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ON THE ROLE OF IMAGE PROCESSING TECHNIQUES IN THE QUANTITATIVE IMAGE ANALYSIS

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Abstract: The article explores how qualitative image analysis impacts the process of image interpretation, particularly in composite microstructure analysis. It highlights the importance of high-quality images for accurate computer-based object detection, emphasizing the limitations of rigid pixel-based rules compared to human visual perception. The study underscores the need for optimal imaging conditions to avoid image defects that hinder precise computational analyses in scientific and industrial applications.
Keywords: image processing, digital measurements, stereology

1. INTRODUCTION

Quantitative object analysis of digital images is a routine in many fields of science and technology. It is applied to quality control systems in the production lines, in material science laboratories, and as an element of computer vision systems (Gadek et al., 2006; Russ and DeHoff, 2000; Szeliski, 2022). The research's goal was to study how the method of observation and process of image processing can influence the image analysis process in the example of composite microstructure analysis.

Using sophisticated techniques for imaging the material structure does not guarantee correct interpretation. This requires appropriate knowledge of the material and the technological processes to which it has been subjected, as well as knowledge of the physical phenomena occurring on the surface or in the volume of the sample that enables its image to be created.

Once we have digital images of the materials' microstructure, we can subject them to computer analysis to make measurements and determine the values of stereological parameters.

Analyzing good or excellent-quality images is usually easy and can be performed using automatic procedures provided by imaging equipment manufacturers. Images subjected to computer analysis must be of higher quality than in the case of manual measurements. This is because, for the human sense of sight, such defects in the image as scratches, noise, or a slight lack of sharpness do not constitute an obstacle to recognizing the correct objects. Thanks to complex processes in our brain, analyzing the images we perceive is multi-track and contextual. The image is analyzed as a whole, but its interpretation is aided by the ability to analyze each object individually, which translates into higher efficiency in recognizing them despite any interference.

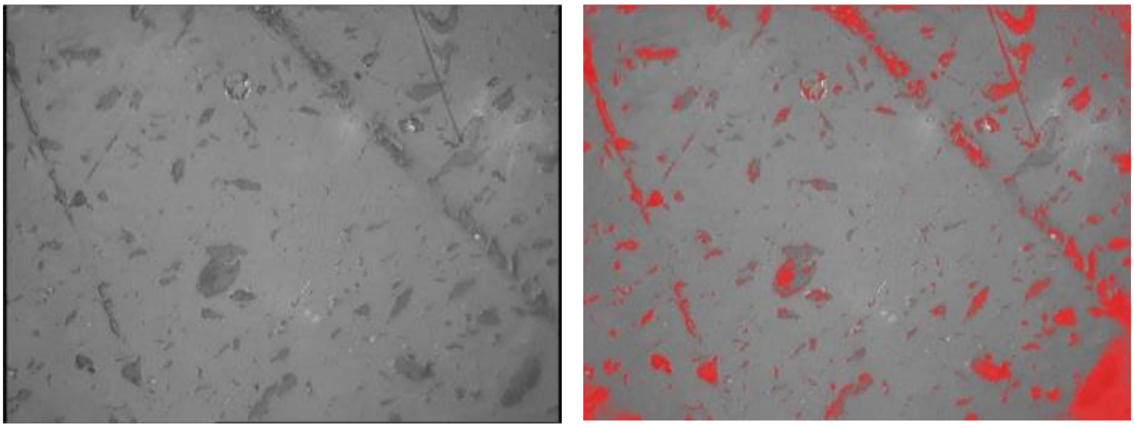
Image analysis techniques are commonly used in materials engineering (Opydo et al., 2019; Szczotok, 2023), sintered powder alloys (Szewczyk-Nykiel, 2023), plastic composites (Franta and Zając, 2022), specialized coating technologies (Radek, 2009), including laser-modified ones (Radek et al., 2008; Radek and Antoszewski, 2009). These applications have a significant impact on the quality of industrial processes and products (Ulewicz, 2018; Ulewicz et al., 2020), and practical industrial tests (Siwiec et al., 2020; Radek et al., 2020). This influence can be detected and modeled using Design of Experiments (DOE) methodologies (Pietraszek et al., 2020), and the obtained information can be conveyed in relevant training sessions (Radek et al., 2023).

