ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

INFLUENCE OF THE COMBINED DYNAMIC AND STATIC STRAINS ON THE SELF-HEATING PHENOMENON IN VISCOELASTIC DAMPERS

Antonio Marcos Gonçalves de Lima
Federal University of Uberlândia, School of Mechanical Engineering, Campus Santa Mônica, P.O.Box 593, CEP 38400-902, Uberlândia, MG, Brazil
amglima@mecanica.ufu.br
Domingos Alves Rade
Federal University of Uberlândia, School of Mechanical Engineering, Campus Santa Mônica, P.O.Box 593, CEP 38400-902, Uberlândia, MG, Brazil
domingos@ufu.br
Helder Barbieri Lacerda
Federal University of Uberlândia, School of Mechanical Engineering, Campus Santa Mônica, P.O.Box 593, CEP 38400-902, Uberlândia, MG, Brazil
helder@mecanica.ufu.br
Cleudimar Amaral Araújo
Federal University of Uberlândia, School of Mechanical Engineering, Campus Santa Mônica, P.O.Box 593, CEP 38400-902, Uberlândia, MG, Brazil
cleudmar@mecanica.ufu.br

Abstract. *It has been demonstrated by many authors that the internal damping mechanism of the viscoelastic materials has many possibilities for practical engineering applications. However, traditional guideline procedures of analysis and design of viscoelastic dampers subjected to cyclic loadings, uniform, constant temperature is generally assumed and do not take into account the self-heating phenomenon. Moreover, for viscoelastic materials subjected to dynamic loadings superimposed on static preloads, such as engine mounts, these procedures can lead to poor designs or even severe failures since the energy dissipated within the volume of the material lead to temperature rises. In this paper, a hybrid numerical-experimental investigation of the static preloads effects on the self-heating phenomenon in viscoelastic dampers subjected to harmonic loadings is reported. After presenting the theoretical foundations, the numerical and experimental results obtained in terms of the temperature evolutions of the viscoelastic material for various static preloads are compared, and the main features of the methodology are discussed.*

Keywords: *viscoelastic materials, thermoviscoelasticity, self-heating, static preloads*

1. INTRODUCTION

It is well-known that viscoelastic materials are efficient in mitigating the undesirable vibrations levels of engineering systems such as automobiles, airplanes, civil engineering structures and flexible mechanisms at moderate application and maintenance costs. However, one of the most distinguishable features of viscoelastic materials is that their mechanical behavior varies strongly with different environments such as the temperature, the frequency and the amplitude of the excitation, and the static preloads (Nashif et al., 1985; Schapery, 1964). This fact makes indispensable the availability of efficient models capable of predicting various aspects of the combined static and dynamic responses of viscoelastic materials.

In most traditional design guidelines of viscoelastic dampers it is assumed uniform and time-independent temperature distribution within the viscoelastic material, whose value is chosen to be coincident with the ambient temperature under which the damper is intended to operate. However, due to their inherent properties, when viscoelastic materials are subjected to cyclic loadings, the well-known self-heating phenomenon can causes local temperature increases, and may affect significantly the damping capability, or even lead to the complete failure of viscoelastic damping devices (Cazenove et al., 2012; Rittel, 1999; Gopalakrishna and Lai, 1998). Also, in applications in which dynamic and static loads are involved, such as engine mounts, the interest in achieving high isolation characteristics becomes of capital importance as vibration amplitudes are directly related to fatigue and, as a result, to structural integrity (Nashif et al., 1985). Thus, the determination of the temperature distribution within viscoelastic materials subjected to linear dynamic loadings superimposed on static preloads is an interesting and hard-to-solve thermoviscoelastic problem. Although heat transfer analysis of elastomers has been conducted, the main contribution intended for this study is its extension to the case of the combined effects of dynamic loading with static preloads on the self-heating phenomenon in viscoelastic materials for vibration attenuation.

More recently, Cazenove et al. (2012) have proposed a new hybrid numerical-experimental methodology to investigate the influence of the frequency and the amplitude of the excitation on the self-heating phenomenon in a translational viscoelastic mount. They observed that as the excitation frequency and the excitation amplitude increase, the self-heating phenomenon becomes more pronounced resulting in a significant temperature augmentation inside the

ISSN 2176-5480

volume of the material. Also, the authors have demonstrated that the temperature rise leads to maximum decreases of the loss factor of 70%, resulting in a significant decrease of the damping capability of the viscoelastic damper device. However, the effects of the static preloads have not been addressed by the authors. According to Gopalakrishna and Lai (1998), the local temperature values inside the viscoelastic materials used to mitigate the vibrations levels in tall buildings, can increase up to $10^{\circ}C$ in a few seconds during a storm. However, this is thought to be a limiting assumption as it has been not assumed a complete tridimensional strain state to compute the heat source and the prestressed effects on the viscoelastic damping devices. Rittel (1999) has been demonstrated experimentally that the conversation ratio used to measure the mechanical energy transformed into heat for polycarbonates deformed in a range of strain rates, is strongly dependent on strain and strain rate. Also, as they are very difficult to estimate, their values have been assumed rather arbitrarily in the range [0.1; 1.0], such as in the study reported by Rittel and Rabin (2000) in which it is performed finite element (FE) based numerical thermal analysis of the cyclic compression of Polymethylmethacrylate (PMMA) and polycarbonate cylindrical specimens.

