THE SECOND C: Leaving Limbo

By Keith Hoover

It is said that "simplicity is managed complexity."[1] In "The Second C" series, we have seen that the complexities of Light, Object, and Observer impact how we perceive color. Now, we will see how digital color management provides that layer of simplicity in the same way that the face and hands of a watch manage the complexity of the gears inside.

Decades of work in digital color management have produced a repeatable and scalable approach to identify and manage "acceptable color difference." This article 1) explains how colors are converted to numbers and 2) reviews tolerances. Finally, a comprehensive template for understanding color difference metrics is provided, complete with standardized comments for each use case.

Color by Numbers

There are two accepted models for assigning numbers to represent colors—L*a*b* and LCH, both of which are based on CIELAB color space shown in Figure 1. Both models define Lightness (L) as the vertical axis with 0 representing absolute black and

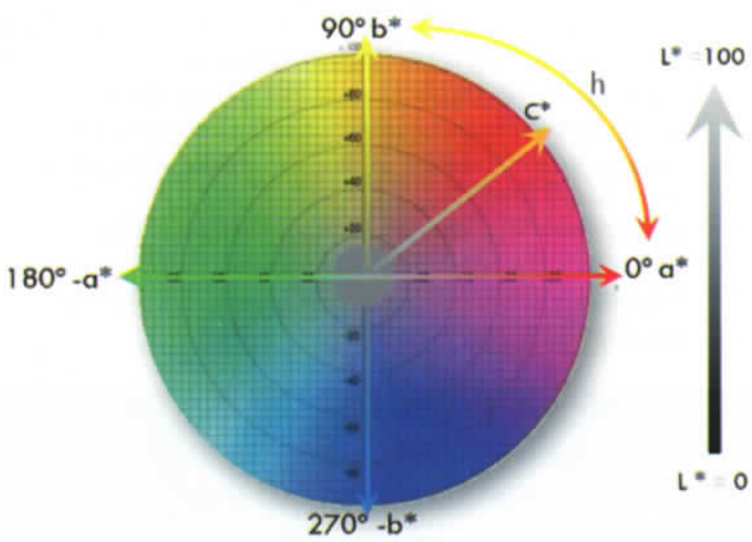


Figure 1. CIELAB color space.

100 representing absolute white (we will discuss optically brightened whites—whose values exceed 100— in a later installment).

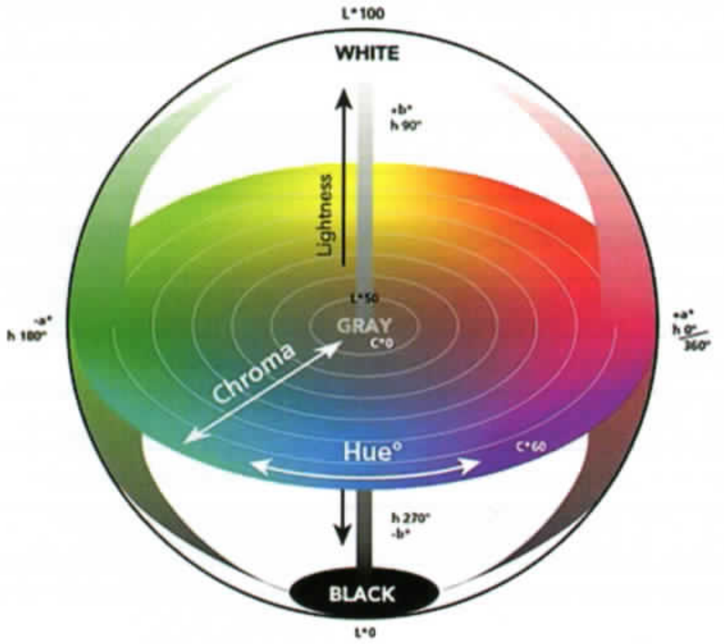
In the L*a*b* model, the horizontal plane is divided by two axes. The x-axis is labeled "a*" and describes a continuum between green on the left (-a*) and red on the right (+a*). The y-axis is labeled "b*" and describes a continuum between yellow on the top (+b*) and blue on the bottom (-b*). There are no set limits on a* or b* values, which can exceed 150.[2]

In the LCH model, the a* and b* values are transformed into different coordinates. H (or hue angle) denotes where the hue of a color would fall if a circle (like a color wheel) were superimposed on the a*b* grid. There are 360 possible whole numbers representing H (degrees in a circle), with red at 0° (3:00), yellow at 90° (12:00), green at 180° (9:00), and blue at 270° (6:00).

