# Contemporary Techniques for the Assessment of Coloured Concrete

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**Synopsis**: There are three main factors which influence the way we see colour; the light source, the object itself, and the observer. Unless each of these variables are notionally 'fixed', then colour cannot be objectively quantified, nor samples compared. Standards relating to concrete have traditionally employed a grey-scale tonal guidance for colour specification/assessment. Such material colour standards rely on subjective assessment and provide no direct guidance for the quantifiable measurement/assessment of colour. From references cited and survey data gathered it is obvious that there is significant room for improvement in how specification and assessment of coloured concrete is addressed in Australia. The paper proposes improved colour specification/assessment techniques for reference in project/construction documentation, and potential revision of the AS 3610 series of standards.

**Keywords**: Assessment, AS3610, AS/NZS 2633, CIB, CIE, Colour, Color, Decorative, Finish, Oxide, Techniques.

## 1. An Introduction to Colour Measurement

### *1.1 Colour Perception*

There are three primary factors which influence the way we see/perceive colour:

#### *1.1.1 Type of Light*

Illumination represents the spectral characteristics of a light source. Most people will have acknowledged that incandescent and types of florescent globes have different characteristics and providing different 'light'. Colours which match under one light source may not match under another. As spectral illumination from the sun depends on solar elevation, the daylight at noon is different from morning or afternoon light. Even the winter and summer illuminance spectrums are different, as are the spectrums at different locations about the world.

#### *1.1.2 Object*

The perceived colour of a viewed object is also influenced by its surface characteristics: glossy surfaces appear darker, and matt or textured surfaces appear lighter. Pigments or dyes in the object result in the absorption of some wave lengths of incident light, whilst others are reflected, by diffuse and specular reflection; the rougher the surface, the greater the specular reflectance.

#### *1.1.3 The Observer*

Often two people who have "normal" colour perception will see the same colours differently, as each human eye has different sensitivity to various wavelengths of light. Tests conducted by Seceleanu et al (1) indicate males are 50% more likely to exhibit minor colour perception deficiencies than females. About 8 percent of men and 0.5 percent of women have an inherited colour vision defect, of differing degrees, which would preclude them from making colour matches with accuracy. Some would not make them with precision either. It must be realized that there is considerable variation in colour vision within a normal population. This leads to two problems. Firstly, a match or assessment made by one person may not be accepted by others. Secondly, a match or assessment made by a person may not agree with an instrumental measure or prediction (2).

Unless each of the above three variables (light source, object, and observer) are notionally 'fixed', then colour cannot be objectively quantified, nor samples compared.

### 1.2 Colour Measurement

Most standards on the definition and measurement of colour are influenced by the CIE (Commission Internationale de l'Eclairge, or, International Commission on Illumination). To accommodate for the variables introduced in section 1.1, different light sources/standards are defined and named with reference to spectral wave length (eg A – incandescent or tungsten, D50 – sunrise or sunset, D65 average noon daylight all over the world, D75 – overcast daylight, F2 – cool white florescent). The differences in surface finishes, opacity, etc, are taken into account by analysis of diffuse and specular reflection. To replace the variable and subjective assessment provided by the human eye, the CIE established an average or 'standard' human observer (called the $2^o$ Standard Observer) in the 1930s, based on a survey of volunteers who judged colours through an aperture which permitted a $2^o$ field of view. This standard observer function was updated by the CIE in the 1960s to a $10^o$ Standard Observer function following an improved appreciation of the structure of the human eye.

#### 1.2.1 Colour Scales

The experiments which informed the CIE $2^o$ Standard Observer function used red, green and blue to quantify the cone sensitivity of the 'average' human eye. Each colour was then able to be identified/quantified as primary colours to define x, y and z functions (red, green, and blue respectively) in a three-dimensional, right-angled coordinate system. This contributed to the initial colour value system referred to as CIE Tristimulus, giving rise to the Tristimuls Colorimeter (see section 1.3.1 below).

Additionally and subsequent to CIE Tristimulus, HunterLab developed a three-dimensional rectangular colour space, based on what is known as Opponent-Colors Theory – which states that the human-eye cone response to the primary colours are remixed by the optic nerve. Instead of defining a colour in terms of its component red, green and blue, the Opponent-Colors Theory quantifies a colour in terms of blue/yellow, black/white, and red/green.

The CIE adopted the Hunter L, a, b scale in the 1960s (CIE L, a, b), and then recommended and revised the CIE L*a*b* scale in 1976. According to HunterLab (3) neither scale is perfectly uniform throughout colour space, and both are in popular use today. CIELAB reportedly gives a better approximation for dark colours. Both scales are mathematically derived from x y z colour values. It is proposed that which of the two scales used is less important than consistency in using the same scale for measurements compared/shared. Both scales plot tone (white/black) as 'L' on the vertical axis, and hue (colour) in the horizontal plane. With reference to a traditional Cartesian system red/green, 'a', is plotted on the X-axis, with blue/yellow, 'b', on the Z axis.

