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Magnetoacoustic properties of self-biased Terfenol-D 2-2 composites

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Self-biased Terfenol-D 2-2 composites exhibit high frequency of actuation and good magnetoacoustic properties; however, their potential usefulness is highly dependent on their magnetoacoustic properties, particularly for ultrasonic applications. The speed of sound, c , and its variation with an externally applied magnetic field have been measured for the above composites using a 10 MHz longitudinal pulse. When the sound propagates parallel to the layers, the acoustic impedance was found to be independent of the external applied field, and lower than that for bulk Terfenol-D. The magnetomechanical coupling coefficient was found to be generally low (up to 0.35) and dependent on the volume ratio of materials, being higher for the specimens with greater content of Terfenol-D. The low attenuation, low acoustic impedance, and high frequency of actuation make this structure an interesting alternative for use in underwater/sound navigation and ranging and other ultrasonic applications. When the pulse propagates orthogonal to the layers, c was found to vary by up to 3% with the application of an external field, but the acoustic attenuation was found to be very high due to the multiple reflections produced at the interfaces between the layers. This latter phenomenon has been calculated theoretically. © 2007 American Institute of Physics. [DOI: [10.1063/1.2712028](https://doi.org/10.1063/1.2712028)]

INTRODUCTION

Terfenol-D ($\text{Tb}_{0.3}\text{Dy}_{0.7}\text{Fe}_2$) has been shown to have excellent room temperature magnetomechanical properties, but its use is limited at high frequencies due to the existence of eddy current losses.^{1,2} The usefulness of magnetostrictive materials is not only influenced by their frequency of actuation, but also is highly dependent on their acoustic properties, particularly for ultrasonic applications. For example, for their use in sound navigation and ranging (SONAR) applications, it is important that the material has a low attenuation and acoustic impedance matching that of water. Their use as wave phase conjugators (WPCs) requires the propagation of an acoustic wave through the magnetostrictive material with a velocity that is under external control. The use of the WPCs in medical applications also requires acoustic impedance matching that of the human body (typically 1.5 Mrayl, where 1 Mrayl = $10^6 \text{ kg s}^{-1} \text{ m}^{-2}$).

Metallic powder/polymer matrix 0-3 and 1-3 composites are known to increase the frequency of actuation of magnetostrictive materials, but usually at the expense of their magnetomechanical properties.^{3,4} Terfenol-D 2-2 composites with internal field biasing have been shown to improve the magnetomechanical performance of Terfenol-D by reducing the eddy current losses at high frequencies (via electrically insulated metallic layers) while keeping optimum magneto-mechanical properties.^{5,6}

In this paper the acoustic properties of self-biased Terfenol-D 2-2 composites are reported. Suggestions are

made as to how to improve their performance for several applications in the light of the results obtained.⁶

EXPERIMENTAL RESULTS

Seven composites formed by Terfenol-D, an insulating material (cyanoacrylate adhesive), and $\text{Nd}_2\text{Fe}_{14}\text{B}$ have been produced with different volume fractions and layer thicknesses on the order of micrometers by alternatively bonding layers of Terfenol-D and $\text{Nd}_2\text{Fe}_{14}\text{B}$ with cyanoacrylate adhesive. The $\text{Nd}_2\text{Fe}_{14}\text{B}$ was magnetized perpendicular to the layers to give a theoretical increase in the magnetostriction of the Terfenol-D layers due to premagnetization domain alignment.⁵

The speed of sound, c , and its variation with an externally applied field have been measured in bulk Terfenol-D and $\text{Nd}_2\text{Fe}_{14}\text{B}$. In Terfenol-D a change of up to 7% has been observed when a 150 kA/m external magnetic field was applied, while no change has been observed in $\text{Nd}_2\text{Fe}_{14}\text{B}$. The attenuation in Terfenol-D was measured to be much higher than in the permanent magnet. Figure 1 shows the variation in the speed of a 10 MHz longitudinal pulse along the [112] crystallographic direction in Terfenol-D. The externally applied magnetic field was applied along [112] and $[\bar{1}\bar{1}1]$.

The propagation of sound along the permanent magnet is important to understand the propagation of sound through the composites. The sound speed was measured in a rod of $\text{Nd}_2\text{Fe}_{14}\text{B}$ and was found to be 5025 m/s, independently on the state of magnetization of the rod.

