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Quality Control of Concrete Units to Interlocking Pavement by the Colorimetric Method

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Summary

Paving units for interlocking concrete pavement, when pigmented, are used for esthetic aspects of the project or as horizontal signalization on the pavement. In this case, concrete units with different colors from the remaining of the pavement, may compound traffic signs or the pedestrian crosswalk itself.

Coloring control is often neglected during the steps of manufacturing, quality control and reception of units and, only when using the units that color variation draws attention. The lack of homogeneity of paving units results in an unwanted mosaic of tonalities, that changes the result conceived by the architect, maybe even loosing the esthetic expected with pigmentation.

However, more than esthetic considerations involved, the color change may be the result of a lack of homogeneity on manufacture, resulting in variations of the physical-mechanical performance of the units.

This study presents aspects that may lead to color variation on a single batch of concrete units for paving and discusses cares to minimize the lack of homogeneity during the manufacturing process, introducing colorimetric methods on production control.

The results gathered shows that colorimetric control may help on production control and be an indicator for the adjustment of factors that contribute most to keep concrete homogeneity and the final quality of paving units.

Keywords: paving blocks. quality control. colorimetric method.

1. INTRODUCTION

In production of paving units for interlocking pavement or masonry the most common system uses vibropress equipments that use dry concretes who should present at the same time a fluidity allowing a fast launch on the molds, reflecting on lower cycle times and enough cohesion to allow the demolding without cracking or collapsing the units. The fluidity and cohesion properties of the dry concrete are determined by the total granulometric distribution and by the moisture of the mixture.

Considering that all adjustment conditions of the vibropress are adequate and kept constant during production, the reasons for variations of density of units are tied to the concrete itself. Deficiencies on reception control, materials proportioning and humidity of aggregates and mixture are the main reasons of those variations.

The ideal production control should happen immediately after demolding, not interrupting the production and before the curing period. The most adequate indicator for this verification would be the density control of the units. However, to measure the density with units still fresh, carries some difficulties. First, in a pallet several units are produced on a same cycle. Any lack of adjustment on distribution and spreading of concrete, vibration and compressing may harm the compression uniformity of units, being necessary to measure the density of every unit and not only of all units together.

Besides the time involved in this operation, measurement inaccuracies would be inevitable, since the units are still fresh and cannot be placed on hydrostatic scales, being thus necessary to estimate the volume of the units and control only the mass of each one.

The proposal of this work is the utilization of colorimetric control that, by previous establishment of patterns, would be used on production control of units. The viability of this application was tested by ROJAS; OLIVEIRA SILVA (2002).

2. COLORIMETRY

Colors may be split on colorimetric axes, in other words, Cartesian measures of color, by reading the magnetic waves that compose them. A colorimeter is used for this. It is a device who sends a controlled flash light, that might mimic daylight for example, and that, by reading the amount of reflected color may, by breaking apart this light in the photomagnetic specter, characterizes the color being read (ROJAS; SILVA, 2002).

It depends on factors such as:

- Type of incident light (as in a real situation, considering its environment, the perception of a color may change from what is perceived in an artificially lightened environment to a natural lightened one).
- Rugosity of units: directly influencing on light reflection.
- Porosity of units: low influence, however it is related with light absorption.

Measure on colorimeter is made according to axes a, b and L, as shown on Figure 1.

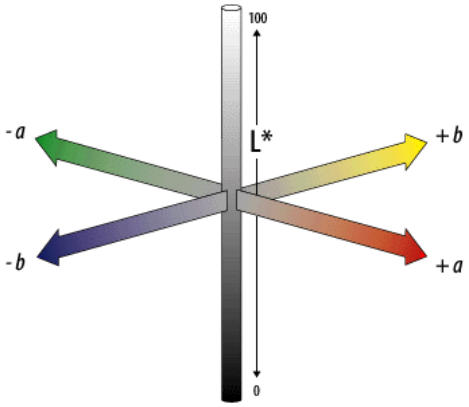

Figure 1. Reading axes on calorimeter standard CIELAB. Axes a, b and L are colorimetric coordinates. Coordinate *a* corresponds to variation from red (+a) to green (-a). Coordinate *b* represents variation from yellow (+b) to blue (-b) and coordinate *L* variation from white (100) to black (0). (MARQUES FILHO, 2001).

