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INVESTIGATING THE MICROSTRUCTURE OF SILICONE RUBBER RECOVERED FROM COMPOSITE ELECTRICAL INSULATORS

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Abstract: The paper presents the results obtained using a modern method for investigating the microstructure of silicone rubber recovered from used composite electrical insulators. The method is based on scanning probe microscopy (SPM), an advanced technique in atomic scale spectroscopy and imagery. Using AFM in designated interest areas there were obtained microphotographs with surface resolutions of 25, 50 and 100 µm.

1. INTRODUCTION

It is known the fact that micro-manufacturing techniques are adapted for dimensions in the 1mm - 1µm range. Lately there was an increased interest in submicro (1µm – 100nm) and nanostructures (100-1nm), resulting in specific investigation methods. The most widely used investigation techniques offering very good surface resolution are SEM (Scanning Electron Microscopy), and AFM (Atomic Force Microscopy).

Comparing the two methods, the difference lays in the method of measuring the vertical modifications in the probe topography. For instance, AFM can measure in 3D (x, y, z) in a single scan, whereas SEM cannot. In case of rough probes, SEM provides a key advantage due to the relatively large field depth (≥ 6 µm).

Given the surface characteristics of the recovered silicone rubber, the technique used was AFM.

2. TECHNOLOGICAL MODEL FOR SILICONE RUBBER RECOVERY

Silicone coated composite insulators (fig.1) are designed for mounting in 20kV aerial power lines. Among the advantages offered by these are:

- longer life span
- robustness and reduced specific weight
- low maintenance cost
- hydrophobic
- resistance to chemical and atmospheric wear

It is necessary to recover the rubber silicone coating after a certain number of functioning hours, in order to reuse it in various technological applications.

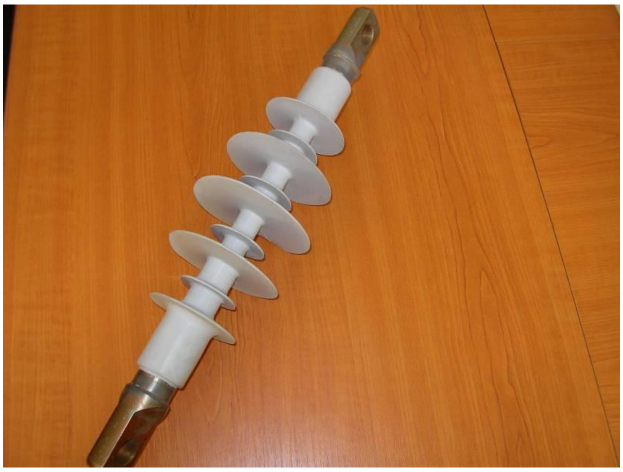

Fig.1 – Rubber silicone coated electrical insulator

Rubber silicone is a composite material with physical and chemical characteristics that allows only mechanical recovery operations, in order to maintain the initial properties. As result of mechanical, physical and chemical operations, the following technological product was obtained (fig.2):

Fig.2 – Technological product obtained from silicone rubber recovery

For obtaining the recovered silicone rubber, the solid component of the used insulator coating (40%) was combined with a liquid additive (60%).

3. TECHNIQUES FOR INVESTIGATING THE SURFACE MICROSTRUCTURE OF RECOVERED SILICONE RUBBER

In AFM (fig.3) the sample surface is scanned by the tip mounted on the cantilever. The system can detect and measure forces as low as nN using optically-assisted detection.

