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Dynamic Qualities of Smart Textiles: Study of Stimuli Magnitude with Chromic Pigments

CABRAL Isabel[1,a*] and SOUTO António Pedro[1,b]

[1]2C2T – Centro de Ciência e Tecnologia Têxtil, University of Minho, School of Engineering, Campus Azurém 4800-058 Guimarães, Portugal

[a]diascabral@gmail.com, [b]souto@det.uminho.pt

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Abstract. Smart textile behaviour encompasses changes over time, which are triggered upon a sensed stimulus. With a focus on dynamic qualities, this research sought to study how gradual and reversible transitions of smart textiles can be influenced by the activation variable – stimuli magnitude. Taking into account an analysis of different external stimuli for the same property change, the experimental work was conducted with Colour Change Materials, namely textiles screen printed with thermo, photo and hydrochromic pigments. The results attained demonstrate how stimuli magnitude can affect textile temporal expressions, in this case: hue, saturation and lightness, as well as pace change. In addition, different considerations also arose in respect to each stimulus' energy type and interdependencies between stimuli types. Contributing to the understanding of dynamic qualities of smart textiles and chromic materials' properties, this research also discusses further alternatives to explore textile behaviour towards new design possibilities for smart textiles as dynamic interfaces.

Introduction

Considering that smart textiles are able to sense and react reversibly to an external stimulus [1], they present a behaviour that can be described as dynamic and interactive, due to their property change ability and the response being triggered upon a sensed stimulus. In this sense, designing smart textiles includes exploring and working with the properties and qualities of the smart textile behaviour.

Dynamic behaviour is not a familiar dimension in conventional textiles. It is found more comprehensively in fields such as dance, music and even robotics, namely addressing time and movement concepts. For example, the design of a robot movement, besides concerning the trajectory definition that is accomplished by a physical medium, can also be described according to the movement properties and expressions, namely if the movement appears more organic or mechanical, if it occurs in a perceived fast or slow pace.

Therefore, as an emergent dimension in textile design and engineering, smart textiles behaviour presents new opportunities and challenges, including to provide new means to extend textiles conventional functions and expressions; to create new potential to interact with our environment and transform it; as well as to add new variables and competence requirements design research and practice [2-6].

To study the dynamic qualities of smart textiles, it is important to focus on how the materials changes between one state to another and the variables that can influence their expressions during gradual transitions and in different states. Previous research was conducted to study how the combination of smart materials and their integration processes in textile substrates can affect their expressions and behaviour [7-8], which was developed with stimulus-sensitive colourants.

The present research sought to study how gradual and reversible transitions of smart textiles can be influenced by the activation variable – stimuli magnitude. Taking into account an analysis of different external stimuli for the same property change, the experimental work was conducted with Colour Change Materials, namely textiles screen printed with photochromic (PC), thermochromic (TC) and hydrochromic (HC) pigments, which react to Ultraviolet (UV) radiation, heat and water, respectively [9].

Considering the intrinsic dynamic behaviour of each pigment type, PC are colourless in the stimulus absence, acquiring their predefined colour when exposed to it; the colour of TC textiles fades away above their activation temperature and returns to colourized below it; HC are opaque in dried state, changing to transparent when exposed to water [10-11]. Analysis on chromic behaviour conducted in this study, encompassed textile samples development and exposure to different stimulus types that address different magnitude levels for each pigment studied.

Materials and Methods

The chromic pigments handled were: SFXC water based PC dispersion yellow (PCy), magenta (PCm) and blue (PCb); SFXC water based HC ink white; ATUSMIC water based TC dispersion red with activation temperature of 27ºC. PC and HC were supplied as ready-made pastes, and TC screen printing paste was formulated with 10% pigment and 90% Gilaba vinyl acrylic binder.

Samples were screen printed on a Zimmer Mini MDF R541 table. After being screen printed, each sample completed a process of drying and thermo setting in a laboratory oven with time and duration parameters according to the materials applied: 150ºC during 3 minutes for TC; 130ºC during 3 minutes for PC and HC pigments.

