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Towards Multi-Angle Multispectral Optical 3D Porometry and Lens-Less Porometry of Civil Engineering Composites and Geocomposites Including Biodegradable Ones

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Abstract. In this work we demonstrate the images of multi-angle porometry of civil engineering composites with the static pores. We also demonstrate an example of the application of multi-angle scanning methods where each pore visualization angle corresponds to the certain time moment. The light source can be either incoherent or coherent, which determines the data interpretation principles and data processing algorithms. The light detector can be either optical microscopic (with lenses) or lens-less, that is, either a microscope with an objective or a lens-less one, especially a holographic lens-less microscope. The latter is by definition compatible with multi-angle microporometry. The data on reconstruction of the surface texture of a complex pore using an incoherent light source and the Sobel-Feldman operator (Stanford Artificial Intelligence Laboratory (SAIL)) is presented.

Keywords. LDPE, porometry, holographic microscopy, lens-less microscopy

1. Introduction

Porometry / porosimetry of engineering composites and building materials is the basis of their quality assessment, which characterizes mechanical properties of their constituents [1,2], resistance to the chemically and physically unstable environment [3-11]. Pore measurements can be used not only for solidified construction composites, but also for their precursors (such as mineral aggregates and nodules - from clays and lime to sand) [12,13]. For polymer composite materials in real construction building environmental conditions (such as soil, atmospheric and hydrospheric media for geopolymers [14] and geotextiles [15-18]), porosimetry or porometry is a very important element of the protocols of their physical characterization for hygroscopicity and percolation testing. It is possible to consider two concurrent trends in application of fiber geocomposites and geotextiles for the above mentioned purposes. The first one is geocomposite engineering using rigid mineral fibers, and the second one is application

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of geocomposites with elastic and plastic polymeric (soft matter) fibers. However, for all of them pore size measurements are applicable and informative [19,20].

As an example of polymer construction materials it is possible to consider the most simple and frequently used (in construction industry and building) polymer - LDPE (Low-Density Polyethylene), which can be also used in composites with biogenic raw materials and wastes [21-23] (including biodegradable ones). Some building \ engineering examples of LDPE applications include building blocks, bricks and panels [24-30]; asphalt [31-47] and other road surfaces [48-52], etc. It is well known that permeability \ percolation of roads and watertight geomembranes (for arid regions), as well as the air permeability is achieved due to porosity. Hence, LDPE can be used for such purposes [53-56], and it is possible to use LDPE-filled geomembrane / geocomposite porometry for *in situ* investigation of dynamic pore size variations (from their formation to collapse). The most interesting is the analysis of biodegradable LDPE-containing composites in real soils and aquatic environments (due to the fact that biodegradable composites for ecological building are very popular nowadays [57-62]). Another investigation area of such environment-friendly composites is the stability measurements during melting under environmental heating [63-70], including visualization of filler particle flows (in PIV or other similar modes) in melting filled composites in climatrons / weatherometers under the modeled global heating conditions [71-73].

One of the most progressive approaches in geopolymer pore measurements is complex electron microscopic morphometric analysis, including electron tomography techniques. It can be used also for biodegradable composites and polymer-containing systems [74,75] (including LDPE-based) and LDPE-asphalt systems [76], including such systems in model climatic vapor-phase conditions in ESEM/ASEM [77], as well as glaciological / geocryological freezing testing of porous LDPE [78]. Also in some interesting modifications, such as CLEM (correlating light and electron microscopy), it is possible to compare results of optical and electron microscopy of filled LDPE-based structures, including multiangle visualization or holographic / tomographic registration [79-83], including spectrozonal and multispectral lens-less one.

The most progressive complementary method for the above mentioned purposes is correlation-spectral (spectral-correlation) analysis based on FFTW library, which can be used for Fourier descriptor extraction from the raw imaging data, including IFC (integral frequency characteristics) and ISC (integral spatial characteristics) [84-87].

However, SEM techniques are inapplicable for most building developers and construction engineering labs in field conditions.

