acoustic emission techniques have a wide range of applications in non-destructive testing and can detect cracking and mechanical damage. Yet sources generating AE in different materials are unique. Experiments from I-214 poplar samples under static loading parallel to the grain suggest that AE is associated with damage to the cell walls before buckling.

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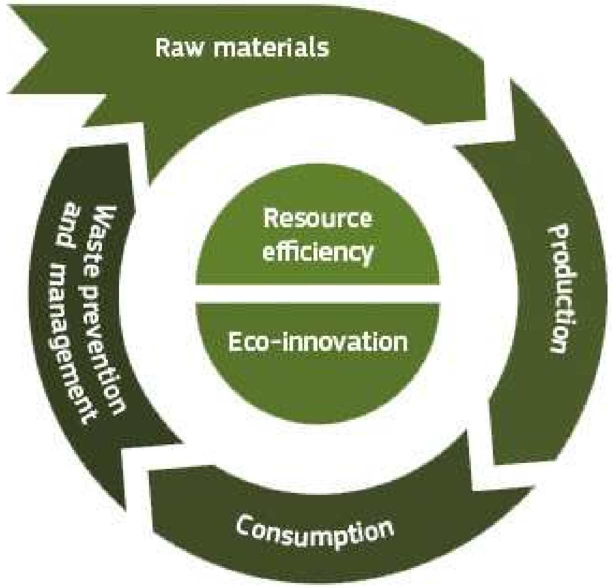
Outline

1. **Motivation**
2. **Wood in compression**
3. **Mechanical testing program**
4. **AE data analysis**
5. **Mechanical results**
6. **AE emission results**
7. **Main conclusions**

- **Climate change** is currently one of the biggest challenges of our Planet
- **Construction sector** represents 40% of the final energy consumption, 35% of the greenhouse gas emissions, and 35% of the total waste generated in the World
- Against this situation, **renewable materials like wood** will play an important role in the near future



The **main advantages** of building with wood:

- **Fast:** shorter building times
- **Light:** very good strength-weight ratio
- **Green:** sustainable especially when using bioenergy

The **poplar wood** resources are providing alternative materials to the softwood-based building products

Main advantages:

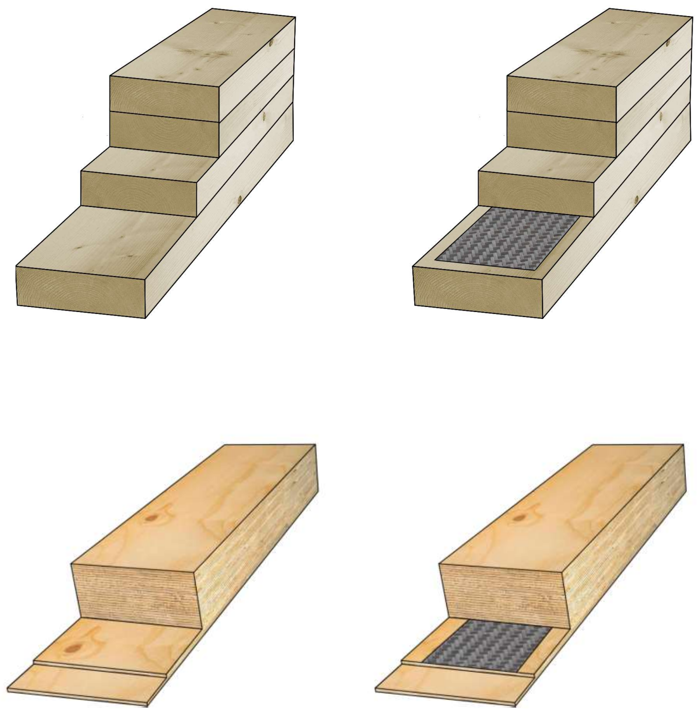
- Poplar trees can be growth in planted forest
- Poplar trees have high growth rate and high carbon sequestration rate

The main objective (COMPOP Project) is:

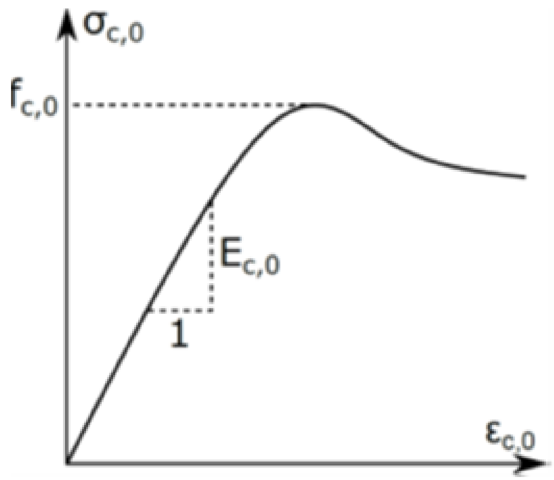
- To develop **engineered wood products (EWPs) based on poplar** like GLULAM (*Glued Laminated Timber*) and LVL (*Laminated Veneer Lumber*)

- **In order to meet the safety and stability requirements, the resistant capacity and the stiffness of the wood under loading need to be determined**

- In this work: **Behaviour of poplar wood under compression is evaluated** with the help of the AE method



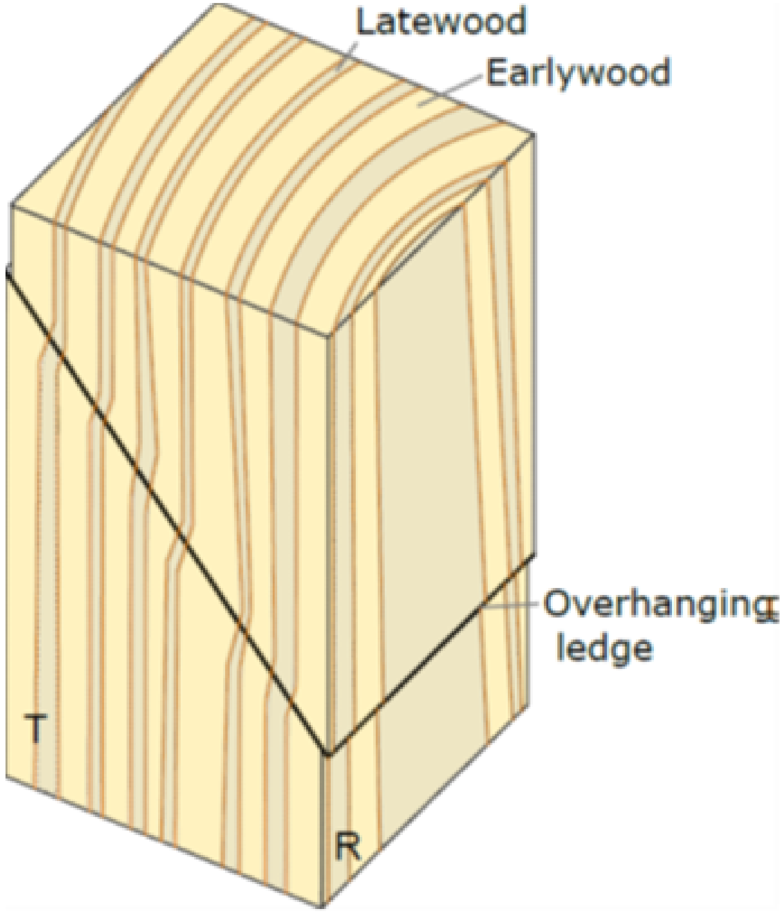
- **Timber is an anisotropic material**, with different elasticity and strength parallel and perpendicular to the grains
- **Wooden specimens under compression parallel to the grain typically show an elasto-plastic behavior**
- **The mechanical behavior can be described by the modulus of elasticity Ec,0 and the strength fc,0 (maximum stress)**



