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IMPORTANT INFORMATION FOR SPECIFIERS AND PRE-MIXED CONCRETE SUPPLIERS

'COLOURING PIGMENTS FOR CONCRETE: THEIR POSSIBILITIES FOR ENHANCING ARCHITECTURE, LANDSCAPE ARCHITECTURE & CIVIL ENGINEERING'

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FORWARD:

Whilst inorganic mineral oxide pigments themselves do not fade as a reader of this paper will come to realise, there are FOUR (4) *important* things which *affect* colour perception by individuals of cast-in-place pigmented through-coloured concrete and concrete products. These are:

1. **TIME OF COLOUR ASSESSMENT:**
   People tend to look at, and judge, coloured concrete *the day after* it has been laid and *set*, whereas the final **true** colour of slowly *hardening* Portland cement-bound concrete is not achieved for some seven (7) (in actuality more than twenty eight, **28)** days.

   In concrete construction where the adoption of the important and beneficial procedure of curing (prevention of the evaporation of the water used to mix the concrete commencing immediately after it sets) the colouration will generally appear darker and more intense at the same age (particularly at 28 days) than uncured concrete which is allowed to dry out.

   At ambient temperatures, it takes a month for concrete to achieve about 85% of its ultimate hardness and strength whereas at 24 hours after setting it has reached only about 26% of this mechanical strength. That is, a month is required for most of the (preferably low quantity of) mixing water to chemically combine with the cement or cementitious component by the chemical process of hydration to completely produce the hardened cement paste 'glue' which binds the mixture into a composite mass. Prior to this period, concrete therefore contains some 'free' chemically uncombined water which has not (yet) been used up in completely hydrating the cement. The colour often appears darker, brighter and more intense with this 'wet look' as wet surfaces generally appear darker and more intense in colour than those which are dry.

2. **FORMATION OF LAITANCE:**
   Should a weak surface layer of weak light coloured cement 'scum' called laitance occur, mainly due to the use of pre-mixed plastic (unset) concrete that bleeds water to the surface after placement and screeding [see page 10 item (e)], it will, when the concrete has hardened, tend to 'mask' the colouring effect of the dispersed pigment, at the surface, making it appear to have 'faded'.

For effective integral colouration - particularly at the surface, it is mandatory to specify, use, and place, only **non**-bleeding concrete - so that laitance does **not** occur.

3. FORMATION OF EFFLORESCENCE:

Efflorescence is white ‘frosty’ looking salt bloom. It is different to laitance and is caused by the migration of soluble salts to the surface of *hardened* concrete. These white salts can chemically combine with Carbon Dioxide in the air (that is, they may *carbonate*) and become insoluble by forming Calcium Carbonate (marble). This is very difficult to remove permanently. After washing or acid etching it off, it usually returns. Efflorescent salts, like laitance may also ‘mask’ the true colour effect of pigmentation *at the surface*, resulting in the incorrect impression that the colouring pigment has ‘faded’.

Avoid efflorescence by specifying a *suitable* strength grade of pre-mixed concrete (possibly the next highest strength grade than is typically used) for the particular performance requirements of use as well as to ensure the use of suitable site placing and processing procedures - including moist curing** for this concrete grade to ensure impermeable (waterproof/watertight) hardened concrete in place.*

4. POOR ABRASION RESISTANCE:

Hardened concrete (pigmented *or* plain uncoloured) in place with poor abrasion resistance wears rapidly, – even under mild traffic conditions. Abrasion removes the pigmented hardened (hydrated) cementitious paste binder ‘glue’ (or matrix) and the pigment particles with it at the surface.

Eventually further abrasion reveals first the fine and then the coarse aggregate which, if **not** of the **same** colour as the hydrated cement paste matrix, has the overall effect of severely ‘diluting’ the pigmented coloured effect of the binder matrix to a viewer’s eyes, ie the overall colour of the concrete appears more muted and less intense than when it was originally cast as there is less of it per unit area.

To ensure wear resistant concrete and avoid the problems of excessive wear, you could specify and use a pre-mixed **concrete strength grade** having high wear and abrasion resistance (perhaps the *next* highest grade than that indicated in your current specification.) plus all of the factors mentioned in this paper *including* the incorporation of an *optimum* amount of cementitious binding material per m^3 of concrete, and the use of correct site processing procedures and practices including **compaction** by vibration to eliminate air bubbles and the use of good curing techniques such as the use of a liquid **curing compound**** for immediate application to just-set concrete.

SYNOPSIS:

The use of a suitable strength and performance grade of pre-mixed or factory mixed plastic type (flowing) concrete from the many available from pre-mixed concrete suppliers, suitable colourants and the use of proper handling placing and finishing procedures for obtaining durable, *integrally coloured* cast-in-place concrete are explored in this paper.

It should be noted that no attempt has been made to outline these issues in the completely different methods of manufacture and use of **machine made** concrete products - such as concrete masonry blocks, bricks and pavers. Most machine made concrete blocks, bricks, flagstones, interlocking set pavers etc are made with a very ‘dryish’, (non-plastic non-flowing) wet mix consistency. These are different to those of plastic semi-flowable consistency mixes which ‘slump’ and which are used for cast-in-place or in-situ concrete pavements and structures.

***** *To **really** make sure, Ability’s **‘EFFLOREIN®’ Mark 2** powder **–** an anti-efflorescent and multi-functional quality-enhancing admixture for concrete may be specified - with or without an ‘abilox®’ mineral oxide colouring pigment(s) - at the dose rate of 1.5kg per 100kg of cementitious material. (1½ % by weight).*

****** *The use of Ability’s ‘DURO-SEEL’ liquid membrane curing compound and combined surface ‘sealer’ coating (‘same-day sealer’) for concreting available in translucent clear and a range of 20 colours including ‘White’ and ‘Concrete Grey’ - is a highly recommended method of moist curing.*

These semi-dry mixes contain a *minimum* of water and involve the use of high shear mixing equipment and heavy compactive machinery. Although some characteristics are similar and the colouring materials used are the same as for producing flowing plastic concrete mixes (and in particular specific pigments of a *particular* shade can be specified by you to obtain any of these concrete products in a *particular* colour for a project) the cost, manufacturing criteria, methods and results are typically different.

For those interested, reference can be made to Ability's published article: "ACHIEVING COLOUR PERMANENCY IN THE MANUFACTURE OF MACHINE MADE SEMI-DRY MIX, NO-SLUMP CONCRETE PRODUCTS - A SUGGESTED CHECK LIST". This is available upon request.

