Paper A27

Color prediction in wet leather – Mathematical modeling using linear regression

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Abstract

Dry colour prediction of leather based on its colour in wet condition using optimal regression model is described in the present investigation. Delay in the time for drying of thick substance in wet leather to obtain final dry colour can be avoided in color matching using such a prediction. The use of computer technology interfaced with reflectance spectrophotometer provides a novel approach to the prediction of dry colour from that of wet leather. The study was carried out for brown shades on full chrome goat upper leather. An empirical equation relating wet and dry reflectance value for the commonly used brown dyed leathers were developed. Based on the reflectance data, mathematical model was developed by taking dry reflectance of the leather sample as dependent variable and wet reflectance of the leather as independent variable. The present study suggests that the cubic model $R_d = -5.01 * R^3_w + 0.2616 * R^2_w + 18.63 * R_w + 13.34$ with R^2 (total variance of Y) value of 0.9826 and Root Mean Square Error (RMSE) value of 1.533 can be used for accurate prediction of dry colour from that in wet stage for brown dyed leathers.

Introduction

Leather products are fashion-oriented commodities in international trade and consumer acceptance and marketability are highly influenced by the colour of the leather. The role of a dyer is very crucial in getting the right shade to meet customer demands in dyeing process during the leather manufacture. The subjective way the humans see and perceive color makes it very difficult to define and quantify a particular shade. It is necessary to employ a reliable and objective instrumental method of color measurement and quantification for effective and transparent communication between dyer and the ultimate consumer. On the other hand, as the manufacturing locations have become more dispersed, the pressure to reduce the time between design and delivery of the finished product to the consumer has also increased. There is a need for the leather industry to shift to reliable automated or computer controlled quality control systems from the traditionally used subjective methods. Earlier attempts were made in our Institute to develop instrumental methods for the objective assessment of fastness characteristics [1], dye levelness [2] and studies are being continued to develop a software for instrumental colour matching for leathers by taking care of the influence of important parameters in dyeing [3]. This paper examines the prediction of 'dry' colour from 'wet' colour for full chrome goat upper leather dyed with brown dyes.

The color of wet leather is different from the color of the same in dry condition. Many researchers have attempted to predict dry colour from wet stage in textile dyeing [4-7]. However, there are no study reported so far to predict dry color from wet stage in leather dyeing. The reflectance of objects which are optically discontinuous like leather are controlled by a combination of absorbance properties of its constituents and their light scattering efficiency. The leather looks darker in wet than in dry condition due to the reduction of ratio of the refractive indices of the scattering particles to that of the continuous medium, and thus the scattering efficiency of the system is reduced. The wet to dry color change slows down the process of color matching because, in present practice, a sample from a dye bath must be dried and conditioned before it can be assessed. If the dyed leather sample deviates from the swatch, re-dyeing and reprocessing of leather may be necessary, which is time consuming and results in high cost. The process would be much more efficient if the final color of the leather sample could be accurately predicted after assessing it in wet condition, fresh from the dye bath. Hence, color prediction of dry leathers in wet stage is important for efficient color matching in leather dyeing.

In the present investigation, the system for dry color prediction was developed using brown dye. For the leather dyed with brown combinations, reflectance spectra were measured at different stages of drying [8]. The colour measurement was carried out according to CIELAB 1976 and the modified CIELCH system [9-21]. Empirical equation was developed relating the reflectance values of leather substrate under dry and wet conditions [23-27].

Experimental

Materials

Good quality wet blue goat skins of size 4-5 sq.ft without any major surface defects were chosen for the study. All the chemicals used for leather processing were of technical grade and the proprietary auxiliaries were from BASF India Ltd. Dyes with Color Index No. C.I. Acid Brown 165, C.I. Acid Yellow 110 and C.I. Acid Red 131 were purchased from Clariant India Ltd and were of commercial grade.

