ACOUSTIC SIGNATURE OF DEFECTS IN SiC/POROUS SiC LAMINATED CERAMICS

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ABSTRACT

The sensitivity of acoustic techniques to topological and morphological variations in SiC/porous SiC laminated ceramics is studied using a transfer matrix formalism. To implement this transfer matrix technique, the mechanical properties of the SiC porous layers are characterized using the effective medium approximation of Kuster and Toksoz. We show that topological defects have a stronger acoustic signature than morphological defects. Also, we observe that there are particular frequencies at which the defects do not present any acoustic signature.

INTRODUCTION

Compositional modulation of ceramic materials has opened the possibility of constructing tougher and stronger ceramic materials. A simple and economic way of achieving compositional modulation of a material is by introducing weak interfaces. This interfaces act as crack deflectors, that prevent a catastrophic failure when the sample is subject to high stresses [1].

Weak interfaces have been successfully introduced in SiC ceramic materials by sintering alternate layers of SiC and carbon. During sintering the carbon layers will have become porous SiC layers due to the reaction between volatile SiO and carbon [2]. The resulting structure consists of alternate layers of SiC and porous SiC. This structure has a higher fracture toughness than the pure SiC ceramic [2].

Due to their potential applications in material science [3], the characterization of these structures is important. Ultrasound is a non-destructive method suitable for this purpose. The sensitivity of this technique to topological (changes in layer thickness) and morphological (changes in porosity) is the subject of this paper.

THEORY

To study the acoustic signature of topological and/or morphological changes, we will compare the transmissivity spectra $T(\omega)$ of a reference system with the spectra of a system that presents such variations. Our reference system consists of a periodic laminated structure made of 5 bilayers each made of a SiC layer of thickness $d_1 = 100$ μm and a porous SiC layer of thickness $d_2 = 10$ μm and porosity $\varphi = 35\%$.

The transmissivity spectra, an experimentally measurable quantity, is calculated using a transfer matrix formalism. This formalism has been previously developed for the study of dielectric, metallic and elastic superlattices [4-6]. For the implementation of this formalism, the elastic properties of each layer has to be known. These parameters are

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the density (ρ), the bulk (κ) and the shear modulus (μ), that for SiC are: ρ_s=13.8 g/cm^3, κ_s=6.12 Mbar and μ_s= 3.06 Mbar [7]. The respective properties (ρ_p, κ_p, μ_p) of the porous SiC layers are determined, within an effective medium approximation, using the Kuster and Toksoz (KT) model [8]. For the implementation of the KT model we assume that the porous SiC layers are made of a uniform matrix of SiC with spherical air saturated pores randomly placed in the matrix. For acoustic waves with a wavelength much larger than the mean diameter of the pores, the elastic constants are determined from the equations:

$$\rho_p = \varphi\rho_a + (1-\varphi)\rho_s, \tag{1}$$

$$\frac{\kappa_p - \kappa_s}{3\kappa_p + 4\mu_s} = \varphi\frac{\kappa_a - \kappa_s}{3\kappa_a + 4\mu_s}, \tag{2}$$

and

$$\frac{\mu_p - \mu_s}{6\mu_p(\kappa_s + 2\mu_s) + \mu_s(9\kappa_s + 8\mu_s)} = \varphi\frac{-\mu_s}{\mu_s(9\kappa_s + 8\mu_s)}. \tag{3}$$

The subindex p refers to the effective properties of the porous media and the subindex a to the properties of air. Notice that the effective properties of the porous layers depend only on the porosity φ.

With the elastic parameters of both layers determined, the transmissivity spectra can be calculated using the transfer matrix technique fully described in Reference [6]. In this work we assume a longitudinal wave propagating perpendicular to the layered system. To be consistent with an experimental situation we assume that the whole laminated SiC structure in embedded in water [9].

RESULTS

In Figure 1, the transmissivity spectra of the reference system is shown. Even with only 5 bilayers, a pass/stop band-like structure becomes apparent. In the case of an infinite number of layers, the band structure predicted using Bloch's theorem will be obtained. We have plotted the natural log of the transmissivity (Nepers), to be consistent with an ultrasonic experimental situation.

The SiC laminated structure can present topological and morphological defects due to use, wear, fabrication induced defects etc., that will change the acoustic response of the system. The presence of defects is simulated by varying the topology and/or morphology of the system using a random variable γ that can take any value in the range [-ε, ε]. The variable ε is a measure of the maximum amount of disorder allowed with respect to the reference system. The transmissivity of the disorder or "defective" system is calculated by taking an average ($\langle\cdots\rangle$) over 500 different representations. The sensitivity to the disorder of the acoustic wave is measured by the difference $\Delta(\omega)=|\ln T_0(\omega) - \langle \ln T(\omega)\rangle|$ between the ordered (T_0) and disordered or defective laminated systems.

