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Abstract

ABSTRACT Objectives: To evaluate color, translucency parameter and optical properties (scattering (S), absorption (K) and transmittance (T)) of a multi-color polymer-infiltrated ceramic-network (PICN) material. Methods: Samples of shades 1M1-HT, 1M2-HT, 2M2-HT, 3M2-HT, and 4M2-HT from VITA ENAMIC® multiColor (E-MC) High Translucent were fabricated ($n=3$). CAD–CAM blocks were cut and polished to 1.00±0.01mm of thickness. Diffuse reflectance and color coordinates were measured against white and black backgrounds, using a calibrated spectroradiometer, CIE D65 illuminant and the CIE 45°/0° geometry. Color and translucency differences were evaluated using 50:50% perceptibility (PT and TPT) and 50:50% acceptability (AT and TAT) thresholds. S and K coefficients and T were calculated using Kubelka–Munk's equations. Data was statistically analyzed using Kruskal–Wallis, Mann–Whitney tests, and VAF coefficient. Results: Mean C* and b* values increased from incisal to cervical layers with statistically significant differences ($p<0.05$). In general, △E00 between sequential layers were above PT for all shades. In addition, translucency parameter (TP) increased from cervical to incisal and ΔTP00 values were greater than TPT00 and lower than TAT00 between all sequential layers. Layers from all shades showed similar spectral behavior for S (97.4%≤ VAF), K (85.0%≤ VAF) coefficients and T (95.3%≤ VAF). However, these values presented significant differences ($p<0.05$) from cervical to incisal layers. Significance: The gradient in color and translucency of this novel CAD-CAM multi-color PICN material can assist dental technicians and dentists to reach greater esthetics than the pre-existing CAD-CAM monolithic materials.

Keywords	PINC materials; color; translucency parameter; optical properties; indirect restoration
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Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
Data will be made available on request

ABSTRACT

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Significance: The gradient in color and translucency of this novel CAD-CAM multi-color PICN material can assist dental technicians and dentists to reach greater esthetics than the pre-existing CAD-CAM monolithic materials.

Optical and colorimetric evaluation of a multi-color polymer-infiltrated ceramic network material

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Declaration of interest: none

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Optical and colorimetric evaluation of a multi-color polymer-infiltrated ceramic-network material

1. INTRODUCTION

Ceramics and resin-based composites are the most popular esthetic dental materials. Traditionally, clinical performance of direct composite restorations has been inferior compared to ceramic restorations, considering marginal adaptation, color matching, and anatomical shape [1]. Concerning CAD-CAM restorations, ceramics showed superior esthetic and wear resistance compared to indirect composite [2]. However, indirect resin composites may produce less wear to antagonist teeth compared to ceramics [3-5]. Despite of such differences, survival rates of direct [1] and indirect resin-based composite restorations [6, 7] were similar to ceramic restorations.

Hybrid materials were introduced as an attempt to combine good material properties of polymers and ceramics [8]. Among them, are included the polymerinfiltrated ceramic-network (PICN)e.g. VITA ENAMIC®) materials (and the nanoceramic resins3M-Espe Lava Ultimate (NCR) (e.g.) materials [9]. PICN materials offer similar flexural resiliency and improved fractured resistance compared to composite resin [10], and lower hardness than ceramics [11].

Physical-mechanical properties of the restorative materials play a fundamental role in long-term clinical success of a restoration. But esthetic success depends mainly on their optical properties, which must also imitate those of the natural tooth. The color of natural teeth results from the combination of optical properties of enamel and dentine [12]. The thickness, structure and composition of these tissues change through different areas of the tooth, which explain an overall gradation in color from cervical, which is the most saturated, to incisal region [13].

A previous publication [14] compared chromatic properties of PICN specimens (ENAMIC, Vita) to dentine extracted from anterior and posterior teeth. Results showed that none of the best matches were below the color acceptability threshold (AT), concluding that improvements to the optical properties of this material were needed.

With the intention to simulate the color gradient of natural tooth, a new generation of ENAMIC was recently introduced: the VITA ENAMIC® multicolor (E-MC).

The manufacturer states that E-MC presents a natural chromatic transition integrated in six layers from the cervical to incisal layer. However, to the best of our knowledge, no information is available on color and optical properties of such material.

The purpose of this study was to evaluate the color, translucency parameter (TP) and optical properties of a multi-color PICN material. The study hypotheses were that (1) the E-MC material presents a perceptible difference in color and TP from cervical to incisal layer, and (2) there is a significant difference in optical properties among layers from cervical to incisal for all evaluated shades.

2. MATERIALS AND METHODS

2.1. Preparation of samples

This study used VITA ENAMIC® multiColor (E-MC) High Translucent (HT) (Vita Zahnfabrik, Bad Sackingen, Germany) in the following shades: 1M1-HT, 1M2-HT, 2M2HT, 3M2-HT, and 4M2-HT. According to the manufacturer, E-MC is a porous presintered fine structure feldspathic ceramic block (86 wt%) with the following composition: SiO_2 (58 wt%), Al_2O_3 (20 wt%), Na_2O (9wt%), K_2O (4wt%), B_2O_3 (0.5 wt%), ZrO_2 (<1%) and CaO (<1%). This ceramic phase is infiltrated with a polymer (14 wt%) composed by UDMA and TEGDMA monomers. An integrated natural color gradient in six finely nuanced layers from cervical (E-MC1) to incisal (E-MC6) is present in each block [15].

