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Identification of the dynamic characteristics of a viscoelastic, nonlinear adhesive joint

T. Naraghi [a], A.S. Nobari [a,b,*]

[a] *Aerospace Engineering Department, Amirkabir University of Technology, Hafez Av. Tehran, Iran*
[b] *Centre of Excellence in Computational Aerospace Engineering Amirkabir University of Technology, Hafez Av. Tehran, Iran*

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ABSTRACT

In this paper, the nonlinear mechanical characteristics of an adhesive (Sikaflex-252) are identified over frequency range, using eigenvalues of nonlinear system and inverse eigensensitivity method and experimental data. Sikaflex-252 is selected as an adhesive which is mainly used as a joining medium (joint) in structural applications. In order to simulate the viscoelastic behaviour of the adhesive, the frequency dependent Young's modulus and damping coefficient are assumed in identification process leading to the updating process being repeated for different ranges of frequencies to identify stiffness and damping properties of the adhesive. Using the optimum equivalent linear frequency response function (OELF) concept, in order to realize the nonlinear nature of the adhesive, modal tests are performed under two different random excitation levels which illustrate the stiffness softening characteristic of adhesive which can have serious implications regarding dynamic stability of structures. Furthermore, based on the identified characteristics, the paper examines the possibility of tuning of the Standard Linear Solid model (SLS), in representing the adhesive viscoelastic behaviour. Results of this attempt proved that the S.L.S. model with tuned parameters significantly improves the fidelity of finite element (FE) model to experimental results.

1. Introduction

With the current trend of designing lighter, more efficient, high speed structures, the issue of the most appropriate method of joining the substructures is becoming more and more important. In this respect, amongst all joining techniques which are widely used in structural applications, adhesive bonding is getting ever increasing attention. This is due to the several advantages that this type of joining offers. Advantages like, no drilling or high temperature involved in joining process (a big advantage for light structures), sealing as well as connecting, damping noise and (to some extent) vibrations, smoothing transition of mechanical properties across the joint and hence reducing stress concentration at joint (impedance transition), etc.

Drawbacks associated with adhesives like, needing curing, changing properties with time, etc are easily outweighed by its advantages.

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* Corresponding author at: Aerospace Engineering Department, Amirkabir University of Technology, Hafez Av. Tehran, Iran Tel.: +98 2164543208.
E-mail addresses: tahereh.naraghi@gmail.com (T. Naraghi), sal1358@aut.ac.ir (A.S. Nobari).

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Due to the structure being light, the accurate modelling of the adhesive bonding in a FE analysis of the structure becomes very important. He [1] has done an extensive review relating to FE analysis of adhesively bonded joints in terms of static loading analysis, environmental behaviours, fatigue loading analysis and dynamic characteristics. Based on this study, proper modelling of the adhesive plays an important role in the accuracy of the results. It has been reported [2] that proper modelling of the adhesive bond stiffness in the modelling of a bus structure can change its torsional stiffness as much as $20-30$ percent. This effect becomes more important if it is noticed that both ride and handling of a commercial vehicle is greatly affected by the torsional stiffness of its structure. The same effect on the torsional stiffness of a beam structure is reported in [3]. The issue of incorporating a proper model of the adhesive bond in a FE modelling of a structure becomes even more important for Dynamic problems, as the industrial adhesives are viscoelastic, polymeric, materials. The same consideration applies to the nonlinear, large deformation, response of the structure which necessitates considering material nonlinearity of the adhesive. The need for accurate modelling of adhesive bond brings about the need for mechanical properties of the adhesive.

The mechanical properties of adhesives are not readily available. Manufacturers usually provide minimal mechanical properties which are related to static, linear behavior of adhesives. The static data, provided by manufacturer, can be useful for modelling of the thin adhesive layers of up to $1-1.5$ mm thickness [4]. So, the required nonlinear, viscoelastic, properties of the adhesive must be identified. To this end, different approaches are used by researchers. These approaches can be categorized into following groups [5]:

a- Methods based on the static tensile tests of either lap-shear specimens or bulk (solid) specimens of cured adhesives [6–11]. As far as these methods are concerned, tests based onlap-shear specimens suffer from complex stress and strain distribution at the interface of adhesive and adherents which makes the accurate determination of the adhesive characteristic very difficult, if not impossible. On the other hand, tests that are based on the bulk specimens suffer from the fact that it would be very difficult to make defect free bulk specimens and, obviously, presence of random defects will make the task of determination of Young's and shear moduli of adhesive very difficult. Also, the works in this category cannot identify any viscoelastic effects of adhesives.

b- Methods based on the impact test; Sato and Ikegami developed the FE model for adhesively bonded joints considering Voigt viscoelastic model for adhesive. They obtained the Voigt parameters from stress distribution and time variation of stress and strain in the joints under tensile impact test [12]. Another work in the field of adhesively bonded lap joint subjected to impact tensile loads is done by Liao et al. They analyzed the stress wave propagations and interface stress distributions in a lap joint using three-dimensional FE method and measured the strength of the joint [13]. All the works in this category, suffer from the fact that the local strain/stress effects at interface due to the adhesive cannot be isolated from those due to the adherents and it is assumed that static parameters are only affected by adhesive. This assumption may not be valid if the adhesive and adherents have a comparable order of strength. In the proposed method, the contribution of the adherent is already isolated and will not get involved in the identification process.

c- Methods based on resonance testing [14–17]. These methods are more suitable for the determination of the dynamic Young's and shear moduli, nevertheless, they can also be used for the determination of static (low frequency) moduli if the test method and specimens of adherents are selected properly. The resonance testing based methods suffer from the fact that if the ratio of the stiffness of adhesive bonding to that of the adherents is not negligible (i.e. adhesive bonding compliance is not significantly more than that of adherents at interface), the determination of an accurate Young's and shear moduli will be impossible, due to the fact that the elasticity of the adherents at the interface will interact with the elastic behaviour of the adhesive and as such what are being determined are a mixed adhesive–adherents Young's and shear moduli [13].

d- Methods based on the experimental modal analyses and FE model updating [5,18–19]. Methods in this category are free of the problem associated with the methods in categories ‘b’ and ‘c’. This is due to the fact that in this class of methods, the effects of boundary conditions and the mechanical properties of adherents’ are separated from those of adhesive and hence the identification results are independent of the mechanical properties of the adherents and boundary conditions.

The method proposed in this paper falls in the category ‘c’. The main purpose of this paper is to present the identification method, for nonlinear-viscoelastic characteristics of the Sikaflex-252 adhesive, which is both computationally and experimentally straightforward. To this end, in our experimental study, advantage is taken from the beneficial property of optimum equivalent linear frequency response function (OELF) concept, i.e. the time saving modal test with random excitation. On the other hand, on the computational side, a simple linear FE model is used. Using OELF has made it possible to model the nonlinear system with a corresponding optimum linear system at each individual excitation level, as will be explained in Section 2. As a practical application of the identified adhesive characteristics, the parameters of the Standard Linear Solid model (SLS) [20] are determined for Sikaflex-252.

Sikaflex-252 is selected for the purpose of identification as it is suitable for bonding of variety of materials. It is particularly suitable for structural joints that will be subjected to dynamic loadings [21].