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Development and Performance Evaluation of a New Compound Humidity Control Building Material

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Abstract. A power-free "precise" humidity control building material is made of porous inorganic minerals as carriers to be coated with the liquid of the humidity control composition, which is used to regulate humidity in indoor environment. The selected mineral substrates are made of inorganic materials such as fibers, cement, quartz sand and expanded vermiculite. Porous vermiculite is the main adsorption carrier. In order to increase the speed of moisture absorption and desorption, mineral substrates with thickness of 5mm and weight of 7kg/m² are selected. According to the actual conditions of museums all over the country, the design requirement of suitable humidity-regulating board should involve the following points: it does not need to depend on the maintenance of power system, and can presuppose "intelligent" humidity-regulating board with "precise humidity". It has the characteristics of large humidity-regulating capacity, rapid moisture absorption and desorption, high cost performance and convenient construction.

1. Introduction

According to the regulation of indoor environmental humidity, there are two kinds of active and passive energy consumption. "Active" regulation, also known as "active" method, uses energy-consuming power systems to humidify and dehumidify; passive regulation, also known as non-dynamic humidity regulation, regulates humidity in relatively closed territory by material's own moisture adsorption and desorption capacity, which is an ecological regulation mode [1].

Japan has developed a kind of non-power humidity-regulating building materials for indoor use very early, such as NHML humidity-regulating board produced by JIC Company of Japan, which is a special calcium silicate crystallization by hydrothermal reaction of lime, silicate raw materials and water, and then added some auxiliary materials such as reinforcing fibers to the crystallization, finally compacted and formed after drying. This kind of humidity-regulating building material requires strict waterproof and airproof treatment of the space, and needs "maintenance" before use so that the indoor humidity can be adjusted to the target humidity range by constant temperature and humidity power system. The humidity in the space would be in a stable state only when the corresponding "balance" is achieved.

The important application area of humidity-regulating building materials is the heritage protection industry, forming an appropriate space for the protection of valuable cultural heritage materials. It not only has a stable humidity range, but also has a special function space for the protection of cultural relics such as fire prevention, inferior (anti-aging), mildew prevention, insect prevention and so on.

For the collection industry in China, the temperature and humidity control of the warehouse has always been a problem. Especially in some economically backward areas, the warehouse does not



have a constant temperature and humidity system installed, even if there is, because of the cost problem, it can not achieve 24-hour power system to maintain the warehouse temperature and humidity, forcing some warehouses to become "concentrated destruction of cultural relics" place. Therefore, the development and application of high-efficiency and energy-saving composite humidity-regulating building materials has important application value and social significance for energy saving and improving the quality of goods preservation.

2. Experiment

2.1 Raw Material

The porous mineral substrates selected here are made of inorganic materials such as fibers, cement, quartz sand and expanded vermiculite. The fibre reinforced calcium silicate plate products are manufactured by belt slurry conveying drum pressing, high temperature pressure curing, drying and grinding.

The mineral substrates contain expanded vermiculite, which is a group of hydrated trioctahedral iron-aluminium-magnesium flake or mica silicate minerals, consisting of lattice layered minerals such as chlorite, hydromica and clay minerals [2]. Vermiculite has higher specific surface area, negative surface charge, higher surface porosity, and more developed pores. Vermiculite is chemically inert, non-toxic and does not release toxic gases during combustion. So it is very suitable for building materials.

In order to increase the speed of moisture absorption and desorption, mineral substrates choose "thin plate" instead of "thick plate" to increase the surface area of adsorption. The thickness of JIC in Japan is 12 mm and 20 mm, while the thickness of mineral substrates selected in this study is 5 mm and the weight is 7 kg/m².

In addition to the mineral substrate itself has a certain moisture absorption and desorption performance, it will also be coated with the composite solution of precise humidity, forming a new type of composite humidity control building materials.

The composition solution is made up of at least one mixture of polyols, macromolecules and water. Since RH40~60% is the basic requirement of the cultural relics warehouse, this research work is to coat the composite solution of targeted humidity range on the mineral substrates, not only can the "precise humidity" be entrusted to the ordinary mineral substrates with certain humidity-regulating function, but also greatly improve the moisture absorption and desorption capacity of the original substrates.

2.2 Preparation of Compound Humidity Control Building Materials

1) Select 100*100mm's mineral substrate. In order to eliminate the error of water content of mineral substrates, the samples were dried in oven at 120 °C for 2 hours.

2) The RH 55% solution was prepared. After all dissolution, it was coated on the mineral substrates according to 4g, 6g, 8g, 10g and 12g quantitatively. Two sides were coated in turn. Because the viscosity of the hot liquid is low, it can quickly penetrate into the porous structure of vermiculite on the mineral substrate.

