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Localized analysis of paint-coat drying using dynamic speckle interferometry

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ABSTRACT

The paint-coating is part of several industrial processes, including the automotive industry, architectural coatings, machinery and appliances. These paint-coatings must comply with high quality standards, for this reason evaluation techniques from paint-coatings are in constant development. One important factor from the paint-coating process is the drying, as it has influence on the quality of final results. In this work we present an assessment technique based on the optical dynamic speckle interferometry, this technique allows for the temporal activity evaluation of the paint-coating drying process, providing localized information from drying. This localized information is relevant in order to address the drying homogeneity, optimal drying, and quality control. The technique relies in the definition of a new temporal history of the speckle patterns to obtain the local activity; this information is then clustered to provide a convenient indicative of different drying process stages. The experimental results presented were validated using the gravimetric drying curves

1. Introduction

When an optically rough surface is illuminated by coherent light, a granular high contrast pattern distributed in space with a homogeneous mean intensity can be observed–these patterns are known as speckle. Characteristics of speckle are related to the macroscopic properties of the illuminated surface under analysis [1].

Over the years several speckle measurement techniques have being developed. Some of those techniques rely in the changes over time of the speckle patterns. The dynamic speckle phenomenon occurs when laser light is scattered by samples with a time-dependent activity, for example to characterize fruit slices, confirm seed viability, fungi detection and ultrasound imaging [2–7].

The activity could be observed in non-biological and biological samples and it is a consequence of the changes in the phase of light produced, for example, by movements of the scatters centers. As analyzed in several contributions, the mentioned effect produces variation in local intensity known as “boiling speckle” due to its visual appearance.

In a previous work, dynamic speckle pattern method was applied to study the drying of paint process [8-10]. The dynamic speckle pattern is generated when the paint surface is illuminated with coherent light. In fact, the illuminated surface changes mainly due to solvent evaporation and layer formation, thus giving rise to mentioned speckle activity.

Amalvy et al. [8] introduced the use of the co-occurrence matrix of the time history from dynamic speckle pattern as a method to measure the activity. The temporal history of the speckle pattern (THSP) is generated by setting side by side a certain column of pixels corresponding to successive images. The activity of the THSP image appears as intensity changes in the horizontal direction.

Different descriptors to address the dynamic speckle patterns activity using THSP have been developed, including some based on wavelets transforms [10-12], taking as a starting point, the sequence of data generated in the original work of Amalvy et al. In particular, the authors demonstrate that all the measures tested performs better than the one used in the original work. It should be noted that with these methods provide a global assessment of the paint drying process and could not be used to determine the local evolution.

In [8] the image is divided into columns and the middle one is used in each speckle image in order to generate the THSP. The column is purposely selected in the center of the speckle pattern record. This supposition considers small activity changes along the center of the sample as compared to the edges. However, the activity change is related to the paint layer thickness.

Therefore, we propose an alternative method in order to identify areas with different activity in the drying of paints process. This dynamic speckle method can be used to evaluate the local activity on the surface, by means of a new temporal view of intensity levels The speckle images

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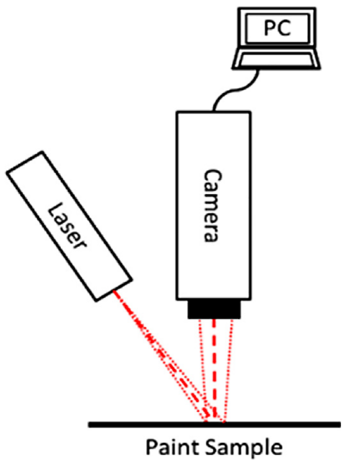

Fig. 1. Experimental setup schema for dynamic speckle recording and coating thickness in samples.

are subdivided in 5 × 5 pixels sub-images. Then, a 2-dimensional temporal history speckle pattern (2D-THSP) can be obtained by adequate gathering and processing successive speckle images. As in the conventional case, the 2D-THSP image shows a temporal variation of the gray levels of each pixel of the original speckle along the horizontal axis, nonetheless, the local activity can be evaluated.

The drying process of latex paint is accompanied to the loss of weight as it dries [8]. We also performed a gravimetric measurement in order to validate the proposed method and the experimental results obtained were compared with the gravimetric technique. We found that the resulting curves from the speckle-time evolution compares favorably with gravimetric drying curves.