Three slices (12 mm x14 mm) were obtained from cutting each CAD-CAM block with a diamond disk in an Accutom-50 (Struers, Ballerup, Denmark). Specimens were polished on a wet polishing wheel with silicon carbide paper discs (500, 800, 1000, 2000, and 2500 grits). The final specimen thickness (1.00 mm ± 0.01mm) was measured using a digital caliper (Mitutoyo, Europe GmbH, Germany). After polishing, specimens were sonically cleaned in distilled water for 3 min and stored in distilled water for 24h. Specimens were dried with oil-free air for 10s before optical measurements.

2.2. Spectral reflectance and color coordinates

A non-contact measuring system consisting of a calibrated spectroradiometer (SpectraScan® PR-670, Photo Research Inc., Chatsworth, CA, USA) and two fiber optic light cables (Model 70050; Newport Stratford Inc., Franklin, MA, USA), with a xenon arc lamp (300W, Newport Stratford Inc., Franklin, MA, USA) on a custom-made optical table was used to measure spectral reflectance. A manual XYZ axis translation stage (MAXYZR-60L-P-H, Optics Focus Instruments Co., Ltd., Beijing, China) was used to obtain precise manual translations between layers. The spectroradiometer was placed away from the samples (40 cm) and the illuminating/measuring geometry corresponded to CIE 45°/0°. Values of spectral reflectance for wavelengths at 2nm were obtained from 380 to 780 nm with a focus measuring aperture 1/8° at the center of each layer. The spectral reflectance of all specimens was measured against both white and black 50 mm x 50 mm ceramic tile backgrounds (Ceram, Staffordshire, United Kingdom). Saturated sucrose solution having an index of refraction of approximately 1.5 was placed as the optical contact between specimen and background [16, 17].

Spectral reflectance values were converted into CIE L*a*b* color coordinates using the CIE 2° Standard Observer and the CIE D65 Standard Illuminant [18]. Three short-term repeated reflectance measurements without replacement were performed, and the results were averaged.

Computations for CIEDE2000 color difference (ΔE_{00}) metric was used according to the following equation [18, 19]:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2} \qquad (1)$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue, respectively, for a pair of layers.The weighting functions (S_L, S_C and S_H) adjust the total color difference for variation in the location of the color difference pair in L', a', b' coordinates. The parametric factors (K_L, K_C and K_H) are correction terms for experimental conditions. Finally, a rotation function (R_T) accounts for the interaction between chroma and hue differences in the blue region [18, 19]. Color differences were finally evaluated in accordance to recent data about 50:50% perceptibility (PT = 0.81 ΔE_{00}units) and 50:50% acceptability (AT = 1.77 ΔE_{00} units) color thresholds [20].

2.3. *Translucency parameter (TP)*

TP values were determined by calculating the color difference between readings over the black and white backgrounds for the same layer, according to the following CIELAB color difference formula [21].

$$TP = [(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2]^{1/2} \qquad (2)$$

where the subscripts “B” and “W” refer to color coordinates over the black and the white backgrounds, respectively.

In addition, CIEDE2000 (1:1:1) color difference formula was also used to calculate the translucency parameter (TP_{00}) [22]:

$$TP_{00} = \left[\left(\frac{L'_B - L'_W}{K_L S_L} \right)^2 + \left(\frac{C'_B - C'_W}{K_C S_C} \right)^2 + \left(\frac{H'_B - H'_W}{K_H S_H} \right)^2 + R_T \left(\frac{C'_B - C'_W}{K_C S_C} \right) \left(\frac{H'_B - H'_W}{K_H S_H} \right) \right]^{\frac{1}{2}} \qquad (3)$$

where the subscripts “B” and “W” for L′, C′ and H′ refer to lightness, chroma and hue of each layer over the black and the white backgrounds, respectively.

Translucency differences between two adjacent layers from the same block were finally evaluated using published data about 50:50% translucency perceptibility (TPT_{00}= 0.62) and acceptability (TAT_{00}= 2.62) thresholds [22].

2.4. *Kubelka-Munk coefficients*

The Kubelka-Munk transmittance (T), scattering (S) and absorption (K) coefficients were calculated algebraically as previously described [23]. These optical parameters are wavelength dependent, hence, their values vary across the visible spectrum.

2.5. *Microstructural characterization*

Specimens were sonically cleaned in acetone for 5 min, gold coated and examined under a scanning electron microscope (SEM- VEGA3 LM, TESCAN, Brno, Czech Republic). Qualitative analyses using SEI (secondary electron image) and BSI (backscattered electron image), and semi-quantitative analysis using EDS (energy dispersive X-ray spectroscopy, EDS-X-Max, Oxford Instruments, Oxford, UK) were performed. Material composition and elements concentration (wt%) from three different locations in each layer of all specimens were recorded using EDS. Average values were calculated and reported.

2.6. Statistical analysis

Since the normality and variance homogeneity assumptions were satisfied (Levene test), one-way ANOVA and Tukey's multiple comparison tests with Bonferroni correction were used to compare mean values of L*, a*, b*, C* and hº, of the six layers of each E-MC specimen. The level of significance was setting as $p<0.05$. The statistical software package used was IBM SPSS 22.0 (IBM Corp. Armonk, NY, USA).

To study the variations in scattering, absorption, and transmittance, two statistical tests were used: the Kruskal-Wallis one-way analysis of variance by ranks and the Mann-Whitney U test for pair-wise comparisons. In addition, to determine the level of similarity regarding spectral behavior of Kubelka-Munk coefficients, the VAF (Variance Accounting For) coefficient with Cauchy-Schwarz inequality was used as follows:

$$VAF = \frac{\left(\sum_{k=380}^{780} a_k . b_k\right)^2}{\left(\sum_{k=380}^{780} a_k^2\right)\left(\sum_{k=380}^{780} b_k^2\right)} \quad (4)$$

Where a_k is the spectral value of each layer for K, S, and T coefficients (from 380780nm) and b_k is the equivalent for another measurement. The closer this coefficient gets to unity (100%), the more similar the two curves become.