The colorimeter shows the reading Da*, Db* and DL*, that are the variations in the space between two points of colors measured according to coordinates a*, b*, L*, besides the DE* reading that is the geometric sum of variations of coordinates.

Those results allow the characterization of colors from a physical point of view quantitatively and not qualitatively as on visual methods. Figure 2 shows a manual colorimeter used in tests for color stability in grout.



Figure 2. Manual Colorimeter used on color evaluation. Photo ABCP.

3. METHODOLOGY

The study was performed collecting units produced by a manufacturer using an hydraulic vibropress. The units were chosen from a same batch, produced with concrete made of grey Portland cement, natural sand, gravel, inorganic pigment based on iron oxide and water. The units were collected after the curing period, with age over 28 days and selected by visual criteria, being chosen the units that showed a qualitative difference of color. That way four units of a same batch were selected, all produced on a same day, therefore, in theory the samples were made with the same proportioning of materials. Figure 3 presents the collected samples.



Figure 3. Visual aspect of samples of pigmented mortar used on interlocked pavers, collected on a same batch.

By visual analysis on the moment of collecting the samples presented in Figure 3, the following aspects were observed:

- Sample 1: There are small streaks, formed during demolding. Has color more uniform in relation to the other samples.
- Sample 2: Unable to verify the formation of streaks, the sample has an opaque appearance;
- Sample 3: Unable to verify the formation of streaks, the sample has an opaque appearance and jagged edges;
- Sample 4: Unable to verify the formation of streaks, the sample has an opaque appearance;

4. PHYSICAL AND MECHANICAL CARACHTERIZATION OF SAMPLES

Samples were characterized according dimensional aspects, mass and compressive strength, as defined in standard NBR 9780 (ABNT, 1987). Table 1 shows the results.

Table 1. Determination of compressive strength (ABNT, 1987).

SAMPLE	AVERAGE SIZE OF UNITS (mm)			MASS (g)	DENSITY (g/cm^3)	TENSILE STRENGTH (N)	COMPRESSIVE STRENGTH(MPa)
	LENGTH	WIDTH	HEIGHT				
1	200	100	61	2 698	2.21	237 800	35.5
2	201	101	62	2 519	2.00	172 300	25.7
3	201	100	61	2 558	2.09	227 600	33.9
4	200	101	60	2 488	2.07	212 700	31.8
Age of samples over 28 days. Load was applied on a standard area of 6 362 mm^2 according NBR 9780 (ABNT, 1987).							

Only sample 1 complies with the specification of compressive strength in NBR 9781 (ABNT, 1987), who specifies a minimum compressive strength of 35 MPa for light traffic conditions.

Table 2 shows the results of water absorption and humidity essays, performed according the standard NBR 12118 (ABNT 2007), adapted for pavers.

Table 2. Determination of water absorption and humidity NBR 12118 (ABNT, 2007), adapted.

SAMPLE	MASS WHEN RECEIVED (g)	MASS DRIED IN STOVE (g)	SATURATED MASS 24 h (g)	ABSORPTION (%)	HUMIDITY (%)
1	2 698	2 642	2 765	4.6	46.5
2	2 519	2 477	2 633	7.1	23.9
3	2 558	2 517	2 680	6.5	25.2
4	2 488	2 452	2 622	6.9	21.2
Age of samples over 28 days.					

The standard NBR 9781 (ABNT, 1987) does not specifies limits for water absorption. Applying the specification of EN 1338 (CEN, 2003) that specifies water absorption as ≤ 6%, the only sample who meets the requirement is number 1.

Table 3 and Figure 4 show the results of essays performed according to a NBR 14082 (ABNT, 2003), adapted for pavers.

Table 3. Determination of water penetration – glass column method - NBR 14082 (ABNT, 2003).

