Three Dimensional Topographic Characterization of Lithographic Printing Plates

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Abstract;

Surface characterization of lithographic printing plates is of crucial importance in defining the lithographic printing process. Historically techniques for characterization, e.g. conventional profilometry, electron and optical microscopy, have not provided sufficient information to model the lithographic process. It is the purpose of this paper to extend topographic characterization over a range of scale from macroscopic to microscopic to "nano-scopic". The technologies employed include scanning mechanical microscopy, scanning electron microscopy and atomic force microscopy. Two dimensional and three dimensional "pictures" of different grained litho plates which fully describe mechanical roughness, water carrying capacity, true surface area will be described. These detailed pictures should provide significant data towards modelling performance of lithoplates on press.

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INTRODUCTION:

Surface phenomena and processes occurring at interfaces are becoming increasingly important in a wide variety of industrial applications including printing. Accompanying this is an ever-growing need for surface characterization allowing better definition of processes occurring both at the macroscopic and microscopic level. Indeed, the properties of surfaces control how a material will interact with its environment and thus govern phenomena such as adhesion, corrosion and wettability.

In the specific context of lithographic printing a better knowledge of the relationship between plate topography and coating properties on one hand, and plate topography and ink-water balance on the other hand, are fundamental. However, the quantification of the topography is not an easy task.

In the literature, only a relatively few articles deal with this particular subject, while the authors agree that the surface structure of an offset plate is crucial for a good working product[1,2,3]. The problem is that the idea of a relationship between graining and water receptivity is often mentioned but never really quantified.

Generally, the only way of measuring the surface structure of plates is by determining the surface roughness profile. Nevertheless it is difficult to correlate the classical values of roughness to the properties of plates.[4].

Although, in 1981 Pearson[5,6] developed a new idea to objectively evaluate lithographic plate structure and prints produced from different plates, surface texture is still characterized by a profile from which several numerical factors are obtained.

The original idea of our study is to introduce a new concept for the characterization of the offset plate surface. We will demonstrate that the quantification of true surface area of a plate is a useful parameter in the understanding of all physico-chemical phenomena which take place on plate surfaces. New microscopic methods such as scanning

mechanical microscopy, atomic force microscopy combined with image analysis treatment have been used to achieve this quantification. These techniques are complementary because of the need to characterize the complex texture of plate surfaces at different scales of observation.

That is, at what level of detail does topography influence lithography?

In this article, we will limit our discussion to the methods of measurement and leave to the future the relationship between obtained results and the functional properties of offset plates.

Surface Characterization, Definition

To give an overview, we will discuss some basic concepts of roughness which provide a foundation for the future discussion of the methods of measurement.

According to the literature, a mechanical profilometer is often used to measure the roughness of lithographic offset plates. The correlation between roughness and contrast, or maximum density was found in the density measurements of prints[4]. However, no correlation was found between surface energy and contrast in the density measurements of prints.

In fact, surface energy is a function of surface texture, true surface area, and surface geometry. Therefore, these topographic factors are functionally significant for many phenomena such as adsorption, wetting, and adhesion.

This is why, Wenzel[7,8] defines a roughness factor equal to the area ratio (R). He proposed the following generalization of Young's equation for wetting angles:

$$\cos \Theta = R \cdot \cos\Theta' = R \cdot \frac{Y_S - Y_\ell}{Y_\ell}$$

R denotes the ratio of true (real) surface area to apparent (geometric) area.

$$R = \frac{\text{The surface area}}{\text{Apparent (geometric) area}}$$

Conflicting views of the effects of surface structure on adhesion and wetting exist because quantitative verification of the concepts such as roughness and surface area is difficult, and definitions are often ambiguous[9].

Bikerman[10] measured surface roughness with a tracer instrument on different samples. Because he was unable to show a relation between surface roughness and contact angle, he concluded that the Wenzel equation was not valid. Failure to obtain such relationships can be attributed to the fact that no apparent relation exists between surface area and surface roughness.

Indeed, it is easy to show on model surfaces that the values of roughness obtained from profile tracers in terms of root mean square height, center-line average height and peak-to-valley depth are not functionally related to the true surface area[7].

Simple mathematical models representing possible types of real surfaces demonstrate that numerical assessment of roughness is not functionally dependent on, or related to the real surface area (figure 1).

Symbols are:

L = apparent sampling length of profile.
s = length of roughness.
2h = peak on valley height of roughness and,
W = width of surface

The figure 1 and the table 1 indicate that by diminishing h and s to one half and doubling frequency of roughness the real surface area remains constant, while CLA (center line average) decreases. Conversely, if h is kept constant and s is diminishing, the CLA remains constant and the surface area increases. Moreover, Marian[9] demonstrated that this independence is valid

ırfaces exhibiting "lay" or for non directional surfaces. This ıstifies the application of these results to all kind of offset plates.