Leather Sample Preparation

Required quantity of wet blue goat skins were processed into full chrome undyed crust as given in Annexure I. The amount of dye offered to all the leather sample was maintained constant at 4%. Different brown shades were obtained using yellow and red dye along with brown dye in two dye combinations under the ratio 1:3, 3:1, 2:2 and 4:0.

After the dyeing process, the leathers were piled for 10 minutes to drain excess water. 4x3 sq.inch samples were cut and marked as left and right sample. Left cut samples were taken for reflectance measurement and the right cut samples for moisture content analysis. All the samples were air dried at room temperature (24±2^{o}C). Reflectance measurement was made for every one hour up to 24 hours till the leather becomes completely dry.

Colour Analysis

All the reflectance measurements were carried out using Gretag Macbeth Spectrolino Spectrophotometer interfaced to a digital PC. Before measuring the samples, instrument was calibrated against white MgO tile with illuminant D-65, 10-degree standard observer including UV component and excluding specular component with measurement geometry of 45^{o}/0^{o}. The reflectance of each sample was measured at 36 discrete wavelengths in the visible range 380nm – 730nm, at 10nm intervals. For reflectance measurement the 8mm aperture was used and four readings were taken. The sample was moved between each reading and the final reflectance data were averaged over these four readings [8]. Wet reflectance values were measured for every one hour up to 24 hours at various time intervals. CIELab color values were calculated from the measured reflectance values for all wet and dried leathers. The L,a,b values obtained lead to better understanding of color and the change in color between wet and dry samples. The influence of moisture content on surface leather color was also analyzed [9-21].

Prediction of dry color from wet stage

An empirical relationship between the color of the wet and dry samples was derived using the reflectance values of the brown dyed leather samples *i.e.* pairs of dry and wet reflectance values. Curve fitting data analysis was used to compute unknown coefficients of the linear function that relate wet and dry reflectance using the above pair of reflectance data [23].

In this study, the dependent variable was dry reflectance (R_d) while the independent variable was wet reflectance(R_w). SYSSTAT software was used for finding the values for the coefficients such that the function matches the wet reflectance data with the corresponding dry reflectance data [24-27].

Five different curve fitting methods such as linear fit, quadratic fit, cubic fit, 4th and 5th degree polynomial fit were employed to relate the wet and dry reflectance values.

Linear fit, $R_d = P_1 * R_w + P_2$ (1)

Quadratic fit, $R_d = P_1 * R_w^2 + P_2 * R_w + P_3$ (2)

Cubic fit, $y = P_1 * R_w^3 + P_2 * R_w^2 + P_3 * R_w + P_4$ (3)

4th degree polynomial fit, $y = P_1 * R_w^4 + P_2 * R_w^3 + P_3 * R_w^2 + P_4 * R_w + P_5$ (4)

5th degree polynomial fit, $y = P_1 * R_w^5 + P_2 * R_w^4 + P_3 * R_w^3 + P_4 * R_w^2 + P_5 * R_w + P_6$ (5)

where P_1, P_2, P_3, P_4,P_5 and P_6 are the regression constants of the respective functions.

The wet reflectance and the corresponding dry reflectance data were placed on the data grid and the curve fitting method was chosen. The measured dry reflectance data were taken as the standard. SYSSTAT software based on the curve fitting model selected calculates the parameter regression constants (P_1, P_2, P_3, P_4, P_5 and P_6) as given in the above equations 1 to 5 and predicts the dry reflectance value (R_d) from the wet reflectance value (R_w).

Prediction of dry reflectance data

Using the derived empirical equations [Eqn 1 to Eqn 5] mentioned above, dry reflectance values were predicted from the measured wet reflectance values of the dyed leathers for five randomly selected unknown shades. After drying the leathers, the actual dry reflectance values were measured. Color values were also calculated for the predicted and measured dry reflectance values [9-21]. The color values were compared for the predicted and measured dry reflectance values and the equation corresponding to the best fit was identified. This equation was taken as the developed equation to predict the dry reflectance values from the wet reflectance values.

