12

Heat-insulating Materials and Sound-absorbing Materials

This chapter mainly discusses the basic properties of the heat-insulating materials and sound-absorbing materials and introduces several varieties of them which are commonly used in construction.

Students are required to select and use the heat-insulating materials and sound-absorbing materials properly after studying this chapter.

12.1 Heat-insulating Materials

12.1.1 The Basic Properties of Heat-insulating Material

In architecture, the material which prevents the outflow of indoor heat is normally called adiabator. On the other hand, the material which prevents the inflow of outdoor heat is called heat insulator. These two are collectively called heat-insulating materials.

This kind of material is mainly used for walls, ceilings, thermal equipments and thermal pipelines. It is sometimes used to preserve heat in winter construction. Generally, it may also be used a lot for refrigerating chamber and equipments.

It is known that heat current flows from high temperature to low temperature. In order to keep the room warm in winter, constant indoor heat supply must be provided to compensate for the heat loss due to the temperature difference. This problem can be partly addressed by using the heat-insulating material. For example, a six-storey residential building of four units in Beijing, China, uses the frame structure of mineral cotton composite plate, and this reduces the heat loss by 40% compared with masonry-concrete structure. According to the statistics, a good insulation building can cut down the fuel consumption by 25% ~ 50%. And to achieve this, one should consider the following questions: what kind of structure is easy to lose heat, and vice versa; how the composition of the material relates to its heat-insulating property; what are the factors that influence the material's heat-insulating property, and how to select the proper material.

Exterior protected construction is made of different building materials, the thermal conductivity and specific heat of which are the important parameters to the designation of the wall, roof, floor, and to the heat engineering calculation. The material with low thermal conductivity and high specific heat can improve the heat-insulating property of the exterior protected construction and keep the indoor temperature stable. For more details, please refer to Chapter Two.

The basic requirement for selecting heat-insulating material is that the thermal conductivity is well below 0.23W/ (m•K), the apparent density below 600kg/m^3, and the compression strength above 0.3MPa. Moreover, the material's hygroscopicity, temperature stability, and corrosion resistance all need taking into account according to the characteristics of the project.

The following is an introduction of the basic properties of the heat-insulating material.

1. Thermal Conductivity

Thermal conductivity is the measurement of the heat transfer ability of the material itself. It is influenced by the material constitution, porosity, temperature of the surroundings, and the direction of the heat current.

(1) The Material Constitution

The thermal conductivity can be influenced by the material's chemical composition and molecular structure. Material with simple chemical composition and molecular structure has higher thermal conductivity than the complex.

(2) Porosity

The thermal conductivity of solid matter is higher than that of air. Therefore, the higher the porosity is, the lower the thermal conductivity will be. In this aspect, not only the porosity matters, but also the size, distribution, shape, and connectivity of the pores.

(3) Humidity

Materials in damp conditions have higher thermal conductivity. What should be noted is that if water is frozen, its thermal conductivity will become higher. This is because the thermal conductivity of water is 20 times higher than that of air while that of ice is 80 times higher than air. Therefore, special attention should be taken to guard the heat insulating material against damp.

(4) Temperature

If the temperature becomes higher, the thermal conductivity increases accordingly. As the temperature rises, the thermal motion of the molecular solids becomes more active; the heat conduction of the air in the pore gets boosted, and the radiation effect of the pore wall is strengthened.

(5) The Direction of Heat Current

In case of the material being anisotropic (like the fibrous material wood), when the heat current flows parallel to the fibers, there will be no strong resistance; However, when the heat current flows against the fibers, strong resistance will be incurred.

2. Temperature Stability

Temperature stability is the ability of the material to retain its original property when exposed to heat. It is generally expressed by the ultimate temperature, exceeding the point of which the material will lose its heat-insulating function.

3. Strength

The heat insulating material is usually measured by its compression strength and flexural strength. As the material is highly porous, its strength is weak. Thus it is better not to allow the heat insulating material to carry more weight.