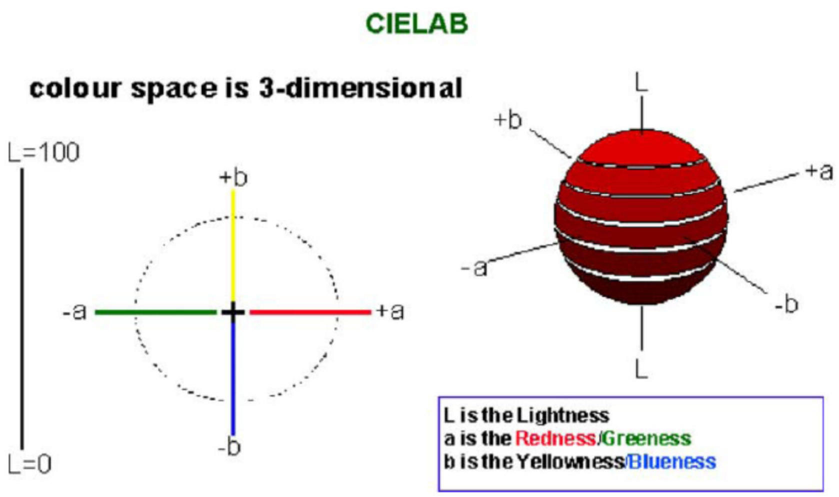


**Figure 1. Visual representation of CIE L, a, b colour scale (reproduced from Lemaire et al (5)).**

### 1.3 Equipment

Whilst sensitive, the human eye can only provide a subjective assessment of colour. Utilising colour measuring equipment enables the capture of unsubjective, quantifiable, and permanent data.

Light which is not absorbed by an object is reflected as either diffuse or specular. Colour is seen in the Diffuse reflection, whereas gloss is seen in the Specular. Whilst only 4% of light is reflected in the specular range surface finish has significant impact on how we perceive colour, with glossy surfaces appearing darker, and matt appearing lighter.

Specular reflection can either be included or excluded, dependant on the set-up geometry of the measurement equipment. There are essentially two types of instrument geometry, defined by the arrangement of the:

- light source,
- sample plane,
- detector or notional 'observer'.

### *1.3.1 Directional Geometry ($45^{o/}0^o$ or $0^o$ /$45^o$) Instruments*

Tristimulus Colorimeters (Colorimeters) are directional geometry instruments. This type of equipment illuminates a sample at either 45 degrees, with the 'observer' at zero degrees (ie perpendicular to the surface) or vice versa. Illumination by this type of directional light source results in observation exclusive of specular reflectance caused by the surface finish. Colour as measured by this technique is influenced by surface-texture/gloss-level, and represents how humans perceive or 'see' colour, or how colours appear to the human eye.

### *1.3.2 Diffuse Geometry (d/$0^o$, or d/$8^o$) Instruments*

Spectrophotometers are diffuse geometry instruments. The directional light in diffuse geometry equipment is first reflected off a sphere, thus lighting the sample plane from multiple angles. The detector/observer is either at zero (d/$0^o$) or eight degrees (d/$8^o$) in relation to the sample plane. Whilst some diffuse geometry equipment can be used for observation exclusive of specular reflection (as per directional geometry), this type of equipment excels at specular inclusive measurements. Diffuse geometry equipment must be used when colour is to be measured in isolation of surface-texture/gloss-level.

Dr Gunter Teichmann (4) nominates a diffuse geometry (d/$0^o$, or d/$8^o$) equipment with specular inclusion as being suitable for colour measurement for concrete. Based on testing of the concrete pavers in a paper entitled, *"The Use of Colorimetric Methods in the Concrete Industry"* he indicates that it is not possible to use directional geometry ($45^{o/}0^o$ or $0^o$ /$45^o$) equipment to accurately measure rough surfaces, and cites that gloss may have a negative effect on measurement results.

## 2. Standards Relevant to Specification/Assessment of Coloured Concrete.

### 2.1 CIB Report No.24: Concrete Finishes – Tolerance for Blemishes

CIB Report No.24, published in 1973 is a seminal work regarding the quantitive assessment of concrete surface quality. It nominates four classes of surface finish, based on purpose/appearance, and also percentile acceptance for each appearance class. For example an 'elaborate' class applies to finishes with a definite requirement for visual appearance, with 'special' class applying to surfaces requiring the highest standards. Indicative 80% and 95% acceptance rates are proposed for elaborate and special classes respectively.

The report tabulates standards for blemishes or defects for each surface class inclusive of:

- planar deviation,
- surface discontinuities or face steps,
- joints,
- patterning,
- stains and local surface defects,
- blow holes,
- colour variation

Colour variation is addressed via a 'grey scale', to be used when concrete is dry, in the shade, and viewed from at least 3m distant. The report includes a seven tone scale, nominating a two tone variance as being acceptable for adjacent elaborate finishes, and a maximum allowable three tone difference for elaborate surfaces which are distant.

The report also nominates size criteria in relation to 'stains', which are also applied to colour variation. A maximum allowable area of $4xL(cm^2)$ is deemed acceptable, where L is the distance between the surface and the observer. Small areas of variation are assessed as per blow holes, for which photographic scales are provided.

It should be noted with reference to section 1.2.1 of this paper, that the grey scale range provided by the report represents only the L-scale or tone on the Hunter L,a,b or CIE L*a*b* scales. With respect assessing actual coloured concrete the report recommends employing black and white photography to capture an image of the grey scale against the concrete element. With reference to the colour theory presented this particular recommendation appears to be flawed in that the process cannot provide a measurement of hue, ie the horizontal plane in Hunter L,a,b or CIE L*a*b* scales.

