Final Report for Definition of Orange for Lifesaving Equipment

UL Project Number 4788671356

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333 Pfingsten Rd
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The report defines a range of orange colors for USCG approved lifesaving appliances per 46 CFR Part 160 with references to color chips FED-STD 595C to visually compare the color of lifesaving appliances. FED-STD 595C was withdrawn in 2015 and replaced by SAE AMS STD 595. The colors were measured in a ColorFlex spectrophotometer CIE chromaticity coordinates and compared with ISO 12402-7, Personal Flotation Devices – Part 7: Materials and Components – Safety Requirements and Test Methods (ISO 12402-7) clause 4.3.3. CIE chromaticity color coordinates were determined for the "orange" colors referenced by the CFR and various other color samples submitted by the USCG. The CIE coordinates for the reference color samples and USCG supplied samples were plotted to identify alignment or conflicts with the "orange" chromaticity coordinates defined in ISO 12402-7 clause 4.3.3 Tables 3 and 4. Based on the findings detailed in the report, a range of acceptable orange colors for lifesaving appliances was developed as a feasible replacement to the current reference to FED-STD 595C in the CFR for defining "orange".

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US Coast Guard, lifesaving equipment, International Orange, PFD, lifejacket, liferaft, lifeboat, buoyant apparatus, lifering, ring buoy,chromaticity coordinates, CIE, ISO 12402, SOLAS, LSA Code, fluorescent orange, fluorescent yellow, fluorescent red, orange-red, reddish-orange, Munsell red, indian orange, fabric color, textile color, weathering, spectrophotometer, Q specs, conspicuity, FED-STD 595C, AMS STD 595, 46 CFR 160

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ABSTRACT

The United State Coast Guard (USCG) currently defines acceptable orange colors for lifesaving appliances within various subparts of Title 46 of the United States Code of Federal Regulations (CFR) Part 160. To determine acceptability, the CFR references color chips contained in Federal Standard (FED-STD) 595C that are used to visually compare the color of the outer material for a lifesaving appliance. FED-STD 595C was withdrawn in 2015 and replaced by Society of Automotive Engineers (SAE) AMS STD 595. Utilizing a ColorFlex spectrophotometer by Hunter Labs for conducting color chromaticity testing in accordance with ISO 12402-7, Personal Flotation Devices – Part 7: Materials and Components – Safety Requirements and Test Methods (ISO 12402-7) clause 4.3.3, the CIE (International Commission on Illumination) chromaticity color coordinates were determined for the "orange" colors referenced by the CFR and various color samples submitted by the USCG. The CIE coordinates for the reference color samples and USCG supplied samples were plotted to identify alignment or conflicts with the "orange" chromaticity coordinates defined in ISO 12402-7 clause 4.3.3 Tables 3 and 4. Based on the findings detailed in this report, referring to the CIE coordinates that define a polygon that encloses acceptable orange colors for lifesaving appliances is a feasible replacement to the current reference to FED-STD 595C in the CFR for defining "orange".

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INTRODUCTION

To replace the current reference to Federal Standard (FED-STD) 595C within various subparts of Title 46 U.S. Code of Federal Regulations (CFR) Part 160 for Vivid Reddish Orange/International Orange and Indian Orange, the United State Coast Guard (USCG) contracted UL LLC (UL) to define acceptable "orange" colors for the approval of lifesaving appliances.

The Commercial Regulations & Standards Directorate (CG-5PS) of the USCG is considering referring to the orange colors defined by ISO 12402-7, Personal Flotation Devices – Part 7: Materials and Components, clause 4.3.3, Tables 3 and 4 which detail color chromaticity coordinates of polygons that encompass colors in the range of yellow to red on the 1931 CIE chromaticity diagram. The CIE chromaticity coordinate system is used for identifying any color in the spectrum by assigning a set of *x* and *y* coordinates onto the two-dimensional CIE chromaticity diagram.