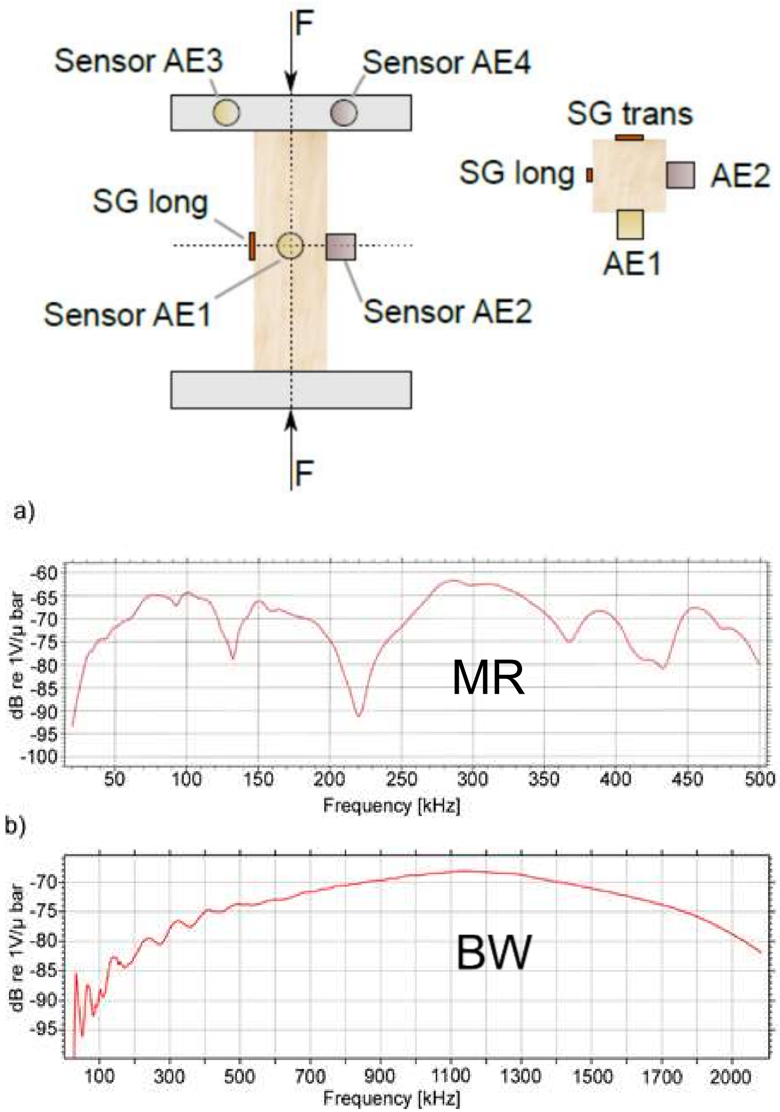
2. Wood in compression

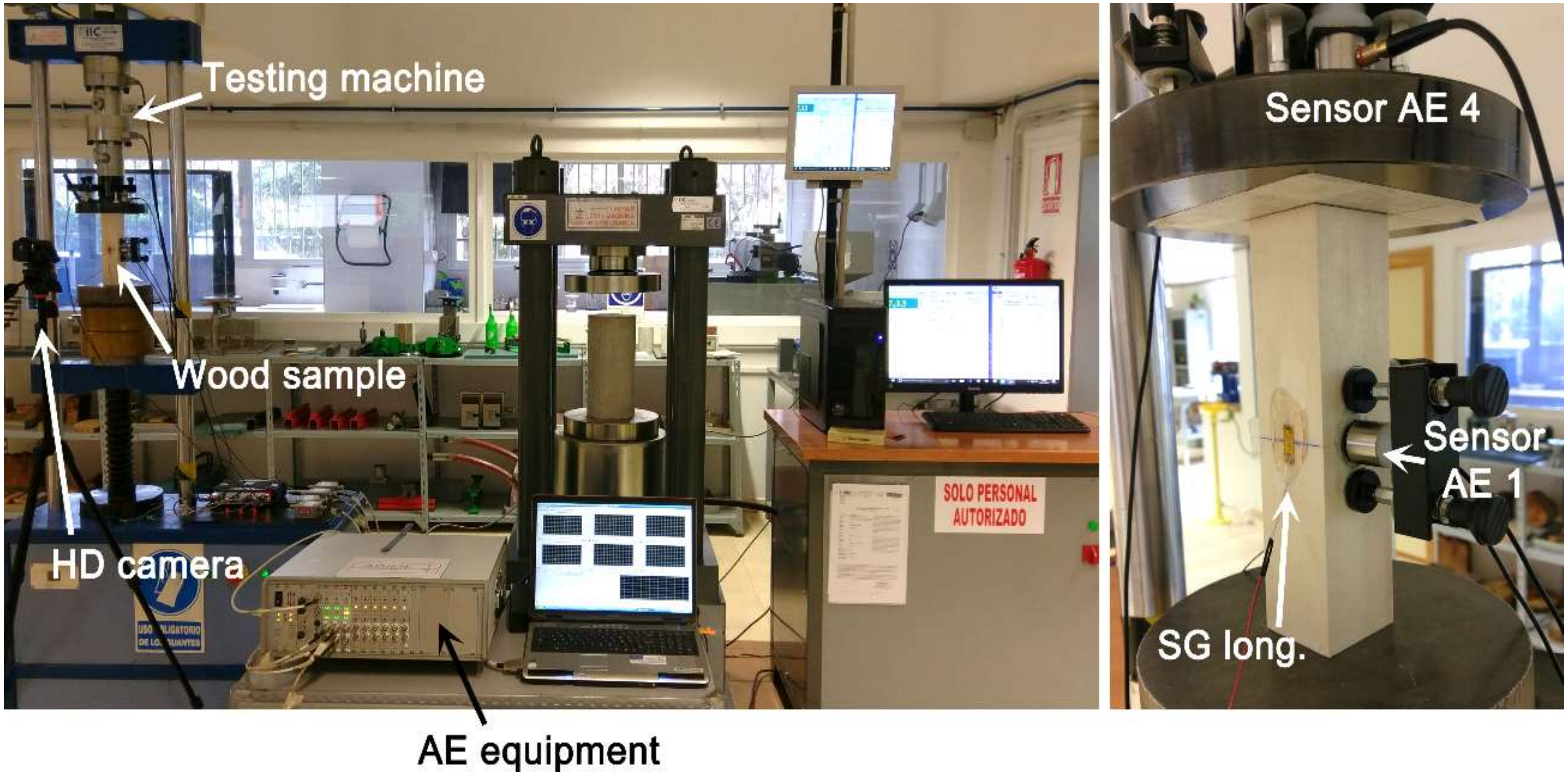
- The expected failure in compression shows fracture bands running perpendicular to the grain on the radial face and obliquely on the tangential face
- Fracture occurs due to buckling of timber fibres in a thin layer (~0.2 mm wide)