INTRODUCTION:

Integrally coloured in situ concrete pavements, shapes and construction elements, concrete products, grouts and mortars with different colours obtained with suitable pigments plus surface finishes and effects provided by concreters are construction materials which offer architects, building and landscape architectural designers a multitude of attractive and durable project alternatives in a wide variety of permanent colours.

Good quality, long lasting, integrally coloured in situ concrete and mortar is made from an ideal combination of its raw materials which should also be of optimum quality and ideal handling, application and finishing of these after precisely mixing them into concrete. Bad coloured concretes/mortars are made from the same materials! All things being equal, there is virtually no difference between unpigmented concrete/mortar and permanently coloured concrete/mortar except for the fade-free inorganic pigment(s) used to obtain the colour.

The quality and durability of all hardened concretes and mortars - coloured or uncoloured - in place, is almost entirely related to the quality of the hardened (hydrated) **cement paste** or cementitious metal silicate *binder* ('glue) which binds and holds the aggregates together by concrescence. This binder quality and binder durability in turn is largely related to the concrete's water:cement ratio or water to cementitious material ratio (w/c ratio). The *lower* the better!

PIGMENTS ARE USED FOR COLOURING VIRTUALLY ALL COMPOSITE PRODUCTS:

Pigment grains are ultrafine particulate, non-dissolving solids. Pigments are supplied in the form of a coloured powder. Like dyes, pigments are contained in many items of nature. In particular, *inorganic* mineral oxide pigments occur as *ochres* or *earth colours* of various colour shades in the earth's crust and are contained in soils, minerals and rocks. Both dyes and pigments are manufactured synthetically and are used to colour many man-made products of industry. However, dyes are chemically organic and therefore different to all pigments that are chemically inorganic. Most dyes have limited resistance to light. They are therefore unsuitable for permanently colouring concrete and mortars.

Quality, manufactured, as well as suitably processed natural or 'native' mineral oxide powder pigments are used to impart colouration to composite products. These may include items such as different classes and strength grades of pre-mixed concrete, precast concrete units, concrete products, baked clay bricks and other ceramic products, asphalt, paints, inks, plastics, rubbers, flooring compositions and wallpapers as well as many other coloured products around us that we may tend to take for granted - even most *cosmetics* and some toiletries such as *zinc cream* are essentially based on pigments, and in most cases a suitable binder, hardening/setting matrix or vehicle/carrier.

Dyes, or more correctly *dyestuffs*, are mostly used to colour fibres - particularly textile fibres, as well as other fibres such as human, and other, hair. Dyes are mostly *unsuitable* for colouring the composite products previously mentioned. This is because they are not always permanent to UV rays in light - resulting in fading, but suitable types are occasionally used for minor uses in the building industries such as for certain wood/timber stains designed for *interior* use.

Unlike a dye powder, the particles of which usually dissolve in the liquid 'carrier' used in the dyeing process, a pigment is *insoluble* and its particles do *not* dissolve in the product mixes, medium or 'binder' in which the pigment powder particles or grains are dispersed and encapsulated by the mixing process and which later set or harden.

In a colouring process using pigments the billions of ultra-fine particles of a coloured pigment powder are required to be *DISPERSED*, (uniformly, discreetly and homogeneously distributed by mixing) throughout the mass of the material – and specifically in the binder being coloured. For instance, in its final hardened form, a coloured petrochemical derived ***plastic*** product is usually a moulded or extruded, flexible, solid - a basically hard substance. However, at one stage in their manufacture, plastic articles are usually liquids, or semi-liquids, and it is at this stage the pigment powder is usually added. After addition the pigment is then intensively mixed/dispersed **into** this materials' liquid phase so that ideally the minute pigment grains are uniformly, discreetly equally, and separately distributed throughout its total volume or mass. The process of adequate dispersion by adequate mixing results in colour uniformity and maximises the intensity of colouration in relationship to the dose rate.

The human eye unable to determine individual pigment grains sees the result of this process as a particular, as well as a uniform ***colour*** - either *white, green, blue, brown, black, red, yellow*, etc - depending on the colour shade of the particular pigment powder used.

If a green pigment is used, the clear or translucent plastic will be turned into a green plastic. If a white and the same green pigment are used together, the resultant colour of the plastic will be a paler *pastel* green. Most colours of manufactured products around us are pastel (or reduced) colours, that is, in addition to a colouring of pigment, they either contain or appear to contain a fairly large proportion of *white* pigmentation.

PIGMENTS USED TO MAKE COLOURED CONCRETE.

Similarly, for concrete, mortars, gypsum plasters, cement 'plasters' or renders and other cement bound products for the building industry, *special* pigments of a certain, suitable type are **dispersed** into the cement/water paste. The cement paste or 'glue', firstly *sets* and, if the original mix water is retained by a water vapour evaporation prevention, curing procedure, later *hardens* fully to form a stronger 'glue' which permanently binds the aggregates together. Thus, a very strong, hard 'stone-like', very long-lasting product is formed - and in **this** case - a very long-lasting **coloured** 'stone-like' product.

This ultra-fine particle colouring pigment may be added at any stage of the concrete manufacturing process whilst the concrete is in its '**plastic'** non-hardened state before placement. For instance, pigments may be purchased and used by the cement (powder) manufacturer to produce **coloured** cements of various types and shades by dry-mixing and/or grinding them with the cement grains. The resultant *coloured* cements may then be sold to various clients, including *premixed concrete* suppliers to make integrally **coloured concrete** - or perhaps to a *brick-laying contractor* to make and lay **coloured** brick/block jointing mortars, to match or contrast with the colour of bricks, blocks or other masonry units used to construct walls.

Additionally, coloured cements may be used by *master painters* for on-site mixing and later application of long-lasting, acrylic polymer resin reinforced cementitious (cement-bound) paints and applied surface coatings for walls, roofs and pavements, by *plasterers* for interior coloured cement 'plasters' and exterior renders or by *tilers and slaters* for integrally coloured grouts and mortar joints between individual wall, floor tile mosaic or slate pieces and the 'pointing' mortars for roofing tiles.

Suitable UV resistant pigments for the permanent colouration of concrete, mortars, grouts etc are those known as *inorganic* mineral (metal) oxide pigments. The man-made synthetic versions of this pigment type are usually *preferred* as they are invariably slightly cleaner/brighter, tinctorially stronger, more uniform from lot to lot and purer than the native variety. Mineral oxide pigments - native or man-made - are the most permanent and durable of all pigment types. Most may be regarded as immutable.