IDENTIFICATION	TIME INTERVAL OF TEST (min)	WATER PENETRATION (cm^3)
1	20	1,0
2		> 4,0*
3		> 4,0*
4		> 4,0*
Note: *Water penetration happened simultaneously to glass column filling.		

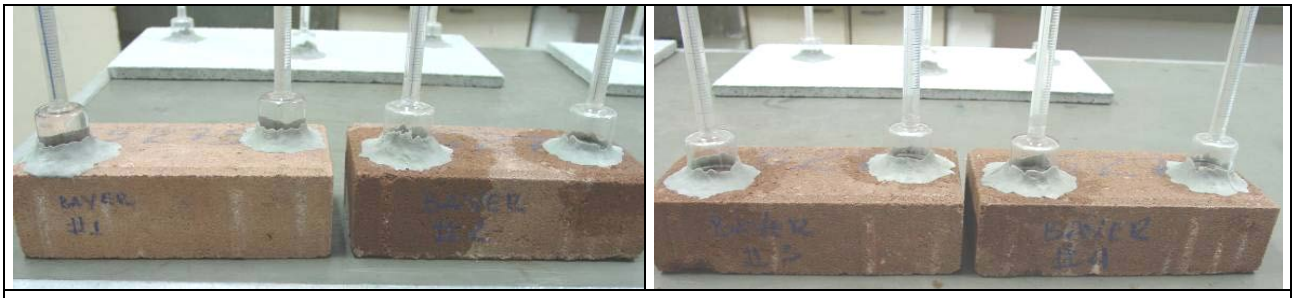

Figure 4. Determination of water penetration on samples using the glass column method. The larger water penetration on sample 2 is seen, it happened almost simultaneously to the water column filling, while sample 1 remains with the glass column full of water, demonstrating its lower permeability. Penetration of water on samples 3 and 4 happened similarly to sample 2.

This test is not specified in any national or international standard for concrete units used on interlocking paving, however it represents well the condition of the block permeability, due to lack of compression. To consolidate the information of physical mechanical tests, Table 4 shows a resume of results.

Table 4. Summary of testing.

PROPERTIES	SAMPLES				AVERAGE	STANDARD DEVIATION	COEFFICIENT OF VARIATION (%)
	1	2	3	4			
Received weight (g)	2 698	2 519	2 558	2 488	2 566	93	4
Dried weight (g)	2 642	2 477	2 517	2 452	2 522	84	3
Water absorption (%)	4.6	7.1	6.5	6.9	6	1	18
Humidity (%)	46.5	23.9	25.2	21.2	29	12	40
Water penetration, in 20 min (cm^3)	1.0	>4.0*	>4.0*	>4.0*	3	2	-
Compressive strength (MPa)	35.5	25.7	33.9	31.8	32	4	14
Units height (mm)	61	62	61	60	61	1	1
Note: * Water penetration happened simultaneously to glass column filling.							

The requisites with higher coefficient of variation among the samples are respectively, compressive strength, water absorption and humidity. Those variations reflect failures on the manufacturing process.

5. COLORIMETRIC CARACHTERIZATION OF SAMPLES

Sample 3 was used as the standard for colorimetric readings, and in this case the results of colorimetric readings (Da*, Db*, DL* e DE*) of samples 1, 2 and 4 show how much those samples distance themselves from sample 3 on colorimetric terms. Sample 3 was chosen as standard for colorimetric readings because it presents and intermediate physical-mechanical characterization between the higher and lower value for water absorption and mechanical strength. Table 5 shows the results.

Table 5. Colorimetric variations of samples.

SAMPLES	Da*	Db*	DL*	DE*
1	3.07	- 4.61	+ 10.04	11.46
2	1.90	- 9.51	+ 13.70	16.78
3	Reference	Reference	Reference	Reference
4	- 0.13	- 4.69	- 1.44	4.91

Results demonstrate that samples 1 and 2 have more distant colorimetric results to sample 3 (reference), while sample 4 presents results very close to the reference. The results confirm the visual analysis, with sample 4 having luminosity values (DL*) much close to sample 3 (reference). Those two samples visually show a darker color in relation to sample 1 and 2, being sample 2 the one with higher luminosity (DL*) in relation to reference and also visually the one with brighter color.