12.1.2 Common Heat-insulating Materials and Their Functions

Commonly used heat insulating materials can be divided into two types: organic and inorganic. The inorganic, often granular, fibrous or porous, is made from minerals.

1. Inorganic Fibrous Heat-insulating Materials

(1) Glass Wool and the Relative Products

Glass wool is a kind of fibrous material made from the melted glass raw materials or cullet. It consists of two types: loose wool and superfine wool. The fiber of the loose wool is 50 ~ 150mm in length and 12×10^{-3}mm in diameter. By contrast, the fiber of the superfine wool is much thinner in diameter, normally under 4×10^{-3}mm. And it is also called superfine glass wool.

The loose wool can be used to make asphalt-bonded glass blanket and glass wool board. The superfine glass wool can be used to make common superfine glass blanket, glass wool board, alkali free superfine glass blanket, hyperoxic silica superfine glass blanket, and it is also used to preserve heat in the exterior-protected construction and the pipelines.

(2) Mineral Cotton and the Relative Products

Mineral cotton takes the industrial waste and slag as its main raw material. After being melted, these waste and slag are made into cotton-silk like heat-insulating material through blowing or centrifugal process. The mineral cotton is light in weight, non-combustible, heat-insulating and electric-insulating. Moreover, its raw material is cheap and has a rich source. The mineral cotton can be used to make mineral wool board, mineral wool waterproof felt, and pipe shroud, etc. In addition to these, it can also be used to build walls, roofs, and ceilings in order to preserve heat and absorb sound.

2. Inorganic Granular Heat-insulating Materials

(1) Expanded Vermiculite and the Relative Products

Expanded vermiculite, made by roasting the vermiculite until it gets expanded, is a kind of loose granular material. The stacking density of this material is 80 ~ 200kg/m^3, λ=0.046 ~ 0.07W/(m•K), And the temperature limit is 1000 ~ 1100℃. Expanded vermiculite can be used to preserve heat in walls, floor slabs, and flat roofs. However, it should be guarded against damp when being used.

Expanded vermiculite, blended with cement, water glass or other cementitious material, can be made into slabs which are utilized in the wall, floor slab, and flat roof. The relative cement composite (cement accounting for 10% ~ 15%, while expanded vermiculite accounting for 85% ~ 90%) is made through the blending, molding, and maintaining process. On the other hand, the relative water glass composite is made by blending the expanded vermiculite, water glass, and adequate sodium fluorosilicate together.

(2) Expanded Perlite and the Relative Products

Expanded perlite, honey-comb like or bubble-like, white or grayish-white granules, is made by calcining the natural perlite. It is high-efficient heat insulating material, and has the advantages of light weight, good performance in low temperature, better hygroscopicity, better chemical stability, incombustibility, corrosion resistance, and easy application, etc. In construction, expanded perlite is widely utilized in exterior protected construction, low- temperature insulation equipments, thermal equipments, and also sound-absorbing products.

The relative expanded perlite products contain, for the most part, expanded perlite, and a certain amount of cementitious materials, such as cement, water glass, phosphate, and asphalt, etc. The products are made through the processes of blending, molding, and maintaining (drying or solidifying) and take the shape of slab, chunk, and tube.

3. Inorganic Porous Heat-insulating Materials

(1) Foamed Concrete

Foamed concrete is a mixture of cement, water and colophony foamable composition. It is porous concrete made through the blending, molding, maintaining, and hardening processes. The foamed concrete has the properties of porousness, light weight, heat preservation, heat insulation, and sound absorption. Fly ash foamed concrete can be made out of fly ash, lime, gypsum, and foamable composition. And this material can be used to preserve heat in the exterior protected construction.

