

# Study on Sound Insulation of Integrated Composite Wallboard Made of ALC and Rock Wool Panel

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**Abstract.** The integrated composite wallboard made of ALC (autoclaved aerated concrete) and rock wool panel is a new type of prefabricated building enclosure wallboard, which can meet the thermal requirements of cold areas in China without additional insulation. The ALC of the integrated composite wallboard is divided into local four-sided supported plates by vertical and horizontal ribs. Therefore, its sound insulation performance is different from that of the single uniform material wallboard and the composite wallboard of double layers light thin plates. The sound insulation performance of the integrated composite wallboard is studied experimentally and compared with other lightweight wallboards. The air-borne sound insulation has obvious coincidence frequency region, and the coincidence frequency is consistent with the natural vibration frequency of the local four-sided supported plate of ALC. The anastomosis effect seriously affects the weighed sound reduction index  $R_w$ , which reduces the weighed sound reduction index by 6dB~8dB. The sound insulation experiment of ALC rock wool integrated composite wallboard objectively reflects the adverse effects of the sandwiched wallboard structure, which provides a reference for improving the sound insulation performance through the improvement of integrated composite wallboard structure.

**Keywords:** Autoclaved aerated concrete, Integrated composite wallboard, Sound insulation in buildings, Sound insulation experiment.

## 1. Introduction

Prefabricated buildings are developing in China recent years, and the prefabricated envelope structure is an important part of prefabricated buildings. The external envelope and internal partition wall account for 20 points out of 100 points in prefabricated building in the *Standard of assessment of Prefabricated Building GB/T51129-2017*. Light weight concrete insulation integrated composite wallboard is an important form of prefabricated building envelope structure, and many types of composite wallboard products have been developed in China.

Autoclaved aerated concrete (ALC) is a porous concrete product made of fly ash (or silica sand), lime, cement, aerating agent and other raw materials cured by high pressure steam. It has the characteristics of light weight, high strength, heat preservation and insulation, fire resistance and sound insulation, easy processing, etc. Autoclaved aerated concrete slab has been widely used in building envelope structure, and a lot of researches have been done. However, the autoclaved aerated concrete slab cannot meet the requirement of thermal insulation in the cold area of north China, and additional thermal insulation layer is needed. Combined with the subject "technology and products of lightweight environmental protection envelope system of steel structure building" of the National Key Research and Development Program "key technology and demonstration of steel structure building industrialization", and with the engineering of research and experimental building in China Metallurgical Construction Research Institute Co., Ltd., Using autoclaved aerated concrete as load-bearing material and rock wool as sandwich insulation material, we developed ALC+rock wool insulation integrated composite exterior wallboard. The composite exterior wallboard can meet the insulation requirements in cold areas without additional insulation [1, 2]. The paper will study its sound insulation performance.

For ordinary reinforced concrete, the exterior wall with thickness of 180mm~200mm can achieve good sound insulation performance. For lightweight concrete, the sound insulation performance of the exterior wall with the same thickness is greatly reduced because of the low density, so the sound insulation panels need to be added to meet the requirements of sound insulation [3]. The sound insulation of wallboard of single-layer uniform lightweight concrete basically meets the mass law of sound insulation [4]. The composite wallboard is composed of two layers of thin plates with air layer and sound-absorbing material layer, and many studies have also been carried out on sound insulation of double-layer composite wallboard [5, 6]. Similar to the integrated wallboard structure presented in the paper, two-layer LSP panels composite exterior wall [7] and the prefabricated composite wall [8] with a layer of rock wool sandwiched between the two-layer ALC panels have been studied. Among them, the composite wall of ALC board with rock wool board is widely used, and there is an obvious coincidence frequency region in the sound insulation.

The ALC+ rock wool integrated composite wallboard we have developed has a standard width of 600mm, longitudinal ribs of 75mm width on both sides of the wallboard, transverse ribs at both ends and in the middle span of the wallboard. In the middle thickness of the composite board is the rock wool sandwich board, it play the role of heat preservation not only, but also improves the performance of sound insulation. The structural form of ALC+ rock wool integrated composite wallboard will affect the sound insulation performance of the wallboard. Its structure does not conform to the characteristics of two-layer thin plate structure [5, 6], nor does it conform to the characteristics of two-layer thick plates + interlayer [7, 8]. This paper will study the sound insulation performance of ALC + rock wool integrated composite wallboard.