Samples of the Vivid Reddish Orange/International Orange and Indian Orange colors referenced within the CFR and twenty color samples provided by the USCG were tested to the requirements of ISO 12402-7 clause 4.3.3.2 in the as-received condition to determine the *x* and *y* chromaticity coordinates of each sample. The objective of this project is to plot the color chromaticity coordinates onto a CIE coordinate plane to define polygons that encompass the colors and compare the data to polygons defined by ISO 12402-7 Tables 3 and 4, and to report observations, if any, that effect color chromaticity coordinates based on the different substrate materials.

REFERENCE COLOR SAMPLES:

Sample ID	Color and Material
R1	Vivid Reddish Orange/International Orange, FED-STD-595C No. 12197, color card
R2A	Indian Orange, FED-STD-595C No. 70072, woven fabric swatch, uncoated side
R2B	Indian Orange, FED-STD-595C No. 70072, woven fabric swatch, coated side

USCG COLOR SAMPLES:

Samples submitted by the USCG met the following specifications:

Minimum: 3 inches long by 3 inches wide

Maximum: 5 inches long by 5 inches wide

Thickness: No greater than 4 inches thick and free of perforations or holes.

IMPORTANT NOTE: Official color names and material composition for the USCG samples were not provided for this project. The color descriptions below were assigned by UL from visual perception of the samples before testing.

Sample ID	Color and Material	Date Sample Received at UL LLC
0003A	Orange Vinyl dipped PVC foam	2019-01-03
0003B	Orange Vinyl dipped PVC foam	2019-01-03
0007A	Orange Fabric-laminated foam	2019-01-03
0007B	Orange Fabric-laminated foam	2019-01-03
0012	Orange Woven fabric	2019-01-03
0015	Orange Woven fabric	2019-01-03
0017A	Orange Woven fabric, uncoated side	2019-01-03
0017B	Orange Woven fabric, coated side	2019-01-03

USCG COLOR SAMPLES - continued:

Sample ID	Color and Material	Date Sample Received at UL LLC
0019A	Reddish-Orange Woven fabric, uncoated side	2019-01-03
0019B	Reddish-Orange Woven fabric, coated side	2019-01-03
0020	Red Tile	2019-01-03
0021	Orange Tile	2019-01-03
0022	Yellow-Orange Tile	2019-01-03
0025	Orange Tile	2019-01-03
0026	Red Fabric-laminated foam	2019-01-03
0027A	Yellow Woven fabric (FA1723-45)	2019-01-03
0027B	Yellow Woven fabric (FA1723-45)	2019-01-03
0028A	Yellow Woven fabric (FA1791-193)	2019-01-03
0028B	Yellow Woven fabric (FA1791-193)	2019-01-03
0032A1	Reddish-Orange Woven fabric (FA1281-46), uncoated side	2019-01-03
0032A2	Reddish-Orange Woven fabric (FA1281-46), coated side	2019-01-03
0032B1	Reddish-Orange Woven fabric (FA1281-46), uncoated side	2019-01-03
0032B2	Reddish-Orange Woven fabric (FA1281-46), coated side	2019-01-03
0033	Orange Tile	2019-01-03
0034	Orange Vinyl dipped fabric	2019-01-03

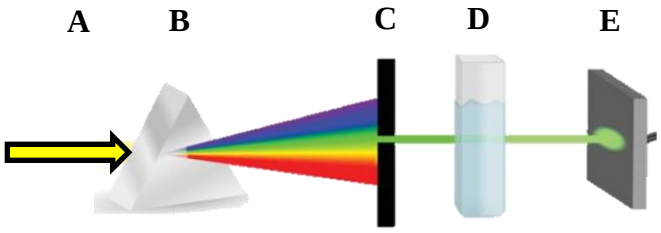
USCG COLOR SAMPLES - continued:

Sample ID	Color and Material	Date Sample Received at UL LLC
0001A	Orange Vinyl dipped PVC foam	2019-02-04
0001B	Orange Vinyl dipped PVC foam	2019-02-04
0004A	Orange Hard-shell Ring Buoy Section	2019-02-04
0004B	Orange Hard-shell Ring Buoy Section	2019-02-04
0005A	Red Soft-shell Ring Buoy Section	2019-02-04
0005B	Red Soft-shell Ring Buoy Section	2019-02-04
0006A	Orange Soft-shell Ring Buoy Section	2019-02-04
0006B	Orange Soft-shell Ring Buoy Section	2019-02-04

