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Research on sound absorbing mechanism and the preparation of new backing material for ultrasound transducers

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Based on acoustical designing demand of backing material for ultrasound transducer， multiple scattering(MS) theory has been carried out by studying the methods of impedance matching for different layered materials. Typical acoustic properties of the periodic structure in ultrasonic frequency band have been given as well. In order to increase acoustic impedance to match the active materials and improve the absorption performance at the same time, it's a good way to fill metallic particles in the viscoelastic materials. Preliminary test results show that these composites behave good acoustical and mechanical performance. It makes a solid foundation and good prospect for the application of backing material in broadband ultrasonic transducer.

1 INTRODUCTION

The lossy backing is used to absorb the ultrasonic energy of piezocomposite transducers. In order to obtain shorter pulse at the expense of sensitivity, the acoustic impedance of the backing demands to match to the active materials. To achieve greater acoustic impedance, we may select to fill metallic particles in the viscoelastic materials[1]. The absorption performance can greatly improved for energy dissipation for viscoelastic materials such as epoxy resin and rubber. The multiple scattering of metallic particles in viscoelastic materials can increase number of propagation routes and improve energy dissipation at the same time.

It is known that the MS method can be used to analyze reflection, transmission and absorption performance. The periodic structure for the spherical[2,3] and axisymmetric cavities[4] were investigated, and the results indicate that the acoustic energy dissipation depends on MS effect. In this paper, we used the MS method to analyze absorption performance of viscoelastic

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materials containing periodic metallic particles such as tungsten powder for the backing of piezocomposite transducers. The computational results indicate that the metallic particles scattering and impedance matching are very important for the sound absorption of backing material.

2 THEORY

The displacement $\mathbf{u}$ for harmonic elastic wave propagation in a homogeneous medium can be written as a time-independent equation[3]

$$(\lambda+2\mu)\nabla(\nabla\cdot\mathbf{u})-\mu\nabla\times(\nabla\times\mathbf{u})+\rho\omega^2\mathbf{u}=0 \tag{1}$$

where ρ is density, ω is angular frequency, and λ,μ are Lamé coefficient and shear modulus, respectively. For a viscoelastic medium containing energy losses, Lamé coefficient and shear modulus can be regarded as complex numbers.

The $\boldsymbol{a}_1,\boldsymbol{a}_2$ are lattice primitive vectors of one cavity element along in the x,y directions. The other lattice vectors in these two dimensions are obtained as follows:

$$\boldsymbol{R}_n=n_1\boldsymbol{a}_1+n_2\boldsymbol{a}_2,\quad n_1,n_2=0,\pm1,\pm2,\pm3,\cdots \tag{2}$$

One of the particle centers can be seen as the origin of the coordinate system. In spherical coordinate system, the solution can be decomposed into one longitudinal and two transverse solutions [2] :

$$\boldsymbol{u}(\boldsymbol{r})=\sum_{lm\sigma}[a_{lm}^{\sigma}J_{lm\sigma}(\boldsymbol{r})+b_{lm}^{\sigma}H_{lm\sigma}(\boldsymbol{r})] \tag{3}$$

For solid medium, $\sigma=L$ denotes longitudinal mode, $\sigma=M,N$ denote SH and SV transverse modes, respectively. a_{lm}^{σ} , b_{lm}^{σ} are the expansion coefficients for the incident and scattered waves, respectively. $J_{lm\sigma}(r),H_{lm\sigma}(r)$ are the combined spherical Bessel function and spherical Hankel function where the subscripts are the function orders[3].

