THE INFLUENCE OF PIGMENTS ON MIX DESIGNS FOR BLOCK PAVING UNITS

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SUMMARY

The colouring of block paving units in New Zealand is most commonly achieved by the addition of powdered pigments. The influence of these pigments on the mix design for block paving units is considered in this paper. The particle size and particle shape of nine commonly used pigments was assessed using electron microscopy and Lea-Nurse fineness apparatus. Standard mortars were then produced to measure the influence of the pigments' particle characteristics on both workability and water/ cement ratio. The influence of different pigments on block mix design, and the durability of concrete block pavements, is discussed.

Introduction

The usage of interlocking concrete block pavements in New Zealand has increased markedly in recent years. These blocks provide a durable and aesthetically pleasing pavement, the latter being governed by the numerous colours and shapes of blocks available. The durability of these blocks is influenced by the design of the concrete mix used to manufacture the blocks. The mix must satisfy two main criteria:

1. A sufficiently low water:cement ratio to give adequate compressive strength for the expected traffic loading and to promote durability.

2. A suitable workability and cohesiveness to give optimum compaction with the block-making plant in use. Fully compacted concrete will have reduced porosity which will minimise the penetration of water, liquid contaminants and detritus, and enhance durability.

The colour of interlocking concrete blocks is achieved by the addition of powdered pigments and the majority of manufacturing plants in New Zealand use pigments supplied by Bayer (NZ) Ltd. These powders are significantly finer than cement so their water demand is likely to be high and will vary between pigments depending upon their particle size and shape. The water demand of the pigment in conjunction with the addition rate required to achieve satisfactory colour saturation and colour durability will define the influence each pigment has on the block mix design.

This work was initiated to assess the differences between the pigments with respect to their influence on water demand and hence mix design. The work was undertaken in three discrete phases:

1. Characterisation of the pigments in terms of particle size and particle shape using Lea-Nurse fineness apparatus, electron microscopy and sedigraph techniques.

2. Production of mortars using each pigment at a constant water : cement ratio to assess their influence on workability.

3. Production of standard mortars at a constant workability to assess the influence of pigments on the water:cement ratio.

Characterisation of Pigments

The fundamental properties of the pigments are detailed in Table 1.

The Lea-nurse apparatus results show fineness ranges between 2300 m^2/kg (Black 4-91/14) and 4795 m^2/kg (Yellow 4-91/12). There is a correlation between colour and fineness of the pigments; the finenesses increase from the blacks and dark brown through the reds to the light brown and yellow-based colours.

The photomicrographs provide useful information on both particle size and particle shape. Six of the nine pigments analysed (black, red, dark brown) are made up entirely of spheroidal (equant) particles (Figure 1). Twenty percent of particles in the light brown pigment are elongated. Two pigments, yellow and marigold are dominated by elongated particles but there is a distinct shape difference between the particles. Particles in the marigold pigment are quite truncated or rod-like (Figure 2) whereas the yellow pigment particles are more needle-like or acicular (Figure 3) .

Measurement of particle size from the photomicrographs was complicated by the need to identify individual grain outlines. For this reason the results are expressed as a range of predominant particle diameter. The black, light and dark brown pigments were coarsest, with grains ranging up to 0.4-0.5 μm in diameter. The red pigments were marginally finer with a predominant particle size up to 0.3 μm (Red 120, Red 130) and 0.25 μm (Red 110). The elongated particles showed a constant particle diameter (0.15-0.2 μm) but length varied from 0.9 μm (light brown) up to 2.0 μm (yellow).

Mortars - Constant Water:Cement Ratio

The properties of mortars produced in this series of tests are presented in Table 2. By maintaining the w/c ratio and addition rate of pigments constant throughout these tests the influence of each pigment on the mortar properties, particulary workability, could be assessed.

As expected all mortars made with 2% addition of pigments have reduced workability in comparison to the control mix. The magnitude of this reduction can be ranked in order of decreasing workability, as shown in Table 3.

Both tests have ranked the pigments in a similar order although the flow test is more definitive.