Results and Discussions

Prediction of dry reflectance values from wet reflectance

Using SYSSTAT software, five different models i.e. linear fit, quadratic fit, cubic fit, 4th and 5th degree polynomial fit were used to relate the wet and dry reflectance values. The derived equations establishing the relationship between wet and dry reflectance values, coefficient of determination (R^2) and the RMSE values of the five selected regression models are tabulated [Table 1].

TABLE I. Linear Regression Analysis

Model	Equation	R^2	RMSE
Linear Fit	$R_d = 11.14 * R_w + 13.19$	0.9291	3.069
Quadratic Fit	$R_d = -0.7825 * R^2_w + 11.11 * R_w + 13.97$	0.9315	3.029
Cubic Fit	$R_d = -5.007 * R^3_w + 0.2616 * R^2_w + 18.63 * R_w + 13.34$	0.9826	1.533
4th Degree Polynomial Fit	$R_d = 1.326 * R^4_w - 5.337 * R^3_w - 2.398 * R^2_w + 18.93 * R_w + 14.01$	0.9848	1.439
5th Degree Polynomial fit	$R_d = 3.803 * R^5_w - 0.3467 * R^4_w - 15.15 * R^3_w + 0.4168 * R^2_w + 24.23 * R_w + 13.35$	0.9954	0.7971

Model Validation and Interpretations

All five models showed the ability to predict dry reflectance value from its wet stage. From Table 1, it can be observed that all the five models showed good model stability ($R^2 > 0.9$). Highest R^2 value was obtained for the 5th degree polynomial fit (0.9952) [Table 1].

All the five models were further evaluated for their ability to predict dry reflectance characteristics for unknown swatches. CIE color difference values were used to compare the predictive capability of the model. The reflectance values of the unknown samples were measured and the color difference values (L,a,b) were calculated and taken as control. The reflectance values of unknown samples were also predicted using the five models and the color difference values (L,a,b) were computed. The color values of the measured reflectance were taken as control and compared against the color values of the predicted reflectance values of the five models and the overall color difference (ΔE) was computed. Figure 2 illustrate the comparison of ΔE for 5 unknown swatches.

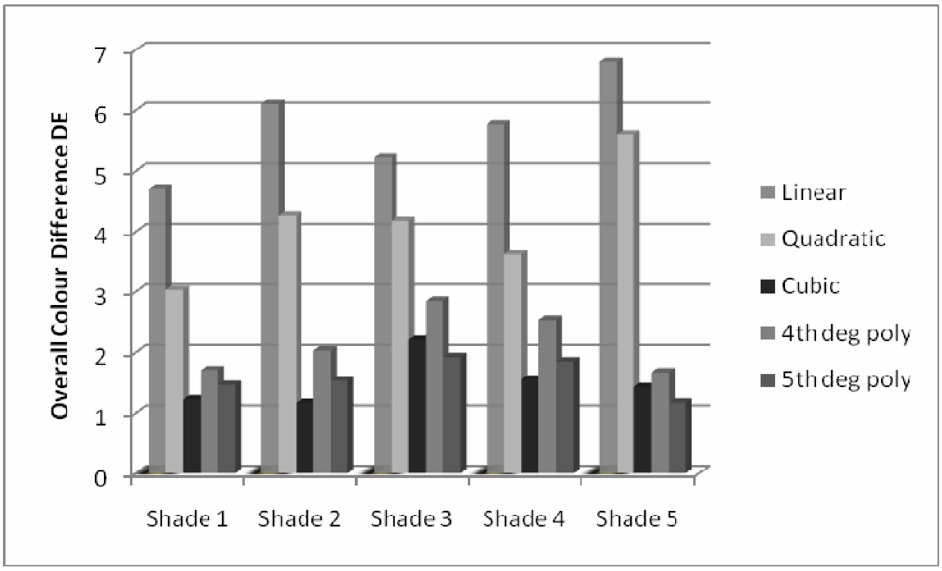

Figure 2 Color Difference Value (DE) for shades 1, 2, 3, 4 and 5 Predicted using five models

Observing the data from Figure 2, it can be inferred that the overall color difference values for linear and quadratic model were more than 3.0 for all shades indicating poor performance in predicting the reflectance values. Overall Color difference value was less than 2.0 for all the shades for cubic, 4th degree and 5th degree polynomial fit signifying closer match to the unknown swatch.

