Laboratory tests with liquid nano-ceramic thermal insulation coating

David Bozsaky*

Széchenyi István University, Faculty of Architecture, Civil Engineering and Transportation Engineering, Egyetem tér 1, Győr 9026, Hungary

Abstract

Liquid nano-ceramic thermal insulation coatings appeared in the last decades on the market of thermal insulation materials. This paint-on insulation contains microscopic cellular ceramic microspheres. These vacuum-hollow balls were made of on high temperature melted ceramic. Its binding material is a mixture of synthetic rubber and other polymers. After mixing with water, using brush or vacuum vaporizer can be taken on the surface to be insulated.

The special literature of liquid nano-ceramic thermal insulation coatings gives different and contradictory thermodynamic details about this material. According to some sources its thermal conductivity is around 0.001-0.003 W/mK, but other papers publish much higher thermal conductivity values (from 0.01 W/mK to 0.14 W/mK).

In the Laboratory of Building Materials and Building Physics at Széchenyi István University (Győr, Hungary) several thermodynamic test were made with liquid nano-ceramic thermal insulation coatings. On basis of European Standards (EN) the thermal conductivity and water absorption of this material was determined. The relationship between thermal conductivity and water content was analyzed. Experiments were performed with conventional thermal insulation materials with additional ceramic coating on one side, two sides and beside two plates. Results were analyzed in order to prove the low thermal conductivity and heat mirror effect of this material.

Keywords: liquid ceramic, nanotechnology, thermal insulation.

1. Introduction

Nano (symbol: n) is an SI prefix meaning one billionth. In the metric system this prefix denotes a factor of 10^-9. Nanotechnology is the engineering of functional systems at the molecular scale. In its traditional sense, means building things from the bottom up, with atomic precision [4].

1.1. Brief history of nanotechnology

This theoretical capability was envisioned as early as 1959 by the renowned physicist Richard P. Feynman (1918-1988). The first fundamental studies about nanotechnology were written by C. G. Granqvist and R. A. Buhrman in 1976. In the early 1980s, S. Komarneni and R. Roy developed the first way to synthesize nanoparticles, specifically nano-ceramics [2]. He used a process called sol-gel and enabled researchers to test the properties of nano-ceramics. This process was later replaced by sintering in the early 2000s and continued to advance to microwave sintering. Because of the advancements, researchers are able to produce nano-ceramics at a more efficient rate.
1.2. Nanotechnology in architecture

Nano-technology can be used also in architecture. Nano-silica addition to cement based materials can increase the durability and compressive strength [3]. Wood can be composed with nanotubes or nanofibres and this products can be twice stronger than steel [5]. Titanium dioxide (TiO2) is used in nanoparticle form to coat glazing because of its sterilizing and anti-fouling properties [1]. Nanoparticle based coatings can provide better adhesion, transparency, self-cleaning, corrosion and fire protection. Liquid nano-ceramic coatings are used for thermal insulation [4].

1.3. Liquid nano-ceramic thermal insulation coatings

Paint-on insulation products like ThermoShield, Protector, Manti and TSM Ceramic contain microscopic (with a diameter of 20-120 μm) cellular ceramic microspheres. These vacuum-hollow balls were made of on high temperature melted ceramic. Its binding material is a mixture of synthetic rubber and other polymers. Main components are styrene (20%) and acryl latex (80%). Styrene guarantees the mechanical strength. Acryl latex makes this material resistant against weather conditions and provides adequate flexibility. Other environmental additives (biocides, anti-fouling and antifungal materials) make the final product durable and mould-proofing. After mixing the ceramic microspheres with the binding material, the additives and with water, using brush or vacuum vaporizer can be taken on the surface to be insulated [4,7].

In these microscopic vacuum spaces thermal transmission processes happen in non-traditional ways. The inner surface of cellular ceramic microspheres works as a heat mirror and reflect the 60-80% of heat radiation. Thermal conduction is very difficult between the small interfaces of ceramic microspheres and in vacuum space minimizes thermal convection [1,7].