## 2. Sound insulation requirements and measurement of enclosure walls

With the development of economy and science and technology, there are more and more vehicles and more and more outdoor recreational activities, which make noise sources increase continuously. At the same time, there are many new lightweight building materials, which weaken the ability of sound insulation and noise reduction of civil buildings. To improve the sound insulation index of building envelope is an important measure to solve the problem of noise interference in civil buildings. The standards of foreign developed countries have high requirements for building sound insulation, such as the British standard is  $D_{nt,w} + C_{tr} = 43\text{dB} \sim 45\text{dB}$ , The Australian standard is  $D_{nt,w} + C_{tr} = 45\text{dB}$ , American standard is STC 45, equivalent to  $D_{nt,w} + C_{tr} = 45\text{dB}$ . *Code for Design of Sound Insulation of Civil Buildings* (GB50118-2010) of China clearly stipulates the air sound insulation index of the exterior wall. Air sound insulation single value evaluation + traffic noise correction should be more than 45dB.

The measurement of sound insulation of the outer envelope is divided into field measurement and laboratory measurement. The field measured data results can be evaluated by single value of standardized sound pressure level difference  $D_{nT}$ :

$$D_{nT} = L_1 - L_2 + 10\lg \frac{T}{T_0} \quad (1)$$

The data results measured in the laboratory can be evaluated by the single value of weighted sound insulation  $R_w$ :

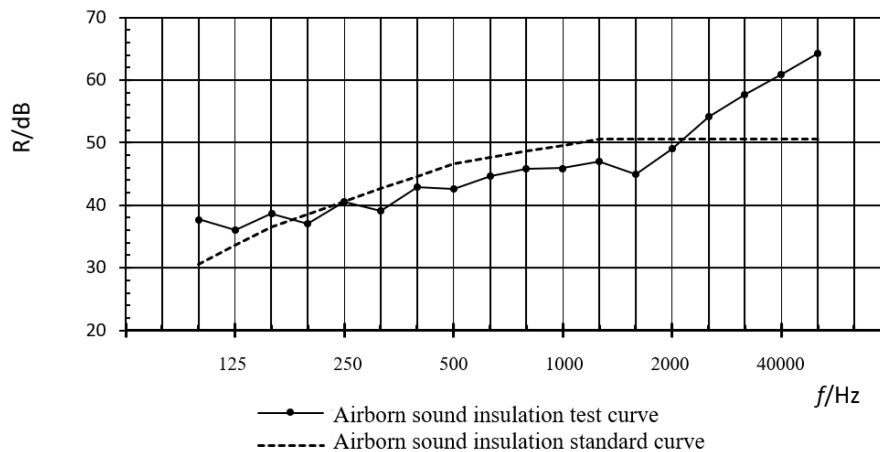
$$R_w = L_1 - L_2 + 10\lg \frac{ST}{0.161V} \quad (2)$$

Where,  $L_1$  is the average sound pressure level in the sound chamber(dB);  $L_2$  is the average sound pressure level in the sound receiving chamber(dB); T is the reverberation time of the sound receiving chamber (s);  $T_0$  is the reference reverberation time (s), which is generally 0.5s for residential buildings;  $S$  is the area of the specimen ( $\text{m}^2$ ), which is equivalent to the area of the test hole; V is the volume of the sound receiving chamber ( $\text{m}^3$ ). According to Equations (1) and (2), the

air sound insulation of 1/3 frequency band can be calculated. Then draw the sound insulation characteristic curve on the sound insulation value-frequency coordinate system, the weight of single value of sound insulation evaluation can be calculated according to the code *Rating Standard of Sound Insulation in Buildings* GB 50121.