Thus, only optical instruments can be used for the analysis of the pore size of building polymeric materials and composites in field conditions. In most compact or mobile cases (for the pocket-size instrumentation class) it is optimal to implement the lens-less technique with LEDs or diode lasers (including DPSSLs), but for most mobile laboratories in wagons / automobile laboratories it is possible to use calibrated motorized optical microscopic setups with illumination modules which can be positioned at different angles using stepping motors.

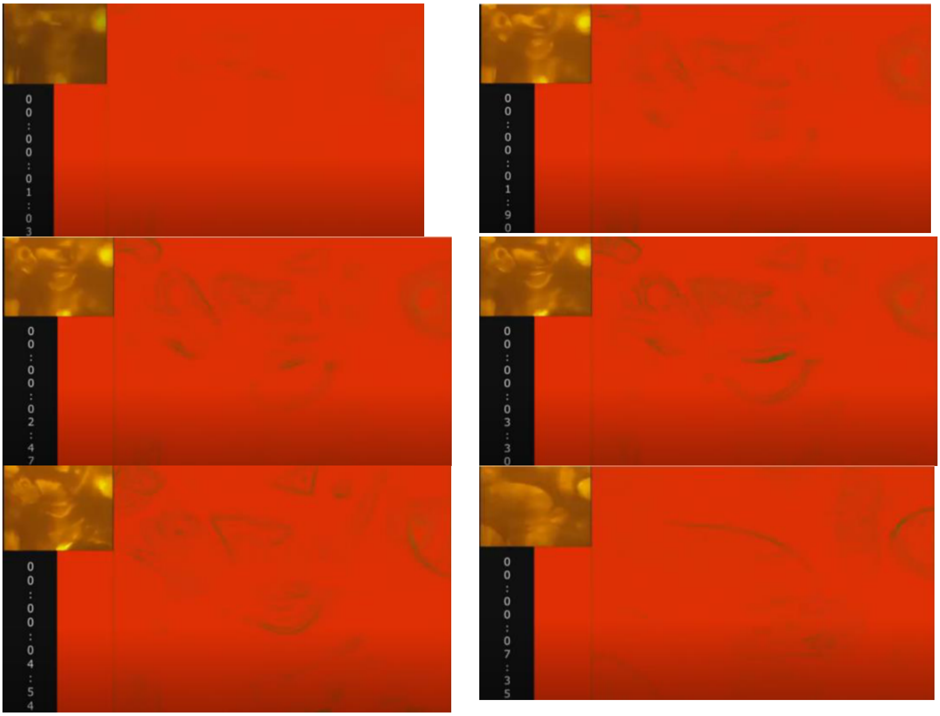


Figure 1. 3D reconstruction of the deep complex pore geometry using an incoherent Vis radiation source and the Sobel-Feldman operator. In the upper corner the original images (screenshots) are given with the time code (hh; min; sec; msec) in the bottom (visualization regime B).

2. Materials and Methods

2.1. Materials and Sample Preparation

Composite materials under investigation were based on the LDPE and wood floor or corn starch fillers. We also used porous LDPE with the pores generated by endothermic foaming agent Hydrocerol BIF, which decomposed into CO_2 and H_2O during the pore formation.

2.2. Dynamical Multi-Channel Multi-angle Optical Porometry

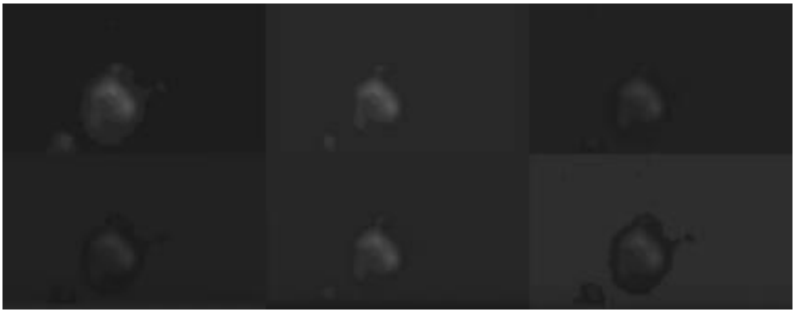
The pore structure was studied using a setup including an inverted trinocular optical microscope BIOSTAR. Registration was performed with an angular resolution (under the sample illumination at different angles) by scanning the sample in depth (when moving the focus due to the vertical movement of the lens). The final images or frames of the video stream were subjected to the gradient image processing similar to binarization, but for different spectrozonal channels. We have also implemented a novel approach towards the analysis of porometric video stream using gradient Sobel-Feldman operator. In this case, timecode or scanning angle parameters (when using an encoder) can be either displayed on the screen or inscribed into the video stream metadata.

