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OPTIMISING THE MECHANICAL CHARACTERISATION OF A RESILIENT INTERLAYER FOR THE USE IN TIMBER CONSTRUCTION

Luca Barbaresi, Federica Morandi, Juri Belcari, Andrea Zucchelli and Alice Speranza
University of Bologna – Department of Industrial Engineering, V.le Risorgimento 2, 40136 Bologna, Italy
Rotho Blaas GmbH
email: *luca.barbaresi@unibo.it*

Resilient interlayers are used in the field of building acoustics to reduce the transmission of vibrations through the flanking transmission paths. To this end, EPDM rubber or polyurethane strips are often used as dampers and therefore a complete mechanical characterisation for these materials is required. Most of the time, the mechanical characterisation has been related to the use as damping materials to be used in “standardised" application, such as industry. This paper reports the mechanical characterisation of an extruded polyurethane strip to be used in timber buildings. The mechanical characterisation of the strip was conducted according to standard tests (tensile, compression) on macro samples as well as using the DMA in tensile and shear mode, over a wide temperature range. The stress strain relation in compression was evaluated loading the sample with different boundary conditions in order to take into account the friction provided by different supports. Steel plates, timber lamellas and the “ideal" situation without friction were tested, pointing out the peculiar characteristics of the material when used as interlayer in CLT buildings. Considerations are made relative to the extraction of the E modulus over different ranges and related to the real on-site application of the loads that might render necessary an insight into the definition of the elastic properties of such materials.
Keywords: building acoustics, resilient interlayer, polyurethane

1. Introduction

In building construction it is a good practice to uncouple elements which could be responsible for the transmission of vibration through flanking transmission paths. In frame structures the continuity of the structure across the junction allows the positioning of the resilient interlayer under non-load bearing elements. In CLT buildings the resilient stripes are placed between load-bearing elements and therefore a special attention must be paid to in analysing their mechanical behaviour. One has to consider various factors related to the use of those resilient interlayers in timber buildings. For instance, the profiles must be easily placed and fixed to the structure; they must provide little open porosity for on site installation might be done in critical weather conditions and finally the thickness of those profiles cannot exceed a certain limit due to structural constraints.

What has little been studied so far is the actual use of these interlayers from the side of the mechanical characterisation when used in timber structures. In particular while concrete or other heavy weight solutions can be regarded as infinitely rigid, timber profiles deform under the permanent structural and non structural loads. Therefore it is not totally correct to simplify the system as a mass-spring-mass system but the deflection of wood must be considered as well.

The aim of this work is to discuss the results of the measurements of the mechanical characteristics of a polyurethane cast profile used as resilient interlayer in timber buildings. This is done by characterising the material according to different ISO standards and adding some tests where boundary conditions have been changed in order to meet the most realistic situation of application and compare it to an ideal asymptotic behaviour.

2. Mechanical characterisation of viscoelastic materials

Viscoelastic materials are characterised by their elastic properties and by the long-term effects. They are usually described starting from two simple mechanical models that account for the overall behaviour through a spring, representing the elastic behaviour and a dashpot, representing the lossy behaviour.

The elastic properties can be analysed in static or quasi-static and in dynamic conditions. Dealing with Young's modulus, it can be evaluated using a quasi-static test, i.e. determining the ratio between the incremental stress and the incremental strain applying Hooke's law. Hysteresis cycles can be used to evaluate the energy dissipated due to the material internal loss. The dynamic elastic modulus can be derived from the Dynamic Mechanical Analysis as using a harmonic excitation and monitoring the response to deformation as a function of time. The stress/strain ration and the phase delay between the applied stress and strain response allow the definition of the Storage Modulus (E') as the ability of the materials to store energy and of the Loss Modulus (E"), the ability of the material to dissipate energy.