The experimental work consisted of two phases for each pigment type. The first phase studied the effect of activation magnitude in the textile expressions of each stimulus sensitive material, and the analysis was conducted with samples screen printed with individual pigments' colours. The second phase studied the speed in which the textiles change between states according to the stimuli conditions.

Colour change behaviour was studied through a qualitative analysis by direct observation and video recording, which also enabled the comparing of results attained through video frame images and the evaluation of pace of change.

For the study with UV radiation stimulus, PC samples were produced with a 100% cotton plain weave substrate and the conditions defined to analyse textile behaviour included natural and artificial light. Experiments in natural light encompassed direct and indirect exposure. In artificial light, the tests were conducted with a standardized light booth under the exposure of three lighting conditions: D65, UV and D65 combined with UV. The light source D65 is a CIE Standard Illuminant that represents average daylight, referring to diffuse skylight without direct sunlight and has a colour temperature of 6504 K [12].

Heat stimulus activates chromatic changes of TC pigments, leading to a decolourization process with changes from a coloured to a colourless state. Depending on the way the heating source activates the changes, dynamic textile patterns can be distinguished as direct or reported – concepts that were introduced by Worbin [2]. Direct patterns account for colour change as a direct response to the thermal stimulus, while reported patterns involve the use of conductive and electronic components, which are programmed to induce temperature variation through resistive heating.

This work discusses a section of the studies conducted with reported activation [6], which were developed with a textile sample woven with conductive threads. The TC sample was woven in the Jacquard Vamatex loom with 41.2 tex cotton warp and 14.7 tex polyester weft, integrating the Karl Grimm High Flex 3981 conductive thread in the weft of a plain weave structure at 1 cm distance each (13 picks PES and 1 pick conductive thread per cm). Conductive thread insertion in the weaving was programmed through the loom software.

TC sample activation through resistive heating was conducted with a DC power supply and different electrical current values were tested, enabling temperature transfer from the conductive threads to the textile chromic surface at different magnitude levels. To study sample temperature during activation, thermal images were also recorded with a Testo 876 Infrared camera and analysed with Testo IRSoft software.

The study with the HC pigment analysed textile behaviour of opacity decrease, when exposed to water and colour return upon drying through different environmental conditions, namely direct sunlight at 30 and 27ºC and shadow at 25 and 20ºC. Considering that this pigment was commercially available just in white, the HC sample used in this study was developed through overprinting process with a 100% cotton plain weave substrate previously screen printed with ATUSMIC Magnaprint black H3B.

Results and Discussion

PC pigments. Experiments conducted with PC samples yellow, magenta and blue exposed to different light conditions, which present different UV radiation levels, were video record and frames of each sample in the colourized state was combined in image frameworks. Fig.1 shows the PC samples under natural light – direct, indirect exterior and interior – where different colour saturation was attained in the 3 samples – PCy, PCm and PCb. Variations reflect that the higher the stimulus magnitude, the more saturated is the PC pigment colour, as observed through samples in direct sunlight activation. When PC samples are exposed to indirect sunlight, either in interior or exterior environment, colour strength is considerably lower and, in the case of PC blue pigment, besides colour saturation, differences appear to regard also to hue: instead of blue, colour observed is a very light greenish shade.

Fig. 1. PC samples exposed to different natural lighting conditions.

Artificial lighting conditions also interfered in textile PC behaviour in respect to saturation and hue, as observed in Fig.2. Samples under D65 illuminant present a very low colourization, particularly with yellow and blue pigment. With UV light, the blue light colour does not allow perception of the samples activated colour, rather, lightness dimension differentiates chromic behaviour results ranging from darker to lighter with magenta, yellow and blue PC samples, respectively, as depicted in Fig.2 – 2nd column. When D65 is combined with UV light, the last enables a higher UV radiation and, whereas it still assigns a blue shade to the samples' colour, D65 light enables hue perception.

