Color Matching for Pultruded Composites

Obstacles & Answers

By Glenn Barefoot

Figure 1. Glass rovings

The standard pultruded polyester flame retardant FRP shade is a dark gray which, to some pultruders, is known as slate gray. Applications may often be a different shade than the structural pultruded FRP members. The slate gray shade typically resists color changes when exposed to UV more than other pigmentations. Occasionally, customers request other shades for their applications such as beige (tan) or light gray. However, changing pigmentation for various structural applications is an extremely involved process, and various pitfalls could occur.

Pultruded profiles have the capability of being produced in multiple shades, although these shades will not exactly duplicate painted wood, painted metal or natural wood. Also, FRP pultruded profiles are composite

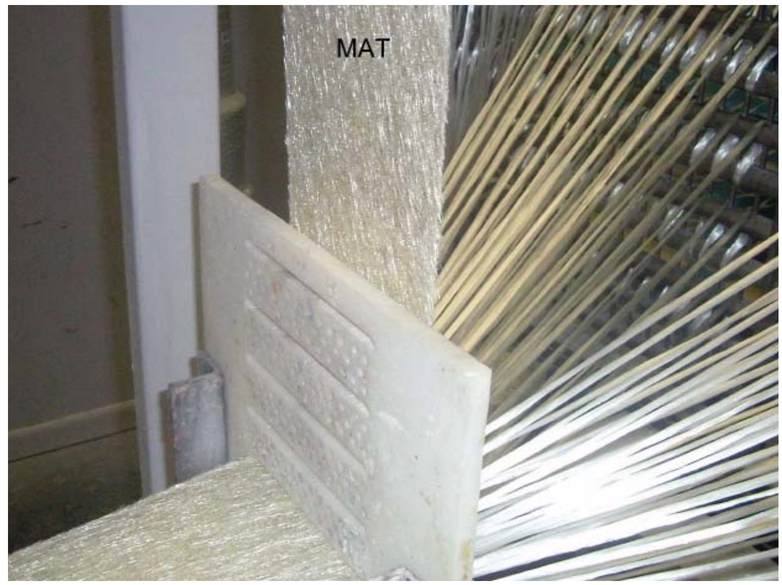

Figure 2. Continuous strand mat

materials and the presence of reinforcement will alter the color perception to the observer when compared to unreinforced thermoplastics or painted products. The cut cross section of the pultruded structural member will also appear different because pultruded FRP products are not uniform. Color matching is a service offered by pultruders to their customers; however, this process requires careful technique.

Color Matching

It is necessary to review FRP pultrusion composites in general to have a better understanding of some of the potential issues with color matching. The pultruded profile in structural applications is composed of the following:

1. Glass rovings, which are the longitudinal reinforcements. These are rarely on the surface of a pultruded FRP profile except in applications such as all roving rods and bars. See figure 1.
2. Glass mat, which provides the off axis reinforcement. There are different grades of continuous strand mat, each of which has a specific function in the composite and each of which can impart a different background shade for color matching. Some mats are more white than others which is related to the binder on the mat. Some pultruders will use stitched reinforcements for the off axis reinforcements, but stitched reinforcements can have shear issues. Stitched reinforcements on the surface can present a color perception issue with surface smoothness. Figure 2 is an example of continuous strand mat.
3. Surfacing veil, a synthetic polyester which protects the FRP profile against fiber blooming and corrosive attack. Different veils can impact the background on which the color is matched. The impact of veil can affect the perception of the depth of the color and the texture of the surface. The absence of veil in a portion of the part can cause a significant shade difference. Figure 3 is an example of veil.
4. Polymer resin, which can be polyester or vinyl ester in FRP structural applications. There are different types of polyester resins that can be used. The resin can impact the background for the color match, especially with the change from polyester to vinyl ester resins. Vinyl