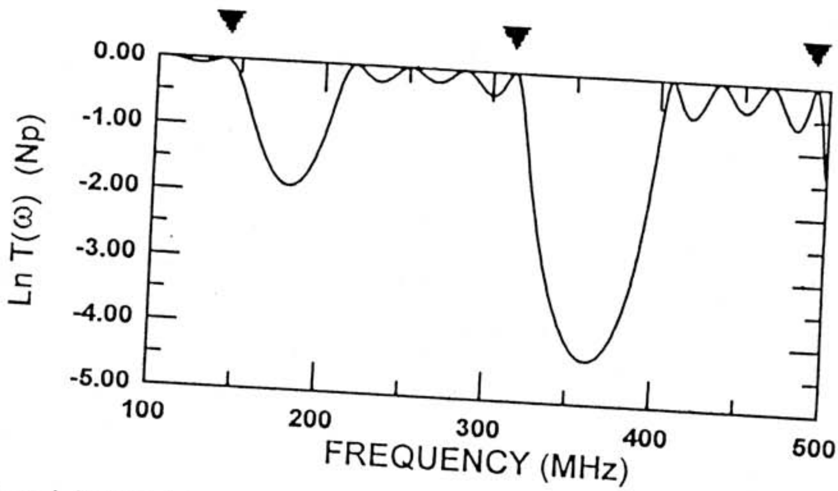

Figure 1. Transmissivity spectra for a SiC/porous SiC laminated ceramic with 5 bilayers. The arrows indicate the frequency at which the stop bands begin.

Three separate cases of disorder are considered:

a) Topological defects. We assume that the thickness of the porous layers varies according to the rule: $d'_2=d_2(1+\gamma)$, while the porosity and the thickness of the SiC layers remain constant. Figure 2 shows the difference $\Delta(\omega)$ as a function of frequency for three different values of ε. For ε=10%, $\Delta(\omega)$ is very small except at frequencies corresponding to the beginning and end of the stop bands of the reference structure. As the disorder parameter ε increases, $\Delta(\omega)$ becomes larger due to the effects of disorder. It is important to notice that there are particular frequencies at which $\Delta(\omega)\approx 0$, falsely indicating the absence of defects.

b) Morphological defects. When the defects are attributed to changes in porosity, the effective elastic parameters change according to the KT model, and hence a different transmissivity is obtained. The changes in porosity, in terms of the random variable γ, are given by $\varphi'= \varphi(1+\gamma)$. For fixed layer thickness' and changing porosity, the difference $\Delta(\omega)$ is shown in Figure 3. The values of $\Delta(\omega)$ are smaller than in case (a) of topological disorder. The biggest difference $\Delta(\omega)$ is observed on the edges of the stop bands. This results also show that the acoustic impedance does not change significantly with variations of porosity. As in case (a), there are frequencies at which $\Delta(\omega)\approx 0$.

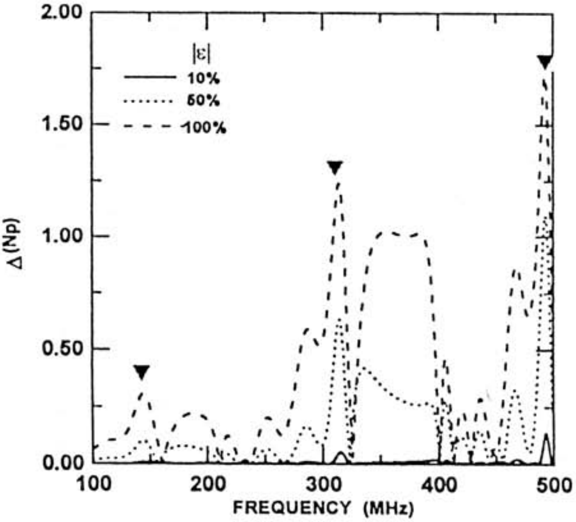

Figure 2. Δ(ω) for topological defects. The porosity remains constant and the thickness of the porous layers varies.

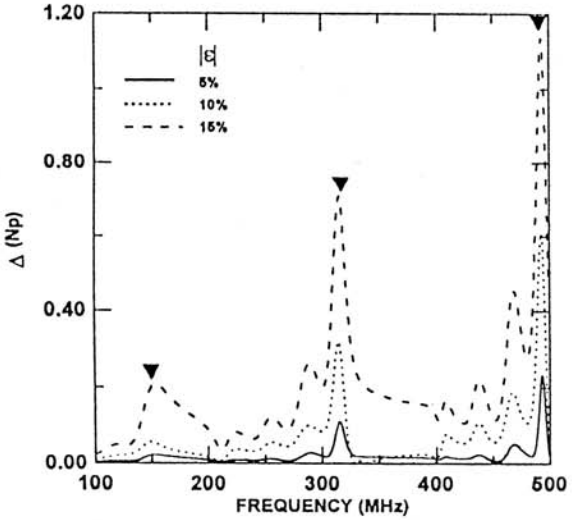

Figure 3. Sensitivity Δ(ω) as a function of frequency, when the porosity is varied and the period of each bilayer remains constant.

c) Mixed defects. A more realistic physical situation is when both, topological and morphological defects are present. This is shown in Figure 4, where the variations in layer thickness corresponds to $|\varepsilon|$= 10% for all curves and the porosity is varied as in Figure 3. The acoustic signature is distinct from having topological or morphological disorders only. For this particular case the morphological disorders seems to dominate over the topological ones.