The fresh density and air content of these mixes show little variation both in comparison to the control and between pigments. The lowest air content (4.1%) was shown by a red pigment (4-91/17) and was matched by a relatively high fresh density (2200 kg/m^3) , the highest air content (5.0%) was shown by the marigold pigment (4-91/9) and the fresh density was correspondingly low (2180 kg/m^3) .

The compressive strength of these mortars varies between 36.0 MPa (4-91/9 Marigold) and 42.5 MPa (4-91/15 Red) . With the knowledge that these mortars were produced with a constant water:cement ratio and that the cylinders tested in compression were adequately compacted the likely influence on compressive strength is a variation in air content. The marigold pigment entrained the most air (5.0%) and shows the lowest compressive strength; the two mortars entraining 4.9% air show the next lowest compressive strengths. However there is no clear correlation between air content and compressive strength for all other mortars produced and it is likely the variation of air content was too small to make a discernible difference to the compressive strength.

TABLE 1: Pigment Properties

Pigment			Lea-Nurse Fineness Apparatus		Scanning Electron Microscope	
Sample No.	**Colour**	**Bayer (NZ) Identification**	**Density mg/m^3**	**Specific Surface m^2/kg**	**Particle Shape**	**Particle Size* (µm)**
4-91/9	Marigold	960/4	4.76	3615	90% elongated 10% spheroidal	0.2 × 1.3 0.2 - 0.4
4-91/10	Black	330	4.88	2380	spheroidal	0.25 - 0.5
4-91/11	Dark brown	686	5.03	2625	spheroidal	0.25 - 0.5
4-91/12	Yellow	420	4.64	4795	elongated	0.15 × 2.0
4-91/13	Light brown	610	4.87	3640	80% spheroidal 20% elongated	0.25 - 0.4 0.15 × 0.9
4-19/14	Black	318	4.49	2300	spheroidal	0.2 - 0.4
4-91/15	Red	120	5.29	2895	spheroidal	0.15 - 0.3
4-91/16	Red	130	5.34	2645	spheroidal	0.15 - 0.3
4-91/17	Red	no	5.48	3365	spheroidal	0.1 - 0.25

* Particle size quoted in terms of:

1) spheroidal particles - range of predominant particle diameter
2) elongated particles - predominant particle size expressed as diameter x length

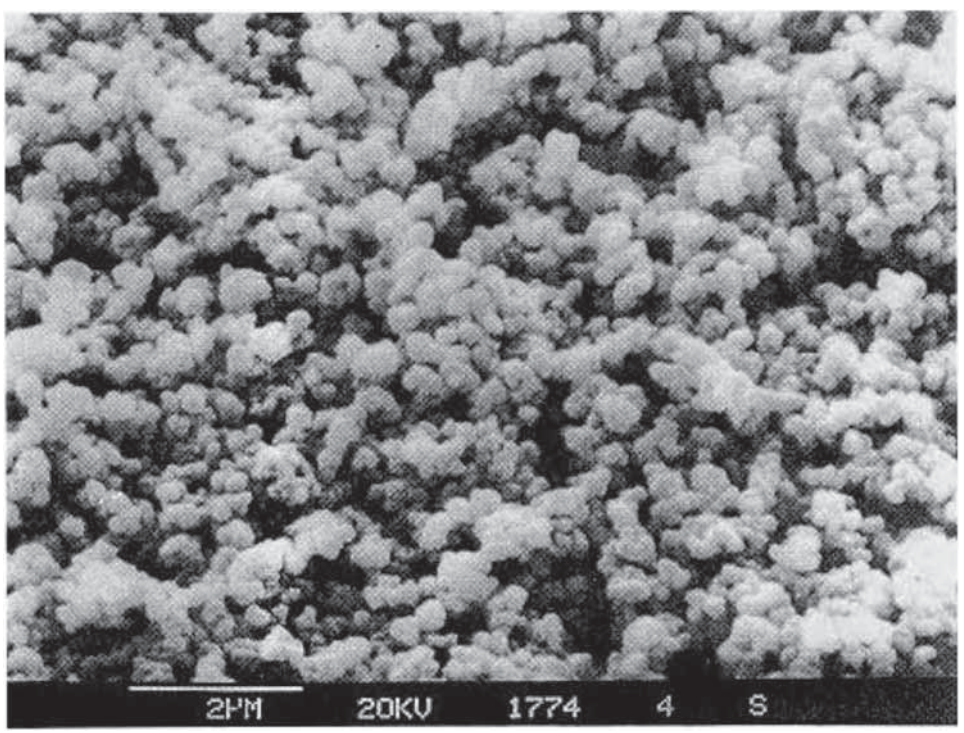

FIGURE 1: Pigment-. 4-91/17, Red. Typical photomicrograph showing equal sized, spheroidal shaped grains. Size is indicated by 2 µm scale bar in bottom left corner

