Structural analysis of innovative ceramic nano-coatings used for thermal insulation of buildings

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Synopsis:
In times of progressing environmental degradation, depleting fossil fuels and problems with energy availability and prices, it is becoming extremely important to reduce energy consumption in every aspect of human life. The right direction, from the point of view of environmental protection and rationalisation of energy consumption, are activities aimed at reducing energy losses occurring in the processes of energy transport in heat exchangers from solutions used in the building industry to industrial installations. Research has been carried out to assess the applicability of innovative liquid ceramic nano-coatings for the thermal insulation of industrial plant components. The nanocoatings were applied to various metallic materials and microscopic examination was carried out to assess the surface condition. It is assumed that the research will result in a positive assessment of the impact of the application of liquid nanocoatings in terms of both thermal, anti-moisture and anti-corrosion properties, which will translate into longer component life, increased process energy efficiency and a reduced carbon footprint of the engineering solutions in which they can be applied.

Keywords:

Ceramic isolation, nano-coatings, computed tomography, scanning electron microscope

1. Introduction

Thermal insulation is an important aspect of building design and different materials have been used as insulation over the years, as they are responsible for reducing energy consumption and providing comfort to occupants. Traditional materials such as fibreglass and cellulose insulation are effective in reducing heat transfer, but they also have limitations such as low durability, moisture absorption and low fire resistance. In recent years, nanotechnology has been used to develop innovative materials that offer excellent thermal insulation properties. These materials, known as nano-insulators, have been shown to offer superior thermal insulation properties compared to traditional materials and even to air, which is considered the best natural insulator.

Nano-insulators are characterised by their small size, high surface-to-volume ratio and unique physicochemical properties that make them ideal for thermal insulation applications. These include materials such as aerogels, carbon nanotubes and graphene. Aerogels, for example, have extremely low thermal conductivity due to their porous structure, while carbon nanotubes and graphene offer excellent mechanical strength and thermal stability.

Numerous studies have been carried out on the thermal insulation properties of various nanomaterials. As reported by [1], SEM morphology showed that the interfacial compatibility of vacuum ceramic beads modified with an organic-inorganic hybrid agent and a membrane-forming material was improved, the dispersivity was significantly improved and the beads were tightly aligned; the thermal conductivity of the coating reached 0.1587 W/(m-K), which decreased by 50% with the addition of 20% ceramic beads, ANSYS finite element simulation showed that the coating had good thermal insulation properties.

In recent years, advanced imaging techniques such as computed tomography (CT) and scanning electron microscopy (SEM) have been widely used to study the internal and surface structure of materials. CT provides three-dimensional images of the internal structure of materials, enabling the identification of defects, cracks and voids. On the other hand, SEM provides high-resolution images of the surface of materials, allowing observation of surface morphology and identification of surface features.

Although nano-insulators have shown promising results in thermal insulation, their application in building design is still limited due to their high cost and lack of large-scale production processes. Therefore, further research into these materials is needed to optimise their properties and reduce their cost. Furthermore, understanding the internal structure of these materials is crucial to optimise their thermal insulation properties. Advanced imaging techniques such as CT and SEM have been used to investigate the internal and surface structure of these materials, providing valuable insights into their structure and properties.

According to [2], the properties of pure VO2 may not be fully suitable for buildings, and they are working on the use of additives such as anti-reflective layers, nanostructuring and protective top coatings to achieve better performance and durability. Experiments conducted by [3] have shown that a small addition (~1 wt%) of polymer fibres is sufficient to significantly improve the mechanical strength of the composite at ambient temperature, presenting a reproducible flexural strength of ~0.2 MPa. As reported in [4], successful segmentation in combination with neural networks trained on synthetic data will accelerate scientific results using neural networks to automatically segment microstructural tomography data. According to [5], the technical capabilities that currently exist provide opportunities to develop pre-engineered porous graphene architectures and their thermally conductive composites. By performing a morphological analysis [6], it was observed that the functionalisation of cellulose nanotubes shows good dispersion in the polymer matrix without the formation of agglomerates. Research [7] confirms that the use of nano-coatings on glazing can be beneficial in reducing the overall energy consumption of a building by up to 9.5% compared to the original state. As [8] writes, currently the rapid heating and heat dissipation of electronic equipment and associated components are important reasons limiting the miniaturisation, high integration and high power of electronic equipment. This has a serious impact on the performance and lifetime of electronic equipment. Therefore, improving the thermal conductivity of polymer composites (TCPCs) is key to solving this problem. The article [9] discusses nanoceramics synthesis methodologies, fabrication techniques and properties, and applications in batteries, capacitors and solid oxide fuel cells. This review highlights key developments in nanoceramics that have taken place from the beginning of the 21st century until recently in versatile branches of the energy sector, such as energy harvesting, energy conversion and energy storage.