This paper is devoted to the numerical and experimental investigation of the influence of the dynamic loads superimposed on static preloads on the self-heating phenomenon in a translational viscoelastic mount used for vibration mitigation, with the capacity of accounting for complex geometry and complete tridimensional strain state, by assuming weak coupling between both fields and the nonlinear coupled thermal and structural analyses, which are performed in ANSYS™ software. The results in terms of the temperature evolution within the volume of the viscoelastic material can be characterized as a function of time or number of cycles.

2. COMPLEX MODULUS FOR THE COMBINED STATIC AND DYNAMIC LOADS

The dynamic behavior of viscoelastic materials depends on a number of factors, among which the most relevant are the excitation frequency and the temperature [4]. Various mathematical models have been developed to represent this behavior and have been shown to be particularly suitable to be used in combination with FE discretization [15-17]. However, for many applications in which the viscoelastic materials are subjected to dynamic loads superimposed on static preloads, it is necessary to evaluate the *Complex Modulus* to describe the combined static and dynamic strains. Thus, based on the fact that the static and dynamic properties of a linear viscoelastic material can be measured independently of each other (Nashif et al., 1985), and taking into account the *Frequency-Temperature Correspondence Principle* for one-dimensional stress-strain relation, the *Complex Modulus* can be expressed as follows:

$$G(\omega_r,T_0,\delta)=F(\delta)G(\omega_r,T_0)=G'(\omega_r,T_0,\delta)+iG''(\omega_r,T_0,\delta) \quad (1)$$

where $\omega_r=\alpha_T(T)\omega$ is the *reduced frequency*, ω is the actual excitation frequency, T indicates the temperature, T_0 is a reference value of temperature, δ is the static strains, and $\alpha_T(T)$ represents the *shift function*. $G'(\omega_r,T_0,\delta)$, $G''(\omega_r,T_0,\delta)$ and $\eta(\omega_r,T_0,\delta)=G''(\omega_r,T_0,\delta)/G'(\omega_r,T_0,\delta)$ are defined, respectively, as *storage modulus*, *loss modulus* and *loss factor*. Any pair formed from these three parameters completely characterizes the viscoelastic behavior under combined static and dynamic loading conditions in the frequency domain.

In equation above, functions $G(\omega_r,T_0)$ and $\alpha_T(T)$ can be measured dynamically from experimental tests for specific viscoelastic materials. Drake and Soovere (1984) suggest the analytical expressions (2) for the complex modulus and shift factor for the 3M™ ISD112 viscoelastic material defined in the following temperature and frequency intervals $210\le T\le 360\,K$ and $1.0\le\omega\le 1.0\times 10^6\,Hz$, respectively, where $T_0=290\,K$. The parameters appearing in relations (2) are presented in Tab. 1.

$$G(\omega_r,T_0)=B_1+B_2\Big/\left(1+B_5(i\omega_r/B_3)^{-B_6}+(i\omega_r/B_3)^{-B_4}\right) \quad (2a)$$

$$\log_{10}(\alpha_T)=a\left(\frac{1}{T}-\frac{1}{T_0}\right)+2.303\left(\frac{2a}{T_0}-b\right)\log_{10}\left(\frac{T}{T_0}\right)+\left(\frac{b}{T_0}-\frac{a}{T_0^2}-S_{AZ}\right)(T-T_0) \quad (2b)$$

However, the derivation of a function of strain, $F(\delta)$, for linear viscoelastic materials is more delicate, and the difficulty in predicting general accurate analytical expressions comes from the fact that it could take several forms depending on the relation between the static, δ, and engineering, ε, strains involved in the stress-strain relationship accounting for the type of viscoelastic damping device to be used. Also, a supplementary difficulty arises from the large number of combinations for the dynamic and static loading parameters involved in the experimentally measurements techniques for viscoelastic materials. However, for simple extension problems, the Mooney-Rivlin equation (Nashif et al., 1985) can be used to describe the static stress-strain relations, where the strategy is to generate a set of material properties measured statically and used to determine the constants appearing in the function of strain, and a set of

ISSN 2176-5480

material properties measured dynamically without static preloads to derive the complex modulus function. Then, Eq. (1) can be used to predict the combined static and dynamic behaviors in terms of the complex modulus, $G(\omega_r, T_0, \delta)$, and the loss factor, $\eta(\omega_r, T_0, \delta)$.

In the numerical study addressed herein, the viscoelastic material data measured dynamically as a function of excitation frequency and temperature are provided by expressions (2), and the static preloads are directly applied in the viscoelastic damper device by using the ANSYS™ finite element software.

Table 1. Parameters of the 3M™ ISD112 provided by Drake and Soovere (1984).