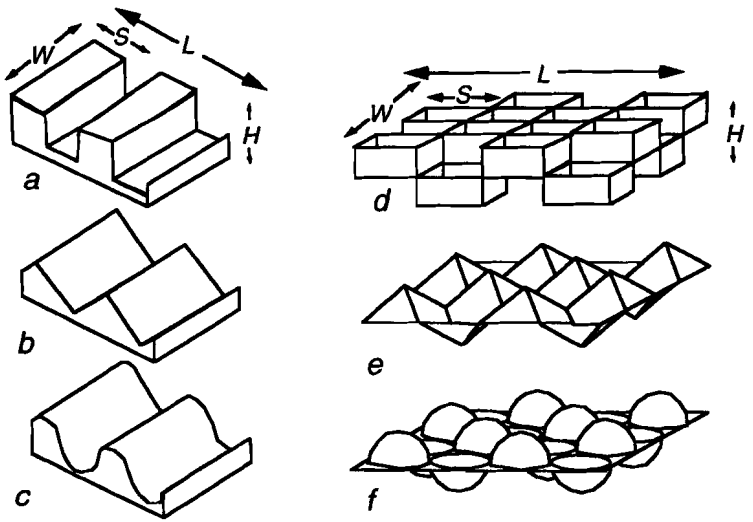


Fig. 1
MODEL SURFACES SHOWING LAY FOR DEMONSTRATION OF INDEPENDENCE OF ROUGHNESS AND SURFACE AREA.

Model	Assuming h = L/8, s = L/11			Assuming h = L/16, s = L/8			Assuming h = L/8, s = L/8		
	CLA	Surface Area	CLA/ Surface Area	CLA	Surface Area	CLA/ Surface Area	CLA	Surface Area	CLA/ Surf. Area
Fig. 1a	1/8L	2L	1/16	1/16L	2L	1/32	1/8L	3L	1/24
Fig. 1b	1/16L	1.4L	1/23	1/32L	1.4L	1/45	1/16L	1.24L	1/36
Fig. 1c	1/10L	1.57L	1/16	1/41L	1.57L	1/64			
Fig. 1d	1/8L	$3L^2$	1/24L	1/16L	$3L^2$	1/48L	1/8L	$2L^2$	1/16L
Fig. 1e	1/16L	$1.4L^2$	1/23L	1/32L	$1.41L^2$	1/45L	1/16L	$1.12L^2$	1/18L
Fig. 1f	1/10L	$1.78L^2$	1/18L	1/41L	$1.78L^2$	1/73L			

Table 1:
Calculation for model surfaces illustrated in figure 1, by showing independence of roughness and true surface area [9].

Surface Area Measurement (Scanning Election Microscopy)
We demonstrated in the previous section the necessity to appreciate the surface area parameter for studying the topography of plates and its relationship to the different properties of these particular plates. Among all the existing microscopic techniques, few are able to provide accurate values of the surface area of a rough surface, and fewer still can provide this information for very small details of surface.

A convenient way to establish the topography of a surface is SEM/scanning electronic microscopy. The main advantage of this method is the ease of sample preparation. However, whereas single SEM photographs yield some perception of depth, a three-dimensional view is sometimes necessary for an accurate picture of the surface topography.

Depth can be perceived on SEM photomicrography using a stereo - imaging technique when photographs of the same image are taken at two different angles. The pair of photographs is then viewed using stereo-glasses. Image analysis can then be used to derive the horizontal surface characteristics (pit widths, shapes, etc.). The only problem with this technique is that it is impossible to calculate the true surface area because the quantification relationship between the depth and grayscale on the picture is not available. A recent advance[15] utilizes secondary election detectors. By imposing phase information on the election beam, analysis of phase differences between detectors gives topographic information. This instrument is not readily available as yet.

Both aluminum and chromium plates have been studied. These substrates are really different from one to the other. The SEM photographs of these plates show the substrates at several magnifications. [Photographs 1,2,3,7,8,9 in appendix]

Apart from the fact of visually describing the surface structure, the views of plates at different magnifications points out a particularity concerning the scale of observation. Indeed each time the magnification of the plate surface increases, new interesting fine details appear. This observation indicates that the characterization of the surface of offset plates must be considered over the whole range of submicron, microscopic and near macroscopic scale to be valid. Our study will deal with two methods for the determination of true surface area each of these being associated with a given resolution of inspection.