3. RESULTS

Mean and standard deviation values of colorimetric parameters L*, a*, b*, C* and h^o for all layers from all E-MC shades are presented in Table 1. For all shades, mean C* and b* values increased from incisal to cervical layers with statistically significant differences ($p<0.05$). Mean a^* and h^o values showed no significant differences between layers for all shades (p□0.05). Differences in lightness lower than lightness acceptability thresholds (□L’=2.92) [25] were found for sequential layers for all shades. In addition, there was a significant difference ($p<0.05$) in lightness only between E-MC1 and E-MC6 layers from all shades.

The range of color differences (ΔE_{00}) among all layers within the same shade can be calculated from data in Table I, which are as follows: 0.76-7.52 (1M1-HT), 0.976.93 (1M2-HT), 1.24-8.84 (2M2-HT), 1.06-8.29 (3M3-HT), and 0.80-7.87 (4M2-HT). ΔE_{00} values were below PT (Table 1) between layers E-MC1 and E-MC2 for 1M1-HT (0.76 ΔE_{00} units) and 4M2-HT (0.80 ΔE_{00} units). In general, ΔE_{00} between some sequential layers (E-MC1 and E-MC2, E-MC2 and E-MC3, and E-MC5 and E-MC6) for all shades were below AT and above PT values (Table 1).

Figure 1 shows mean and standard deviation values of TP_{00} and TP for all layers from different shades of E-MC. For all shades, translucency increased from cervical to incisal layers. The range of translucency differences (□TP_{00}) among all layers within the same shade were 0.49-5.80 (1M1-HT), 0.05-4.20 (1M2-HT), 0.77-6.77 (2M2-HT), 0.196.33 (3M2-HT), and 1.01-8.45 (4M2-HT). □TP_{00} values were below TPT_{00} between layers E-MC1 and E-MC2 for 1M1-HT (0.49 □TP_{00} units) and 3M2-HT (0.19 □TP_{00} units) and between layers E-MC2 and E-MC3 (0.62 □TP_{00} units) and E-MC5 and E-MC6 (0.05 □TP_{00} units) for 1M2-HT. □TP_{00} values above TPT_{00} and below TAT_{00} were found between all sequential layers for all shades (Figure 2).

Figure 3 shows the spectral distribution of K-M scattering (*S*) and absorption (*K*) coefficients (Figure 3a and 3b, respectively), and transmittance (T) (Figure 3c) as a function of wavelength for all layers (from E-MC1 to E-MC6) from shade 2M2-HT. All layers from all shades showed similar spectral behavior for *S* (97.4%≤ VAF≤ 99.9%) and *K* (85.0%≤ VAF≤ 99.9%) coefficients and T (95.3%≤ VAF≤ 99.9%). E-MC1 (cervical layer) showed the highest mean *S* and *K* values, decreasing from cervical to incisal with sequential order ($p<0.05$), and the lowest mean T values, increasing from cervical to incisal region with sequentially order ($p<0.05$) (Figure 3c).

Representative microstructural images of the six layers of E-MC shows a two-phase material: a ceramic-based and a polymer-based. The average composition (element range in wt%) of the ceramic-based phase was estimated using EDS: O (37.4 50.2), Si (26.7 - 35.3), Al (11.4 - 13.8), Na (6.6 - 7.5) and K (4.0 - 6.3). Other elements were found showing less than 1 wt%, such as: Ca (0.2 - 0.4), Zr (0.1 - 1), Fe (0.1) and Ti (0.1). Fe, Zr and Ti were only found in more chromatic layers (Figure 4).

4. DISCUSSION

As most biological structures, enamel and dentin are heterogeneous tissues [25]. Their thickness, structure and composition show regional variations, resulting in progressive and significant differences in optical properties throughout the tooth crown. Therefore, monolithic restorations cannot be able to replicate the complex appearance of natural teeth [26].

This study characterized the optical properties, including color, and the microstructure of a novel multi-color polymer-infiltrated ceramic-network (PICN) material (VITA ENAMIC multiColor), composed by six optically different layers. Indications of PICN materials include not only restorations such as crowns, inlays and onlays for posterior teeth, but also laminate veneer restorations for anterior teeth [9], justifying the relevance of the present research.

The present study confirmed the first hypothesis, since all layers (from cervical to incisal) from all shades of E-MC groups showed perceptible differences in color coordinates and translucency parameter. Nevertheless, these properties should be evaluated considering the same characteristics of the natural teeth.

There is not much information about the optical properties of human teeth. Moreover, published data are often contradictory, due to the biological variability between different persons or between different teeth from the same person, or even as a result of diversity of measuring instruments used. Dozic et al. [27] found perceptible color differences (ranging from 4.8 to 10 ΔE_{ab^*} units) between the cervical middle, middle-incisal and cervical-incisal regions from different teeth. In the present study, color differences (ΔE_{00}) between E-MC2 and E-MC3 as well as E-MC4 and EMC5 (i.e. layers of transition between dental thirds) were higher than PT, and, therefore, visually perceptible for all E-MC shades evaluated.

With respect to a* and b* color coordinates, their values in natural teeth tend to increase from incisal to cervical regions [13, 28]. This gradation of color in human teeth seems to be related with the pattern of thickness distribution of dentin and enamel [27]. Thus, the color of the cervical third, with a thinner enamel layer, might be dominated by dentin colorimetric properties [28, 29]. Data from Table 1 show that b* values decreased from cervical to incisal layers for all shades evaluated, however, this trend was no found for a*.

