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Experimental research on sound absorption properties of impedance gradient composite with multiphase

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Abstract. In order to improve the sound absorption performance of the sound absorbing material in water, impedance gradient underwater sound absorbing composite with multiphase (IGCM） is prepared in this study. By superposing several layer materials of different impedance gradients, the mixture is poured in the mold layer by layer so that three kinds of IGCM with different mass density gradients of iron powder, tungsten powder and mixture of iron powder and tungsten powder are prepared. Under two operating conditions of the incident angle of 0°and 20°, the results show that the three IGCMs have good broadband absorption characteristics. The sound absorption frequency ranges of the three samples of IGCM under normal incident conditions are concentrated between 6kHz and 10kHz. The sound absorption performance of IGCM under oblique incidence is better than that under normal incidence, especially the IGCM with iron-tungsten powder, which could achieve wide-band strong sound absorption from 2kHz to 10kHz under the condition of oblique incident. The IGCM with iron-tungsten phase under sound wave's incident angle of 20° exhibits better sound absorption performance than the other two，which provides a theoretical reference for the design and manufacture of gradient sound absorbing materials.

1. Introduction
It is well known that sound waves propagate in water in the form of longitudinal waves that are not easily attenuated, which becomes the main means of underwater detection information[1]. In order to improve the stealth ability of underwater detectors, underwater sound absorbing materials are used[2]. The impedance gradual sound absorbing material is a sound absorbing material whose impedance changes according to certain gradients in the thickness direction of the material. It is strongly designable and easy to realize the multi-physics coupling requirement [3], and expected to realize the ultra-wide frequency sound absorption effect.

As for studies published, Pedersen et al. found that the impedance-transition-type acoustic structure can obtain a wider sound absorption band[4]. Emery discovered that impedance could reduce the reflection coefficient at high frequency, and the problem of the peak value of the reflection coefficient could be solved by employing multi-layer structures with different thickness and impedance[5]. Beretti et al. found that the four-layer silencing structure had the functions of sound absorption and vibration reduction when the thickness was constant[6]. Forest et al. chose SiO_2 aerogel particles with particle size of 80um and 3.5mm to make double-layer sound absorption structure, including impedance matching layer and sound absorbing layer. It was found that its sound absorption

performance was higher than that of the uniform structure of the same thickness in the low frequency range[7]. Spivack et al. studied the problem of acoustic scattering of irregular surfaces of impedance changes, and derived the acoustic scattering field formula under random impedance changes[8]. Andrew studied the problem of acoustic propagation in air layers of different heights and performed simulation analysis using the finite element method[9]. Shang Erchang studied the approximation of the reflectivity of the gradient absorption layer, and theoretically explained the effectiveness of the impedance gradient sound absorption layer[10]. The method of approximate solution layer by layer to transfer matrix was proposed, and the acoustic characteristics of the sound absorbing structure were discussed by He Zuoyong[11]. Yang Xue et al. found the optimized design of the material in the low frequency range of 1kHz-4kHz improved the sound absorption coefficient [12]. Li Bo found that the sound absorption coefficient of the composite polymer particles was higher in the range of 1 kHz to 6 kHz than that of the single polymer particles[13]. Tang Huiping et al. found that the arrangement of different porosity had a significant effect on the sound absorption performance of the gradient structure, and to some extent, the sound absorption coefficient in the frequency band of 0.8 kHz-1.6 kHz was improved to Between 0.8-1[14]. In summary, the acoustic wave frequency band of the impedance gradient sound absorbing material needs to be broadened, and the research on the sound absorption characteristics of the material under oblique incidence is less, so its application is easily limited.

Aiming at the problems above, this paper develops a new type of impedance gradient underwater sound absorbing composite with multiphase（IGCM）, and tests the sound absorption performance of the material under normal incidence (0°)and oblique incidence (20°). The results of the wide-band strong sound absorption experiment with oblique incidence are obtained, which broadens the sound absorption band of the underwater impedance gradient sound absorbing material, and provides a theoretical reference for the broadband design of the underwater impedance gradient sound absorbing material.

2. Experimental

2.1. Preparation of IGCM

In the experiment, PTMG/TDI produced by Wanhua Chemical Co. Ltd. was used to prepare the polyether polyurethane for the experiment as the matrix material, because the polyether polyurethane has strong water resistance[15][16],strong adhesion and the same acoustic impedance as that of water so that it could be permanently and firmly paste with the coated object. According to the fact that the thickness of the viscoelastic substrate sound absorbing material is no less than 50mm[3], three kinds of IGCM with the thickness of 55mm were prepared by respectively blending iron powder, tungsten powder and iron-tungsten powder. The acoustic impedance of each layer of materials was close to that of water medium by one side, whereas gradually increased to that of steel body surface by the other side. And there was a superposition of the sound absorbing layers whose impedance gradient changes due to different mass densities inside so that sound waves could be absorbed and attenuated. Iron powder, tungsten powder were used as the additional phase (the average particle diameter is 25um), three sets of IGCM were prepared by blending method. The composition is shown in Table 1.

