Verification of acoustic superiority of MDI-based gradient structural material on high water pressure

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Abstract. Considering the limitation on high water pressure resistance of traditional underwater acoustic material, an optimization on material structure is conducted so as to improve the ability of sound absorption. Monolayer Acoustic Samples (MAS) and Gradient Acoustic Sample (GAS) are produced with the raw materials, such as diphenylmethane diisocyanate(MDI) polyurethane prepolymer(PUP) and butylene glycol (BDO). The samples are tested in the frequency range from 1000Hz to 4000Hz under pressure from 0 MPa to 2MPa. Then the differences of acoustic performance between MAS and GAS are analyzed and compared. The tests results show that the stability of GAS sound absorption coefficient increases gradually with the increasing of frequency under various pressures and the value of GAS sound absorption coefficient tends to be 1 in high frequency range. On the other hand, the value of MAS sound absorption coefficient fluctuates obviously. Compared with average sound absorption coefficient of two samples at 1000Hz, 2000Hz and 4000Hz, the GAS has a better sound absorption performance than the MAS.

1. Introduction

Sound-absorbing materials are widely used in underwater acoustic engineering because of their characteristic ability to absorb sound waves. Among many sound-absorbing materials, viscoelastic material has attracted widely attention due to the special movements of molecular chains, which can effectively absorb and attenuate sound energy in a thermal way. Researches show that it’s difficult to combine impedance matching with excellent acoustic attenuation performance from a single homogeneous polymer material, such as polyurethane rubber[1], whose characteristic acoustic impedance is close to water. Although acoustic performance can be improved by adding different components[2], impedance matching is unavoidably affected, and it’s hard to meet the urgent needs in the rapid development of underwater acoustic engineering.

Nowadays, The development of new underwater acoustic materials are focus on water pressure resistance, broadband and high absorption, especially in military field. Naval powers around the world lay noise-absorbing tile materials on its surface in pursuit of deep ocean submarine stealth performance, Not only have the sound-absorbing materials good acoustic performance, but also puts forward strict requirements for its pressure resistance[3]. Traditional cavity material, better as the resonance sound absorption ability has[4][5], is not a good pressure-resistant material because of the cavity inside. Once the submarine surface is subjected to pressure. As shown in Figure 1, the performance of the equipment will be greatly effected, which will result in potential safety hazards. It’s reported that the depth of advanced

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submarines abroad is not more than 1000 m and the safe working depth is not more than 600 m, which is related to the lack of sound absorbing materials in deep sea.

![Schematic diagram of polymer sound absorbing materials with porous filled before and after compression](image)

Considering the limitation of traditional cavity sound absorption materials such as single uniform rubber, The paper starts with the selection of pressure-resistant polymer materials[6], then three gradient composite nonporous acoustic material is designed and fabricated. According to the analysis of sound absorption principle and sound tube test results from gradient and single-layer structure materials[7][8], the superiority of gradient acoustic absorption material is proven.

### 2. Experiment

#### 2.1 Experimental preparation

PUP, Polyurethane Additive(PA), BDO and N,N-Dimethylethanolamine(DABCO) are prepared with the corresponding formulation as shown in Table 1. PUP is recorded as A. The latter three reagents are mixed proportionally for reserve, which is recorded as B. The three gradients of MAS correspond to the three formulations of MAS.

| Items      | MAS1 | MAS2 | MAS3 | GAS    |
|------------|------|------|------|--------|
| PUP(phr)   | 100  | 100  | 100  | A      |
| PA(phr)    | 20   | 35   | 50   | Formula 1 |
| BDO(phr)   | 13   | 12   | 11   | Formula 2 |
| DABCO(phr) | 0.15 | 0.17 | 0.19 | Formula 3 |
| Thickness(mm) | 50  | 50   | 50   | 25/15/10 |
| Diameter(mm) | 208 | 208  | 208  | 208    |

#### 2.2 Mould preparation

First of all, Brush the mould twice with release agent, then transfer mould to oven and control the temperature of 75℃. Finally, Adjust mould to ensure the uniformity of casting thickness.

#### 2.3 Casting of Sound Tube Samples

According to Table 1, Transfer B to A rapidly and stir mixture in fully, then put them into self-made vacuum device quickly to remove bubbles and pour mixture in mould. the whole process must be controlled not more than 5 minutes. Finally, the oven temperature is set at 100℃ for 12 hours, then put it in normal temperature for 7 days.

#### 2.4 Testing

Send samples for testing, The whole process is shown in Figure 2.
3. Contrastive analysis

3.1 schematic diagram of formed sample

Figure 3 is a schematic diagram of single layer (MAS) and gradient structure (GAS) respectively.

