VISCOELASTIC CHARACTERISATION OF ADHESIVES USING INVERSE TECHNIQUES

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ABSTRACT

Active or passive damping treatments are usually applied to vibrating structures for noise and vibration control by means of an adhesive layer. There is a high number of environmental parameters, such as temperature or frequency, which may influence the behaviour of the bonding layer and modify the damping efficiency of the treatment. Therefore it is desired to take into account the behaviour of that layer in the model.

The goal of this work is to present a procedure to characterise and model the adhesive layer. To that purpose, an experimental-numerical method for inverse characterisation of the frequency dependent properties of the glue is presented. The proposed inverse approach is a two-step gradient-based method (BFGS) based on a fractional derivative viscoelastic model whose parameters are identified by minimising the difference between the simulated and the measured dynamic response of a multi-layered structure assembled by bonding. In the finite element model used for the inverse approach, the bonding layer is modelled by interface finite elements, i.e. by bi-dimensional elements representative of the three-dimensional behaviour of the bonding layer. The identification procedure is applied to the characterisation of a double coated tape.

1 INTRODUCTION

Noise and vibration control is a major concern in several industries and a lot of work has been dedicated to the design of efficient active or passive damping treatments. Such treatments are usually applied to the vibrating structure by means of an adhesive layer. Being generally made of polymers, adhesive layers may have their properties influenced by a number of environmental parameters, such as temperature or frequency. For instance, Figure 1 evidences the viscoelastic behaviour of a double coated tape used for the assembly of sandwich structures, while the epoxy adhesive has little influence on the dynamic behaviour of the assembled structure. A consequence of the viscoelastic behaviour of the adhesive layer is that it may modify the dynamics of the structure and affect the damping efficiency of the active or passive treatment applied (see Figure 2 and [1]). In some cases, the adhesive layer must be modelled to have a predictive model of the treated structure [2]. Therefore, there is a need for a characterisation procedure to identify to frequency-dependent properties of the adhesive. DMA (Dynamical Mechanical Analysis) measurements are classically used to determine the viscoelastic properties of a material [3]. However, the bonding process generally has an important influence on the mechanical behaviour of the bonding layer, which makes inverse characterisation a more appropriate way of identifying the dynamic properties of the adhesive.

The goal of this work is to present a methodology to characterise and model the adhesive layer. To that purpose, an experimental-numerical method for inverse characterisation of the frequency dependent properties of the adhesive layer is applied. The proposed inverse approach is based on a fractional derivative model whose parameters are identified by minimising the difference between the simulated and the measured dynamic response of a multi-layered structure assembled by bonding. The fractional derivative model presents the advantage of describing accurately the viscoelastic behaviour of many polymers with only four parameters. In the finite element model used for the inverse method, the adhesive layer is modelled by interface finite elements, i.e. by bi-dimensional elements representative of the three-dimensional behaviour of the bonding layer.

The proposed characterisation and modelling procedure is applied to dynamic measurements of a structure assembled with a double coated tape.

2 INVERSE CHARACTERISATION PROCEDURE

In this work, a four-parameter fractional derivative model is used to describe the frequency dependency of the complex shear modulus of the adhesive:

$$G^*(\omega) = \frac{G_0 + G_\infty(\mathrm{i}\omega\tau)^\alpha}{1 + (\mathrm{i}\omega\tau)^\alpha} \tag{1}$$

where G_0 and G_∞ are respectively the relaxed and unrelaxed moduli, τ is the relaxation time, and α is a fractional parameter comprised between 0 and 1 which corresponds to the non-integer order of derivation in the $\sigma(t) - \epsilon(t)$ relationships [4].

The goal of the inverse method is to identify the parameters of this viscoelastic model by minimising a cost function which is defined as the normalised mean square error between a measured and a simulated response. At each step of the optimisation, the simulated response is computed from a finite element model with updated viscoelastic parameters. Consequently, if the model contains a lot of degrees of freedom or if the optimisation procedure requires a lot of iterations to converge, the inverse procedure may be time-consuming. The former occurs when the thin adhesive layer is modelled with three-dimensional elements since it would require a very fine mesh to avoid numerical problems related to the aspect ratio of the elements. Therefore, interface finite element are used to model the thin adhesive layer. These elements, initially

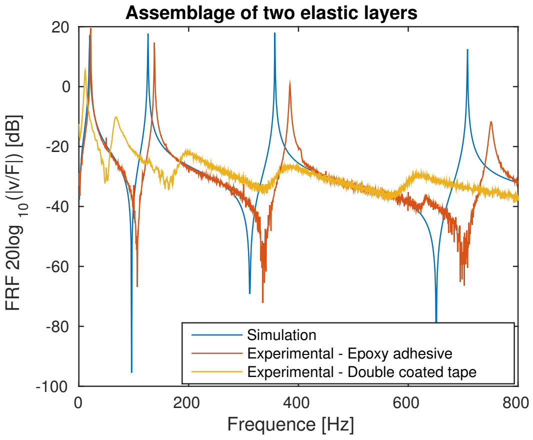

Figure 1: Measured frequency response functions of an assemblage of two 0.26m ×0.026m ×1mm steel beams realised by application of an epoxy adhesive (red) or a double coated tape (orange), compared to the simulated response computed by a finite element model neglecting the adhesive layer (blue).

