JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 5, October 2006, p. 1748 - 1751

Thermal and mechanical ageing of the elastomagnetic core material

C. HISON[a*], G. AUSANIO[b], V. IANNOTTI[b], G. LUCIANI[c], C. LUPONIO[c], L. LANOTTE[b]
[a]CRS-Coherentia-CNR and Dip. di Ingegneria dei Materiali e della Produzione, Facoltà di Ingegneria, Università "Federico II", P.le V. Tecchio 80, 80125 Napoli, Italy
[b]CRS-Coherentia-CNR, Dip.to di Scienze Fisiche, Facoltà di Ingegneria, Università "Federico II", P.le V. Tecchio 80, 80125 Napoli, Italy
[c]Dip. di Ingegneria dei Materiali e della Produzione, Facoltà di Ingegneria, Università "Federico II", P.le V. Tecchio 80, 80125 Napoli, Italy

The stability under dynamic mechanical solicitation and with the temperature of the elastomagnetic composite made of Sm_2Co_7 particles embedded in a silicone matrix is investigated. The thermal stability was examined by DSC measurements. The thermal (up to ≅340°C) and mechanical ageing effects on the material elastomagnetic response were investigated by measuring the amplitude, V_0, of the electromotive force induced in a pick-up coil during the dynamic mechanical solicitation of the sample. It was found that for the whole investigation range of temperatures, the V_o dependence on the frequency, ν, and amplitude, D, of the externally induced deformation is linear and its amplitude is not changing for treatments up to 150°C; for higher temperature treatments the response amplitude is decreasing. The analysis of the response signal (registered at 1 h intervals) after dynamic mechanical solicitation carried out during 48 h, shows the excellent output reliability and no decrease in amplitude with time.

(Received September 6, 2006; accepted September 13, 2006)

Keywords: Elastomagnetic core material, Mechanical ageing, Thermal stability

1. Introduction

The interest in the magnetoelastic materials for technological applications are continuously increasing [1,2]. Among them, especially the composites made of magnetic particles inside a non-magnetic elastic matrix have regained interest in the last few years due to their fundamental physics potential for the thorough understanding of the micromagnetic interactions between the filling particles and peculiar properties used in a wide range of applications as sensor and actuator cores, controlled vibration dampers, variable stiffness components, etc [3-5]. The recently developed elastomagnetic composites made of ferromagnetic micro-particles uniformly dispersed into a silicone matrix exhibit a strong coupling between elastic deformation and magnetization, named elastomagnetic effect [3,6-8] in order to distinguish it from the classical magnetoelasticity. More specifically, it is possible to have a sensible deformation of the material, consequent to the application of an external magnetizing field (direct elastomagnetic effect), as well as a magnetization change induced by an external strain (inverse elastomagnetic effect), due to the particles rotation inside the elastic matrix, and these effects are as strong as the coupling between the particles magnetic moment and their body [6].

In this paper we investigate the stability under dynamic mechanical solicitation and with the temperature of the elastomagnetic composite made of Sm_2Co_7 particles embedded in a silicone matrix.

2. Experimental

The investigated elastomagnetic composite was made of irregular shape Sm_2Co_7 micro-particles (average size of 4 μm) uniformly dispersed inside a silicone matrix in a volume percentage of 9%. The samples were prepared in bar shape, 4.5×10^{-2} m in length and $(5\times5)\times10^{-6}$ m^2 transversal cross section (Fig. 1), following the manufacturing process described in [6,9].

The composite was permanently magnetized at room temperature so that all the magnetic moments, **m**, of the micro-particles were aligned at 45° with respect to the bar main axis (Fig. 1). For this purpose, a magnetic field of 4T was applied along the required axis of the sample, by means of a vibrating sample magnetometer, VSM.

The thermal stability of the samples was analyzed by differential scanning calorimetric (DSC) measurements.

The thermal treatment and mechanical ageing effects on the elastomagnetic response of the sample under longitudinal dynamic deformation (of variable frequency, ν, and amplitude, D) were investigated using the experimental set-up presented in Fig. 2.

