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2D Fractal Models of Textured Polymer Coatings of Steel Sheet

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Surface roughness plays an important role in many physical phenomena, including wave scattering, friction, adhesion, electrical conductivity, capacitance and heat transfer, as well as applications of thin films for sensors. We studied microphotographies of polyester coatings surfaces of metal sheets, and concluded that they are rough ones. Using the scanning probe microscopy method, we investigated the surface texture of these samples and found that the largest number of peaks on the surface has a height in the range exceeding the roughness level, and their distribution on surfaces has a fractal character. We used the method of 2D fractal functions for modeling of surface texture of these samples. The optimal fractal model was chosen on the basis of comparison of the geometrical profiles for polymer coating surface of metal sheet obtained by the opticale microscopy method and calculated on the basis of fractal models.

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1. Introduction

Surfaces of polymer coatings for the metal sheets may be changed from smooth to rough one depending on the conditions of their formation. The surface roughness plays an important role in many physical phenomena, including wave scattering, friction, adhesion, electrical conductivity, capacitance and heat transfer, as well as applications of thin films for different sensors [1]. The solution of the problem of creating surfaces with certain properties is necessary both for stable functioning and technological control of surface quality of the products [2]. Therefore, the development of mathematical models describing the relief of such surfaces is an actual problem.

A preliminary study of the surface of sheet metal with polyester coatings by means of the optical microscope method with 56-times magnification showed that it consists of grooves that collect into star-shaped thickenings randomly scattered over the entire surface of the sheet (Fig. 1a).

We investigated also the texture of the surface of these samples by the scanning probe microscopy (SPM) method (Fig. 1b). We have found that the greatest number of peaks on the surface has a height in the range exceeding the roughness level and the distribution of defects on the surface is neither deterministic nor purely random. The analysis of figures obtained by the optical microscope and the scanning probe microscopy method (see Fig. 1a and Fig. 1b) showed that the distribution of defects on the surface of polymer coating has a fractal character.

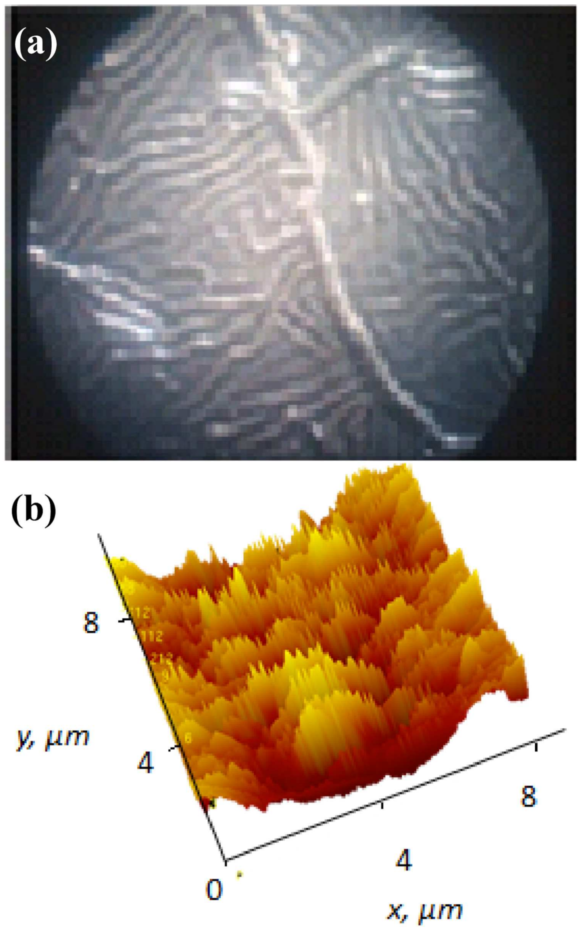

Fig. 1. Images of the textured polymer coating “Steel Velvet” surface (a) the optical microscope method with 56-times increase and (b) the SPM method.

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It is known that the different fractal models (Sierpinski rug, Mandelbrot set etc.), describe well the real imperfection (Brownian) surfaces of metal layers, dielectric layers [2], semiconductor surfaces [3], surfaces with the distribution of defects of symmetric type [4, 5]. In Refs. [6–10], not just real surfaces, but surface aggregates with such defects have been simulated also sufficienly well by different 2D fractal functions. However, in the SPM study of the textured surfaces of polymer sheet metal sheet coatings, we have found anisotropic defects [11]. These defects lead to a strong light scattering in special optical devices primarily intended for the analysis of the smooth surfaces.

Therefore, to simulate the scattering of light on rough surfaces with such a relief, it is necessary to develop new fractal functions for modeling of texured surfaces and methods for calculating the characteristics of scattering light waves.