The variation of sound speed has also been measured for the 2-2 composites along the direction of actuation (parallel to the layers) and through the layers of the composite. At the

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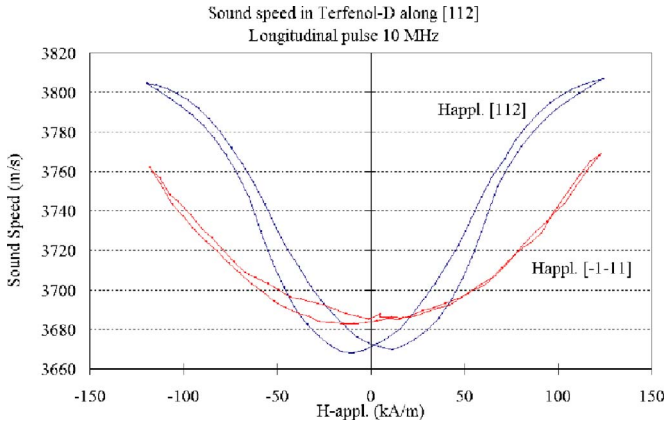


FIG. 1. (Color online) Variation of speed of a 10 MHz longitudinal pulse in Terfenol-D along the [112] crystallographic direction with the external field applied along the [112] and $[\bar{1}\bar{1}1]$ directions.

frequency used, with corresponding wavelength higher than the thickness of the layers, no change in the sound speed was observed with the application of an external magnetic field, c being within the range 4200–4400 m/s in all the samples. Since the attenuation in the permanent magnet is less than in Terfenol-D, this layer is thought to have a greater influence on the sound speed. The fact that the sound speed within the permanent magnet is independent of its state of magnetization explains the fact that no variation of sound speed was found along this direction. The acoustic impedance was found to be on the order of 8.5 Mrayl, which is lower than that of bulk Terfenol-D (~ 33 Mrayl). The coupling coefficients were found to be generally low, varying between 0.2 and 0.35, and dependent on the volume ratio of materials, being higher for the specimens with a greater content of Terfenol-D. The fact that the acoustic impedance and the attenuation have both been reduced with respect to that of the Terfenol-D, and the frequency of actuation is higher, make these composites an interesting alternative for use as underwater actuators. By removing the magnet layer, lower acoustic impedances would be achieved, although the attenuation would increase with respect to the bulk material.

The relative variation of sound speed through the layers of the composites is of the order of 2%–3%. The variation of sound speed is produced in the Terfenol-D layers, since the application of an external field does not change the sound speed in either $\text{Nd}_2\text{Fe}_{14}\text{B}$ or in the insulating material. The acoustic impedance is reduced even further to values below 4 Mrayl (for the sample with higher content of insulating material). However, the attenuation was found to be very high due to the multiple reflections produced at the interfaces of the layers.

CALCULATION OF THE ATTENUATION THROUGH THE LAYERS OF THE COMPOSITES

If a pulse of sound of intensity U_0 is sent to the sample, as shown in Fig. 2, the intensity of the pulse U_N detected by the receiver is related to U_0 through the following equations:

$$U_1 = U_0 T_{01} e^{-\alpha_1 l_1}, \quad (1)$$

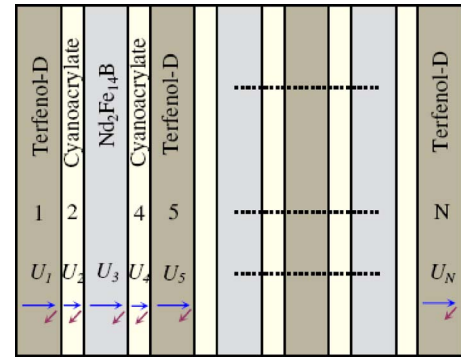


FIG. 2. (Color online) Multiple reflections produced at the interfaces of the layers in the composites. The intensity of the pulse in the last layer, U_N , is much smaller than the initial intensity U_0 .

$$U_2 = U_1 T_{12} e^{-\alpha_2 l_2} = U_0 T_{01} T_{12} e^{-\alpha_1 l_1 - \alpha_2 l_2}, \quad (2)$$

$$U_N = U_{N-1} T_{(N-1)N} e^{-\alpha_N l_N} = U_0 \left[\prod_{i=1}^{i=N} T_{(i-1)i} \right] e^{-\sum_{i=1}^{i=N} \alpha_i l_i}, \quad (3)$$

where α is the attenuation coefficient and T_{ij} is the transmission coefficient, which is given by

$$T_{ij} = \frac{4Z_i Z_j}{(Z_i + Z_j)^2} \quad (4)$$

and verifies $0 < T_{ij} < 1$.