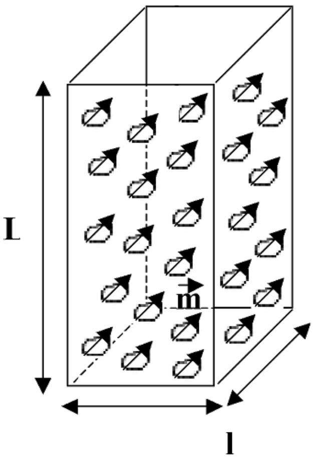

Fig. 1. Schematic view of the elastomagnetic composite sample (length, $L=4.5\times10^{-2}$ m and width, $l=5\times10^{-3}$ m). ***m*** *– permanent magnetic moment of the Sm_2Co_7 micro - particles.*

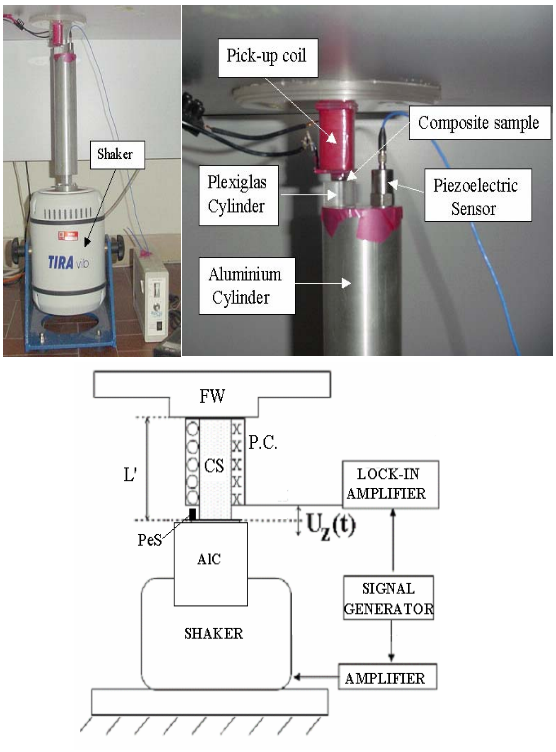

Fig. 2. Experimental arrangement used to study the elastomagnetic response of the composite sample under external dynamic deformation produced by a shaker. FW = fixed wall, P.C. = pick-up coil, CS = composite sample, AlC = aluminium cylinder, PeS = piezoelectric sensor, L' = pre-stressed sample length, L-L' > D, $U_z(t) = D\sin(2\pi\nu t)$ = dynamic longitudinal deformation induced by the shaker vibration.

The dynamic deformation of the composite sample was produced by means of a shaker. The sample cross section does not change due to the coil framework around it and the shaker vibration induces therefore an uniaxial volume deformation. The sample was pre-stressed in order to have an initial length *L'* so that *L-L'* > *D*, where *D* is the amplitude of the dynamic longitudinal deformation, $U_z(t) = D\sin(2\pi\nu t)$, produced by the shaker vibration. Hence, the sample works all the time in compression, which assures always a response signal in the pickup coil P.C. The signal generator drives the shaker by means of the amplifier, giving also the reference frequency to the lock-in amplifier which detects the electromotive force induced in the pickup coil as the sample elastomagnetic response to the external dynamic deformation. Practically, the material deformation induced by the shaker vibration determines a change in the longitudinal magnetization, due to the inverse elastomagnetic effect, which induces a voltage, V_{ind}, in the pickup coil [10]:

$$V_{ind} = \mu_0 \frac{D}{L'} V\% N S M_r 2\pi\nu \cos^3\theta_i \cos(2\pi\nu t) = V_o \cos(2\pi\nu t) \qquad (1)$$

where *V*% is the volume fraction of magnetic particles inside the silicone matrix, *N* is the coil turns number, *S* is the sample cross-section, M_r is the macroscopic remanent magnetization of the sample, $\theta_i=45°$ is the initial orientation of **m** with respect to the sample longitudinal axis and $V_o = \mu_0 \frac{D}{L'} V\% N S M_r 2\pi\nu \cos^3\theta_i$ is the amplitude of the induced voltage in the pickup coil.