C (chromaticity) denotes the brightness or dullness of a color. Whereas H goes around the color wheel from hue to hue, C cuts directly across the color wheel through the center changing the brightness of a single hue. C ranges from 0 (no discernable hue) at the center of the plot to 100 (the brightest version of a hue) at the perimeter.

When describing the difference between two colors, each model uses different descriptors. Both use DL (delta or difference in lightness) or a version thereof. L*a*b* uses Da* to describe the red or green difference and Db* to describe the yellow or blue difference between the pair.

Describing the difference between two colors in the LCH model is more visually intuitive. DH (technically, DH^*_{ab}/S_H) describes a difference in hue (for instance, a blue hue can only differ on the red or green side since those two hues fall on either side of blue on



CIELAB color space.

the color wheel). DH (technically, $DC^*_{ab}/{}_cS_c$) metric describes a difference in chromaticity indicating whether one color is brighter or duller than the other.

Each model has its uses. LCH is best for describing the color difference for chromatic colors (colors with discernable hues). L*a*b* is best for describing achromatic or neutral colors (greys).

Why Tolerances Are Important

A tolerance sets the limit for color difference and defines three types of "acceptability."

Customer Expectations

Color accuracy in the store is an indicator of the overall brand quality. After all, if customers see shading in racks of garments, they might think something is wrong. So, the right tolerance defines the maximum color difference that a customer will accept and still purchase the product.

Dyehouse Process Capability

This is a measure of how effectively a dyehouse controls variables that cause offshade dyeing. Raw materials, machine control, processes, people, and technology all factor in to determine the amount of color variation that will occur when multiple lots of fabric are dyed the same color. It is expressed as a specific number of units of color difference. If a brand's tolerance is less than the mill's process capability, then the mill will either have to scrap fabric that falls out of tolerance or ship it anyway (and hope the brand does not find out).

Garment Factory Quality

Whereas lab dip approval focuses on the accuracy of one swatch compared to a standard, the factory must focus on the color precision (or lot-to-lot repeatability) of all production fabric. Most garments are made of cut fabric pieces sewn together. Since there is a slight amount of shading between dyelots, "same shade" production lots are important so that those pieces sewn together match each other. Shading within the garment is a significant product defect that can be avoided with proper dyehouse color management.

This textile series will share technical insights and wisdom of AATCC members. The "Second C" series will focus on color. If you wish to contribute your own technical insights on topics of interest to AATCC members, contact Communications Director, Maria Thiry; **thirym@aatcc.org.**

CHROMATIC COLORS		
CMC Hue Difference		
Yellow color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too green**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too red**
Orange color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too yellow**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too red**
Red color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too yellow**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too blue**
Purple color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too red**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too blue**
Blue color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too red**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too green**
Turquoise color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too blue**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too green**
Green color group standards	If the Hue difference shows a positive DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too blue**
	If the Hue difference shows a negative DH^*_{ab}/S_H value, the comment should be	**Hue: The sample is too yellow**
CMC Chromaticity Difference		
Chromaticity	If the Chromaticity difference shows a positive DC^*_{ab}/cS_C value, the comment should be	**Chromaticity: The sample is too bright**
	If the Chromaticity difference shows a negative DC^*_{ab}/cS_C value, the comment should be	**Chromaticity: The sample is too dull**
CMC Lightness Difference		
Lightness	If the Lightness difference shows a positive DL^*/lS_L value, the comment should be	**Lightness: The sample is too light**
	If the Lightness difference shows a negative DL^*/lS_L value, the comment should be	**Lightness: The sample is too dark**
ACHROMATIC COLORS		
CIELAB Lightness Difference		
Lightness	If the Lightness difference shows a positive CIE DL* value, the comment should be	**Lightness: The sample is too light**
	If the Lightness difference shows a negative CIE DL* value, the comment should be	**Lightness: The sample is too dark**
	CIELAB color difference values do not correlate to DECMC, so only consider their relative scale to each other	
CIELAB Cast Difference		
Cast	If the Red/Green axis difference shows a positive CIE Da* value, the comment should be	**Cast: The sample is too red**
	If the Red/Green axis difference shows a negative CIE Da* value, the comment should be	**Cast: The sample is too green**
	Red/Green and Yellow/Blue cast difference descriptions should be combined in one comment - Cast: The sample is too X and Y	
CIELAB Cast Difference		
Cast	If the Yellow/Blue axis difference shows a positive CIE Db* value, the comment should be	**Cast: The sample is too yellow**
	If the Yellow/Blue axis difference shows a negative CIE Db* value, the comment should be	**Cast: The sample is too blue**

Figure 2. What color difference numbers mean.