Complex Modulus – Eq. (2a)					
B_1 [MPa]	B_2 [MPa]	B_3	B_4	B_5	B_6
0.4307	1200	1543000	0.6847	3.241	0.18
Shift factor – Eq. (2b)					
T_0 [K]	T_L [K]	T_H [K]	S_{AZ} [K]$^{-1}$	S_{AL} [K]$^{-1}$	S_{AH} [K]$^{-1}$
290	210	360	0.05956	0.1474	0.009725
$a = (D_B C_C - C_B D_C)/D_E$, $b = (D_C C_A - C_C D_A)/D_E$, $C_A = (1/T_L - 1/T_0)^2$, $C_B = (1/T_L - 1/T_0)$					
$C_C = (S_{AL} - S_{AZ})$, $D_A = (1/T_H - 1/T_0)^2$, $D_B = (1/T_H - 1/T_0)$, $D_C = (S_{AH} - S_{AZ})$, $D_E = (D_B C_A - D_A C_B)$					

From the reduced temperature nomogram generated by the computation of Eqs. (2), the designer can obtain the complex modulus and the loss factor at any given temperature into a frequency band of interest, as illustrated in Fig. 1.

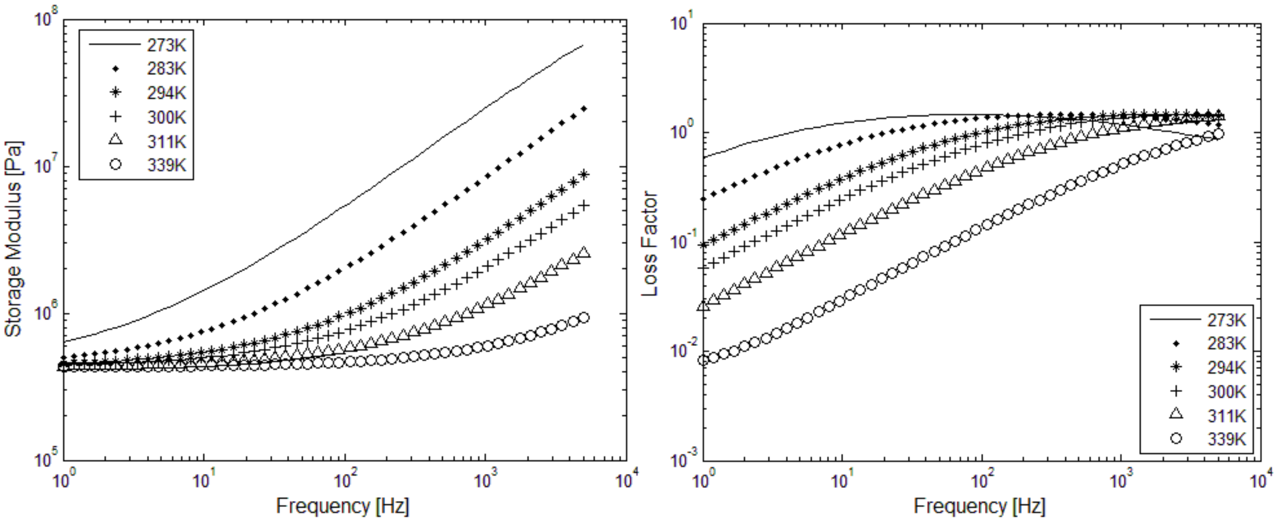


Figure 1. (a) Storage modulus and (b) loss factor for different temperatures for the 3M™ ISD112 viscoelastic material.

3. HEAT GENERATION RATE FOR THE COMBINED STATIC AND DYNAMIC LOADS

When a viscoelastic damper device such as the translational mount illustrated in Fig. 2 is subjected to sinusoidal stresses, $\boldsymbol{\sigma}(t) = \boldsymbol{\sigma}_0 \sin(\omega t)$, superimposed on a static preload, δ, a significant amount of mechanical power, $\dot{w}_m$, is transformed into heat within the viscoelastic material volume, resulting a local temperature increases. This heat generation rate, q_g, can be related to the dissipated mechanical power according to the following expression (Cazenove et al., 2012):

$$q_g = \beta \dot{w}_m \tag{3}$$

where β represents the thermal conversion ratio defined as a fraction of the mechanical power dissipated by the viscoelastic effects, $(1-\beta)\dot{w}_m$ is the complementary part of the dissipated power which is stored within the viscoelastic through microstructural changes, and the dissipated mechanical power can be determined as follows:

$$\dot{w}_m(t,\omega,T,\delta)=\boldsymbol{\sigma}(t)^T\,\dot{\boldsymbol{\varepsilon}}(t,\omega,T,\delta)=G(\omega,T,\delta)\boldsymbol{\varepsilon}^T(t,\omega,T,\delta)\overline{\boldsymbol{C}}\dot{\boldsymbol{\varepsilon}}(t,\omega,T,\delta) \tag{4}$$

where $\boldsymbol{\varepsilon}(t,\omega,T,\delta)=\boldsymbol{\varepsilon}_0(\omega,T,\delta)\sin(\omega t+\varphi)$ indicates the strain responses due to the sinusoidal stresses where ω is the frequency, and φ is the phase angle. $\boldsymbol{C}(\omega,T,\delta)=G(\omega,T,\delta)\overline{\boldsymbol{C}}$ is the material properties matrix dependent on the environmental factors, and defined in such a way that $\boldsymbol{\varepsilon}(t,\omega,T,\delta)=\boldsymbol{C}^{-1}(\omega,T,\delta)\boldsymbol{\sigma}(t)$.