Z is the acoustic impedance which is obtained from the sound speed and the mass density of the medium as in

$$Z = \rho c. \quad (5)$$

The acoustic impedance can therefore be evaluated for Terfenol-D, $\text{Nd}_2\text{Fe}_{14}\text{B}$, and cyanoacrylate, and it is shown in Table I.

From the values in Table I it is possible to estimate the values of the transmission coefficients $T_{\text{Terf-cyano}} \approx 0.39$ and $T_{\text{magnet-cyano}} \approx 0.35$. Since the number of layers of the composites is large, the term $\prod_{i=1}^{i=N} T_{(i-1)i}$ in Eq. (3) becomes very small,

$$\prod_{i=1}^{i=N} T_{(i-1)i} \rightarrow 0. \quad (6)$$

The attenuation coefficient in the three constituent materials is greater than 1 and therefore the term $e^{-\sum_{i=1}^{i=N+1} \alpha_i l_i}$ will be less than 1,

$$e^{-\sum_{i=1}^{i=N+1} \alpha_i l_i} < 1. \quad (7)$$

The product

TABLE I. Acoustic impedance calculated for Terfenol-D, $\text{Nd}_2\text{Fe}_{14}\text{B}$, and cyanoacrylate.

Material	Z (Mrayl)
Terfenol-D	$(33 \pm 3)\%$
$\text{Nd}_2\text{Fe}_{14}\text{B}$	$(37 \pm 3)\%$
Cyanoacrylate	$(4 \pm 3)\%$

$$\left[\prod_{i=1}^{i=N} T_{(i-1)i} \right] e^{-\sum_{i=1}^{i=N+1} \alpha_i l_i} \rightarrow 0 \quad (8)$$

and therefore from Eq. (3), $U_N \ll U_0$.

The samples produced in this work are formed by 25 layers. The intensity of pulse U_N was calculated using Eq. (3) and found to be $U_N \approx 10^{-11} U_0$. An intensity of pulse in the last layer, U_N , similar to the intensity of the initial pulse, U_0 , could be achieved only in a sample with a small number of layers, in which the constituent materials have low attenuation and similar acoustic impedances.

The high attenuation due to the multiple reflections produced at the interfaces of the layers, and the fact that the highest frequency of actuation of the specimens is the same as in the bulk material because the insulating layers are unable to interrupt the eddy currents, makes this configuration less attractive than the previous one.

CONCLUSIONS

Terfenol-D 2-2 composites with internal field biasing have been shown to improve the magnetoacoustic properties of Terfenol-D for their use in ultrasound/SONAR applications. Along the direction of actuation, the acoustic imped-

ance is reduced with respect to that of the bulk material, from 33 to 8.5 Mrayl, the latter being closer to the value of the acoustic impedance of water. The acoustic attenuation has also been reduced by a factor of 3. This, together with the high frequency of actuation exhibited by the composites, makes these magnetostrictive composites an attractive choice for their use in underwater applications.

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¹D. Kendall and A. R. Piercy, *Magnetoelastic Effects and Applications* (Elsevier Science, New York, 1993), p. 111.

²D. Kendall and A. R. Piercy, *J. Appl. Phys.* **73**, 6174 (1993).

³L. Sandlund, M. Fahlander, T. Cedell, A. E. Clark, J. B. Restorff, and M. Wun-Fogle, *J. Appl. Phys.* **75**, 5656 (1994).

⁴O. J. Thomas, S. C. Busbridge, and G. J. Tomka, *IEEE Trans. Magn.* **40**, 2763 (2004).

⁵L. G. Gancedo, S. C. Busbridge, and S. J. Eaton, *IEEE Trans. Magn.* **41**, 2781 (2005).

⁶L. Garcia-Gancedo, S. C. Busbridge, P. Pernod, V. Preobrazhensky, and O. Ducloux, *J. Magn. Magn. Mater.* **310**, 2627 (2007).