Measurement of Time-Dependent Colour Variation in Concrete

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ABSTRACT: The phenomenon of colour variation in finished concrete has become a contentious issue in recent years as engineers and designers strive, not only for blemish free finishes, but crisp "white" concretes with uniformity throughout. Three factors determine what colour an observer perceives: (i) the light source, (ii) the object surface and (iii) the observer himself. Several methods have been identified for the evaluation of colour yet in most cases in the absence of suitable measuring equipment; it is the observer who will decide. Given that colour variation may present differently depending on aspects such as the viewing distance, the ambient light and the viewing angle, this typically results in a subjective assessment devoid of any quantitative metrics. This paper presents the results from an experimental programme aimed at developing a robust and repeatable quantitative methodology for concrete colour measurement. Controlled concrete specimens have been studied over a 3 year period, for 3 different exposure conditions. Initially the exposure conditions are evaluated against each other but, more importantly, changes, monitored over time have also been recorded.

KEY WORDS: Chroma Meter; Colorimetry; Curing

1. INTRODUCTION

The most consistent thing about concrete is its inconsistency. Today with advances in computer batching technology and state of the art plant, anecdotal evidence suggests that variation still exists. The aim of this paper is to investigate colour variation in concrete exposed to 3 different curing regimes, but more importantly to investigate if changes occur over time. In tandem, the hypothesis that colour and durability measurements may be linked shall be investigated.

1.1 Concrete Colour Measurement

The real concern with colour measurement is the subjectivity of the assessment of colour variation. Objects modify light, colorants such as pigments or dyes, in the object, selectively absorb some wave lengths of incident light while reflecting or transmitting others (Tominaga, 1985).

Colorimetry is the science of measuring and evaluating colour. The colour specification of a self-luminous colour (sources, CRTs, VDUs, LCDs) or a surface colour (opaque or transparent materials) consists of a set of three numbers – X, Y and Z, termed the tristimulus values, which give the relative amount of three reference primary colours required for a colour match (Zwinkels 1991). It should be noted that Luminosity is the relative sensitivity of the human eye to various wave lengths of light (Tominaga, 1985).

A variety of instruments are available for colour measurement.

Tristimulus colorimeters use a filtered light source and three or four filtered detectors whose modified spectral response approximates that of a particular CIE standard illuminant/observer combination. They give a direct measure of colorimetric quantities (tristimulus values) but provide no information on the underlying spectral data. They are used for Colour measurement of both surface colours and self-luminous colours. Their advantages are their speed, ease of operation, and good measurement repeatability, which makes them well suited for field use and for production quality control, particularly for colour-difference evaluation.

In their paper, Yuzer et al. (2004) employed the Munsell Colour System in identifying colour changes in mortars subjected to high temperatures. In this system, the attributes hue, value and chroma of colour are divided into equal perceptual intervals and denoted through the use of decimals. Hue is the dimension which distinguishes one colour family from another, as red from yellow, or green from blue.

In their work, Lemaire (2005) and Shang (2005) employed a method proposed by CIE (International Commission of Lighting) referred to as CIE-*Lab*, due to its use of ***L*** (luminance) and ***a*** & ***b*** (chromatic values) respectively. The methodology effectively defines colour in a three-dimensional light space. Three factors determine what colour an observer perceives: the light source, the object surface and the observer himself (Lemaire, 2005).

Figure 1 shows the AFNOR standard's seven levels of grey and their corresponding luminance values. Determination of these properties of colour requires the use of specific Colorimetry equipment.

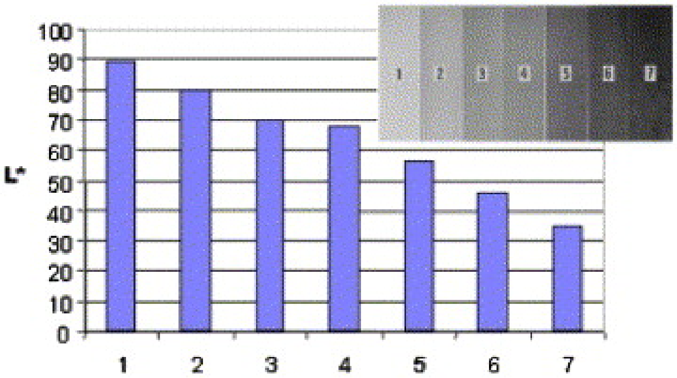


Figure 1 – Grey classes of the standard NFP 18-503 and corresponding luminance's (Lemaire, 2001)

Adopted by CIE in 1976 as models that better showed uniform colour spacing in their values. CIE-*Lab* is an opponent colour system based on the earlier system of Richard Hunter developed in 1942, called L, a, b. Colour opposition correlates with discoveries in the mid-1960s that somewhere between the optical nerve and the brain, retinal colour stimuli are translated into distinctions between light and dark, red and green, and blue and yellow. CIE-*Lab* indicates these values with three axes: L*, a*, and b* (the full nomenclature is 1976 CIE L*a*b* space).

