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Study of drying process of paint by dynamic speckle with B/D pixel counting technique

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ABSTRACT

The aim of the work is the assessment of drying process of latex paint by dynamic Laser speckle method. The basic concept of dynamic speckle technique is described. Laser light scattering by water borne sample is a time dependent surface activity. The variation of laser speckle intensity is due to the change of refractive index and the particle movements of the latex paint. A novel method, B/D counting technique to measure the dynamic activity of drying paint using co-occurrence matrix of Time History of Speckle Pattern (THSP) is presented. The result of drying process of latex paint by dynamic laser speckle method is compared with the gravimetric method and agreed well.

1. Introduction

The characterization of coatings on the surfaces of materials is a major industrial application. In many manufacturing processes, it is of great importance to monitoring and control of the thickness evaluation in film coatings. Drying of the paint is a part of coating process. There are different industrial techniques to assess drying times and studying the curing properties of coatings. The basic technique is BK recorder test [1] in which the distance, end to end of a line, left by a needle drawn through the drying film surface with a known rate, provides the drying time. But, this technique has a limitation of interpretation of results and poor reproducibility.

Low cost standard techniques such as the paper test, solvent scrub test, the cotton fibre test [2] are some of the other methods. However, these methods are tedious to carry out, labour-intensive and user variability. Dynamic mechanical analysis (DMA), Dynamic mechanical thermal analysis (DMTA) and Differential scanning calorimetry (DSC) gives more quantitative results. But, they are not suitable to measure in-situ condition in drying films and coatings due to the situation of solvent evaporation on the appropriate substrate. Microscopy techniques such as AFM, SEM and TEM methods are used to study the drying process of coatings. Mid infrared (IR) spectroscopy and Fourier transform infrared (FTIR) instruments have the ability to do this, but FTIR instruments require contact with the surface. These methods are not suitable in many manufacturing processes because of time consuming and results are obtained in contamination or damage of the surface and of course costlier than other techniques.

Non-contact methods developed for the monitoring of drying process of paint including the use of terahertz electromagnetic pulsed imaging [3], diffusing wave spectroscopy [4], ultrasonic reflection [5], nuclear magnetic resonance (NMR), confocal Raman microscopy [6] and complex dielectric measurement [7]. Numbers of works are carried out on measuring evaporation rates of water from paint films using Evaporometer [8]. Digital speckle correlation [9] and gravimetric [10] are noteworthy techniques in the analysis the drying and film formation of latex paint.

1.1. Speckle interferometry

A highly coherent laser beam illuminates an optically rough surface object, a typical granular interference pattern named speckle is observed [11–13]. Very small movement of surface of the object, changes the intensity and shape of the observed speckle pattern with respect to time. This phenomenon is one of the characteristics of biological samples named as biospeckle [14].

The study of the speckle patterns, due to their random nature, requires statistical tools. Optically rough surface and the coherence of the incident light ray are the factors affecting the statistical property of laser speckle. Hence, the laser speckle and the corresponding statistical values are used to measure vibrations [15], velocity measurements [16] and displacements [17]. Two types of dynamic speckles [18] named as *translational speckle* and *boiling speckle*. When a diffuser moves, the entire speckle grains move as a whole; but speckle shapes remain unchanged even after considerable displacements. This phe-

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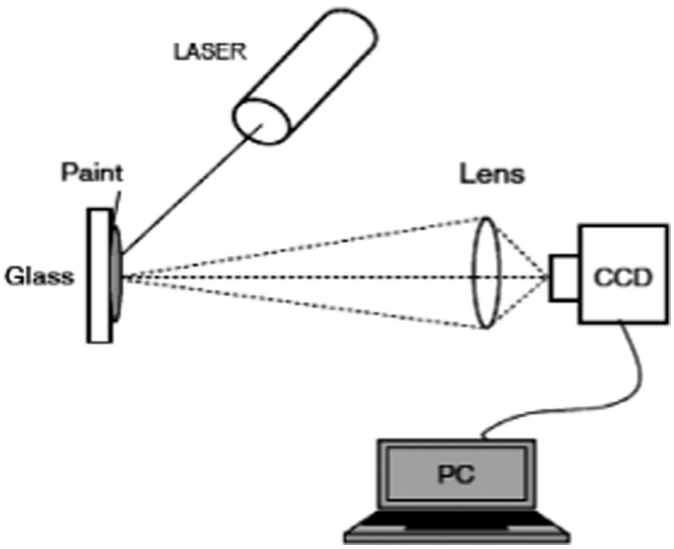

Fig. 1. Experimental setup of Paint drying process by Laser speckle.

nomenon occurs in solid diffuse object displacements and the speckles are called translational speckles. In the second case, when a diffuser moves, deformation disappears and reappears without any significant displacement of their position known as 'boiling speckles'.

Dynamic speckle uses in non biological industrial processes, including the drying of paint [19], corrosion [20], evolution of foams [21], salt efflorescence on stone surfaces [22], hydro adsorption in gels [23] etc. Biospeckle or boiling speckle gives information on biological activity happens in the inside of biological samples. In the medical field, measurements of blood flow [24], parasite motility [25], atherosclerotic plaque [26], cerebral activity in rats [27], characterization of regional mesenteric blood flow [28], health tumor tissue [29], botanical specimens [30] etc., are carried out by laser speckle technique.