Grossman, P. U. A., & Wold, M. B. (1971). Compression fracture of wood parallel to the grain. Wood Science and Technology, 5(2), 147-156. https://doi.org/10.1007/BF01134225



- **90 samples of clear poplar** clone “I-214” from 15 trees
- Cross section: S=50x50 mm^2; L=200 mm
- **Monotonic test parallel to grain** at 0.6 mm/min.
- **Two strain gauges perpendicular each other**:
  Poisson ratio: $\boldsymbol{\nu} = -\varepsilon 90 / \varepsilon 0$
- **Sensors 1, 2:** MR (VS45-H) and BW (FC 2045S)
  Sensors 3, 4: Guard sensors
- MR sensors have maximum sensitivity
  at 100, 150, and 300 kHz
- BW sensors have a flatter response and
  low sensitivity below 300 kHz





Testing machine
Wood sample
HD camera
AE equipment
SOLO PERSONAL AUTORIZADO
Sensor AE 4
Sensor AE 1
SG long.

4. AE data analysis

For each AE signal, the next features were obtained:

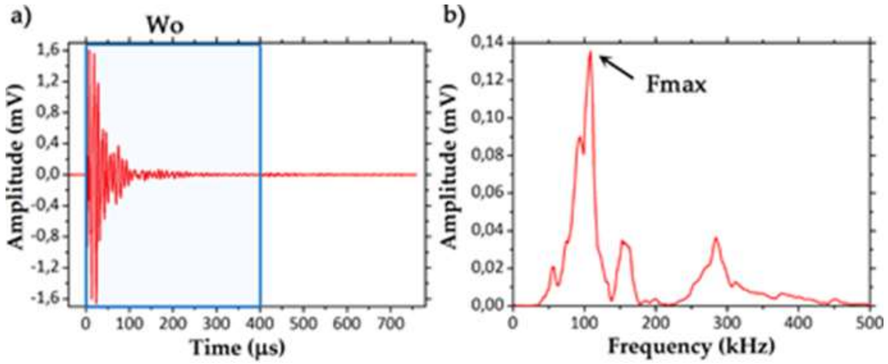
- The **peak amplitude** and **duration**

- **Fmax:** Frequency at which its spectrum reaches the maximum value

- **Spectral ratio:**

$$SR1 = \frac{\sum_{[50-250]kHz} S}{\sum_{[50-500]kHz} S} \ (low\ frequencies)$$

$$SR2 = \frac{\sum_{[250-500]kHz} S}{\sum_{[50-500]kHz} S} \ (high\ frequencies)$$

