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PHYSICAL CHARACTERIZATION OF IRIDESCENT TEXTILES

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ABSTRACT

In recent years, iridescent materials have come to play an increasingly important role in the world of the industries like cosmetics, textile, automotive, etc. They belong to the goniochromic materials, that they have a variable and changing colour appearance, according to the conditions of observation or lighting. The extension of these materials and the complexity of their use and their reproduction in textile reveal new research orientations in this field. These consist in studying the origin of these colours, their optical properties, their various perceptible effects on the textiles.

The aim of our work is to develop a physical protocol of characterization which identifies the iridescence textiles and reveals their particularities in regard to the ordinary textiles without appealing to the human evaluation. An instrumental analysis has allowed defining the physicals characteristic of the iridescent textiles.

KEYWORDS

Special effect colours; Iridescence; Pigments; Goniochromic textile; Metallic effect

1. INTRODUCTION

Iridescent materials present striking colour changes under different illumination-viewing conditions. They are used in textile (Asano et al., 2001), so that their control is becoming a technological issue. The researches in this area consist in studying the parameters influencing their aspect, the different processing conditions and characterization methods (Perales et al., 2010) (Höpe et al., 2010).

We focus on these last ones. The present colorimetric formalism is particularly well suited to coloured light sources and plain objects. From a stimulus light spectrum, one can compute the coordinates of the perceived colour, represented as a dot in a colour space. In the case of an iridescent textile, the reflection spectrum strongly depends on the measurement geometry (Bakes, 2003) (Berthier, 2001). So that it is possible to associate to this object a cluster of points in the colour space. New tools have to be developed to characterize and control such materials.

Until now research developed are based on the identification of geometries of measures that characterize iridescence (determination of the angles of incidence and detection) and this by means of physical and sensorial measurements (Pfaff et al., 2003). (Kirchner, 2007). These previous studies have concerned the

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metallic and iridescent painting of automotive (McCamy, 1996). Research in the case of textile, have studied the iridescent effect obtained by the application of structured fibers and the influence of the structure of these materials on the colour variation (McCamy, 1998) (Kajiwara, 2000). In our present study we characterized the colour effect obtained by another type of functionalization by coating interferential pigments onto textile. The structure of fabrics in this case does not affect the colour variation, but only the structure of pigments that influence the results.

Here we describe a few physical methods to identify the colour change of iridescent textile relative to the various observation configurations, in order to distinguish the variation of colour without appealing to a visual evaluation. In this work, we present the colour variation in the CIELAB space, we analyze the topology of the cloud of points in the specular direction and we present a method that explains the orientation of pigments in the coating.

2. MATERIALS AND METHODS

The number of samples on which we based our study is on a set of 20 textile samples. We chose them representative of the various physical phenomena likely to appear. These samples are classified according to their appearances in four large families (see Figure 1):

- Plain samples: they present a plain effect. The main physical phenomena are absorption and scattering;
- Glossy samples: they present a glossy effect. The main physical phenomena are absorption, scattering and specular reflection at the interface between air and the material;
- Metallic samples: they present a sparkling effect. Main physical phenomena are absorption, scattering, specular reflection at the interface between air and the material, and specular reflection on metallic pigments;
- Iridescent samples: they present an iridescent effect. Main physical phenomena are interference reflection, absorption and scattering.

On a material point of view, the two first ones rather correspond to a textile samples coated with classical colour pigments. The third sample is coated with a metallic pigment in order to have a scattering effect. The last one rather corresponds to a textile sample coated with flake pigments (interferential pigments with different refractive indexes). The coating of different samples is constituted of 4% of pigments prepared in a varnish base. Here the three first ones are only considered as references for iridescent one (the fourth sample family in figure 1). This classification is only a first presentation, note that some samples present both sparkling and iridescent effect.

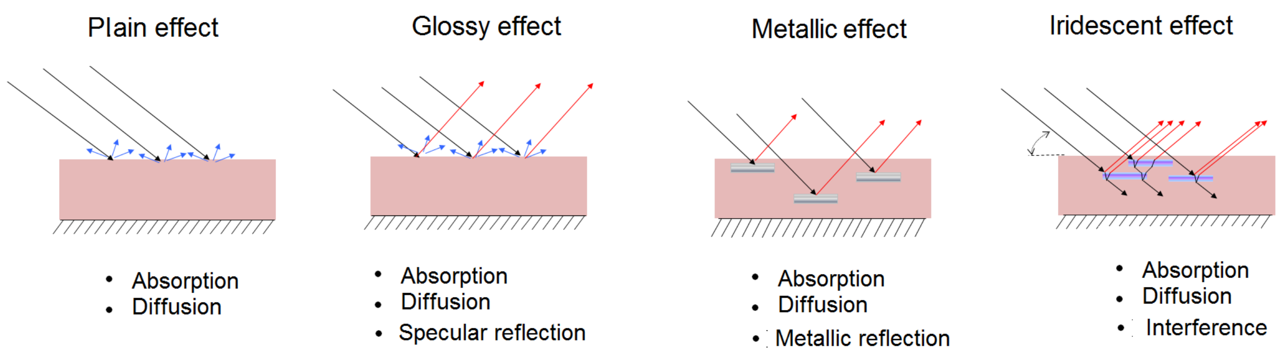

Figure 1: The type of samples used in our study and the physical phenomena, origins of their appearances

These goniochromic materials require unusual instrumental methods; the ordinary colorimetric instruments with a single geometry of measurement are not enough to characterize the variety of perceived colours (Alman, 1987) In order to investigate the different spectral responses of the materials, we used a multi-angle spectrophotometer X-Rite MA98 (see Figure 2). This spectrophotometer is equipped with two incidences. The first one is placed at 15° of the normal of the sample. The second is placed with 45° of the sample. This instrument is equipped with 6 detectors in the plan of incidence and 4 detectors out of the plan of incidence (see Figure 3). We can measure 19 reflection spectra. A 19 reflection spectra, is the result of measurement of 19 geometries of observation. The association of an incidence and a detector forms geometry of observation.

