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Comparison of fractal and profilometric methods for surface topography characterization

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Abstract

In this study microstructural and roughness characterization of surface of aluminium foils used in lithographic printing process was performed by contact and non-contact profilometric methods and fractal analysis. Significant differences in roughness parameters values inferred from stylus method in respect to those inferred from the non-contact measurements were observed. The investigation of correlation between various fractal dimensions obtained from gray-scale SEM micrographs and binary images resulting from median filtering of the original SEM micrographs as well as selected relevant roughness parameters shows that there is a strong correlation between certain roughness parameters and particular fractal dimensions. This correlations permit better physical understanding of fractal characteristics and interpretation of the dynamics of surface roughness change through processing. Generally these correlations are more suitable for parameters obtained by stylus method than those inferred from the laser-based measurements.

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1. Introduction

Precise characterization of roughness and surface topography is of prime importance in many engineering industries because certain functional properties of the materials are often determined by the surface structure and characteristics. This is especially important for surfaces characterized by various and diversified microstructures with number of irregular peaks and valleys which cannot be easily defined. There are many methods for analysis and description of surface topographies. Among these methods the scanning electron microscopy (SEM) and the atomic force microscopy (AFM) are widely used for surface imaging and characterization. Due to its high depth of focus SEM can provide detailed topographical information about the surface, but cannot provide quantitative topographical information. For that purpose the mechanical stylus profilometry (MSP) and non-contact laser profilometry (LPM) are commonly used. However, the comparison of these methods indicated that due to different measurement principles there can be significant quantitative difference between the results [1]. With MSP stylus tip must be in contact with the surface during the measuring. This can cause surface deformation due to a high local pressure. Furthermore, in some cases stylus tip could not reach all the irregularities of the surface profile, especially if the surface has a sharp ridge profile with deep valleys. In non-contact LPM the laser beam spot is small and inflicts no changes to the surface texture. Consequently, the values of roughness parameters are usually higher. However, one must be careful in interpretation of the results as the described method has a tendency to create optical artifacts on sharp edges and steep local slopes [2]. To quantify the measurement's results in two dimensions and three dimensions, i.e. as $z(x)$ or $z(x, y)$ a large number of different surface roughness parameters have been observed [3–5], but their usage is often of limited value for characterization of real surfaces. Moreover, the profiles of the material surface could be completely different, but have similar R_a and R_q values [1] or

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same R_a and R_{zDIN} values [6]. The processing of data results in number of roughness parameters that are used for quantitative characterization of the surface, but they cannot describe its irregularity or complexity. In order to describe the surface geometry, the concept of fractals was introduced. This concept is based on self-similarity of surfaces at different scales. Its advantage is that it is insensitive to the structural details, and the structure is characterized by single descriptor, the fractal dimension D. The fractal dimension lies within the range $2 \leq D \leq 3$, where a smooth surface has a value of $D = 2$, and an increasing value of D represents an increasing surface roughness. It provides information on the degree of complexity of different surface topographies [7], and can be correlated with various surface roughness parameters [8–16]. Thus, fractal dimension becomes convenient for characterization of different topographies such as those obtained by electrochemical processes of controlled anodic dissolution commonly used for shaping and surface structuring of metals [17]. Moreover, the application of fractal geometry is convenient since the fractal models comprise topography parameters which are independent of the resolution of the instrument.

The aim of this study was to compare the results of fractal approach to surface characterization with the results of contact and non-contact profilometry methods. The measurements and fractal analysis were performed on aluminium foils mostly used in lithographic printing process where size and quality of the grained surface microstructure influences the printing performance and durability of the printing plates [18]. Aluminium surface suitable for use as a printing plate consists of two different areas: ink-receptive image areas which carry a photosensitive coating and fountain solution-retaining non-image areas. In order to improve the fountain solution adhesion on the aluminium oxide film and to enhance the adhesion of the photosensitive coating, during the printing process [19,20] the foil needs to be roughened by electrochemical graining and anodic oxidation [21]. After exposure during the printing plate making procedure, the photosensitive coating has to be removed from aluminium oxide substrate by chemical processing in an alkaline solution, without significantly affecting the roughness of the substrate that is essential for its function. Nevertheless, the chemical processing can also affect the substrate microstructural roughness inducing changes that impair the quality of printing plate. The extent of these undesired effects presumably will depend on the working age of the processing solution.

2. Materials and methods

2.1. Preparation of samples

In this study the topography of the non-image areas (aluminium oxide areas) of the printing plates (commercial grade 0.3 mm tick AA1050 aluminium foils) was investigated. After the exposition the photosensitive coating was removed from exposed (non-image) areas of the plate. The removal is achieved by chemical processing in alkaline solution (pH $\approx$ 13) according to the standardized processing procedure: at the temperature of the processing solution 22 ± 3 °C, processing speed in the range of 0.9–1.3 m/min and the processing time (duration of the printing plate immersion in the alkaline solution) of 22 ± 4 s. The reference sample (hereafter designated B0) was roughened and anodized by electrochemical processes without application of photosensitive coating and was not immersed into the processing alkaline solution. After application of photosensitive coating and exposure other samples, initially identically prepared were processed in alkaline solutions of different age: from freshly prepared (sample designated B1) up to 84 h-usage-old solution (B8). Quality control of all printing plate samples was compliant to the graphic technology standards [22,23], and conducted after the processing. The influence of solution age on processing was checked on samples selected at 12 h intervals of solutions usage. The process of selecting and analyzing the plates was terminated after the selected printing plate did not comply any more with the requests of the applied standards.

2.2. Microstructural characterization

The optical micrographs used in this study were made by JEOL JMS T300 scanning electron microscope. To assure the uniform electrical properties and to avoid charging/discharging of aluminium oxide surfaces, the aluminium plate samples 5 mm × 5 mm were gold coated (>30 nm thick) by magnetron sputter SC7620 Quorum Technologies, Polaron. The images were taken at different magnifications in range from 1500× to 10,000×.

In Fig. 1 SEM micrographs of reference (untreated) aluminium foil (B0) at different magnifications are presented. One can see that the aluminium oxide surface consists of fine microstructures, irregular in their size and shape. At the smallest magnification one can see that the surface is dotted

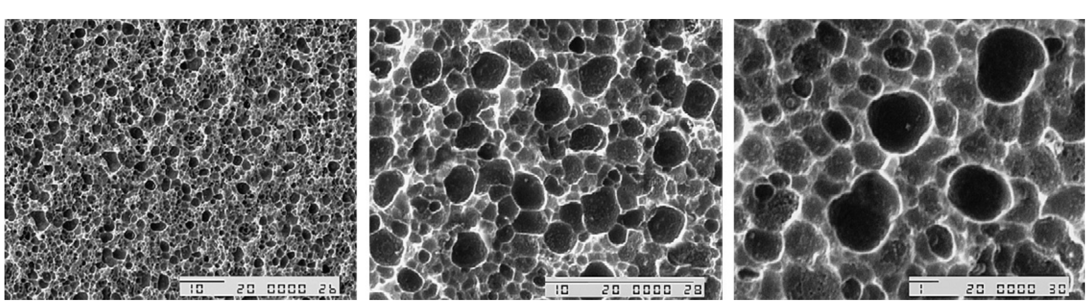

Fig. 1. SEM micrographs of reference aluminium foils at magnification 1500×, 5000× and 10,000×, respectively.