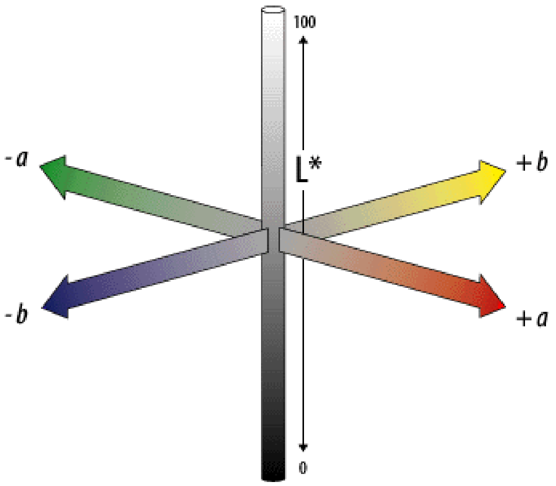


Figure 2 - CIELAB

The central vertical axis represents lightness (signified as L*) whose values run from 0 (black) to 100 (white). This scale is closely related to Munsell's value axis except that the value of each step is much greater. This is the same lightness valuation used in CIELUV.

The colour axes are based on the fact that a colour can't be both red and green, or both blue and yellow, because these colours oppose each other. On each axis the values run from positive to negative. On the a-a' axis, positive values indicate amounts of red while negative values indicate amounts of green. On the b-b' axis, yellow is positive and blue is negative. For both axes, zero is neutral grey. Therefore, values are only needed for two colour axes and for the lightness or grayscale axis (L*), which is separate (unlike in RGB, CMY or XYZ where lightness depends on relative amount of the three colour channels).

The instrument chosen for this experiment is a Konica Minolta Chroma meter data processor DP-400 as shown in Fig. 3.The instrument is first calibrated with a true white Calibration plate before sampling begins and then readings may be taken at 3 second intervals. Results may be recorded manually or stored on the unit (max 2000 results) and printed on completion.

Figure 3 - Chroma Meter

2. EXPERIMENTAL PROGRAMME

The experimental programme consisted of producing concrete samples from two discrete concrete mixes – a self-compacting concrete with a design strength of 60N/mm^2 (SCC) [Mix A] and a second mix, again a semi self-compacting concrete with a design strength of 60N/mm^2, but with 30% GGBS cement replacement (GGBS) [Mix B]. This forms part of a PhD study over three years and year 1 (2010) will be presented.

2.1 Sample Preparation

The aggregates for both mixes are locally sourced limestone gravel of a carboniferous age and are both of pale and dark variety in almost equal measure. The concrete has been batched in a 1.5 m^3 pan mixer with microwave moisture control and a computer controlled weigh system accurate to 0.2%. The trial moulds (300mm x 300mm x 100mm) were made from steel to reflect the type of mould most used in an Irish precast operation.

The moulds were cleaned and an application of release agent - Gemleaze, GP Bio - was applied. The concrete mixes were taken to the lab and poured into the moulds. The SCC mix received no vibration but the GGBS samples were placed on a vibrating table for 10 seconds. The samples were then left uncovered to cure overnight in the laboratory and stripped the following morning approximately 18 hours later. Once stripped, the samples were left for 2 hours before being initially photographed. A total of 72 samples were prepared.

2.2 *Curing Conditions*

Normal industrial practice offers a variety of curing conditions for precast concrete specimens. Moreover, practical experience has shown that colour variation tends to present more frequently in specimens which are developed and cured in winter months, inferring that ambient curing conditions may be influential in terms of achieving uniformity of colour. In an attempt to replicate these conditions and to examine the effects of curing on the finished colour of the specimens, three different curing scenarios were employed for each of the concrete mix samples as follows:

Curing Tank (Tank)
Samples were placed in a curing tank, with the temperature maintained at 20°C for the entire period. Samples cured in the curing tank will be denoted as Tank herein. A photograph of a curing tank used can be seen in Figure 3(a).