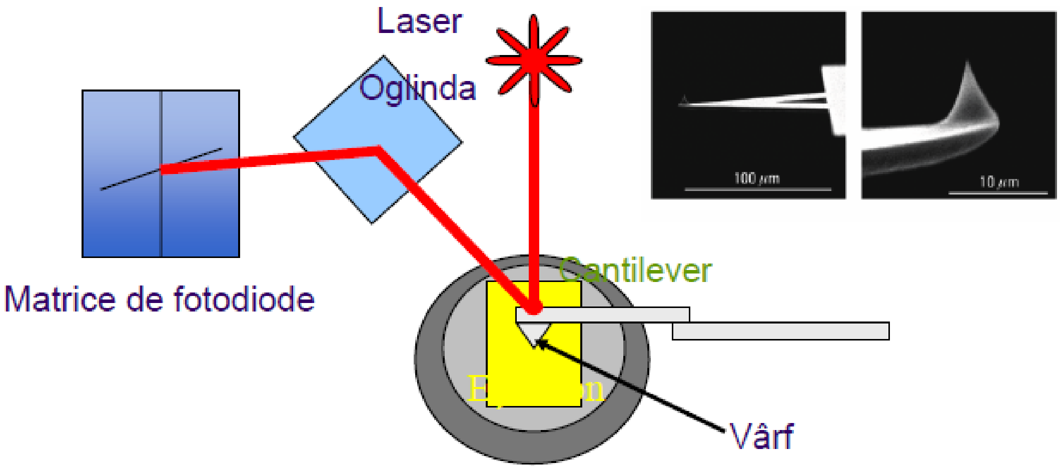

Fig.3 – Atomic Force Microscopy (AFM) principle schematic

In this particular case, a contact mode AFM (which is based on the interaction between individual atoms of the tip and the sample surface) was used for investigation. Based on this the morphological description of the sample surface is obtained.

AFM presents a series of characteristics that allow atomic scale resolution, among which:

a. phase sensitive lock-in
b. sensitive cantilevers with low elastic constant
c. highly accurate tip placement
d. negative force feedback control

In this particular case, the average surface roughness is computed with:

$$R = \frac{1}{D}\int_0^D \left| z_0 - z(x) \right| dx \tag{1}$$

Where:
$$z_0 = \frac{1}{D}\int_0^D z(x)dx$$

Figures 4a,b and 5a,b present sample electronic microphotographs of silicone rubber surface micro-structure obtained in constant force mode for two types of analysis: lines filling and height sense.