The displacement of scattered waves are given by

$$\sum_{l'm'\sigma'}[\boldsymbol{I}_{ll'}\boldsymbol{I}_{mm'}\boldsymbol{I}_{\sigma\sigma'}-\sum_{l''m''\sigma''}\boldsymbol{T}_{lm;l''m''}^{\sigma\sigma''}\boldsymbol{\Omega}_{l''m'';l'm'}^{\sigma''\sigma'}]\boldsymbol{B}_{l'm'}^{\sigma'}=\sum_{l'm'\sigma'}\boldsymbol{T}_{lm;l'm'}^{\sigma\sigma'}\boldsymbol{A}_{l'm'}^{O\sigma'} \tag{4}$$

where $\boldsymbol{I}$ is the unit matrix, $\boldsymbol{A}=[a_{lm}^{\sigma}]$, $\boldsymbol{B}=[b_{lm}^{\sigma}]$. $\boldsymbol{T}$ matrix of equation can describe the relation between the incident waves and scattered waves, both depend on the geometry of the cavity. $\boldsymbol{\Omega}$ describes the scattering effect between the total scattered waves and the sum of the waves from all the other cavities, which in turn depends on the lattice geometry, frequency and the material properties[5].

Acoustic performance of viscoelastic layers containing periodic particles can be given from MS and sound propagation theory in the layered medium[4]. The acoustic energy of the reflection and transmission waves is associated with the displacement of the plane waves. The reflection coefficient R is defined to be the ratio of acoustic energy of the reflected waves to that of the incident waves. The transmission coefficient T is the acoustic energy ratio of the transmission waves to the incident waves, and the absorption coefficient is defined to be

$$\alpha=1-R-T \tag{5}$$

3 RESULTS AND DISCUSSIONS

Figure 2 and Figure 3 show absorption coefficient curves of tungsten powder in viscoelastic materials in ultrasonic frequency by using multiple scattering method and transfer matrix, where the sound impedance of piezoelectric medium is 15MPa m/s, the viscoelastic material density is 1039kg/m^3, the longitudinal velocity and transverse wave velocity are 1478m/s and 207m/s respectively. Tungsten powder material evenly distributed like spherical particles in viscoelastic medium. Each unit is assumed a cube lattice containing tungsten particle. Here the lattice length is 3 micrometers, the total sample thickness is 3mm. For example the tungsten particles are 2.5 micrometers in diameter, volume fraction of tungsten powder is 30%.

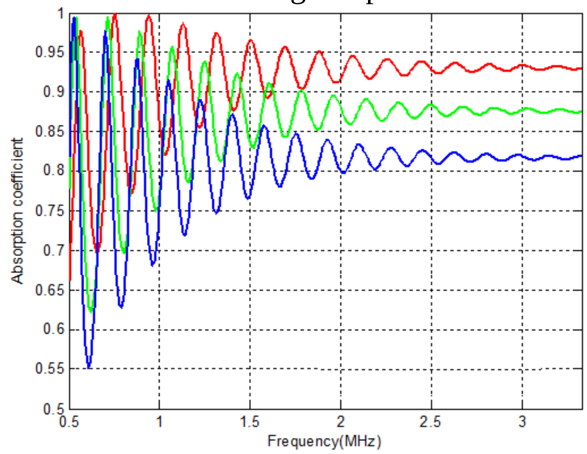

Fig. 1 – Absorption coefficient curves of backing material for different volume content of tungsten powder (red line:20%, green line:30%, blue line:40%)

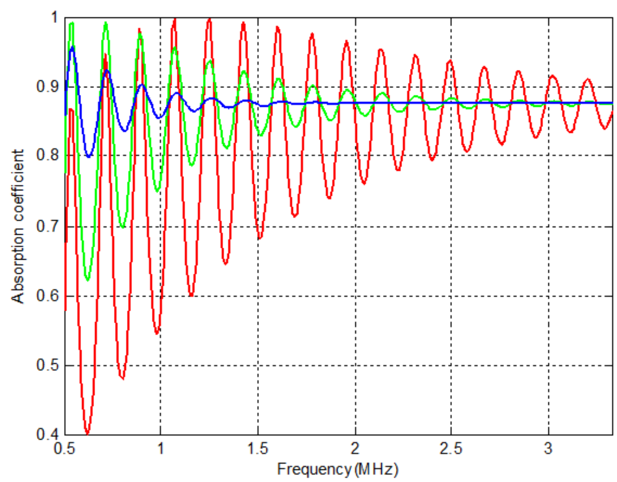

Fig. 2 – Absorption coefficient curves of backing material for different loss factor of base material (red line:0.05, green line:0.1, blue line:0.2)