In this study, we want to investigate the thermal insulation properties of innovative ceramic nano-coatings in comparison with traditional insulating materials and air. We will use CT and SEM to analyse the internal and surface structure of the coatings and evaluate their structural and surface properties towards thermal insulation. The results of this study will provide valuable insights into the potential of nano-insulators in thermal insulation applications.

2. Materials and methods

Computed tomography (CT) is a non-destructive testing technique that is becoming increasingly important in civil engineering applications. CT allows engineers to obtain detailed images of the internal structure of materials without damaging them, providing valuable information about their composition, defects and other properties. This includes the detection and mapping of internal defects such as cracks, voids and delamination, which can have a significant impact on the strength and durability of a material. CT can also be used to analyse the distribution of reinforcement, such as steel bars and fibres, in concrete structures. By providing detailed information about the internal structure of concrete, CT can help engineers identify potential problems and make informed decisions about repairs and maintenance, ultimately ensuring the safety and longevity of the structure. Analysis of CT images can identify potential problems with the insulation, such as voids, cracks and compression, which can affect its thermal properties and contribute to energy loss. Using CT can also identify the type and density of insulation material, which can provide important information for building energy modelling and design. To obtain an accurate model of the insulation sample, a Phoenix V Tome xS CT scanner manufactured by Waygate Technologies in Germany was used (Fig. 1). This system includes a 16-bit greyscale detector with a resolution of 1000 x 1000 pixels and a pixel size of 200 μm, a rotary table and a microfocus X-ray tube with a maximum accelerating voltage of 240 kV. The data were analysed and the structure was reconstructed using VGSTUDIO software

MAX 3.5.1 The scanning process parameters are shown in Table 1.

Figure. 1. Phoenix V Tome xS CT scanner

Table 1. scanning specifications.

Sample	Resolution content
Voltage (kV)	60
Current (μA)	60
Voxel size (μm)	6.54
Time (ms)	750
Number of images	1200
Sensitivity	0,500

The test object was a liquid thermal insulation coating, which has very low absorption. This means that its density is very close to that of atmospheric air. Despite this problem, it was able to be isolated. Figure 2, on the other hand, shows the preparatory process of the CT test.

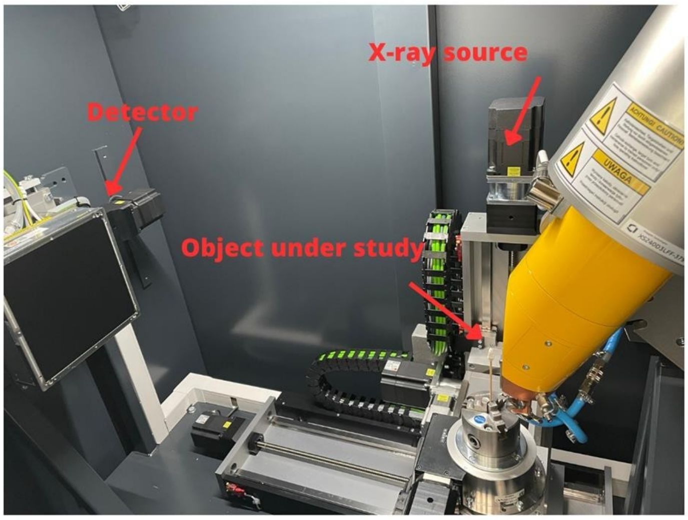

Figure. 2. preparation of the thermopile coating for testing

3. Results

It can be seen from the experiment that the liquid ceramic coating has a density very close to that of air. The internal structure, shown in image 3, is spherical. In addition, individual larger inclusions, characterised by a higher density, are visible. In addition, individual larger inclusions, characterised by a higher density, are visible. Figure 4 shows the upper cut plane, where the maximum particle size was observed. This value is approximately 97 µm.