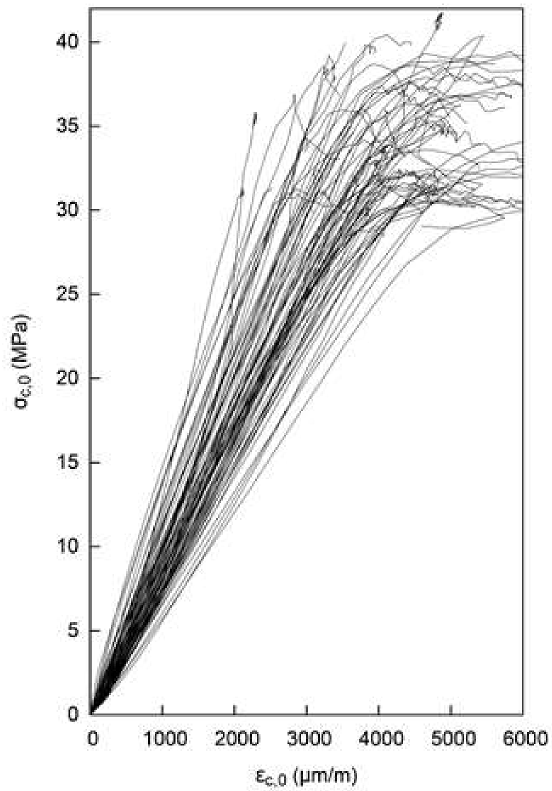


- **Ratio of spectral energy**:

$$S12 = \frac{SR2}{SR1}$$

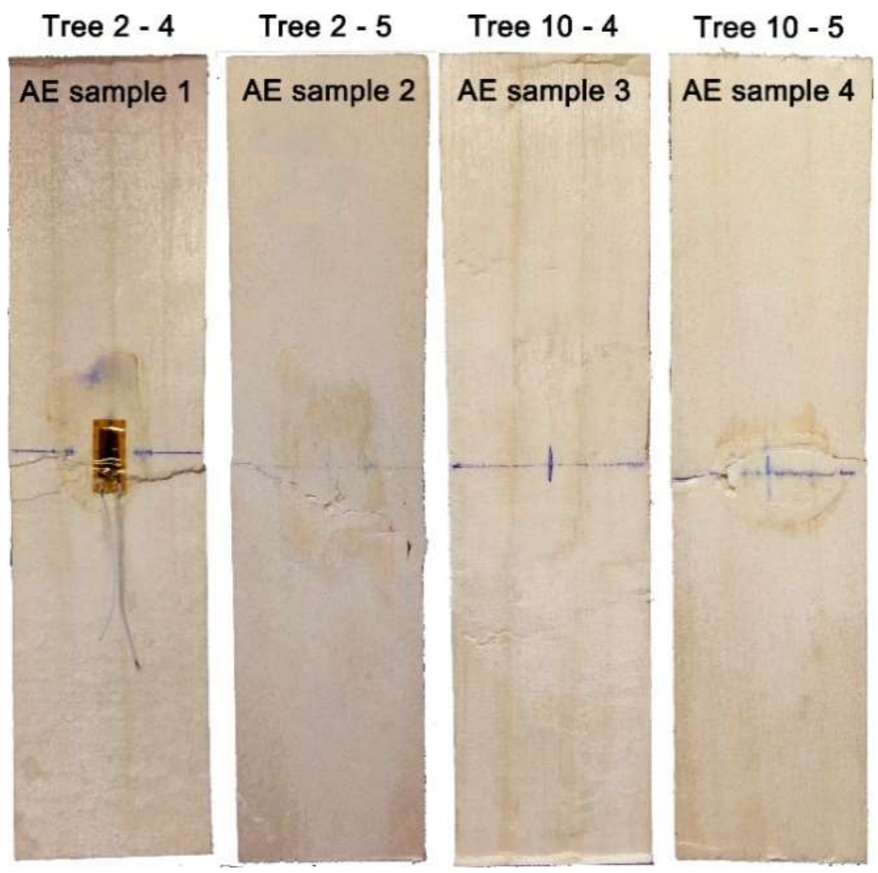
5. Mechanical results

- **A high variation of the mechanical properties is observed, which is inherent to the biological materials**
- All the samples show an expected elastic-plastic behaviour
- Compressive strength ranges between 28.9 and 41.4 MPa and the modulus of elasticity ranges between 6652 and 11857 MPa
- The average Poisson ratio was 0.37



