Color Measurement:
Methods and Effects of Sample Presentation

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INTRODUCTION

Typically the objective of instrumental color measurement is to obtain repeatable numeric values that correspond to visual assessment. The method of sample preparation, sample presentation and instrument geometry used for measurement can effect both correlation of the measurement to visual assessment and precision of the measurement. There are a variety of techniques that can be used in handling yarn samples so that the most valid and repeatable measurements are achieved.

SAMPLE PREPARATION

Yarn can be measured by using one of several sample preparation methods. One method for both bench top and portable color measurement instruments is to measure the cone or package directly. In this case no sample preparation is required, however a positioning device should be used at the instrument measuring port. This method will be discussed further under Sample Presentation.

A second method is to prepare a wad of randomly oriented yarn large enough so that no light can penetrate through it and place it inside a container with a window in the bottom. Place a specified weight on top of the yarn and measure through the glass. A more consistent method would be to use a **compression cell** in which a specified amount of yarn is placed in the container and a specified pressure is applied to a piston to compresses the yarn. Using a consistent amount of weight on a fixed weight of yarn or applying a consistent amount of pressure to the piston of the compression cell is important since a consistent yarn density is needed for reproducible measurements. Since the yarn is being measured through a glass interface, the instrument will measure the sample as a duller color than it actually is. Methods of compensating for this will be discussed in Sample Presentation.

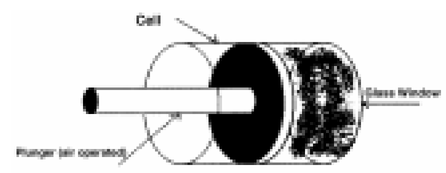

Fig.1 *Compression Cell*

Another method that often gives measurements that correlate well with visual assessment is to wind the yarn closely and parallel on a card to a sufficient thickness to prevent show-through. Commercial **card winders** are available for this purpose to ensure consistent tension and a constant number of windings. Ensure that there is not too much tension on the yarn so that it does not stretch. The card should have enough stiffness that it does not bend when the yarn is wound on it. If the card is bent when the yarn is wound, the front side will give a different measurement than will the back. The card can be made of cardboard, plastic or metal and should be a uniform, neutral color. Ensure that it does not contain fluorescing agents.

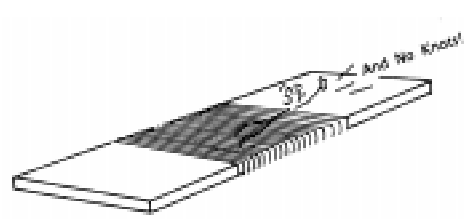

Fig.2 *Card Wound*

Skeins of yarn can be prepared by clamping or taping one end to the edge of a rigid backing material, stretching the skein across the form keeping the strands of yarn parallel and clamping or taping to the other edge of the form. Commercially available **skein holders** can be used for this purpose.

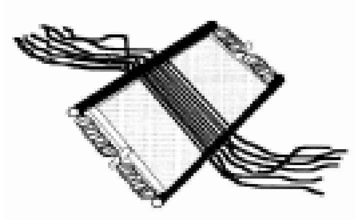

Fig.3 *Skein Holder*

The yarn can also be knitted into a sock for measurement. Since a knitted sock is flat, it can be measured without a support or compression device. A disadvantage is that knits tend to easily stretch which causes the opacity of the fabric to vary. This is because various tensions will cause the holes in the fabric to change size, and allow more or less light to pass through. When this occurs, the measurement instrument will "see" more or less of the sample backing material and will give varying measurement results. When necessary, to increase the opacity of the sample, the knitted sock can be folded such that multiple layers are produced. The number of layers can be increased until the reading does not change significantly. An example is shown in Table I. However as can happen with thicker socks, the sample may "pillow" or protrude into the measurement port of the instrument. In addition, Knitted socks may have distinct lines or textures which can effect measurement repeatability. Averaging techniques can be used to minimize this problem and will be discussed later in this paper.

Table I: Example of Knitted Sock Readings as Related to Number of Layers
(Average of 4 Readings, White Backing)

Color Scale	2 Layers	4 Layers	8 Layers
L*	52.11	50.78	50.70
a*	4.14	3.84	3.80
b*	11.28	10.75	10.74

SAMPLE PRESENTATION

The method of sample presentation to the instrument can effect the measurement results in terms of both the measurement value obtained as well as the repeatability of the measurement. In the case of yarn measurement the primary areas of concern are consistency of sample presentation, sample pillowing and sample directionality.

If a cone or package of yarn is being measured directly (with either a bench top or portable instrument), it is very important that a positioning device be used to reproducibly position the sample at the instrument measuring port. This is because the sample is curved and does not lie flat on the sample port and thus does not completely fill the port. Any position change by rocking the cone slightly in either direction would cause a reading change. By using a cradle shaped positioning device at the instrument sample port, having a radius that is the same as the cone or package, will securely and reproducibly position the sample for measurement.