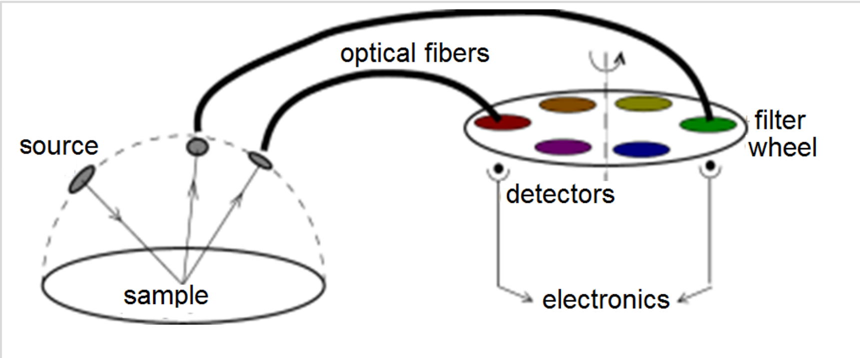

Figure 2: Principle of the spectrophotometer used the X-Rite MA98

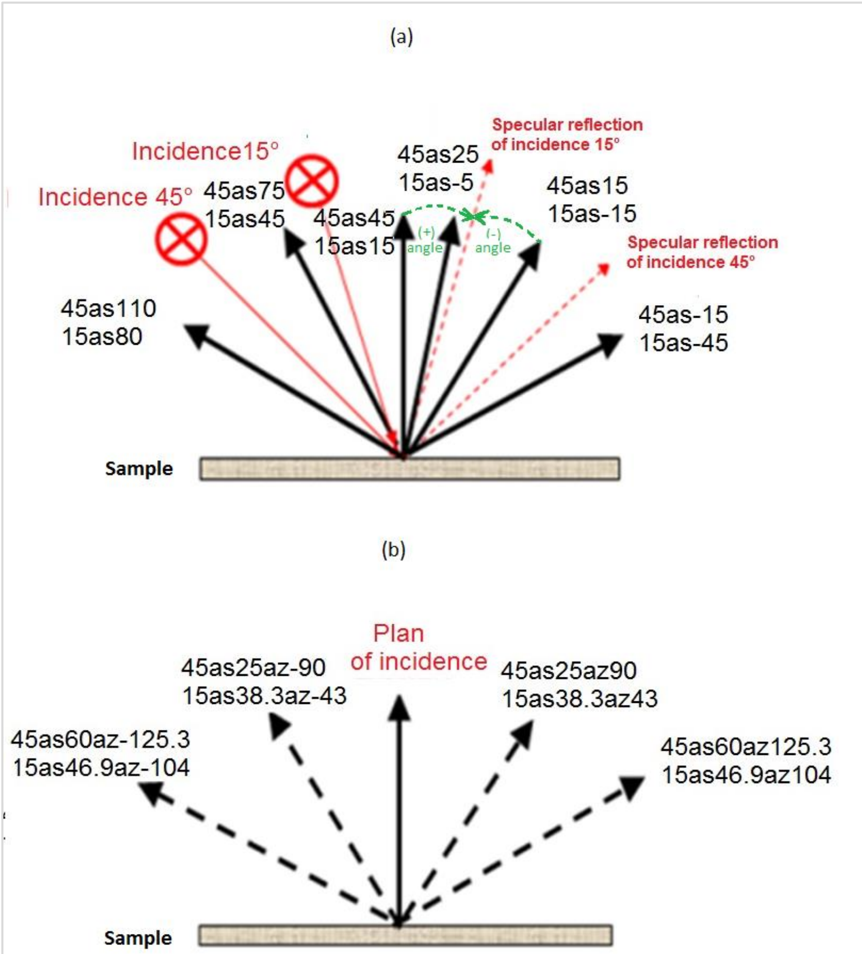

Figure 3 : a/Angles in the plan of incidence; b/ Angles out of the plan of incidence

Measurements with the two incidences at the same time allow a characterization of a metallic and iridescent effect (Bolomey et al., 1972). It allows measuring the reflection spectra in 19 geometries; thus we get 19 points in the CIELAB space. All reflection spectra are measured out of the specular direction, at least 15° from it.