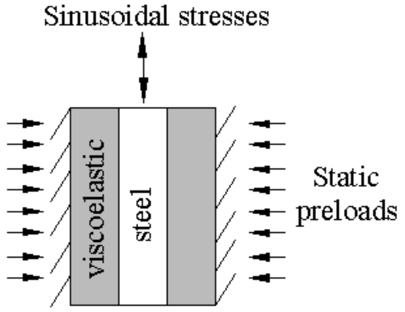


Figure 2. Illustration of a viscoelastic mount subjected to dynamic and static loadings.

Upon introduction of the complex modulus function (1) into expression (4), it is possible to show that the contribution of the real part of the complex modulus to the dissipated mechanical energy, which is associated to the purely elastic power stored in the viscoelastic material, vanishes over a cycle of vibration. On the other hand, the imaginary part corresponds to the viscous power, resulting in the following heat generation:

$$q_g(\omega,T,\delta)=\left|\beta\,\dot{w}_m(t,\omega,T,\delta)\right|=\frac{1}{2}\beta\,\omega G''(\omega,T,\delta)\boldsymbol{\varepsilon}_0^T(\omega,T,\delta)\overline{\boldsymbol{C}}\boldsymbol{\varepsilon}_0(\omega,T,\delta) \tag{5}$$

It must be emphasize that the exact solutions of the nonlinear thermoviscoelastic problem, resulting from the association between the heat generation rate (5) and the transient heat equation (Lienhard and Lienhard, 2004), taking into account the thermal boundary conditions, cannot be obtained easily and numerical resolution schemes must be used. Also, it accounts for general strain states (two- or three-dimensional) by the proper inclusion of the strain components into the strain vector $\boldsymbol{\varepsilon}_0(\omega,T,\delta)$. Furthermore, the computation of the loss modulus, $G''(\omega,T,\delta)$, which is most frequently a nonlinear function of the temperature evolution to be determined, is made by considering the analytical expressions (2) and the static preloads are directly applied on the viscoelastic device.

In the context of a finite element modeling procedure, the heat generation rate must be calculated for each viscoelastic element from displacement amplitudes obtained from the harmonic analyses superimposed on the static preloads. This can be done by integrating Eq. (5) over the volume of each viscoelastic element, as follows:

$$q_g(\omega,T,\delta)=\frac{\beta\omega}{2V_{(e)}}\int_V G''(\omega,T,\delta)\boldsymbol{\varepsilon}_0^T(\omega,T,\delta)\overline{\boldsymbol{C}}\boldsymbol{\varepsilon}_0(\omega,T,\delta)dV_{(e)} \tag{6a}$$

or,

$$q_g(\omega,T,\delta)=\frac{\beta\omega\eta(\omega,T,\delta)}{2V_{(e)}}\boldsymbol{U}_{(e)}^T\boldsymbol{K}'_v(\omega,T,\delta)_{(e)}\boldsymbol{U}_{(e)} \tag{6b}$$

where $\boldsymbol{K}'_v(\omega,T,\delta)_{(e)}=G'(\omega,T,\delta)\int\boldsymbol{B}^T\overline{\boldsymbol{C}}\boldsymbol{B}dV_{(e)}$ is the real part of the viscoelastic stiffness matrix, and $\boldsymbol{B}$ is the matrix formed by the differential operators which intervene in the strain-displacement relations, and $V_{(e)}$ is the volume of the viscoelastic element.

4. NUMERICAL PROCEDURE

An iterative resolution procedure has been implemented in ANSYS™ (2009) finite element software by using the ANSYS Parametric Design Language (APDL) intended to perform the transient thermal and prestressed harmonic structural fields accounting for the self-heating phenomenon.

ISSN 2176-5480

At this point, it is important to consider that, in the context of the present study a strategy must used to incorporate the viscoelastic behavior into ANSYS FE software. It can be done by assuming that the stiffness matrix of the damper depicted in Fig. 2 can be decomposed into a stiffness matrix associated to the purely elastic part, $\boldsymbol{K}_e$, and a stiffness matrix related to the viscoelastic substructure, $\boldsymbol{K}_v(\omega,T,\delta)$, the equations of motion in the frequency domain of the viscoelastic damper containing N degrees of freedom (DOFs), are given as (de Lima et al., 2009):

$$\left[\boldsymbol{K}^*(\omega,T,\delta)+i\omega\boldsymbol{C}_{eq}(\omega,T,\delta)-\omega^2\boldsymbol{M}\right]\boldsymbol{U}(\omega,T,\delta)=\boldsymbol{F}(\omega) \tag{7}$$

where $\boldsymbol{C}_{eq}(\omega,T,\delta)=\alpha(\omega,T,\delta)\overline{\boldsymbol{K}}_v$ and $\boldsymbol{K}^*(\omega,T,\delta)=\boldsymbol{K}_e+G'(\omega,T,\delta)\overline{\boldsymbol{K}}_v$.