The data given in Figures 3, 4 and 5 allow us to draw a comparison between predicted and measured reflectance values for cubic fit, 4th degree polynomial fit and 5th degree polynomial fit model.

Figure 2 shows that the overall color difference for all the shades was less than 1.5 for cubic fit model and Figure 3 shows the prediction of reflectance data using cubic fit model was closer to the measured reflectance data. Therefore, it can be concluded that the cubic fit is the best mathematical model to predict dry reflectance values from that in wet condition for commonly used brown shades**.** The cubic model was taken as the empherical equation to calculate dry reflectance values at the point of dyeing itself.

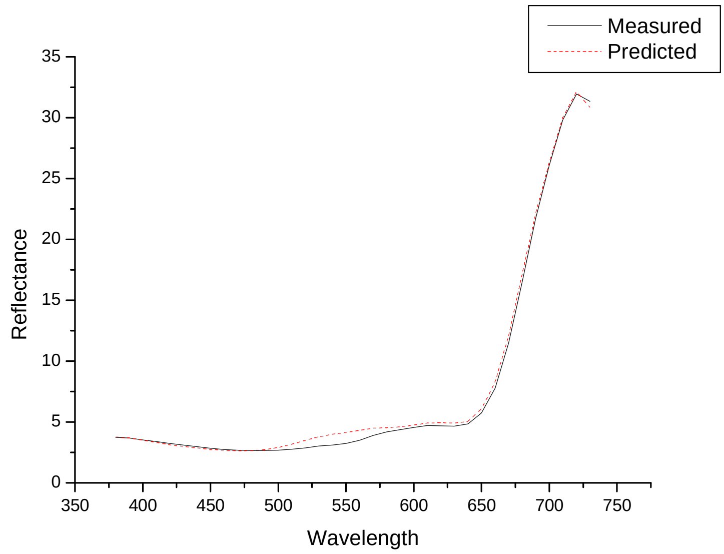

Figure 3 Comparison between measured and predicted dry reflectance derived using cubic fit model.

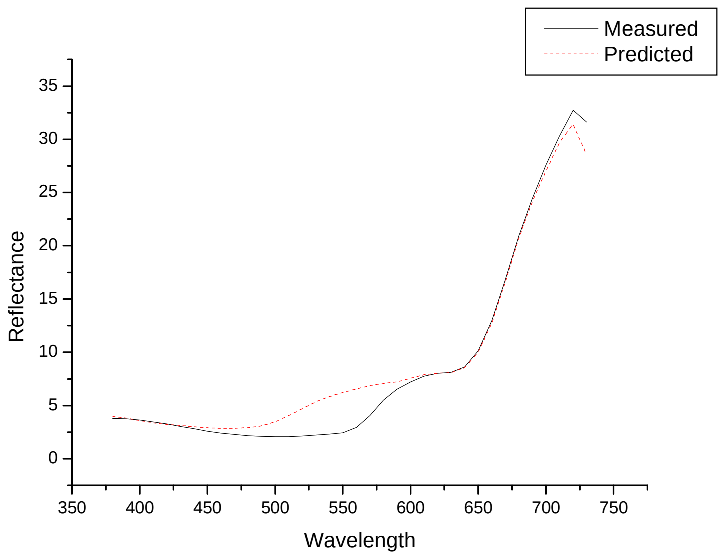

Figure 4 Comparison between measured and predicted dry reflectance derived using 4th Degree Polynomial Model.