2. METHODOLOGY OF RESEARCH

In the case of image analysis systems, object detection is based on rules using pixel values that represent them and is much less flexible than the human sense of sight. Scratches on the sample surface and cutting through the cross-section of objects, high noise levels, or lack of full image sharpness may be a source of artifacts and even effectively prevent proper detection. One of the essential principles of computer image analysis is to ensure the best possible conditions during image acquisition to avoid its defects, which is a more practical solution than later constructing complex algorithms for their correction.

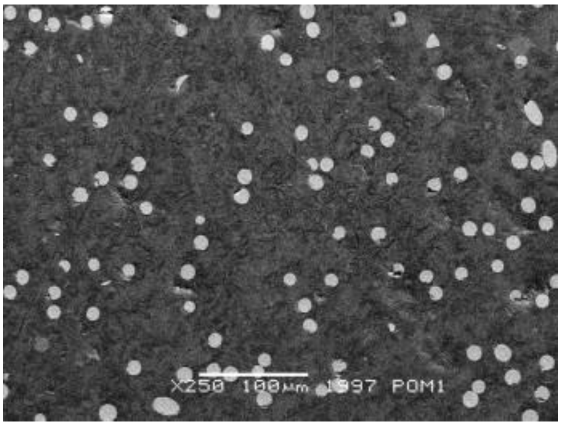
Suppose we have microstructure images for quantitative analysis that are of poor quality, and their defects prevent correct detection. In that case, it is necessary to repeat their acquisition so that the image defects do not recur. It may also turn out that the selection of the original imaging technique needed to be corrected and changed. An example illustrating such a situation is research carried out as part of the project PB-850/T08/2002/22, financed by the Committee for Scientific Research (Gadek et al. 2006). One of the research goals was to assess the degree of degradation of glass fibers in Polyoxymethylene (POM) matrix composites, which was caused by fatigue tests simulating operational loads. The quantitative analysis of the cross-section of the POM matrix samples delivered information describing glass fibers: the volume fraction of V_V glass fiber cross-sections, their average surface area, the number of cross-sections per unit of the examined area N_A, Feret diameters d, the mean free path λ and the average surface area of the influence zone. Initial microstructure observation was performed under a light microscope (Fig. 1). The obtained images did not allow for effective detection of objects, i.e., cross-sections of glass fibers. The polymer matrix and the fibers reflect the light beam similarly, which is visible in the image as areas with similar gray levels. Additionally, due to the significant difference in hardness between the matrix and the reinforcement, deep cracks were created during the microsection preparation, running across the entire observed surface.

Changes in observation parameters, such as light beam intensity and observation in a dark field of view, did not obtain a better image that would meet the requirements for images intended for quantitative analysis. Therefore, changing the method of observing the structure to scanning electron microscopy was necessary. Because the material and the matrix are made of elements that differ significantly in atomic number, the microstructure image obtained from the BSE detector (Fig. 2) is characterized by a high contrast between the matrix and the glass fibers.

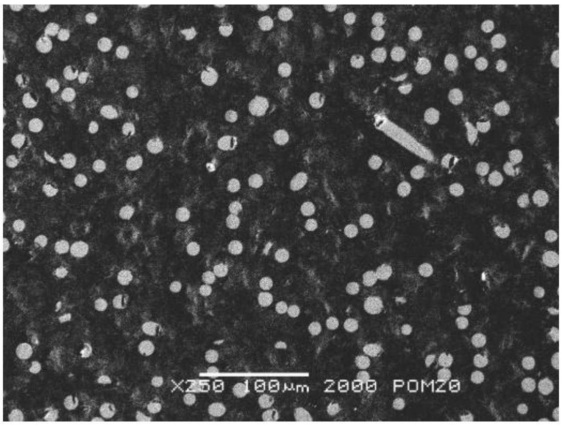


(a) (b)