In addition, L* and C* values decreased towards the incisal layer for all shades (Table 1). Values of L* coordinate found at different layers of E-CM partially agree with previous reports on luminosity of natural teeth. Yet, there is no consensus on the variation of such parameter across tooth crown. A study found no significant differences between cervical and middle thirds, which presented more luminosity than the incisal third [30]. While in others studies the cervical [27] or the middle third [28, 31, 32] shown the highest value.

Considering color, E-MC layers show a gradient in luminosity and saturation, and to a lesser extent, present differences in the blue-yellow axis, while no perceptible variations in a* and h^o were found, according published thresholds [24].

Translucency is one of the primary factors in maintaining esthetics and, therefore, it is crucial during the selection of materials [33-35]. Usually, translucency is quantified with the translucency parameter using CIELAB color difference formula (TP). Recently, the recommended CIEDE2000 color difference formula [18, 36] has been used to calculate this parameter (TP_{00}). In this study, both TP and TP_{00} formulas have been used to provide immediate application as future interpretations of new research data on translucency differences [37].

TP and TP_{00} values from different shades of E-MC tend to decrease from incisal to cervical layers (Figure1), as described for natural teeth [29]. Translucency differences (ΔTP_{00}) between E-MC layers (Figure 2) were, in general, higher than TPT_{00}, and, in all cases, lower than TAT_{00}. This finding is congruent with the translucent appearance of natural teeth by visual observation [28].

Previous studies compared the translucency of several monolithic CAD-CAM restorative materials. Sen et al. [38], reported that translucency of VITA ENAMIC was significantly lower compared to zirconia-reinforced glass ceramic (Vita Suprinity), feldespatic ceramic (Vitablocks Mark II) and lithium disilicate ceramic (IPS e.max CAD). In addition, in several studies Vita Enamic exhibited significantly lower translucency when compared with nanoceramic-resins as Lava Ultimate and GC Cerasmart [39-41]. The present study showed TP values for 1mm thick specimens of E-MC1 (cervical layer) ranged from 14.05 to 19.50 (Figure 1). Previous studies showed similar TP values (TP= 14.15) for 1mm thick specimens [41] and for 1.2 mm thick specimens (TP=16) [39] of VITA ENAMIC. However, in the present study, incisal layers showed higher TP values (22.49 - 24.81, Figure 1). Moreover, the variation of the translucency is gradual throughout the six layers (Figure 1). These findings indicate an improvement in the esthetic properties for VITA ENAMIC multiColor regarding to VITA ENAMIC regular material.

Translucent materials are needed to obtain dental restorations with natural-like appearance [41]. However, the shade of remaining tooth structure should be also considered when choosing the esthetic restorative material [42]. Although highly translucent materials should be used for thin restorations to replace non-discolored enamel tissue [41], opaque restorative material is recommended to mask the remaining underlying discolored tissue [43, 44].

The present study evaluated optical properties (scattering and absorption coefficients and transmittance) of different layers from different shades of E-MC. The S coefficient of E-MC varies across the visible spectrum (Figure 3a). The smallest values for S were found for short wavelengths, independently of the layer and shade evaluated. For medium wavelengths, higher values of S were found, especially for cervical and middle E-MC layers, while S values remained constant or slightly decreases in larger wavelengths (600 - 700 nm). The spectral design of K distribution (Figure 3b) showed the highest values for shorter wavelength (with maximum K mean values recorded for wavelengths near to 400 nm) and decreased considerably with longer wavelength. In general, the scattering prevails over the absorption at wavelenghts longer than 420 nm; therefore, this is the most determining parameter in the transmittance of the material.

Regarding the distribution of T, all shades exhibited similar spectral behavior. The smallest values of transmittance were registered for shorter wavelengths and an increasing trend of T values was found independently of the layer and shade evaluated (Figure 3c).

Overall, the spectral behaviour of E-MC has been similar to those described for human dentine [17, 45], ceramic materials [46], zirconia ceramics [45] and resin-based composites [47-49].

Although similar spectral behavior of S, K and T has been found for all layers of the five shades evaluated (VAF, near to 100%), their values presented significant differences from one layer to another. The highest S and K values were found for the most cervical layer, while the highest T values were recorded for the incisal layer of all shades. Therefore, optical properties were significantly different between E-MC layers, which confirms the second study hypothesis.

On the spectral transmittance, the most clinically relevant data is their value at 480 nm, because this wavelength match with maximum absorption peak of camphorquinone, the photo-initiator used in most of the resin-based cements [50]. For each shade, the lowest T value at 480 nm was recorded in the cervical layer. In addition, the more chromatic the shade, the lower the value of T, which was expected considering the important role played by pigments in light absorption [14]. Therefore, to achieve adequate polymerization of resin-based cements, a longer light curing time could be needed, especially for the most chromatic E-MC shades.

The differences of S, K and T values found between different layers from the same shade could be related to variations in the structure and composition of these layers [51]. The microstructure of a dental material dictates both the mechanical and the optical properties of the material [46]. Significant changes on color and translucency can be achieved by adding small amounts of inorganic oxides. Iron oxide (Fe_2O_3) and Iron hydroxide ($FeO(OH)$), which provide red and yellow pigments, respectively, are used to obtain shades similar to dental structures [52, 53]. Metal oxides such as zirconium dioxide (ZrO_2), titanium dioxide (TiO_2) and aluminum dioxide (Al_2O_3) are commonly added to obtain opaque composite materials [53, 54]. Although in small amounts (≤1%), the present study showed Fe, Ti and Zr in more chromatic and more opaque layers for different shades from E-MC material.