As can be noted from the expression above, the introduction of the viscoelastic effect into the FE model gives rise to a system of equations of motion of the same form as those based on the assumption of a viscous damping matrix proportional to the stiffness matrix, with the following frequency-dependent proportionality coefficient, $\alpha(\omega,T)=\eta(\omega,T)G'(\omega,T)/\omega$. This fact will be explored for the computation of the viscoelastic stiffness, $\boldsymbol{K}_v(\omega_0,T_0,\delta)$, and the equivalent viscous damping, $\boldsymbol{C}_{eq}(\omega_0,T_0,\delta)$, matrices for a given excitation frequency, ω_0, and for an initial temperature value, T_0, using the ANSYS FE software.

1. Initialization: at the beginning of the process, the viscoelastic stiffness and equivalent viscous damping matrices for an excitation frequency ω_0 and for an initial temperature value T_0 are computed, taking into account the mechanical boundary conditions;

2. Static structural analysis in order to introduce the effects of the static preloads;

3. Prestressed harmonic structural analysis: the strain rates for each viscoelastic element for the actual operational and environmental conditions of the viscoelastic material are computed by performing the following prestressed harmonic structural analysis:

$$\boldsymbol{U}(\omega_0,T_0,\delta)=\left[\boldsymbol{K}^*(\omega_0,T_0,\delta)+i\omega\boldsymbol{C}_{eq}(\omega_0,T_0,\delta)-\omega_0^2\boldsymbol{M}\right]^{-1}\boldsymbol{F}(\omega_0) \tag{8}$$

4. Computation of the heat generation rate by performing expression (6b).

5. Transient thermal analysis: a new set of temperature values are generated by performing a transient thermal analysis, taking into account the thermal boundary conditions applied on the boundary of the domain.

6. Update the viscoelastic material properties: if the convergence criterion based on temperature variations between two consecutive iterations is not satisfied within a specified tolerance, a new iteration is initiated and the structural and thermal analyses are performed based on the latest set of temperature values generated, taking into account the updated viscoelastic stiffness and equivalent viscous damping.

5. NUMERICAL SIMULATIONS AND EXPERIMENTAL RESULTS

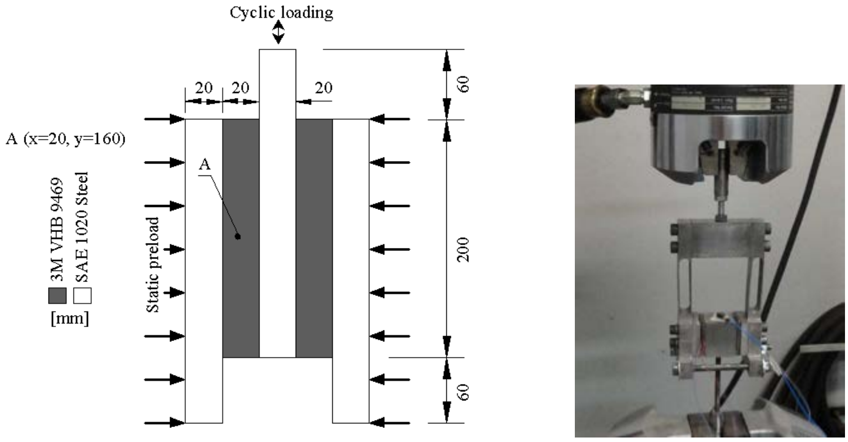
To illustrate the computation procedure of the influence of the combined dynamic and static strains on the self-heating phenomenon in viscoelastic materials, numerical tests were performed using the translational viscoelastic mount depicted in Fig. 3(a), and Fig. 3(b) shows the translational viscoelastic mount constructed by inserting two 5mm-thick layers of 3M™ VHB 9469 rubber-like material between three rigid steel blocks attached to a rigid frame, which is mounted on a universal test machine MTS-800. The thermal properties assumed for the steel and the viscoelastic material are those given in Tab. 2. The point A of the specimen, whose position is indicated in Fig. 3(a) had its temperature measured by using a thermocouple. Moreover, another thermocouple was used to measure the room temperature. Voltage signals were acquired and processed using a signal analyzer Agilent™ 34970.

Table 2. Thermal properties for the SAE 1020 steel and ISD112 material

Material	$\rho\left[kg/m^3\right]$	$c_p\left[J/(kg.K)\right]$	$k\left[W/(m.K)\right]$	β
VHB 9469	1100[(1)]	2000[(1)]	0.16[(1)]	0.0777
SAE 1020	7850	476	35	0

[(1)] From 3M™ technical report.