Surface Area Measurement by Scanning Mechanical Microscopy

In this first part, we suggest a new approach based on three-dimensional roughness measurement. The apparatus named the Scanning Mechanical Microscope (MMB) developed by the laboratory of Micro Analysis of Besancon [(II)] (France), provides accurate visualization and quantification of the surfaces of offset plates. This microscope used a micro computer software to drive conventional profilometers transforming them into MMB.

For the data acquisition, a computerized tactile profilometer (fig 2) with a position sensitive pickup is used. The external reference is provided by a skid. The stylus has a tip radius of 1.5 μm which bears on the sample with a 1mN force. Its vertical resolution is 10 nm.

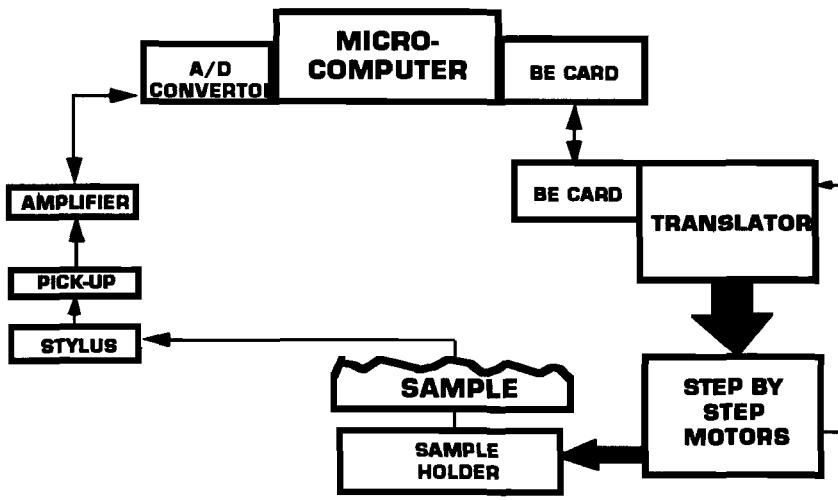


Fig. 2 SCHEMA OF THE SCANNING MECHANICAL MICROSCOPE.

The approach of this apparatus consists of taking several closely spaced parallel traces in order to build up a three dimensional map of the sample surface. For that purpose, two step-by-step motors allow the sample to be moved along the Ox and Oy axes with a minimum step of 0.1 μm. A square area (Np^2) is obtained by scanning N equidistant profiles, each being made up of N points. The sampling length along the two axes is p.

The coordinates of each point of the area are (Xi, Yi,Zi,j) with i = 1 - N and j = 1-N and Zi, j being measured with respect to the external reference. The analogue data are digitized (8-bit digitization providing a 1/256 resolution consistent with that of the stylus) and then stored. The maps are produced with a 45° perspective angle. In order to bring out the correct relief, the hidden surfaces were systematically deleted from the representation.

Specific mathematic tools used in statistics and in signal treatment are then applied to obtain characteristic data for the amplitudes and frequencies of sample; before obtaining the results some preliminary filtering treatments are necessary (electrical, mechanical and numerical treatments).

Topographic Results

Systematic three dimensional maps were made on all the samples studied.

The conditions of analysis are:
-in 3D mode
256 x 256 points, step = 1 μm, Thus surface of evaluation, $L = 256x256\ \mu m^2$
-in 2D mode
2000 points
step = 1 um, thus length of evaluation, $L = 1500\ \mu m^2$

PLATE A = Electrograined Aluminum Plate
PLATE B = Electrograined Aluminum Plate
PLATE C = Electrochromed Aluminum Plate

Figures 3,4,5 illustrate the surface representation of each plate and the tables 2,3 show the results of roughness measurement from profile and from surface.