Lemaire et al (5) conclude that the seven-tone grey-scale classification presented by Report 24, although simple in principle, is problematic for many reasons, the most important being:

1. the variability between different printed scales of the standard;
2. the subjectivity of the human eye;
3. the different optical properties of concrete and paper;
4. a lack of information on homogeneity;
5. the fact that the tonal scale is non-linear throughout the range.

This last item, as measured by Lemaire et al (5) is approximated and represented graphically by Figure 2. Note the deviation of tones 3 and 4 from the line of best fit.

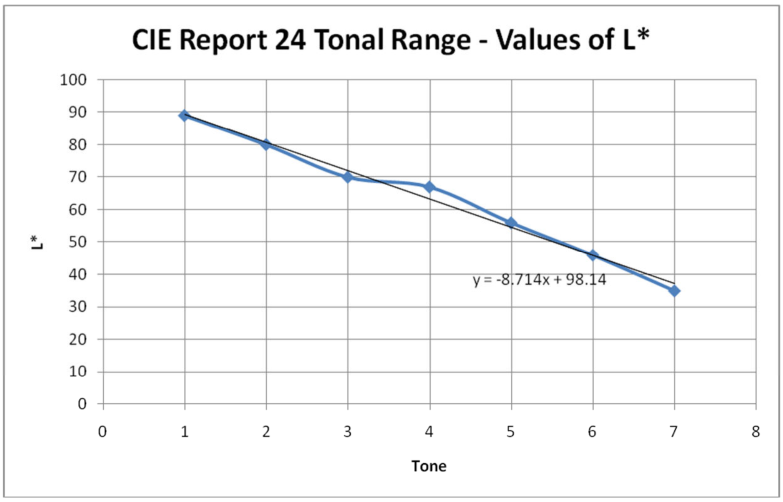


**Figure 2. Graphical representation of 7-tonal range nominated by CIE Report 24 (approximated from graphical representation by Lemaire et al (5)).**

In the Hunter L,a,b or CIE L*a*b* scales an L = 100 equates to white, and L = 0 equates to black. Report 24 provides no guidance as to the assessment of tones our side of the proposed seven-tonal range, which stops at approximately L = 35.

### 2.2 AS/NZS 2633:1996 Guide to the Specification of Colours

AS/NZS 2633 presents much of the colour theory presented in section 1 of this paper, and is significant in providing a foundation reference for colour measurement as applicable to the construction industry. The standard categorises the 'grey scale' tonal range nominated by CIB Report No.24 as a 'material colour standard', being similar to paint samples/scales. It recognises the deficiencies of this type of assessment citing:

- visual colour matching to a material colour standard as being dependent on the light source, the colour vision of the observer, size of samples and the viewing conditions;
- Metameric failure - where two material samples match when viewed under one light source but not another.

This 1996 standard describes the CIE Colorimetric system as being able to identify five million individual colours and recognises this as an obvious advantage for use in quantitive assessment.

### 2.3 AS 2001.4.A02—2005 (ISO 105-A02:1993) Methods of test for textiles: Method 4.A02: Colourfastness tests—Grey scale for assessing change in colour

This standard was reviewed for the opportunity to compare grey-scale tonal ranges. The standard references a 5-step scale (also termed a 9-step scale with the inclusion of half tones) for the assessment of colour fastness. Whilst nominating a tonal scale concept not dissimilar to CIB Report 24: Concrete Finishes – Tolerance for Blemishes, the standard (based on ISO 105-A02, 1993) defines a precise colorimetric scale with reference to CIE 1964 Lab (ie Hunter L, a, b).

A spectrophotometer with specular component included (ie excludes influence of gloss-level/surface texture) is nominated for comparative measurement. Figure 3 is a graphical representation of the 9-tonal range. In the Hunter L,a,b or CIE L*a*b* scales an L = 100 equates to white, and L = 0 equates to black. Note the tonal scale is best defined by a power function as opposed to linear, with greater tonal increases deemed acceptable in the lighter shades.