One potential limitation of E-MC is that the gradient of the optical properties is unidimensional, from cervical to incisal, while in natural teeth the color variability is three-dimensional (cervical to incisal, mesial to distal and from deep dentine to superficial enamel), which could jeopardize the appearance of the restorations.

A functionally graded biomimetic material (FG-PICN) for CAD-CAM has been recently manufactured as an attempt to achieve a gradient of mechanical and optical properties throughout the entire thickness of the block. The FG-PICN material has experimentally demonstrated a favorable gradient of mechanical properties [25]. However, as far as we know, optical properties of the material are yet to be determined.

Finally, as VITA ENAMIC multi-color has been recently introduced, additional studies evaluating the influence of relevant factors, such as the thickness, on optical properties of the material are encouraged.

5. CONCLUSIONS

This is the first study to report on the new multi-color graded (E-MC) PICN material for CAD-CAM restorations. The E-MC PICN material showed a gradient of color, translucency and optical properties (absorption, scattering and transmittance) from cervical to incisal, resembling the color grading of natural tooth. Such optical behavior can assist dental technicians and dentists to reach greater esthetics than the pre-existing CAD-CAM monolithic materials.

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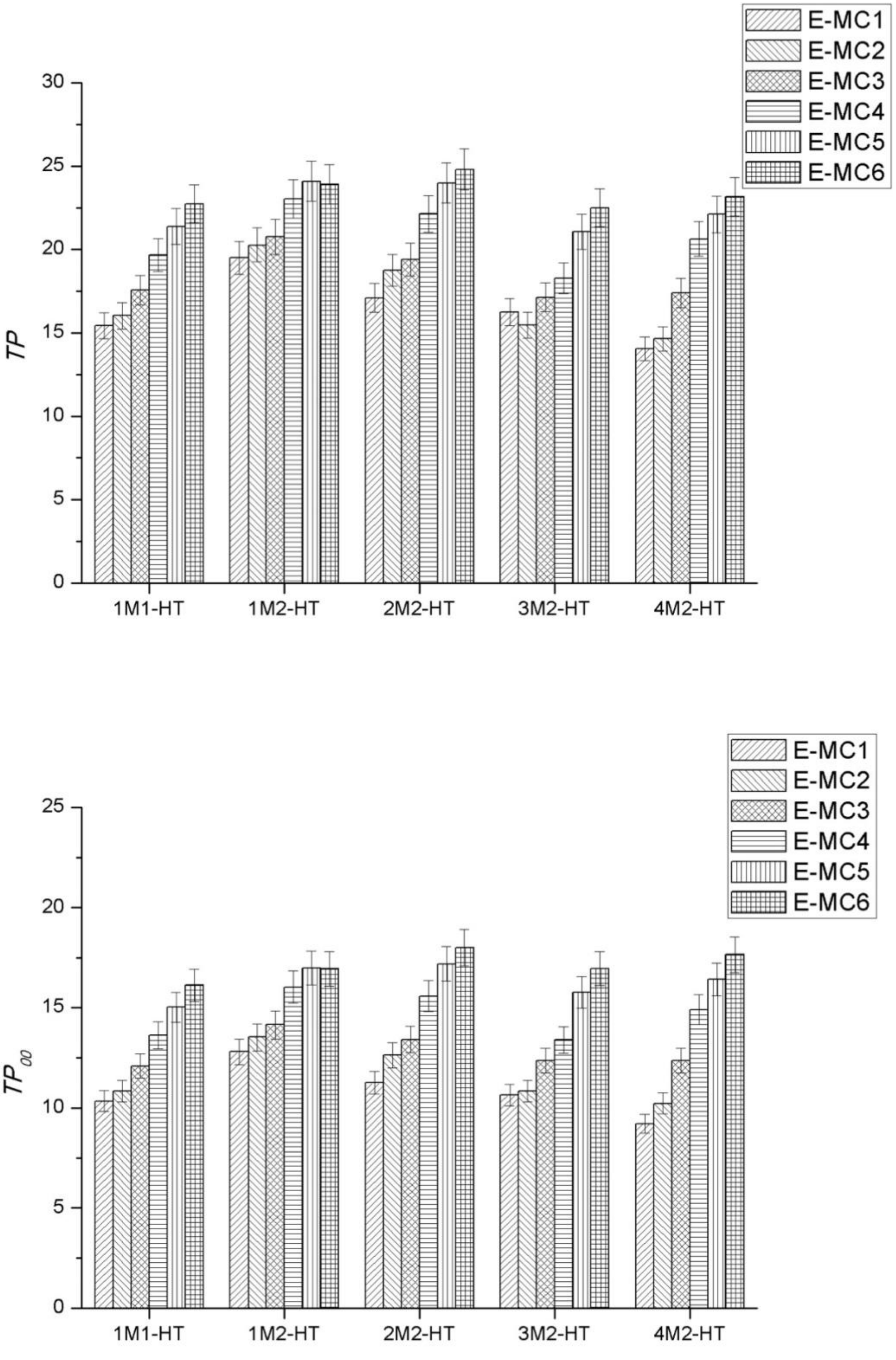
Figure 1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E-MC6
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25
20
15
10
5
0
TP
1M1-HT
1M2-HT
2M2-HT
3M2-HT
4M2-HT
E-MC1
E-MC2
E-MC3
E-MC4
E-MC5
E-MC6
25
20
15
10
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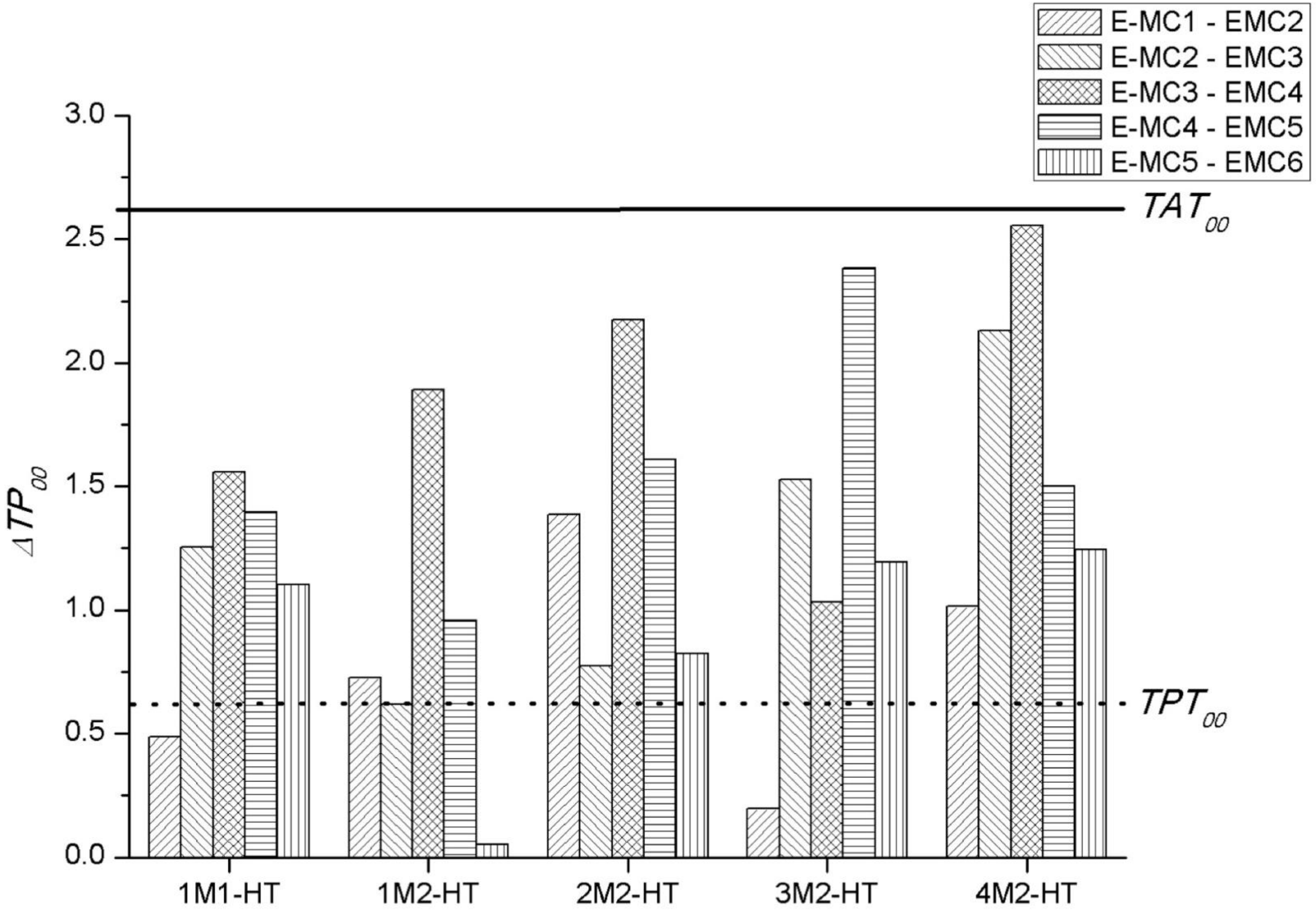
0
TP_{00}
1M1-HT
1M2-HT
2M2-HT
3M2-HT
4M2-HT