### 3. Comparison of sound insulation performance of lightweight concrete walls

#### 3.1. Foamed cement composite wallboard

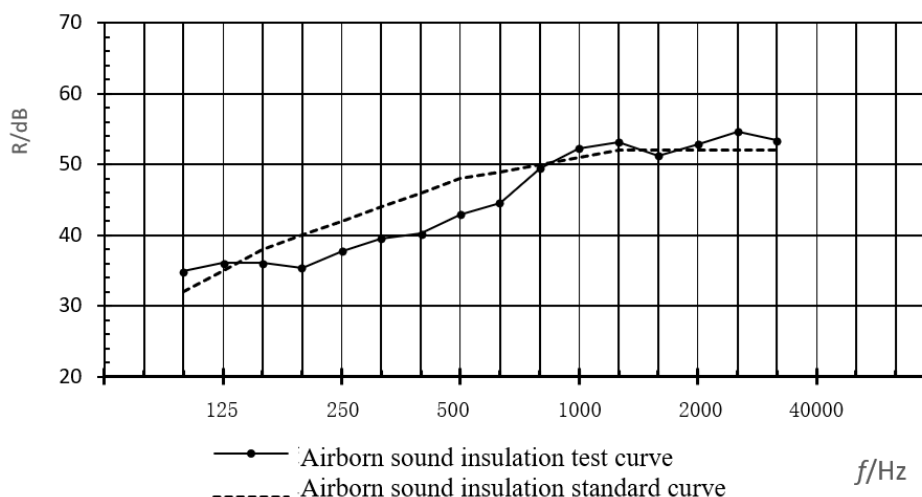


**Figure 1.** Sound insulation frequency characteristic curve of foamed cement composite wallboard

The research group has conducted sound insulation research on foamed cement composite wall panels. The bulk density of foamed cement is  $680\text{kg/m}^3$ , the thickness of the wall is 250mm, and the surface density is  $170\text{kg/m}^2$ . The size of a piece of wallboard is 1965mmx2500mm, two pieces put together for test, and the gap is filled by cement mortar. The size of the wall for sound insulation test is 4000mmx2500mm, and the total area is  $10\text{m}^2$ . The experimental data are shown in figure 1. The single value evaluation of air sound insulation is obtained, it is  $R_w(C; C_{tr})=47(0; -2)\text{dB}$ , and the curve have no obvious coincidence frequency valley.

#### 3.2. ALC block wall

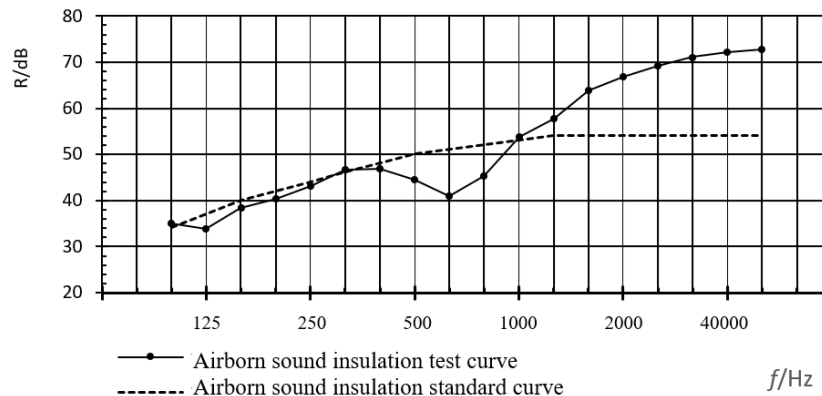
The size of autoclaved aerated concrete block is 600mmx180mmx240mm, and the density grade is  $750\text{kg/m}^3$ . The weight of the single block is 19.8kg. After the putty is put on the wall for 10mm, the thickness of the wall is 200mm, and the surface density is  $170\text{kg/m}^2$ . The size of the sound insulation test hole is 3585mmx2800mm, and the total area is  $10.04\text{m}^2$ .



**Figure 2.** Sound insulation frequency characteristic curve of ALC block wall

The experimental data [4] are shown in figure 2. The single value evaluation of air sound insulation is  $R_w(C; C_{tr})=48(-1;-4)$  dB, and the curve has no obvious coincidence frequency valley. The surface densities of ALC block wall and foamed cement wall are both  $170\text{kg/m}^2$ , and the sound insulation values obtained have only 1dB difference, they are basically the same, because they were made of uniform materials.

### 3.3. Composite wall with rock wool board sandwiched between two-layer ALC panels



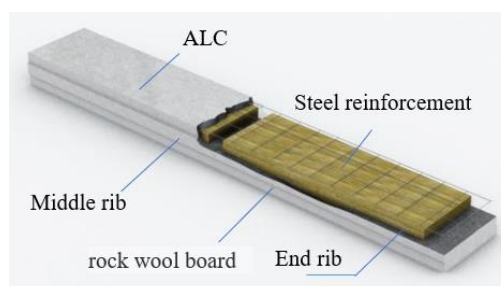
**Figure 3.** Sound insulation characteristic curve of two-layer ALC panels with rock wool

Experimental study of sound insulation on the composite wall of 75mm thick ALC board +50mm rock wool board +75mm thick ALC board was introduced in reference [8]. The structure of the wall is shown in Figure 3, the ALC density is  $650\text{kg/m}^3$ , the rock wool board density is  $100\text{kg/m}^3$ , and the wall surface density is  $102.5\text{kg/m}^2$ . The experimental curve is shown in figure 3. As can be seen from the curve, there is an obvious sound insulation anastomosis valley near 630Hz, which ranges from 500Hz to 800Hz. When the frequency passes the anastomosis zone, the sound insulation increases with the increase of the sound frequency.