ALTERNATIVELY, in the case of premixed concrete and *other* hardened cement bound materials and products such as concrete pavers and flagstones, the pigment powder may be added to the product mix at the paver manufacturing plant with plain (uncoloured) ordinary Portland cement - known as OPC in the UK and many other countries - and in Australia as General Purpose (GP) Portland cement. In this case, the dry pigment powder is an important raw material used in manufacturing processes for producing coloured building material components such as coloured architectural, pre-cast concrete panels, concrete roofing tiles, coloured concrete masonry blocks, bricks and pavers, as well as moulded coloured cement-based 'slates', 'flags' etc

To keep this permanent colouring process *easy and simple*, and because mineral oxide pigments vary in bulk density from colour to colour eg yellow iron oxide has a much higher bulk density than black iron oxide, a fixed quantity ***by weight*** of pigment, often, is added to a fixed quantity ***by weight*** of Portland cement - or if *supplementary* cementitious materials are used - the weight of the *total* cementitious binding material. This weight ratio is often expressed as a percentage.

All types of cement including GP Portland cement (which is usually a light to mid grey colour), Off-white* Portland (Type HE or GP) or imported White Portland cements may be used. The whiter and 'cleaner' the cement, with a given dose of a particular shade of pigment - particularly pale coloured shades, generally the cleaner and brighter the final colour of the cementitious bound composite will be.

PIGMENT DOSE RATES:

Pigment dose rates of five (5) to ten (10) percent pigment by weight of the cementitious weight in concrete and mortar are typical.

> EXAMPLE: 300kg of cementitious binder per production batch of concrete is found to require 15kg of pigment for the required ultimate (28 day) colour shade and intensity. Thus, the dose in this case is 5% pigment by weight of the weight of cementitious material.

Although each particular pigment *shade* of a given pigment *type* is unique and varies slightly – one to another in characteristics, for most uses of cast-in-place premixed concrete, most concrete technologists and specialty pigment consultants agree with pigment manufacturers, that for a good strong SATURATED colour shade, in say concrete used for paving, the typical dose rate should be between 5-10% pigment by weight of the total cementitious binder weight. Lower percentages produce less saturated colour shades. For example, 2% used in precast concrete panels will result in panels having a **much** weaker colour shade which is, unless the manufacture has a reputation of producing products having a very low co-efficiency of variation *unlikely* to be uniform in colour and opacity from one load of concrete to the next**.

As a STARTING POINT average for evaluation, Ability recommends 8.3%. *This* percentage is represented by the addition of ONE (1) STANDARD (25kg NET) SACK (BAG) OF PIGMENT TO ONE (1) CUBIC METRE (m^3) OF PRE-MIXED PLASTIC CONCRETE CONTAINING A MINIMUM OF 300kg OF CEMENTITIOUS MATERIAL for a compressive strength grade of 32MPa. (Megapascals) – called Normal 32 (N32) grade - at 28 days compared with the lower N20 and N25 grades. This strength grade of concrete is recommended for ideal ***durability*** potential for most paving (Please read pages 6,7,8,9,10 and 11).

Example: A transit truck load containing $4m^3$ of *f/c* (target strength) 32 MPa (N32) plastic (liquid) concrete, will therefore consist of the optimum quantities of water and aggregates plus 1200kg (1.2

* *Off-White cements typically have a whiteness index of 60 on a 1 – 100 unit scale whereas grey cements have an index of only around 30 units. Off-White cements can be made whiter by the addition of suitable white pigments such as Ability's titanium dioxide based 'abilox®' Illumin-ite White oxide. In this way they can also be made to* ***exceed the whiteness*** *of imported white cements which typically have a whiteness index on this scale of 90 units.*

** *Low pigment to cement dose rates tend to allow the occurrence of colour* ***variation*** *in hardened concrete products from one unit to the next. Colour variation in terms of 'greys' often occurs in plain,* ***unpigmented*** *concrete. A non uniform grey colour in unpigmented concrete may be caused by variations in the size, colour and shape of sand, variations in water:cement ratio; use of a procedure for curing vs. non-curing variation, etc. Dose rates of a* ***minimum*** *of 4% pigment by weight of the cementitious material weight invariably overrides this problem potential to ensure easy-to-obtain colour uniformity of coloured concrete and coloured concrete products from batch to batch.*

tonnes) of cementitious binder material as well as 4 x 25kg 'Concrete Friendly®' degradable sacks or bags of **'abilox®'** mineral oxide powder pigment of a selected colouring shade.*

EXPRESSED AS A PERCENTAGE, THIS RECOMMENDED OPTIMUM PIGMENT DOSE IS 8.3% 'abilox®' WEIGHT OF THE CEMENTITIOUS BINDER WEIGHT.**

***ANY* GRADE OR CLASS OF PRE-MIXED CONCRETE MAY BE INTEGRALLY AND PERMANENTLY PIGMENTED USING QUALITY PIGMENTS OF THE MINERAL OXIDE TYPE OF DRY POWDER COLOURANTS SUCH AS ABILITY'S 'abilox®' BRAND. *Paving, architectural* and *structural* concrete may *all* be permanently coloured.**

THE IMPORTANCE OF A LOW WATER CONTENT (WATER:CEMENT RATIO) IN CONCRETE/MORTAR:

The strength and *durability* of ***all*** Portland cement-based mixes is inversely proportional to the water:cementitious material (w/c) ratio. Therefore, the water content for *ALL* concrete/mortars etc should be *carefully* controlled to result in a measured degree of plastic consistency (viscosity or 'slump') – which for a particular project should be consistently the *same* for **every** mix batch of premixed concrete/mortar supplied. The consistency specified is typically represented by a slump of 80mm (3 inches approximately). This should be the maximum slump used for durable concrete pavements.

*To **ensure colour uniformity**, the water content, slump and **all other factors should be uniformly the same** for each transit truck load of integrally coloured concrete for the same job. **The use of a high range or superplasticising admixture in concrete to result in a low w/c's at a higher cost is highly recommended.***

NOTE: Ability Building Chemicals now provides **'abilox®'** in 'Concrete Friendly®' *degradable* bag/sack packaging having a variety of net contents. Examples: net 25kg, 12.5kg, and 6.25 kg bags.

PIGMENTING THE CEMENT OR CEMENTITIOUS BINDER IN CONCRETE, MORTARS, ETC:

In the colouring process, the aggregates used in concrete (crushed stone, gravel, pebbles etc - constituting the *coarse* aggregate, and the sand - the *fine* aggregate) which are colourless or self-coloured (with ***natural***, mineral oxides), being solid, virtually impermeable materials, are *not* actually pigmented.