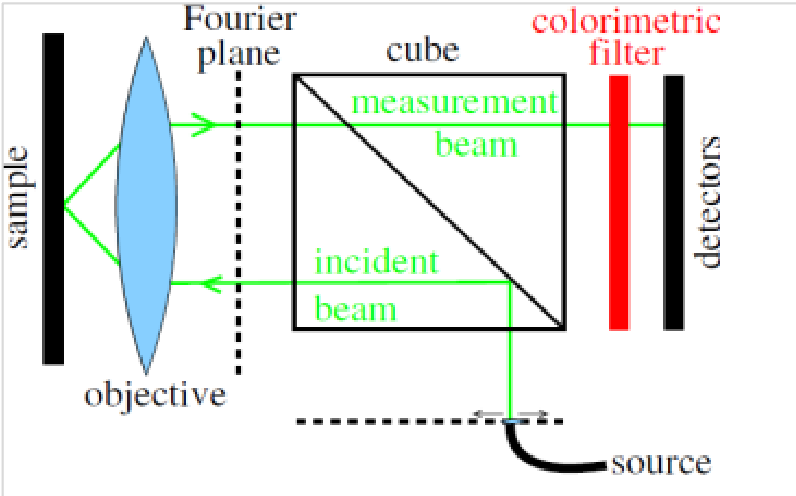

Figure 4: Principle of ELDIM-EZ-Lite-scatterometer

3. RESULTS AND DISCUSSIONS

3.1. Study of the evolution of the reflectance spectra with the multi-angle spectrophotometer (X-Rite MA98)

The first method to characterize iridescence is the evolution of the spectral response with the measurement geometry; we used the measures of the multi-angle spectrophotometer (X-Rite MA98). We have realized five measures for each sample with multiple measures in the longitudinal direction. The surface of measures of samples is spherical with axes L= 3 mm and l= 1.75 mm.

In figure 3, we presented only the reflectance spectra in the incidence plan under an incidence of 45°. They correspond to the reflectance spectra measured by the six detectors in the plan of incidence.

With an incidence of 15°, we have the same phenomenon. From 6 spectra: for plain and glossy samples (figure 5/a/b), only the amplitude of reflectance spectra varies. for metallic samples (see Figure (5/c), the more the detector is close to the specular direction (specular reflection), the more the spectrum is peaked; for iridescent ones, close to the specular direction, spectra present peaks whose wavelengths change with the measurement geometry (see Figure 5/d). With each geometry of observation, X-rite MA98 provides a reflectance values. Each reflectance values corresponds to the reflection values calibrated compared to a perfect diffusion standard. This makes it possible to increase the coefficients of reflectance and can exceed 100 % in the case of the ordinary samples.