	$f_{c,0}$ (MPa)	$E_{c,0}$ (MPa)	ν
Average value	34.4	8775	0.37
5% percentile	30.4	7021	0.28
95% percentile	39.8	11333	0.45
CoV (%)	9.3	15.4	14.7

The failure pattern: Fracture ocured by local buckling of the timber fibres



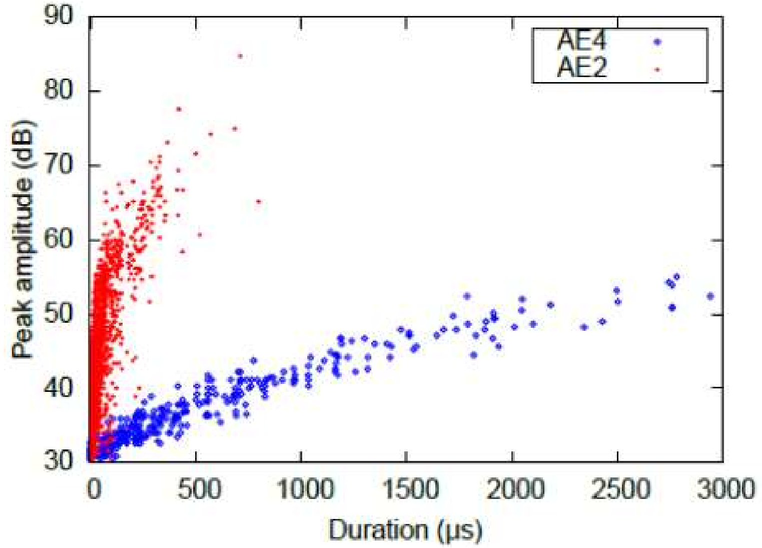
- **The signals are grouped in two separated clusters**

- **Blue-cluster** corresponds to the signals hitting first the sensors mounted on the clamps

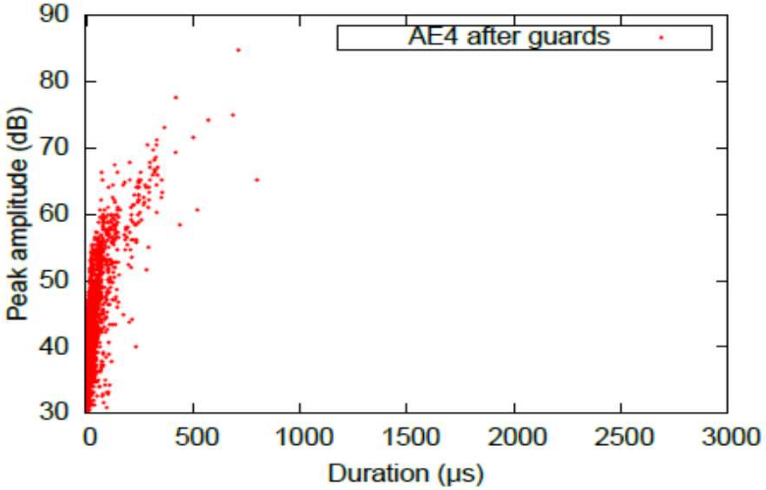
- All these signals of the **blue-cluster** are eliminated by the guard filter