(2) Aerated concrete

Aerated concrete is a compound of cement, lime, fly ash, and gas former (aluminum powder). It is a high-efficient heat- insulating material made through the molding and steam curing processes. It has the properties of heat preservation, heat insulation, and sound absorption. The apparent density of the aerated concrete is small and the thermal conductivity of it is even several times smaller than that of the clay brick. Therefore, the aerated concrete wall of 24cm wide is better than the brick wall of 37cm wide. Moreover, the aerated concrete has strong fire resistance.

(3) Diatomite

Diatomite is the remains of a water plant called diatom and is made of diatom test which is constituted by lots of tiny pores. The porosity of diatomite is 50% ~ 80%, which explains why it has excellent heat insulating property. The chemical composition of diatomite is hydrous amorphous silicon dioxide; its thermal conductivity is λ=0.060W/ (m•K); and its maximum operation temperature is 900℃. Diatomite is constantly used as filling material or used to make diatomite brick.

(4) Micro-porous Sodium Silicate

Micro-porous sodium silicate is a kind of new material. It is made of 65% of diatomite, 35% of lime, and 5% of asbestos, water glass, and water in proportion to the whole weight of diatomite and lime. This mixture must go through a series of processes like blending, molding, steam pressing and drying. Micro-porous sodium silicate can be utilized in exterior-protected construction and pipeline. And it is better than expanded perlite and expanded vermiculite in the heat-preserving aspect.

(5) Foam Glass

Foam glass takes cullet and one or two types of adjuvant (foaming agent, limestone, calcium carbide, or coke) as the raw material. After grinding, blending, and fitting die, the raw material is roasted at the temperature of 800 ℃ until a lot of closed and disconnected pores are formed. The porosity of the foam glass reaches high up to 80% ~ 90%, and the diameter of each pore is 0.1 ~ 5mm. The foam glass has the properties of low thermal conductivity, high compression strength, high frost resistance, and better durability. This material can be used to build walls, regulate heat in refrigerating equipment, or used as floating and filtering material. It is an advanced heat insulating material, easy to be cut and cemented.

4. Organic Heat-insulating Materials

Organic heat-insulating material takes organic materials as its raw material. Lightweight panel can be only used in low temperature for it is porous, highly hygroscopic, but not durable and not highly temperature-resistant.

(1) Foamed Plastics

Foamed plastics take all kinds of resin as the raw material. With certain amount of auxiliary materials such as foaming agent, catalyst, and stabilizer, the resins are heated until foams appear. Foamed plastics are a new type with the properties of lightweight, heat preservation, sound absorption, and quakeproof. This material can be used in wall and cold storage insulation, and can also be used to make sandwich board. At present, the relative products are polystyrene foamed plastics, polyvinyl chloride foamed plastics, Pentaerythrite foamed plastics and urea formaldehyde foamed plastics. The rigid foam is often used in construction.

(2) Vegetable Fiber Insulation Board

Among the different kinds of boards whose main component is vegetable fiber, low density fiberboards are often used as heat insulating material.

1) Cork Board. Cork board is made of the bark of Shuan tree and pineapple tree. After the bark being crushed, blended with the hide glue solution, pressed and molded, it is dried for a whole day in a drying chamber, the temperature of which is set at 80℃. Cork board is known for its light weight, low thermal conductivity, impermeability, and high corrosion resistance.

2) Wood Fiber Board. Wood fiber board takes the regular wood wool as its raw material, which, in its turn, is made of the leftover bits of wood. Firstly, the wood wool is blended with sodium silicate solution and common silicate cement, and then the compound goes through a series of processes: molding, cold pressing, maintaining, and drying. The wood fiber is often used to make ceilings, partition boards, or wall panels.

3) Celotex. Celotex takes Bagasse as its raw material. Celotex is made through the processes of steaming and drying. It has the properties of light weight, sound absorption, and heat insulation.

