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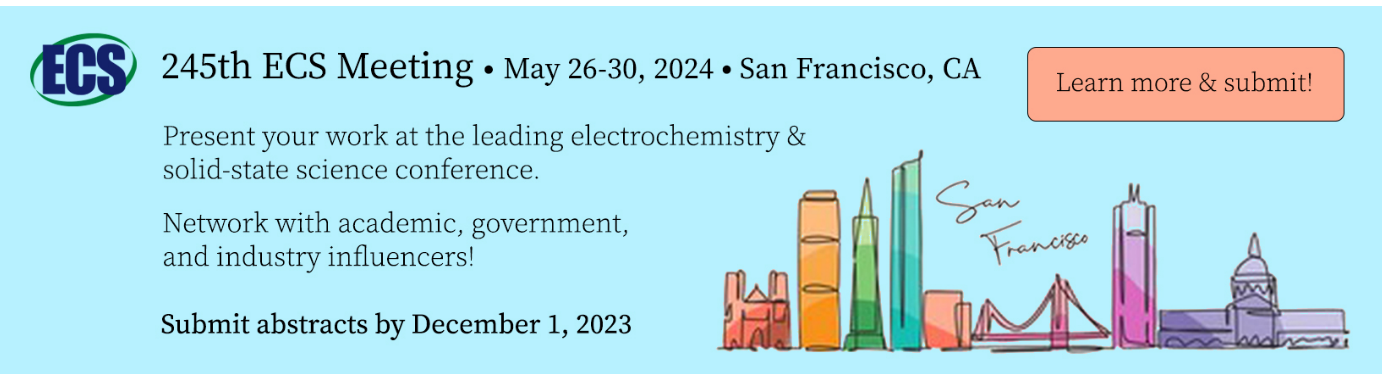

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Dynamic colour in textiles: combination of thermo, photo and hydrochromic pigments

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Abstract. Colour Change Materials are a class of smart materials that present distinct characteristics relative to conventional pigments and dyes. When exposed to a given stimulus, these materials exhibit reversible chromatic changes, allowing the introduction of dynamic and interactive qualities to textiles. Currently, the combination of various chromic materials presents an under-developed area. The objective of this research is to study the integration and combination processes of different types of dynamic colourants in textiles, namely thermo, photo and hydrochromic pigments. The experimental work conducted demonstrates the effect of screen printing variables in textile chromatic qualities, being the variables set: screen mesh count, magnetic field of the screen printing table, printed layers (number and process) and pigments' combination method – overprinting and combination in the screen printing paste. The results attained also highlight design possibilities to further research colour change effects and outline a methodology to explore and design screen printed textiles with multi-sensitive qualities.

1. Introduction

The emergence of Colour Change Materials (CCMs) has enabled the introduction of dynamic chromatic qualities to textiles by sensing and reacting reversibly in response to an external stimulus. This chromic behaviour is based on the variation of the substances microstructure or electronic state, affecting their optical characteristics; absorptance, reflectance, scattering or transmittance [1-2].

CCMs are denominated according to the stimulus that triggers the changes, also presenting different properties and behaviour [3].

Thermochromic (TC) leuco dyes change colour upon heat. They fade away above their activation temperature and return to the predefined colour below it. TC pigments can be combined with conventional pigments, according to the defined binder type. In this case, the effect of thermal variation reaches variations between colours [4, 5].

Photochromic (PC) pigments react to Ultraviolet (UV) radiation, being colourless in the stimulus absence and acquiring their predefined colour when exposed to it. Transition between colours can be also attained through combination of PC and conventional pigments [6].

The presence of moisture or water changes the optical characteristics of hydrochromic (HC) pigments. These materials are usually white and opaque in dry conditions, changing to transparent when exposed to water [3-7].

Currently, limited research has focused on systematic methods to develop colour changing textiles and the combination of various chromic materials presents an under-developed area. This research

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explores colour as a dynamic variable of textile design through three materials' types: TC, PC and HC pigments. The main objectives are to study the integration and combination processes of these colourants in textiles and to develop a methodology to create chromic textiles with multi-sensitive qualities.