It is only the water reactive cementitious binder which, after the addition of water, - is called the cement paste - which with the addition of an inert, non-reactive colouring pigment such as one from the **'abilox®'** range, becomes the coloured '*glue'*. This glue, 'matrix' or hydrating (chemically combining with water) cement paste, stiffens, sets and finally hardens to *bind* the mixture together, by a process, often referred to as *concrescence*, into a durable 'stone-like' mass called concrete. A mortar is concrete without coarse aggregate.

Quality inorganic mineral oxide type colouring pigments, like **'**abilox®**',** do *not* detract from the qualities, characteristics and durability of different grades and classes of hardened, pre-mixed concrete, reduce their durability or mechanical strength. In fact, they tend to *enhance* these qualities just as they enhance the qualities of UV (Ultra Violet) light resistance, weathering resistance and durability, of an UV degradable *clear* organic resin binder in a paint or ink film.

***** *__This__ dose rate for a particular 'abilox®' pigment dispersed in this mechanical strength grade of concrete is recommended for paving and general use to obtain with proper site handling and processing and the use of a suitable curing (moisture retention) procedure, **long-lasting, durable** and **abrasion resistant** coloured concrete of a reasonably saturated colour shade. For the same intensity of colour in a higher mechanical strength grade of structural and/or architectural concrete containing higher cementitious contents per m³, a proportionally higher pigment dose will be required whilst the percentage of pigment to cementitious material remains the same.*

A pigment suitable for use with Portland or other types of cement should have *all* of the following properties:

1. Satisfactory, adequate colouring strength or staining power and obliterating *opacity*, at relatively conservative dose rates, to give a strong, fully saturated colour to the final ultimately (cured and) fully hardened product, either a mortar or a particular grade or class of concrete, in place.

2. As the hardening of concrete is a **chemical** reaction, like those occurring in our own bodies, cement pigments must be highly resistant too, and not be destroyed by chemical reactions - particularly strong alkaline chemical reactions - such as hydrating cement as well as aqueous (water) mixtures of Hydrated Lime or Quicklime as used for making Sand-Lime bricks, lime-bound mortars and renders, etc. Suitable pigments for concrete and mortars must therefore be *inert* (chemically, non-reactive).

   Please note: Many types of pigments that are used commercially and very effectively in paints, lacquers (for automobiles, trucks and freight cars), inks, plastics, rubbers etc, may **not** be suitable for cement-bound products. Although they may be of relatively light-fast and weather-fast varieties, they may not be resistant to strong alkalies and are therefore *destroyed* by the highly alkaline reaction which occurs when cement is mixed with water. Typically, the mixture of cement and water has the highly alkaline pH of 12-13.5.(the maximum number on the pH scale is 14).

3. Have the property of rapid, efficient *dispersion* (de-agglomeration and uniform distribution of **ultra-**fine pigment particles) when *adequately* mixed into the semi-liquid concrete mixture, ie to be easily, homogeneously and adequately dispersed (spread out) throughout the mixture with the other ingredients, *without* agglomerating, in reasonable mixing shear rates and times.

4. Be of a *permanent*, non-fading nature. This involves the **highest** chemical resistance, as mentioned in No 2 above, as well as being **highly** resistant to the ravages of photo-chemical degrading reactions from sunlight (UV) and weathering.

5. Be *economically* feasible. Some *organic* pigments used to result in strong, vivid colours used in, say, automotive lacquers, cost more than A$300.00 per kg (A$300,000.00 per Australian tonne) and could not normally, on purely a cost basis, be entertained, by the customer for, or specifier of, integrally coloured concrete or coloured concrete products, as this would increase the cost of a cubic metre (m^3) of concrete or mortar by more than 25 times. For 100mm thick concrete the pigment cost would therefore be $750 per square metre ($m^2$) for an 8.3% pigment dose by weight of cementitious material and half that ($375/$m^2$) for a 4.15% dose.

TYPICAL COSTS OF CAST-IN-PLACE INTEGRALLY COLOURED CONCRETE USED FOR PRECAST ARCHITECTURAL PANELS, PAVING ETC:

The current cost of 100mm thick, through-coloured in situ concrete paving **in place** or panels using suitable pigments such as those from Ability's 'abilox®' range, typically falls in the range of A$25 to A$50 per **square metre (m^2)**, *including* the cost of the pre-mixed concrete and the labour to handle, place and 'site-process' it. The cost of the pigment alone typically varies from approximately A$7 to A$15 per m^2 depending on the cost of the particular pigment which vary from one to another eg greens are more expensive than yellows.

The *actual* cost depends on the following factors:

(a) The **thickness/volume** of the concrete slab, beam, column, spandrell, wall or other concrete unit type.

(b) The **type of finish** specified for the concrete surface. Either that obtained before **or** after concrete sets and hardens.

For example: a standard low cost wood or power trowel floated, or a non-slip broom finish for concrete costs less than more complex finishes - such as imprinted pattern paving or 'slate' look, low profile, imprinted finishes which usually include protective, and matching applied coloured ***sealer/curing compound finish coatings*** such as Ability's **'***Duro-Seel'* (a coloured or clear coating product for concrete to be applied *correctly* and at the correct *time* after placement to the surface in a *minimum* of two (2) coats)**.**

In the case of permanent through-coloured, *architectural* concrete, with or without decorative **coloured** coarse aggregates, certain ***after*** *finish techniques* may be used. These are usually *tooled finishes* which are achieved after setting and early hardening and subsequent stripping of precast concrete from form-work (moulds or shuttering). Tooled finishes for many types of concrete units, including columns, can include 'Bush' Hammering, 'Hammered Knib', as well as sand/grit blasting and ***high*** pressure water blasted finishes. All of these processes remove the hardened surface cement paste 'glue' or 'matrix' at the surface to reveal the aggregates and, of course, their colour.

Another type of concrete surface finish, referred to as *exposed aggregate*, may be achieved, *prior* to the setting of a particular grade or class of pre-mixed concrete, by hosing it lightly with water, and at the same time, gently brooming the unset surface to reveal the coarse aggregate. Or, for precast concrete by using a suitable surface set-retarding paper or coating on the inside of the mould and, after stripping, lightly hosing the low depth *set-retarded* cement paste (unset to a predetermined depth) away to uniformly reveal the coarse aggregate. This is particularly attractive when a coloured aggregate is chosen to blend with coloured cement paste of a suitable colour.