Table 1. Components of three kinds of IGCM

Layers	1	2	3	4	5	6	7	8	9	10	11
Matrix material	1	1	1	1	1	1	1	1	1	1	1
Iron	0	0.2	0.4	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Tungsten	0	0.2	0.4	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Iron / Tungsten	0	0.2	0.4	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0
$\rho(g/cm^3)$	1	1.2	1.4	1.8	2.0	2.5	3.0	3.5	4.0	4.5	5.0

The physical maps of the three sets of IGCM prepared in the experiment are shown in Fig.1.After testing and calculation, it is verified that the acoustic impedance of the three groups of materials increases by gradients in the thickness direction, shape rules, and size also meet the sound absorption coefficient test requirements as is shown in Fig. 2.
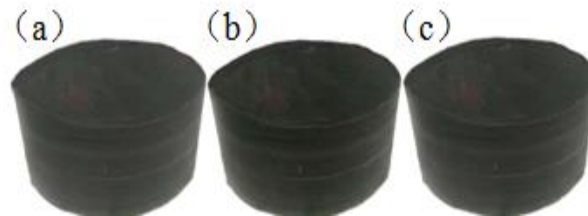

Figure 1. Experimental sample material: (a) IGCM with Iron powder additional phase; (b) IGCM with Tungsten powder additional phase ; (c) IGCM with Iron-tungsten powder additional two-phase.
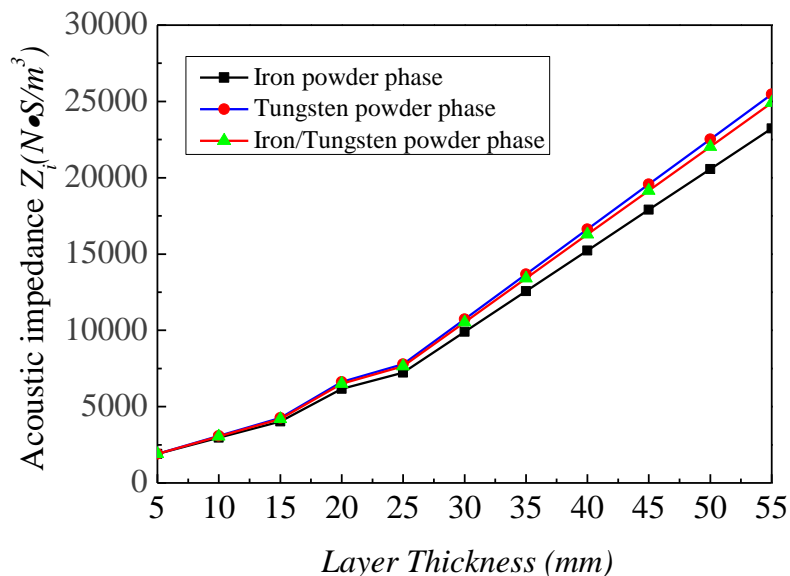

Figure 2. Impedance curves of three IGCM.