2. Materials and methods

The chromic pigments handled in this research were supplied by SFXC: water based TC dispersion black, blue, magenta and yellow, with 31ºC activation temperature; water based PC ready formulated ink blue, magenta and yellow; water based HC ready formulated ink white. Conventional pigments were ATUSMIC Magnaprint yellow HG, pink H5B, blue HG and black H3B. Screen printing pastes were formulated with Gilaba vinyl acrylic binder.

Samples were screen printed on a Zimmer Mini MDF R541 table on a cotton substrate. The selection of the table's magnetic field level defines the pressure that the metallic rod-squeegee applies during paste application on the substrate. The levels tested were 1; 3 and 6 from a range of 1 to 6 available, low to higher pressure. The diameter of the rod-squeegees used was 12 and 6 mm and the mesh count of the screens were 46; 89 and 107 TPI.

After being screen printed, each sample completed a process of drying and thermo setting in a Werner Mathis AG laboratory oven at 160ºC during 2 minutes for TC; 130ºC during 3 minutes for PC and HC pigments.

Based on experimental practices in textile engineering and design, the experimental work consisted on three phases focused on a) individual use of each chromic material; b) combination of each stimulus-sensitive colourant with conventional pigments; c) combination of chromic materials.

The first phase studied the effect of printing parameters in the chromatic qualities of TC, PC and HC textiles. The variables set were screen mesh count, magnetic field level and printed layers (number and process). Considering that the HC colour was commercially available in white, HC samples were developed with the substrate previously screen printed with 3% conventional pigment black.

The second phase studied the combination of each CCM with conventional pigments, applied to textile substrate by different processes: overprinting of conventional and chromic pigments in different pastes and screen printing with the pigments combined in the same paste.

The third phase explored the possibility to combine different typologies of chromic materials, mixed in the screen printing paste or screen printed with overlapped layers. The combinations studied were TC & PC; TC & HC; PC & HC and TC, PC & HC.

Samples analysis encompassed qualitative and quantitative methods through laboratory studies, namely colour measurement using a spectrophotometer Datacolor International SF600 Plus – CT with Datacolor TOOLS software, direct observation, photographic and video record.

3. Results and discussion

3.1. Individual use of each chromic material

The analysis of printing parameters' influence on chromatic qualities of each pigment type was conducted with a set of sample frameworks. Screen printed samples were developed with the 12 mm rod and encompassed a relationship between screen mesh counts – 46, 89 and 107 TPI – and magnetic field levels (Mf) – 1; 3 and 6. A framework of samples screen printed with each pigment type is presented in figure 1 with samples in colourized state: TC blue below 31ºC, PC blue under UV radiation and HC in dried state.

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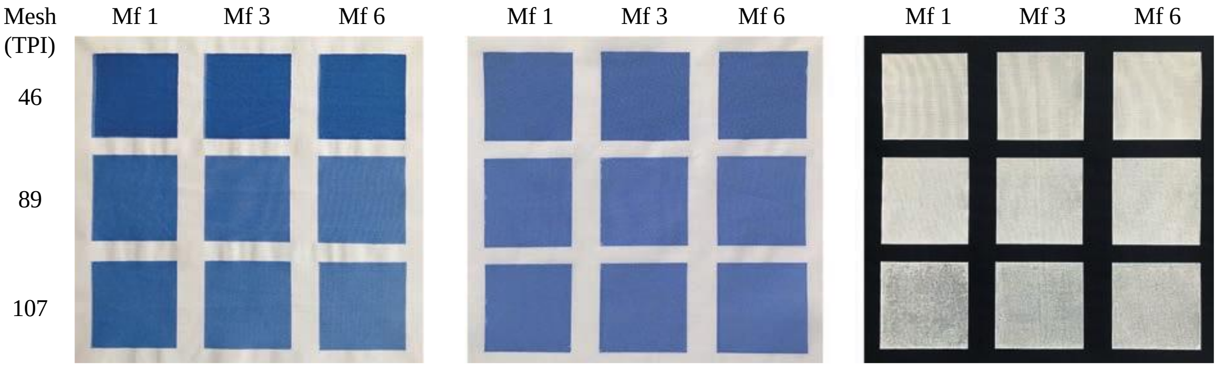

Figure 1. Samples framework: screen mesh count vs. magnetic field level. Left: TC blue samples below 31ºC. Centre: PC blue samples under UV radiation. Right: HC samples in dried state.