The viscous response of a materials is observed from the behaviour of the material in the long term, when subject either to a constant strain or a constant stress. Creep behaviour is the decrease in thickness of a system which is subject to the same load while stress-relaxation, the dual phenomenon, is the loss in load that must be provided to get the same displacement over time. Both phenomena can be modelled in terms of springs and dashpots. The Maxwell model, made by spring and dashpot connected in series, is used to represent stress relaxation while the Voigt model, made by spring and dashpot connected in parallel, is used to describe the creep behaviour. These simple models can be arranged to generate combined Maxwell-Voigt models but still suffer from the timescale needed to characterise the material in the long term. Therefore generalised Maxwell models, generalised Voigt models of Zener models can be used for better quantitative predictions [5].

Usually creep can be modelled as a simple Debye exponential decay, i.e.

$$y(t) = e^{-\frac{t}{\tau}} \tag{1}$$

being τ the time constant associated to the decay. It is commonly accepted that creep behaviour of polymeric materials is better fit by a non-linear exponential decay, expressed as:

$$y(t) = e^{-(\frac{t}{\tau})^{\beta}} \tag{2}$$

where τ is still the time constant and β is the non-linearity metric that ranges between 0 and 1. This is known as the Kohlrausch-Williams-Watts (KWW) function or *stretched* exponential function [4].

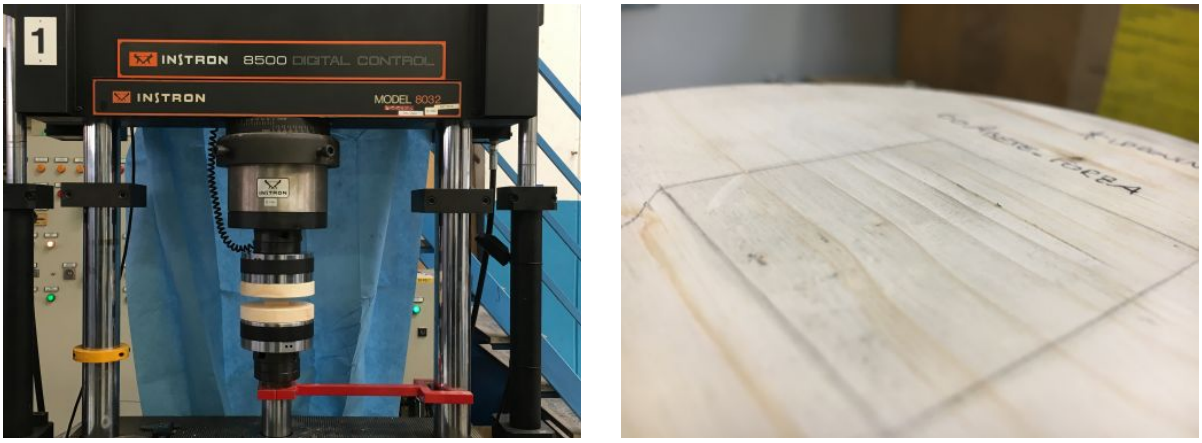
3. Method and tests

The material under test is a polyurethane profile which undergoes a spin-casting process. It is produced with different hardnesses and this work presents the analysis performed on samples displaying a hardness of 60 Sh (A) samples. The tests conducted in this preliminary campaign included quasi-static and dynamic characterisation with different boundary conditions. Here the testing procedure is briefly described and commented.

3.1 Compressive properties - ISO 604

Rectangular specimens were tested in compression using an Instron machinery, with a load cell with a capacity up to 100 kN. The standard procedure defined in ISO 604 [1] consider the sample compressed between steel plates. In this work, the measurements were repeated with different boundary conditions, i.e. changing the support in order to provide different frictions at the sample-support interface. In particular, these interfaces were used:

- steel-steel
- steel-steel + vaseline (no friction)
- wood-wood (fir)
- wood-wood (beech)



(a) Instron (b) Fir support

Figure 1: Sample of fir support deformed by the polyurethane specimen.

Two different wood species were chosen: fir, with a density of about 450 kg/m^3, and beech, with a density of about 750 kg/m^3. The two essences provide different superficial roughness (fir the highest) but also provide different superficial hardness; therefore it was deemed interesting to test the effect of the compression of the resilient profile with different timber elements.