Stacking (Stack)
Samples were stacked on top of one another with the mould face, facing down and placed outside for the test period. These samples will be referred to as Stack in this paper. A photograph of a stack used can be seen in Figure 6(b).

Storage Rack (Rack)
Samples were placed on a storage rack, facing due south to maximize exposure to sunlight. A photograph of the rack used can be seen in Figure 3(c).

3. TESTING PROGRAMME

Experiments began in spring 2010 with follow on sampling in summer and winter of the same year. Once stripped, samples are given a specific identity mark and photographed using a digital camera in a designated photobooth. They are then placed in their respective curing conditions for the duration of the test. Chroma readings are taken at 28 days, 6 months and 1 year intervals. For the purpose of this paper only 28 day and 1 year intervals will be presented.

The instrument employed to take Chroma readings in this experiment is a Konica Minolta Chroma meter data processor DP-400 as shown in Figure 4.The instrument is first calibrated with a true white Calibration plate before sampling begins and then readings may be taken at 3 second intervals. Results may be recorded manually or stored on the unit (max 2000 results) and printed on completion.

(a) Tank (b) Stack

(c) Rack

Figure 3 – Samples in Curing Regimes Employed

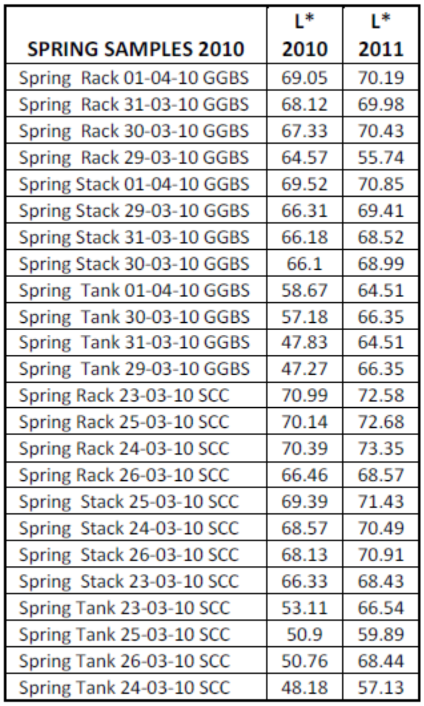
3.1 *Chroma Testing*

Each sample is measured and divided into 9 equal squares. The data processors photo lens is placed in the center of each square and an image taken, this result is recorded and the average of all 9 results will be used as the individual result.

Figure 4 - Chroma Meter

4. RESULTS

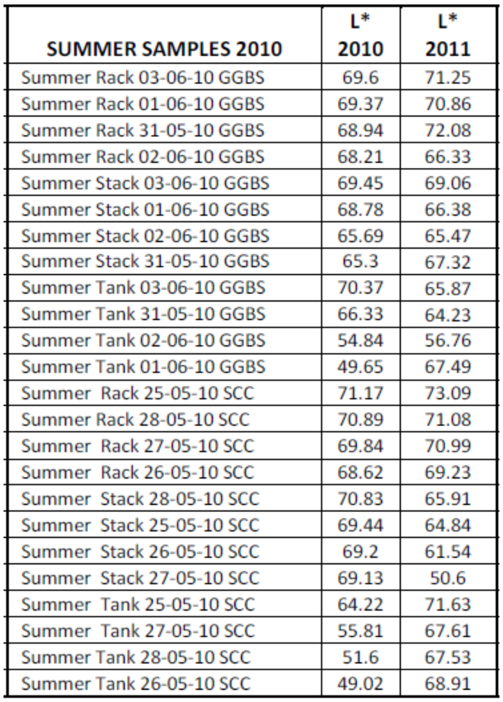
Tables 1, 2 and 3 present the chroma readings from year 1 samples. For the purpose of this paper Mix A and Mix B are presented together to assess changes over seasons and time rather than between individual mixes.