4) Perforated Plate. Perforated plate, also called honeycomb sandwich structure, is made by fixing two thin panels, each by one side, to a thick layer of honeycomb-like core material. The core material is a hexagonal hollow slab made by cementing together the Kraft paper and glass cloth or aluminum sheet, which have been soaked in the synthetic resin (phenolic aldehyde, polyester, etc.). The panels are made of the Kraft paper, glass cloth, veneer board, fiber board, and plaster board, etc, which are all soaked in the resin. The panels must be glued to the core material firmly by the proper adhesive. Perforated plate has the properties of great strength, low thermal conductivity and better shock resistance. It can be used to make light strong structural board, and also products with good heat insulation property, such as sound-insulating materials and other non-structural boards. Its heat insulation property will be enhanced if the core material is replaced by the foamed plastics.

(3) Adiabatic Diaphragm for Windows

Adiabatic diaphragm for windows, also called neotype heat-protector, is 12 ~ 50μm thick. This material is utilized in the window insulation. It is used to prevent sunshine from entering and the color of the furniture from fading. Moreover, it can reduce the heat loss in winter, thus save the energy and create a comfortable environment. Adiabatic diaphragm is stuck to the glass, and works to reflect outwards a majority of the sunshine which has permeated. The reflectivity is as high as 80%. In addition to this, adiabatic diaphragm can reduce the permeation rate of ultraviolet rays; alleviate the harm of ultraviolet radiation to the furniture and textile; regulate the temperature changes indoors; and overcome the non-uniformity in the appearance of the building. It can also prevent the broken glass from flying to wound people.

Adiabatic diaphragm is generally used in window insulation of commercial and industrial buildings, public buildings, apartments, and hotels, etc. It is also used to protect the artworks and paintings in the museum from ultraviolet harm. At present, some hotels in Beijing and Guangzhou have already started to use it.

12.1.3 Technical Properties of Common Heat-insulating Materials

Table 12.1 shows the technical properties of common heat-insulating materials.

Table12.1 Technical Parameters of Common Heat Insulating Materials

Name	Surface Density(kg/m^3)	Strength (MPa)	Thermal Conductivity [W/(m•K)]	Uses
Expanded Perlite	40 ~ 300		Normal Temperature 0.02 ~ 0.044 High Temperature 0.06 ~ 0.17 Low Temperature 0.02 ~ 0.038	High-efficient filling material heat insulation cold insulation
Cement Expanded Perlite	300 ~ 400	f_c0.5 ~ 1.0	Normal Temperature 0.05 ~ 0.081 Low Temperature 0.081 ~ 0.12	Heat Preservation Heat Insulation
Water Glass Expanded Perlite	200 ~ 300	f_c0.6 ~ 1.2	Normal Temperature 0.056 ~ 0.065	Heat Preservation Heat Insulation
Asphalt Expanded Perlite	400 ~ 500	f_c0.2 ~ 1.2	0.093 ~ 0.12	Used in normal temperature or negative temperature
Cement Expanded Vermiculite	300 ~ 500	f_c0.2 ~ 1.0	0.076 ~ 0.105	Heat Preservation Heat Insulation
Micro Porous Calcium Silicate Product	250	f_c>0.5 f_t>0.3	0.041	Heat insulation of exterior protected construction and pipeline