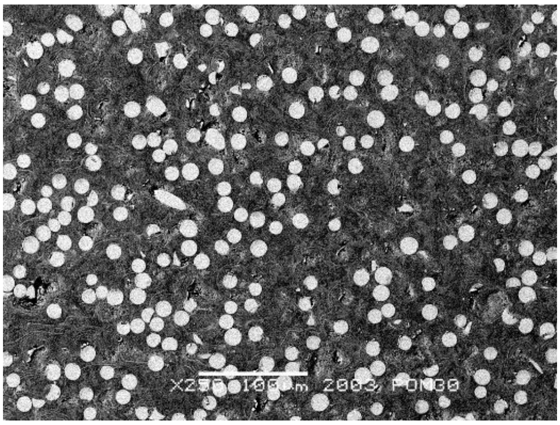
Fig. 1. a) Example image of POM 10% with glass fiber, area 200x; b) an attempt to binarize glass fiber cross-sections



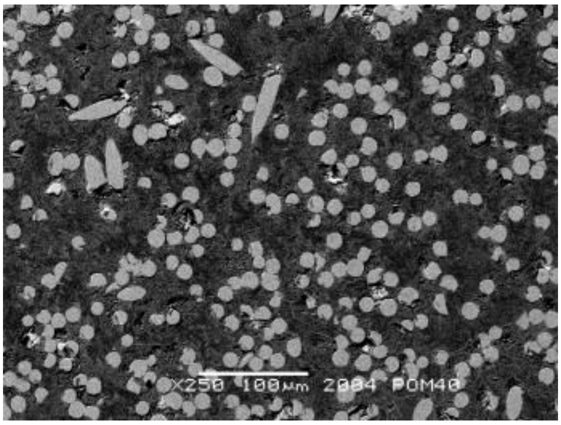
POM 10% glass fiber



POM 20% glass fiber



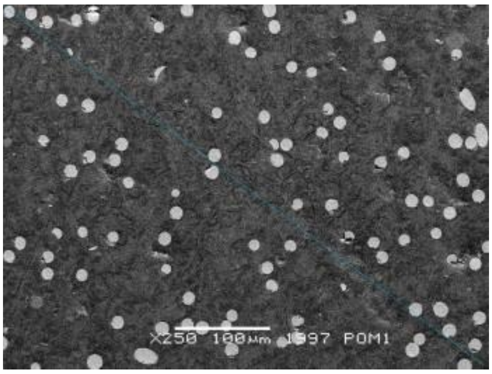
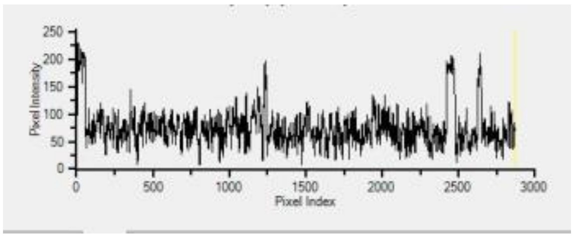
POM 30% glass fiber



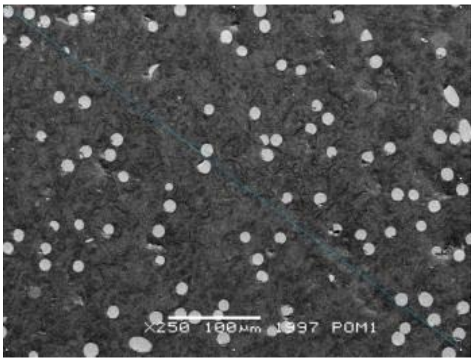
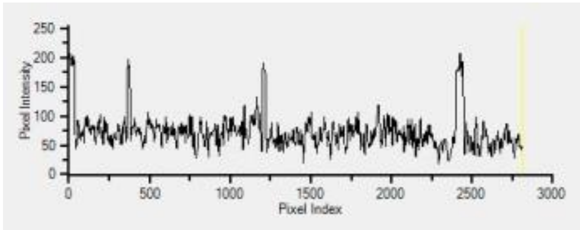
POM 40% glass fiber