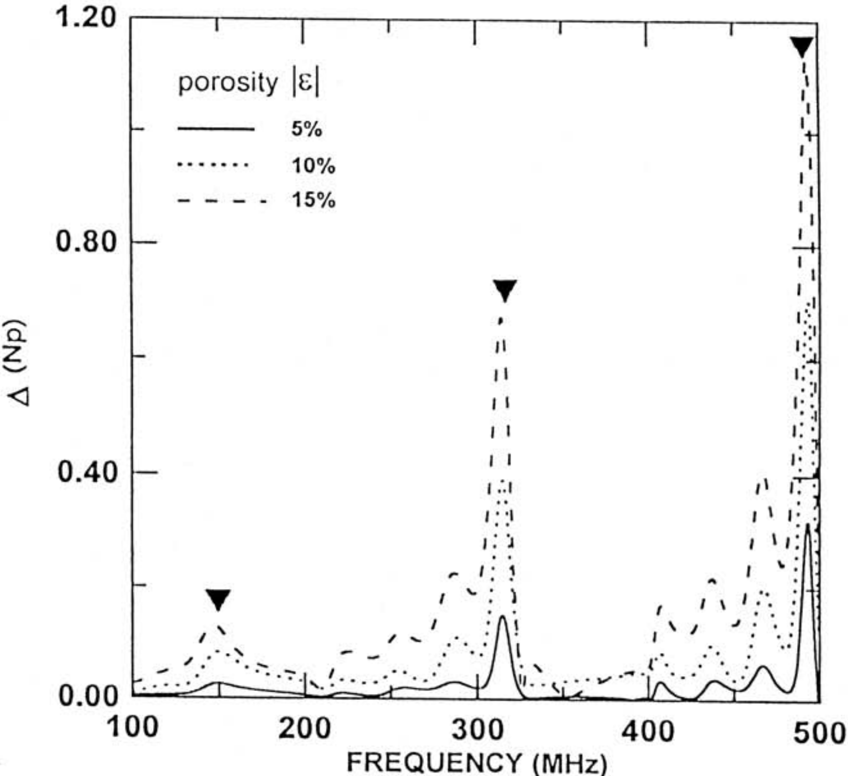

Figure 4. Sensitivity $\Delta(\omega)$ for different values of porosity and variations in the thickness of the porous layers of at most $|\varepsilon|$= 10%.

CONCLUSIONS

The acoustic signature of defects present in SiC/porous SiC can be determined using ultrasonic techniques, by comparing the transmissivity of a reference structure with one presenting some type of defect. Our results suggest that care should be taken when choosing the working frequencies. There are frequency regions in the three cases (a,b,c), for which $\Delta(\omega) \approx 0$ that can be falsely interpreted as the absence of any defects. The value of these particular frequencies depend on the type and amount of disorder present. At frequencies corresponding to the edges of the stop bands (indicated by the arrows in the Figures 1-4), the sensitivity of the acoustic waves to the defects is greater and thus more reliable measurements can be made at these frequencies. We also showed that topological defects have a stronger acoustic signature as compared to variations in porosity. The technique presented here, enables the detection and identification of the types of defects. The quantification or ammount of disorder present in the laminated structure remains an open issue.

REFERENCES

[1] J. Cook and J.E. Gordon, Proc. R. Soc. A **282**, 508-520 (1964).
[2] V.D. Krstic, MRS Bulletin **21**, 46-49 (1995).
[3] J.A. Jacobs and T.F. Kilduff, *Engineering Materials Technology*, (Prentice Hall International, Englewoods Cliffs, New Jersey), 1985.
[4] A.R. McGurn and A.A. Maradudin, Physica A **207**, 435-439 (1994).
[5] E.L. Olazagasti, G.H. Cocoletzi and W.L. Mochán, Solid State Commun. **78**, 9-12 (1991).
[6] R. Esquivel-Sirvent and G.H. Cocoletzi, J. Acoust. Soc. Am. **95**, 86-90 (1994).
[7] A.R. Selfridge, IEEE Transactions on Sonics and Ultrasonics SU-**32**, 381-394 (1985).
[8] G.T. Kuster and M.N. Toksoz, Geophysics **39**, 587-606 (1974).
[9] R. James, S. M. Woodley, C. M. Dyer and V. F. Humphrey, J. Acoust. Soc. Am. **97**, 2041-2048 (1995).