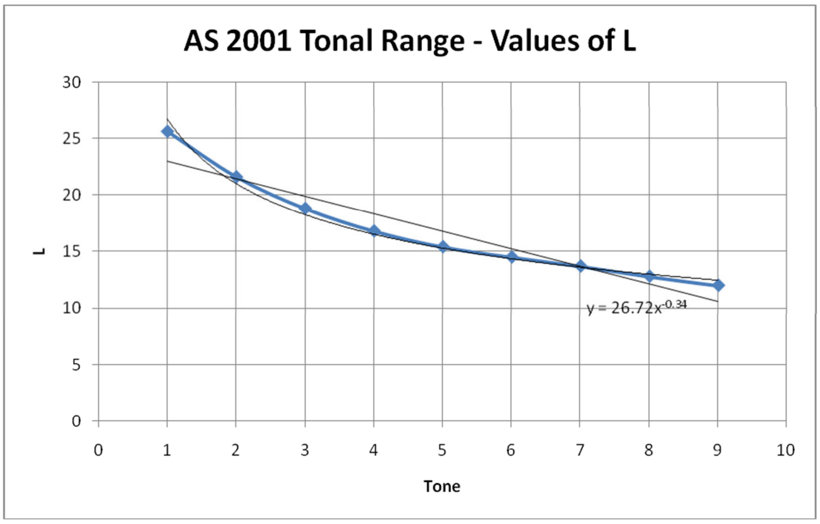


**Figure 3. Graphical representation of 9-step grey-scale nominated by AS 2001.4.A02—2005**

### *2.4 AS3610 Formwork for Concrete*

AS3610 has been the primary reference source in Australia for specifying and assessing coloured concrete since 1990. The latest version of the standard released in 1996 is superseded in part by AS3610.1 *Part 1: Documentation and surface finish.* Prior to the publication of *Part 2* (to cover design and testing), it is intended that AS 3610 and AS 3610.1 will coexist. Sections 2, 3, 4 and 5 AS3610.1 supersede Sections 2, 3 and 5, as well as Clause 4.7 of AS 3610—1995 (6). A commentary exists for AS 3610—1995*, Formwork for Concrete - Commentary (AS3610 Supp2-1996 Incorporating Amendment No. 1),* which is yet to be superseded, however a commentary has been added to AS 3610.1—2010 Table 3.5.3 to clarify the intent of tonal ranges.

### *2.4.1 AS 3610—1995*

Similar to CIB Report 24, Table 3.3.1 of the standard nominates classes of surface finish, based on purpose/appearance. Three visual classes are nominated (Class 1, 2 and 3 – where 1 is the highest) and these can be directly compared with the intent of the special, elaborate and ordinary classes of Report 24. AS 3610 divides visually insignificant finishes into two classes, 4, and 5.

Colour control may be specified for the visually significant Classes (as per CIB Report 24), and a ten-tone grey-scale ('material colour standard' – as defined by AS/NZS 2633:1996) is provided in Appendix B of the standard. The standard provides no quantitive reference from which to measure the nominated grey-scale, or how it was derived. Specular inclusive measurements of each tone were undertaken using a HunterLab MiniScan Spectrophotometer as part of the research informing this paper. Measurements were taken directly from a commercially published version of AS 3610 Supp 1-1995 Formwork for concrete - Blowhole and colour evaluation charts (as opposed to a print out of the online version). The supplement provides several copies of the tonal charts, and these were laid on top of each other in an attempt to minimise an influence on the readings by the paper opacity. Graphical representation of the ten-tone grey-scale as included in AS 3610 Supp 1-1995 is provided in Figure 4.

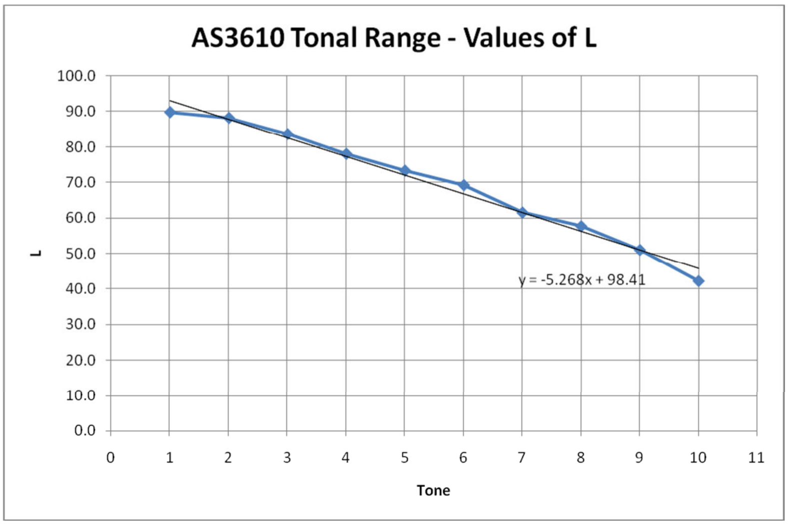


**Figure 4. Graphical representation of 10-step grey-scale nominated by AS 3610-1995, AS 3610 Supp 1-1995 (and AS 3610.1-2010).**

As opposed to the curved function of AS 2001.4.A02—2005, the line of best fit for the AS 3610-1995 tonal range is linear – similar to the CIB Report 24 scale. In the Hunter L,a,b scale an L = 100 equates to white, and L = 0 equates to black. The tonal range nominated in AS 3610 is also very similar to Report 24, starting close to L=90, and finishing around L=40. As with Report 24, the tonal scale deviates from linear along the range.

Clause 3.5.4 nominates the requirement for manufacturing and referencing a test panel to define acceptability with respect to coloured concrete. Clause 3.6.3(b) and Table 3.6.1 nominate that tonal variation of an assessed Class 2 element is deemed permissible where not outside the range of five tones as recorded from the test panel. The commentary correctly identifies that the test panel itself cannot be used in the future for colour evaluation, citing the effects of pollution, and a gradual change and varying extent of colour change over time. Comparison of the standard's five-tonal range across the ten-tone scale to CIB Report 24's 3-tonal range across the seven-tone scale, for Class 2 and Elaborate Class respectively, is provided in Figure 5. It can be seen that Delta L, or change in tone, is actually equivalent for both references. As the actual extent of each scale is also equivalent it is apparent that the ‘material colour standard’ tonal range of AS 3610-1995, and AS 3610.1-2010, and nominated acceptance criteria predates 1973.