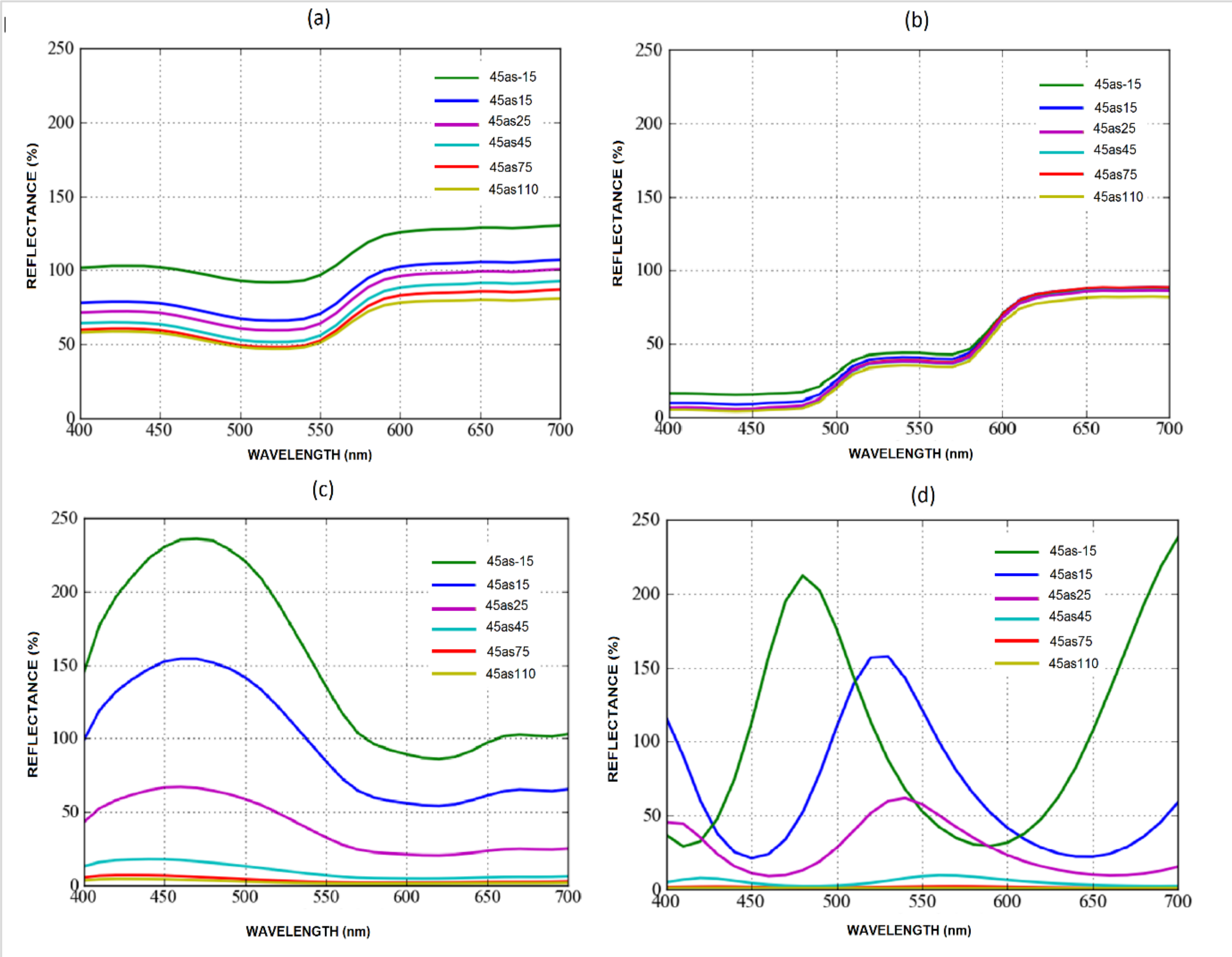

Figure 5: The reflectation spectra in the incidence plan under an incidence of 45°; a) Textile with plain effect; b) Textile with glossy effect; c) Textile with metallic effect; d) Textile with iridescent effect

3.2. Study of the evolution of the spatial distribution of the reflection spectrum with the multi-angle spectrophotometer (X-Rite MA98)

For a given incidence, the evolution with the wavelength of the intensity diffusion function (diffuse reflection), i.e. of the angular distribution of the reflected light in the plan of incidence, is an indication of iridescence. An important evolution of the spectral position of the reflection peak with the measurement geometry is a feature of interference that is considered as an important characteristic of iridescence.

For a given incidence we studied the dispersion of the intensity of reflected light in the plan of incidence according to the wavelength. It corresponds to the reflection measured by the six detectors in the plan of incidence.

On a figure 6, we presented for a given incidence (an incidence of 15°) the evolution of the intensity of reflection. This variation of intensity corresponds to the reflection measured by the six detectors in the plan of incidence. It is expressed by a variation of level of gray. The darkest zone represents a small percentage of reflection and the most clearly represents a strong intensity of reflection.

Here in figure 6: a/b, from 6 spectra: for plain and glossy textile samples, only the amplitude of the intensity diffusion function varies with the wavelength. For metallic samples (see Figure 6/c), around the specular direction there is a strong spectral selection: the specular lobe appears only in a given wavelength range. For iridescent ones (Figure 6/d), around the specular direction there is a strong spectral selection, whose central wavelength changes with the measurement geometry.