Figure 2. 3D reconstruction of the deep complex pore geometry using an incoherent Vis radiation source and the Sobel-Feldman operator. In the upper corner the original images (screenshots) are given with the time code (hh; min; sec; msec) in the bottom (visualization regime B).

3. Results

3.1. Dynamic Multi-Channel Multi-angle Optical Porometry

Examples of reconstruction and visualization of the LDPE pore shape at different angles and focusing levels are shown in figures 1-2. Spectrozonal or multispectral (color-multiplexed) images of a simpler pore in different modes, illustrating the principles of scanning multi-angle porometry, are shown in figures 3-4.



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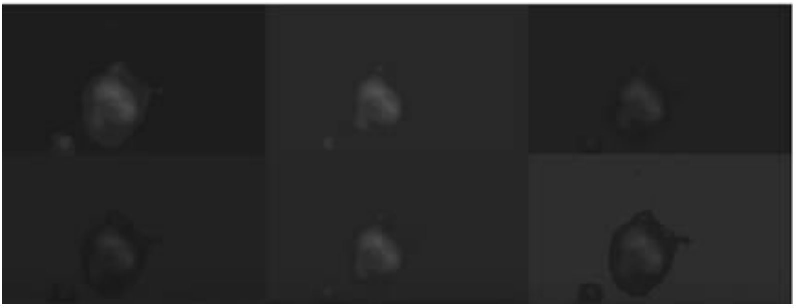

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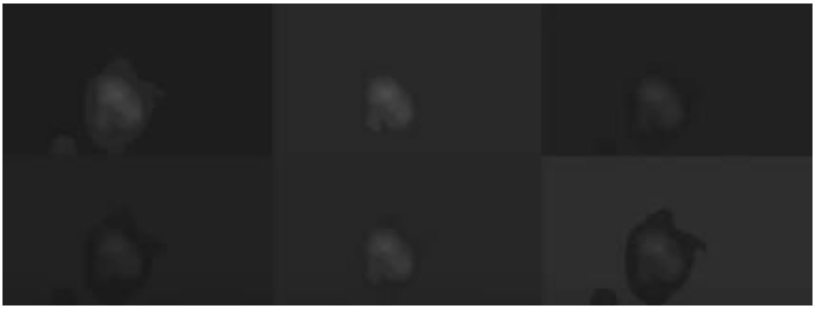

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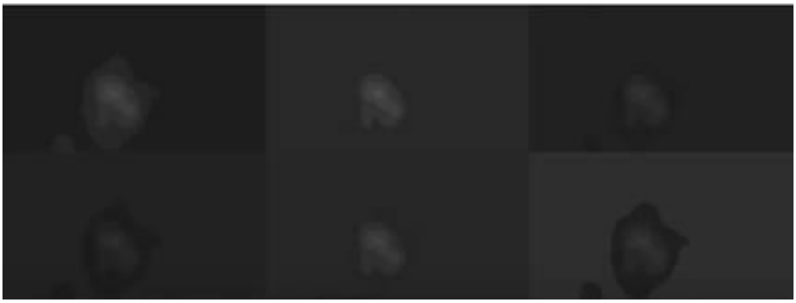