The sample underwent a force-controlled compression up to a deflection of 30%. Measurements were also performed in a displacement-controlled compression, in order to verify the actual deformation of the sample when pliable supports are used. The data from the DMA were used to predetermine the loads and compression rates. When the 30% deformation was reached, the load was kept the same with a force-controlled observation period, which allowed a short-range estimate of the viscous behaviour of the material.

3.2 Dynamic Mechanical Thermal Analysis - ISO 4664

Another tool to determine the characteristics of the sample was using the Dynamic Mechanical Thermal Analysis (DMTA). The measurement equipment consisted of a DMA 242E Artemis NETZSCH and measurements were performed in compliance to the standard ISO 4664-1:2011 [2].

Three samples were analysed in tension mode, with dimensions 5 x 2 x 30 mm (15 mm maximum gauge length), a strain amplitude of $\pm 1\% \approx 150\ \mu$m, a strain force of 0.01 N and a temperature of 25 ^{o}C.

Table 1: DMA for a 60 Sh (A) polyurethane profile - Isothermal 25 °C

Metric	1 Hz	5 Hz	10 Hz	50 Hz
E' [MPa]	5.0	5.2	5.3	5.7
E" [MPa]	0.18	0.274	0.329	0.57
tan δ (tensile)	0.036	0.053	0.062	0.100

4. Analysis of the results

The results are presented in terms of elastic properties, through the evaluation of the stress-strain relation and the elastic Young's modulus, and in terms of viscous response, analysing the stress relaxation behaviour of some samples.

4.1 Elastic properties: stress-strain relation

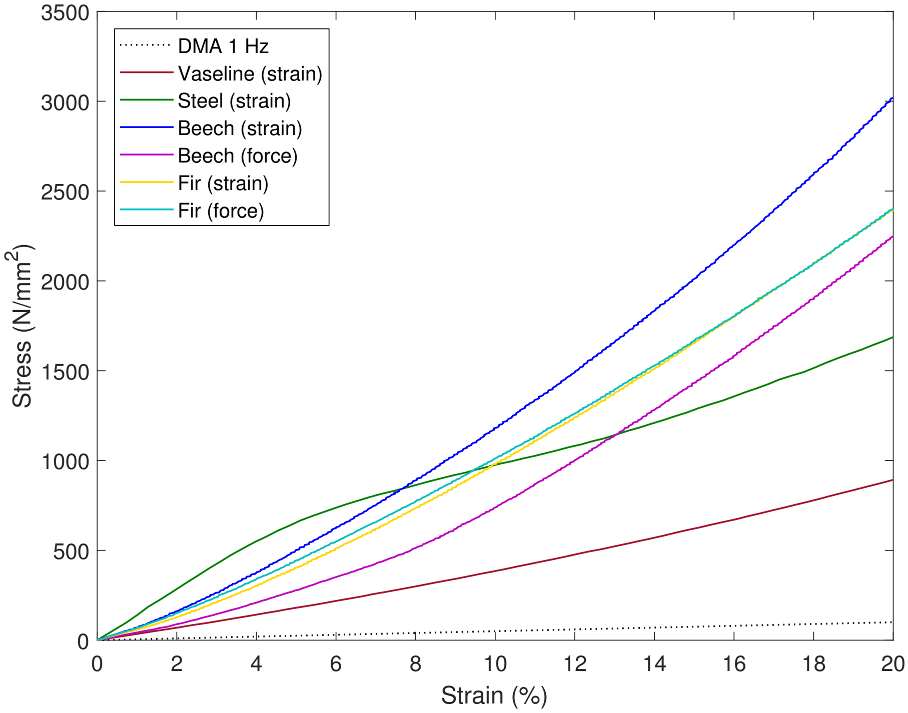


Figure 2: Stress-strain relation tested in compression under different friction conditions.

Depending on the system under analysis, the Young's modulus can be extracted over different frequency ranges. In general, for stiff materials the modulus is extracted over a stress-strain region at the very beginning. When dealing with viscoelastic material, the stress-strain relation can hardly be evaluated in this narrow region. Figure 2 shows the stress-strain relation for samples compressed approximately up to 30%. The strain rate was evaluated from the estimate of the Young's moduli obtained through the DMA, in order to provide comparable results.