6. RESULTS EVALUATION

Considering the objective of the work, results of colorimetry were compared with some of the physical-mechanical requisites of samples. Table 6 shows the comparison between results.

Table 6 – Comparison of phyisical-mechanical and colorimetric results.

PROPERTIES	SAMPLES			
	1	**2**	**3**	**4**
Compressive Strength (MPa)	35.5	25.7	33.9	31.8
Density (g/cm^3)	2.21	2.00	2.09	2.07
Water absorption (%)	4.6	7.1	6.5	6.9
Water penetration, in 20 min (cm^3)	1.0	> 4.0*	> 4.0*	> 4.0*
DL*	+ 10.04	+ 13.70	Reference	- 1.44
DE*	11.46	16.78	Reference	4.91

The two samples with lower luminosity (lower value on DL* axe) correspond to samples 3 and 4, who showed, besides very close DL* values, very similar density, compressive strength, water absorption and water penetration. On the other extreme, sample 2, who presents higher DL* in relation to reference, was the one presenting worse performance to compressive strength, a result compatible with the lower density between the samples. When analyzing sample 2, the higher values of water absorption and water penetration are compatible with a lower density sample.

Sample 1 was the one with better physical-mechanical performance, its compressive strength is according to the minimum limits of NBR 9781 (ABNT, 1987). Once again, the higher value of compressive strength is compatible with lower density, showing higher compression on

this sample. The lower water absorption and higher water penetration resistance, according to Table 6, also confirm this higher compression.

Besides the density values of samples, the compression may be evaluated by images obtained using a stereoscopic microscope of reflected light. Figures 5 and 6 illustrate this assertion.

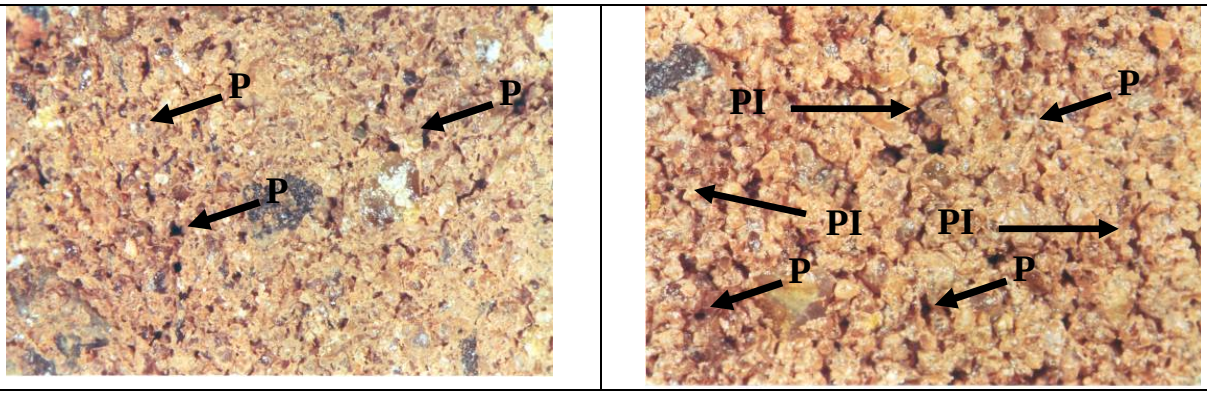

Figure 5.
Analysis of Sample 1 (right) and Sample 2 (left) in a stereoscopic microscope of reflected light. Is possible to evidence on Sample 1 a more compact structure, characterized by individual pores without communication (P). On Sample 2 the structure is less compact, characterized by a high amount of interlinked pores (PI) and also individual pores (P). Magnification 6X.