Fig. 2. Images of the tested composites obtained using SEM x250

When designing an algorithm for automatic image processing and analysis, the necessary transformations to improve image quality should be considered. The quality of the images, in terms of the presence of possible noise or shadow effect, was assessed using a profile that presents changes in the degrees of gray in the image along the test line in the form of a graph (Fig. 3). Noise effect is visible on the profile. The profile curve corresponding to the warp areas is on one level and does not curve, which means the background is even, and the image does not require shadow correction. The designed automatic analysis algorithm must introduce preliminary smoothing filtering, reducing random fluctuations in pixel values and simplifying the automatic detection procedure. Binarization using the Otsu method (Otsu, 1979) automatically determines the cut-off threshold values based on the analysis of the image histogram.

a) image before profile noise correction profile

b) noise-corrected profile b) noise-corrected profile

Fig. 3. Pre-correction of the image to reduce noise

Binary image processing using morphological transformations helps to remove possible artifacts that could affect the result of the stereological analysis of the structure. The entire process of analyzing the image of the microstructure of the tested composite can be presented in the form of a simple diagram (Fig. 4). The proposed scheme of the microstructure image analysis algorithm is not a universal solution. However, it indicates subsequent, essential stages of the process that ultimately lead to obtaining results in the form of numbers. Quantitative analysis results in values describing the measured object's parameters. The interpretation of which researchers deal with and connect with the material's properties.

The comparison of the results of stereological measurements for samples before and after fatigue tests allows for the analysis of the degree of degradation of fibers resulting from fatigue tests. For example, the analysis of the NA parameter allows for the assessment of the impact of fatigue tests and the volume fraction of fibers in the composite on the cracking and fragmentation of glass fibers (Fig. 5). The increase in the number of fibers per unit area for POM 30 and POM 40 samples means that as a result of fatigue tests, the fibers cracked and fragmented, which resulted in an increase in the number of detected particles by almost 30%.