## 4. Integrated composite wallboard ALC+ rock wool sound insulation

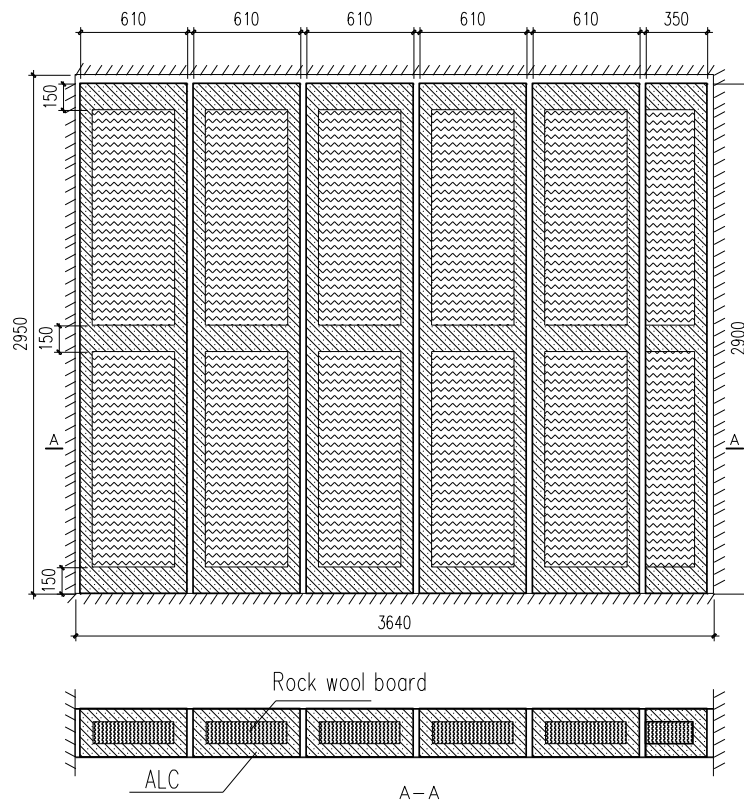
### 4.1. ALC + rock wool integrated composite wallboard structure

ALC (Autoclaved Aerated Concrete) + rock wool integrated composite wallboard is formed by autoclaved aerated concrete and rock wool at same time to become a integration, and arranging reinforcement to improve the bearing capacity and crack resistance, as shown in Figure 4. The density of ALC is controlled from  $500\text{kg/m}^3$  to  $800\text{kg/m}^3$ , and the strength is not less than 3.5MPa, which can meet the strength requirements of wallboard. The density of rock wool is not less than  $120\text{kg/m}^3$ . The composite density of ALC and rock wool board is generally  $400\text{kg/m}^3 \sim 600\text{kg/m}^3$ , equivalent to the weight of wallboard is  $100\text{kg/m}^2 \sim 150\text{kg/m}^2$ , which can effectively reduce the weight of the wall and the seismic response of the structure. The thermal conductivity of ALC is no more than  $0.15\text{W}/(\text{m}\cdot\text{K})$ , the thermal conductivity of rock wool is no more than  $0.04\text{W}/(\text{m}\cdot\text{K})$ , and the heat transfer coefficient of composite wallboard can reach  $0.31\text{W}/(\text{m}^2\cdot\text{K})$  [1]. Rock wool is water-repellent, has the highest fire rating, and has combustion performance grade A1.



**Figure 4.** Structure of ALC+ rock wool integrated composite wallboard

#### 4.2. Sound insulation experimental scheme



**Figure 5.** Layout of wallboard for sound insulation experiment



**Figure 6.** Installation of wallboard for sound insulation experiment

The sound insulation experiment was carried out on ALC+ rock wool composite wallboards according to the standard method [9]. The measured wall was installed by five standard boards and one non-standard board, as shown in Figure 5. The gaps were sealed by cement mortar, as shown in Figure 6.