Other surface finishes for concrete may be achieved with *form liners* which are available to builders/pre-casters at low cost. Hundreds of different patterns are available. Designed to give a certain texture and pattern are usually made of pre-formed, semi-rigid, moulded plastic and are attached inside the form-work so that the surface of the through coloured concrete unit, intended as the final exposed face or surface, sets in the decorative shape, texture and pattern of the particular form liner used. Quality form liners may be used scores of times before being discarded and replaced. They can therefore be used to good effect in industrialised precast concrete panel production, as well as for on-site, off-the-form in-situ architectural concrete finishes.

(c) The ***particular*** colour desired – *all* colouring pigments vary from one colour to another in their cost-to-make and therefore their price – will have an effect on actual cost.

For example: iron oxide reds, red-browns and light and mid 'charcoal' colour shades (using black pigments) are the *lowest* in cost. Buffs, yellows, 'beiges' and 'sandstone' shades are generally only slightly higher. These are followed at slightly higher cost by terra cottas, light-reds and browns. Light browns ('tans'/'cinnamons'), depending on the degree of colour saturation or intensity required, cost slightly more than dark or mid browns.

It should be pointed out that *green cement pigments* - usually based on Chromium Oxide and **particularly** *blue pigments*, derived from Cobalt metal have a *definite* extra *on-cost* over the prices/costs indicated above. This is because suitable permanent pigments of these colours are *considerably* more costly to produce.

(d) The cost of integrally coloured concrete pavements and precast concrete products also vary according to their *colour intensity* or degree of colour saturation. This is based on the actual *amount*, by weight, of pigment used with a fixed amount (by weight) of cement or cementitious binding material.

Obviously, 4% pigment by weight of the cementitious binder weight will cost less than 8%. However, at 8% pigment, providing that the pigment is mixed into the concrete thoroughly, the colour of the concrete will usually not only be more intense, or '*saturated',* but tend to be more uniform from section to section or panel to panel.

NB: THE READER IS ADVISED TO BEWARE OF CONTRACTORS, NOT CONTROLLED BY ARCHITECTURAL **SUPERVISION** AND **STRICT** SPECIFIC SPECIFICATIONS, WHO USE **LOW** PIGMENT QUANTITIES AND CHARGE FOR HIGH!

Contractors of dubious reputation may not even use a pigment at all - charging for a coloured concrete pavement job and using only a *single* coat of a coloured concrete 'sealer' coating of equally dubious quality! Compared to concrete having good *integral* colouration most people do ***not*** want 'painted' concrete and particularly, *poorly* 'painted' concrete*.

CONCLUSION:

Good, sound, durable, cast-in-place concrete ('slump' or pourable type concrete) and quality concrete products may, by using reasonably consistent and uniform processing steps be attractively and permanently through-coloured both easily and at reasonable cost with the use of suitable powder pigments.

The reader is advised to always use or ***specify*** a pre-mixed concrete strength grade with a performance potential adequate for the intended life cycle of use containing an adequate cement or cementitious material content. This will assist in providing a suitable degree of durability, hardness, abrasion resistance, freedom from rusting corrosion of the essential steel reinforcement and subsequent concrete 'cancer' *in addition* to the required compressive or load bearing mechanical strengths.

It is **also** strongly suggested to the Specifier to always seek the best advice for producing a correct, ***tight*** job specification, which specifies *how* the site is to be prepared with the mandatory installation of the correct grade of reinforcing steel placed at the correct height on bar chairs and how the concrete is to be discharged, placed, vibrated and compacted, finished and cured, or have one produced by a consultant. This, with the provision of an adequate cement or cementitious content, ***if enforced*, **by specifier supervision should ensure that the best possible job is obtained - either for integrally coloured *or* ***plain*** (unpigmented) concrete!

There are, unfortunately *too* many bad/inefficient contractors and *far too many* who, *lacking the quality ethic* that, when handling and placing concrete, are prepared to 'cut corners' in any way possible to reduce their cost and increase their profit. Always *pre-check the quality* of their coloured work by viewing and checking out several of their past jobs prior to their engagement.

A strict, '*tight'* but easy-to-understand concrete specification designed for adequate durability and performance, in conjunction with effective *on-site communication* with the people involved, to *ensure quality* for *you* as a specifier and *your clients'* benefit, will usually include the following:

1. With the realisation that the hardened cement binder in concrete shrinks with time (particularly at around 90-180 days after placing/casting), *and on the other hand,* increased cement content, with the **same** water content, increases *wear resistance* and lasting qualities, a statement of the *cementitious material content* per cubic metre (m^3) and a figure of the maximum concrete shrinkage could be included in the specification to obtain an *optimum* balance of the hardened concrete *properties* required.

* *Ability offers free of charge for your assistance coloured 'biscuits'. These are small disks of integrally coloured concrete made in biscuit ('cookie') moulds. These incorporate from a range of 39 a particular 'abilox®' UV resistant mineral oxide pigment at a specified dose rate and may be used for visual reference to indicate approximately the intended colour result of the relevant coloured concrete in place.*

PLEASE NOTE:
We **again** point out for your consideration the suggested ***ideal*** grade of pre-mixed concrete for most purposes is normal 32 (N32) grade concrete (32MPa compressive strength at 28 days) - compared with lower grades. If pure (Type GP) Portland cement is to be used without supplementary cementitious materials to make this concrete by the concrete supplier, the quantity should be 300kg/m³ minimum.

Some of the reasons for this recommendation are:

(a) No more, no less than 300kg cement per cubic metre of concrete is the ideal compromise between longevity (durability), wear resistance, (abrasion resistance) and shrinkage which may, after about 90-180 days, lead to unsightly cracking of the hardened concrete and therefore rain water leakage of suspended slabs.

Whereas, higher *cement contents* at the same water content and liquid consistency will increase hardness, strength and impermeability but without water reducing admixtures and/or physical water:cement ratio control to achieve a suitable maximum water content compared to the total cementitious binder content these will decrease workability and site processing ease, increase shrinkage cracking and often - particularly if the concrete is uncured, may increase creep (dimensional change under sustained load) potential.

(b) Allowance for concrete to be placed and spread fairly easily with a ***safe*** water/cementitious material (W/C) ratio of 0.5 (50% water to cement by weight) together with a reasonably practical, easy-to-lay and finish liquid *consistency* represented by a typical slump of 80mm. (approximately 3 inches).

Decreasing the cement content from 300kg/m³ and placement at the *same* slump of 80mm. will *increase* the W/C ratio thereby reducing strength, durability, abrasion resistance and impermeability of the hardened concrete.

Increasing the cement content and maintaining the slump without an optimum dose of viscosity reducing and *water reducing* 'plasticiser' or 'SUPER plasticiser' admixtures will make placement and finishing more difficult due to plastic concrete '*stickiness*'/'*stodginess*'.