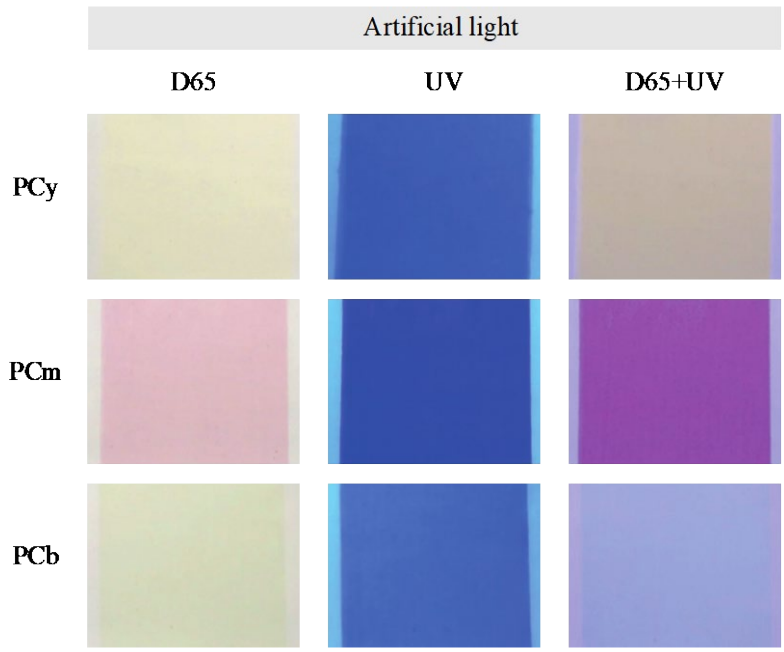

Fig. 2. PC samples exposed to different artificial lighting conditions.

Regarding the pace of change, when PC pigments are activated by direct sunlight, they appear to almost immediately change colour to their fully saturated state. With other lighting conditions that present lower UV stimuli magnitude, the chromic behaviour can be perceived overtime through a more gradual transition. With natural light, the colouration process was more obviously perceived previously to the first seconds 5'' for direct exposure and in between 15 to 20'' to exterior and interior indirect exposure (Fig.3).

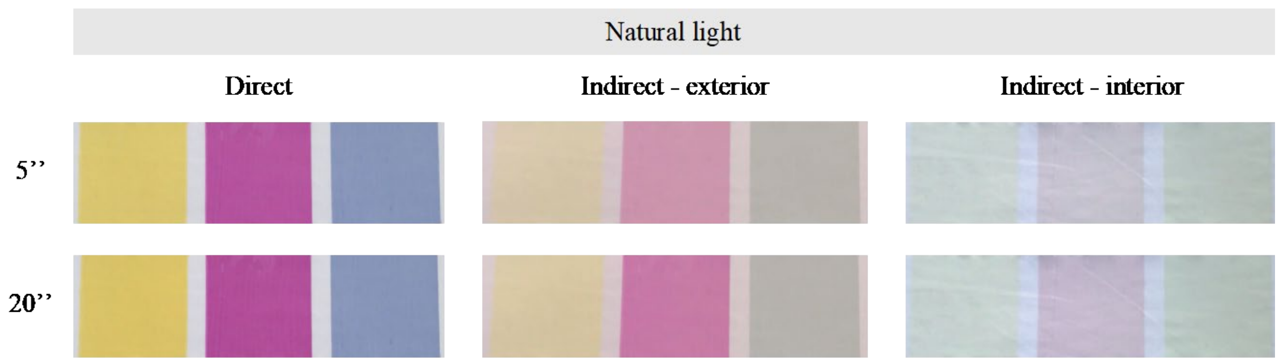

Fig. 3. Dynamic behaviour of PC pigments, upon different natural lighting conditions.

The time required for the PC to return to its colourless state, after exposure with natural light, was difficult to quantify, as samples have to be contained from UV light, but exposed to other lighting to be observed. In addition, PC pigments show a residual colour according to its hue, which also interferes in the analysis. Nevertheless, the study highlighted that a higher stimulus magnitude triggers faster changes, but it can also slow down the pace at which the textile returns to the initial colour.

For artificial light with D65, dynamic behaviour occurred during approximately 40'' in the colourization process (Fig.4 left). Regarding decolourization, pace of change is observed slowly, also being difficult to identify by direct observation when the transition is complete. In the D65 test, 1'20'' appear to be required for the decolourization process with PC magenta, whereas with PC yellow and PC blue, the decolouration appears to be complete at approximately between 40'' and 1'(Fig.4 right).

