Sensing paint thickness

Improving the accuracy of contrast ratio assessment using a specially developed laser unit.
Alfonso Leite, Ana Pereira, Fernanda Oliveira, Joaquim Mendes, Adélio Mendes, José Alves, José Nogueira.

An automatic unit, based on a laser sensor, can accurately determine the thickness of wet paint films. This enables the contrast ratio (CR) to be determined with far better accuracy because it is possible to determine, with the proposed mathematical relationship, a CR corresponding to a certain thickness. This work could help the development of methods to measure the CR and the colour strength of tinting bases with improved accuracy and speed. This would greatly speed up the quality control normally performed before the approval of any batch of paint, without any loss in the reliability of the results.

The quality of a paint is assured by controlling several characteristics. One of the most important is the opacity; it quantifies how effectively a paint covers the surface on which it is applied. There are several ways to measure the opacity of a paint, the most frequent being the determination of the Contrast Ratio (CR).

The contrast ratio (CR) is an important characteristic of a paint, which is experimentally determined by using a spectrophotometric method. The CR is highly dependent on the paint film thickness, among other factors. The drawdown bars, which are normally used for spreading the paint over the paper cards, produce films with a large standard deviation in thickness. This is due to various factors; among them, the paint rheology and the normal pressure and speed at which the drawdown bar is moved. Also, the paint film thickness is normally assumed to be equal to the gap depth of the drawdown bar which is far from being correct.

The CR is usually determined by a spectrophotometric method. It consists on spreading the paint over a paper card (which is half white, half black), and measuring the reflectance of the dried paint film in the white (Rw) and black (Rb) areas. The ratio between these two reflectances is the definition of CR, usually expressed as a percentage (equation 1 [formula see PDF page 3]).

The application of the paint is done with a drawdown bar (a metallic bar with a gap between the bar itself and the surface beneath). The paint is placed on top of the card. Moving the drawdown bar at a constant velocity causes the paint to be spread over the card, in a thick film. The thickness of this film is directly related and normally assumed to be equal to the gap depth of the drawdown bar used. The paint is left to dry, and the CR is then determined.

Several influencing factors
The CR depends on two major factors:
- the paint itself: its composition determines its capacity to cover the surface underneath;
- the thickness of the paint film: the thicker the film is, the higher its opacity.

The CR is usually associated with the wet thickness, that is, the thickness of the film immediately after being applied (according to the ISO 2814 standard). The wet thickness of a paint film is affected by several factors, the most important being:
- the gap depth of the drawdown bar;
- the paint rheology;
- the velocity and the pressure applied on the drawdown bar.

Some of these factors are difficult to account for. The same paint applied with the same drawdown bar, by the same person, will not always lead to the same thickness. There are currently several conventional methods for determining the thickness of wet paint films, but they normally demand contact with their surfaces, disabling the determination of the CR. In addition, these methods do not have the required accuracy.

Developing a new device
The objective of the current project was to develop a new device, able to determine the thickness of wet paint films, with high accuracy (± 1µm), avoiding the contact with the surface. The devised technique was the laser, because of its ability to obtain highly accurate and reproducible values, without the need to physically interact with the object under study.

After a market survey for the best-suited sensor, the "OMRON Z4M-N30V" laser was selected. This sensor uses a red laser beam (λ=670nm) designed for measuring short range distances (28~32mm) with high accuracy (± 0.4µm).

As required, it is capable of producing outputs independent of the paint composition, with no contact with the measured object. To determine the distance to the surface over which the light is reflected, this laser uses an internally implemented triangulation method. This method is based on the measurement of the time-of-flight of the light. In order to improve the results, lenses are placed in the reception, to amplify the signal. In addition, "smart" electronic circuits and optical filters prevent the measurements from being dependent on the ambient light.

Description of the laser unit
The unit for measuring the thickness of wet paint films was based on the laser sensor that has been referred to (Figure 1). The unit developed comprises:
- a laser sensor, previously described;
- a vacuum table, where paper cards are placed. Vacuum is then applied in order to keep the cards perfectly in place;
- a "STAR SGK 12-85" laser carrier, which is responsible for holding the sensor and moving it along an axis.

This motor was selected because of its high precision and smoothness. The angular position is known with a resolution of 0.12°, which corresponds to a linear motion of 0.8µm. The unit is controlled by a PC equipped with a 16bits data acquisition card. The controlling software was developed in "LabView 6.1".

The laser sensor determines the distance to the surface beneath. To evaluate the thickness of a paint film one has to determine two distances: before and after applying the paint film. The difference between these two distances is the coating thickness.