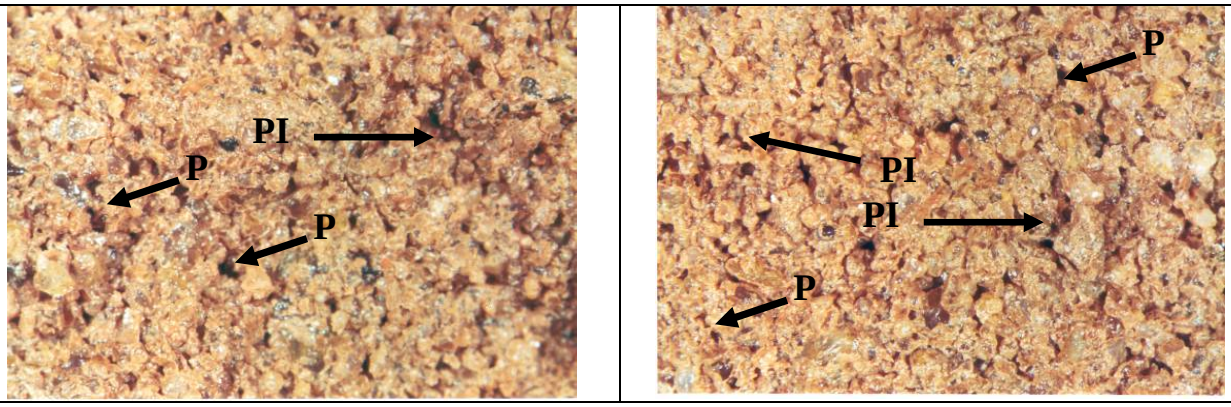

Figure 6. Analysis of Sample 3(right) and Sample 4 (left) in a stereoscopic microscope of reflected light. On Samples 3 and 4 is possible to evidence less compact structures with interlinked pores (PI) and individual pores (P). Magnification 6X.

7. FINAL CONSIDERATIONS

Values presented by the calorimeter showed to be sensible to physical-mechanical variations of the samples. This fact enables the possibility of controlling the production using colorimetric standards previously established.

Variations on luminosity of colors show variations on porosity and rugosity of the samples. The variation of porosity interferes directly on the physical-mechanical performance of the sample, affecting its water absorption and its compressive strength. By quickly detecting those variations, it is possible to take action shortly, actuating over the reasons for those variations.

However the control during production should be made with the units right after molding and, besides that, there must be full knowledge of the most possible reasons involved on variations

of density and rugosity of units. Due to the large variety of kinds and sizes of equipments and to production systems with different automation levels, the quantity of involved variables is quite large.

On the diagram below are highlighted the main points of a production system of interlocking concrete units that must be checked.

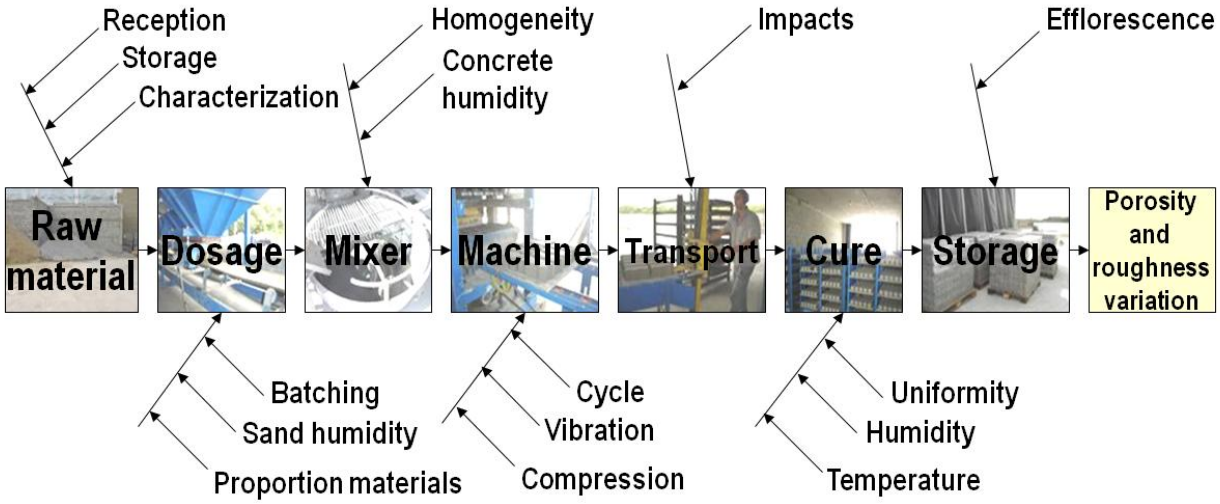

Figure 7. Cause and effect diagram (ISHIKAWA) for production system of manufacturing paving units for interlocking pavement. Evaluation of causes and effects that generate variations on porosity and rugosity of units. Proposed by the author.