Figure 2 plots the stress-strain relation measured with the different friction conditions (coloured lines), together with the results of the test conducted using the DMA (dotted black line). The compression test conducted with no friction led to a quite regular stress-strain curve, with a small concavity.

The case in which the test is conducted with a steel-steel support shows a flex occurring around a 10% strain, resulting in a steeper slope region for small deformations and a moderate slope for higher deformations. When the interface is timber-timber, the stress-strain relation does not display a bending point: the curve is similar to the frictionless behaviour, even though with a steeper slope, no matter the kind of essence. This lack of deformation might be due to the capacity of timber to compensate to the deformation of the specimen with a viscous capacity to respond to the deformation. For this reason, since timber provides a pliable support, measurements were repeated in force-controlled experiment, while with rigid support measurements were conducted in strain-controlled mode. As far as it concerns fir support, the two measurements superimpose with a very high correlation. As it concerns beech, the slope of the stress-strain relation is the same starting from a 10% strain, while for lower deformations there is a slight difference, being the strain-controlled test steeper in slope.

Starting from this data, the E modulus was calculated for each configuration over different strain ranges, i.e. 1-5%, 5-10%, 10-15% and 15-20%. Finally, the elastic modulus is evaluated over the whole curve. The results are shown in Figure 3. The quasi-static value of the E modulus tested with the DMA is 5 MPa (cfr Table 1), way different from the values determined here.

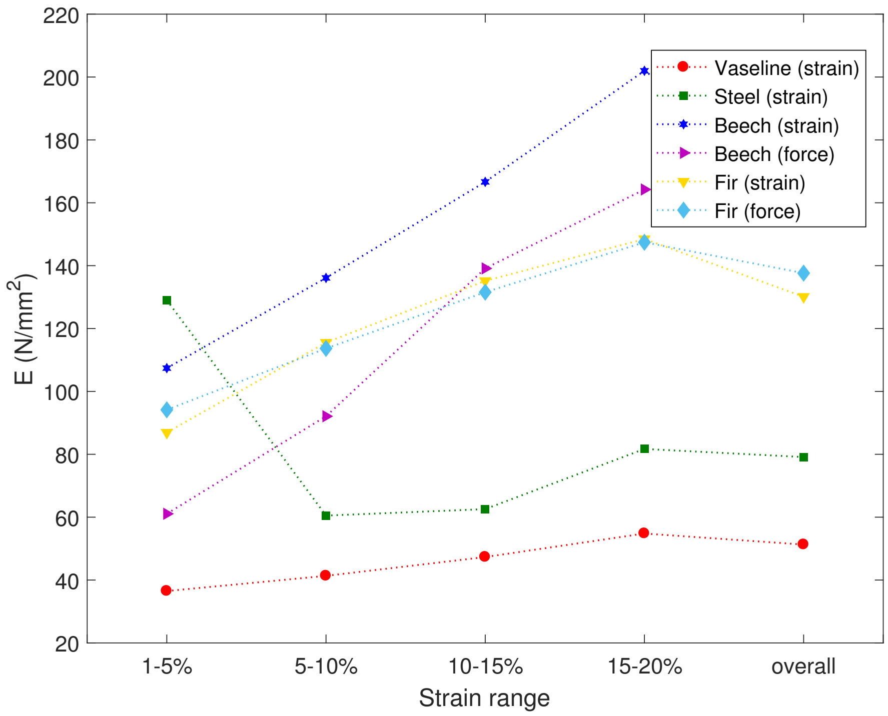


Figure 3: E-moduli calculated over different strain ranges for different friction conditions.

4.2 Viscous properties: creep and stress relaxation

After the compression, the sample was kept at a fixed strain (or stress when force-controlled measurements were performed) and the stress relaxation (or creep with force-controlled measurements) was evaluated. Figure 4 shows the stress relaxation phenomenon spot with different friction conditions: frictionless, steel-steel, beech-beech, fir-fir. The diagrams mark again a distinction between the different supports: regular trend for the vaseline, extremely steep slope and quick settling for steel-steel interface and a marked exponential decay for both kinds of timber, being the slight difference relative to the class of timber used. Together with the measured data, the simple Debye exponential is reported, derived from a least square fitting of the experimental data. The time constant of the exponential functions are reported in Table 2.