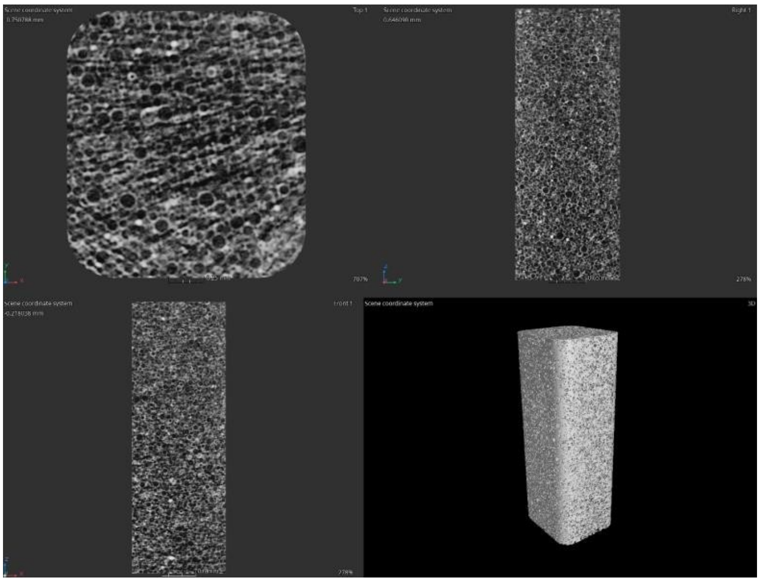

Fig. 3. Distribution of internal structure in the three cutting planes for spherulite

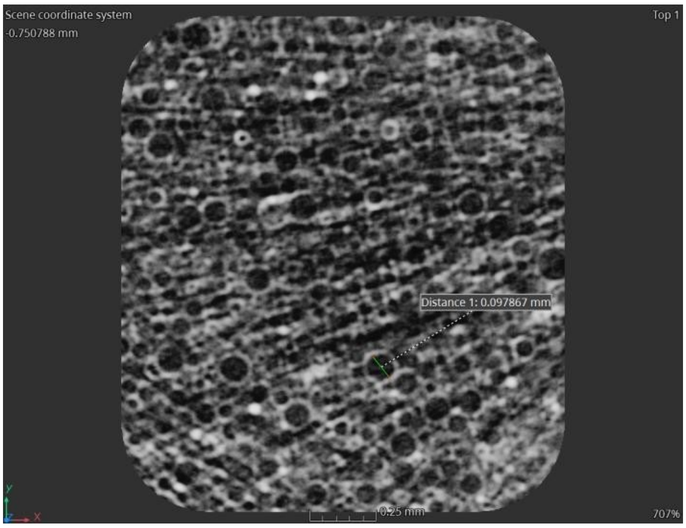

Figure. 4. Internal structure of spherulite in the upper plane with measurement of one pore

The SEM images shown below show the surface morphology of the sheet and coating for the sample shown in Figure 5 (a, b, c, d), and the coating shown in Figure 6 (a, b, c, d) shows an image of the surface topography of a structure between 1.5 and 2 mmm thick. Secondary electron (SE) detection was used to obtain the surface topography images.

The observed external surface of the plate is characterised by the presence of areas of high inhomogeneity, discontinuity and convexity. In all cases, the surface is not perfectly flat or even. It is possible to distinguish areas with a smooth surface, a rough surface and the presence of pores on the surface, most likely dependent on the preparation of the surface layer.

Observations of the coating surface highlight the presence of spherical particles of relatively uniform thickness and continuity. A uniform layer consisting of agglomerates of particles with distinct voids between them was recorded. The shape of the observed particles is spherical and spherical, with local inclusions of irregular disordered particles.

Locally, you may notice the presence of particles that have a damaged structure. This may be due to excessive pressure during their application. Which may adversely affect the thermal insulation properties. This will be investigated further.