Tolerances by the Numbers

Using a numerical tolerance that correlates with visual assessment is the simplest way to determine if specifications have been met. Several equations have been written over the years attempting to define acceptable color difference. The CMC equation is the accepted model in the apparel industry because it works.[3]

There are four metrics used in CMC to describe the difference between a color standard and a sample:

Hue difference: DH^*_{ab}/S_H This value can be positive or negative.

Lightness difference: DL^*/lS_L This value can be positive or negative.

Chromaticity difference: DC^*_{ab}/cS_C This value can be positive or negative.

Total color difference: DE_{CMC} 2:1 A value of 1.00 (called "commercial factor") represents the industry tolerance for acceptable color difference. A value >1.00 is offshade whereas a value <1.00 defines a progressively closer match as it decreases.

The CMC equation automatically adjusts the hue, lightness, and chromaticity difference tolerances based on the shade of the color standard, *so the only tolerance needed is for DE_{CMC} 2:1.*[4]

Keys to the Kingdom

Okay, you've made it this far.... Now what? Figure 2 puts it all together. It is the color cheat-sheet of all cheat-sheets, converting gobbledygook color difference numbers into simple and consistent language to describe color difference. Use this chart to determine the proper color comments to make for any lab dip that measures greater than 1.00 DE_{CMC} 2:1.

No matter how tempted you are, NEVER use other descriptions like "not romantic enough" or "too bubble-gummy" or "I don't know, it's just not what's in my head."[5] And, for the love of Pete, never uses percentages, like "20% too dark" (the percentages you see in Adobe CS bear no resemblance to recipe revisions in dyeing).

When commenting, remember to state your observations in order of importance (based on the size of the delta numbers). If one of the values (like DC^*_{ab}/cS_C) is insignificant, then do not mention it.

Additionally, remember, the color standard is the fixed reference point. Describe how the sample differs from the color standard. Describe ONLY what you see in terms of color difference—DON'T tell the dyers how to fix it (or they might follow your directions and show you how little you know about dye chemistry).

Let's Roll

Okay, enough talk. It's time to review some lab dips. Applying a digital process takes all of the guesswork out of color assessment. What follows are all possible outcomes. I recommend that you use the exact comment wording below (copy/paste)—it is accurate and properly instructive to the dyer.

Conventional Approvals

APPROVED:

When a lab dip measures within tolerance in both illuminants compared to the standard.

Notes:

- No comment needed (unless it's a compliment).
- Never reject a lab dip that is in tolerance because "the next one might be even better."
- Never add comments like "no lighter in production" —it either passes or fails.
- Never "conditionally approve" a lab dip—it either passes or fails.