Fig. 3
MMB view
of electrograined
aluminum plate A

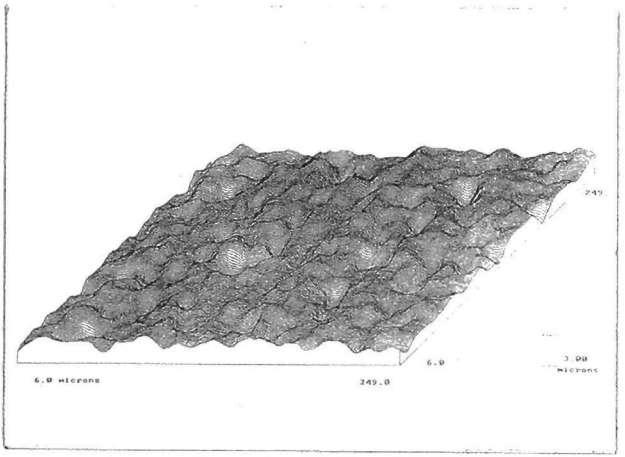


Fig. 4
MMB view
of electrograined
aluminum plate B

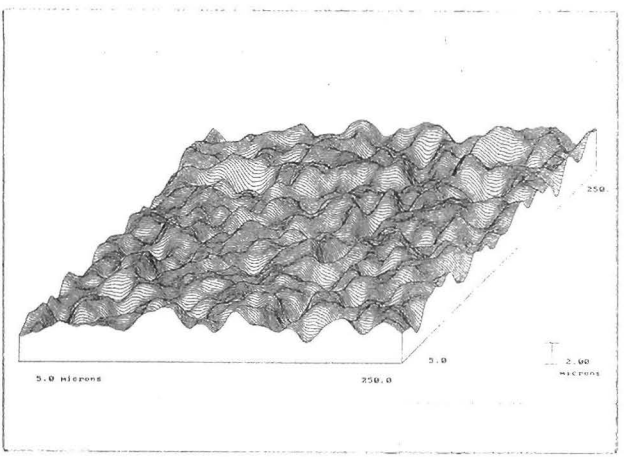
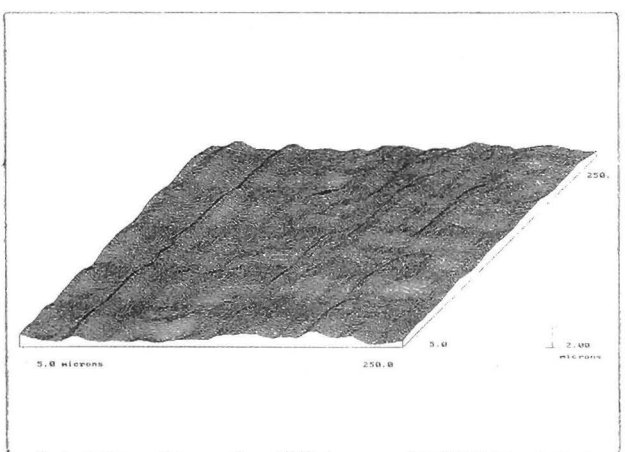


Fig. 5
MMB view
of electrochromed
aluminum plate C



We made all these measurements to prove the validity of the three dimension representation. And from the surface we obtained the value of true surface area limited by the resolution of this microscope which is around 1 μm.

As we can see it from the SEM pictures, the surface textures of plates A, B, C are very different. The Ra from 2D data for chromium plate (Plate C) is the lowest (0.28 μm). Then, the aluminum plates can be classified concerning the Ra, plate B < plate A.

$$A > B > C$$

The results of roughness, from 3D data, are slightly different, but the order is still the same. Aluminum plates present a greater roughness factor.

$$A > B > C$$

Concerning the results of the surface area again the discrimination between plates is possible. It is very interesting to see that the aluminum plate which had the highest Ra, now presents a true surface area lower than the other aluminum plate. We demonstrate here that Ra and surface area are not dependent.

$$B > A > C$$

	Rt μm	Ra μm	σμm	SK	EK
A	4.8	0.63	0.8	-0.6	3.3
B	3.8	0.65	0.75	-0.3	2.4
C	2.3	0.29	0.37	0.6	3.7

Table 2. Roughness parameters calculated from 2D data MMB.

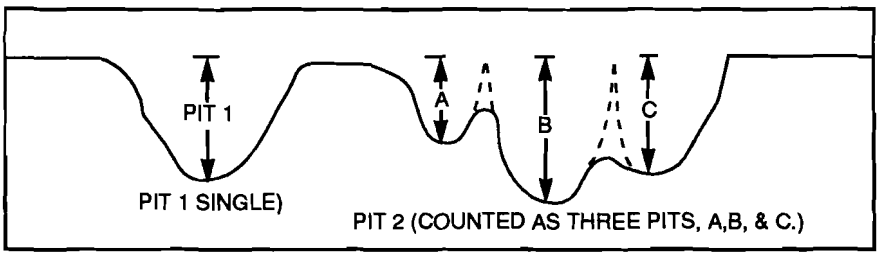
	Rt µm	Ra µm	σ µm	SK	EK	Surface area (%)
A	5.6	0.54	0.69	-0.6	3.7	145
B	5.5	0.68	0.83	-0.4	2.9	184
C	2,8	0,28	0,36	0,2	3,1	109

Table 3. Roughness parameters of aluminum and chromium plates calculated from 3D data (MMB)