For the three chromic pigments handled, screen mesh count variable showed a greater effect on textile printed results than the magnetic field level. Screens with lower mesh count present larger open areas, allowing more paste to flow onto the substrate and with TC and PC pigments, samples developed with 46 TPI screen are darker than other samples, but they present uneven printing. This effect suggests an excessive paste layer thickness printed. In samples developed with higher mesh counts, the printing was more uniform, although a subtle moiré pattern was perceived. An additional experiment was conducted with a lower diameter rod – 6 mm – that reduced this effect.

HC samples screen printed with the 46 TPI screen present a thicker layer in relation to samples developed with higher mesh counts, which was obviously perceived through the white layer coverage level above the black background and through touch. Mean values of samples thickness varied from 0.45, 0.35 and 0.33 mm for 46, 89 and 107 TPI screen, respectively. Besides colour qualities, the printing can change textile characteristics, such as thickness, weight, stiffness and handle, becoming an important design consideration as these variables also build up the textile expression(s).

The change of magnetic field levels produced slight variations between the samples' qualities. TC and PC textiles screen printed with the lowest pressure (Mf 1) have a subtle darker nuance than samples with higher levels, whereas for HC a more uniform printing was attained with Mf 6.

To study the variable printed layers, number and process, a framework for each chromic material and colours was developed with samples screen printed with one layer (1L), one layer applied on top of a previously printed and dried layer (1+1L) and two consecutive rod-squeegee passages of printed layers (2L). Figure 2 presents an example of the results, for each pigment type.

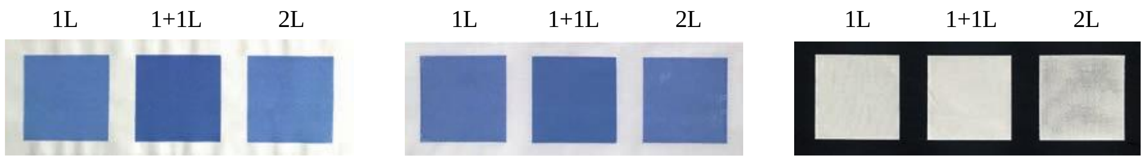

Figure 2. Samples screen printed with different layer number and process. Left: TC blue samples below 31ºC. Centre: PC blue samples under UV radiation. Right: HC samples in dried state.

Number and process of the printed layers showed a similar effect along the chromic materials tested. In relation to one layer application (1L), the overprinting of a second layer (1+1L) increases colour saturation and thickness, also contributing to the evenness of the printed surface. Samples with two layers consecutively applied (2L) attained a blurred effect with areas of different colourization.

When chromic pigments are in colourless state, printing parameters were not expected to influence textile colours. Nevertheless, an incomplete decolourization was observed in samples with all pigments used and thus, the subtle colours or opacity can also present slight differences, particularly comparing samples with the smaller screen mesh count and overprinted layers, as well as samples of different colours or large concentration ranges. Colour difference (dE*) measured of HC samples wet in relation to the black background were 26,20 for 1L and 33,55 for 1+1L (samples developed with 89 TPI screen and Mf6). At a temperature above 31ºC, the sample screen printed with 2% TC blue presented 10,48 dE* in relation to 10% TC blue (samples developed with 107 TPI screen and Mf3). The residual colouration or opacity of chromic pigments can affect how colours or colour change ratios with pigments combination will behave, being an important variable to assess.

3.2. *Chromic materials and conventional pigments*

Combinations of chromic materials with conventional pigments were studied through two processes: overprinting and pigments mixed in the paste. Samples developed by overprinting present the static pigment at the background and different colours at various concentrations were tested. A relationship between these parameters was applied for paste elaboration with mixed pigments. For example, if a sample was developed with 1% conventional pigment magenta at the background and overprinted with 100% HC, the corresponding samples' paste has 1% conventional pigment magenta with 99% HC.

Figure 3 presents an example of each chromic set, developed by different processes.