3. Results and discussion

The DSC curves for Sm_2Co_7 powder (a), pure silicone (b) and composite material made of Sm_2Co_7 micro-particles uniformly dispersed inside the silicone matrix (b) are presented in Fig. 3. The obtained DSC curve for Sm_2Co_7 powder confirms the well known outstanding thermal stability of this composite which has the maximum working temperature of 250 °C. The exothermic peak that occurs around 380°C is likely caused by the material oxidation. The pure silicone DSC curve shows two endothermic peaks which possibly correspond to the melting point of one of the silicone components (first peak) and to the silicone decomposition (second peak). The DSC curve of the composite material exhibits two endothermic peaks and one exothermic, following the superposition of the two components behaviour, the slight shift in the peaks position being probably determined by the interaction between the filling particles and the silicone matrix.

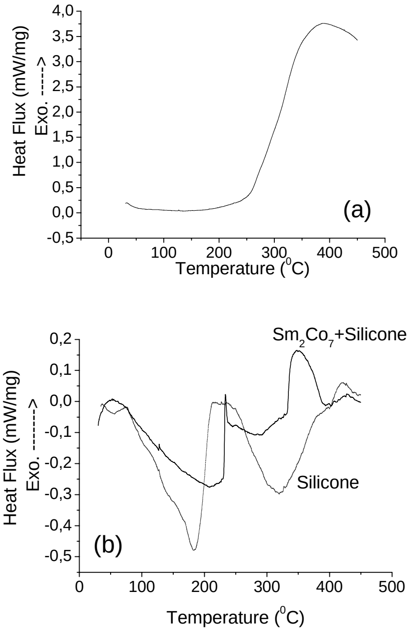

Fig. 3. DSC curves for Sm_2Co_7 powder (a), pure silicone (b) and composite material made of Sm_2Co_7 powder uniformly dispersed inside the silicone matrix (b) (heating rate of 5 K/min).

The effect of thermal treatments up to ≅345°C on the elastomagnetic response of the material was examined by measuring the amplitude, V_o, of the electromotive force induced in the pick-up coil during the dynamic mechanical solicitation of the annealed sample. Subsequent thermal treatments (at 50, 100, 150, 200, 234, 260, 300 and 343°C, respectively, following the important temperature regions from the composite DSC curve) were performed for 2 minutes each, in argon atmosphere. The curves of the sample elastomagnetic response, V_o, as function of frequency, ν, and amplitude, *D*, of the dynamic mechanical solicitation, after different thermal treatments are presented in Fig. 4 (a) and (b), respectively. It can be seen that for the whole investigation range of temperatures, the dependence of the composite response, V_o, on the frequency, ν, and amplitude, *D*, of the externally induced deformation is linear, as predicted by Eq. (1). The amplitude of the material response is not changing for the as-prepared samples, as well as for those thermally treated up to 150°C. With increasing the treatment temperature, the response amplitude is decreasing, due to the joint action of the silicone worst elastic characteristics, determined by the viscosity increase with the treatment temperature (due to some component evaporation) and of the worst magnetic properties of the Sm_2Co_7 particles whose working temperature is generally limited to ≅ 250°C.

The analysis of the material response, regularly registered at 1 h intervals, after dynamic mechanical solicitation (at ν=30 Hz and *D*=0.7 mm) carried out during 48 h shows the excellent output reliability and no decrease in amplitude with the treatment time-Fig. 5.

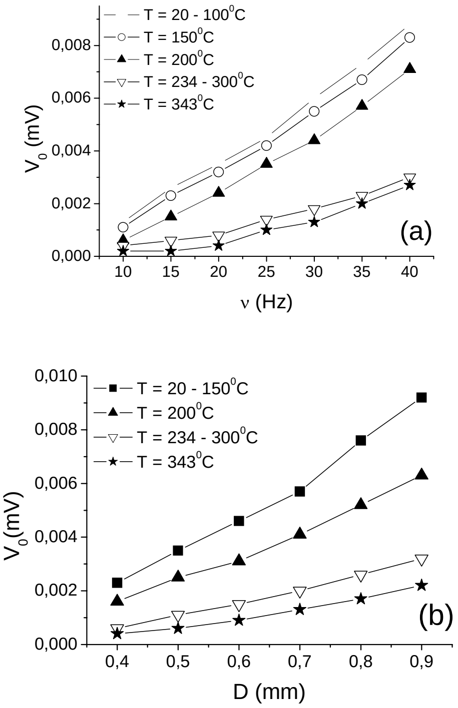

Fig. 4. Elastomagnetic response of the sample, V_O, as function of frequency, ν, (a) and amplitude, D, (b) of the dynamic mechanical solicitation, after different thermal treatments.