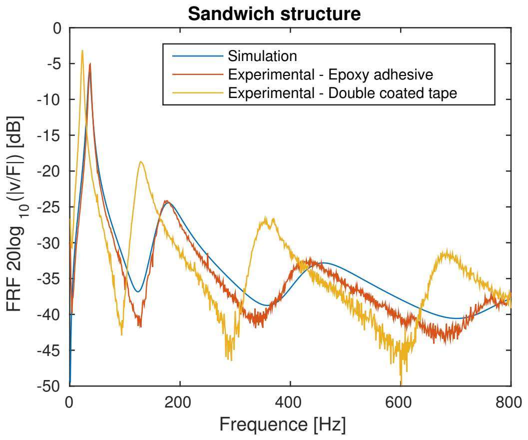

Figure 2: Measured frequency response functions of a sandwich beam with a viscoelastic core assembled by an epoxy adhesive (red) or a double coated tape (orange), compared with the simulated response computed by a finite element model neglecting the adhesive layer (blue).

developed for the modelling of thin constrained viscoelastic layers, consist of a mean surface and a fictive thickness, assumed constant [5]. Moreover, in order to keep the overall number of cost function evaluations reasonable, a gradient-based method (BFGS) is used to update the viscoelastic model's parameters and the gradient of the cost function is evaluated by a direct differentiation approach [6]. Since the problem to be solved is not convex, an initialisation step is introduced. It consists in optimising the model's parameters by minimising a cost function representing the difference between the measured and the simulated resonant frequencies of the structure. In this way, the risk of converging towards a local minimum is reduced.

3 APPLICATION AND RESULTS

The previously described inverse identification method is applied to dynamic measurements of a steel assemblage for the characterisation of a double coated tape (see Figure 1). Figure 3 shows the experimental response compared to the frequency response function computed with the optimised parameters of the viscoelastic model:

$$G_0 = 2.53\ 10^4 \text{ Pa}, \qquad G_\infty = 1.51\ 10^8 \text{ Pa}, \qquad \tau = 1.32\ 10^{-6} \text{ s} \qquad \alpha = 0.88, \qquad (2)$$

The corresponding master curves of the adhesive are plotted in Figure 4. The identified properties of the double coated tape allow a good representation of the dynamic behaviour of the assembled structure. The slight overestimation of the damping on some modes may be due to the fact that a four-parameter fractional derivative model may not be the most appropriate model to describe the frequency dependency of the adhesive's properties.

4 CONCLUSION

The inverse characterisation technique presented in this paper aims at determining the parameters of a fractional derivative model which describes the frequency-dependent mechanical properties of adhesives. This can be used to improve the accuracy of a finite element model of a damped structure by taking into account the assembly procedure, and thus better predict the efficiency of the damping treatment.

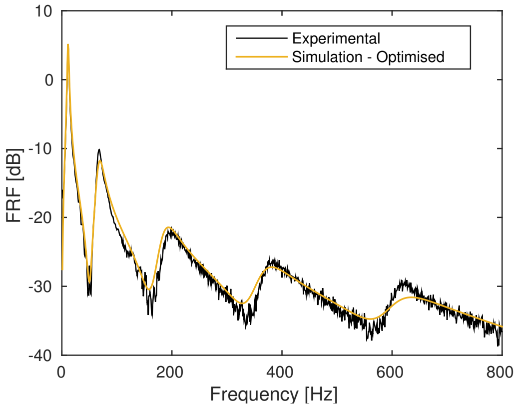

Figure 3: Measured frequency response functions of an assemblage of two 0.26m ×0.026m ×1mm steel beams realised by application of a double coated tape compared to the simulated response computed with the identified properties of the adhesive.

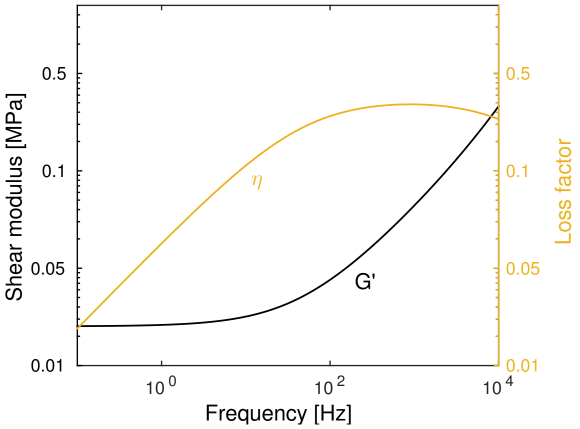

Figure 4: Master curves of the double coated tape, after inverse characterisation, at $T = 20^o$C.

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