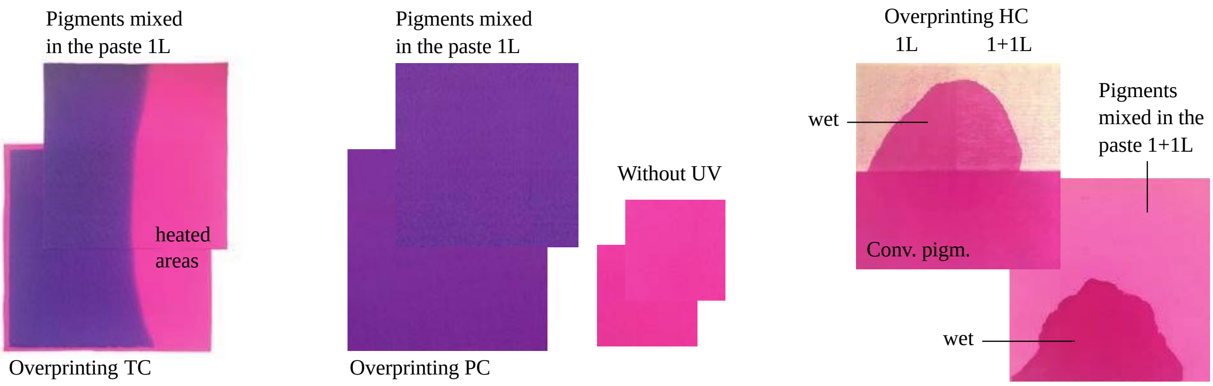

Figure 3. Combination of chromic and conventional pigments through different processes.

Considering the relationship between dynamic and static colourants, colour change behaviour can encompass a transition between colours and tones. Besides colours and concentration of the pigments combined, application processes can also influence textile chromatic behaviour. TC and PC examples presented in figure 3 attained a slightly darker colour in samples where pigments were combined in the paste than by overprinting. Although, by decreasing the conventional pigment concentration, the colour of the chromic pigment was more apparent in samples developed by overprinting. HC pigment is white and also displays a lighter surface through overprinting process.

Furthermore, when the conventional pigment selected presents a dark colour or is applied in high concentration, TC and PC colour change effect is subtle or not perceived. The same occurs for HC pigment when combined with lighter colour or low concentration of the static colourant.

Definition of screen printing paste colours, concentrations and application processes involves a set of relationships. The results attained also highlight the importance of a systematic practice-based approach to explore these materials' potential for designing colour change effects.

3.3. *Combination of chromic materials*

The results discussed in the previous sections set a basis to study the combination of different chromic materials types, which initially focused on two pigment types at a time, followed by an experiment with the three chromic materials.

When combining different CCMs, colour change effect of each chromic pigment type is not just influenced by the stimulus that it reacts to, but also by the stimuli of other pigments as they also influence its colour. In this sense, the relationship between several stimuli is an important parameter in textile colour change behaviour. For example, if a TC blue with 31ºC activation temperature is combined with a PC yellow, below 31ºC the textile is green when exposed to UV radiation (also depending on

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concentrations applied) and blue without UV; above 31ºC the textile colour is yellow with UV radiation and colourless without.

In addition, when mixing chromic materials in the paste, printing parameters such as screen mesh count and magnetic field, are defined for an individual paste with different pigment types mixed. In overprinting processes, each pigment type can be screen printed with selected printing variables for each layer, using for example a different screen mesh count for each chromic paste.

The combination of three pigment types was researched with pigments mixed in the paste and overprinting process. The pigments selected for the study were 10% TC yellow, PC blue and HC. Sample 1 was screen printed with pigments combined in the paste. Through overprinting, sequence order of printed layers encompasses six options. For the following analysis, just four samples were considered (samples 2 to 5), excluding the two samples with the HC background. Figure 4 presents an image of each sample at a selection of different stimuli conditions.