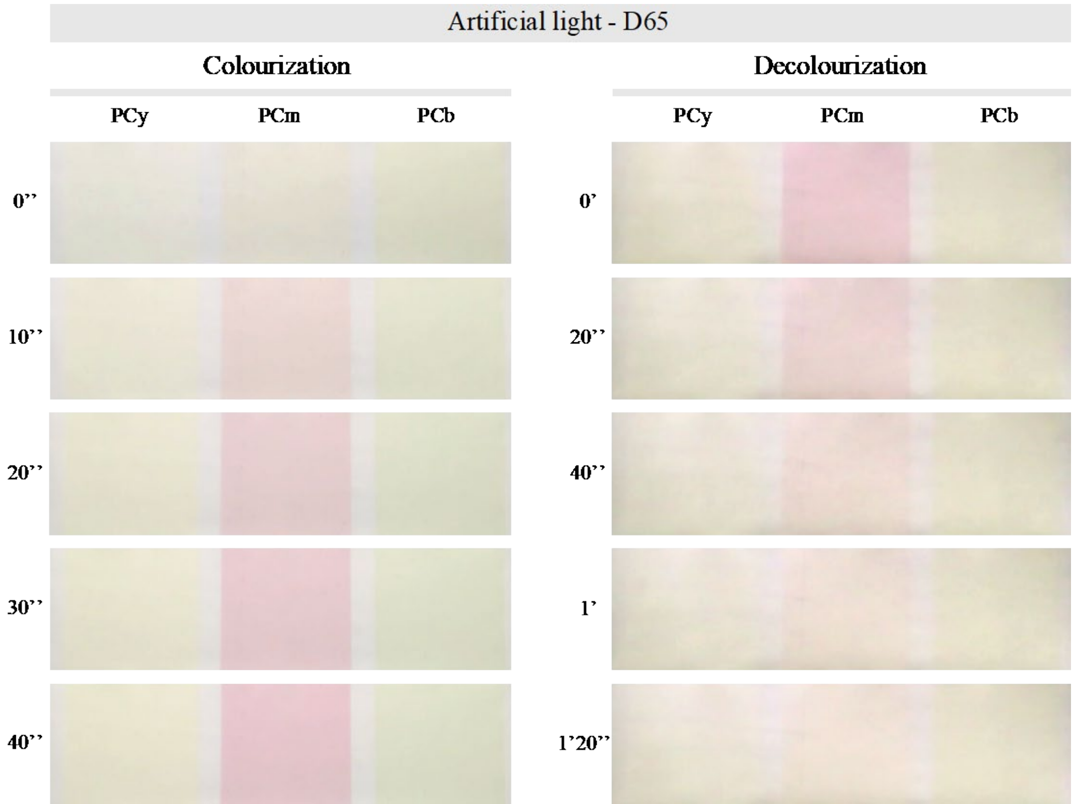

Fig. 4. Dynamic behaviour of PC samples under D65 standard illuminant.

The results attained with natural and artificial light stimulus, also highlight the possibility to design colour change behaviour that can perform transitions with different chromatic expressions by combining two or more PC pigments' colours and according to the stimulus magnitude supplied, as they present different saturation levels and change rates.

TC pigments. The study of magnitude stimulus influence on TC textile behaviour report to resistive heating activation experiments [6]. In the initial test, the objective was to study the influence of the electrical current value in the heating process of the TC sample. The test setup was defined with 1' duration of power supply, after which colour return was analysed during the same period. The electrical current values tested ranged between 1 and 1,5A and the experiments were all conducted at a room temperature of 20ºC.

Fig.5 presents the results attained with 1,3A and displays frames of the video record and IR images at each 15'' of the timeline. When power supply was switched ON, the conductive thread pattern was revealed through the transition from textile solid colour to parallel colourless lines. This change was perceived in the 1st 15'' of activation, after which thermal expansion in the textile areas in between the conductive threads, performed a slower pace, until attain an overall colourless expression, after 1' of activation. When power supply was interrupted, colour return occurred slowly, through a more blurred expression than on heating.