- **This result demonstrates the effectiveness of the use of guard sensors**

BEFORE GUARD SENSORS

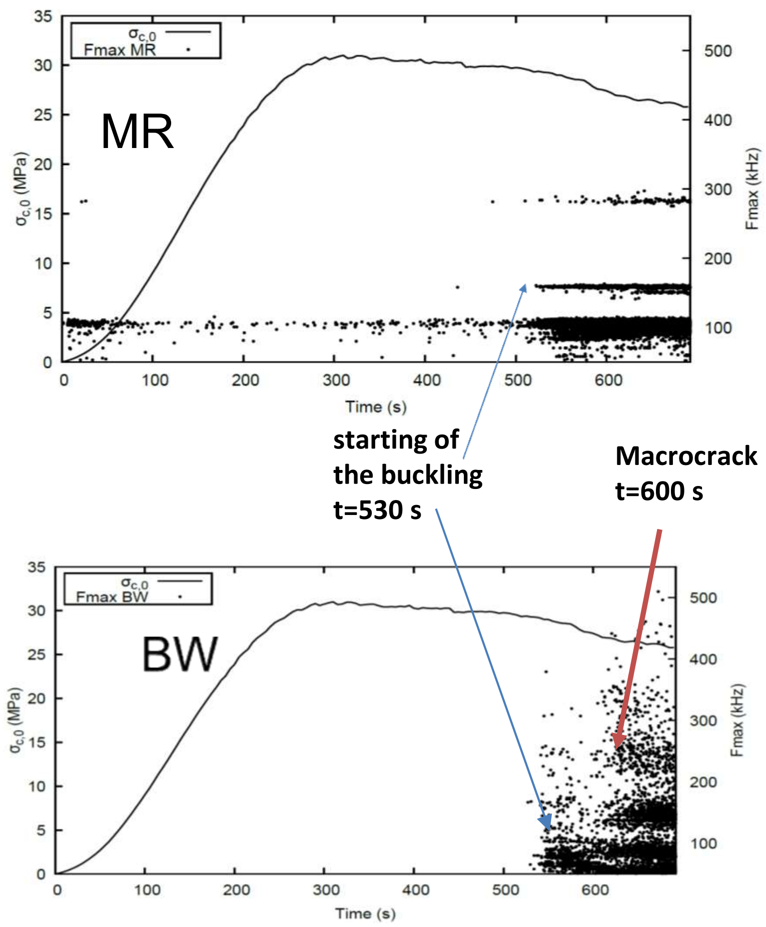


AFTER GUARD SENSORS



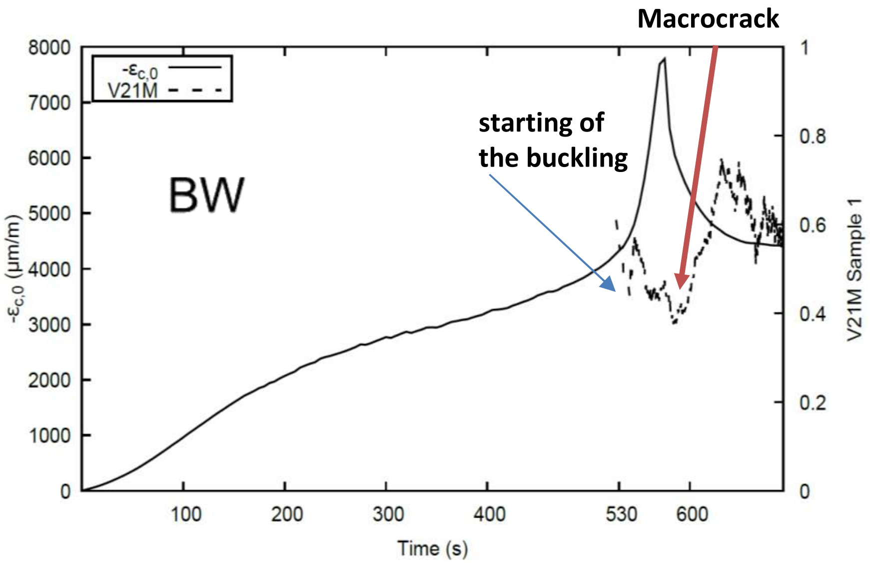
6. AE results

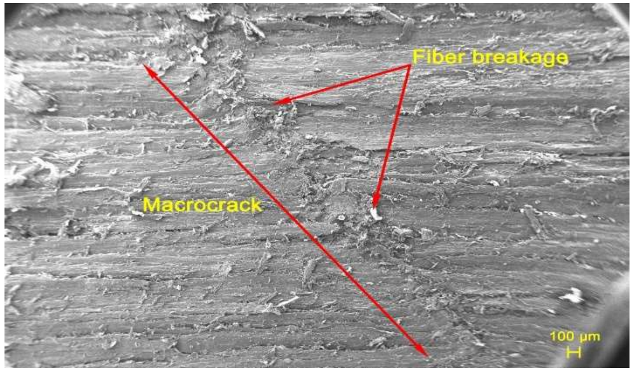
- Before t=530 s, **Fmax** is around 100 kHz for MR sensors and no emission is recorded for BW sensors
- From t=530 s, **Fmax** starts to increase for both MR and BW sensors
- For MR sensors, **Fmax** is distributed around the three resonances and no significant changes are observed beyond t=530 s
- For BW sensor, **Fmax** decreases around t=600 s
- These results show that although **MR sensors detect the onset of the global buckling of the specimen at t=530 s, they are not able to detect the appearance of the final macrocrack**
- **However, BW are able to detect the onset of the fibre buckling and also the appearance of the macrocrack**