![Fig.3 Schematic diagram of acoustic samples](image3)

3.2 Contrastive Analysis of Sound Absorption Principles

3.2.1 Sound Absorption Principle

Figure 4 is a schematic diagram of sound-absorbing materials. As shown in the figure above, when acoustic wave E propagates to material surface, it’s generally transformed in three forms: interface reflection acoustic wave (Er), transmission acoustic wave (Et) and internal absorption acoustic wave (Ea). α is usually used to judge sound absorption performance of a material as formula (1) showed. For example, 0 shows that sound energy is totally reflected and there is no sound absorption capacity, 1 means that material sound absorption performance is excellent. Generally, 0 < α < 1.

\[
\alpha = \frac{Ea + Et}{E} = 1 - \frac{Er}{E}
\]  

3.2.2 Comparison of sound absorption principles of two structural tubes based on MDI System

Internal molecular chains of two kinds of sound tube samples are simulated from Figure 5. It can be seen that both structural samples have complete macromolecular chains, which is the basis for determining sound absorption performance of viscoelastic polymer materials. Once sound waves act on polymer materials, energy will transmit to macromolecular chains along with sound wave propagation. meanwhile, it will inevitably cause the thermal motion of polymer chains, then partial molecular chains motion will gradually lead to whole molecule movement to make sound energy attenuated in a thermal way.
At the same time, the right picture has a distinct gradient structure compared with the left, and there are two clear interfaces inside the molecule, which is the reason for the difference of Sound Absorption between the two structures. When sound wave propagates to the material surface, as shown in Figure 6 below, part of them is reflected back instantly on contact surface, and rest of them enters material interior. From the sound wave propagation model in material interior, it can be seen intuitively that sound energy propagates slowly along with the thermal motion of macromolecule chain in the single layer acoustic material until it passes through the material. Meanwhile, part of energy has been attenuated by the thermal motion, and a small amount of acoustic wave is reflected back. Finally, acoustic energy propagates through the material, Which is called transmissive acoustic wave. Unlike sound wave propagation path in a single layer material, there are many reflective acoustic waves in gradient acoustic material, due to the boundary of gradient structure designed. Once the attenuated acoustic wave contacts the internal interface, part of them is reflected back again, and the remaining acoustic wave continues to transmit. Sound wave propagates repeatedly between the interfaces, which is increasing the attenuation path of acoustic wave in polymer material and prolonging the thermal motion time of macromolecular chain segment, It's good for increasing acoustic energy attenuation and achieving a good sound absorption effect.

![Fig.6 Schematic diagram of the sound wave propagation in acoustic samples](image)

3.3 Contrastive Analysis of Sound Absorption Performance of Sound Tube Samples

3.3.1 Comparison of sound absorption performance of two kinds of sound tubes

Figure 7 shows the curves of three MASs and one GAS sound absorption coefficient with the gradient of above three formulation at five pressures, it can be seen that sound absorption coefficient of two kinds of samples increase with the increase of test frequency. When test frequency exceeds 2500Hz, curve of MAS fluctuates obviously, while GAS sound absorption coefficient is stable to 0.9. It can be found that sound absorption coefficient of two series samples show a downward trend with the increase of pressure, Because the free space of macromolecule chains in material is extruded, which affects the thermal movement of molecular chains. Finally, sound absorption coefficient of polymer viscoelastic materials is decreased.
3.3.2 Average Absorption Coefficient Comparison

There is a comparison of the average sound absorption coefficients of four kinds of sound tubes at three frequencies (1000Hz, 2000Hz, 4000Hz) as Figure 8 showed. Combining with the stability of sound absorption coefficients from Figure 7, it can be seen that both the average sound absorption coefficients of MAS and GAS show a downward trend with the increase of pressure, which is related to the thermal motion limitation of macromolecular chains under high pressure. But it can be seen easily that average sound absorption coefficient of GAS is better than MAS.

4. Conclusions

Considering the developments of a new sound-absorbing material used in underwater acoustic engineering, High-strength MDI polyurethane is chosen as raw material, to designs and pours gradient non-cavity structure sound-absorbing material. At the same time, the design feasibility of gradient sound-absorbing material is demonstrated by comparing single-layer structure with gradient structure. The study provide a proper reference for underwater acoustic material, In particular, it's suitable for sound absorption material used in deep ocean.

In the next work, the gradients of GAS based on MDI polyurethane system can be simulated and optimized by theoretical calculation and the thickness ratio between gradients will be the focus.

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