| **Reference** | AS 3610 | CIB Report 24 |
|---|---|---|
| **Tonal Scale** | 10 Tones | 7 Tones |
| **Line of best fit (CIE L, a, b),** where y = L, and x = tonal step | y = -5.268x + 98.41 (Figure 4) | y = -8.714x + 98.14 (Figure 2) |
| **Comparative class of finish** | Class 2 | Elaborate |
| **Permissible tonal variation** | 5 Tones | 3 Tones |
| **Delta L =** | 26 | 26 |

**Figure 5. Comparison of tonal variation for AS 3610 and CIB Report 24 – for uniform colour quality as nominated for large areas.**

Clause C.3.5.4 of the commentary indicates that the standard contains very few direct statements that give unequivocal guidance on contract decisions. It is noted that no prescriptive criteria is provided relating to the size of colour defects, or the total accepted conglomerate area which may be deemed acceptable is provided in the standard. Clause C.3.5.4 of the commentary includes a statement which promotes that there may be situations where the subject work will be accepted, even though elements have tonal variations outside those recorded. Examples cited are:

a) some elements slightly darker (or lighter) overall than the specified tone, but with the overall effect acceptable; and

b) some elements with local dark (or light) patches of colour, which do not detract from the overall appearance.

Obviously these examples are open to subjective interpretation by different observers.

Where a tonal scale is used for assessment, clause 5.6.4 of the standard nominates the scale should be held up against the element to be examined, and comparison made. It nominates that lighting conditions and also the amount of time after stripping of formwork should be consistent for all elements being assessed. The viewing distance is not seemingly nominated for the assessment of colour, however clause 5.6.2.1(a) indicates a minimum distance of 2m, or the closest distance from which the subject area will normally be observed, for assessing blow holes, and 5.6.2.1 (c) indicates the same for surface treatments.

Clause 5.6.4 also nominates that colour evaluation shall be carried out before any surface treatment, with AS 3610 Supp 2—1996 Clause C5.6.2.1 identifying tooling or sandblasting as examples of surface finishing. As the standard makes no reference to definitive colour measurement equipment the requirements of the clause are seemingly incidental to the inability of standard measuring equipment to accurately measure a surface texture created by these finishing procedures.

The standard provides no direct guidance on the quantifiable measurement/assessment for actual colours (ie hue as opposed to tone), but does indicate in clause 3.6.3(b) that if the tonal scale provided by Appendix B is not suitable, then the approved test panel shall be permitted to have tonal variations which are consistent with the intent of the standard. From Figure 5 it could be extrapolated is that the intent is a tonal variance of L = 26 (CIE L, a, b) for Class 2.

### *2.4.2 AS 3610.1—2010*

AS 3610.1—2010 supersedes Sections 2, 3 and 5, as well as Clause 4.7 of AS 3610—1995. As a comparison of the current standard and superseded sections of AS 3610 it is noted that clause 2.2.2 includes an additional documentation criteria as item, (u). This item nominates that specified concrete ingredients or admixtures that may affect colour control must be included in project documentation. This requirement is reiterated in clause 2.3.2 (l). New clauses 2.4 and 2.5 pertaining to formwork and proprietary documentation will also assist in the improved production of decorative concrete.

Section 3 has been renamed from ‘Surface Finish’ to ‘Surface Finish and Colour Control’. The requirement of AS-3610-1995 clause 3.5.1 for colour control to be evaluated before any surface treatment is carried out is not evident in the equivalent AS3610.1-2005 Clause 3.4. Clause 3.5.3.of the 2010 standard is far clearer in nominating that the tonal range of the accepted test panel, as well as the final work, shall be determined by the use of either the tonal scale or the other means referred to in Clause 3.4.3, and that a test panel shall be used to fix the standard required for the final work.

### *2.4.3 AS 3610 – Deficiencies: the Specification and Assessment of Colour*

The 2010 revisions to the 1995 content still provide no quantitive reference from which to measure the nominated grey-scale, or how it was derived. Nor does the revision provide direct guidance on the quantifiable measurement/assessment for actual colours (ie hue as opposed to tone). For example, what if a brown-grey concrete is specified, documented and produced in the test panel, whereas the assessed complete works were observed as blue-grey? Prescriptive criteria are also not provided relating to the permissible size or distribution of colour defects, or the total conglomerate area which may be deemed permissible. The viewing distance is not seemingly nominated for the assessment of colour.

With respect to concrete colour where visual quality is deemed important (Classes 1, 2 and 3), the normative and informative elements of the standards and commentary are provided to ensure a nominated resultant, and guidance on how to achieve it. To assess suitability of the tonal scale (derived pre-1973), a survey was undertaken to ascertain specifier perception of the five-tone variation deemed permissible for Class 2 finishes. 769 Australian architects were approached to participate, of which 9.5% responded. Respondents were presented with and requested to comment on five-tonal variations with reference to the AS3610 tonal chart. In sequential order images presented which depicted Tone 1 and Tone 2 side by side, Tone 1 and Tone 3, Tone 1 and Tone 4, and Tone 1 and Tone 5 – representing a five tone range at the lighter end of the scale. Additionally images were provided for Tone 6 and Tone 7, Tone 6 and Tone 8, and so on, representing a five-tone variation at the darker end of the scale. Respondents were requested to provide yes/no answers as to the acceptability of each tonal variation presented, and were presented with the following qualifications:

1. The tonal variations presented are taken from the scale appended to AS3610 Formwork for Concrete;
2. This is not a test. Please feel free to answer 'Yes' or 'No' for all variations as you deem appropriate;
3. Concrete is a composite material and as everything from which it is made varies in consistency, it is not possible to produce concrete with absolutely no variation in quality;
4. Building facades are rarely viewed up close and in detail - consider the tonal variations as if you were viewing a building facade from no closer than 2m.