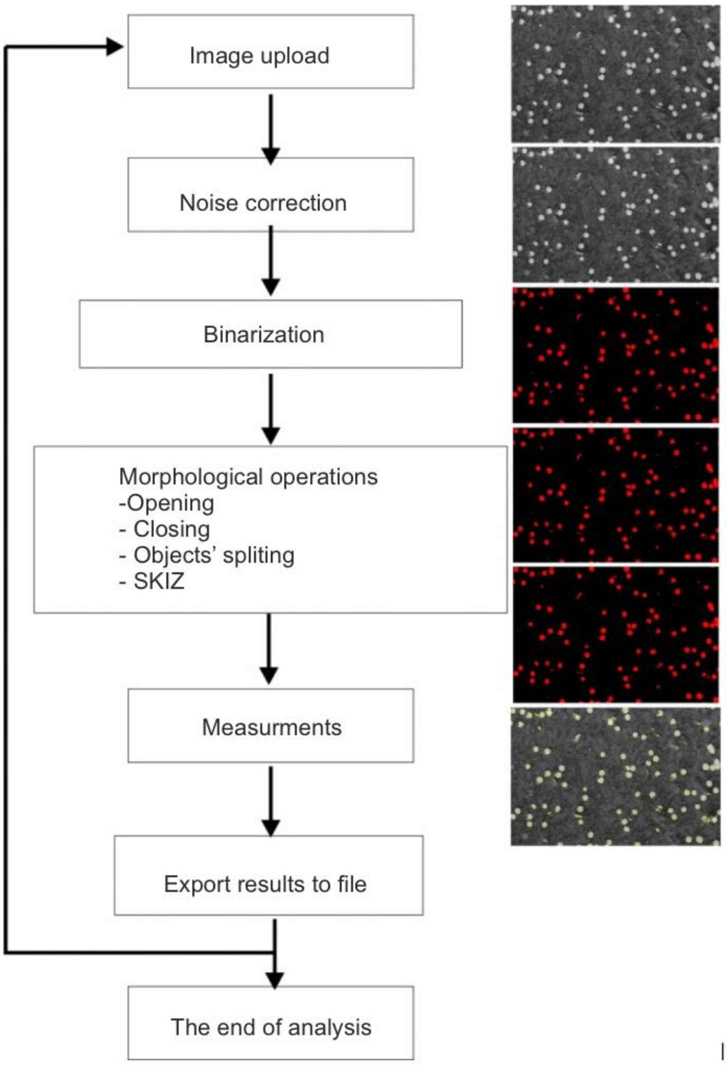


Fig. 4. Detection of glass fibers using an automatic image analysis algorithm

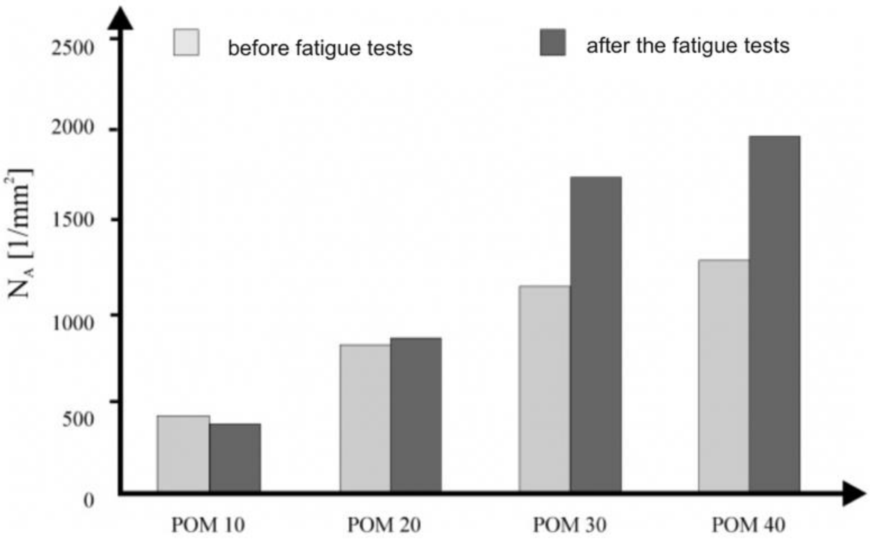


Fig. 5. Change in the number of objects per unit area as a result of fatigue tests

The results of stereological analyses provide information about fiber degradation. Combining them with the test results of other material properties (physical, mechanical, and chemical) allows the selection of a composite with the optimal content of glass fibers, ensuring minimum operational requirements of the material.

3. DISCUSSION

Analyzing images of excellent quality is the best solution, but in practice, it happens rarely. The reason may be economic reasons that do not allow more advanced microstructure observation techniques. It may also be caused by the specific properties of the tested material, which do not allow for obtaining a good image from the point of view of analysis using computer methods. Reliable and precise results of quantitative image analysis depend on numerous factors. Presented examples of different observation methods of the structures show that a proper image acquisition technique allows one to register objects that stand out significantly from the background, facilitating their correct detection. Applied algorithm of the image analysis which efficiently reduced noise and artifacts on the images after binarization on the image and at the same time did not interfere with the image of the object, showing that even if the images are not very good quality, its quantitative analysis is possible, due to algorithm designed to solve this problem.

4. CONCLUSION

Automatic algorithms delivered with the equipment software are helpful for the simple analysis of good-quality images. More sophisticated analysis, like, for example, analysis of composite structure, demands dedicated algorithms that will help solve unusual problems with image quality or object detection, which was discussed in the example of the POM composite with glass fibers. Each analysis stage is essential, beginning with the image acquisition, further preprocessing stage, and detection supported by morphological operation, and ending with the measurements.

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