2. Model

To simulate rough surfaces, the normalized 2D Weierstrass fractal function was used in [6, 11]. However, this function may be used only to investigate the distribution of defects having central (axial) symmetry. Therefore, we must select another 2D fractal function. In this work, we will use the fractal called Julia set [12]. To construct its three-dimensional fractal image the following algorithm was used:

1. The area in which the fractal is calculated is divided into 1000×1000 squares. Each rectangle in the lattice (r, s) is represented by the coordinates $X_{r\,s}$, $Y_{r\,s}$ of the origin located in its center.

2. The n-th term of the generated sequence is defined by the recurrence formula [12]

$$z_{r,s}^{(n)} = \left(z_{r,s}^{(n-1)}\right)^2 + p + \mathrm{i}q, \quad (1)$$

where $\mathrm{i} = \sqrt{-1}$, p and q are the parameters of the fractal function. The first term of the sequence $(n = 1)$ is initialized by the formula $z_{r,s}^{(1)} = X_{r,s} + \mathrm{i}Y_{r,s}$

3. The peak height H of fractal surface relief is defined as the inverse to divergence rate of the sequence (1). It is equal to the smallest number of the sequence term when $|z_i| > M$. In our calculations, we took $M = 10^6$. The obtained fractal functions for different values of the parameters p and q are shown in Fig. 2a, b.

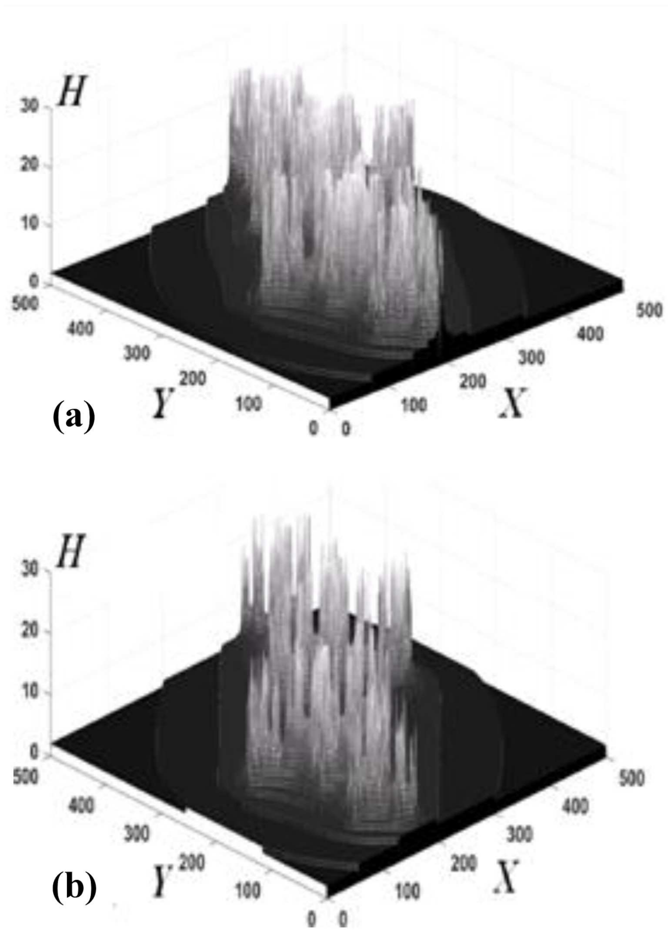

Fig. 2. The textures constructed for different values of the parameters of fractal function (1): (a) $p = -0.65847$, $q = 0.651828$ and (b) $p = -0.386673$, $q = 0.866329$.

3. Results and discussion

To determine the scale $m = L/L_0$, the average length L_0 of the groove measured with the optical microscope was compared with the median line length L calculated from texture constructed on the base of the fractal function Eq. (1) (Fig. 3a, b). To do this, in the area of constructing of the fractal, we approximated this line by a cubic polynomial (Fig. 3a) and calculated its length. To determine the parameters of the fractal function, we calculated the width d of the fractal polygon section, the length L and the radius of curvature. R the average radius of curvature of the median line. Figure 3c and d shows the dependence of d and R on the parameters of the fractal function p and q comparing the obtained dependences with experimental data. The following values of fractal parameters were obtained: $p = -0.55375$, $q = 0.5508$.

4. Conclusion

Surfaces of polymer coatings of metal sheet are rough and can change their shape under different conditions of their formation. At first glance, the texture of such rough surfaces of polymer coatings seems chaotic, so a theoretical study of the phenomena occurring on them, for example, the scattering of light is difficult. The physical phenomena occurring on these surfaces cannot be described in terms of the standard deviation of the peak height of the correlation function for them [13].