Images were emailed to the survey group due to a restricted survey time frame. Thus each assessment was influenced by light source, object, and observer, being each variable identified in section 1 of this paper.

Survey questionnaire and results are included as Appendix A. Figure 6 includes graphical results for specifier acceptability of the tonal variations presented. The figure indicates that the lighter tonal shades that no respondents deemed a five-tonal variation to be acceptable (Tone 1-5), and only eight percent deemed a four tonal variation acceptable (Tone 1-4). At the darker end of the scale no respondents deemed a five (Tone 6-10) or even four-tonal range (Tone 6-9) to be acceptable, with just five percent considering a two-tone variance acceptable (Tone 6-8).

Not a single architect considered the five-tonal variation nominated for Class 2 finishes by AS 3610, as presented by the survey questionnaire, to be appropriate. The survey data also indicates that a greater tonal variation may be acceptable for lighter shades/tones, suggesting that a curvilinear tonal scale as presented by AS 2001.4.A02—2005 may be more appropriate than the linear line-of-best fit extrapolated for CIB Report 24, and AS3610.

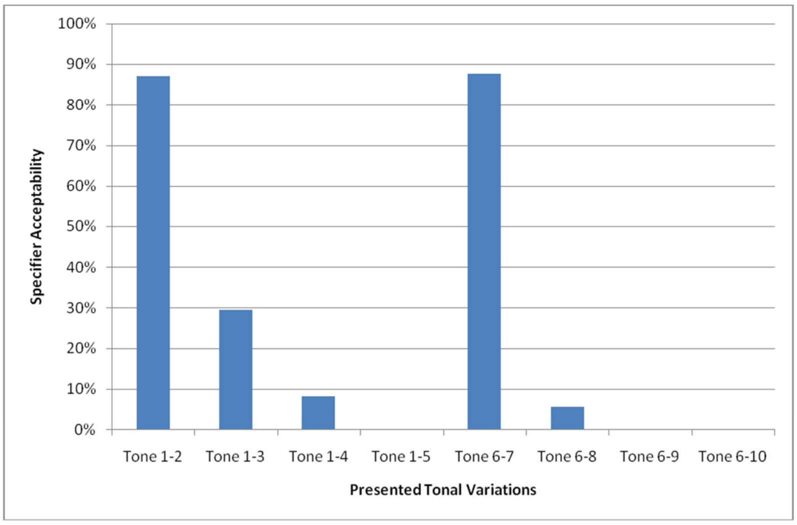


**Figure 5. Graphical results of specifier acceptability of the tonal variations presented.**

### *3. Techniques for the Assessment of Coloured Concrete*

In addition to the material colour standard technique as nominated by CIB Report 24, and AS3610, section 1 of this paper nominates instrumentation which can provide unsubjective, quantifiable and permanent assessment data. These techniques are also referenced in AS/NZS 2633:1996.

Dr Gunter Teichmann, 1990, (4) nominates a Spectrophotometer (d/0$^{o}$, or d/8 $^{o}$) instrumentation, with specular inclusion, as being suitable for colour measurement for concrete. Lemaire et al , 2005, (5) nominate a Spectrocolorimeter (a Spectrophotometer which can *calculate* tristimulus values). Whilst not noted in the paper by Lemaire et al, it is likely in using a Spectrophotometer, that specular reflectance has been included (ie negating the impact of surface texture/gloss-level).

Lemaire et al (5) propose the *GTM–LMDC process,* developed by GTM-Construction and the LMDC. The process correlates digital photography of off-form elements by use of spot Spectrophotometer readings. Use of digital photography enables global measurement on concrete surfaces of several square meters (whereas the aperture of Spectrophotometers is generally in the order of 25mm), and correlation with the Spectrophotometer negates the variability of the colour due to the specific camera system and illumination of the object. Figure 6, reproduced from Lemaire et al (5) displays one method of presenting output from the *GTM–LMDC process* of measurement.