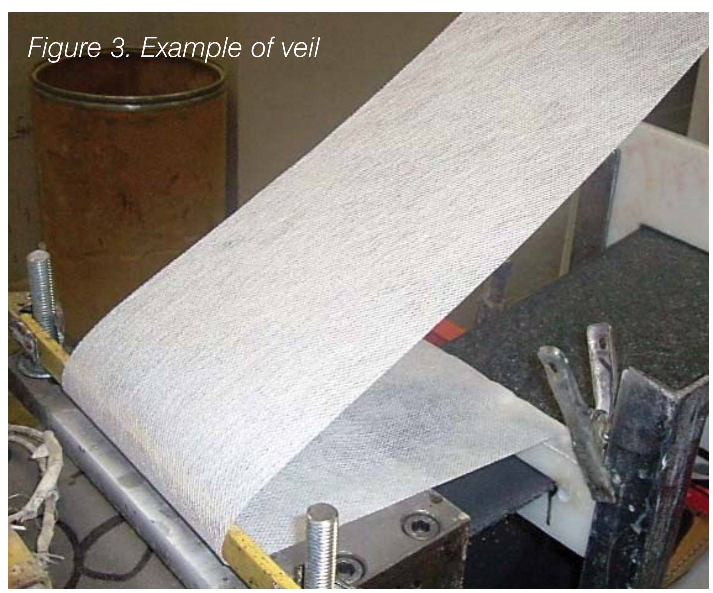

Figure 3. Example of veil

ester resins occasionally contain an inhibitor package which makes the color match more difficult. Both of these resins contain styrene. Using epoxy resins present different color matching problems.
5. Fillers, which can be clay, calcium carbonate, or ATH (aluminum tryihydrate). Fillers provide a background shade for the color match and can impact weathering performance. Typically, calcium carbonate has the worst weathering performance.
6. Halogen flame retardant system, which can substantially impact the shade. The halogen system requires antimony oxide, and functions as a white pigment in the pultruded FRP composite.
7. Pigments, which are added to the resin mix to impart color to the FRP structural shape. The normal shade of the pultruded profile without pigment would be off white. The quantity of pigment often impacts the final perceived shade.

Different combinations of these ingredients, especially reinforcements, will be used for the different structural shapes due to the normal function of these shapes. For example, a clip angle must perform differently than a tension member and will contain more continuous strand mat or other off axis reinforcement. Establishing a color match for a combination of FRP pultruded profiles is more difficult than for just one profile; structural applications typically involve multiple profiles. Some shades will resist the changes in the reinforcements better than other shades.

Some of the more dominant composite factors in the color match follow.

A. The use of the halogen flame retardant system will make the shade, using the same pigment, lighter than not using the halogen flame retardant system. This is because of the presence of antimony oxide which is always used with a halogen.
B. The use of certain resins such as a low profile resin can dramatically alter the color match. Low profile resins are not often used in structural applications but could impart a strong white background to the composite. Low profile resins are used when cosmetics are an issue. However, vinyl ester resins will also give a different shade than polyester resins, and vinyl ester resins can react differently with the pigments than polyester resin.
C. The calcium carbonate filler will be lighter in the composite than clay.
D. A-glass surfacing mat will be lighter than E-glass surfacing mat.

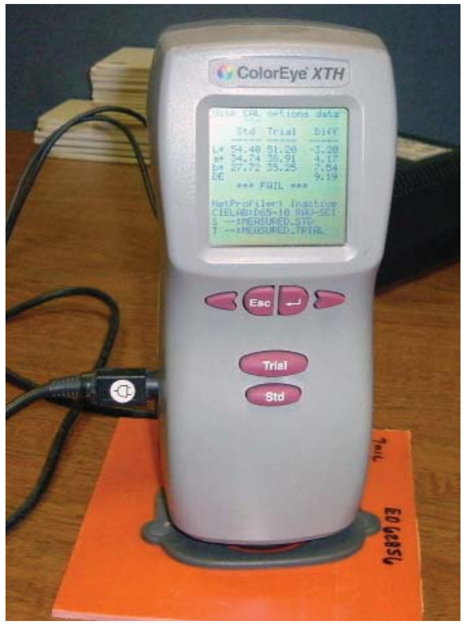

Figure 4. Color Eye XTH color matching equipment

E. Thicker surfacing veils will have a different shade than thinner surfacing veils because thicker veils absorb more resin. Thicker surfacing veils can improve the corrosion protection.
F. Higher glass contents may give a different perception of the color than lower glass contents due to fiber "show through." This is when the high fiber loading pushes against the surfacing veil causing a whitish appearance on the surface.
G. The level of pigment can impact the color match because there is more "hiding" power with higher loads of pigment. Higher pigment loads may negatively impact other properties.
H. Different surfacing veils have different textures in addition to different thicknesses. The different textures reflect light differently.