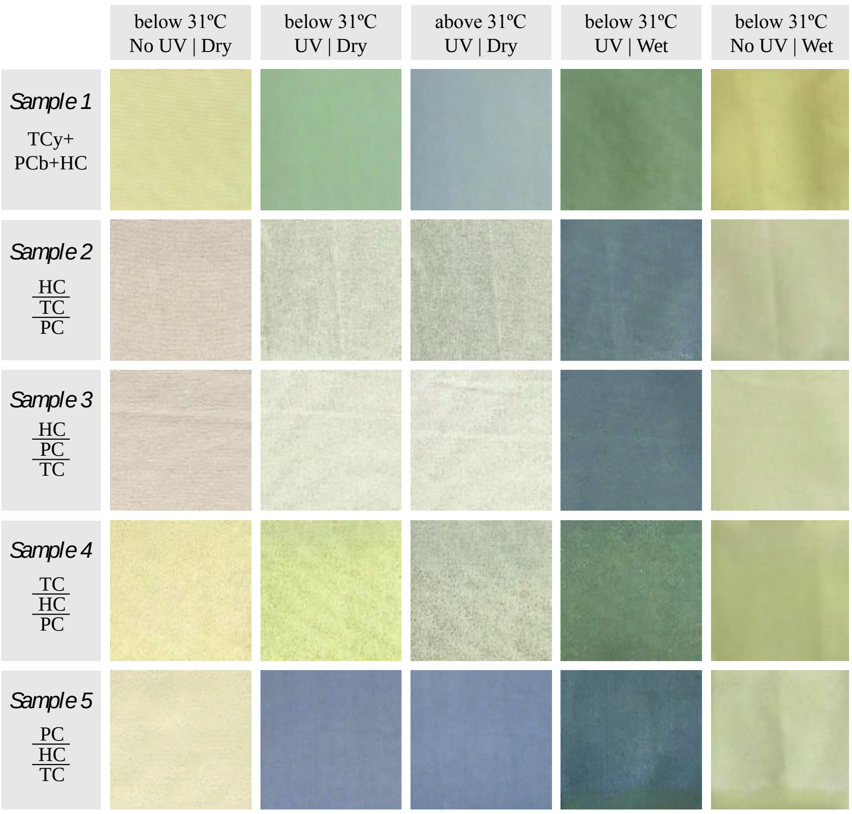

Figure 4. Framework of chromic samples that combine the same pigments by different processes. Each line presents the sample description and an image at a specific stimuli condition, as identified at the framework top.

Considering the intrinsic dynamic behaviour of the pigments researched, screen printing decisions play a crucial role in colour change effects. Samples presented in figure 4 applied the same pigment types vs. colours and similar concentrations between mixture in the paste and overprinting, although their chromatic behaviour at each stimuli condition tested have varied significantly, as can be analysed through samples' colours at each framework column.

When HC pigment is printed at the top layer (Samples 2 & 3), its opacity in colourized state does not allow an evident perception of changes between hues of the pigments below it. The effect observed relies on a variation between colour nuances. By mixing the HC in the paste, colour changes can be observed in HC dry state, varying between yellow, green and blue.

Layer order sequence of HC pigment also affects how the textile dries and becomes wet, particularly when PC layer is above the HC, when it was perceived that sample 5 did not become wet as fast as the other samples.

TC yellow concentration applied displays a light colour. In this sense, when PC is at decolourized state, the change between TC and HC states does not create an evident change between yellow and white hues. The pigments' incomplete decolourization discussed also contribute for this effect.

PC pigment selected has a dark colour and the transition between UV absence and exposure displayed a clear influence on textile chromatics. During experimentation, PC sensibility to heat was observed. When heating up the textile, PC colour saturation has decreased but returned to colourized while TC pigment was still colourless. This behaviour will be further researched.

In addition, chromic materials studied present gradual colour transitions at different rates in colourizing and decolourizing processes, according to each stimulus-sensitive type. According to the work developed, chromic textiles may exhibit different chromatic and dynamic qualities in response to the external stimuli combination and printing parameters.

4. Conclusion

This research studied processes to combine and integrate chromic pigments in textiles, exploring colour as a dynamic variable of textile design.

The results demonstrate the interdependency of textile colours and colour change behaviour in relation to pigment types, colours, concentrations, fabrication processes and stimuli parameters.

When working with chromic materials, decisions on pigments' combination and printing processes through paste mixture or overprinting are critical, as they significantly affect textile expressions and performance. Printing processes present designers with enhanced opportunities to explore colour change effects, namely to work with textile patterns, where each pigment type printed can add to more than a colour change effect, interacting with other pigments in the composition.

The systematic approach conducted to study the colour change effects through independent variables creates an understanding of TC, PC and HC behaviour and proposes a design methodology to explore and create interactive textile surfaces capable of displaying a wide range of chromatic changes, under diverse external stimuli.

The samples framework developed demonstrates colour change effects and can be used to assist design decisions when creating chromic textiles for expressive and functional purposes.

Acknowledgements

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