continued

Name	Surface Density(kg/m^3)	Strength (MPa)	Thermal Conductivity [W/(m•K)]	Uses
Foamed Concrete	300 ~ 500	$f_c \geqslant 0.4$	0.081 ~ 0.19	Exterior protected construction
Aerated Concrete	400 ~ 700	$f_c \geqslant 0.4$	0.093 ~ 0.16	Exterior protected construction
Wood Fiber Board	300 ~ 600	f_v0.4 ~ 0.5	0.11 ~ 0.26	Ceiling, Partition Board, Wall Panel
Soft Fiber Board	150 ~ 400		0.047 ~ 0.093	Ditto Smooth surface
Reed Board	250 ~ 400		0.093 ~ 0.13	Ceiling Partition Board
Cork Board	150 ~ 350	f_v0.15 ~ 2.5	0.052 ~ 0.70	Low water absorption non-corrosion non-combustion Heat insulation
Polystyrene Foamed Plastics	20 ~ 50	f_v=0.15	0.031 ~ 0.047	Heat insulation of roof and wall
Hard Polyurethane Foamed Plastics	30 ~ 40	$f_c \geqslant 0.2$	0.037 ~ 0.055	Heat preservation of roof and wall Heat insulation of cold storage
Glass Fiber Product	120 ~ 150		0.035 ~ 0.041	Heat preservation of exterior protected construction and pipeline
Soft Calcified Plastic Board	100 ~ 150	f_c0.1 ~ 0.3 f_t0.7 ~ 0.11	0.047	Heat preservation Heat insulation Water resistance decoration
Foamed Glass	150 ~ 200	f_c0.55 ~ 1.6	0.042	Wall construction Heat insulation of cold storage

12.2 Sound-absorbing Materials

12.2.1 The Sound Absorption

When the sound waves encounter the surface of the material: part of them reflects; part of them permeates, and the rest are absorbed by the material itself. The ratio of absorbed sound energy (E) to incident sound energy (E_0) is called sound absorption coefficient (α). This ratio is the main indicator used to evaluate the sound-absorbing property of the material. A formula can be used to demonstrate this.

$$\alpha = \frac{E}{E_0} \tag{12.1}$$

In this formula: α is the sound absorption coefficient;
E is the absorbed sound energy (including the permeating part);
E_0 is the incident sound energy.

If 65% of the incident sound is absorbed and the rest 35% is reflected, the sound absorption coefficient of the material is 0.65. When all sound waves are absorbed, the ratio will be one, and when the door and window is open, the ratio equals to one. Generally, the sound absorption coefficient of the materials is between $0 \sim 1$. The larger the numeral is, the better the sound absorbing property is. The sound absorption coefficient of suspended absorber may be more than one because its effective sound-absorbing area is larger than its calculated area.

The sound absorption of the material is not only related to its other properties, its thickness, and the surface conditions (the air layer and thickness), but also related to the incident angle and frequency of the sound waves. The sound absorption coefficient will change according to high, middle, and low frequencies. In order to reflect the sound-absorbing property of one material comprehensively, six frequencies (125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz) are set to show the changes of the sound absorption coefficient. If the average ratio of the six frequencies is more than 0.2, the material can be classified as sound-absorbing material. These materials can be used for sound insulation of walls, floors, and ceilings of concert hall, cinema, auditorium, and broadcasting studio. By using the sound absorbing material properly, the indoor transmittance of sound waves can be enhanced to create better sound effects.

12.2.2 The Basic Requirements for Selecting Sound-absorbing Materials

1) One must choose material with open and connected pores in order that it can work well. If the pores are more closely connected together, the sound absorbing property will become better. This is quite different from the heat insulating material which requires that the pores be closed and unconnected. In one word, porous materials can be used for various purposes each of which has different demands on the shape of the pores.

2) Most of the sound absorbing materials have weak strength, so that they should be fixed above the height of wall protective plate to avoid being

damaged. For the sound absorbing materials are easy to absorb heat, the resultative expansion and shrinkage have to be taken into consideration.

3) It is advisable to choose material with high sound absorption coefficient, so that a fewer amount will do.

4) Attention should be paid to the differences between sound-absorbing material and sound insulation shield.

12.2.3 Sound Absorption Coefficients of the Common Materials

Table 12.2 shows the sound absorption coefficients of common materials.