2.2. Test Methods

The underwater acoustic impedance sound tube is used to test the sound absorption coefficient of IGCM under the condition of normal and oblique incidence sound waves. Fig. 3 (a) is a schematic diagram of the underwater acoustic impedance sound tube, in which the incidence of sound wave comes from the side which has the same acoustic impedance with water. Fig. 3(b) is an enlarged schematic view of a sample of IGCM placed in the sound tube. According to the method provided by literature [17], a wedge-shaped metal tube structure with the oblique angle of 20° is made for the incidence of sound wave. Since the sound wave is a longitudinal wave, there is no cutoff frequency for the sound wave propagating in the impedance tube. When the wavelength is much larger than the transverse dimension of the tube, the sound waves propagating in the tube are always plane waves, and the wave vector is parallel to the axial direction of the tube. The frequency range and the wavelength of the sound tested in this study satisfies this condition, so it is still plane wave parallel to the axial direction of the tube. Under the conditions of normal temperature, normal pressure and frequency range of 0.2 kHz to 10 kHz, the underwater sound absorption coefficients of the material under normal incidence of 0° and oblique incidence of 20° were tested.
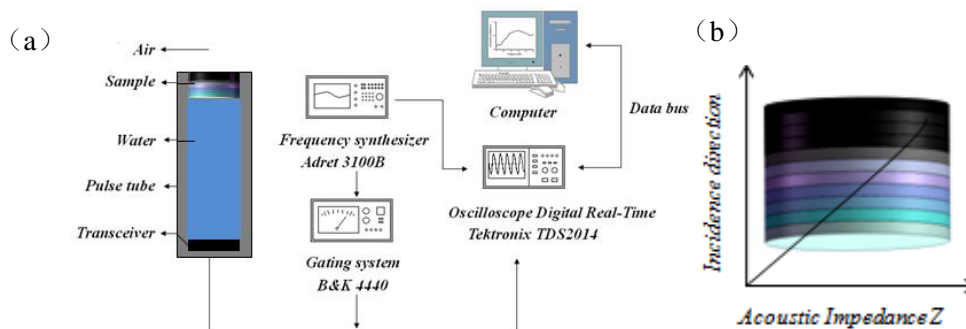
Figure 3. Schematic diagram for (a) sound absorption coefficient of acoustic impedance tube test and (b)sample and its acoustic impedance.

3. Results and discussion

The underwater sound absorption coefficients of different samples into which sound wave transmit are shown in Fig. 4. The sound absorption coefficient of IGCM with tungsten powder is larger than that with iron powder when the frequency ranges from 7kHz to 8kHz; The sound absorption coefficient of IGCM with iron-tungsten mixed powder is higher than that with iron or tungsten powder when it comes to frequencies except the range from 6.5 kHz to 7.5 kHz, among which the sound absorption coefficient reaches 1.0 with all the sound waves were absorbed when the frequency is around 10kHz.The reason why the IGCM with tungsten or iron-tungsten powder has higher sound absorption coefficient may be that tungsten has higher density than that of iron, and tungsten particles therefore vibrate stronger than iron particles under lower frequency, which led to intensified fraction at inter-phase and transferring sound energy to heat energy for better sound absorption. The reason why IGCM with iron-tungsten powder has higher sound absorption coefficient may be that some of iron particles vibrate stronger than tungsten particles at higher frequencies, and therefore compensated more sound energy than IGCM with tungsten powder, making better sound absorption performance of IGCM with iron-tungsten powder.
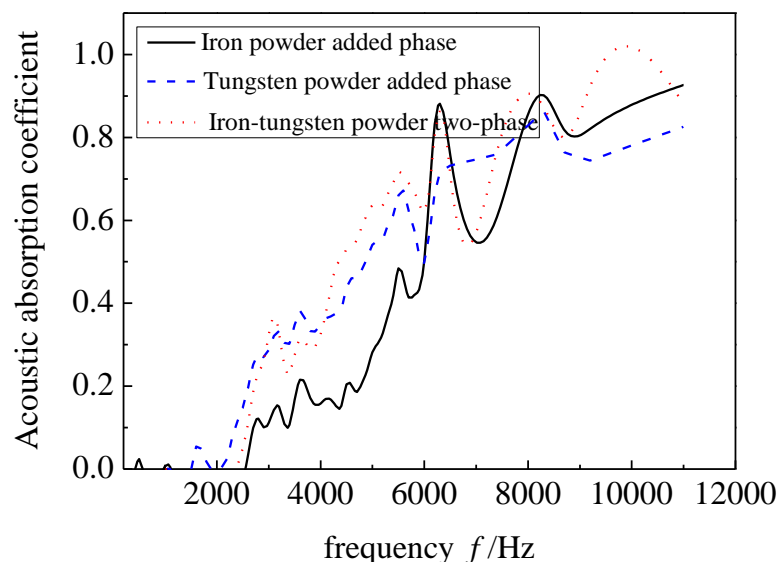