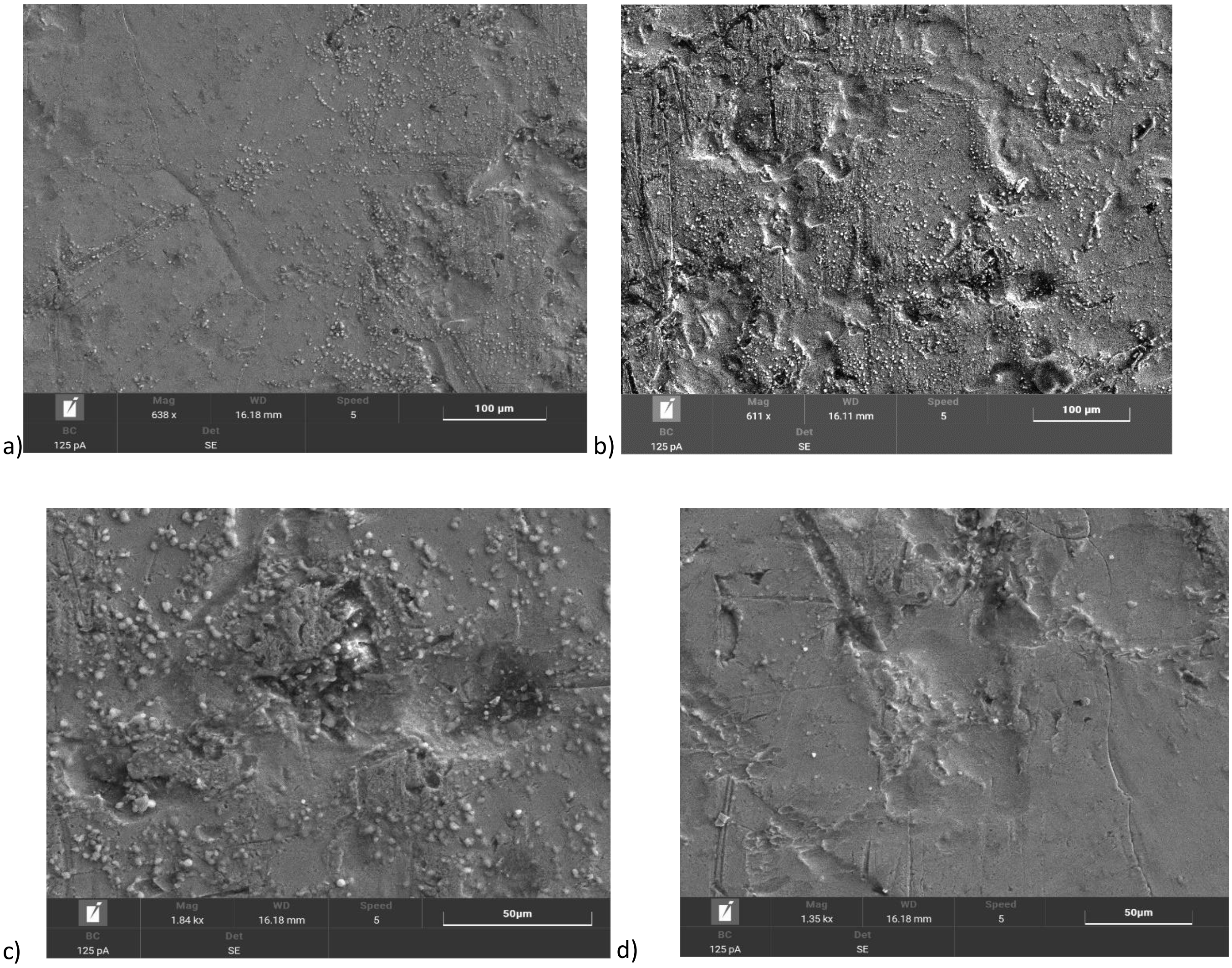

Figure*. 5.* Sheet surface without applied nano-insulation coating.