The typical color match, especially when a number of different FRP profiles are involved, is known as a "ballpark" match. This is the situation when a nominal shade match is acceptable but permitted to vary from nominal in the normal processing of the different shapes. This permitted variation, for example, will not be radical such as changing beige into dark brown. The nominal shade in a "ballpark" color match need not be the exact shade requested but only one approved by the customer as a nominal.

The other color match is known as "almost exact" and is used when the customer wants a very tight approximation to the target shade and tightly held within

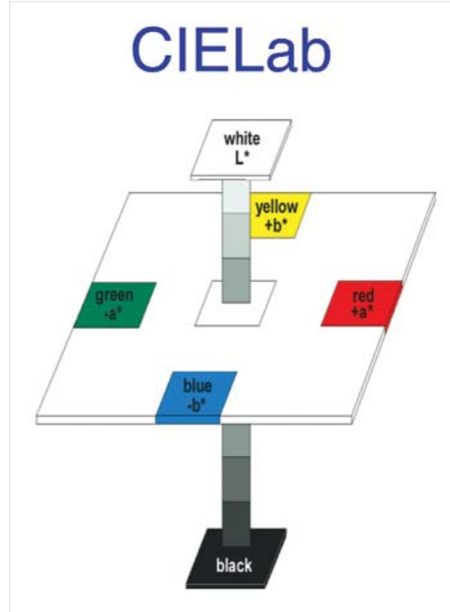

Figure 5. CIE Lab color scale

the process. This "almost exact" color match is very expensive to make and maintain in normal production especially when multiple pultruded shapes are involved. An "exact" color match is probably not possible if this match is to be made against paint chips or processes other than thermoset FRP pultrusion.

The typical color match process contains five steps:

1. The customer supplies a reference standard which may be a Pantone® system, Federal Standard 595, etc. The customer may also supply a sample piece made from another process. This expedites the process rather than just a request for some shade of red, for example. The customer should have some objective for the final shade.
2. The composite, including the choice of resin running the pultruded shape(s), must be determined. This is the first decision for the color match. The synthetic veil must also be selected.
3. A sample pigment is obtained from a pigment supplier based on steps one and two. It may take two to three weeks to receive the pigment sample unless there is a special raw material required for the shade match.
4. A lab trial is made and the sample submitted to the customer for approval. The scheduling of the lab pultruder is made consistent with other R&D priorities and the scheduled receipt of the sample pigment.

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("Color Matching..." from p. 40)

5. Steps three and four are repeated until a satisfactory match is obtained. A satisfactory match is signified by a customer approval.

The color match becomes significantly more complicated if additional lab trials are required to establish a projected color range as with an "almost exact" color match. A one or two day lab trial can become one or two weeks. Ultimately, a sample of the approved color match is added to the formal quality system to act as a reference for production runs with a duplicate sample supplied to the customer. The customer could require formal color measurement instrumentation to function for quality assurance purposes. However, this seldom occurs.

Color Measurement

A number of color measurement references, in addition to information which can be found on the internet, follows. There are three components involved in the perception of color. First is the light source which supplies the energy to view the color. Different light sources have different components of the electromagnetic spectrum which will change the reflection from the object. Indoor fluorescent lighting is different than sunlight. No one can observe color in the dark; some light source is required.

Second, the object modifies the energy from the light source. Light is energy. The different colors in the perceived color from the light source can reflect differently. A red object reflects the red wavelengths of light and absorbs all of the other wavelengths. A bluish red object reflects light differently than a yellowish red object. It is the reflected light that causes an object to appear red. Surface roughness can change the scattering of the reflected light and change the color perception.