Figure 4. Acoustic absorption coefficient of three sets of IGCM at normal incidence
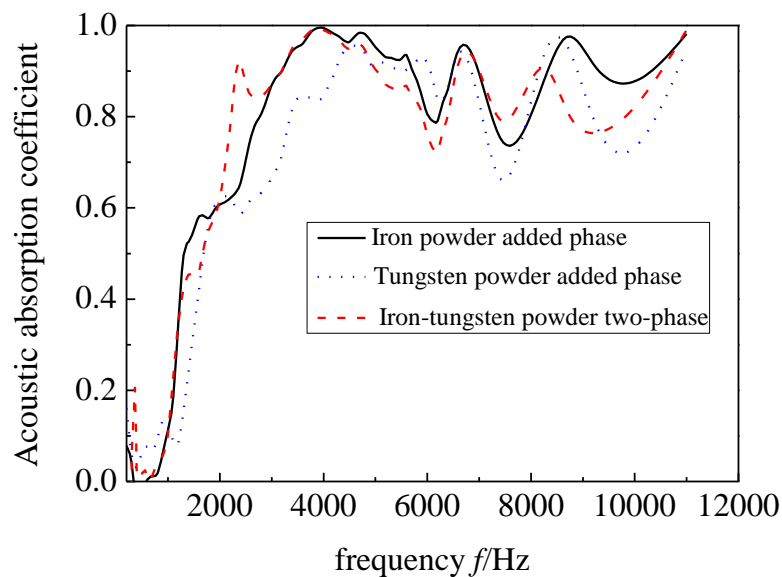
Figure 5. Acoustic absorption coefficient of three sets of IGCM at normal incidence.

Fig.5 shows the sound absorption coefficients of IGCM which the incident angle of the sound wave is 20°.The IGCM with iron-tungsten powder has a relatively high sound absorption coefficient over the entire test frequency range, and the sound absorption performance is relatively optimal. Maybe due to the added iron powder's low density, particles in the sample with iron powder additional phase and that with iron-tungsten powder mixed phase tungsten powder vibrates more strongly in higher frequency range under oblique incidence, leading to a better sound absorption energy consumption effect compared with that with tungsten powder phase. The phase particles vibrate more strongly, so the sound absorption energy consumption effect is better than that of the sample of IGCM with tungsten powder additional phase. At low frequency, the sound absorption coefficients of the sample with tungsten powder additional phase and that with iron-tungsten powder mixed phase are higher than that with the iron powder additional phase when the frequency ranged from 5 kHz to 7 kHz, maybe because the tungsten powder additional phase has particles of a higher density. Meanwhile, it has stronger vibration than iron powder particles, and the phase friction energy consumption is larger. However, in the frequency range lower than the above case between 2 kHz and 4 kHz, maybe due to the heavier phase of the tungsten powder particles, the distance between some tungsten powder particles and the tungsten powder particles is close or closely connected, which is not conducive to the energy dissipation mechanism of scattering and thermal energy conversion in the material in the lower frequency range. As is shown in Fig. 6, after a beam of oblique incidence of acoustic waves, the sound waves are shown in the schematic diagram of the refraction and reflection between the layers in the material.
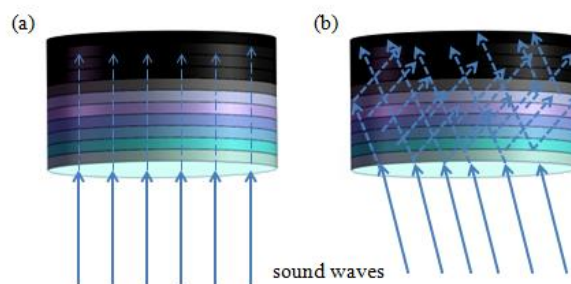

Figure 6. Schematic diagram of acoustic wave propagation in a IGCM at (a) normal incidence and (b) oblique incidence

It is obvious that the sound absorption coefficients measured by the three groups of materials when the sound wave is oblique (20°) were higher than normal incidence, and the frequency range with a good sound absorption coefficient in the case of oblique incidence is wider. Analyzing the reason, it may be that when the sound wave incidence is at an angle of (20°), after the sound waves enter the material, the longitudinal wave in the interlayer of the impedance gradient changes into a transverse wave that is more easily attenuated, causing a large shear deformation and causing the incident wave, making the energy consumed in large quantities. In addition, after the incidence comes obliquely into the material, multiple reflections and refractions occur between the two layers with the impedance gradient changing accompanied by multiple waveform conversions, so that the acoustic waves are attenuated more when oblique incidence occur, thus having better sound absorption effect.

4. Conclusions
In this paper, the underwater sound absorption performance of IGCM is studied under normal and oblique incidence conditions. The experimental materials are prepared by mature techniques, and the sound absorption coefficients of the material samples of IGCM under the above two conditions are measured in the underwater acoustic impedance tube test system. The results showed that the sound waves are effectively absorbed in the IGCM, and the sound absorption frequency range under oblique incidence is wider, the sound absorption coefficient is higher, the effect is better than that under normal incidence. In addition, the sound absorption performance of IGCM with iron-tungsten powder mixed phase is better than that of the other two single-phase samples. Therefore, the broadband sound absorption performance under oblique incidence is obtained by the study of this paper. The impedance gradient underwater sound absorbing composite material can provide theoretical support for the structural design of acoustic impedance gradient materials.

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