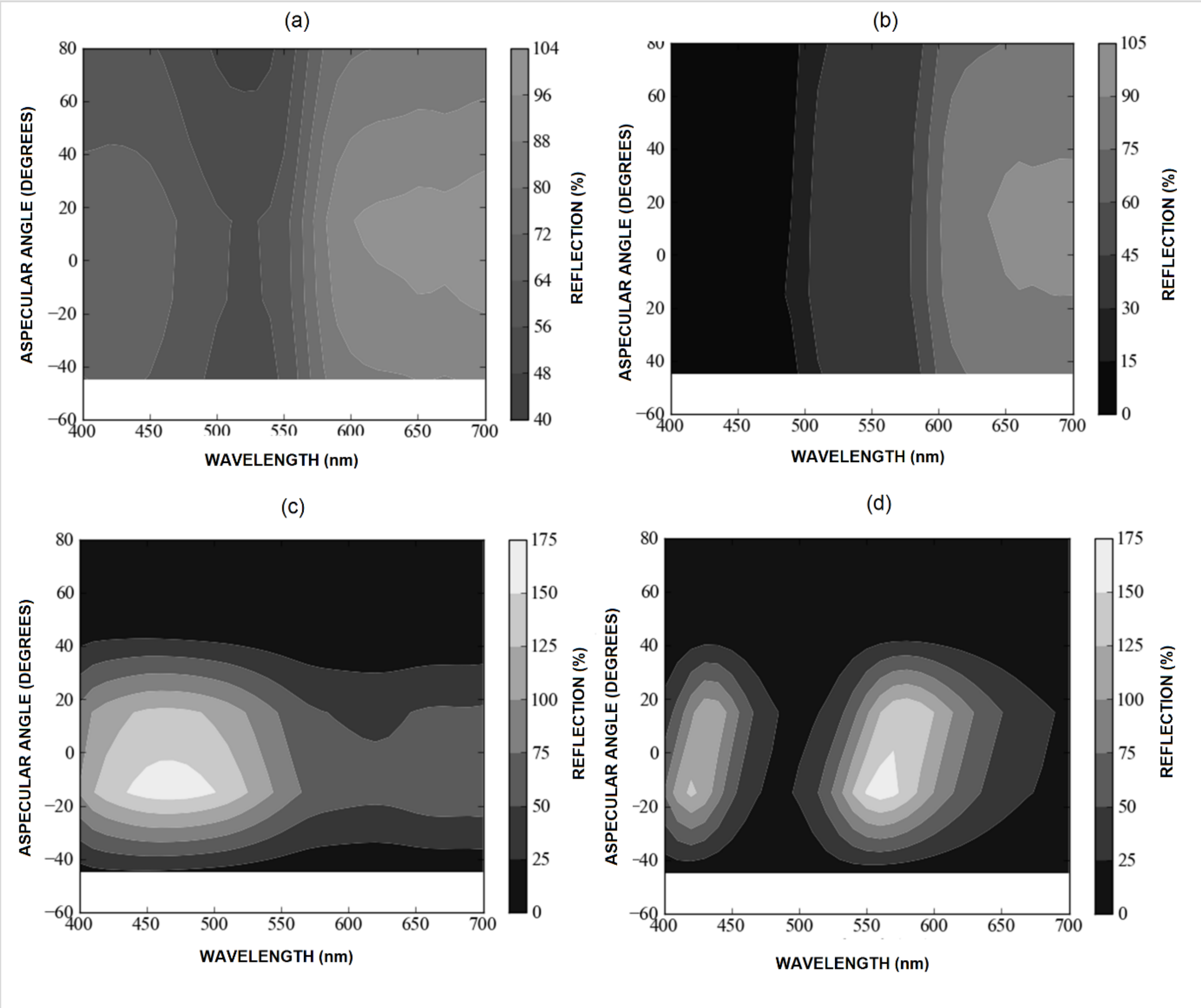

Figure 6: The spatial distribution of the reflection spectrum in the incidence plan under an incidence of 15° (multi-angle spectrophotometer); a) Plain effect; b) Glossy effect; c) Metallic effect; d) Iridescent effect

3.3. Study of the topology of the cloud of points in the CIELAB space with incidence angles = 20°, 45° with the ELDIM-EZ-Lite-scatterometer

To characterize the iridescent effect, a promising approach is to study the topology of the cluster of points in the CIELAB space. The multi-angle spectrophotometer (X-Rite MA98), measures the spectra of reflection in the 19 geometries; thus we get 19 points in the CIELAB space. In our case it is not sufficient to study the topology of the cluster of points in the CIELAB space (Gabel et al. 2008).

In order to have access to more geometries of measurement, we used an EZ-Contrast scatterometer from ELDIM. We have realized five measures for each sample with multiple measures in the longitudinal direction. The surface of measures of samples is circular with diameter of 3 mm.

This instrument is equipped with a D65 source and a set of colorimetric filters. For a given incidence, for every emergence angle (roughly 1000 angles in a cone of 80° semi-aperture), we get the coordinates (L*, a*, b*) of the light reflected in this direction. Thus we can get a cloud of roughly 1000 points per incidence angle in the CIELAB space.

Form these measurements we can study the cloud of points in the CIELAB space. It possesses a certain topology (shape) considered as a characteristic of the different colours of the sample. With this protocol of characterization, we are able to distinguish the special effect colours from ordinary colours without appealing to a visual evaluation. Results of the acquisitions provided by EZ_Contrast cannot be used directly. The approaches of the calibration, the filtering of the interfering signals and the masking of the negative values are to be finalized before calculating the coordinates (L*, a*, b*) from the values X, Y, Z and to present them in space CIELAB. The approach that we followed is presented in the following graph (Figure 7).