6. AE results

- **Moving average of the ratio of the spectral energy, S12**
- A significant increasing of S12 is observed at 530 s due to the increase of AE at high-frequency components. This increase is due to a significant **change in the strain** and the **observation of buckling**
- A clear minimum of S12 is observed at 600 s corresponding with a relevant decrease of the strain and the **observation of the final macrocrack**





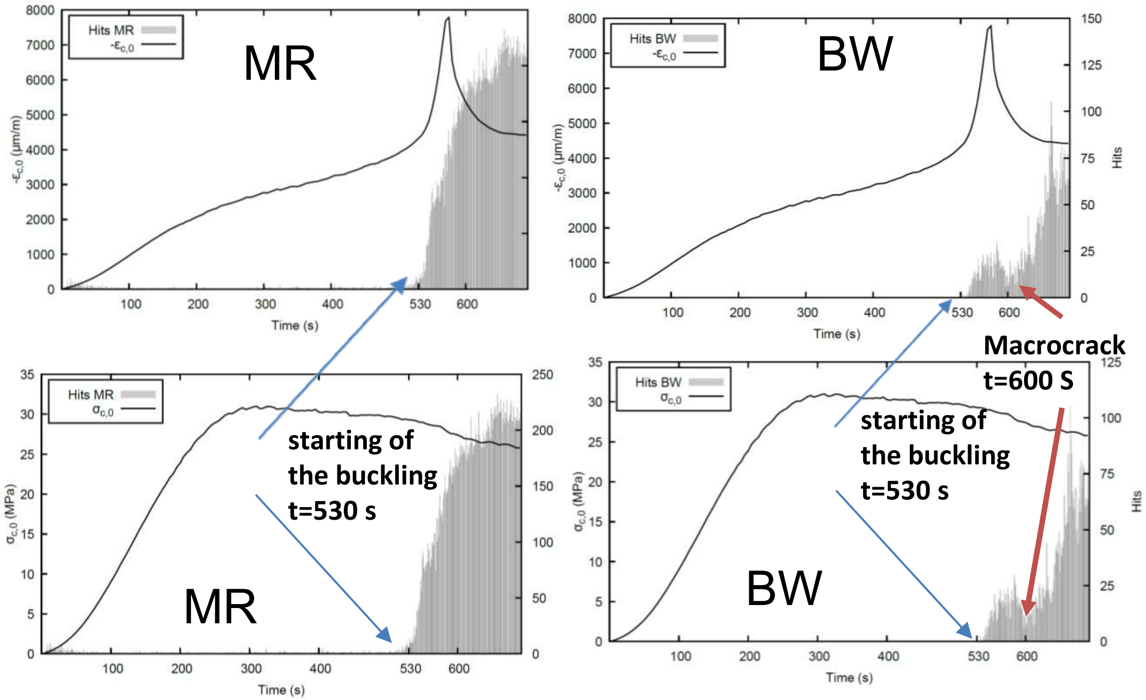
7. Main conclusions

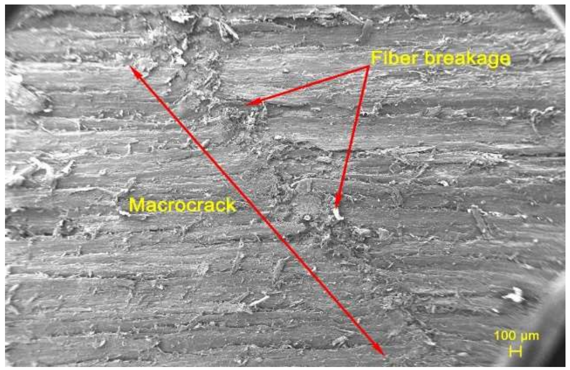
- MR sensors can detect the mechanism of low frequency damage at the beginning of the load, but BW ones outperform at detecting the onset of the fibre buckling and the appearance of macrocracks

- Ratio of the spectral energy, S12, can successfully be used as a reliable AE feature for detecting the onset of the fibre buckling and the appearance of macrocracks

http://ewgae2020.ugr.es/

- Strong difference is observed between both MR and BW sensors
- **For MR sensors**, permanent low-amplitude AE activity from the beginning of the test, increasing at t=530 s
- **BW sensors** did not record activity before t=530 s. From t=530 s, the activity also increases, but decreasing again until a local minimum at t=600 s





Thank you for your attention

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