(c) Compared to N25 and particularly N20 concrete grades made solely with a GP cement binder the amount of 300kg cement/m³ tends to compared to lower amounts be a *safety factor* against the sad and unlawful to the specification practice of adding more water on site. Some contractors who, wanting the 'easy life', tend to add water to increase the flow of the plastic concrete and therefore make placement easier. The unauthorised increase of the specified slump of plastic concrete containing 300kg cement per m³ by adding more water on site does *not* increase the water/cement ratio as much as it would with proportionally lower cement or total cementitious contents ie. for N25 grade (25MPa) and particularly the lowest N20 (20MPa) grade.

(d) The GP cement content stated as optimum (300kg/m³) sets faster in a more ideal placement, working and finishing *time rate* in the cooler conditions of Winter and late Autumn/early Spring compared with concrete having a lower cement content. The speed of any chemical reaction is proportional to the temperature of the reactants. The thickening, setting and hardening of a cement/water mixture is slowed by reducing its temperature and conversely, quickened or accelerated by increasing its temperature. For *maintaining* an ideal setting time rate in summer or other high temperature conditions, a set-retarding admixture***** may be added. Increasing the cement content over 300kg/m³ will not only increase cost - proportional to the increased cement usage - but also by an increased amount for *more pigment* (for the same colour shade and intensity) and for **more** set retarding admixture.

(e) Excellent, hard, wear-resistant concrete surface finishes are easier to achieve on plastic concrete with this ideal cement content. First, compared to lower premixed concrete grades the tendency of concrete, in its plastic state, for the mix water to *bleed* to the surface, is reduced. Bleeding causes, and/or contributes to, increased porosity of the hardened concrete and the occurrence of *laitance* - a weak, unsound, low strength, often dusty, light coloured 'whitish' 'skin' of cement 'scum'. Laitance can vary in thickness on the surface. Good site processing procedures used for the processing of plastic concrete by compacting and densifying it by de-aerating it with a poker vibrator, spiked roller or other suitable means, followed by screeding and bull floating, and then skilful but minimal finishing, with a power or hand float or trowel, are more difficult to achieve when concrete bleeds.

Excessive bleeding is usually caused by *low* lean cement contents, compared with fixed amounts of the other materials but may also be caused, or contributed to, by *poor* grading of the fine aggregate (usually sand).

Secondly, with 300kg cement/m³ there is an adequate amount of cement paste (coloured with pigments *or* plain) *at the surface* after the ***essential processes*** of *vibration* and *compaction*, to remove air voids in the plastic concrete, ten per cent of which, by volume, in hardened concrete will reduce the wear resistance and mechanical strengths by *fifty* per cent!

This ideal cement content makes for easier and more successful quality finishing with any type of finishing methods/tools specified in the ***concrete specification***.

(f) The exothermic *heat* generated by this chemical reaction of cement combining with water (hydration), at any temperature of the concrete, although typically not as high as large volumes of concrete used in mass concrete structures such as dam construction, at the same temperature, is ***optimum*** for efficient, practical curing (immediately after it has set) with liquid ('membrane') ***curing*** and/or combined *curing/sealing/colouring* compounds******.

The efficient, correct use of a liquid film-forming ('membrane') curing compound is considered to be the **best** way of keeping the mixing water *within* the concrete to achieve an IDEAL hydration reaction over a ***lengthy period of time*********, thus resulting in the hardest, most (relatively) flexible, durable, longest lasting concrete.

Decreasing the cement content below 300kg/m³ reduces the quality and amount of the results of the chemical reaction of cement and water (hydrate 'glue'), reduces the heat of hydration and increases the water requirement for a given consistency and, under a given degree of ***evaporative forces*** in the air, increases the evaporation rate of mix water from the placed concrete. Increasing the cement content increases the chances of ***plastic*** or early cracking before the concrete has set properly, under adverse high temperature weather conditions which cause rapid drying.

2. OTHER IMPORTANT DETAILS FOR YOUR COLOURED CONCRETE SPECIFICATION:

In a particular Concrete Specification, to ***ensure*** adequate quality and durability for your ***client***, the concrete strength grade and class should be carefully considered by you. It should also include: (i) the slump in mm, and should also mention, (ii) that the concrete be supplied and placed ***free of bleeding***.

* *Ability offers its **'Cosmotron®' DPU-CA –** a set-retarding or **'slow-setter' type** superplasticising admixture.*

****** *ABILITY offer their 'DURO-SEEL' coating product used for **ideal** curing. This liquid curing membrane and combined sealing material ('same-day sealer') is available in TRANSLUCENT CLEAR and a range of twenty four (24) COLOURS including 'white' and 'concrete grey' to match coloured or unpigmented concrete. The proper use of efficient curing compounds is considered the only **practical** way to ensure that concrete is adequately cured – for 28 days or more!*

Concretes and mortars, based on a Type GP. Portland Cement binder, take 28 days to reach approximately 85% of their ultimate strength, abrasion resistance, durability, etc, at typical ambient temperatures after setting whereas at 24 hours after setting mechanical strengths are, at 23°C, only about 26% of their potential ultimate figures.

3. THE CONFORMANCE WITH RELEVANT AUSTRALIAN STANDARDS AND CODES OF PRACTICE:
eg. for particular serviceability requirements involving the correct site processing procedures and practices, for the placement and finishing of cast-in-place pre-mixed concrete, Specifiers who care should ***particularly*** refer to AS3600-2001 (***AUSTRALIAN STANDARD 3600-01*** '***CONCRETE STRUCTURES'***).

4. THE CONFORMANCE WITH THE *IMPORTANT* ABOVE-MENTIONED AUSTRALIAN STANDARD AND OTHER RELEVANT CODES OF PRACTICE AND/OR INDUSTRY AUTHORITY GUIDELINES SPECIFICALLY FOR THE *IMPORTANT* FUNCTIONS OF CORRECTLY AND ADEQUATELY:

(i) *Re-mixing* the plastic concrete *adequately*, and for exactly the same time for each load, (typically **10 minutes)** at the transit mixer's *fastest* mixer barrel speed is recommended before discharge if pigment and/or admixture powder is added followed by the careful checking of the concrete's slump.
(ii) If the slump is correct as specified, *discharging* the concrete correctly *without* the addition of extra water.
(iii) *Placing* the concrete with the **correct** grade of steel reinforcement bars, or mesh, for the intended loads, in place supported in the correct position within the excavation or mould on bar chairs.
(iv) *Compacting* the concrete with poker vibrators, spiked rollers and/or vibrating screed compacting machines, bars, to *remove* all occluded air voids which, if entrapped in only a small percentage volume in hardened concrete, can **severely** reduce strength, wear resistance and performance.
(v) Skilfully and minimally *finishing* the concrete to the particular surface finish specified.
(vi) *Continuously curing* the concrete for *at least* 7 days, and *preferably* 28 days or more, ***immediately*** *after* it has set.
(vii) Any *after treatment/after finishing* required such as honing and polishing following adequate *hardening* of the concrete.