It can be seen from Fig.1 that the sound absorption characteristics of backing materials are seriously affected by volume content of tungsten powder in viscoelastic medium. The increased volume fraction of tungsten powder makes acoustic impedance of backing materials increased On the other hand the sound absorption performance of backing materials are decreased at the same time. Figure 3 shows the sound absorption performance of backing materials are significantly improved with loss factor of base materials increasing. The simulation results show that the main sound absorption mechanism of backing materials are acoustic scattering of tungsten particles and energy dissipation in sound propagation process in viscoelastic medium. Due to the need to increase acoustic impedance of backing materials, we have to enhance the volume content of tungsten powder In order to improve the sound absorption performance, it is very important for backing material to adjust dynamic mechanical parameters of base materials such as elastic modulus and loss factor.

The traditional backing sound-absorbing materials with composite structure of epoxy resin and tungsten powder are not only poor uniformity but also absorption performance with the increase of the content of tungsten powder volume, so the modification of based materials will effectively solve the bottleneck problem. The new formulation of base materials is including pentaerythritol glycidyl ether, FA resin, curing agent, additives such as silica, tungsten powder, coupling agent and other viscoelastic material. The preparation technology is improved in the composite process of tungsten powder and base materials by adjusting the formulation of coupling agent and silica material. The uniformly mixed materials are obtained after the bubbles eliminated by using three-roller-grinding machine, drying oven, cone plate viscometer and thermodynamic characterization instruments. Figure 3 shows that the pictures are the two formulations molding sample. The square-shaped samples are in the left side of Fig3, which are used to acoustic performance testing. We can see that the samples are mixed evenly and there are no bubbles. The new formula samples have been successfully processed into ultrasonic transducer backing in right side of Fig3. According to the acoustic impedance and attenuation testing, the sound performance of new formula samples were significantly increased. At the temperature of 24.3℃ and 0.7812MHz frequency test conditions, acoustic impedance of one new formula samples is 6.42MPa•s/m and its attenuation coefficient is 40.6dB/cm. Another formula samples is 4.83 MPa•s/m acoustic impedance and its attenuation coefficient reached 64.1dB/cm, which provides excellent backing material for the preparation of medical ultrasonic probe.

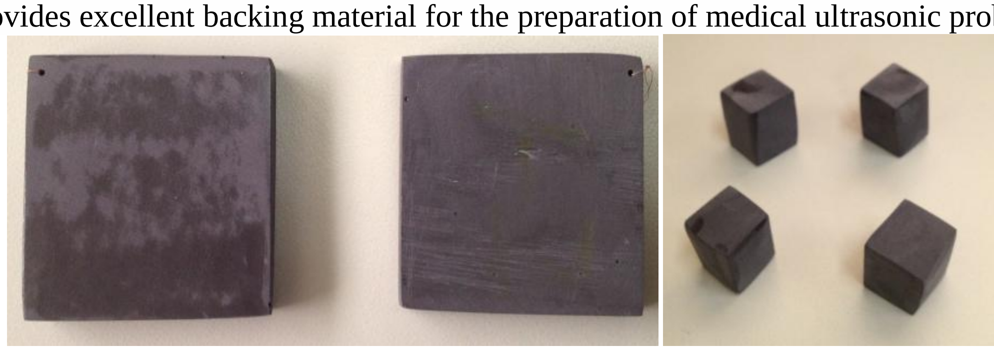

Fig. 3 – The new molded samples of epoxy resin composite structure

4 CONCLUSIONS

The basic MS theory on acoustical performance of the viscoelastic materials containing periodic metallic particles is presented in this paper. The impedance matching and metallic particle scattering are initially analyzed based on the MS method. The metallic particles in viscoelastic material can improve acoustic impedance and change the absorption performance of the backing. If we need to adjust acoustic impedance to match the active materials and improve the absorption performance at the same time, it’s a good way to adjust volume content of metallic particles and mechanical parameters of viscoelastic materials.

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5 ACKNOWLEDGEMENTS

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