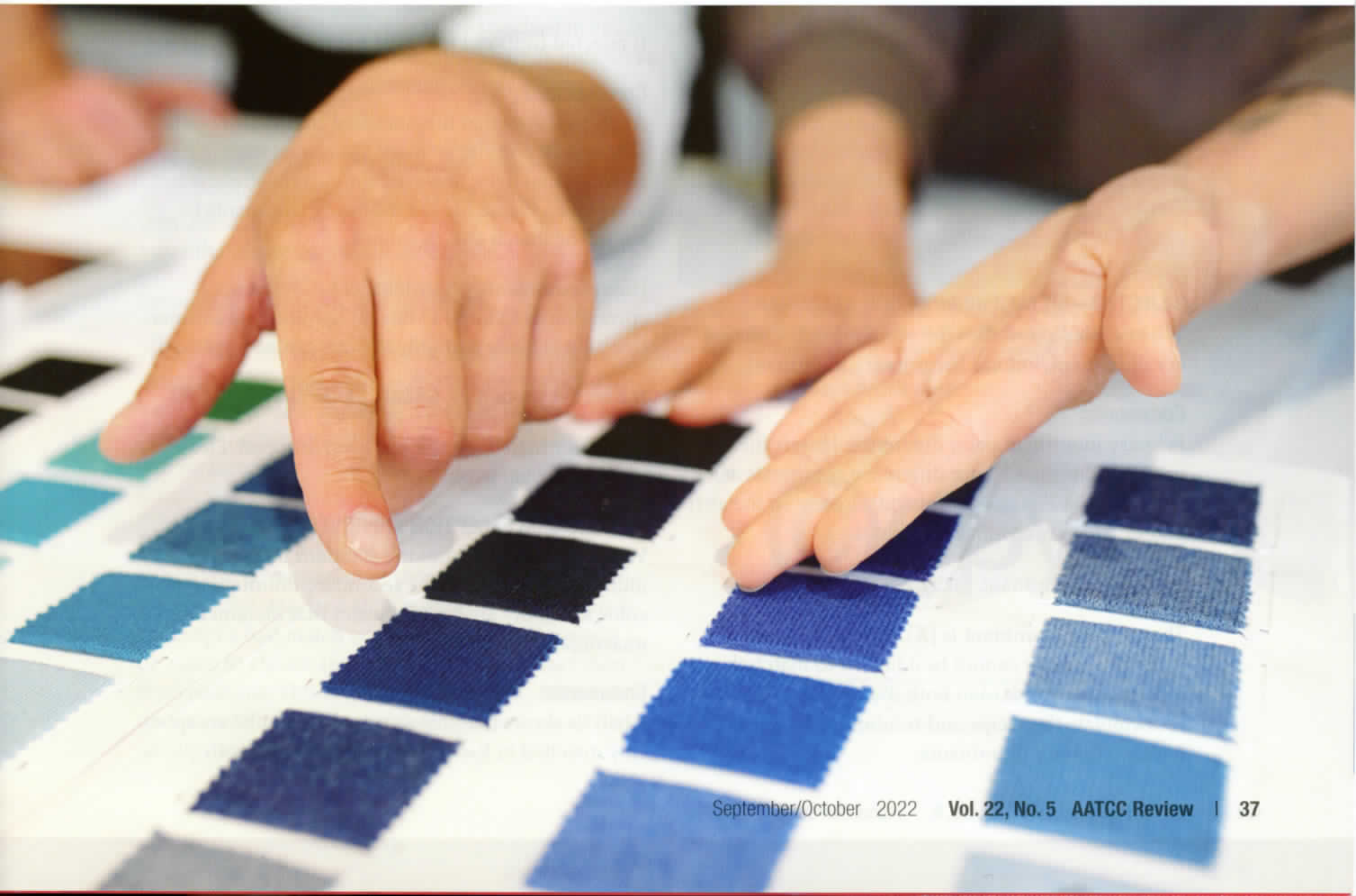
Conventional Rejections

REJECTED—OFFSHADE:

When a lab dip does not match the standard in either illuminant.

Comments:

[Primary illuminant] color difference: [Insert the primary illuminant color difference comments as prescribed in Figure 2, commenting only on the attributes that show significant difference].



[Secondary illuminant] color difference: [Insert the secondary illuminant color difference comments as prescribed in Figure 2, commenting only on the attributes that show significant difference].

Notes:
If in doubt, check your color feasibility report or look for existing color approvals in the same color on a fabric with the same fiber.

It is hard to spot metamerism in a bad color match. It is possible that a *corrected* off-shade lab dip might turn out to be metameric and must be reformulated—and, no, the Metamerism Index (MI) won't help (because it doesn't work).

REJECTED—METAMERISM:
When a lab dip matches the standard in the primary illuminant, but not the secondary illuminant.

Comments:
Primary illuminant: Okay.

Secondary illuminant color difference: [Insert the secondary illuminant color difference comments as prescribed in Figure 2, commenting only on the attributes that show significant difference].

The recipe used to make this submit cannot be adjusted to match the official color standard in both illuminants. Please re-formulate the recipe and resubmit a sample that matches in both illuminants.

Notes:
If in doubt, check your color feasibility report or look for existing color approvals in the same color on a fabric with the same fiber.

REJECTED—METAMERISM/WRONG ILLUMINANT:
When a lab dip matches the standard in the secondary illuminant, but not the primary illuminant.

Comments:
Primary illuminant color difference: [Insert the primary illuminant color difference comments as prescribed in Figure 2, commenting only on the attributes that show significant difference].

Secondary illuminant: Okay.

The primary illuminant is [X]. The recipe used to make this submit cannot be adjusted to match the official color standard in both illuminants. Please re-formulate the recipe and resubmit a sample that matches in both illuminants.

Feasibility Exceptions

This section is intended for use if your color standards provider issues feasibility information indicating if colors are matchable on different fiber types (and you chose to specify an unmatchable color standard anyway). If you do not have this information, evaluate as Best Can Do (BCD).

GAMUT EXCEPTION[6]:
If a lab dip does not match the standard in the primary illuminant (and the color feasibility analysis indicates that it is *not matchable* in the primary illuminant), then set it aside for visual review. Note that the color difference limitation will either be in Lightness or Chromaticity (or both). Hue can always be adjusted.