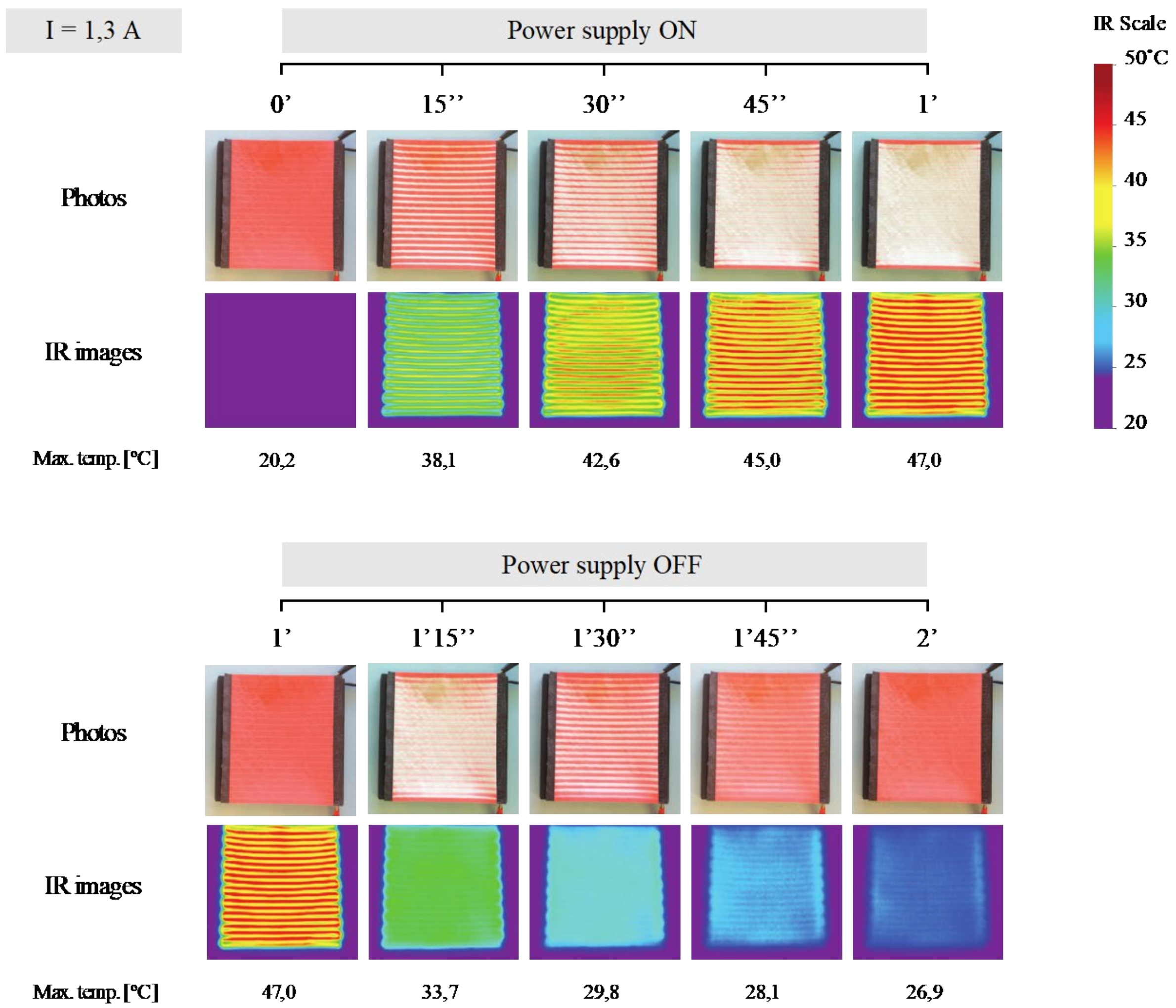

Fig. 5. Dynamic behaviour of TC sample, during and after activation with 1,3 A.

Comparing the results of the experiment with different electrical current values presented in Fig.6, it was observed that they affect the pace and the expressions of colour change. In experiments with 1,2A or lower, full colour change was not attained with 1' power supply. The temperature on the conductive threads changed the textile colour, but was not sufficient to heat up the textile areas between them above 27ºC (TC pigment activation temperature). When power supply was switched OFF, textile temperature affected colour return, which was incomplete in tests with 1,4 and 1,5 A.