The special literature gives different technical details about these materials (Table 1). Moreover, thermodynamic details are extraordinarily contradictory. Some sources say that its thermal conductivity is around 0,001-0,003 W/mK [7,8], but others publish much higher values (from 0,01 W/mK to 0,14 W/mK) [6].

<table>
<thead>
<tr>
<th>Material characteristics</th>
<th>Symbol</th>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (wet)</td>
<td>𝜌_{\text{wet}}</td>
<td>kg/m³</td>
<td>500-745</td>
</tr>
<tr>
<td>Density (dry)</td>
<td>𝜌_{\text{dry}}</td>
<td>kg/m³</td>
<td>290-410</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>𝜎_t</td>
<td>kPa</td>
<td>300-400</td>
</tr>
<tr>
<td>Adhesion strength (concrete)</td>
<td>𝜎_{\text{ad}}</td>
<td>kPa</td>
<td>460-920</td>
</tr>
<tr>
<td>Adhesion strength (steel)</td>
<td>𝜎_{\text{ad}}</td>
<td>kPa</td>
<td>470-900</td>
</tr>
<tr>
<td>Liquid water permeability</td>
<td>w</td>
<td>kg/m²h⁻¹⁻¹</td>
<td>0,16-0,20</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>𝜆</td>
<td>W/mK</td>
<td>0,001-0,003, or 0,014, or 0,14</td>
</tr>
</tbody>
</table>

These details are often not confirmed with laboratory tests or refer non-adequate experiments. For example, some sources determine indirectly the thermal conductivity of this thin coating with heat transfer experiments of wall structures according to MSZ EN 1934:2000 (Title: Thermal performance of buildings. Determination of thermal resistance by hot box method using heat flow meter. Masonry.) and MSZ EN ISO 8990:2000 (Title: Thermal insulation. Determination of steady-state thermal transmission properties using the calibrated and guarded hot boxes) standards [6,7,8]. Nevertheless these methods are suitable only for determining heat transfer coefficient of the global building structure. To measure thermal conductivity of thermal insulation materials the only suitable standard is MSZ EN 12667:2001 (Title: Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance).

2. Laboratory tests and results

In the Laboratory of Building Materials and Building Physics at Széchenyi István University (Győr, Hungary) several laboratory experiments and thermodynamic test were made with liquid nano-ceramic thermal insulation coatings. On basis of MSZ EN 1602:2013 (Title: Thermal insulating products for building applications. Determination of the apparent density) standard the density was determined in wet and air-dry condition. According to MSZ EN 12667:2001 standard the thermal conductivity of this material was determined using Taurus TCA 300
heat flow meter. We also measured long-time water absorption according to MSZ EN 12087:2013 (Title: Thermal insulating products for building applications. Determination of long-term water absorption by immersion.) standard.

The relationship between thermal conductivity and water content was analyzed. Experiments were performed with conventional thermal insulation materials additional ceramic coating on one side, two sides and between two plates.

2.1. Density

For experiments enough pieces of adequate samples were necessary. The fresh liquid nano-ceramic mixture was filled into five surface-treated wood frames and left for solidifying. After two days the samples were solid enough to take out from the formwork and they were suitable for laboratory tests.

At first the dimensions and weight of liquid nano-ceramic coating was determined and density of them in wet condition was calculated 510.84-555.87 kg/m³ with an average of 533.01 kg/m³ (Table 2). Later the samples were placed in a dryer case and left there at 70°C and 50% relative humidity. The density was daily determined until the samples got in air-dry condition. Summarizing the results the air-dry density of nano-ceramic coating was 353.29-386.25 kg/m³ with an average density of 370.28 kg/m³ (Table 2). Comparing with Table 1 is considerable that experimentally measured density values are inserted to the range of density details presented in the special literature.