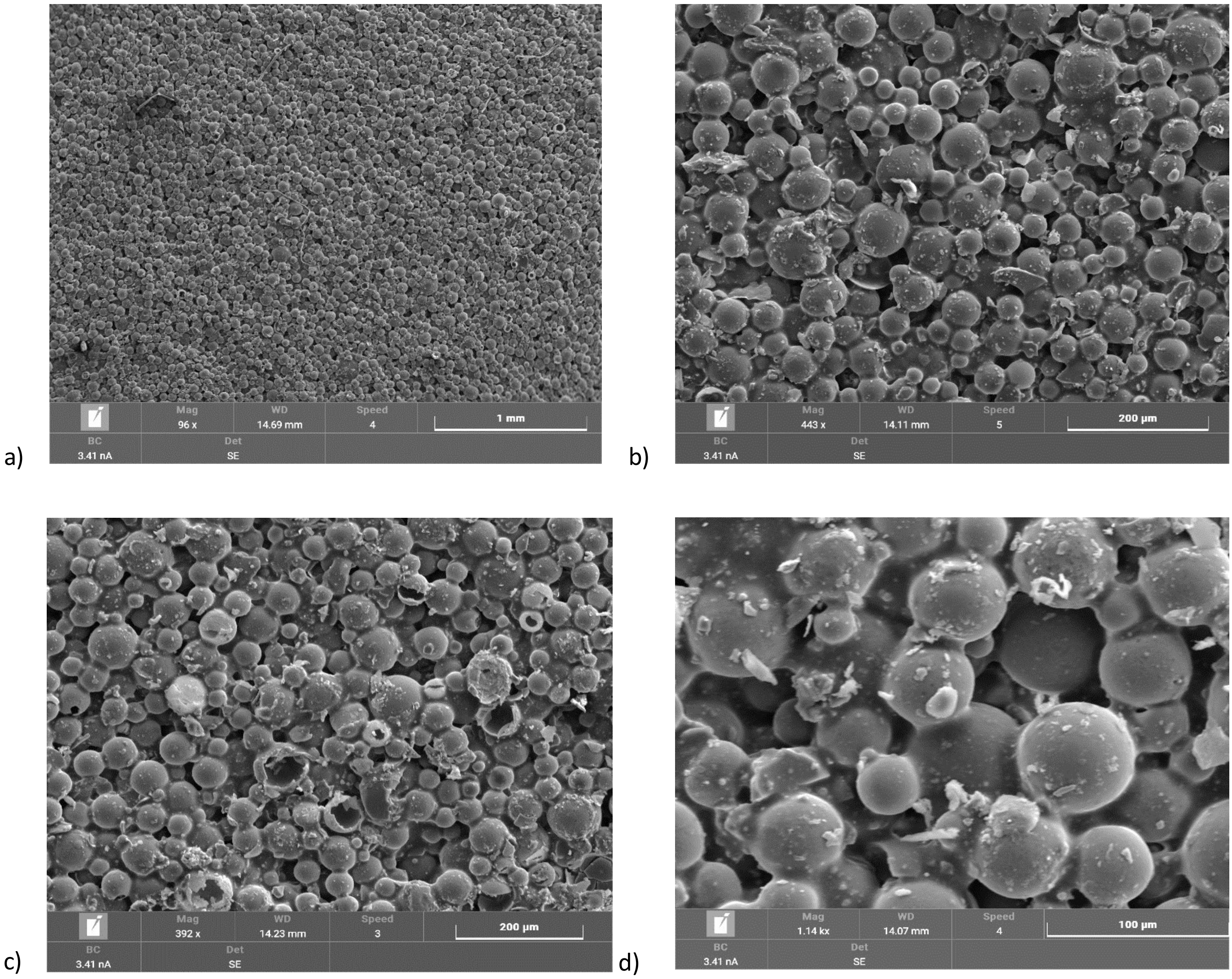

Figure. *6*. Surface of the nano-insulation coating

3. conclusions

Based on the test results, the liquid ceramic coating has a density similar to air and shows a spherical nature in its internal structure with occasional larger inclusions of higher density. The maximum particle size was approximately 97 µm. The surface of the coating is characterised by a relatively uniform thickness and continuity of spherical particles, with voids between particle agglomerates. The shape of the particles is spherical and spherical, with a few irregular particles with disturbed structure. The presence of locally disturbed particles may be due to excessive pressure during application, which may negatively affect the thermal insulation properties. Further research is needed to investigate the effect of excessive pressure on the thermal insulation properties of the coating. Overall, the results obtained provide insights into the properties and structure of the liquid ceramic coating and the sheet surface, which may be useful in optimising their applications in various fields.

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