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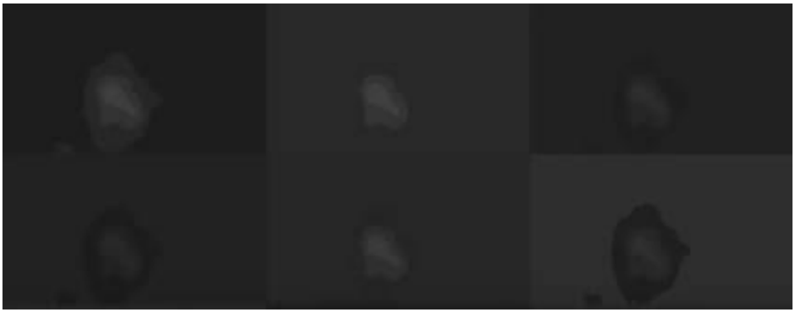

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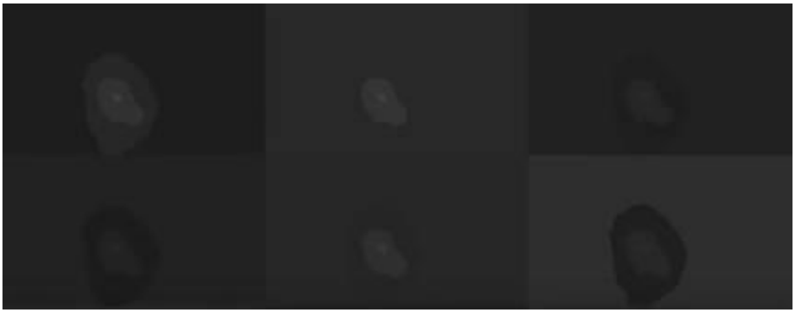

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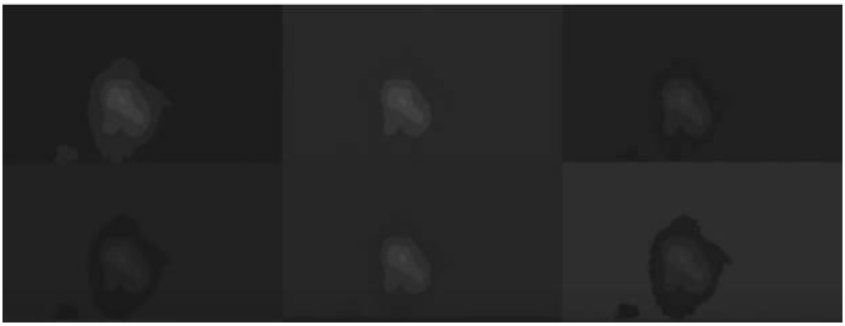
Figure 3. Example of iterative multilevel and multi-channel (spectrozonal / multispectral) patterns of a single pore with multicolor multiplexing.



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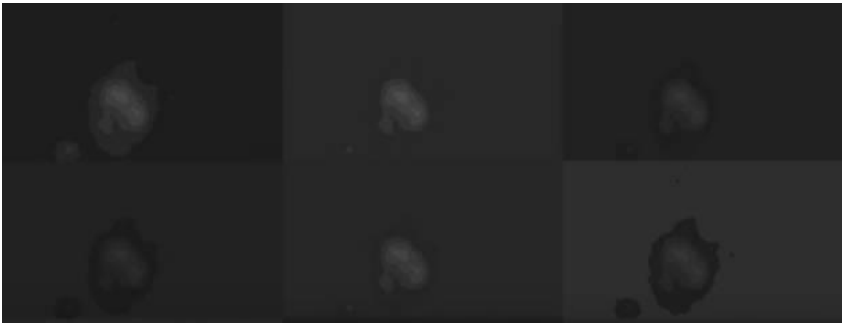

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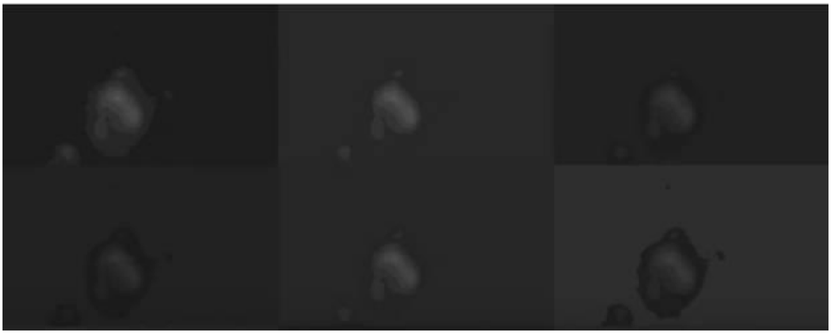