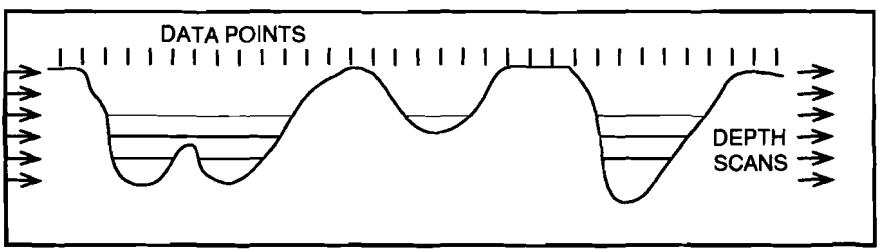
The factors Sk, Ek give indications of the distribution. The parameter Sk (skewness) describes the symmetry of the histogram of distribution of heights related to gaussian, where Sk = 0. This factor gives negative values for the Aluminum plate and positive value for chromium plate. The parameter EK describes sharpness of the histogram of distribution of heights related to Gaussian when Ek = 3. This factor highlights that Aluminum plates favor peaks to valleys , the chrome opposite.

The comparison of the MMB technique and the conventional profilometry for example, used by Pearson [5,6] and described by Luders [13] can best be visualized by comparing figures 3,4,5 with Pearson and Packer's approximation to 3-dimensionality as depicted in figure 6. Conventional profilometry cannot properly account for the complexity of actual lithoplate surfaces. Luders, in fact, does not describe any profilometry technique, but does describe an optimum skewness and Ra "topographic values space" for best performance. To show that more than profilometry (even enhanced by MMB technology) is necessary to define the role of topography in lithography, consider the following.

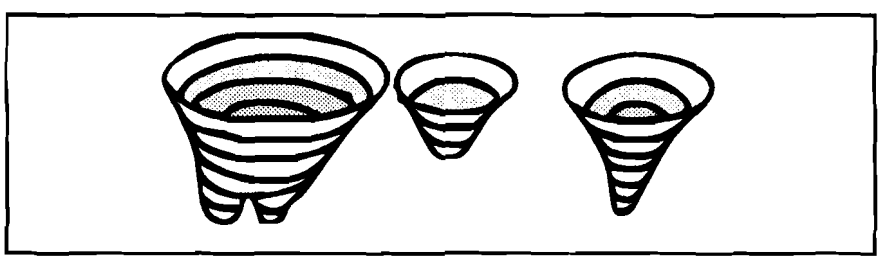
The electrochromed plate has the lowest value of true surface area due to the structure of this plate. Indeed, the crystal size of chromium which gives this plate a very disturbed structure at high magnification on the SEM, is less than one micron. In that case, the MMB cannot take account this kind of structure in the calculation or approximation of true surface area of plates. To improve resolution we choose to use the finest kind of microscopy: the Atomic Force Microscope (AFM).



CLASSIFICATION OF SINGLE AND MULTIPLE PITS.



SCANNING OF PROFILE TO DEFINE PITS.



CONSTRUCTION OF PITS FROM DEFINED SECTIONS.
CALCULATION OF PIT VOLUME.

Fig. 6
CALCULATION OF PIT VOLUME (Pearson [4])

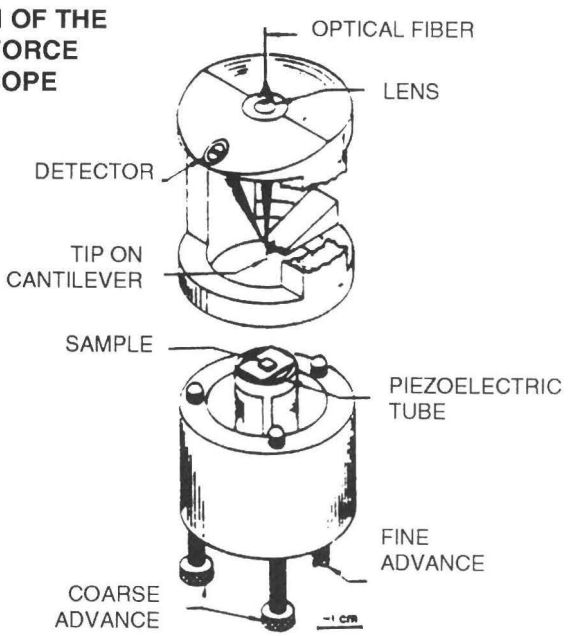
Surface Area Measured by Atomic Force Microscopy

The AFM can be thought as a refinement of the MMB stylus profilometer on which the forces between an atom on a scanning tip and the surface of a solid are measured. The length between two points is here around a nanometer permitting a view of the fine details of the surface texture.

To examine the surface of nonconducting solids at the atomic scale, Binnig (12) developed an instrument called the atomic force microscope (AFM). In the AFM, a fragment of hard material is attached to a spring and brought close enough to a surface to interact with atomic forces at the surfaces. The force is measured by detecting the deflection of the spring with a tunnelling gap with a laser interferometer or, with an optical level. A feedback system is used to adjust the vertical position of the AFM top above the sample surface to keep the detection of the spring and therefore the force constant as the rip is scanned over the sample.