Accuracy and reproducibility of the laser unit
The accuracy of the laser unit was assessed from two different tests: the first used plastic standards and the second a drawdown bar calibrated by a certified laboratory. The standards are small plastic sheets, transparent or opaque, with different colours and all with calibrated thicknesses; being relatively small, the standards were placed secured manually to correctly hold them down. The largest discrepancy obtained between the results of the
laser unit and the standard values for the opaque plastic sheets was 2.5%, corresponding to a thickness difference of 1.6µm. A larger difference was obtained for the transparent standards. This is explained because the laser sensor has difficulties in identifying the surface of transparent objects. Hence, the use of this unit for measuring transparent coating thicknesses, like varnishes, has to be further studied. For the second test, a drawdown bar gap depth that had been calibrated in a certified laboratory, was also measured with the laser unit. The gap dimension of the drawdown bar is referred to be 100µm. An average thickness of 98µm was obtained during the calibration by the laboratory. When using the laser unit, an average gap dimension of 98.1µm was obtained, confirming the accuracy of this system. Moreover, since it is possible to measure the gap along the drawdown bar, one can observe that the gap depth is not constant throughout. The reproducibility was assessed by measuring 10 times the thickness of the same dried paint film. The average thickness was 28.3µm, with a standard deviation of 0.4µm.

Using the laser unit for obtaining the true CR
In order to obtain the relationship between the CR and the thickness of the wet paint films, a series of experiments was performed, where films of different thicknesses were applied and their CR determined. The relationship between the wet thickness and the CR of paint films should verify two limit conditions: a) being linear for very low thicknesses and b) approaching a constant value for very high thicknesses. Two empirical expressions that follow the required limit conditions were proposed (equations 2 and 3 [formula see PDF pages 4 and 5]), where a, b, c and d are parameters and 6 is the film thickness.

Three different white paints, manufactured by CIN S.A., were studied: "Vinylmatt", "Vinylsilk" and "Vinylsoft". These paints were chosen due to their different glosses. For each paint, a series of 12 tests was performed, with applied wet thicknesses ranging between 30 and 130µm (corresponding to drawdown bars with gap depth between 50 and 200µm). It was observed that there is a fairly constant difference of about 30% between the gap depth of the bars and the actual wet thickness of the film, for the gap depths used. The parameters of equations 2 and 3 were obtained by minimizing the sum of the square of the residues. Both expressions proved to fit very well the experimental results. The results are presented in Table 1.

The differences between both fitting curves are not significant. However, equation 3 seems to fit the experimental data slightly better (Figure 2). The relationship proposed can be used to determine, with high accuracy the CR for the wet thickness of 100µm (as required by the ISO 2814 standard). In order to draw the curves in Figure 2 and interpolate the CR for the reference thickness of 100µm, one must experimentally obtain some points above and below 100µm. Once an equation is established for a certain paint, the CR for any batch can be tested even if the applied thickness is not 100µm.

For example, for a "Vinylmatt" sample and using a drawdown bar with 100µm nominal gap depth, the experimental average film thickness obtained was 66.8µm and the CR was 93.77%. It can be seen that the nominal drawdown bar depth is quite different from the real wet film thickness obtained. Using equation 3 applied for "Vinylmatt" (Table 1), one obtains a CR of 93.27%, for the film thickness of 66.8µm. This value is very similar to the one experimentally determined. It is also possible, using the same equation, to determine the CR for the standard wet

CR of a paint is highly dependent on its film thickness
The thickness of paint films, obtained using a drawdown bar, is controlled by several factors, some of which cannot be accounted for. Practical experiments show that wet film thicknesses can differ as much as 35% from the nominal drawdown bar gap depth. If the film thickness is unknown, it is not possible to obtain the CR accurately. This work is a first step in the development of methods for determining CR of white paints and the colour strength of tinting bases in a faster and more accurate way. As both CR and colour strength depend on the amount and the correct dispersion of titanium dioxide, it should be possible to develop a correlation between these characteristics. This correlation will allow, with a single determination, to obtain both characteristics and also to speed up the quality control normally performed before the approval of any paint batch. The laser unit could also find other applications, such as to determine the thickness of dried paint films, or calibrate the gap depth of drawdown bars.

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\[ CR(\%) = 100 \times \frac{R_b}{R_w} \]
\[ CR (\%) = 100 \times \frac{\delta}{a \times \delta + b} \]
\[ CR (\%) = 100 \times c \times \exp \left( \frac{-d}{\delta} \right) \]
Figure 1: Detailed view of the laser unit
Figure 2: Experimental data and fitting curves (equation (3)), for three paints: a) "Vinylmatt", b) "Vinylsilk" and c) "Vinylsoft"
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<td>$a$</td>
<td>$b$(μm)</td>
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<tr>
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