SPRING SAMPLES 2010	L* 2010	L* 2011
Spring Rack 01-04-10 GGBS	69.05	70.19
Spring Rack 31-03-10 GGBS	68.12	69.98
Spring Rack 30-03-10 GGBS	67.33	70.43
Spring Rack 29-03-10 GGBS	64.57	55.74
Spring Stack 01-04-10 GGBS	69.52	70.85
Spring Stack 29-03-10 GGBS	66.31	69.41
Spring Stack 31-03-10 GGBS	66.18	68.52
Spring Stack 30-03-10 GGBS	66.1	68.99
Spring Tank 01-04-10 GGBS	58.67	64.51
Spring Tank 30-03-10 GGBS	57.18	66.35
Spring Tank 31-03-10 GGBS	47.83	64.51
Spring Tank 29-03-10 GGBS	47.27	66.35
Spring Rack 23-03-10 SCC	70.99	72.58
Spring Rack 25-03-10 SCC	70.14	72.68
Spring Rack 24-03-10 SCC	70.39	73.35
Spring Rack 26-03-10 SCC	66.46	68.57
Spring Stack 25-03-10 SCC	69.39	71.43
Spring Stack 24-03-10 SCC	68.57	70.49
Spring Stack 26-03-10 SCC	68.13	70.91
Spring Stack 23-03-10 SCC	66.33	68.43
Spring Tank 23-03-10 SCC	53.11	66.54
Spring Tank 25-03-10 SCC	50.9	59.89
Spring Tank 26-03-10 SCC	50.76	68.44
Spring Tank 24-03-10 SCC	48.18	57.13

Table 1 – Results of Spring Samples 2010

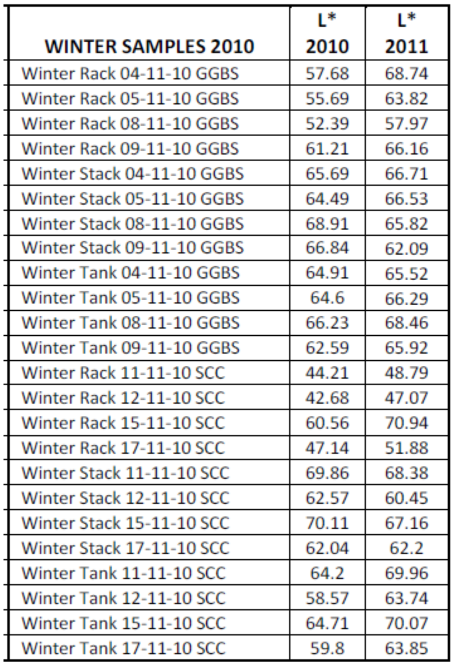
In each table, results are presented in their respective curing conditions. In Spring 2010 Mix A (SCC) produced the brightest colour and similarly an adjacent panel recorded the highest result in 2011, both were cured on the south facing rack system .On completion of sampling in 2010 early indicators suggested that seasonal changes impacted on colour. An average increase in the L* value was recorded from Spring to Summer of 4.79% but equally a drop was recorded in the subsequent winter sampling from Summer to Winter of 5.38%.



SUMMER SAMPLES 2010	L* 2010	L* 2011
Summer Rack 03-06-10 GGBS	69.6	71.25
Summer Rack 01-06-10 GGBS	69.37	70.86
Summer Rack 31-05-10 GGBS	68.94	72.08
Summer Rack 02-06-10 GGBS	68.21	66.33
Summer Stack 03-06-10 GGBS	69.45	69.06
Summer Stack 01-06-10 GGBS	68.78	66.38
Summer Stack 02-06-10 GGBS	65.69	65.47
Summer Stack 31-05-10 GGBS	65.3	67.32
Summer Tank 03-06-10 GGBS	70.37	65.87
Summer Tank 31-05-10 GGBS	66.33	64.23
Summer Tank 02-06-10 GGBS	54.84	56.76
Summer Tank 01-06-10 GGBS	49.65	67.49
Summer Rack 25-05-10 SCC	71.17	73.09
Summer Rack 28-05-10 SCC	70.89	71.08
Summer Rack 27-05-10 SCC	69.84	70.99
Summer Rack 26-05-10 SCC	68.62	69.23
Summer Stack 28-05-10 SCC	70.83	65.91
Summer Stack 25-05-10 SCC	69.44	64.84
Summer Stack 26-05-10 SCC	69.2	61.54
Summer Stack 27-05-10 SCC	69.13	50.6
Summer Tank 25-05-10 SCC	64.22	71.63
Summer Tank 27-05-10 SCC	55.81	67.61
Summer Tank 28-05-10 SCC	51.6	67.53
Summer Tank 26-05-10 SCC	49.02	68.91

Table 2 – Results of Summer Samples 2010

Interestingly, Mix A (SCC) presented a higher % L* value than Mix B (GGBS) in the spring sampling despite the fact that anecdotal evidence suggests that GGBS concrete is brighter.