ISSN 2176-5480



(a) (b)

Figure 3. (a) Illustration of the viscoelastic damper device and its applied loading conditions; (b) experimental setup.

In the thermomechanical simulations, the discretization was done using two-dimensional coupled field elements. For the structural analyses, the 2D plane stress element *PLANE42* was used, having eight nodes and three DOFs per node (displacements in x, y and z directions). For the thermal analysis, the corresponding 2D element *PLANE55* was chosen, having the same number of nodes and one DOF per node (temperature). The total number of mechanical and thermal DOF's are 1677 and 559, respectively. Also, as thermal boundary conditions, it was assumed heat transfer by natural convection between the surfaces of the outer-steel plates and the surrounding air, with a convection coefficient, $h = 13.016 W/\left(m^2 K\right)$, and ambient temperature value, $T_\infty = 25^\circ C$, assumed as the uniform initial temperature in the damper at the beginning of the simulation.

The numerical simulations, which consist in obtaining the temperature values at node A indicated in Fig. 3(a), comprise a loading phase with a vertical displacement $u(t) = u_0 \sin(2\pi f_0 t)$ with $f_0 = 15 Hz$ and $u_0 = 1.5 mm$, imposed to the viscoelastic damper during 28000 seconds superimposed on different values of static displacements, as defined by the following test scenarios: (a) $\delta = 0.0 mm$; (b) $\delta = 2.0 mm$; (c) $\delta = 2.5 mm$; (d) $\delta = 3.5 mm$.

Figure 4(a) shows the temperature distributions for point A indicated in Fig. 3(a) obtained by the numerical simulations, and Fig. 4(b) shows the corresponding temperature distributions obtained by the experimental tests, for all preload scenarios. In both cases it can be noted that as the static strain amplitude increases, the self-heating effects become more pronounced, resulting in a significant augmentation of the temperature values. Also, one can identify a progressive stabilization of the temperatures in the loading phase (from $t = 0s$ to $t = 28000s$), and a steep and immediate decrease of the temperature values after the removal of the dynamic load. Finally, it can be seen that the experimental observations are in agreement with those observed in numerical simulations.

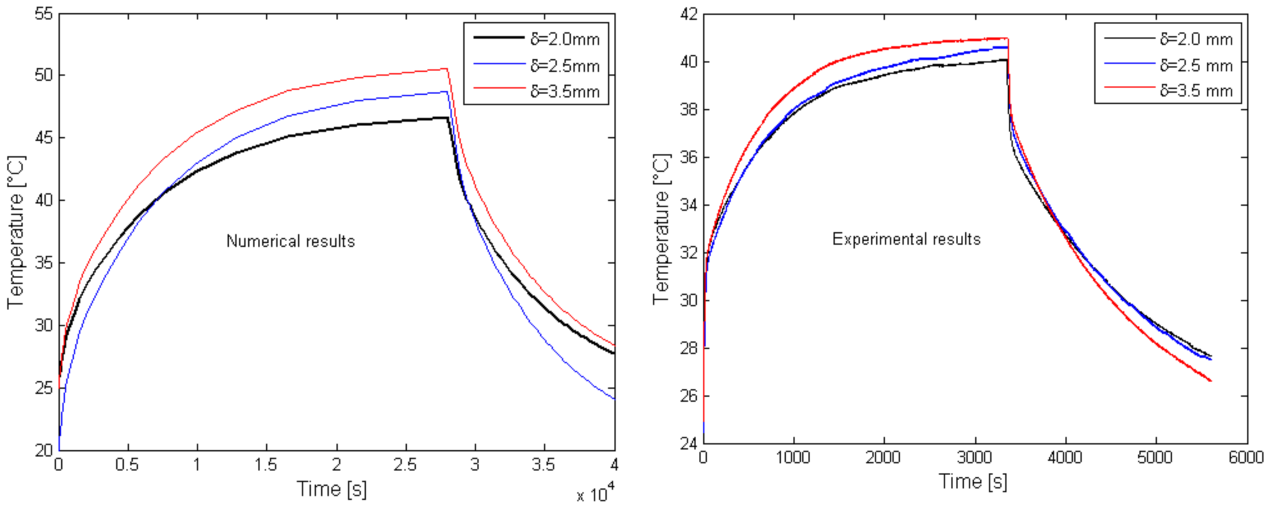


Figure 4. Numerical and experimental time evolutions of the temperature field in the translational damper for various values of static displacements.

ISSN 2176-5480

It is important to mention that the experimentally acquired temperature evolutions for the translational viscoelastic mount subjected to the combined effects of the shear harmonic loading and the static preloads have been shown. However, the direct comparison of these results with those obtained from numerical simulations is not possible, since for this later the values of the thermal conversion ratio, β, and the natural convection coefficient, h, have been assumed arbitrarily according to the values provided by Cazenove et al. (2012). It is widely known that these two parameters vary in a range of values depending upon several conditions such as the geometry of the viscoelastic surface, and operational conditions such as strain amplitudes. Thus, it is interesting to use a curve-fitting procedure in order to identify these parameters for the specific test conditions considered, which is not considered in this work.