2. Dynamic speckle: experimental arrangement

On the scale of an optical wavelength ($\lambda \approx 700$ nm) the paint surfaces are rough. It means that when coherent light coming from a laser is scattered by these surfaces speckle patterns appear as the sum of multiple independent complex components with random amplitude, random phase or both.

During the drying process, the coating's surface is changing mainly due to the solvent evaporation, leveling and particle diffusion. Then, the light scattered by paint surface presents a time-dependent activity. The associated speckle patterns will change over time as the surface changes, leading to the dynamic speckle phenomenon [8].

An experiment was conducted to evaluate the paint-coating drying process using dynamic speckle patterns. These patterns were recorded on different drying stages of a latex painting layer extended over a glass surface. For recording the speckle patterns the experimental set-up depicted in Fig. 1 was used.

An expanded 10 mW Helium–Neon laser beam (with a wavelength $\lambda = 632.8$ nm) attenuated with a neutral density filter illuminates the samples to be analyzed. The paint samples were prepared on a glass substrate using a standard stainless steel drawdown applicator onto a flat substrate. The paint layers were applied horizontally with different wet film thicknesses.

The scattered light is then recorded in a sequence of images, allowing tracking the changes over time thus providing a convenient tool to address the slight changes in the surface related with the drying process. When a phenomenon has low activity, there are less time variations in the speckle patterns. In the limit, when there is no activity at all, the speckle pattern shows no variation in the time direction.

The co-occurrence matrix was then calculated to characterize the speckle pattern activity.

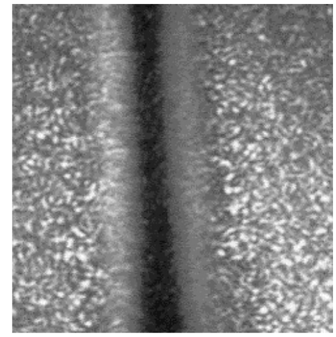

Fig. 2. Recorded speckle samples for local drying evaluation.

Two paint samples were evaluated simultaneously, one with 50 μm and the other 150 μm thicknesses. In this case, the speckle images generated by both paint surfaces were registered by a EO-10012C CMOS Color USB camera connected to a PC. 8 bits' gray scale images (1000 × 1000 pixels) were recorded in the memory of the computer. An example of these patterns is depicted in Fig. 2, where the left side corresponds to the speckle recorded for 50 μm thickness sample and on the right side the speckle corresponding to the 150 μm sample. Care was taken so that the speckles were well resolved by the camera sensor. After drying approximately for 240 min steady state of the dynamic speckle pattern was reached for both thicknesses, indicating that the paint-coating was dry. 1000 successive images were recorded every 15 min. In our case, we define a frame as the results obtained from processing a set of 1000 images recorded over a period of 15 min in 0.9 s time intervals.

In our experiments, we obtained local measurements from the drying process over regions of interest. All the measurements were made in a motionless air and constant temperature room to limit the variables that affect the drying process. The humidity and temperature were those typical of a laboratory and commonly found during drying processes. The room temperature ranged from 20 °C to 25 °C and the relative humidity ranged from 50% to 70%.

Our proposal was validated by comparing the optical measurements with the conventional gravimetric measurements described by Amalvy et al. in [8]. In this case, a single coating layer with an average thickness of 50 μm was applied over the glass substrate. The glass substrate was located on an analytical scale to measure the weight loss due to the drying process and a sequence of 8-bits gray scale images (512 × 512 pixels) dynamic speckle patterns were registered using a PULNIX TM-6CN CCD monochrome camera connected to a PC.

3. Window Operation: local activity evaluation

From the recorded speckle patterns a region of interest was selected for each of different layers. Two paint coating thickness were used in the experiment, and two regions both of 600 rows × 100 columns where selected on each case. Fig. 3 depicts the selected regions used in the experiment, the region marked with blue is the speckle corresponding to the 50 μm layer and the region marked with red the speckle corresponding with the 150 μm layer.

Each region of interest was cropped in 5 × 5 window matrices; these matrices contain a portion of the speckle pattern, the size of these matrices was selected to represent less than 0.05% of the total image, and could be modified based on the recordings resolution and sampling. Note that the window matrix dimension is selected taking into account a compromise between spatial resolution and statistical behavior. As consecutive recordings were made during the drying process, it is expected that this patterns change over time due to the surface activity related to the coating drying. The 5 × 5 matrices will be considered as windows from the speckle pattern allowing for characterize the activity on each region. These windows do not overlap with each other and cover the