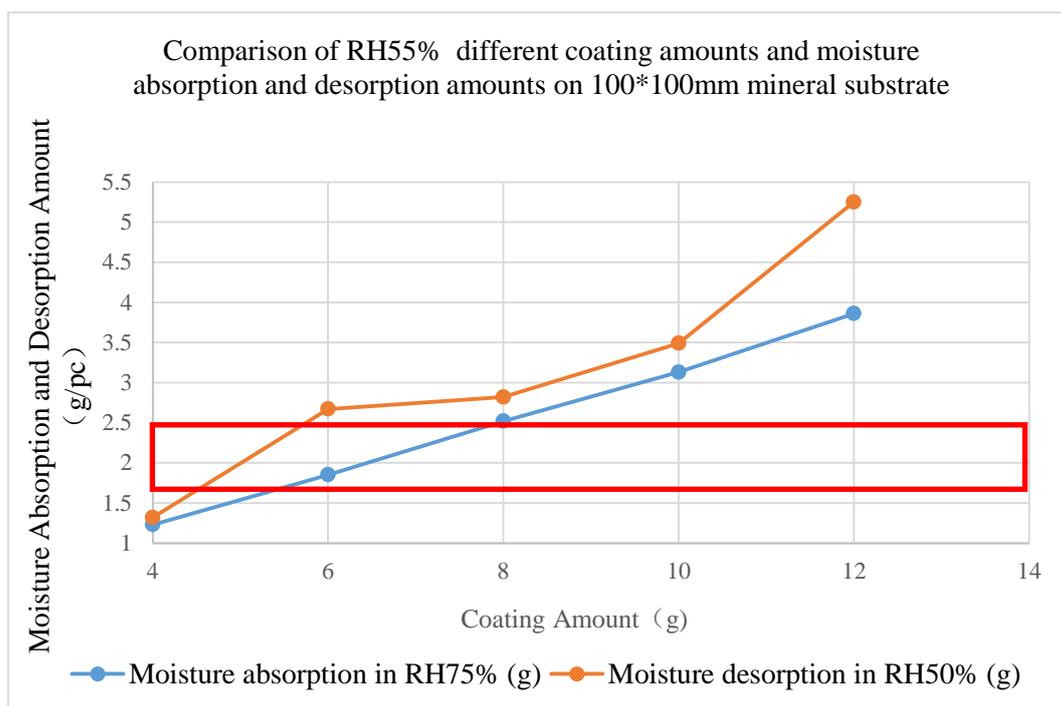
3) According to the standard JC/T 2002-2009 "Test Method for Moisture Absorption and Desorption Performance of Building Materials"[3], the mineral substrates with different coatings will be prepared. After 24-hour balanced in RH 75%, then 24-hour balanced in RH 50%, the weight change will be recorded.

4) Choose the right amount of coating.

The specific data are shown in Table 1.

Table 1. Moisture absorption and desorption properties of different coating amounts on 100*100mm substrate

Coating amount(g)	Weight of coated sheet (g)	Weight of balanced in RH75% (g)	Moisture absorption in RH75% (g)	Weight of balanced in RH50% (g)	Moisture desorption in RH50% (g)
4g	72.04	73.27	1.23	71.95	1.32
6g	73.76	75.61	1.85	72.94	2.67
8g	76.19	78.71	2.52	75.89	2.82
10g	77.89	81.02	3.13	77.53	3.49
12g	79.54	83.4	3.86	78.15	5.25

**Figure 1.** Comparison of RH55% different coating amounts and moisture absorption and desorption amounts on 100*100mm mineral substrates

Combined with Table 1 and Figure 1, we can see:

1) Because the coating solution is the formulation of RH 55%, the moisture absorption increment after moisture absorption equilibrium under RH 75% condition is less than the total moisture release after moisture release equilibrium from RH 75% to RH 50%.

2) With the increase of coating amount, the moisture absorption and moisture release amount also increased.

3) Considering that the market demand is a suitable cost-effective product, and the cost is also the key consideration factor of this research work. So the improvement target is 2-3 times of the existing standard, and the corresponding coating quantity of the points in the red box of Fig. 1 can be used.

3. Performance Evaluation

Usually, the evaluation of "humidity-regulating materials" includes two parts: humidity-regulating capacity (moisture absorption and desorption capacity) and humidity-regulating speed (moisture absorption and desorption speed). "Precise humidity" is added in this research as a new evaluation index.

Comparing the samples of JIC from Japan, the samples of this study (named "humigic") and the

national standard moisture absorption and desorption standards, we will further evaluate the performance of humidity control board.

Taking 250*250mm size as test sample:

Sample of "humigic": Humidity control plate coated with RH 50% composite solution does not need maintenance;

Sample of JIC from Japan should be maintained in RH50% for 24 hours.

The specific comparison is shown in Table 2.