Finally, the way in which the eye and brain perceive color and make decisions on the observations varies from person to person. Different individuals' eyes will function differently; for example, some people are color blind.

Color measurement equipment can be used to obtain standardization in the color measurement. Typically, however, there is an almost total reliance for shade acceptability on a human observer both at the supplier and customer level, using local light sources which may be different.

One version of color matching equipment is the Color Eye XTH which is shown in Figure 4. This uses the CIE Lab color scale which defines the color space in terms of 3 parameters (See Figure 5). The reference for the parameters is from the International Commission on Illumination.

L: This color space parameter measures the black to white aspect of the shade; higher "L" values are whiter.

a: This color space parameter measures the green to red aspect of the shade; higher "a" values are more red.

b: This color space parameter measures the blue to yellow aspect of the shade; higher "b" values are more yellow.

While the color match approval process between the supplier of the pultruded product and the customer is typically a visual decision, equipment such as the Color Eye XTH can be used to mathematically describe changes. This is useful for the Pultruder and Pigment Supplier in deter-

("Color Matching..." continues on p. 62)

	INITIAL (Photo No. 6)			1000-HRS OF WEATHERING (Photo No. 7)			
	L	a	b	L	a	b	¢E
BLACK	28.01	0.21	-1.37	28.76	-0.39	-0.42	1.35
SLATE GRAY	36.86	-1.07	-0.68	40.40	-1.43	0.31	3.69
HAZE GRAY	59.44	-4.65	-5.11	63.10	-4.24	9.28	14.85
LIGHT GRAY	77.03	1.84	2.18	75.94	-0.22	15.67	13.69
WHITE	86.87	-2.35	1.36	83.76	-1.08	17.11	16.10
BEIGE	75.77	2.86	11.02	72.98	4.03	25.02	14.32

Figure 6. Samples prior to weathering

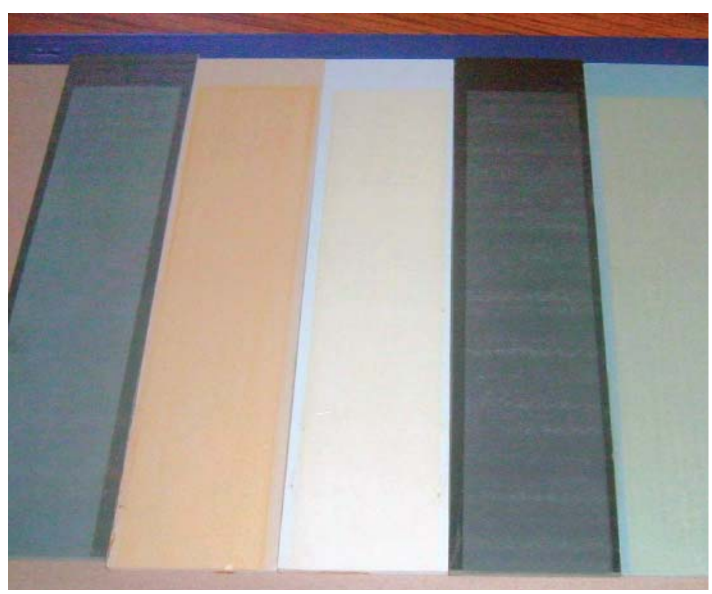

Figure 7. Weathered samples

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mining the change in pigmentation required to match the desired shade. The change in shade can be mathematically measured as:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where:
ΔL = the change in the "L" aspect of the shade (black to white) from one sample to the other (L1 - L2).
Δa = the change in the "a" aspect of the shade (greed to red) from one sample to the other (a1 - a2).
Δb = the change in the "b" aspect of the shade (blue to yellow) from one sample to the other (b1 - b2).

The ΔE equation is a mathematical construction whose only value can be determined by comparing actual shades. Almost no customers use an "ΔE" specification; the whole system relies on visual samples. The "ΔE" concept is very useful in matching shades.