Table 12.2 Sound Absorption Coefficients of Common Materials in Construction

Class and Name	Thickness (cm)	Apparent Density (kg/m³)	Sound Absorption Coefficient at Each Frequency						Installation
			125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
① Inorganic materials									
Plasterboard(with decorative pattern)	-	350	0.03	0.05	0.06	0.09	0.04	0.06	Plaster firmly
Cement vermiculite plate	4.0		-	0.14	0.46	0.78	0.50	0.60	Plaster firmly
Gypsum mortar(blended with cement glass fiber)	2.2		0.24	0.12	0.09	0.30	0.32	0.83	Paint walls
Cement expanded perlite plate	5		0.16	0.46	0.64	0.48	0.56	0.56	
Cement mortar			0.21	0.16	0.25	0.40	0.42	0.48	
Brick (Plain brick wall)	1.7		0.02	0.03	0.04	0.04	0.05	0.05	
② Organic materials									
Cork board	2.5	260	0.05	0.11	0.25	0.63	0.70	0.70	Plaster firmly to the wood keel with an air layer of 10cm or 5cm in between
Shuisi board	3.0		0.10	0.36	0.62	0.53	0.71	0.90	
Veneer board (three layers)	0.3		0.21	0.73	0.21	0.19	0.08	0.12	
perforated plywood (five layers)	0.5		0.01	0.25	0.55	0.30	0.16	0.19	
Zylonite	0.8		0.03	0.02	0.03	0.03	0.04	-	
wood of fiberboard	1.1		0.06	0.15	0.28	0.30	0.33	0.31	
③ Porous material									
Foamed glass	4.4	1260	0.11	0.32	0.52	0.44	0.52	0.33	Plaster firmly
urea formaldehyde foamed plastics	5.0	20	0.22	0.29	0.40	0.68	0.95	0.94	Plaster firmly
Foamed cement(exterior plaster)	2.0		0.18	0.05	0.22	0.48	0.22	0.32	Closely against walls
Sound absorbing perforated plate			0.27	0.12	0.42	0.86	0.48	0.30	
Foamed plastics	1.0		0.03	0.06	0.12	0.41	0.85	0.67	
④ fibrous material									
Slag wool	3.13	210	0.10	0.21	0.60	0.95	0.85	0.72	Plaster firmly
Glass wool	5.0	80	0.06	0.08	0.18	0.44	0.72	0.82	Plaster firmly
Phenolic aldehyde glass fiber board	8.0	100	0.25	0.55	0.80	0.92	0.98	0.95	Plaster firmly
Industrial felt	3.0		0.10	0.28	0.55	0.60	0.60	0.56	Plaster to the wall

12.2.4 Sound-insulating Materials

Sound insulation is a kind of measure to prevent the sound waves from permeating. It is demonstrated by the sound transmission loss which is expressed by the difference of decibels between the incident sound and permeated sound. The higher the numeral is, the better the sound insulating property is.

According to the way of transmittance, the sound that people would like to insulate can be divided into air-borne sound (due to the vibration of the air) and solid-borne sound (due to the impact on solids or solid vibration). The sound permeation complies with the "mass law" in acoustics. The sound insulation property of wall or plate depends on its mass area ratio. The greater the mass is, the harder it is to vibrate this material, thus the better the insulating property will be. Therefore, it is better to choose dense and heavy material (clay brick, reinforced concrete, steel plate, etc) as sound insulating material. The best way to insulate the solid-borne sound is to use the unconnected structure. That means to fill in elastic liner between wall and spandrel girder, as well as between the frame of the building and the wallboard. The elastic liner can be chosen from felt, cork, rubber, and elastic carpet. Do not mistake sound absorbing material for sound insulation material. Note that good sound absorbing material is light, loose and porous.

Questions

12.1 What is heat-insulating material? What are the basic requirements for the heat insulating material?

12.2 What are the main factors which affect the thermal conductivity of constructional materials?

12.3 Why should we guard against water and damp when using the heat-insulating materials?

12.4 What are the heat-insulating materials commonly used in construction?

12.5 What is sound absorption coefficient? What are the differences of technical requirements between sound-absorbing material and heat insulating material?

12.6 Why can't the sound-absorbing materials be replaced with some sound-insulating materials?

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