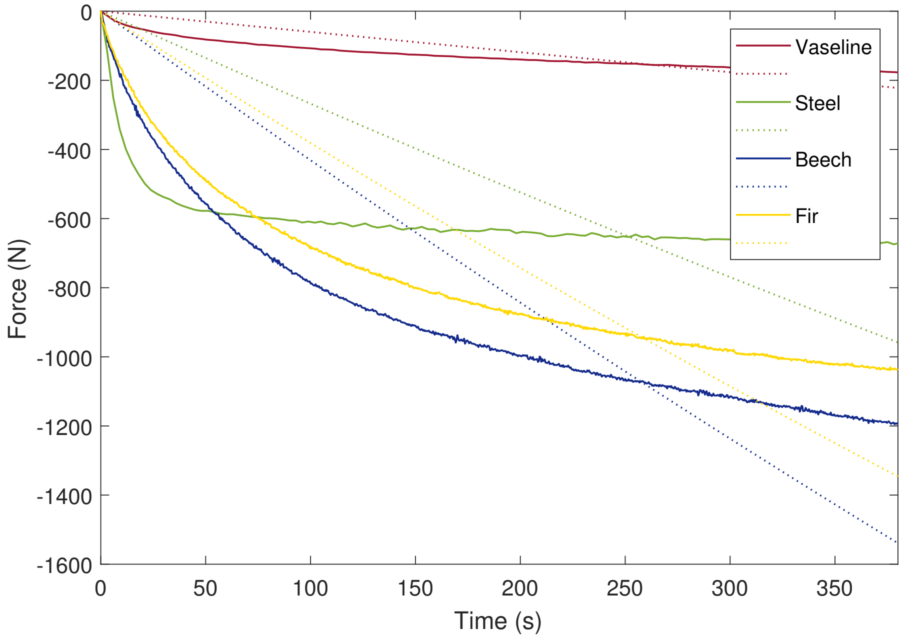


Figure 4: Debye exponentials used to fit the relaxation of the sample.

Table 2: Values of the time constant of a Debye exponential fitting of the relaxation of the stress needed to generate the same deployment of the sample.

	Vaseline	Steel	Beech	Fir
τ [1/s]	6124	2300	2203	1867

It is clear that the simple exponential functions no not match closely the experimental data. The slope of the stress relaxation curve does not even respond to a logic related to the friction provided by the plates: when vaseline is places between infinitely rigid steel plates, time constant wis higher than the test configuration without vaseline. When in comes to timber, the deformation of the material generates a less steep slope and the stress relaxation generated fir and beech plates are 'inverted' in the sense that the surface roughness of fir is greater than the one of beech, but fir is softer, therefore the deformation of the plates causes fir to provide a greater opportunity for the material to expand laterally.

5. Conclusions

This preliminary work analysed the possibility and the need to customise the mechanical characterisation of resilient interlayers when used at timber-timber interface. In this situation, the mechanical behaviour is not matched to the classical evaluation of elastic and viscous parameters. The determination of the correct elastic modulus is made complicate by the fact that the first part of the stress-strain relation strongly depend upon the friction between the sample and the plates. The question rises: which is the part of the stress-strain relation that must be accounted for? These materials work at 5-15% deformation, therefore it seems logical to use this value in its proper load range, even though in the real application, the application of the loading will never occur following the loading ramp used in the laboratory measurements. The determination of the creep behaviour was critical as well; the stress relaxation model follows a non-linear exponential decay and the samples compressed with a wood-wood interface shows an intermediate behaviour between greasy steel plates and clean steel plates, the deformation of the timber plates being probably the responsible for this. Future work will focus on extending the set of measurements to materials with different hardnesses, including tensile tests and DMA in temperature range. This will be aimed at finding correlations between standard tests performed under ideal conditions and real behaviour of the material used as a resilient interlayer in timber structures.

6. Acknowledgements

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