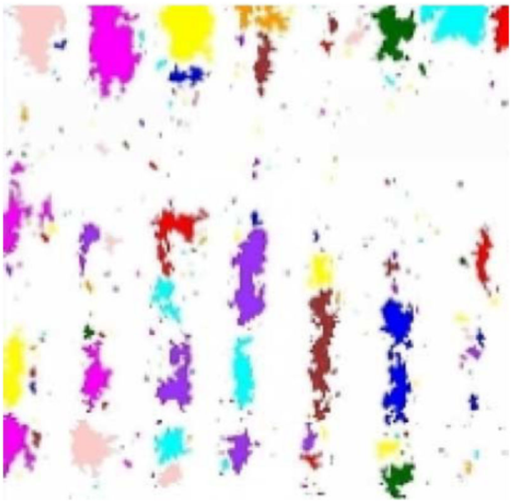

**Figure 6. Tonal variation as presented across a macro portion of concrete panel using the *GTM–LMDC process* (from Lemaire et al (5)).**

In the course of research informing this paper, measurement of precast concrete wall elements with integral oxide tinting was undertaken as shown in Figure 7. An example of tonal variation and related Spectrophotometer measurement is provided as Figure 8. For this project the panel was nominated as the test or reference panel, with precast supplier and client representative agreeing on the extent of variation included. With reference to the AS 3610 tonal scale the variation equates to just one tone. This aligns with the expectations of survey respondents with respect to variation. It may not be visible in the reproduction of this paper; however there is a noticeable blue and brown hue variation within the panel which cannot be quantifiably assessed using the AS3610 grey-scale.

**Figure 7. Measuring tonal variance of coloured precast concrete at hotel, Brisbane Airport, using HunterLab MiniScan Spectrophotometer.**

Lightest reading

L* = 43

Equivalent to AS3610 tone 10.5

Darkest reading

L* = 37.5

Equivalent to AS3610 tone 11.5

Variation = 1 Tone

**Figure 8. Measured tonal variance of precast panel at Hotel, Brisbane Airport, using HunterLab MiniScan Spectrophotometer.**

Undertaking a few discrete readings using a Spectrophotometer can quickly and easily provide quantifiable assessment with respect to AS 3610, with Spectrophotometer readily available for hire or purchase in Australia. The equipment can be portable and operated with minimal training. The *GTM–LMDC process,* however, removes the subjective component of identifying the lightest and darkest tones in a panel. Trials of the *GTM–LMDC process* were also undertaken as part of the research component informing this paper, by using a hand held digital automatic camera and a Microsoft Excel worksheet. The system was found to be reasonably practical, time efficient and state-of-the-art with respect to presenting definitive, quantifiable data.

## *4. Conclusion and Recommendations*

With reference to colour theory and measurement, other Australian Standards, work published by Dr Gunter Teichmann, 1990, (4), Lemaire et al, 2005 (5), and research work undertaken, it is apparent that AS 3610 Formwork for Concrete provides limited practical normative guidelines, or informative support to quantifiably specify or measure concrete colour.

It is proposed that the following criteria be considered to provide an enhanced opportunity to specify and assess off-form coloured concrete, and that it also be considered with respect to future review of the AS 3610 series of publications:

### *4.1 Guidance from other Australian Standards*

AS/NZS 2633:1996 and AS 2001.4.A02—2005 (ISO 105-A02:1993) both provide insight and guidance with respect to quantifying and assessing colour and tonal variation.

### *4.2 Tonal Scale*

An improved tonal scale be adopted. The scale should be quantifiable using CIE L, a, b, or CIE L*a*b* scales, and also identified as a curvilinear equation, as supported by AS 2001.4.A02—2005 (ISO 105-A02:1993), and survey data presented by this report.

### *4.3 Permissible Tonal Variation*

Survey data appended, and the case study mentioned in section 3 of this paper indicate that the permissible tonal variations nominated in AS 3610 may be too lenient to provide optimal project and industry outcomes. The variations nominated in AS 3610 pre-date 1973, and may have been applicable in protecting contractor/supplier interests at that time. Materials and production technology has advanced in the interim years, as perhaps has specifier requirements. With white cements, select aggregates, computer controlled batching, and low-compaction mixes now available, it is likely the industry would be supported by enhanced colour variation criteria.

### *4.4 Reference to CIB Report 24*

Whilst produced in 1973, there are still several areas where Report 24 provides additional guidance on the specification and assessment of coloured concrete. Even if referenced as from an informative perspective, project and/or construction documentation could be improved by nominating:

- nominating indicative percentage acceptance rates;
- nominating a minimum distance from which elements should be viewed;
- size criteria for colour defects.

### *4.5 Specification and Assessment of Hue*

The grey-scale tonal range nominated in AS3610 provides no guidance on assessing actual colour (hue) as opposed to tone (amount of white/black). CIE L, a, b, or CIE L*a*b* colour scales provide a rectangular acceptance zone defining limits for tone (white/black), red/green, and blue/yellow, capable of defining some five million different colours. Assessment using these scales can be quantified by equation.

### *4.6 Colour Measurement*

A colour measurement technique should be nominated, one which eliminates subjective assessment and which supports contractual rigour. It is strongly recommended that Spectrophotometer instrumentation be specified, instead of 'material colour standards' as per AS 3610 grey-scale, with spectral reflectance included or excluded as appropriate for the surface texture.

## 5. References


1. Seceleanu, R., Seceleanu, A., Dudea, D., "Evaluation of Color Perception in a Group Of Dental Students", 42nd Annual Meeting of IADR-Continental European, 0443, 2007.

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**Appendix A: The Assessment of Coloured Concrete Survey**

Green Leaf is preparing a technical paper on the assessment of coloured concrete, for Concrete 2011, being held in Perth this October. I am hoping for less than 1 minute of your time in providing a professional opinion.
For each image adjacent could you please indicate if you would deem the presented tonal variation to be acceptable if adopted for a decorative concrete building facade.
For example, if you would accept the tonal variation in Image 1, then answer: 1-Yes. If not acceptable answer: 1-No.
If Figure 2 is unacceptable then answer: 2-No, and so on, for each of the 8 images.