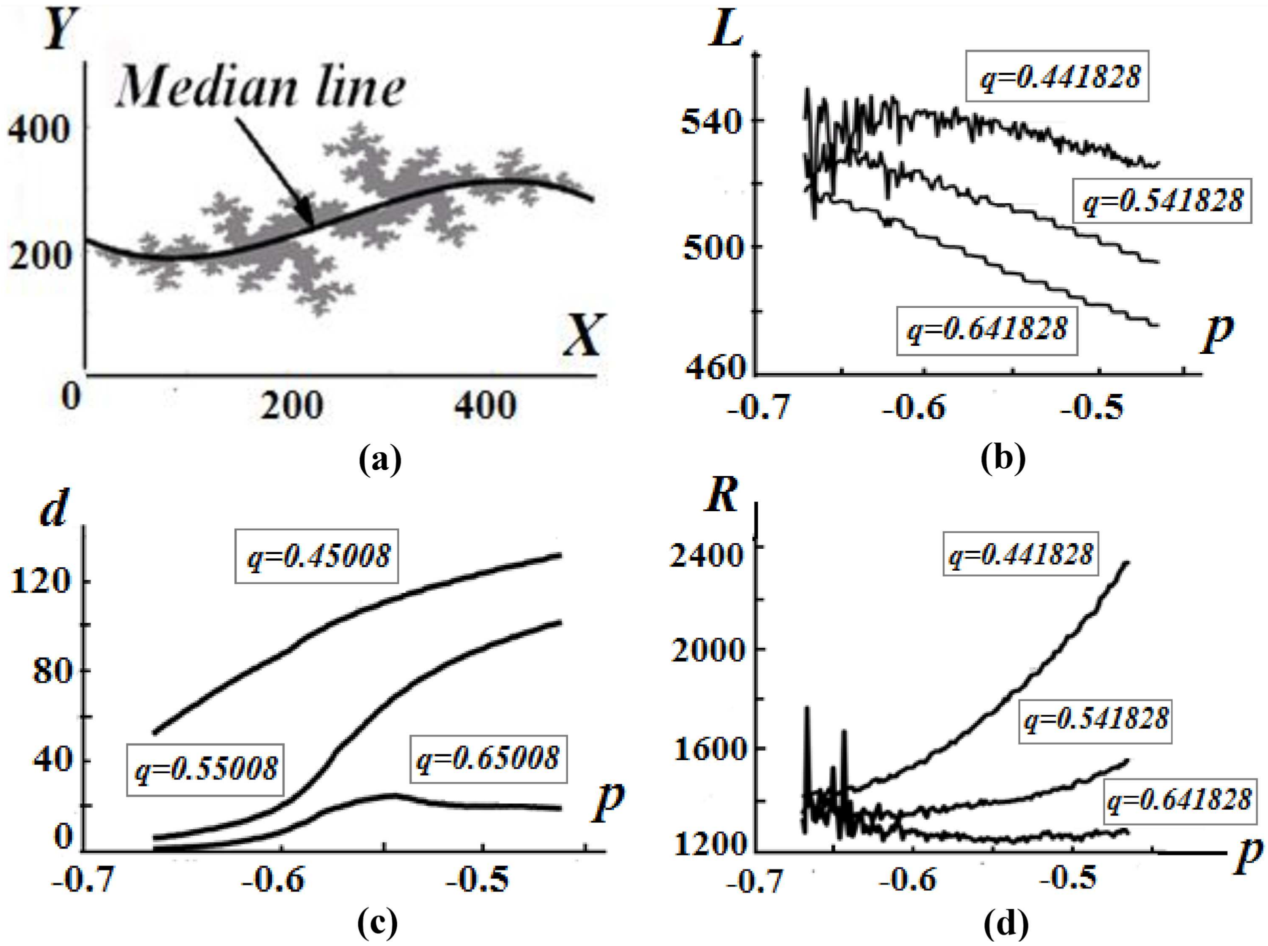

Fig. 3. The approximated procedure allowing to determine the optimal parameters of fractal functions: (a) the construction of the median line; (b) the length of the median line L, (c) the average width of the polygon d, and (d) the average curvature R vs. the parameter p for different values of the parameter q.

The use of the fractal approach to describe structural inhomogeneities, as well as the justification of general regularities, is one of the modern scientific trends in surface physics and chemistry of solids.

The fractal functions method and the technique of treatment of these functions developed in this work may be applied for modeling surface textures with anisotropic defects. Real surfaces in different regimes of surface roughness may bee most adequately described by fractal functions, that is confirmed by experimental results on the scattering of light [14, 15].

The results of this work may be used to study other physical phenomena on the surfaces, such as friction, electrical conductivity, and capacity.

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