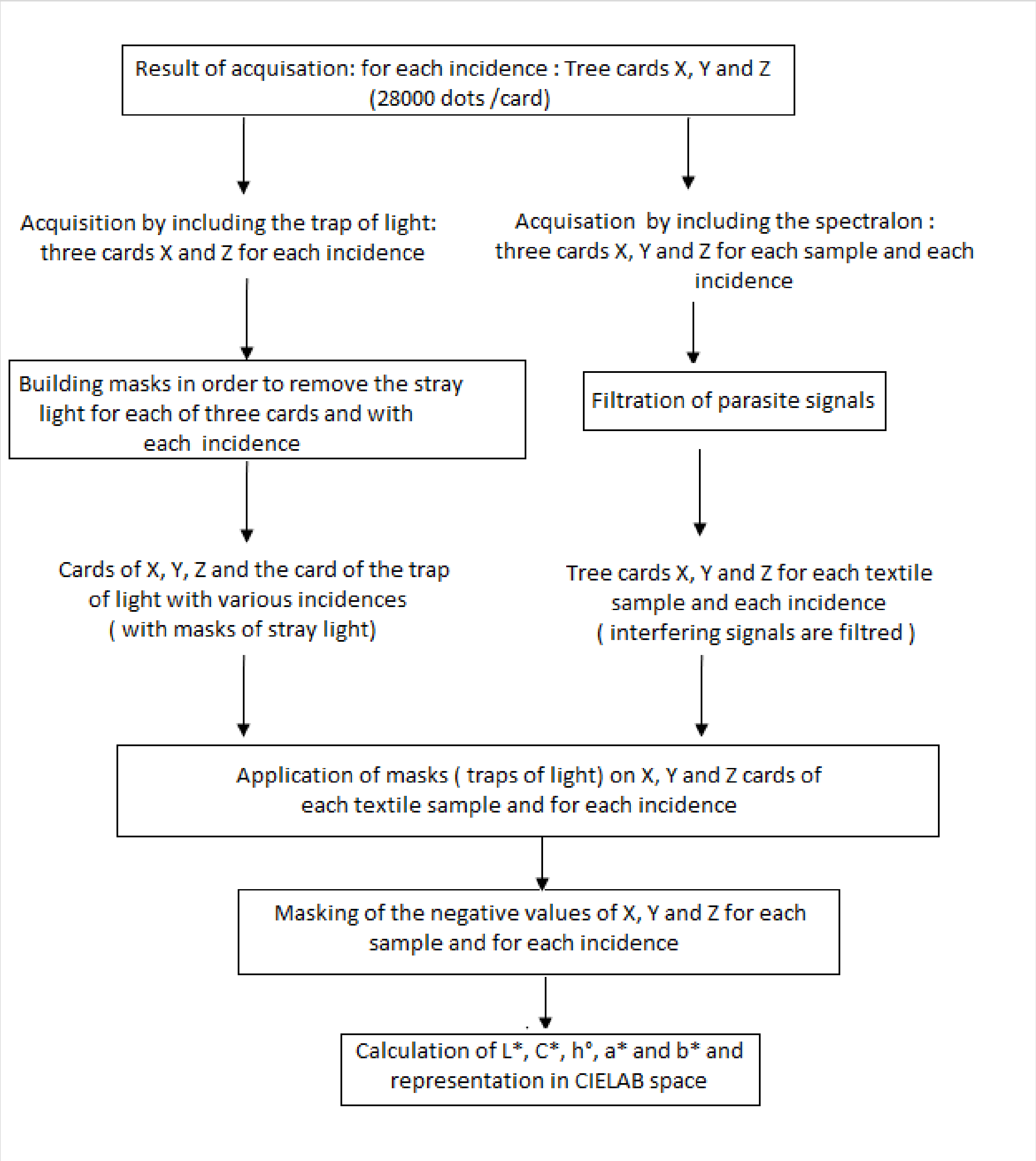

Figure 7: Approaches of the calibration, the filtering of the interfering signals and the masking of negative values

After calculating different coordinates L*, a*, b*, C* and h°, in space CIELAB, we presented the clouds of dots formed by theses values which were calculated from the acquisitions according to two incidences 20°, 45°. Contrary to X-Rite MA 98, EZ-Contrast scatterometer does not present an incidence at 15°. This is why we chose to work with the incidence nearest, available in the instrument which is 20°. Concerning the incidence with 45°, it is the same in the two apparatus.