The figure 7 represents the diagram of an AFM that uses an optical level to detect - bending of a small cantilever that carries a diamond fragment to within the range of surface forces of the sample.

Fig. 7
DIAGRAM OF THE ATOMIC FORCE MICROSCOPE



The photographs [4,5,6,10,11,12 in the Appendix] present the surface of our three plates at two different magnifications. The comparison of AFM and SEM pictures indicates how much the AFM representation of the surface is close to the SEM representation.

However, because of the difference in height between peaks and valleys, we notice on the images obtained lines due to the tip effect. Indeed, when the asperities of the texture present a slope with an angle superior to 60° (angle of the tip), the sides of the tip touched the surface before the bottom point. Thus, the result is a smoother representation of the surface with a maximum angle of 60°. The effects of these perturbations interact with the surface area calculation. However, we know that the surface area calculated is at least the results obtained. With this technique, again surface area measurement is obtained but at a scale much below the micron scale. The results of surface area obtained from AFM are shown in Table 4.

Plate	A	B	C
surface area	155	188	154

Table 4. Values of true surface area of aluminum and chromium plates calculated from AFM.
Surface area results obtained from AFM image of 19 um on a side.

The results of true surface area obtained from AFM image are different because the fine particles of surface are now considered in the calculation of surface area. The big change is for the electrochromed plate including the crystal of chromium. The Aluminum

electrograined plate (plate A) presents almost the same surface area as the electrochromed plate (plate C), but we have to consider that the area of observation is very small and represents only the local perturbation of the surface.

The aluminum plate B keeps its higher true surface area because even at this scale the plate presents a fine texture.

CONCLUSION

The techniques used for the quantitative evaluation of the surface topography (Surface area) and for the characterization of the texture of plates, the MMB and the AFM, are believed to be new in the field of printing.

It has been shown on a few mathematical model surfaces that the true surface area is not functionally dependent on any mathematical evaluation of surface roughness by conventional criteria.

Preliminary experiments indicate that Wenzel equation seems to be valid for the offset plates surface evaluation.

It can be predicted, however that analysis over a whole range of submicroscopic, microscopic and, macroscopic regions are necessary to define a such complex texture of lithographic plates.

The earlier work by Pearson [5,6] did not fully account for the 3-dimensionality of the lithographic plate surface. As we showed earlier, lithoplates often have complex geometric features. We believe the true 3-dimensional determination of topography can provide to the printer "the calculated volume for surface petting as an indicator of the water carrying capacity of the plate" [6] as well as other parameters.

It is the contention of the authors that by determining both surface volume and true surface areas (along with all the other topographic

parameters) at scales from 10-100 nanometer range to 1-10 micrometer range, it will be possible to definitely determine precisely what topographic characteristics are most crucial for particular performance characteristics. Then, relevance of "micro-grains, multigrains, etc." can be objectively determined.

The next objective will be to focus on the relationship between all the results obtained and the surface properties of plates in relation to adhesion of coating or to wetting by the fountain solution on the press.

An investigation on printing tests is at present under way.

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Photo 1
SEM of
Electrograined
Aluminum
Plate A
(5000X)

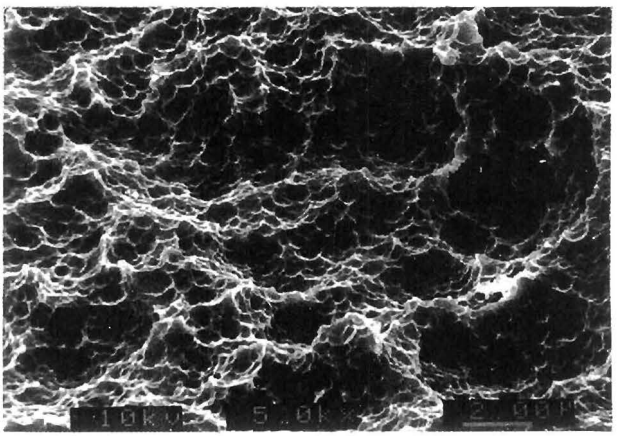


Photo 2
SEM of
Electrograined
Aluminum
Plate B
(5000X)