If accepted: **GAMUT EXCEPTION APPROVED**

Comments:
Analysis shows that this standard cannot be acceptably matched in the primary illuminant with conventional dyes, so this sample is accepted. Please use this **GAMUT EXCEPTION APPROVED** lab dip as the production standard and match it within tolerance using the exact same dyestuffs (adjusting concentrations to maintain shade).

If rejected (option 1): **GAMUT EXCEPTION REJECTED**

Comments:
Analysis shows that this standard cannot be acceptably matched in the primary illuminant with conventional dyes; however, the current shade is not acceptable. Please use the following comments to adjust the match and re-submit.

[Insert comments prioritizing color difference correction as follows: 1) hue, 2) lightness, 3) chromaticity—it is likely that only the hue can be improved].

If rejected (option 2): **GAMUT EXCEPTION DROPPED**

This color match request has been dropped. Please discontinue lab work.

METAMERISM EXCEPTION APPROVED:
When a lab dip matches the standard in the primary illuminant, but not in the secondary illuminant and color feasibility analysis indicates that metamerism is unavoidable on this substrate.

Comments:
Analysis shows that this standard cannot be acceptably matched in the secondary illuminant with

conventional dyes, so this sample is accepted as a match in the primary illuminant. Please use this **METAMERISM EXCEPTION APPROVED** lab dip as the production standard and match it within the official tolerances using the same dyestuffs (adjusting concentrations to maintain shade).

METAMERISM/WRONG ILLUMINANT EXCEPTION REJECTED:

When a lab dip matches the standard in the secondary illuminant, but not the primary illuminant, but color feasibility analysis indicates that metamerism is unavoidable on this substrate

Comments:

Primary illuminant color difference: [Insert the primary illuminant color difference comments as prescribed in Figure 2, commenting only on the attributes that show significant difference].

Analysis shows that this color standard cannot be acceptably matched in both illuminants with conventional dyes. Please adjust the recipe to match in the primary illuminant only and resubmit. Once matched in the primary illuminant, metamerism will be accepted.

OFFSHADE/METAMERISM EXCEPTION REJECTED:

When a lab dip does not match the standard in either illuminant, *and* the color feasibility analysis indicates that metamerism is unavoidable on this substrate.

Comments:

Primary illuminant color difference: [Insert the primary illuminant color difference comments as prescribed in Figure 2, commenting only on the attributes that show significant difference].

Secondary illuminant: Not applicable.

Analysis shows that this color standard cannot be acceptably matched in both illuminants with conventional dyes. Please adjust the recipe to match in the primary illuminant only and resubmit. Metamerism will be accepted.

Best Can Do's (BCD's)

When you have run out of time and the mill has not matched the standard, then a decision must be made to accept a bad match or drop the color. You might be asked to choose the "best one" when in fact there is no best one. This is a business decision, not a color decision. A method to sort through the dregs of bad lab dips will be covered later.

Yeah, But We Do It Differently

No doubt. Every brand is "special." In the next installment, we will review color myths that have somehow persisted to the present and explain why they are wrong. And probably the biggest myth of all is that the conventional lab dipping process is the best way to manage color. It is not. So, next time, we will talk about Repentance.

References/Notes

1. I said it back around 2015. I just made it up. It sounds kind of pithy, don't you think?
2. https://en.wikipedia.org/wiki/CIELAB_color_space
3. AATCC RA-36 is currently assessing DE2000 as a supplement to or replacement for CMC. However, CMC has a long track record of success in the industry.
4. If you set a DH^*_{ab}/S_H or Da*/Db* tolerance in addition to DE_{CMC} 2:1, then shame on you. You risk moving from Limbo directly to the Sixth Circle of Hell: Heresy
5. Yes, I have really seen those comments.
6. Gamut refers to all the colors that can be dyed on a given fabric. There are limits on how dark (lightness) and how bright (chromaticity) a fabric can be dyed. Hue is never limited, however. Gamut is dependent on dye class and fiber fineness.

Keith Hoover, president of Black Swan Textiles, (**www.blackswantextiles.com**), implements manufacturing-centric digital processes for color and fabric development. He has implemented digital color management programs for Ralph Lauren, Target, Lands' End, JCPenney, and Under Armour, ultimately leading to a process that eliminated lab dips altogether. At Under Armour, Hoover championed the UA Lighthouse, driving digitalization and advanced manufacturing processes to explore local-for-local sourcing. He has worked hands-on in mills worldwide and is a frequent AATCC presenter.