Table 2. Comparative data of JIC, humigic and GB

Item	JIC	Humigic	GB
Thickness(mm)	12	5	≥ 5
Size(mm)	251*251	250*250	250*250
Area(m ²)	0.063	0.0625	0.0625
RH50% Maintenance	Need	No need	Need
Weight of balanced in RH50%(g)	457.7	487.5	N/A
Moisture Absorption after 3h (g)	3.29	6.67	1.56
Moisture Absorption after 6h (g)	4.95	9.33	2.19
Moisture Absorption after 12h (g)	7.08	15.79	3.13
Moisture Desorption after 3h (g)	3.08	6.4	1.41
Moisture Desorption after 6h (g)	4.02	8.22	1.75
Moisture Desorption after 12h (g)	4.94	12.6	2.19
Moisture absorption per unit area after 3h(g/m ²)	52.2	106.7	25
Moisture Desorption per unit area after 3h(g/m ²)	48.9	102.4	22.5
Desorption/Absorption after 3h(%)	93.70%	95.97%	90%
Moisture absorption per unit area after 6h(g/m ²)	78.6	149.3	35
Moisture Desorption per unit area after 6h(g/m ²)	63.8	131.5	28
Desorption/Absorption after 6h(%)	81.10%	88.10%	80%
Moisture absorption per unit area after 12h(g/m ²)	112.4	252.7	50
Moisture Desorption per unit area after 12h(g/m ²)	78.4	201.6	35
Desorption/Absorption after 12h(%)	69.80%	80%	70%

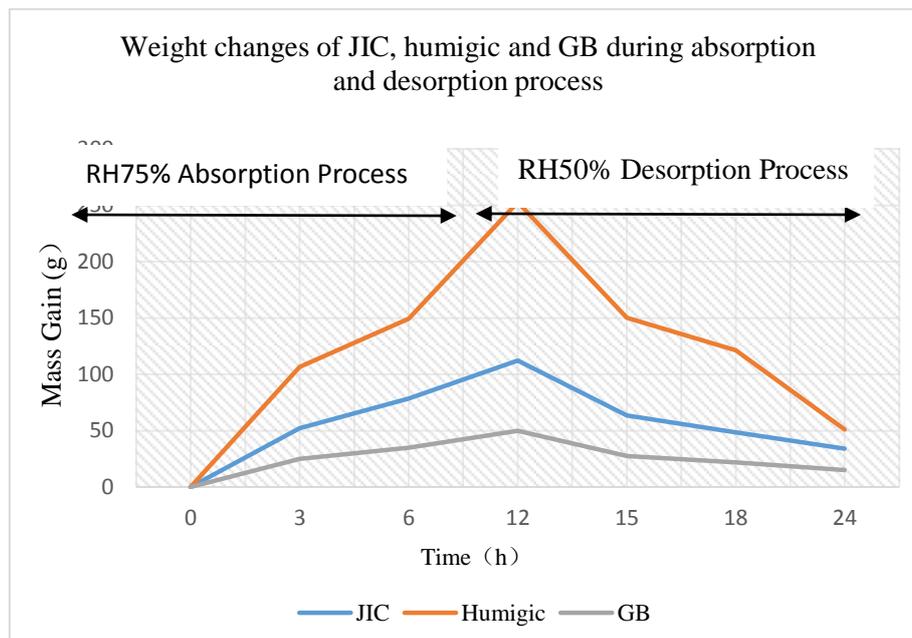


Figure 2. Weight changes of JIC, humigic and GB during absorption and desorption process

Combining Table 2 and Figure 2, we can see that the Humigic in this study is superior to JIC and national standard data in terms of moisture absorption and desorption capacity and speed.

In addition, "Humigic" does not need to be maintained. It can be called "intelligent" humidity control building materials. Compared with ordinary humidity control building materials, it is more efficient and convenient to use.

In order to meet the application requirements of building materials, besides the "humidity regulating performance", the "humigic" also needs to meet other relevant standards, including non-flammability, formaldehyde content, TVOC content, safety, screw holding force and so on. Therefore, after testing and confirmation, the enterprise standard (Q31/0230000039C006-2018) has been formulated to make "humigic" humidity-controlling building materials become standardized products to the market.

4. Conclusion

A new type of compound "precise" humidity-controlling building material is made of porous inorganic minerals as carriers to be coated with the liquid of "precise RH formula" composition in the thermal solution state. When the solution is cooled to form supersaturated state, the crystals will evenly form in the porous structure of inorganic minerals, thus increasing the humidity capacity and having "precise humidity-regulating" property.

It can be seen from the standard [4] and related test methods that: (1) There is no concept of "humidity control accuracy" in the standard; (2) The standard level of humidity control capacity and speed of moisture absorption and desorption is low, especially in most commonly used range RH40-60%, so that energy efficiency and application fields of humidity-controlling building materials are limited.

The important application and development of this research is to develop a humidity-regulating board which is generally applicable in the domestic cultural warehouse. It needs to meet the following characteristics:

- 1) Preset "precise humidity", no need maintenance before use.
- 2) Installation and construction are simple and convenient to replace.
- 3) The humidity control capacity is large, at least several times higher than the existing standard. Only 8 hours of power system each day to maintain 24 hours of humidity.
- 4) Cost of both material and construction is 2~3 times lower than that of Japan JIC

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