Consider the following when making your assessment:

1. The tonal variations presented are taken from the scale appended to AS3610 Formwork for Concrete;
2. This is not a test. Please feel free to answer 'Yes' or 'No' for all variations as you deem appropriate;
3. Concrete is a composite material and as everything from which it is made varies in consistency, it is not possible to produce concrete with absolutely no variation in quality;
4. Building facades are rarely viewed up close and in detail - consider the tonal variations as if you were viewing a building facade from no closer than 2m.

Kind regards,

**John Tuxworth**
B Eng GCertMan MIEAust MIStructE RPEQ NPER


Image 1


Image 2


Image 3


Image 4

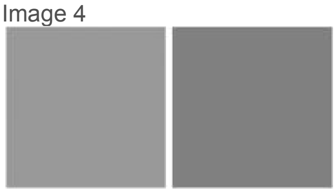
Image 5

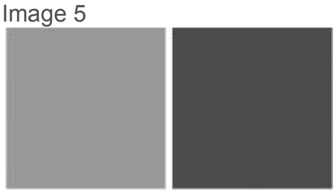
Image 6

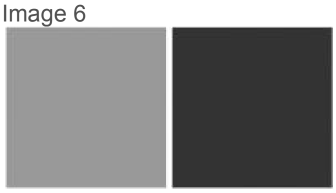
Image 7

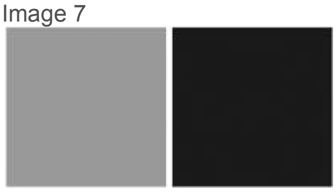
Image 8

## Appendix B: Survey Results

**Table A1. Survey Data**

| Architects received | Responses | % Response | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 769 | 73 | 9% | | Yes = 1 | | No = 0 | | Maybe = 0.5 |

| Response | Tone 1-2 | Tone 1-3 | Tone 1-4 | Tone 1-5 | Tone 6-7 | Tone 6-8 | Tone 6-9 | Tone 6-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 4 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 6 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 8 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 9 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 10 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 12 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 13 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 14 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 15 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 16 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 17 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 18 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| 20 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 21 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 22 | 1 | 0.5 | 0 | 0 | 1 | 0 | 0 | 0 |
| 23 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 26 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 27 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| 28 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 29 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 30 | 0.5 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| 31 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 34 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 38 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 39 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 40 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 41 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 42 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| 45 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 46 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 48 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 49 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 50 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 51 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 52 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **53** | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| **54** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **55** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **56** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **57** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **58** | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **59** | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **60** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **61** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **62** | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| **63** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **64** | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| **65** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **66** | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| **67** | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| **68** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **69** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **70** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **71** | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| **72** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **73** | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **Total** | **63.5** | **21.5** | **6** | **0** | **64** | **4** | **0** | **0** |
| **Percentage** | **87%** | **29%** | **8%** | **0%** | **88%** | **5%** | **0%** | **0%** |

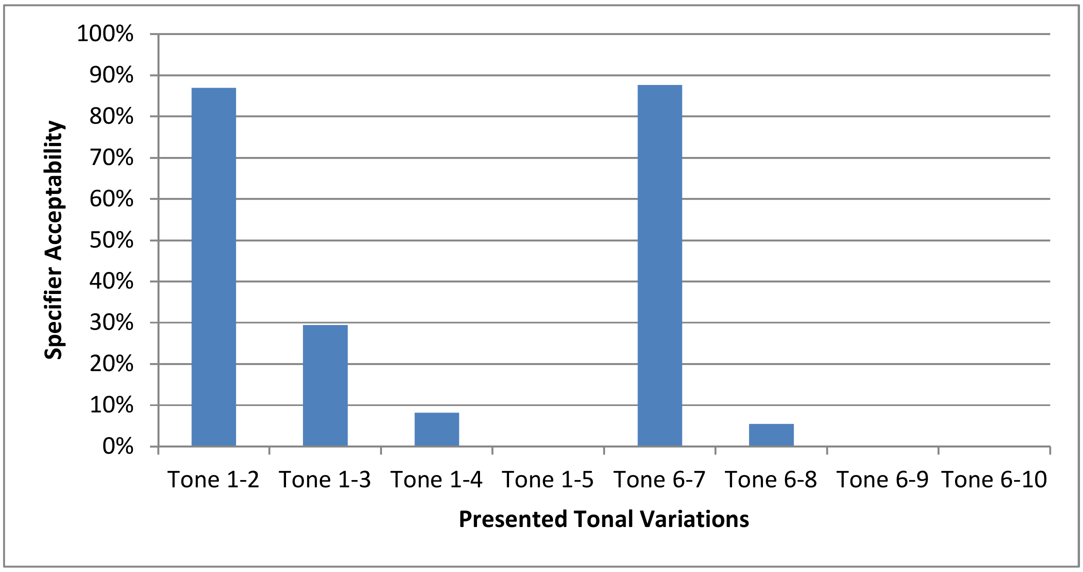


**Figure A1. Percentage of Specifier's Acceptability**