Table II: Example Repeatability Data For Yarn Cone Measurement
(Standard Deviation of 20 Readings)

Color Scale	Without Positioning Device	With Positioning Device
L*	0.20	0.07
a*	0.06	0.07
b*	0.05	0.07

When measuring yarn wound on a card or skein holder, measuring a knitted sock of the yarn sample and in some cases measuring the yarn cone or package, sample pillowing may occur. This occurs when the sample is so thick and soft that it protrudes into the instrument sample port causing poor measurement repeatability. The magnitude of this problem depends on the optical characteristics of the instrument being used as well as the sample being measured. When pillowing is a problem the sample can be measured by pressing it against the instrument equipped with a glass sample port. This will typically give more repeatable results. As previously mentioned, since the yarn is being measured through a glass interface, the instrument will measure the sample as a duller color than it actually is. This is because glass causes low reflectance values to be higher, and high reflectance values to be lower. For quality control applications when the color difference is being measured and the "standard" was measured the same way, the error introduced by the glass is not highly important. However accuracy can be improved by calibrating the instrument through glass, or when a higher absolute accuracy of measurement is desired, a glass correction can be used. This equation is for sphere (d/8°) geometry instrumentation with the specular component included.

$$\textbf{Glass Correction Factor} = R\lambda = (R_g + T_c - 1.0)/(R_g + T_c - 1.0 - (T_d * R_g) + T_d)$$

Where:

R_g = measured %R behind glass

T_c = transmittance of glass to collimated light (normally equal to 0.92 for glass with a refractive index of 1.50 and no absorption)

T_d = transmittance of glass to diffuse light (nominally equal to 0.87 for glass as described above

$R\lambda$ = corrected % reflectance with no glass

Table III: Example Readings Behind Glass
(Knitted Sock, Average of 4 Readings, White Backing)

Scale	Without Glass	No Glass Correction	With Glass Correction
L*	51.41	48.89	50.83

Most yarn samples will have some level of directionality. Directionality is when the sample has distinct lines or texture that when measured at different angles of rotation, yield varying results. Averaging multiple placements of the sample at various angles of rotation will minimize the effect of directionality.

SAMPLE AVERAGING

Averaging multiple readings of samples can compensate for variations in pillowing, directionality, nonuniformity as well as other variables that occur when measuring yarn. Ideally, multiple preparations of the sample will be measured and averaged. However in production environments the ideal approach is not always followed. As a minimum, one preparation of the same sample should be measured and averaged taking three or four readings for each measurement. The sample should be removed from the instrument port, rotated and replaced to the port for each reading. For card wound and knitted samples it is not suitable to simply place the sample on the port and rotate the sample without removing it as there will be no averaging of the variation in pillowing that occurs with placement. Leaving the sample on the port and rotating it may actually screw the sample further into the instrument port.

The best approach is to take and average several readings of the sample for multiple preparations or at multiple positions and at multiple angles of rotation. The appropriate sampling number for each significantly different yarn type should be determined. One approach is to determine a statistically-sound sampling number. This can be done by first selecting a representative sample of the product.

1 Measure the sample at various positions or for multiple preparations. At least twelve readings should be made. These readings need to be evenly apportioned between sample orientations of 0°, 90°, 180°, and 270°. Determine the color difference for each of the scale values (for example DL*, Da*, Db*). The color difference values are determined by using the average reading as the "stan dard" and the individual readings as the "sample" data.

2 Calculate the Mean ($\overline{X}$) for each of the scale values. The mean is the average of the color differ ence readings taken on the sample as compared to the "standard". To determine, add together the color difference values for all readings and divide by the total number of readings. This will deter mine the center point around which all the readings are grouped.

The equation for the mean is:

$$\overline{X} = \frac{1}{N_a}\left(\sum_{i=1}^{N_a} X_i\right)$$

where, X = mean of N_a readings

N_a = total number of readings

X_i = ith reading for each color difference scale

3 Calculate the Standard Deviation (S). The standard deviation of the color difference readings is used to determine how closely grouped the readings are about the mean.

The equation for standard deviation is:

$$S = \sqrt{\left[\frac{\sum_{i=1}^{N_a}\left(X_i - \overline{X}\right)^2}{N_a - 1}\right]}$$

where, S = standard deviation

N_a = total number of readings

$\overline{X}$ = mean of N_a readings

X_i = ith reading

4 Calculate the Tolerance Range and the Standard Error Goal. The tolerance range is the upper tolerance minus the lower tolerance for each of the color difference parameters. Multiply the range by 0.1 and compare this to 0.2 scale units. The larger of 0.2 scale units or the product of the tolerance range multiplied by 0.1 will be equal to the Standard Error Goal ($S_{e,g}$).

5 Determine the Calculated Sampling Number. The calculated sampling number is calculated using the following formula for each of the color difference parameters.

$$N_C = \left(\frac{S}{S_{e,g}}\right)^2$$

where, N_C =calculated sampling number
S = standard deviation
$S_{e,g}$ = standard error goal

6 Determine the sampling number. The minimum sample readings to be made is the largest of the three color scale values rounded to a whole number that is divisible by 4.

GEOMETRY

Color measurement instrument geometry generally falls into one of two categories, sphere (d/8°) geometry or 45°/0°geometry. For sphere instruments, also called diffuse, the source light is projected into the sphere and is diffused by the sphere coating. This diffused light is incident on the sample and the light reflected at 8° is measured. Typically sphere instruments include the specular component in the measurement and have a 1" sample port. For 45°/0° geometry instruments the source light illuminates the sample at 45° and the light reflected at 0°(normal to the surface) is measured. The 45°/0° geometry instruments exclude the specular component and frequently have measurement ports that are at least 2" in diameter giving a better optical average of the sample. The following gives the recommended instrument geometry for the various yarn sample preparation methods.

Cone or Package	45°/0° geometry
Compressed Against Glass	Sphere or 45°/0° geometry
Card Wound	Sphere or 45°/0° geometry
Skein Holder	Sphere or 45°/0° geometry
Knitted Sock	45°/0° best, Sphere suitable

SUMMARY

When measuring yarn it is important to select samples appropriately, use an established measurement method, and handle the sample in a consistent manner.

1. Choose samples that are representative of the product
2. Prepare samples in the same manner each time
3. Present the samples to the instrument in a repeatable manner
4. When possible make multiple preparations of the sample and average results
5. Remember that the measured results depend on the preparation and presentation of the sample as well as the instrument geometry

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(3) Test Method SAE J1545, Instrumental Color Difference Measurement for Exterior Finishes, Textiles and Colored Trim