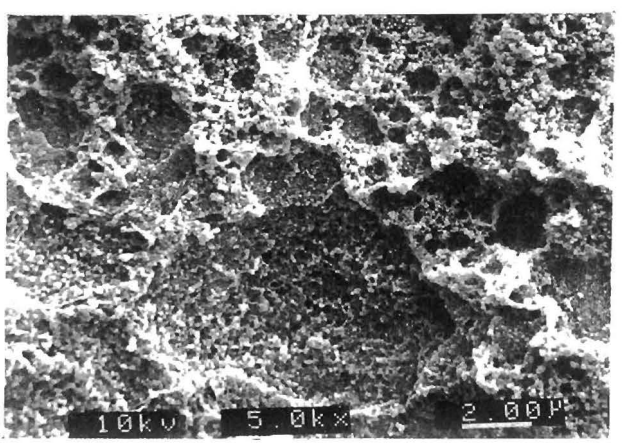


Photo 3
SEM of
Electrochromed
Aluminum Plate C
(5000X)

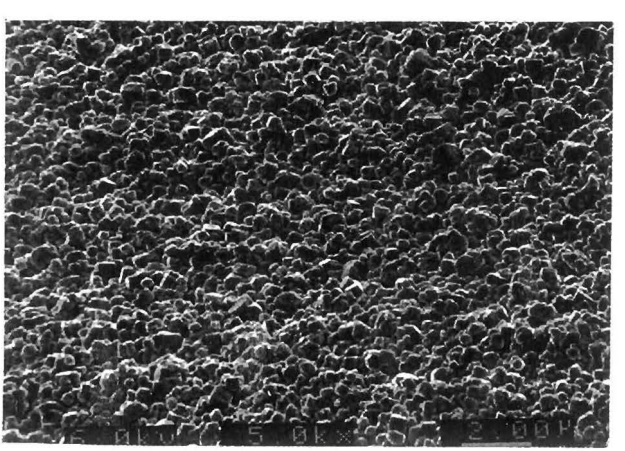


Photo 4
AFM of
Electrograined
Aluminum Plate A
(lower magnification)

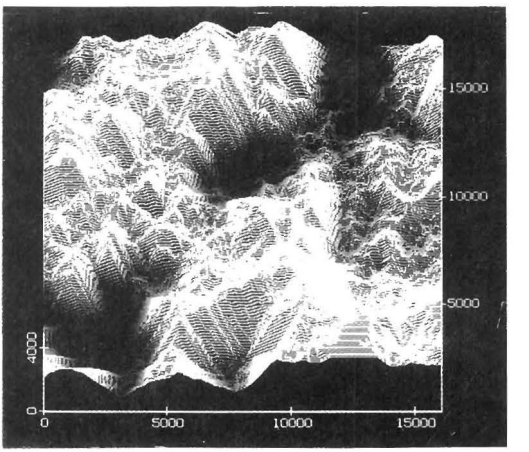


Photo 5
AFM of
Electrograined
Aluminum Plate B
(lower magnification)

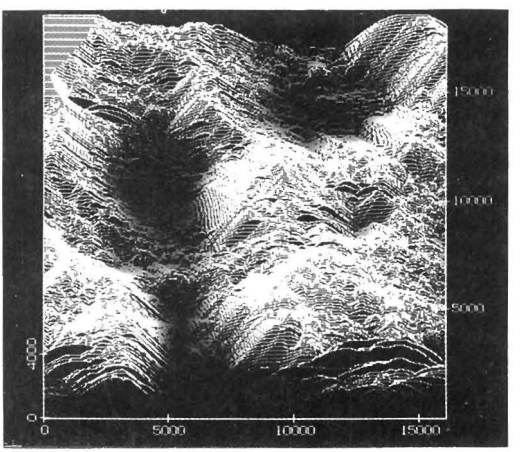
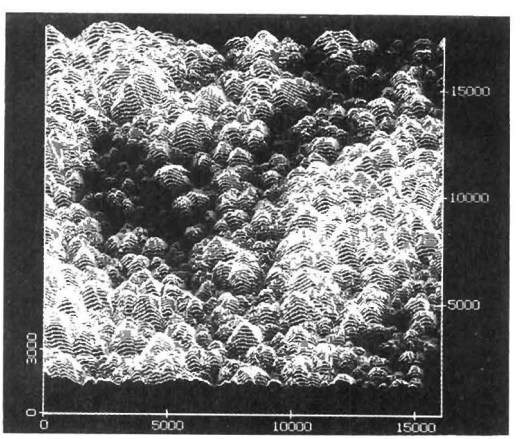


Photo 6
AFM of
Electrochromed
Aluminum Plate C
(lower magnification)