Figure 2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E-MC5 - EMC6
TAT00
TPT00
ΔTP00
3.0
2.5
2.0
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0.5
0.0
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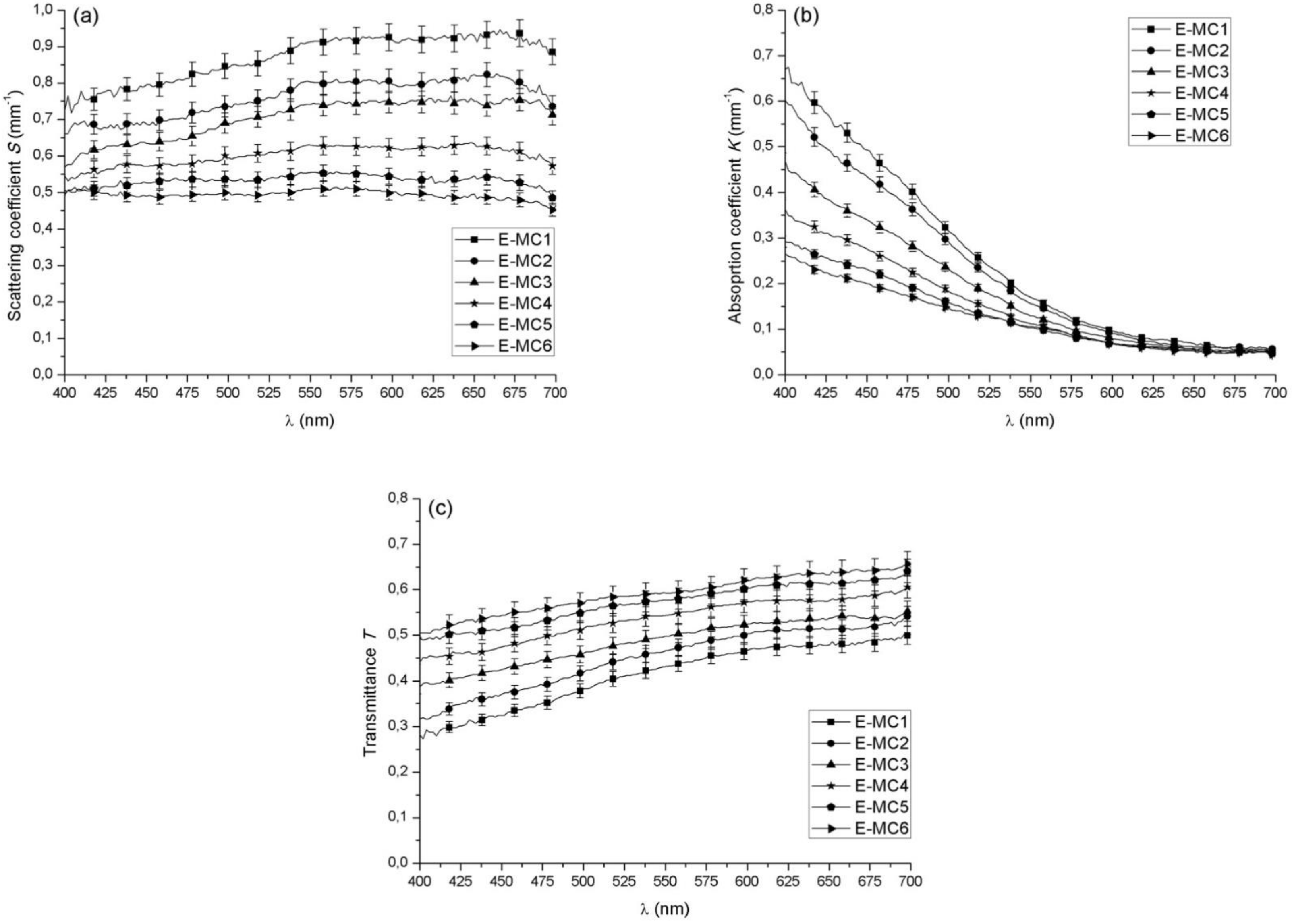
1M2-HT
2M2-HT
3M2-HT
4M2-HT