<table>
<thead>
<tr>
<th>Material characteristics</th>
<th>Symbol</th>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (wet)</td>
<td>( \rho_{\text{wet}} )</td>
<td>kg/m³</td>
<td>533</td>
</tr>
<tr>
<td>Density (dry)</td>
<td>( \rho_{\text{dry}} )</td>
<td>kg/m³</td>
<td>360.28</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>( \lambda )</td>
<td>W/mK</td>
<td>0.069</td>
</tr>
</tbody>
</table>

2.2. Thermal conductivity

After studying the special literature the measuring method of thermal conductivity was augured problematic. Heat flow meter can only measure samples with thickness between 20-120 mm and the practical thickness of this material is only 1-2 mm. Moreover the measuring limits of this machine are between 0.01-0.50 W/mK and some references publish about 0.001-0.003 W/mK, which value is immeasurable with a standard heat flow meter. This is why two different experiments were invented to determine thermal conductivity.

The first idea was to spray 1-2 mm thick liquid nano-ceramic layer on three different types of conventional thermal insulation materials. For this procedure expanded polystyrene (EPS), extruded polystyrene (XPS) and fiberwood were chosen and from these materials four types of samples were made:

- Type 1 sample without coating
- Type 2 coating on the upper (warm) side
- Type 3 coating on the lower (cold) side
- Type 4 coating on two sides
- Type 5 coating between two plates.

All types of samples were tested with heat flow meter. The hypothesis was the following: If the coating has very low thermal conductivity and also thermal mirror effect the heat transfer measurement must show significant difference between Type 1 (without coating) and the other types (Type 2-5) of samples. Moreover samples with coating (no matter where the coating is) should have much lower thermal conductivity than samples without coating. But the results of this measurement traversed this hypothesis (Table 3).

With nano-ceramic coating thermal conductivity became lower only in the case of XPS samples but the decrease of it was not as significant as expected. It was no matter that the coating was on the cold or warm side, the decrease of thermal conductivity was nearly the same (0.91% and 1.01%). The degree of decreasing was triple (3.32%) when the coating was on the two sides and 1.76% when it was between two plates.

Contrarily the thermal conductivity of EPS and fiberwood plates became higher when they got nano-ceramic coating. Only the degree of increasing depended on the material, because fiberwood plates changed twice stronger than EPS plates. One-sided coating caused 0.84% and 1.00% increase by EPS plates and 1.52% and 2.11% increasing by fiberwood plates. Two-sided coating caused 1.76% and 2.60%, inner coating layer caused 3.43% and 7.16% increasing of thermal conductivity. Subsequently it can be stated that low thermal conductivity and thermal mirror
effect of liquid nano-ceramic thermal insulation coating is not provable with heat flow tests of coated thermal insulation plates. Moreover, liquid nano-ceramic coating seems to have a minimal destructive effect on thermal conductivity.

Table 3. Thermodynamic test result of different thermal insulation materials with liquid nano-ceramic coating.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Thermal conductivity</th>
<th>Without coating</th>
<th>With liquid nano-ceramic coating</th>
<th>Δλ (%)</th>
<th>2 Sides</th>
<th>Between 2 plates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>λ (W/mK)</td>
<td>λ (W/mK)</td>
<td>Δλ (%)</td>
<td>λ (W/mK)</td>
<td>Δλ (%)</td>
<td>λ (W/mK)</td>
</tr>
<tr>
<td>EPS plate</td>
<td>0.0399</td>
<td>0.0402</td>
<td>0.84</td>
<td>0.0403</td>
<td>1.00</td>
<td>0.0406</td>
</tr>
<tr>
<td>XPS plate</td>
<td>0.0347</td>
<td>0.0343</td>
<td>-0.91</td>
<td>0.0343</td>
<td>-1.01</td>
<td>0.0335</td>
</tr>
<tr>
<td>Fiberwood</td>
<td>0.0922</td>
<td>0.0936</td>
<td>1.52</td>
<td>0.0942</td>
<td>2.11</td>
<td>0.0946</td>
</tr>
</tbody>
</table>