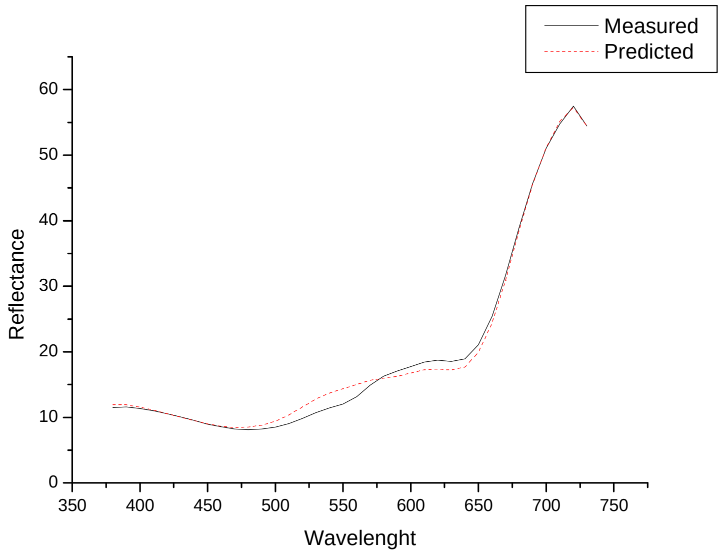

Figure 5 Comparison between measured and predicted dry reflectance derived using 5th Degree Polynomial Model.

Development of computerized dry color prediction

Gretag Machbeth reflectance spectrophotometer interfaced with computer was used for the dry color prediction. Reflectance values at 10 nm intervals in the visible range of 380-700nm measured on the wet leather sample provides the input for the computer. Using the cubic fit equation, dry reflectance values was predicted. From the predicted reflectance values, dry color values were calculated and compared with the swatch leather color values. The steps followed for computerized dry color prediction is shown in Figure 6.

Conclusions

In conclusion, colour difference values for the unknown shades indicate that the differences between the reflectance values predicted using log quadratic model and the actual measured reflectance values were not visually perceptible ($\Delta E < 2.0$). The developed log quadratic model provides a simple and an accurate method to predict dry reflectance values based on wet reflectance values. This method can provide vital clues to the dyer to make the necessary corrections in batch dyeing without the need to dry the leather enabling the avoidance of time delay in colour matching.

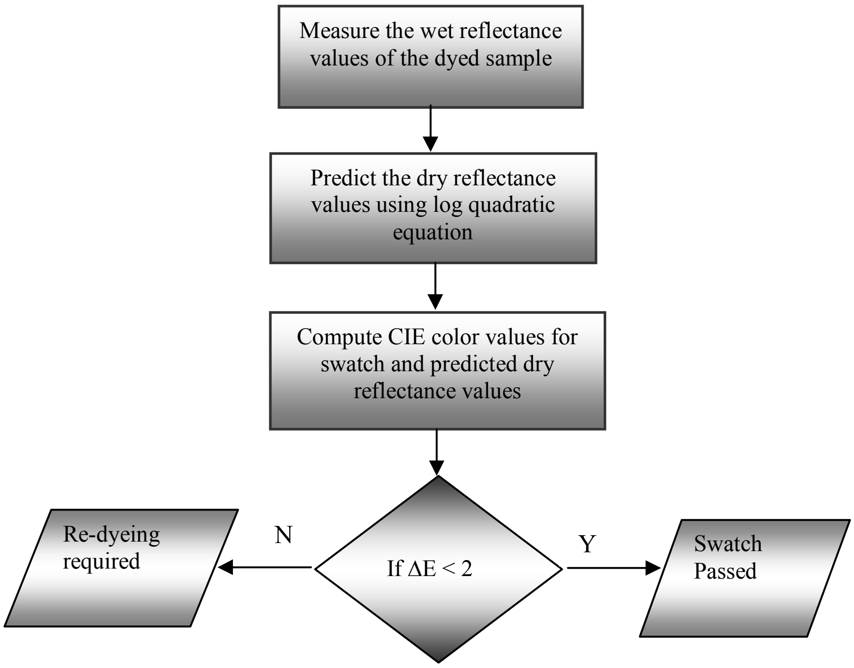

Figure 6 Steps for computerized dry color prediction

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