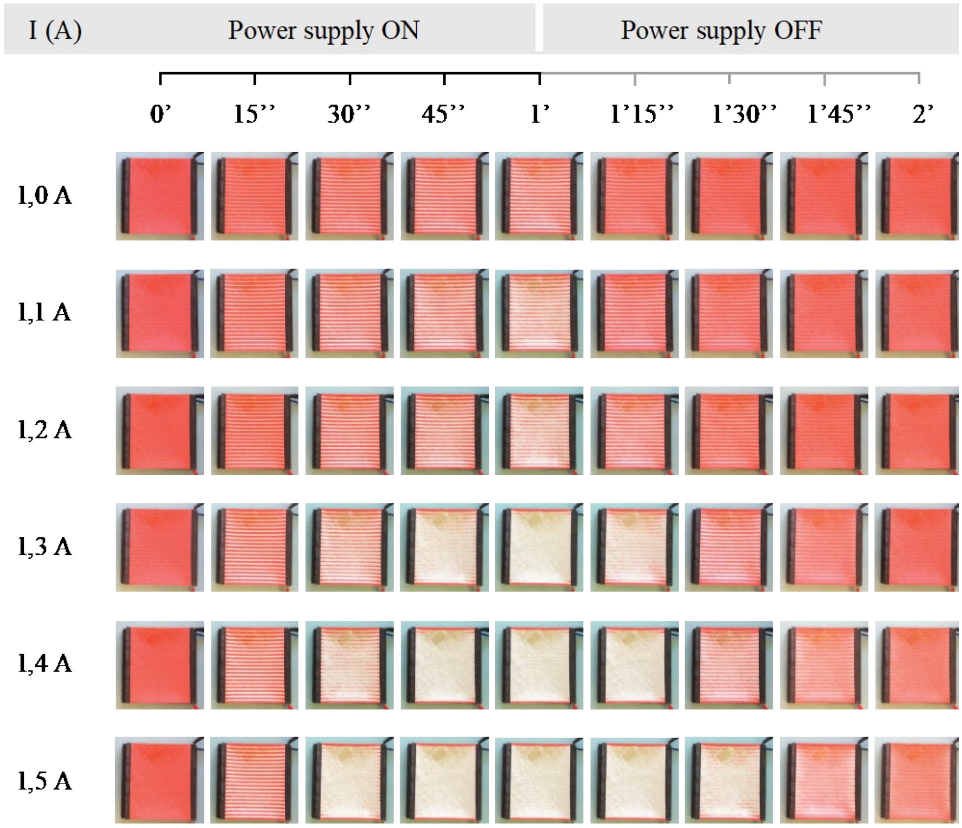

Fig. 6. Dynamic behaviour of TC sample during and after activation through different electrical current values.

Experiments with different room temperatures were conducted, which have shown to significantly affect duration of change. Fig.7 presents the time and maximum temperature measured on TC sample activated with 1,4A electrical current at a room temperature of 16ºC and 20ºC. Results comparison show that with 16ºC room temperature, colour change occurred much slower than in the test at 20ºC; while colour return was slightly faster, stressing their influence on both chromic transitions between colourized and decolourized states.

Room Temp. [ºC]	Heating		Cooling	
	Time	Max. Temp. [ºC]	Time	Max. Temp. [ºC]
20	1’15’’	50,1	1’15’’	26,9
16	2’30’’	49,9	1’	25,3

Fig. 7. Dynamic behaviour of TC sample with 1,4 A activation, at room temperature of 20 and 16ºC.

HC pigments. The experiments on HC behaviour encompassed an initial analysis on chromic activation either in an environment with different relative humidity properties and wetting possibilities. It was observed that the stimulus magnitude does not present an obvious effect on HC pigment decolourization. For example, when the dried samples were exposed to different humidity levels, no visual differences were observed. To identify colour change, the pigment required to be wet, which can occur regarding different scale areas of the printed surface, attaining different expressions such as presented in Fig. 8: sprayed pattern with small droplets, stained area with the HC surface partially or fully wet. In addition, as the other pigments' types, kinetic behaviour of this material is also incomplete, showing a residual opacity.