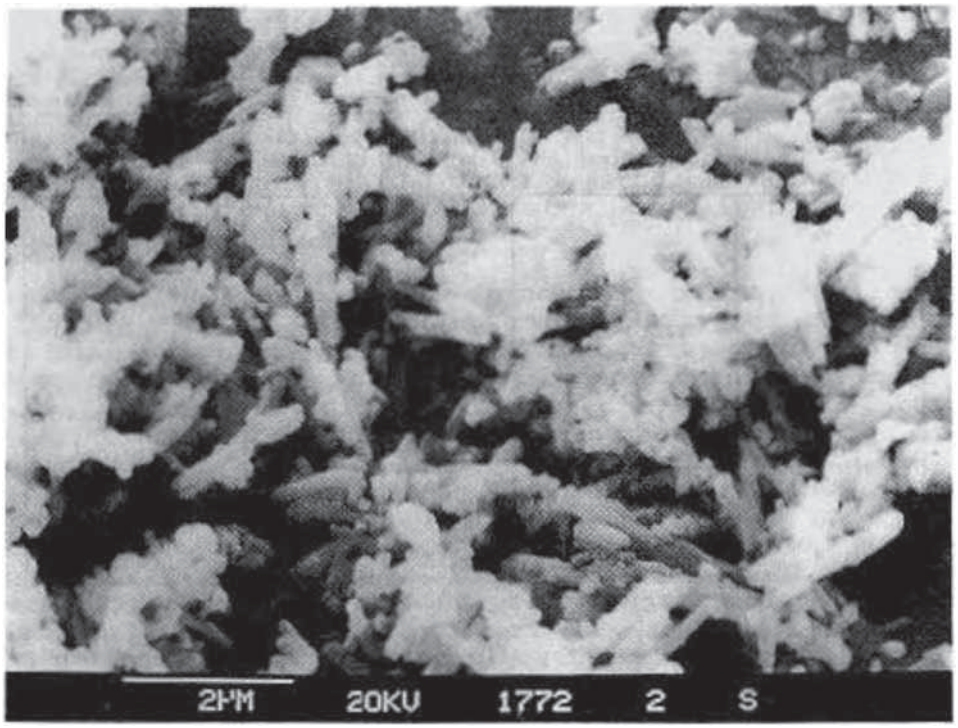

FIGURE 2: Pigment 4-91/9, Marigold. Photomicrograph showing rod-like particles

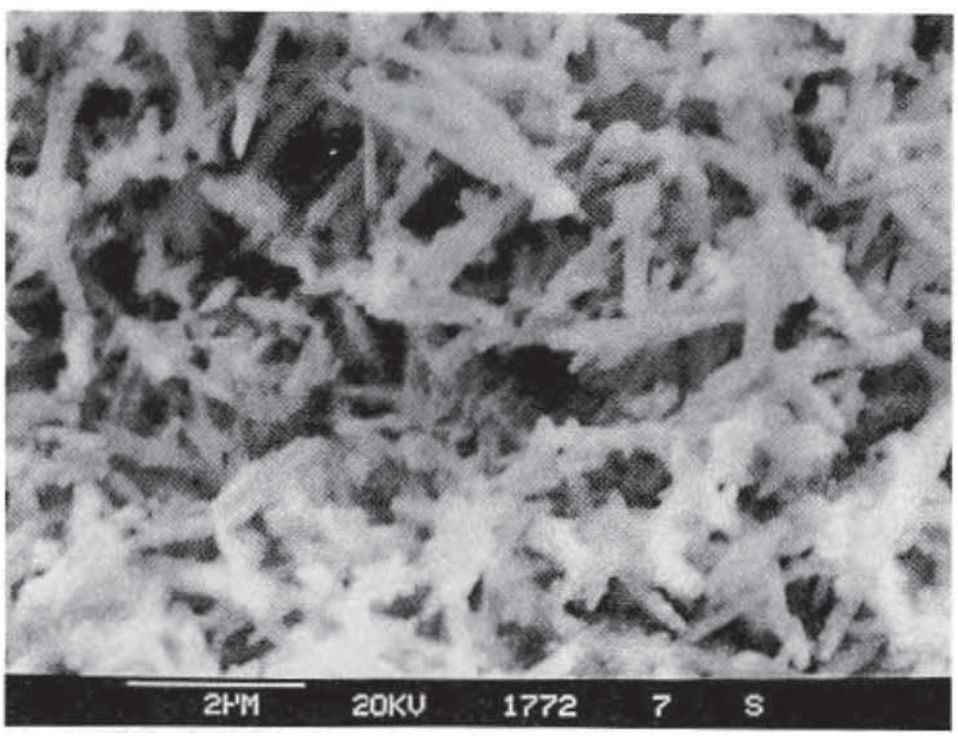

FIGURE 3: Pigment 4-91/12, Yellow. Photomicrograph showing needle-like, acicular particles

TABLE 2: Mortar Properties - 0.56 Water:Cement Ratio

Pigment	Flow (*)	Slump (mm)	Air Content Volume (%)	Fresh Density (kg/m^3)	Compressive Strength (MPa)
Control	84	30	4.9	2180	39.0
4-91/9 Marigold	61	10	5.0	2180	36.0
4-91/10 Black	75	20	4.4	2190	40.5
4-91/11 Dark Brown	66	20	4.9	2180	38.0
4-91/12 Yellow	56	10	4.7	2190	39.5
4-91/13 Light Brown	70	15	4.3	2200	41.0
4-91/14 Black	66	20	4.4	2190	40.5
4-91/15 Red	62	15	4.6	2190	42.5
4-91/16 Red	63	15	4.7	2190	41.0
4-91/17 Red	66	15	4.1	2200	39.5

TABLE 3: Pigments in Order of Decreasing Mortar Workability

Flow Test (1)

Control

1.	4-91/10	Black
2.	4-91/13	Light Brown
3.=	4-91/14	Black
=	4-91/11	Dark Brown
=	4-91/17	Red
4.	4-91/16	Red
5.	4-91/15	Red
6.	4-91/9	Marigold
7 .	4-91/12	Yellow

Slump Test (2)

Control

1. =	4-91/10	Black
=	4-91/11	Dark Brown
=	4-91/14	Black
2. =	4-91/13	Light Brown
=	4-91/17	Red
=	4-91/16	Red
=	4-91/15	Red
3. =	4-91/9	Marigold
=	4-91/12	Yellow

Mortars - Constant Workability

From the results presented above, the pigments showing the greatest influence on workability (4-91/12 yellow) and the least influence on workability (4-91/10 black) were selected for testing. Two sets of tests were undertaken:

- the w/c ratio of the black pigment mortar was reduced to match the workability of the yellow pigment mortar;

  the w/c ratio of the yellow pigment mortar was increased to match the workability of the black pigment mortar.

The results of this testing are presented in Table 4.

To achieve the flow of 56% produced by the mortar made with the yellow pigment (4-91/12) at a 6.56 w/c ratio, the mortar made with the black pigment (4-91/10) had its w/c ratio reduced to 0.51. The average compressive strengths were 39.5 MPa and 42.0 MPa respectively. Similarly, to achieve the flow of 75% produced by the mortar made by the black pigment at a 0.56 w/c ratio, the mortar made with the yellow pigment had its w/c ratio increased to 0.59. The average compressive strengths of these mortars were 40.5 MPa and 37.0 MPa respectively.

Statistically these compressive strengths are not significantly different from each other. It would appear that the compressive strengths are more influenced by the widely varying air content of the mortars at different workability levels rather than by the 0.03-0.05 change in w/c ratio. The air content gives a measure of the cohesiveness of each mortar and the ability to remove air under vibration.