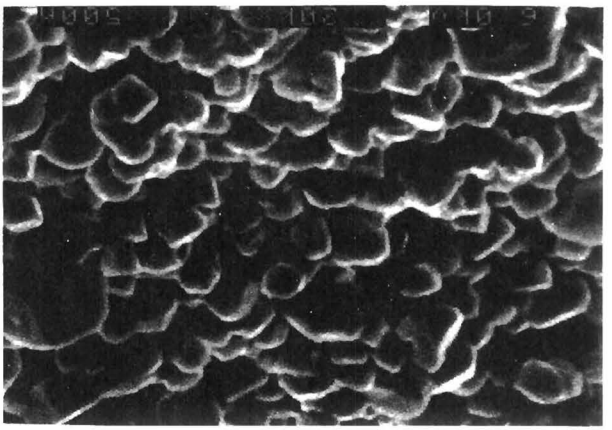


Photo 7
SEM of
Electrograined
Aluminum Plate A
(20000X)

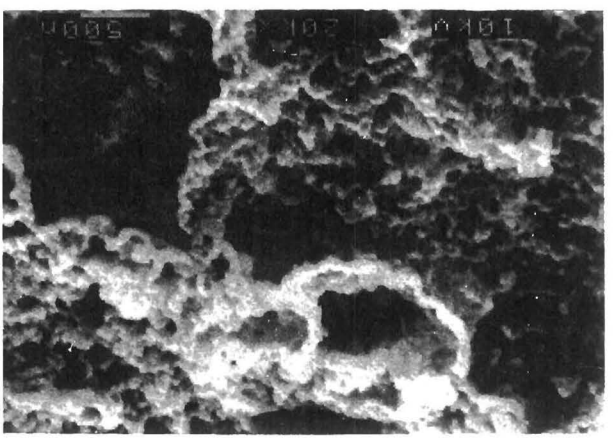


Photo 8
SEM of
Electrograined
Aluminum Plate B
(20000X)

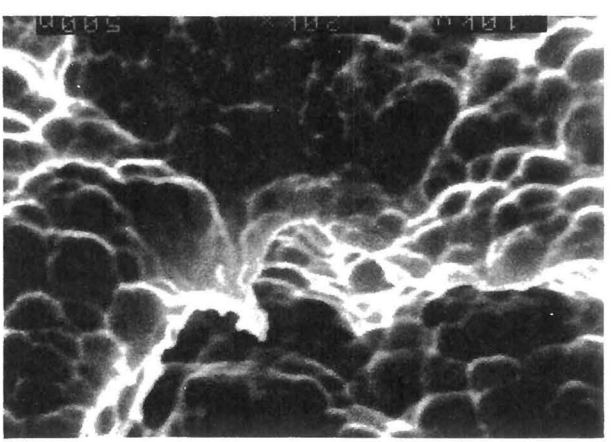


Photo 9
SEM of
Electrochromed
Aluminum Plate C
(20000X)

Photo 10
AFM of
Electrograined
Aluminum Plate A
(higher
magnification)

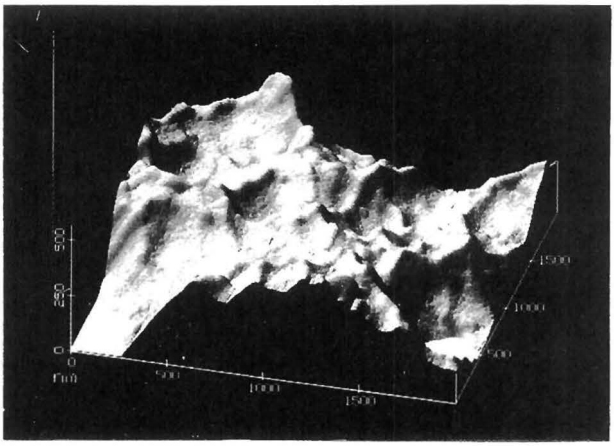


Photo 11
AFM of
Electrograined
Aluminum Plate B
(higher
magnification)

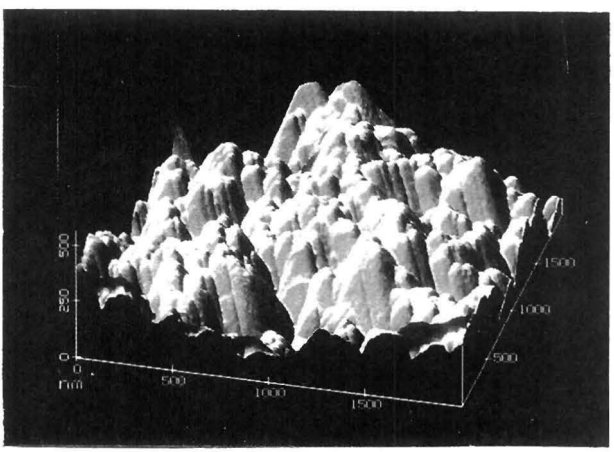


Photo 12
AFM of
Electrochromed
Aluminum Plate C
(higher
magnification)