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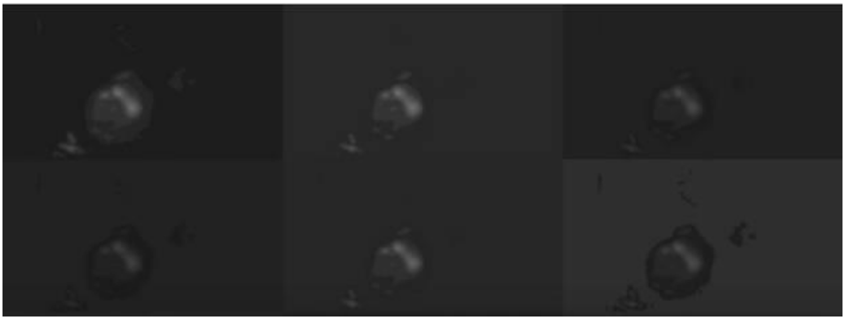

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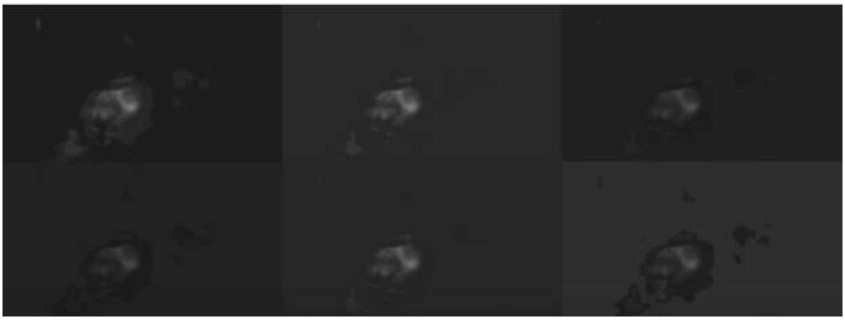

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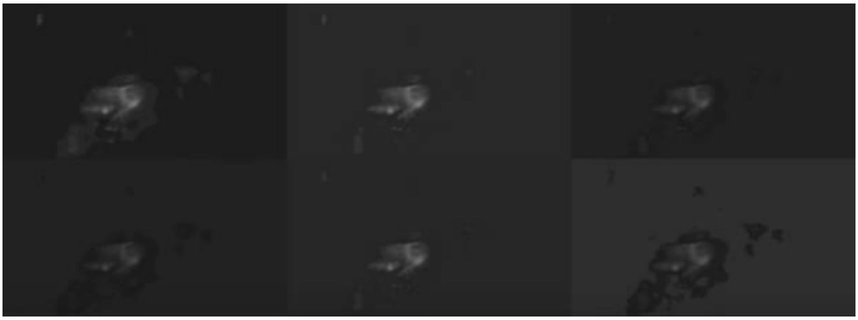

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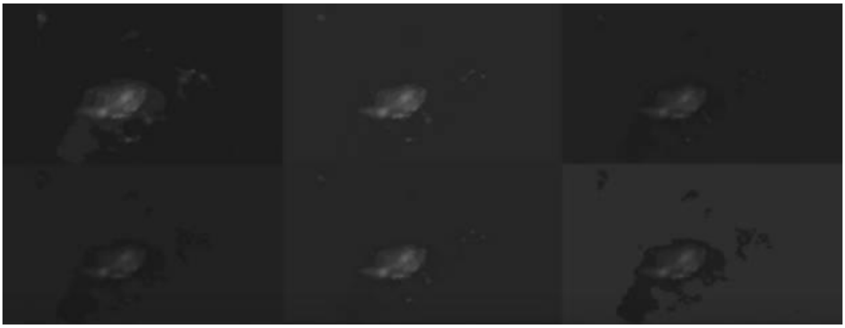