In this paper, a novel method, B/D counting technique to measure the dynamic activity of drying paint using co-occurrence matrix of Time History of Speckle Pattern (THSP) is described. The moment of inertia is used to correlate the amount of water in a latex film. The different stages of drying paint with loss of water are observed by the technique of B/D pixel counting method of binary speckle images. Images of surfaces at different stages visualize the heterogeneities, which are related to the movement of scattering particles and hence the extent of drying latex paint.

2. Experimental setup

The experiments were done with slow drying latex paint prepared by spreading the paint on a glass substrate by means of an extender. Extenders, introduce light scattering which are inexpensive minerals such as calcium carbonate used as fillers, are added. The film is formed on 4×4 cm^2 glass substrate by a standard draw down applicator of stainless steel bar onto a flat substrate. The paint is applied horizontally and the film thickness is approximately 150 μm. To obtain fine measurements of drying process constant room temperature and motionless air conditions were maintained. Room temperature ranged from 24° to 27 °C; humidity from 60% to 70% RH. The source of He-Ne laser (10 mW, λ–633 nm) attenuated with a neutral density filter is used to illuminate the sample at 45°. To avoid the blurring effect due to the influence of boundaries the center of the sample is illuminated. Roughly of 1 mm of radius is the circular cross-section of the incident light beam (Fig. 1).

The CCD camera (Sony XC-ST730) is interfaced to a PC with a frame grabber card (NI1407). The advantages of the CCD camera is having resolution down to about 4 μm and capture the 2D beam profile of weak lasers in real-time. Larger aperture suitable for small size speckle

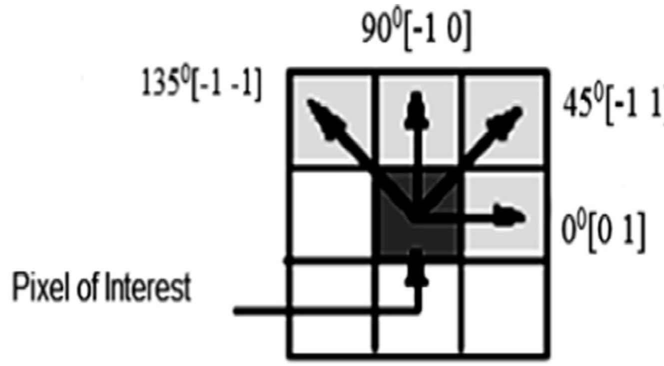

Fig. 2. Basics of Co-occurrence matrix.

pattern preferably with f/8 and f/11. Speckle images were registered by a CCD camera [31] and converted to 8 bits by a frame grabber and stored in PC. The acquisition of signals consists of a column of the speckle pattern image and it is read every 0.08 s. New image of 512×512 pixels by loading consecutive columns and digitized to 256 Gy levels is stored by using Oulamara [32] technique.

3. THSP (Time history of speckle pattern)

Successive images of speckle patterns are registered by a CCD camera. Each speckle image is digitalized to 8 bits gray levels. Just one column (e.g., the middle one) from the consecutive images taken and is stored in the frame grabber memory. It forms a new pseudo image. It is composed by setting each column side by side with m×n values, where m represents the lines, or the time history of each pixel of the column n taken from each speckle pattern. First stage represents fresh paint with highest activity. In the middle stage, the paint beginning to dry and final stage corresponds to almost dried state of paint. It is possible to visualize the changes of granularity in the different stages. Co-occurrence matrix gives the frequency to the repetition of pair of pixels in an image. The square style of co-occurrence matrix is considered and angle is the direction of the pair of pixels such as 0, 45°, 90°, 135°. Some pair of pixels found in the image repeatedly and that number of times is stored in the co-occurrence matrix. Generally, pair of pixels is just neighbors, but it may also be computed between non consecutive pixels. Thus, a distance between pixels could be predefined. THSP is considered for the assessment of drying of paint and the corresponding co-occurrence matrix (COM) is known as:

$$COM = [N_{ij}] \tag{1}$$

N denotes the number of entries of occurrences with intensity value *i* that is immediately followed by an intensity value *j*. This is called 'spatial gray level dependence matrices' characterizing the texture in images. In spatial case high contrast is represented by means of principal diagonal which is related to homogeneous regions and non-zero elements far from it. Here, the variable of interest is time. *N* values are the occurrences of a gray value *i*, followed by a value *j* in the THSP. As the sample shows activity, then intensity values change in time and the number *N* outside the diagonal increases. This matrix is sparse and it is mostly composed by zero. For normalization purpose, divide each row of matrix by number of times the first gray level appeared (Fig. 2).

$$M_{ij} = \frac{N_{ij}}{\sum_j N_{ij}} \tag{2}$$

The sum of the components in each row is equal to unity. This is the transition probability matrix between intensity values in the THSP. Measurement of the *M*-values around the principal diagonal with these features can be constructed. This second-order moment is called inertia moment (IM) of the matrix for the diagonal in the row direction.

$$IM = \sum_{M_{ij}} (i-j)^2 \tag{3}$$