TABLE 4: Mortar Properties - Constant Workability

Pigment	Water:Cement Ratio	Flow (%)	Slump (mm)	Air Content (Volume %)	Fresh Density (kg/m³)	Compressive Strength (MPa)
4-91/10	0.560	75	20	4.4	2190	40.5
Black	0.510	58	0	6.2	2180	42.0
	0.505	48	-	-	-	-
	0.500	43	0	3.7	2100	45.0
4-91/12	0.600	80	20	3.2	2200	35.0
Yellow	0.590	76	25	5.6	2150	37.0
	0.560	56	10	4.7	2190	39.5

Discussion

This testing programme has identified the basic properties of nine pigments commonly used in concrete block paving manufacture and has illustrated the relative performance of these when incorporated into a standard mortar. The particle size and shape of each pigment clearly influences their water demand characteristics. All the pigments are significantly finer than cement and when added at a 2% (by mass of cement) dose rate there is a significant reduction in workability compared to the control mix. The pigments identified as containing predominantly elongated particles (yellow 4-91/12, marigold 4-91/9) show a relatively high water demand and hence low workability when tested at a constant w/c ratio. The pigments composed of spheroidal particles have a lower water demand than the elongated particles. Fineness expressed in terms of specific surface is the most useful guide to the water demand of these pigments.

What effect would a reduction in workability have on the production of concrete paving blocks? In some cases the magnitude of the loss in workability may produce a mix which can not be sufficiently compacted to form a durable block. Addition of more water to the mix will allow adequate compaction to be achieved but with a subsequent increase in the w/c ratio.

The w/c ratio change required to maintain workability between mortars made with the pigments showing the greatest and least water demand is an average of 0.04. This alteration results in no significant change in compressive strength apparently due to the influence of air entrapped by the mortars. However, data from Bayer AG (Germany) indicates that changes to compressive strength due to the water demand of different pigments becomes more noticeable when higher pigment addition rates are used. This testing was undertaken using a dosage of 2% by mass of cement, but information collected recently indicates block plants in New Zealand may use higher dosages than this, dependent on the colour of the aggregate in use and colour saturation required. A higher pigment addition rate is likely therefore to result in a reduction of compressive strength.

The magnitude of w/c ratio increase required to satisfy the requirements of a pigment with a high water demand in a plastic mortar cannot be directly related to its performance in the lean concrete used for paving manufacture. Lean concretes are not suitable for laboratory testing without the use of specialist vibratory compaction equipment. However, the testing of these plastic mortars has adequately demonstrated the relative water demand characteristics of the pigments.

What are the effects of an increased w/c ratio in a concrete paving block? For a given degree of compaction, the durability of the block is likely to be reduced with subsequent reduction in parameters such as freeze-thaw, chemical and physical weathering and abrasion resistance. The latter property is of particular importance at present due to the apparently poor performance of paving blocks in municipal applications where the pedestrian (high-heel) count is high. There is also a perception that yellow—coloured paving blocks, the blocks likely to have a relatively high w/c ratio, may be affected more by abrasion in heavily trafficked pedestrian area. Water:cement ratio and hence compressive strength is one of a number of possible factors affecting abrasion resistance and its importance will be recognised in the 1991 revision of NZS 3116 where municipal pavers will be required to attain a higher compressive strength in an effort to improve abrasion resistance.

Conclusions

(1) The water demand of pigments routinely used in interlocking concrete block production is influenced by both particle size and particle shape. All pigments are significantly finer than cement and all show a high water demand. Pigments composed predominantly of elongated particles have a relatively high water demand in comparison to pigments made up of spheroidal particles.

(2) Production of the lean concrete mixes used for interlocking concrete block manufacture is based on a suitable workability to allow optimum mechanical compaction. The addition of a pigment with a relatively high water demand will reduce this workability. If water is added to the mix to maintain workability the subsequent increase in w/c ratio will reduce durability with probable reduction in performance parameters such as physical and chemical weathering and abrasion resistance.

References

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(2) Freitag, S.A. (1986): "Report on an investigation of mortar and plastering sands in relation to a proposed revision of New Zealand Standard Specification NZS 3103:1976", Report M4.86/11, Central Laboratories, MWD.

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