Weathering

Matching the shade to the customer's satisfaction is not the only issue with pultruded structural shapes. Structural shapes that will be used in the sunlight typically will evolve in shade and some of the evolution may not be satisfactory to the customer especially if the color evolution occurs unevenly over the structure. The uneven change in shade will occur if one part of the structure is located in the sun and the other in the shade. There is also the possibility of a north-south vs. east-west variation. The shade evolution in FRP is related to the choice of resin, the choice of pigment, choice of filler and the presence of styrene. The chart on page 59 gives a mathematical presentation of the same color samples in terms of L, a, b values that have been recently weathered (Figures 6 and 7). The slate gray and black shades which are dark have exhibited less shade evolution than some of the other shades tested after 1000-hrs in a QUV Weatherometer. The weathering was performed in accordance with ANSI A14.5.

Not all of the above systems are in polyester resins; the beige is a vinyl ester system. The actual change in the shade will occur at a much slower rate than that projected by 1000-hours in a Lab Weatherometer. The haze gray parts made a dramatic shift in that the weathered parts appeared green rather than gray. Note, the mathematical "ΔE" calculation does not really reveal the dramatic shift in overall shade for the haze gray. This is one reason for not using "ΔE" as a specification but only as a matching tool. The white and light gray parts yellowed while the beige parts became darker. Not all light grays behave equally. The black and slate gray parts became lighter but were more stable than the other shades.

Figure 6 is a picture of the samples prior to weathering while Figure 7 displays the weathered samples. The edges of the samples in Figure 7 are where the samples were not exposed to the weathering conditions and give an illustration of the change.

Historically, the dark gray shade in pultruded FRP replaced the haze gray shade because of its improved weathering performance and appears to be a very robust shade. Pultruded FRP fading will be different than other forms of plastic or painted wood where light shades may be more stable. This may be a paradigm shift for structural shape customers in selecting the shade.

Shade fastness can be enhanced by the use of specialized polyester resins, additives choice and improved pigments. All of these adjustments substantially increase the cost of the structural pultruded component. The color match for the initial erection of the structure may be more cosmetically acceptable with a specialized shade but the long-term weathering performance may make the choice of a more stable shade such as dark gray more acceptable. The structural shape customer must perform a cost/benefit analysis to justify the increased cost for light shades compared to enhanced weathering performance of darker shades for their structural application. While the technology to make light shades exist with pultruders and the ability to define the issues with lighter shades is available, the overall shade choice is ultimately a customer decision. CM

References

1. Supplement No. 2 to CIE Publication No. 15, Colorimetey.
2. ASTM D2244: "Standard Practice for Calculation of Color Tolerances and Color Differences from instrumentally measured Color Coordinates.
3. ASTM E284: "Standard Terminology of Appearance."
4. ASTM E308: "Standard Practice for Computing the Colors of Objects by using the CIE System."
5. ANSI A14.5-2000: "American National Standard for Ladders - Portable Reinforced Plastic - Safety Requirements."

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("In-Frastructure" from p. 60)

customers is the technology's ability to stop the composite cure reaction at any point in the cure cycle. This means manufacturers can take a large structure and break it down into smaller components with uncured sections. Then restart the curing cycle and co-cure, join and bond one composite to another to create very large, single structures.

Called melding, this Quickstep capability allows one component to literally "fuse" into another to form large components without the need for secondary bonds. The integrated part exhibits no physical differences or separation of surfaces. In addition to eliminating the need for fasteners or adhesive bonds - which can exhibit deficiencies or fail under certain temperature or moisture conditions – melding could also allow a wing component to be constructed in the mold from the outside in, with exact aerodynamic tolerances across the wing.

The ability to introduce new and innovative advanced materials technologies to manufacturers not only expands composite commercialization efforts but helps to equip companies with the tools they need to compete in a global economy. The incubation of unique manufacturing methods also helps to advance the composite industry as new ways of producing parts from advanced materials is developed, demonstrated and effectively applied to a growing range of markets. One of the primary goals of the National Composite Center is to initiate and support new advanced materials and process initiatives. CM

For more information about Quickstep and other advanced processing technologies contact Harry Couch, Senior Technical Consultant for the National Composite Center, at hcouch@compositecenter.org*, or contact NCC Program Manager Alan Fatz at* afatz@compositecenter.org.