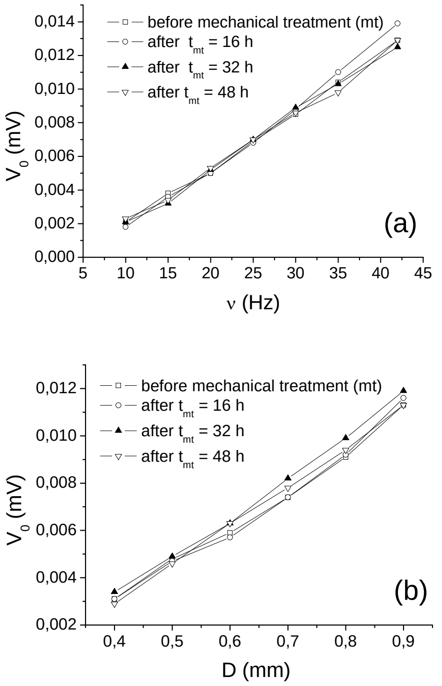

Fig. 5. Elastomagnetic response of the sample, V_O, as function of frequency, ν (at fixed D=0.7 mm) (a), and amplitude, D (at fixed ν=30 Hz) (b), of the dynamic mechanical solicitation. V_O vs. ν and D were registered after 16, 32 and 48 h of dynamic mechanical treatment at ν =30 Hz and D=0.7 mm.

4. Conclusions

The investigation of the thermal (up to 345 °C) and mechanical (by dynamic mechanical solicitations at $\nu = 30$ Hz and D=0.7 mm, during 48 h) ageing effect on the elastomagnetic composite response gives the following results: (i) the amplitude of the material response is not changing for thermal treatments up to 150°C; (ii) the material response after 48 h of continuous mechanical solicitation shows excellent output reliability and no decrease in amplitude with the time of the mechanical treatment.

The obtained results are very important for the assessment of the elastomagnetic composite thermal stability and mechanical ageing which is a matter of strong interest for the engineering process of this material as magnetic core for sensors and actuators.

References

[1] G. Ausanio, C. Hison, V. Iannotti, C. Luponio, L. Lanotte, Magnetoelastic Stress and Strain Sensors to be published in: Encyclopedia of Sensors, Craig A Grimes, Elizabeth C. Dickey, Michael V. Pishko (Eds.), American Scientific Publisher (2006).
[2] E. Hristoforou, Meas. Sci. & Technol. **14**, R15-R47 (2003).
[3] L. Lanotte, G. Ausanio, C. Hison, V. Iannotti, C. Luponio, C. Luponio Jr., J. Optoelectron. Adv. Mater. **6,** 523 (2004).
[4] J. M. Ginder, M. E. Nichols, L. D. Elie, S. M. Clark, in: Smart Structures and Materials, Proceedings of SPIE, Norman M. Weseley (2000).
[5] J. M. Ginder, W. F. Schlotter, M. E. Nichols, in: Smart Structures and Materials, Proceedings of SPIE, SPI- The International Society for Optical Engineering, vol. 4331, 2001, p. 103.
[6] L. Lanotte, G. Ausanio, V. Iannotti, G. Pepe, G. Carotenuto, P. Netti and L. Nicolais, Phys. Rev. B **63**, 054438 (2001).
[7] G. Ausanio, C. Hison, V. Iannotti, C. Luponio Jr., L. Lanotte, J. Magn. Magn. Mater. **272-276**, 2069 (2004).
[8] L. Lanotte, G. Ausanio, C. Hison, V. Iannotti, C. Luponio, Sensors and Actuators A **106**, 56 (2003).
[9] L. Lanotte, G. Ausanio, V. Iannotti, C. Luponio Jr, Appl. Phys. A **77**, 953 (2003).
[10] G. Ausanio, L. De Arcangelis, G. Francese, V. Iannotti, C. Luponio Jr., L. Lanotte, J. Magn. Magn. Mater. **290-291**, 836 (2005).

---

[*] Corresponding author: corneliahison@yahoo.com