CAREFULLY NOTE THAT:
Any of these important functions that are handled ***incorrectly*** or ***mismanaged*****,** will result in anything from less-than-perfect, long-lasting, attractive concrete, to concrete which is a ***complete debacle*** – including weak 'dusting' concrete and possibly the sooner than later problem of ***concrete 'cancer'*** - the continuous rusting of the reinforcing steal causing the disintegration of the concrete.

TO ENSURE A **SOUND, DURABLE AND AN ATTRACTIVE CONCRETE JOB OR CONCRETE PRODUCT *FOR YOU AND YOUR CLIENT, PLEASE* SEEK FURTHER INFORMATION AND FREE SOUND RECOMMENDATIONS** available from the following industry organisations in your capital city. Please consult your telephone directory.

- ✪ **AUSTRALIAN PRE-MIXED CONCRETE ASSOCIATION (APMCA)**
- ✪ **THE STEEL REINFORCEMENT INSTITUTE OF AUSTRALIA (SRI)**
- ✪ **CEMENT AND CONCRETE ASSOCIATION OF AUSTRALIA (C & CAA)**
- ✪ **CEMENT AND CONCRETE SERVICES (in Sydney only) Phone: (02) 9688 6336**
- ✪ **NATIONAL PRECAST CONCRETE ASSOCIATION OF AUSTRALIA (NPCAA)**
- ✪ **CONCRETE INSTITUTE OF AUSTRALIA (CIA)**
- ✪ **CONCRETE MASONRY ASSOCIATION OF AUSTRALIA (CMA)**
- ✪ **CONCRETE ROOFING TILE MANUFACTURERS OF VICTORIA (and in other states).**
- ✪ **BRICK DEVELOPMENT RESEARCH INSTITUTE** (for the specification and correct use of Portland cement-based laying mortars or jointing 'grouts' for baked clay bricks and pavers).

EFFLORESCENCE WHICH MAY OCCUR ON THE SURFACE OF UNPIGMENTED PLAIN OR PIGMENTED COLOURED CONCRETE AND COLOURED CONCRETE PRODUCTS.

Efflorescence is a white or light coloured crystalline salt bloom which may occur on exposed surfaces of virtually any type of cement concrete, mortar, concrete product etc either those coloured with recommended pigments or non-pigmented. It may not be noticeable to any great extent on plain unpigmented concrete, and if it does occur on cast-in-place concrete for pavements, it is usually worn off by foot or vehicle traffic in a short while. Efflorescent defacement is usually variegated and unsightly, sometimes resulting in a hideous architectural expression, and is difficult to remove permanently.

Efflorescent salts are usually much more noticeable on the exposed surfaces of coloured concretes and coloured concrete products – particularly those incorporating **dark colours**. The problem occurs spasmodically and irregularly.

It should **not** generally occur if a '*tight'*, **detailed** Concrete Specification intended for the production of dense, watertight, quality hardened and **cured** concrete in-place, designed for durability and environmental resistance and which is strictly adhered to by the contractor.

An effective chemical admixture is available which can also be specified to control the occurrence of efflorescence.*

A comprehensive, yet easy-to-follow cast-in-place concrete (or concrete product) *specification* provided for, and to be carefully acted upon, by the Contractor or concrete product Manufacturer, written with quality and longevity in view according to items 1. to 4. inclusive on the previous pages (9-12), perhaps with the assistance of the *trade/industry associations* also listed previously or a *consulting civil engineer*, will generally ensure that efflorescence will ***NOT*** occur. If the specifier or customer wishes to be *certain* about this, we suggest the incorporation of Ability's **'EFFLOREIN®' Mark 2** Powder admixture into the concrete or mortar mix according to their published recommendations for use.

The same suggestion(s) apply for the avoidance of *laitance*, a very weak, light coloured, unsound, often dusty thin 'crusty' layer on the surface of cast-in-place concrete (as opposed to a *strong*, *sound* surface - obtained from a ***cured***, adequately ***compacted***, ***low-slump***, relatively, 'dryish' concrete mix - or one having a high slump, but a low w/c ratio obtained with the use of a superplasticising admixture). Laitance is mostly caused by bleeding of a proportion of the total mix water, in excess, to the surface, bringing with it the finer fractions of cement which become 'diluted' and ineffective chemically with too much water.

Both efflorescence and laitance will usually '**mask'** the effect of pigments at the surface, giving the *apparent* effect of colour 'fading'. The *truth of the matter* is that the particular colour, if an adequate and satisfactory amount of a suitable pigment has been added, beneath these *surface* impediments is effective, non-fading and **permanent.**

SEVEN (7) SPECIFICATION ITEMS THAT MAKE CAST-IN-PLACE CONCRETE *PERFECT* - COLOURED *OR* PLAIN!

Both laitance and efflorescence may be avoided by *particularly* ensuring that the concrete will have:

1. An ***adequate*** cementitious binder content together with an ***optimum*** quantity of suitable quality aggregates of the correct size gradation. (Use the recommended strength grade of pre-mixed concrete products of supplier members of the Australian Pre-Mixed Concrete Association).

2. The lowest water-to-cement ratio (W/C ratio). That is, without a superplasticiser, the *lowest slump* possible consistent with adequate workability.

* *Ability Building Chemicals Co. offers its unique **'EFFLOREIN®'** Powder admixture product for cement bound composites. 'Efflorein®' is effectively used by adding it into either freshly mixed plastic pre-mixed concrete or factory made precast concrete product mixes made with about 10% less water then normal. Please request product data for **'Efflorein®'** powder which may also be added to freshly mixed plastic concrete on arrival at the building site - with or without pigment - and the concrete subsequently re-mixed adequately before discharge without the addition of additional water.*

3. ***Freedom*** from bleeding of water to the surface. Only **non-**bleeding pre-mixed concrete conforming to AS1379-97 'The Manufacture and Supply of Pre-mixed Concrete' should be used.

4. *Adequate* and satisfactory mixing (mechanical shear) of the plastic concrete or mortar to result in satisfactory dispersion (the uniform distribution and de-agglomeration) of the cement/cementitious material particles and, if present, the ultra-fine pigment particles in the mix water.