The weight of each piece of each wallboard is 278kg on average, and the surface density of the wallboard is 157kg/m<sup>2</sup>. The volume density of rock wool board is 140kg/m<sup>3</sup>, the volume density of ALC is 750kg/m<sup>3</sup>, and the density of cement mortar is 1800kg/m<sup>3</sup>~1900kg/m<sup>3</sup>. The average surface density of the whole wall is 182kg/m<sup>2</sup>.

#### 4.3. Prediction of sound insulation experimental results

When the sound waves incident at an irregular angle, the mass law of sound insulation of a single-layer homogeneous solid wall can be expressed as:

$$R = 20 \lg f + 20 \lg m - 48 \quad (3)$$

Where  $f$ — the frequency of the incident wave;  $m$ —mass of unit area of wall. When the surface densities are respectively and the material properties are relatively similar, the sound insulation values of two wallboards have the following relationship:

$$R_2 = R_1 + 20 \lg \frac{m_2}{m_1} \quad (4)$$

Firstly, the integrated wallboard is considered as a single material wallboard. According to the experimental data of 3.1 sections of cement foamed concrete wallboard and 3.2 sections of ALC block wall, the surface densities are  $170 \text{kg/m}^2$ , and the sound insulation is 47dB and 48dB respectively. According to Equation (4), it can be approximately obtained that when the surface density is  $182 \text{kg/m}^2$ , the sound insulation is:

$$R_A = 47 + 20 \lg \frac{182}{170} = 47.6(\text{dB}) \quad (5)$$

If the sandwiched rock wool board is considered, the sound insulation will be increased.

#### 4.4. Experimental results of sound insulation

The sound insulation experiment was carried out 4 days after the installation of the experimental wallboard, and the experimental results were shown in Table 1 and Figure 7.  $R_w=43.8\text{dB}$  is obtained, and the integer number is  $R_w(C,C_{tr})=43(0,-2)$  dB. Compared with  $R_w=47.6\text{dB}$  predicted by the previous theoretical analysis, it is 4dB smaller, and the sound insulation is significantly reduced. The abnormal reduction of sound insulation of ALC+ rock wool integrated composite wallboard must be related to the structure of the composite wallboard, which needs further analysis and research.

As can be seen from Figure 7, an anastomosis valley appears between 315Hz and 400Hz. Compared with Fig. 4, the range of anastomosis valley is larger. After the coincidence frequency, the sound insulation is basically proportional to the logarithm of the frequency, and the fitting relationship is shown in Equation (6):

$$R_2 = R_1 + 25.1 \times \lg \frac{f_2}{f_1} \quad (6)$$

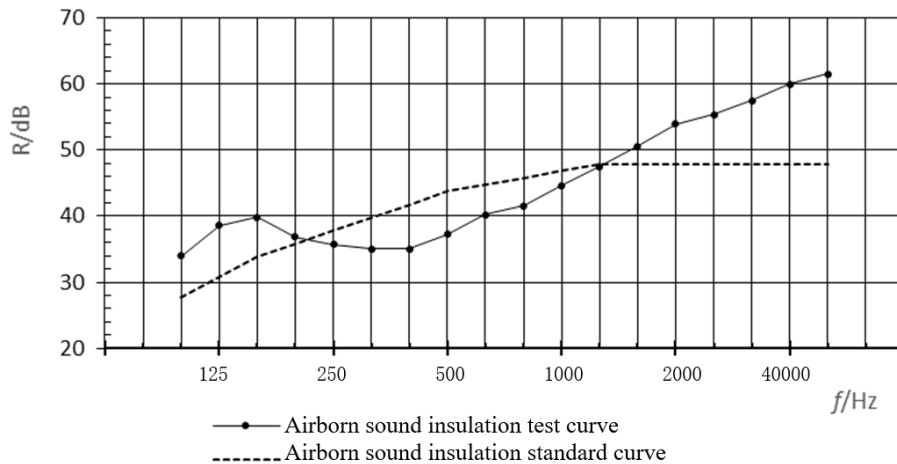
According to Equation (3), the logarithmic relationship between sound insulation value and frequency is shown as Equation (7):

$$R_2 = R_1 + 20 \times \lg \frac{f_2}{f_1} \quad (7)$$

**Table 1.** Experimental data of ALC+ rock wool composite wallboard sound insulation

$f/\text{Hz}$	R/dB	$f/\text{Hz}$	R/dB	$f/\text{Hz}$	R/dB
100	34.0	400	35.0	1600	50.6
125	38.6	500	37.2	2000	53.9
160	39.8	630	40.2	2500	55.4
200	36.9	800	41.6	3150	57.5
250	35.7	1000	44.6	4000	60.0
315	35.0	1250	47.5	5000	61.5

Comparing Equations (6), (7), it can be found that the sound insulation value of the integrated composite wallboard is basically proportional to the logarithm of the frequency after the coincidence frequency of 400Hz to 5000Hz, but the proportional coefficient changes from 20 of the mass law to 25, reflecting the influence of the sandwich rock wool board on the sound insulation.