To provide a sense of the evolution of the temperature distribution over the damper with time, Figs. 5 to 7 represent the temperature contours at three instants of time for the higher value of the static preload. It can be seen that the temperature gradient is oriented towards the center of the viscoelastic core. However, as the thermal boundary conditions are not symmetric, the zone of the highest temperatures is displaced towards the central plate.

These results enable to conclude that, since the temperature distribution is not uniform, the mechanical properties of the viscoelastic material (storage modulus and loss factor) vary from one point to the other. This finding is in contrast with the assumption of uniform temperature within the volume of the viscoelastic medium, which is frequently assumed in the analysis and design of viscoelastic devices.

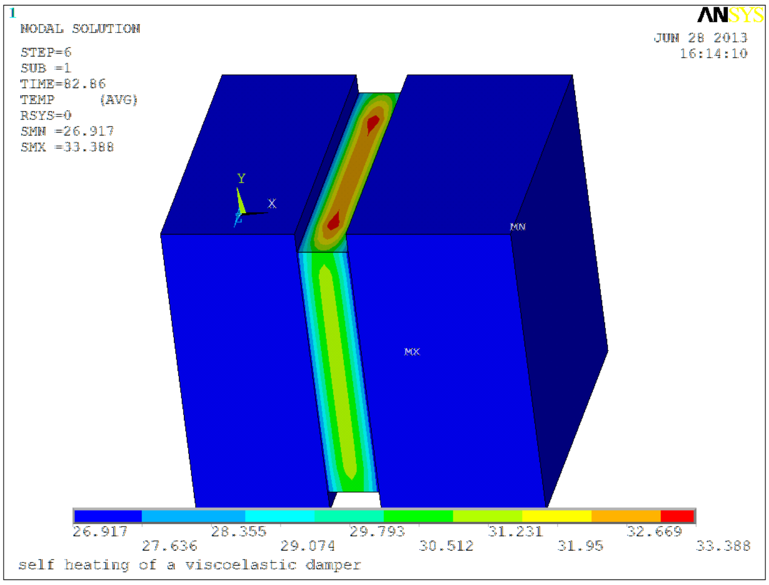


Figure 5. Temperature contours in the translational damper at time $t = 400s$.

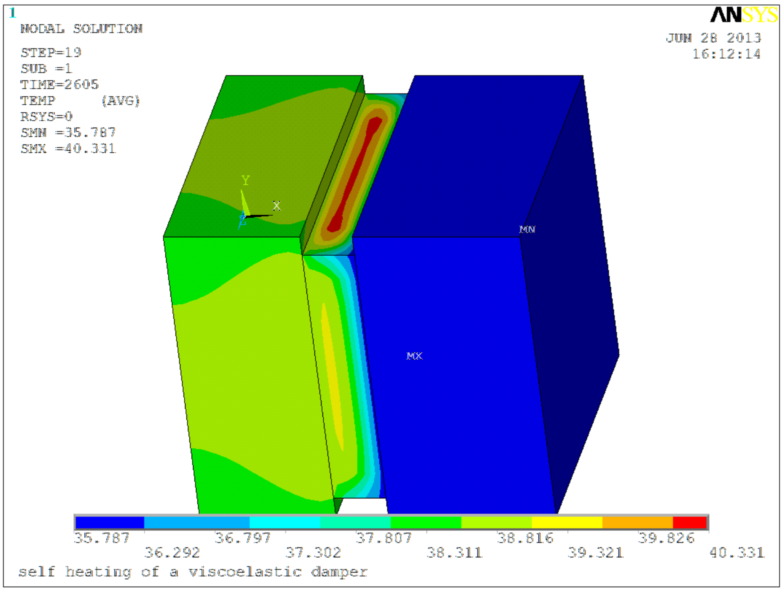


Figure 6. Temperature contours in the translational damper at time $t = 2500s$.