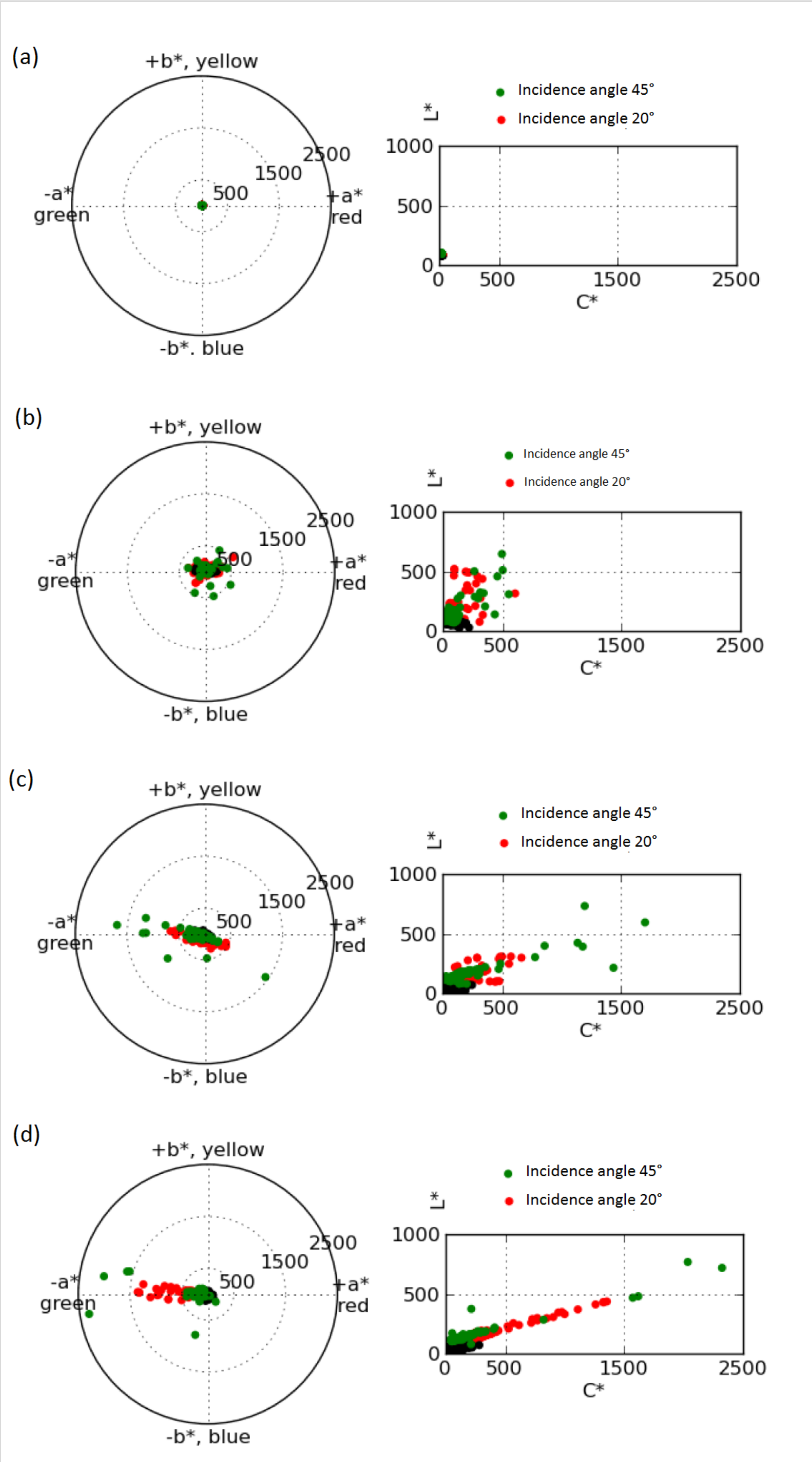

Figure 8: The topologies of the cloud of points in the CIELAB space with incidence angles = 20°, 45° with the ELDIM-EZ-Lite-scatterometer; a/ Plain sample (Grouped cloud of points); b/ Glossy sample (Important variation of L*); c/ Metallic sample (Moderate variation of L*,C*,h°); d/ Iridescent sample (Important variation of L*,C* ,h with saturated colour in the specular direction).

For each graph CIELAB (see Figure 8), we presented on the left, in radial coordinates, the chromaticity: the angle corresponds to the colour and the ray of saturation C*. On the right, we presented the saturation C* in abscissa and the lightness L* in ordinate.

The aim to present L* = f (C*) is to check the state of saturation of the colours measured in the specular direction. Which are always characterized by important values of clearness.

For all textile samples, by studying the shape of the clouds of the points formed by colorimetric coordinates measured following the two incidences, we observed that the form of the cloud of points characterizes each time a particular effect. Four profiles were distinguished. The first profile corresponds to the plain textile (see Figure 8/a), in the CIELAB space, the distance between the various points can be neglected. Points of colour are combined in the same place. On the other hand a light variation in clearness (L*) is sometimes noticed. L* varies slightly while approaching towards the specular direction.

The second profile of different groups of dots is presented in figure 8/ b. It corresponds to the results of measurement on glossy samples. In CIELAB, the points of colours vary essentially in lightness and a little less in saturation. The variation in hue is not considerable. For all glossy samples, a great values of L* are always noticed. The presence of the important white reflection in the specular direction explains this phenomenon.

The third profile of the groups of dots is presented in the figure 8/c. It corresponds to the results of measurement on the textile with metallic effects. They vary essentially in lightness and also in chroma. We observed also a small variation of hue. The points in the space CIELAB present an aligned path with less dispersion than the interferential samples. The reflected energy increases while approaching towards the specular direction. This specular reflection is coloured, what justifies this variation in L* and C*.

Figure 8/ d corresponds to the typical profile of the cloud of points characteristic of the iridescent textiles. They are distinguished by the variety of colours perceived according to the angle of observation and illumination and the great dispersion of the points of colours in the CIELAB space.

A variation in colour, chroma and lightness are always revealed. We notice on all iridescent samples the presence of saturated colours in the specular direction. This behaviour is a characteristic of the interferential nature of an iridescent sample.

3.4. Characterization of interference in iridescent textile sample

This kind of characterization concerns only the iridescent samples because they present generally interferential pigments (Kirchner et al., 2009). The plain, glossy and metallic samples don’t present interference phenomena, only to confirm this we present here the metallic sample.

To identify the presence of interferential pigments in the coating surface of iridescent textiles, our study is based on Merritt method (Merritt, 1925): the interference law is identified when the square of the extremum wavelength of the different spectral distributions varies linearly according to the square of the incidence angle.

In the figure 9, the correlation with the law of interferences is not confirmed with the metallic textile. We notice a very low coefficient of correlation (R=33.7 %), so there is no interference. On the other hand in the figure 10, the iridescent samples present a very high coefficient of correlation (R=99.6 %). A very high coefficient of correlation confirms the existence of interference. If the measured spectrum is explained by interference, so the source, the structure of pigments and the detector are in a "specular" configuration. This can imply that the reflective structure of pigments is tilted with an angel α compared to the average plan of the sample (see Figure 11). In addition we get information about the orientation of pigments in the coating. The angle α depend and change only with the orientation of the interferential pigments which are deposited in different layers with different reflection indexes. So we obtained interferential colours in the specular direction. The angle α doesn’t depend to the structure of textile samples because the surfaces of samples are coated with interferential pigments.

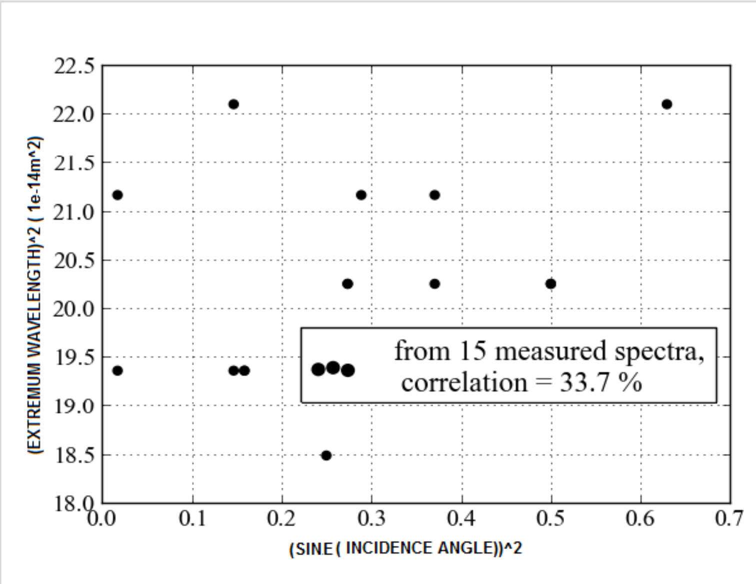

Figure 9: Metallic textile samples coated with metallic pigments: Bad correlation with the interference law