Figure 3


(a)
Scattering coefficient S (mm^{-1})
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0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
400
425
450
475
500
525
550
575
600
625
650
675
700
λ (nm)
E-MC1
E-MC2
E-MC3
E-MC4
E-MC5
E-MC6
(b)
Absorption coefficient K (mm^{-1})
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
400
425
450
475
500
525
550
575
600
625
650
675
700
λ (nm)
E-MC1
E-MC2
E-MC3
E-MC4
E-MC5
E-MC6
(c)
Transmittance T
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
400
425
450
475
500
525
550
575
600
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700
λ (nm)
E-MC1
E-MC2
E-MC3
E-MC4
E-MC5
E-MC6

Figure 4

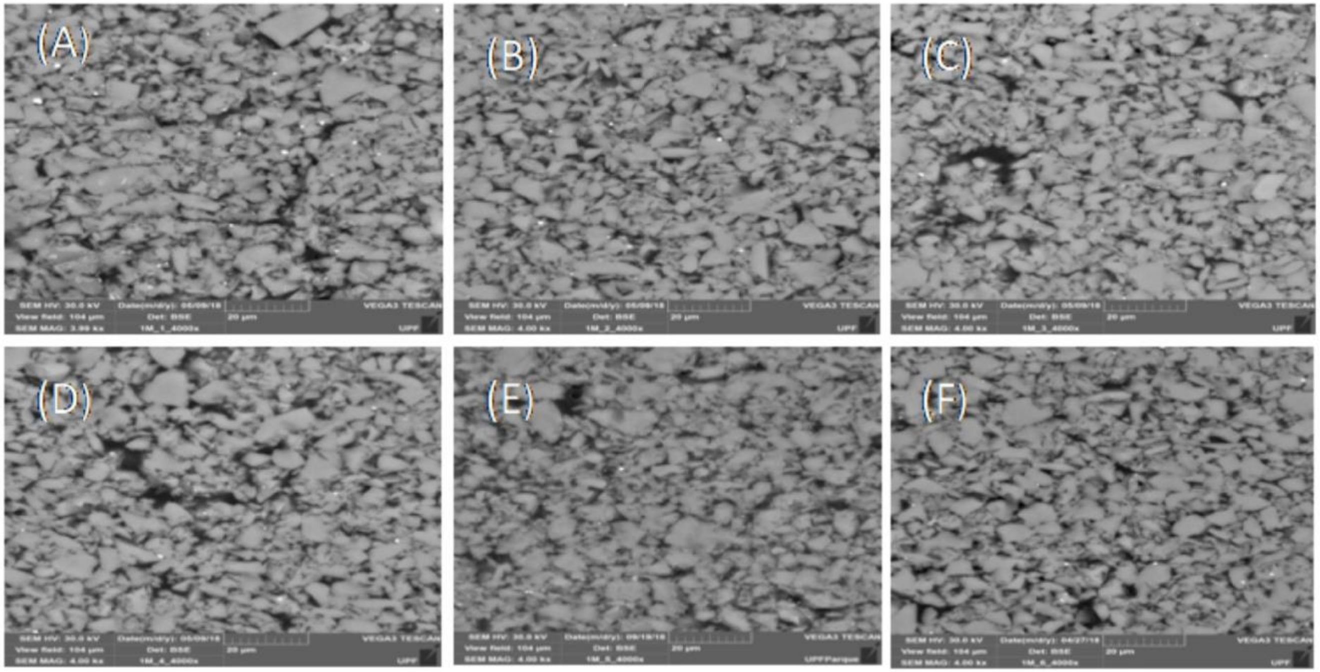

Table 1- Mean and standard deviation values of color coordinates for the E-MC shades evaluated.