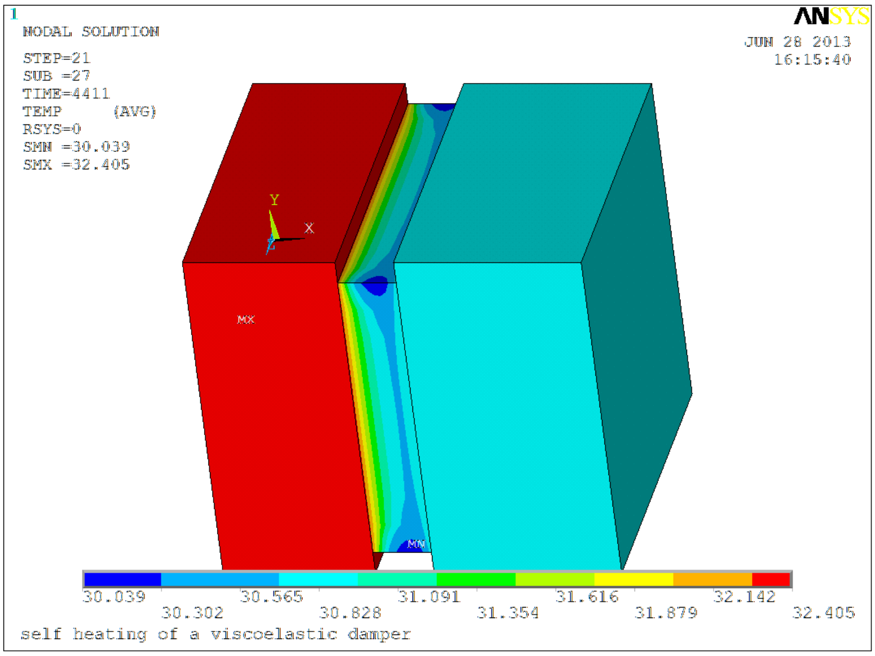


Figure 7. Temperature contours in the translational damper at time $t = 5000s$.

6. CONCLUDING REMARKS

A modelling procedure of the effects of the combined static and dynamic loadings on the self-heating phenomenon in viscoelastic materials has been suggested and evaluated by means of numerical simulations and experimental tests. One important aspect that must be pointed out with respect to the thermal analysis of viscoelastic materials is the difficulty in estimating some of the thermal properties, especially in the case of the static preloads superimposed on the cyclic loadings. To cope with this problem, a curve fitting procedure may used based on the formulation of an optimization problem.

The numerical and experimental results make clear that the amplitude of the static preload can affect significantly the temperature evolutions within the viscoelastic volume. As a result, the temperature increases can affect significantly the mechanical properties of the viscoelastic material and compromises their damping capability. Thus, it can be concluded that the most traditional procedures of analysis and design of viscoelastic damping devices by assuming constant, uniform temperature distributions over the volume of viscoelastic materials can be inadequate in certain circumstances and is likely to lead to unexpected damping performance of viscoelastic dampers.

7. ACKNOWLEDGMENTS

The authors are grateful to the Brazilian Research Council – CNPq for the continued support to their research works, especially through research projects 308310/2010-1 (A.M.G. de Lima) and 482963/2009-3 (D.A. Rade). The authors express their acknowledgements to the Minas Gerais State Agency FAPEMIG for the financial support to their research activities and the Brazilian agency CAPES.

8. REFERENCES

A.D. Nashif, D.I.G. Jones, J.P. Henderson, Vibration damping, John Wiley & Sons, New York, USA, 1985.
R.M. Christensen, Theory of viscoelasticity: An introduction, Academic Press, Inc., New York, USA, 1982.
D. Rittel, On the conversion of plastic work to heat during high strain rate deformation of glassy polymers, Mechanics of Materials 31 (1999) 131-139.
D. Rittel, Y. Rubin, An investigation of the heat generated during cyclic loading of two glassy polymers. Part II: Thermal analysis, Mechanics of Materials 32 (2000) 149-159.
J. Cazenove, D.A. Rade, A.M.G. de Lima, C.A. Araújo, A numerical and experimental investigation on self-heating effects in viscoelastic dampers, Mechanical Systems and Signal Processing 27(2012) 433-445.
H.S. Gopalakrishna, M.L. Lai, Finite element heat transfer analysis of viscoelastic damper for wind applications, Journal of Wind Engineering and Industrial Aerodynamics 77-78 (1998) 283-295.

ISSN 2176-5480

R.A. Schapery, Effect of cyclic loading on the temperature in viscoelastic media with variable properties, AIAA Journal 2 (1964) 827-835.

A.M.G. de Lima, D.A. Rade, F.P. Lépore-Neto, An efficient modeling methodology of structural systems containing viscoelastic dampers based on frequency response function substructuring, Mechanical System and Signal Processing 23 (2009) 1272-1281.

A. Moreau, Identification de propriétés viscoélastiques de matériaux polymères par mesures de réponses en fréquences de structures, Doctorate thesis, INSA, Rouen, France, 2007 (in French).

J.H.I. Lienhard, J.H.V. Lienhard, A heat transfer textbook, Third edition, Phlogiston Press, Cambridge, 2004.

M.B. Bever, D.L. Molt, A.L. Titchener, The stored energy of cold work, Edited by B. Chalmers, J.W. Christian, T.B. Massalski (Editors), Progress in Materials Science 17, 1973.

M.L. Drake, J. Soovere, A design guide for damping of aerospace structures, in: AFWAL Vibration Damping Workshop Proceedings 3 (1984), Atlantic City, USA.

ANSYS User Manuals, Revision 11.0. http://www.ansys.com/ (accessed 01 November 2009)

http://www.3m.com/ (Accessed 01 August 2009)

G.N. Vanderplaats, Numerical optimization techniques for engineering design, fourth ed., Vanderplaats Research and Development, Inc., Colorado Springs, USA, 2005.

9. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.