On basis of these results another idea was raised. If the thermal conductivity of liquid nano-ceramic coating could be between 0.01-0.50 W/mK it can be checked on samples that were used for density measurements. So after determining the density the original pure liquid nano-ceramic samples were placed in the Taurus TCA 300 heat flow meter in order to measure their thermal conductivity. According to MSZ EN 12667:2001 standard these measurements were practicable. It wet condition (58.07% m/m moisture content) the thermal conductivity was set to be 0.1120 W/mK but tending to air-dry condition this value increased until 0.0690 W/mK. It is very different from all details we can find in the special literature (Table 1 and Table 2).

Analyzing the connection of thermal conductivity and moisture content (Figure 1) it was proved that the difference between thermal conductivity in air-dry condition and with a water content of 12% m/m is unnoticeable. Passing this limit a lineal relationship is visible between thermal conductivity and moisture content so it is declarable that thermal conductivity is directly proportional to moisture content after a limit of 12% m/m. This moisture content

![Figure 1: The relationship between moisture content and thermal conductivity](image-url)

\[ R^2 = 0.868 \]
can be termed as natural water content, which has no effect on thermal conductivity. This attribute is very similar to natural thermal insulation products (wood wool, fiberwood, cornstalk insulation blocks etc.) even though liquid nanoceramic insulation coatings are not nearly natural, organic materials.

2.3. Water absorption

Water absorption of thermal insulation materials is a very important material characteristic and it is determinable on basis of MSZ EN 12087:2013. This standard prescribes to store the samples under water for 28 days. The hydrotechnical character of this material was unknown. Moreover the change of water absorption in time was also an interesting point of view. This is why water absorption was not only determined after 28 days but at regular intervals too. If we take a look at Figure 2 (relation between time and moisture content) it is considerable that there is high initial water absorption at the first day. But then as time passing by water absorption is steady. The 28 days water absorption is calculated to be 28.81% m/m but samples are not saturated after that time. Moisture content is continuous after 28 days and it is not either tending to a predictable limit after 44 days. Water absorption experiments are still running in order to find the limit value.

![Figure 2: The change of water content in time (long-term water absorption by immersion)](image)

\[ R^2 = 0.993 \]

3. Conclusions

According to the special literature thermal transmission processes happen in non-traditional ways in liquid nanoceramic paint-on insulations because their inner surface has a heat mirror effect. The special literature gives different and contradictory technical details about these materials.

In the Laboratory of Building Materials and Building Physics at Széchenyi István University (Győr, Hungary) the following characteristics were controlled: density in wet and dry condition, thermal conductivity and water absorption.
On basis of density measurements it is considerable that experimentally measured density values (average density is 533.01 kg/m³ in wet and 370.28 kg/m³ in air-dry condition) are inserted to the range of density details presented in the special literature.

Thermal conductivity measurements came up against difficulties (e.g. measuring limits). To determine thermal conductivity two methods were applied but they were not able to prove the very low thermal conductivity nor yet the thermal mirror effect of liquid nano-ceramic coatings. According to MSZ EN 12667:2001 the thermal conductivity was directly measureable with a standard heat flow meter. Thermal conductivity of liquid nano-ceramic coating was measured to be 0.069 W/mK which detail is very far from the other details presented by the references.

Beyond these experiments the relationship of thermal conductivity and moisture content was analyzed. A water content limit of 12% m/m was determined. Under this value the thermal conductivity is constant but over this value thermal conductivity and moisture content are directly proportional.

On basis of MSZ EN 12087:2013 standard the long-term water absorption was determined by immersion. After the prescribed 28 days water absorption was 28.81% m/m but in contrast with traditional thermal insulation materials it did not tend to a limit. Water absorption is constant after it and even after 44 days 38.44% m/m water absorption is not nearly a limit value.

References