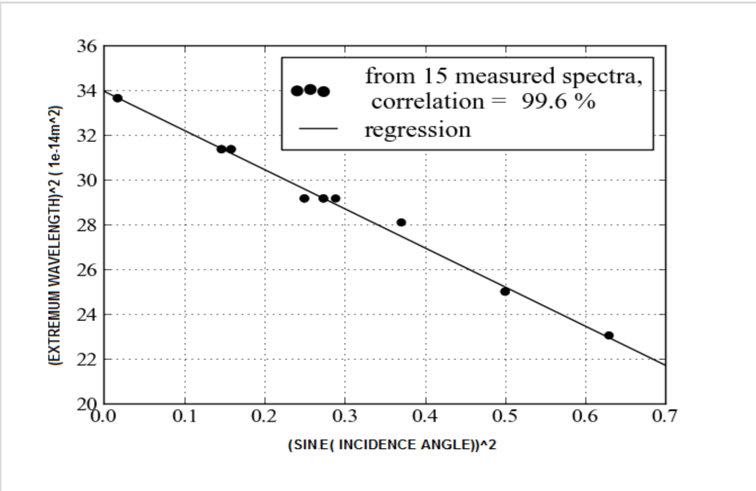

Figure 10: Iridescent textile samples coated with interferencial pigments: Good correlation with the interference law => Geometrical information

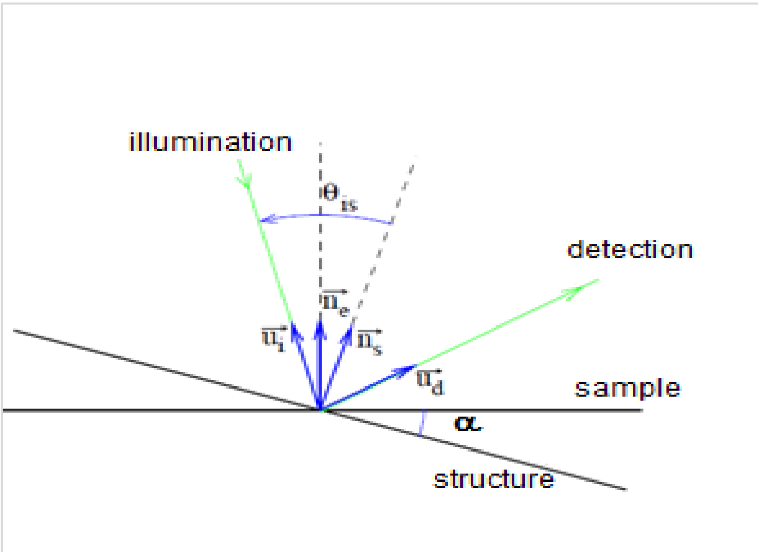

Figure 11: Reflective structure is tilted with an angel α compared to the average plan of the sample

4. CONCLUSION

Iridescent textiles have a very different aspect from classical, plain materials. These last ones have an invariable and uniform colour appearance, whatever the conditions of observation or lighting. The variation between the different spectral responses according to the angle of observation and illumination is the first characteristics which specify iridescence. For a given incidence, the evolution of the intensity diffusion function, i.e. of the angular distribution of the reflected light in the plane of incidence with the wavelength is another method to identify iridescence and to show its difference with a classical colour. An important evolution of the specular peak amplitude with the wavelength is a feature of interference.

In the CIELAB space the cloud of points possesses a certain topology (size, shape and volume) considered as a characteristic of the different colours of the sample. We are able to distinguish the difference between the materials without appealing to a visual evaluation.

Textiles with iridescent colours are distinguished by the important variation in colour, chroma and lightness, the wide dispersion of the points of colours in the CIELAB space and the presence of saturated colours in the specular direction. The textiles with metallic effects vary essentially in lightness. This is expressed by reflection spectra varying essentially in amplitude and not in shape. The points in the space CIELAB present an aligned path with less dispersion than the iridescent samples. Plain colours, vary slightly while approaching towards the specular direction. In the CIELAB space, the distance between the various points can be neglected. The points of colour are combined in the same place. Glossy textiles, present the same reflection spectra whatever the geometry of measurement, except in a specular zone. They scatter light uniformly in all directions, but they reflect significantly in the specular direction. In the CIELAB space, we hypothesized that colours are presented in the form of a “binary cloud” of points.

To identify the presence of interferential pigments in the coating surface of iridescent textiles, our study, based on Merritt method, show that even we have a very high coefficient of correlation between the square of the extremum wavelength of the different spectral distribution and the square of the incidence, this confirms the existence of interference. On an unknown sample, this could be an analysis method to check the presence of interference of visible radiation and get information about the orientation of the multi-layer.

Eventually these methods of characterization allow distinguishing between iridescent textiles and other textiles; without appealing to the human evaluation. This method or protocol of characterization will make it possible to identify the change of colour relative to the various conditions which play a part on the final perception (illumination, observation). This study opens the horizon to the other areas of investigation: calculations of the distance (difference) between two iridescent colours and studies of acceptability and tolerance can be established.

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