E-MC SHADES	LAYERS	L*	a*	b*	C^*_{ab}	h^o(degree)	ΔE_{00}†
1M1-HT	**E-MC1**	76.40 ± 0.04	-0.49 ± 0.02	7.59 ± 0.03	7,60 ± 0.07	-1.51 ± 0.03	A
	E-MC2	75.40 ± 0.05	-0.57 ± 0.02	7.51 ± 0.07	7.54 ± 0.06	-1.49 ± 0.03	A,a
	E-MC3	73.70 ± 0.03	-0.83 ± 0.04	6.32 ± 0.05	6.38 ± 0.08	-1.44 ± 0.02	a
	E-MC4	71.90 ± 0.09	-0.57 ± 0.09	4.72 ± 0.02	4.75 ± 0.04	-1.45 ± 0.05	
	E-MC5	70.00 ± 0.04	-0.48 ± 0.01	3.22 ± 0.05	3.26 ± 0.08	-1.42 ± 0.01	b
	E-MC6	68.50 ± 0.07	-0.03 ± 0.01	1.98 ± 0.03	1.98 ± 0.02	-1.55 ± 0.07	b
1M2-HT	**E-MC1**	72.70 ± 0.08	-0.72 ± 0.04	10.93 ± 0.07	10.96 ± 0.06	-1.50 ± 0.01	a
	E-MC2	71.50 ± 0.06	-0.89 ± 0.05	10.47 ± 0.02	10.52 ± 0.02	-1.48 ± 0.01	a,b
	E-MC3	70.70 ± 0.03	-1.09 ± 0.07	9.19 ± 0.04	9.25 ± 0.02	-1.45 ± 0.05	b
	E-MC4	68.50 ± 0.09	-0.97 ± 0.05	6.56 ± 0.04	6.63 ± 0.04	-1.42 ± 0.02	
	E-MC5	67.40 ± 0.04	-0.87 ± 0.05	4.58 ± 0.01	4.67 ± 0.06	-1.38 ± 0.03	c
	E-MC6	67.40 ± 0.07	-0.77 ± 0.02	3.57 ± 0.06	3.64 ± 0.01	-1.54 ± 0.04	c
2M2-HT	**E-MC1**	71.10 ± 0.07	0.55 ± 0.03	13.95 ± 0.07	13,97 ± 0.09	1.53 ± 0.06	a
	E-MC2	69.40 ± 0.04	0.46 ± 0.02	12.83 ± 0.06	12.84 ± 0.04	1.54 ± 0.04	a,b
	E-MC3	69.00 ± 0.07	0.14 ± 0.04	11.08 ± 0.07	11.09 ± 0.02	1.56 ± 0.05	b
	E-MC4	67.00 ± 0.05	0.01 ± 0.01	8.02 ± 0.05	8.02 ± 0.07	1.57 ± 0.01	
	E-MC5	65.30 ± 0.07	-0.21 ± 0.07	5.72 ± 0.02	5.72 ± 0.02	-1.53 ± 0.07	c
	E-MC6	64.10 ±0.03	0.22 ± 0.05	4.30 ± 0.06	4.31 ± 0.01	1.52 ± 0.06	c
3M2-HT	**E-MC1**	65.40 ± 0.04	0.32 ± 0.08	16.13 ± 0.03	16.14 ± 0.07	1.55 ± 0.04	a,b
	E-MC2	64.90 ± 0.07	0.59 ± 0.03	17.88 ± 0.07	17,89 ± 0.09	1.54 ± 0.07	a,c
	E-MC3	64.10 ± 0.08	0.35 ± 0.04	15.90 ± 0.08	15.91 ± 0.02	1.55 ± 0.05	b,c,d
	E-MC4	63.40 ± 0.04	0.06 ± 0.01	13.42 ± 0.05	13.42 ± 0.05	1.57 ± 0.01	d
	E-MC5	61.30 ± 0.06	-0.09 ± 0.02	9.63 ± 0.02	9.63 ± 0.08	-1.56 ± 0.04	
	E-MC6	60.80 ± 0.03	0.68 ± 0.02	6.32 ± 0.07	6.35 ± 0.02	1.46 ± 0.02	
4M2-HT	**E-MC1**	63.70 ± 0.09	2.25 ± 0.02	17.09 ± 0.07	17.23 ± 0.08	1.44 ± 0.04	A,a
	E-MC2	63.00 ± 0.03	2.55 ± 0.08	17.79 ± 0.06	17.97 ± 0.05	1.43 ± 0.02	A,b
	E-MC3	62.50 ± 0.06	1.72 ± 0.02	15.49 ± 0.09	15.58 ± 0.09	1.46 ± 0.02	a,b
	E-MC4	61.70 ± 0.04	0.73 ± 0.04	11.92 ± 0.02	11.94 ± 0.04	1.51 ± 0.05	c

	E-MC5	60.70 ± 0.07	0.59 ± 0.02	9.95 ± 0.04	9.97 ± 0.06	1.51 ± 0.01	c
	E-MC6	58.50 ± 0.05	2.73 ± 0.02	7.54 ± 0.04	8.02 ± 0.02	1.22 ± 0.01	

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†For layers of same E-MC shade (column), same capital letter shows ΔE_{00} lower than PT (0.81) (Paravina et al., 2015), meaning, they are not perceptible different. For layers of same E-MC shade (column), same lowercase letter shows ΔE_{00} greater than PT (0.81) and lower than AT (1.77) (Paravina et al., 2015), meaning, they are perceptible but acceptable differences.