5. The complete use of correct application/placement, compacting/vibrating procedures to *densify* and *de-aerate* plastic concrete or mortar of macro air bubbles, thus avoiding 'honeycombing' voids which causes ***gross*** weakness and high permeability to liquids.

   NB: ***over*** **vibration**, however, may *also* cause problems such as segregation (inconsistent movement of aggregates at the expense of cement paste or vice versa) - particularly in *lean* cement concrete mixes. Therefore compact concrete according to industry recommendations.

6. The *provision* of *adequate* and *satisfactory crack control jointing* by means of the correct jointing procedure materials and tool(s) to minimise the appearance of unsightly cracking. If saw cutting is used to provide jointing, ensure that this process is carried out **within** 14 hours of concrete placement - otherwise random cracking may occur elsewhere.

7. Long-term *continuous curing* techniques, practices and materials.*

***PLEASE ALSO NOTE THAT* TO ASSIST YOU, PUBLISHED AND VERBAL RECOMMENDATIONS ARE ALWAYS AVAILABLE, FREE OF CHARGE, FROM ABILITY BUILDING CHEMICALS CO.**

REFERENCES:

1. 'Permanent Coloured Concrete (PCC)' – 1974 – a paper by Robert F Barber, Melbourne, Australia.

2. 'Colouring Concrete and Mortars' - 1987 by Robert F Barber, Ability Building Chemicals Co,, Melbourne, Australia.

3. 'Colouring Concrete' - Publication C5 of the Cement and Concrete Association of Australia, 1959.
(An Australian Industry ***Draft*** Mark V of an improved/updated version of this has been produced by and is available from Ability Building Chemicals Co, subsidiary of Australian Oxides Pty Ltd).

4. 'Colour in Architecture - Synthetic Inorganic Pigments in Concrete and Mortar'. Published by Farbenfabriken Bayer AG, Leverkusen, W Germany (May, 1967 O/N P7278/usa USA 186-667/61961).

5. 'Coloured Concrete'. - Published by Bayer AG, W Germany (O/N AC/P13802 Edition: 1/11/71 E 60-714/60360).

***** *Ability offer their 'DURO-SEEL' for **ideal** curing. This liquid curing membrane/sealing material is applied to the surface of freshly finished concrete by suitable means of spray equipment or a soft broom **immediately** after the final set has occurred. This is typically immediately after a time period of about 3½ hours at 20ºC after placement forN32 (32MPa) concrete. 'Duro-Seel' is available in TRANSLUCENT CLEAR and a range of COLOURS including White (to reflect heat) and 'Concrete Grey' to match non-coloured grey cement bound concrete.*

6. ‘Pigments: Their Possibilities and Limitations in the Building Industry’ - by Dr. Peter Kresse (Technical Service Department for Farbenfabriken Bayer AG, Uerdigen Factory). Published December 10th, 1966 in ‘Chemistry and Industry’ magazine.

7. ‘Some Aspects of Pigmentation of Concrete’ 1969 by B Kroone and F A Blakey (Both of Division of Building Research, CSIRO, Highett, Victoria, Australia).
Published in ‘Constructional Review’ periodical published by the Cement and Concrete Association of Australia, July 1968.

8. ‘Guidelines for Colouring Concrete Products’ by C H Love, Manager, Technical Promotion, Pfizer Minerals, Pigments and Metals Division - Chas Pfizer & Co.(USA). Published in the US ‘Concrete Products’ magazine, Volume 17, No 7, July 1968. (NB: Pfizer has since sold their USA and UK pigment businesses to Harcross Chemicals Inc - now called Elementis Pigments Corp)

9. ‘Colour for Concrete Surfaces’ by W.E. Nightingale. (Managing Director, Stipplecote Products Ltd, Lower Hutt, New Zealand). Published in ‘New Zealand Concrete Constructions’, 12 October 1967.

10. ‘Colour in Autoclaved Products’ by C James Gulde, (Executive Vice President of Crowe Gulde Inc). Published by Crowe Gulde Inc, Amarillo, Texas, USA.

11. **‘The Artist’s Handbook of Materials and Techniques’, by Ralph Mayer. Fifth** Edition (1991) published by Faber & Faber, London, Great Britain.

12. ‘Outlines of Paint Technology’ by Noel Heaton. Published, 1947 by Chas Griffin & Co Pty Ltd, London, Great Britain.

13. ‘Admixtures for Concrete’. published by American Concrete Institute (Reported by ACI. COMMITTEE 212 - proceedings V60, No 11, November, 1963. Copies available from ACI, PO Box 4754, Redford Station, Detroit, Michigan, USA, 48219.

14. ‘The Use of Chemical **Admixtures** in Concrete’ - A Workshop. Published December, 1975 by the School of Civil Engineering, The University of New South Wales, P.O. Box 1, Kensington, NSW, Australia, 2033. Copies of proceedings available from Unisearch Ltd, C/- The University of New South Wales.

15. ‘A Concrete Primer’ 2002 edition published by ACI (address as listed in No 13 above).

16. Booklet of technical papers presented at a ‘SEMINAR ON CONCRETE ADMIXTURES’ on April 20th, 1982 - published by the Concrete Institute of Australia.

17. ‘Surface Coatings’ Volumes 1 and 2, published by the Surface Coatings Association of Australia.

18. BS EN 12878-1999 ‘PIGMENTS FOR PORTLAND CEMENTS & PORTLAND CEMENT PRODUCTS’

19. ASTM C979-1999 “COLOR PIGMENTS FOR INTEGRAL COLORATION OF CONCRETES AND MORTARS”

20. AS K54-1935 “COLOUR PIGMENTS FOR USE WITH PORTLAND CEMENT”.

21. C Lynsdale and J Cabrera ‘Coloured Concrete – A State of the Art Review’ published in ‘Concrete’ August, 1989, Pages 29 to 34.

22. DIN 53237 (German Standard) ‘PIGMENTS USED FOR THE COLOURING OF CEMENT AND LIME-BOUND BUILDING MATERIALS’.

23. "Admixtures and Concrete Materials", Hard copies of papers presented at a seminar conducted by the Victorian branch of the Concrete Institute of Australia at the Holmesglen Conference Centre, Melbourne, Australia on 14 February 2001.

24. Technical Paper: ‘MINERAL OXIDE COLOURING PIGMENTS. THE COLOURANT TYPE MOST OFTEN USED IN THE MANUFACTURE OF MACHINE MADE COLOURED CONCRETE FLAGSTONES & OTHER CONCRETE MATERIALS’ by Robert F Barber and available upon request from Ability Building Chemicals Co.