WINTER SAMPLES 2010	L* 2010	L* 2011
Winter Rack 04-11-10 GGBS	57.68	68.74
Winter Rack 05-11-10 GGBS	55.69	63.82
Winter Rack 08-11-10 GGBS	52.39	57.97
Winter Rack 09-11-10 GGBS	61.21	66.16
Winter Stack 04-11-10 GGBS	65.69	66.71
Winter Stack 05-11-10 GGBS	64.49	66.53
Winter Stack 08-11-10 GGBS	68.91	65.82
Winter Stack 09-11-10 GGBS	66.84	62.09
Winter Tank 04-11-10 GGBS	64.91	65.52
Winter Tank 05-11-10 GGBS	64.6	66.29
Winter Tank 08-11-10 GGBS	66.23	68.46
Winter Tank 09-11-10 GGBS	62.59	65.92
Winter Rack 11-11-10 SCC	44.21	48.79
Winter Rack 12-11-10 SCC	42.68	47.07
Winter Rack 15-11-10 SCC	60.56	70.94
Winter Rack 17-11-10 SCC	47.14	51.88
Winter Stack 11-11-10 SCC	69.86	68.38
Winter Stack 12-11-10 SCC	62.57	60.45
Winter Stack 15-11-10 SCC	70.11	67.16
Winter Stack 17-11-10 SCC	62.04	62.2
Winter Tank 11-11-10 SCC	64.2	69.96
Winter Tank 12-11-10 SCC	58.57	63.74
Winter Tank 15-11-10 SCC	64.71	70.07
Winter Tank 17-11-10 SCC	59.8	63.85

Table 3 – Results of Winter Samples 2010

This may be due in some respect to a high crushed limestone content. It must be noted that this was only the case for the spring sampling with the subsequent summer and winter sampling supporting the anecdotal evidence that GGBS concrete is brighter. This variation supports the belief that seasonal change impacts on colour of concrete.

Variation exists between both mixes; however, it too is seasonally affected. Average changes in L* values vary from season to season. The most consistent variable found in all results was a gradual average increase in lightness over time. An average increase is L* values from Spring 2010 to 2011 of 9.73%, Summer 2010 to 2011 of 3.88% and Winter 2010 to 2011 of 5.38%, as illustrated in Figures 5, 6 and 7.

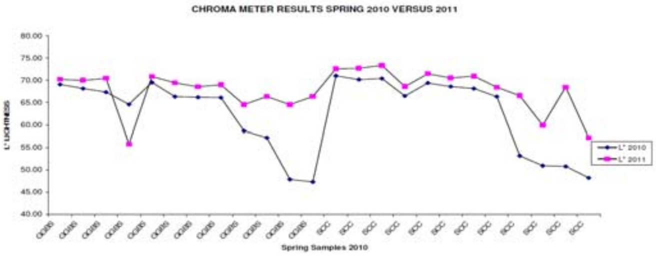


Figure 5 - Spring 2010 vs Spring 2011

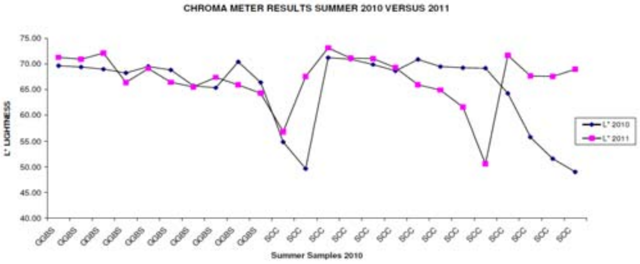


Figure 6 – Summer 2010 vs Summer 2011

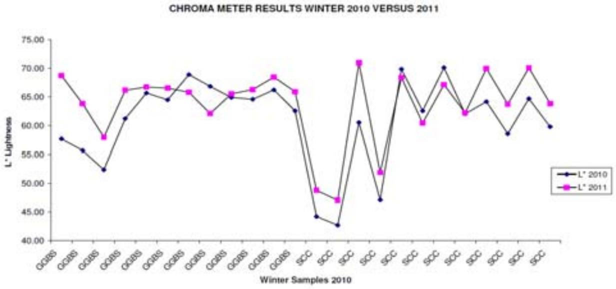


Figure 7 – Winter 2010 vs Winter 2011

6. CONCLUSION

The aim of this study is to monitor colour variation in various curing conditions over time, and the results presented so far suggest that colour does change with time. Similarly the season when casting and type of curing also play a role. The results clearly show that samples cured on a rack, south facing formation presented brighter that those consistently submerged in water (tank). In addition average improvements were found in all curing conditions irrespective of mix constituents or sampling season.

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