**Figure 7.** Sound insulation frequency characteristic curve of ALC+ rock wool integrated wallboard

#### 4.5. Analysis of sound insulation and coincidence frequency of integrated composite wallboard

According to the thin plate sound insulation and anastomosis frequency theory [10], the incident frequency is:

$$f_c = \frac{c_0^2}{2\pi \sin^2 \vartheta} \cdot \sqrt{\frac{\rho}{D}} \quad (8)$$

Where  $D = \frac{h^3 E}{12(1-\nu^2)}$  is the bending stiffness of the single-layer plate,  $h=0.075\text{m}$  is the thickness of the plate,  $\nu$  is the Poisson's ratio,  $E$  is the elastic modulus,  $\rho$  is the surface density,  $c_0$  is the speed of sound in the air, and  $\vartheta$  is the incident Angle. According to Equation (8), the coincidence frequency is  $f_c = \frac{504}{\sin^2 \vartheta}$ ,  $f_c$  is minimum when  $\vartheta = \pi/2$ , which is 504Hz. Obviously, the coincidence frequency of composite plate cannot be reflected by thin plate theory.

The finite element modeling analysis of single ALC+ rock wool composite wallboard was carried out by ANSYS. Since there are two hollow filled rock wool plates in the 610mm wide and 2900mm high single-span wall panels, the rock wool plate has almost no stiffness compared with ALC, so the rock wool stiffness can be ignored for analysis. A single hollow surface is the vibration of half a wave with the lowest frequency of 355Hz. At the fundamental frequency of local vibration of the ALC plate around 355Hz, the front and rear plate resonates with the acoustic resonance, and the sound insulation value shows a coincidence valley, which is completely consistent with the test results.

The experimental results show that there is an obvious sound insulation trough in the frequency 315Hz~400Hz, which is located in the coincidence effect area. Compared with Figure 4, the coincidence effect area has a larger range. The local bending deformation vibration frequency of the composite wallboard is consistent with the acoustic frequency, and the sound insulation ability is significantly reduced, with the reduction amount reaching 6dB~8dB. As the frequency continues to increase, when the frequency of the sound source passes the anastomosed effect area, the bending vibration frequency of the plate increases and becomes the main contributor to the acoustic impedance rate. The sound insulation quantity continues to increase with the increase of frequency.

### 5. Conclusion

The sound insulation of the integrated composite wallboard of ALC+ rock wool board is different from that of the wall of single material, and it is also different from that of the on-site composite wall of two-layer of ALC board and one layer of rock wool board. Both experimental research and theoretical analysis show new sound insulation characteristics, and the following conclusions can be drawn through the experimental research and theoretical analysis:

(1) The integrated composite wallboard of ALC+ rock wool board belongs to non-uniform material wallboard due to structural reasons. Therefore, the relationship between the sound insulation volume and the mass surface density of the wallboard does not conform to the law of mass, which should be measured by experiment.

(2) There are two local four-sided supporting ALC plates on each side of the integrated composite wallboard of ALC+ rock wool board, and there is local vibration. The vibration frequency of the local four-sided supporting plate calculated by the finite element method is 355Hz. In this experiment, the thickness of the local ALC plate is 75mm and the density class is 750kg/m<sup>3</sup>. Since there is no experimental measuring point at 355Hz, the coincidence frequency obtained in the experiment is between 315Hz and 400Hz, which is completely consistent with the finite element calculation results.

(3) The sound insulation single evaluation value of 75mm ALC +125mm rock wool board + 75mm ALC integrated composite wall board is 43.8dB. Compared with the wallboard with the same mass density and considering rock wool interlayer, the sound insulation single evaluation value is reduced by about 6dB~8dB, which is unfavorable to the sound insulation of the wall.

(4) It is necessary to improve the structural form of integrated composite wallboard or add sound insulation measures to meet the standard of sound insulation required by the specification, such as adding 10mm thick sound insulation board, adjusting the thickness of ALC board on both sides of composite wallboard rock wool, to avoid local resonance before and after.

## Acknowledgments

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