Considering the cause and effect diagram, production control by colorimetry must be made in two steps. The first starts right after the molding on vibropress. This step covers the process from raw material until molding, going through metering and mixing. Color variations found on the first step will be straight connected to processes involved until molding, as shown in Figure 7. The second step of colorimetric controls will be made on the final stored product. On this second phase, the internal transportation, cure and storage will be involved. This way, there is a segmentation of actions to eliminate the reasons for color variations caused by porosity and roughness variations of units.

It should be stressed that colorimetric control has the goal to reduce the production of units out of specification, because it allows taking corrective actions quickly, working straight over the causes of problems. On this sense, the execution of compressive strength and water absorption tests, during the production control phase may be reduced, however the tests of batch approval must be kept according to specifications on technical standards.

The gradual reduction on the need for tests applied during production control will happen when the colorimetric standards will be better known.

The understanding of the reasons reported on ISHIKAWA diagram (Figure 7) still depends on a more detailed analysis of every step of the process. Since most of the reasons are related to the concrete itself, we present Table 7, where the influence of the constituents of concrete in the units variations of color is detailed.

Table 7. Variations of color due to changes on dosage (BAYER, 2001).

VARIATIONS ON COLOR DUE TO CHANGES ON DOSAGE (SAME PERCENTAGE OF PIGMENTATION AND COLORS OF AGREGGATES KEPT CONSTANT)		
Lower level of material ←	**Material**	Higher level of material →
Lower cement paste, higher **A / C**: more saturated color due to the increased pigment content	**Gray cement**	Higher cement paste, lower **A / C**: less saturated color due to the lower pigment content
Significantly more saturated color	**Sand**	Increased fines content, much less saturated color
Reduction in particle size, significantly more saturated color than the above situation	**Gravel**	Increase in particle size: less saturated color that the above situation
Darker color due to the lower light reflectance	**Water**	Lighter color due to the greater reflection of light
Darkening of color, less visible aggregates due to less cement paste. A few pigmented particles of cement.	**Paste (water+cement) (a/c constant)**	Lighter and less saturated color due to the greater quantity of cement paste and reduced pigment content

8. REFERENCES

ASSOCIAÇÃO BRASILEIRA DE CIMENTO PORTLAND, ABCP (2002). Relatório de ensaio 21745. São Paulo, 2002.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR 9780: Peças de concreto para pavimentação - Determinação da resistência à compressão. Rio de Janeiro, 1987.

_____. ABNT. NBR 9781: Peças de concreto para pavimentação - Especificação. Rio de Janeiro, 1987.

_____. ABNT. NBR 12118: Blocos vazados de concreto simples para alvenaria - Métodos de ensaio. Rio de Janeiro, 2007.

_____. ABNT. NBR 14082: Argamassa colante industrializada para assentamento de placas cerâmicas - Execução do substrato-padrão e aplicação de argamassa para ensaios. Rio de Janeiro, 2004.

EUROPEAN COMMITTEE FOR STANDARDIZATION – CEN, BS EN-1338 (2003). Concrete paving blocks, requirements and test methods. Brussels, Belgium. 2003.

ROJAS, D. L.; OLIVEIRA SILVA, C. Controle de produção de elementos pré-fabricados de concreto através de métodos colorimétricos. Relatório Bayer 020831. São Paulo, 2002.

MARQUES FILHO, O. Manual de Colorimetria I. Bayer. 59 p. São Paulo, 2001.

BAYER . LS – Matérias-primas Industriais. Divisão de Construção Civil. Treinamento técnico: Colorimetria e Pigmentos. 46 p. São Paulo, 2001.