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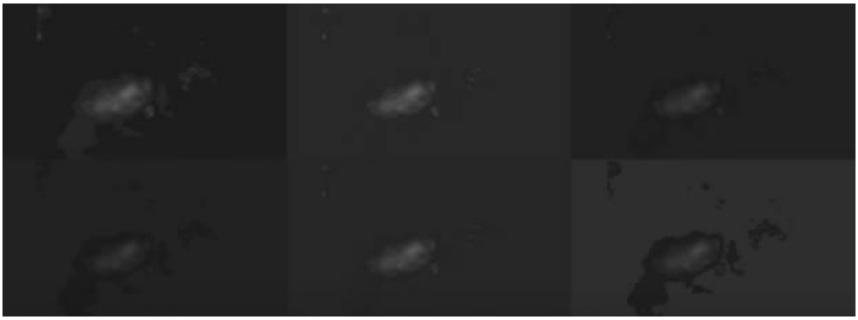

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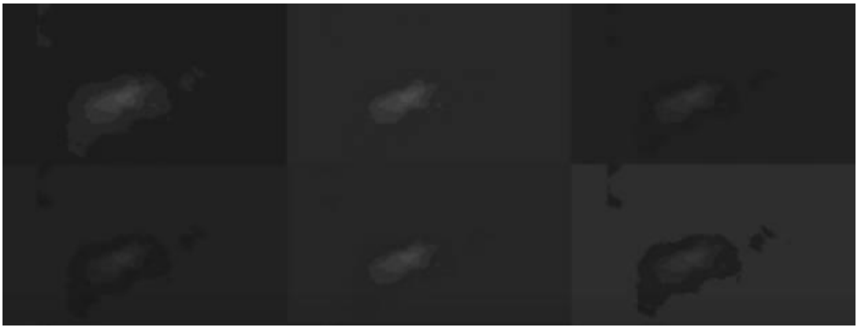

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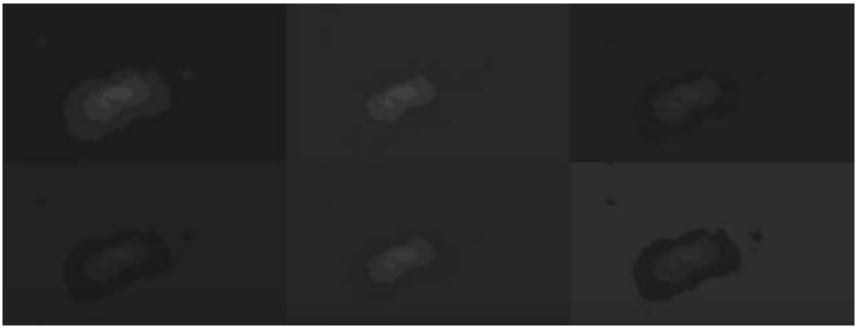

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Figure 4. Another example of iterative multilevel and multi-channel (spectrozonal / multispectral) patterns of a single pore with multicolor multiplexing.

It can be seen that for initially not spectrozonally separated white light the patterns of pore isophotes in different color channels do not differ significantly, which makes it possible to reconstruct the pore morphology using any color / spectrozonal channel. At the same time, it can be seen that 3D structure of the pore, which is especially good visualized in gigured 4 (e-h), successfully reconstructs the pore volume and heterogeneity of its surface, which indicates the possibility of using the above described method as a complementary analytical tool for volumetric porosimetry.

4. Conclusions

The variety of morphology and anisotropy of the pores in polymer composites makes the application of a multi-angle three-dimensional visualization approach necessary anduseful. However, the existing methods of electron microscopy, except from the electron tomography, fail to provide such visualization opportunities and also are very sophisticated and inapplicable in the field conditions. Therefore it is strongly recommended to use multi-angle multispectral optical porometry techniques, including lens-less ones, for the pore characterization in the polymer composites.

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