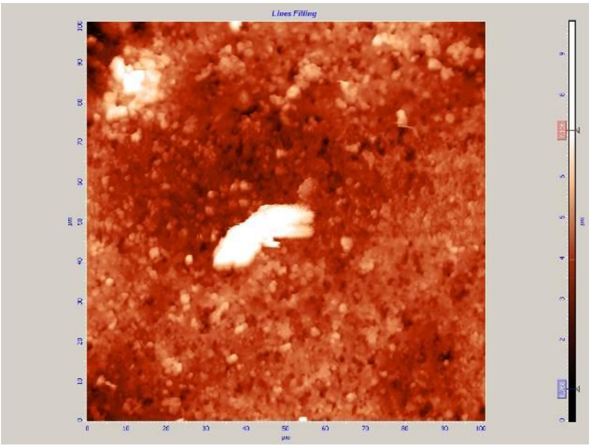

Fig.4a – 2D electronic microphotograph, depth 0.768 – 7.116 µm, reference lines

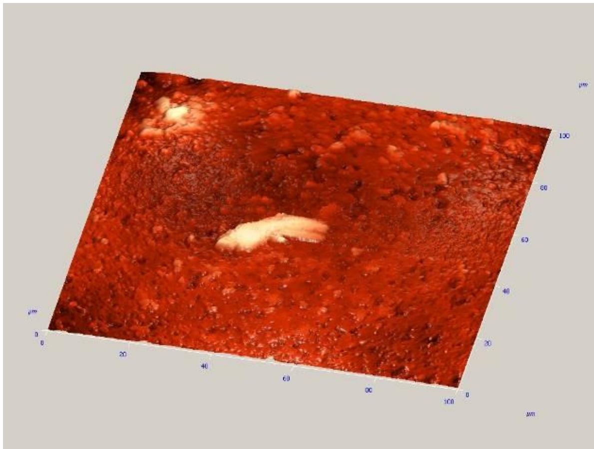

Fig.4b – 3D electronic microphotograph, lines filling

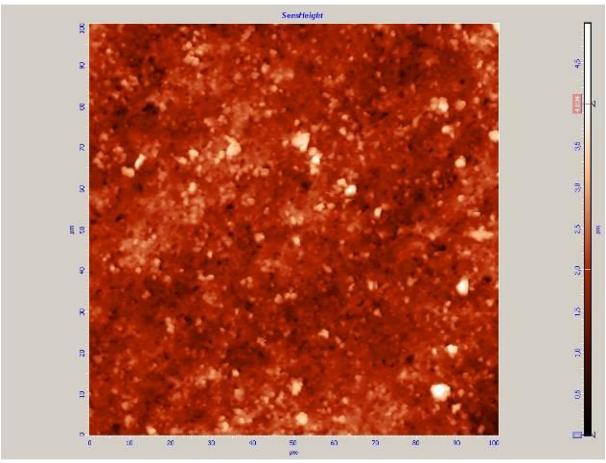

Fig.5a – 2D electronic microphotograph, transversal section, grain height 4.004 µm

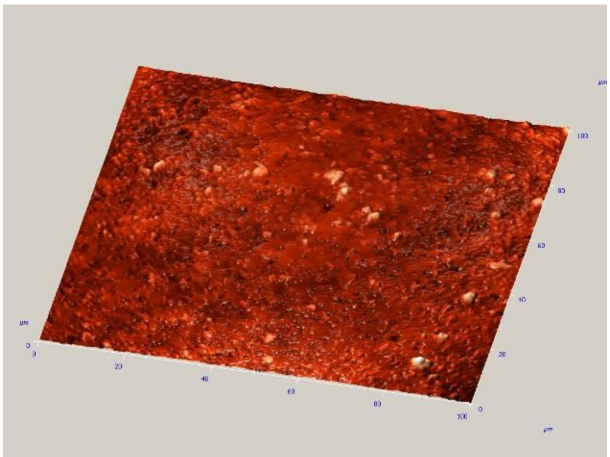

Fig.5b – 3D electronic microphotograph, height sense

Using contact mode AFM imaging provides information regarding the position and size of some anomalies or defects in the analyzed surface.

Some examples are presented in the 2D and 3D microphotographs from fig. 6a, 6b şi 7a and 7b:

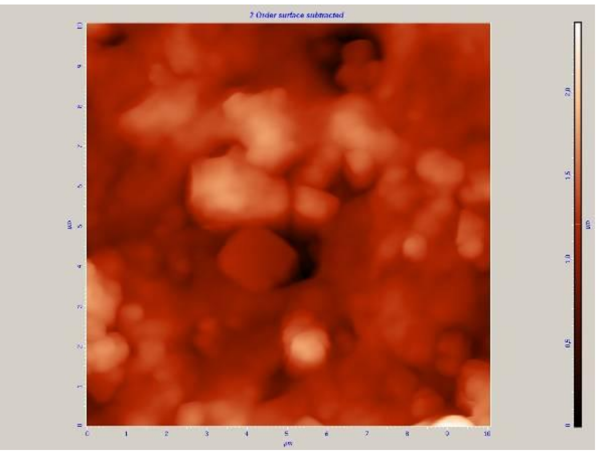

Fig.6a – 2D electronic microphotograph for determining a structural defect area

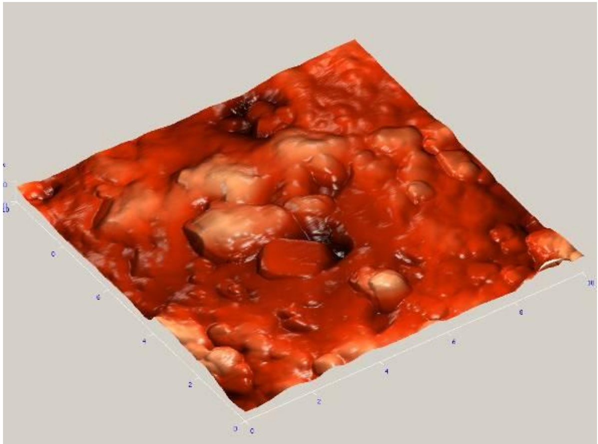

Fig.6b – 3D electronic microphotograph, order surface subtracted variant

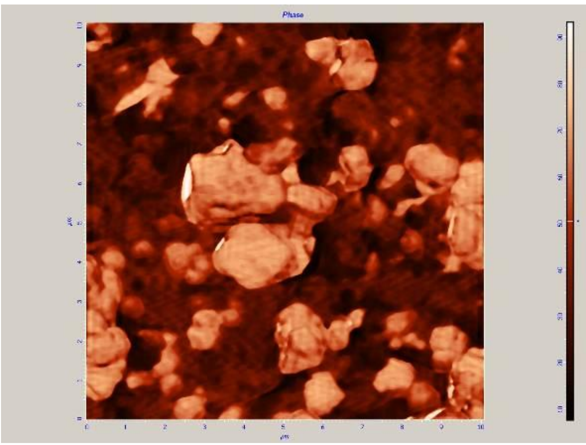

Fig.7a –2D electronic microphotograph, phase variant structure

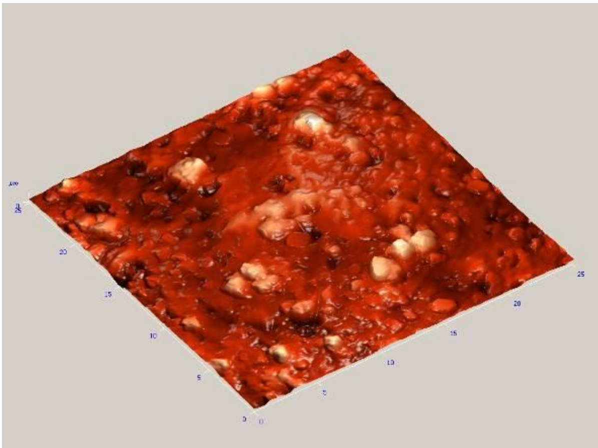

Fig.7b –3D electronic microphotograph

The average roughness profile of the analyzed surface is presented in fig.8.

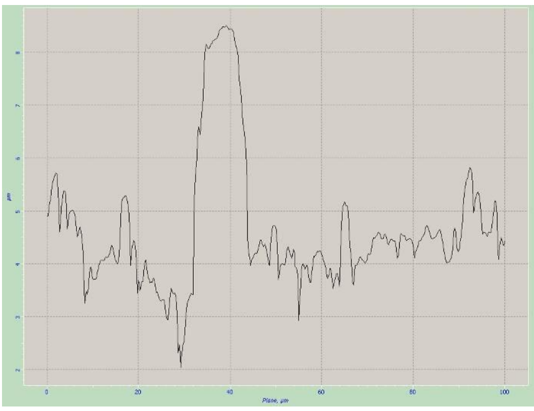

Fig.8 – Average roughness profile of sillicone rubber surface

4. CONCLUSIONS

a. The analysis was performed for investigating the surface topography, micro- and nano-scale quantitative characterization and the 3D morphology in atmospheric, liquid, controlled gas and low vacuum (10-20 torr) conditions, using a work area of 100x100x10 μm, noise level XY: 0.3 nm Z: 0.6 nm, closed loop XY non-linearity <0.15%.

b. The roughness parameters were the following:

Amount of sampling	262144
Max	4971,65 nm
Min	0 nm
Peak-to-peak, Sy	4971,65 nm
Ten point height, Sz	2542,21 nm
Average	1881,88 nm
Average Roughness, Sa	282,506 nm
Second moment	1919,55
Root Mean Square, Sq	378,429 nm
Surface skewness, Ssk	0,909317
Coefficient of kurtosis, Ska	3,27766

5. References

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