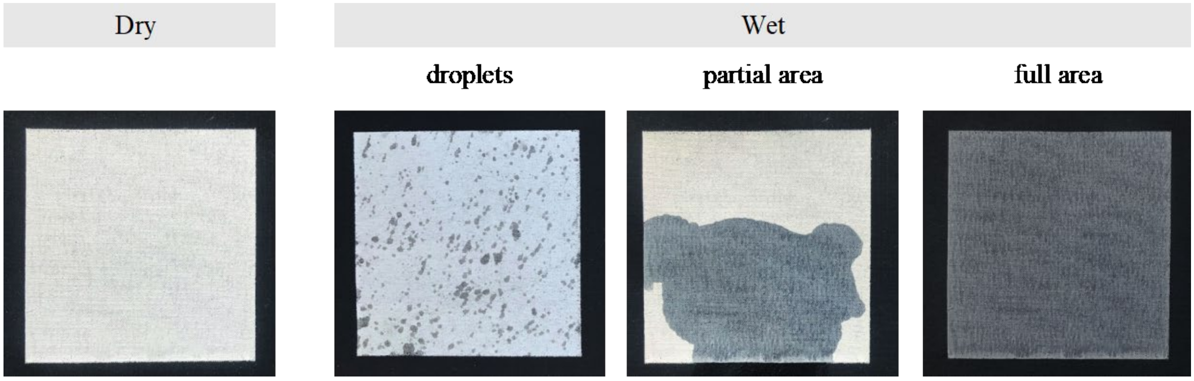

Fig. 8. HC sample at dry and wet states.

After direct water contact, time required to observe colour change is almost immediate, while colour return holds interdependencies between different stimuli conditions, as colourization of HC encompasses a drying process.

Two setups were tested involving direct sunlight and shadow, both comprising of different temperatures, each measured with a thermometer placed in the sample surface. Conditions were 30ºC and 27ºC in direct sunlight and 25ºC and 20ºC in shadow. Time results required for the HC textile surface to become completely colourized are presented in Fig.9, where it can be observed that environmental conditions significantly affect the pace of HC colourization: samples in direct sunlight required 10 to 12 minutes to fully colourized and in shadow, time varied between 45 and 125 minutes.

The analysis highlights that to design dynamic behaviour of HC textiles, it is important to take into consideration that pace of change during decolourization occurs at the seconds rate, while colourization involves minutes or even hours.

	Temperature [ºC]	Colour return [minutes]
Direct sunlight	30	10
	27	12
Shadow	25	45
	20	125

Fig. 9. Dynamic behaviour of HC at different lighting and temperature conditions.

Results obtained highlight that whereas designers can select specific colours for a given textile expression, various chromatic possibilities can arise in dependence of the stimulus type and respective magnitude. For all pigments tested it was observed that the pace of changes is also directly influenced to the stimuli magnitude. A high intensity activation triggers faster changes, but it can also slow down the pace at which the textile returns to the initial state. This relationship holds interdependencies between different stimuli conditions. For example, the stimulus absence in HC textiles involves the drying of the textile sample, thus pace change is also related to temperature, light exposure condition, as well as textile substrate properties.

Conclusions

Stimuli variables are an important consideration in smart textiles design, as they are responsible for triggering textile behaviour, as well as affecting how textile expressions evolve overtime.

The research conducted provides a framework that articulates relationships between stimuli magnitude and dynamic qualities of smart textile behaviour, with stimuli-sensitive colourants. Through this process, the framework can be extended over research with other variables that play an active role the textile performance as well as with other smart materials.

The findings also contribute to understanding of chromic materials properties and behaviour, which enable designers to further explore different rhythms of change, designing dynamic and interactive textiles.

Future work encompasses development of research prototypes to demonstrate colour change effects and potential to design textile behaviour with distinct dynamic qualities. It is also of crucial importance to combine this qualitative study with quantitative analysis of colour change, dependent on stimulus magnitude variable, through colourimetric measurements.

Acknowledgment

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