EQUIPMENT

UL utilized a ColorFlex spectrophotometer by Hunter Labs for conducting color chromaticity evaluation, as shown in Figure 1. A spectrophotometer is an instrument designed for physical sample analysis via full spectrum color measurement. National Institute of Standards and Technology (NIST), defines the spectrum of color in the ultraviolet, visible, and near-infrared spectral regions (250 nm to 2500 nm) (NIST, 2009). By providing wavelength-by-wavelength spectral analysis of a sample's reflectance, absorbance, or transmittance properties, a spectrophotometer produces precise data beyond that observable by the human eye. This instrument is widely used in the textile industry as it is one of few designs that is able to see color in the same manner as the human eye. Figure 2 illustrates how a spectrophotometer works internally.

Figure 1 - ColorFlex Spectrophotometer by Hunter Labs



Key:

A. **Light source**—The light source provides wavelengths of light at great intensity that span from near infrared to within the ultraviolet range, including the visible light spectrum.

B. **Diffraction grating or prism**—The diffraction grating separates the light source into specific portions of spectrum. When you adjust the variable wavelength selector, you change the position of the diffraction grating so different wavelengths of light are directed towards the sample compartment containing the analyte.

C. **Variable wavelength selector**—Found on the exterior of the instrument, a variable wavelength selector allows the instrument to essentially filter the light, transmitting light only at a specific wavelength or range of wavelengths of interest.

D. **Sample compartment**—The sample compartment houses the cuvette (a transparent tube designed to hold samples for spectroscopic experiments), which contains the analyte. Selected wavelengths of light pass through the analyte for detection by a photodetector.

E. **Photodetector**—Light passed through the analyte strikes a photodetector composed of a semiconducting material. Electrons in this material are excited proportionally to the wavelength of light striking the photodetector. Increasing the light intensity generates more electrons, translating to a higher current that is received by the signal processor.

Figure 2 – How a Spectrophotometer Works (Bostick, 2018)

The orange colors referenced within the CFR have an assigned color code from the Federal Standard 595C (FED-STD-595C) and the Standard color card of America. UL obtained color swatches of these reference samples for the shades of orange designated by color codes 12197 as specified in FED-STD-595C and 70072 as specified in the Standard color card of America.

TEST METHODOLGY

The color of the reference samples and USCG supplied samples were examined to determine if the colors were in the range from yellow to red.

The color of the material samples were measured in the As-Received condition only in accordance with ISO 12402-7 Section 4.1.6.4 with the procedures defined in CIE publication No. 15.2 with polychromatic illumination D65, 45/0 geometry and 2° standard observer. A black underlay with reflectance of less than 0.04 was used when testing each color sample.

The CIE color triangle is calculated by using the three tristimulus values, X (red-orange spectrum), Y (green spectrum) and Z (blue spectrum), form a color coordinate system. In order to represent individual colors in a descriptive manner, the standardized red and green color fractions x and y are projected into a planar coordinate system as shown in Figure 3. This x, y representation is independent of the brightness of the coloring and produces all object colors that can be produced. Moreover, it allows the wavelengths of the colors triggering a monochromatic color stimulus to be determined. The so-called line of purples, which represents the violet hues between red and blue, is situated in the lower region (Zeiss, n.d.). The following equations are used to calculate the x and y coordinates:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

Where:

x = x axis coordinate

y = y axis coordinate

X = red-orange spectrum

Y = green spectrum

Z = blue spectrum

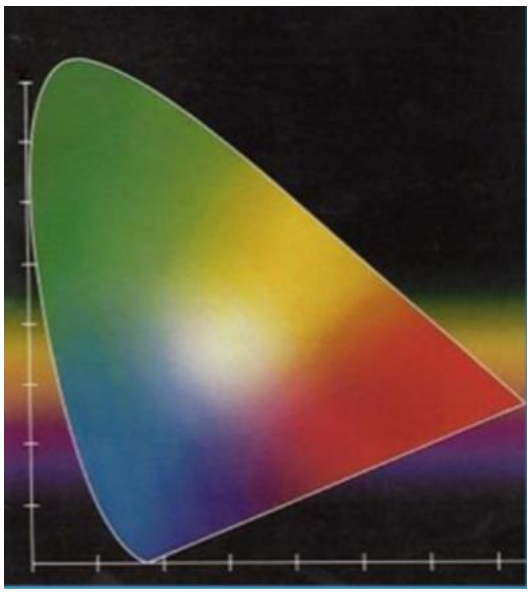


Figure 3 – Planar Coordinate System

The average of three color measurements for each reference and USCG supplied samples were taken. The average CIE coordinates for the reference color samples and USCG supplied samples were plotted to identify alignment or conflict with the chromaticity coordinates defined in ISO 12402-7 clause 4.3.3 Tables 3 and 4 shown in Figure 4. Refer to Figures 5 and 6 for the plotted sample CIE coordinates.

Table 3 — Chromaticity coordinates x and y and luminance factor β for yellow–orange and orange–red non-fluorescent colours of lifejacket material

Colour	Chromaticity coordinates		Minimum luminance factor
	x	y	β_{min}
Yellow–orange	0,387 0,346 0,438 0,525	0,610 0,478 0,400 0,476	0,40
Orange–red	0,610 0,690 0,550 0,485	0,390 0,310 0,275 0,358	0,15

Table 4 — Chromaticity coordinates x and y and luminance factor β for yellow, orange–red and red fluorescent colours of lifejacket material

Colour	Chromaticity coordinates		Minimum luminance factor
	x	y	β_{min}
Fluorescent yellow	0,387 0,356 0,398 0,460	0,610 0,494 0,452 0,540	0,70
Fluorescent orange–red	0,610 0,535 0,570 0,655	0,390 0,375 0,340 0,345	0,40
Fluorescent red	0,655 0,570 0,595 0,690	0,345 0,340 0,315 0,310	0,25

Figure 4 – Chromaticity Coordinate Tables from ISO 12402-7

AVERAGE CIE CHROMATICITY COORDINATES FOR REFERENCE COLOR SAMPLES:

Sample ID	Average Chromaticity Coordinate Result	
	x	*y*
R1	0.594	0.361
R2A	0.556	0.361
R2B	0.557	0.364

AVERAGE CIE CHROMATICITY COORDINATES FOR USCG COLOR SAMPLES:

Sample ID	Average Chromaticity Coordinate Result	
	x	*y*
0003A	0.602	0.352
0003B	0.627	0.353
0007A	0.565	0.342
0007B	0.566	0.342
0012	0.542	0.351
0015	0.544	0.361
0017A	0.547	0.353
0017B	0.519	0.351
0019A	0.538	0.340
0019B	0.549	0.338
0020	0.628	0.324
0021	0.584	0.379
0022*	0.503	0.443
0025	0.596	0.376
0026	0.566	0.322
0027A*	0.381	0.545
0027B*	0.382	0.545
0028A*	0.419	0.501
0028B*	0.420	0.502

* Fluorescent Yellow samples are shown for reference only, and not a part of the orange color analysis for this project.

AVERAGE CIE CHROMATICITY COORDINATES FOR USCG COLOR SAMPLES - continued:

Sample ID	Average Chromaticity Coordinate Result	
	x	*y*
0032A1	0.593	0.350
0032A2	0.569	0.347
0032B1	0.593	0.350
0032B2	0.557	0.346
0033	0.614	0.353
0034	0.596	0.363
0001A	0.600	0.353
0001B	0.608	0.353
0004A	0.579	0.347
0004B	0.562	0.345
0005A	0.626	0.324
0005B	0.640	0.326
0006A	0.588	0.357
0006B	0.595	0.357

ANALYSIS

The average color chromaticity coordinates for the reference samples and USCG samples were plotted onto a CIE plane shown below in Figures 5 and 6 to identify alignment or conflicts with the chromaticity coordinates defined in ISO 12402-7 clause 4.3.3 Tables 3 and 4. Reference samples were plotted with a diamond shape (♦), and USCG samples were plotted with a rectangle shape (▬). All orange, red, and orange-red samples fell within the ISO defined polygons as shown in Figure 5.

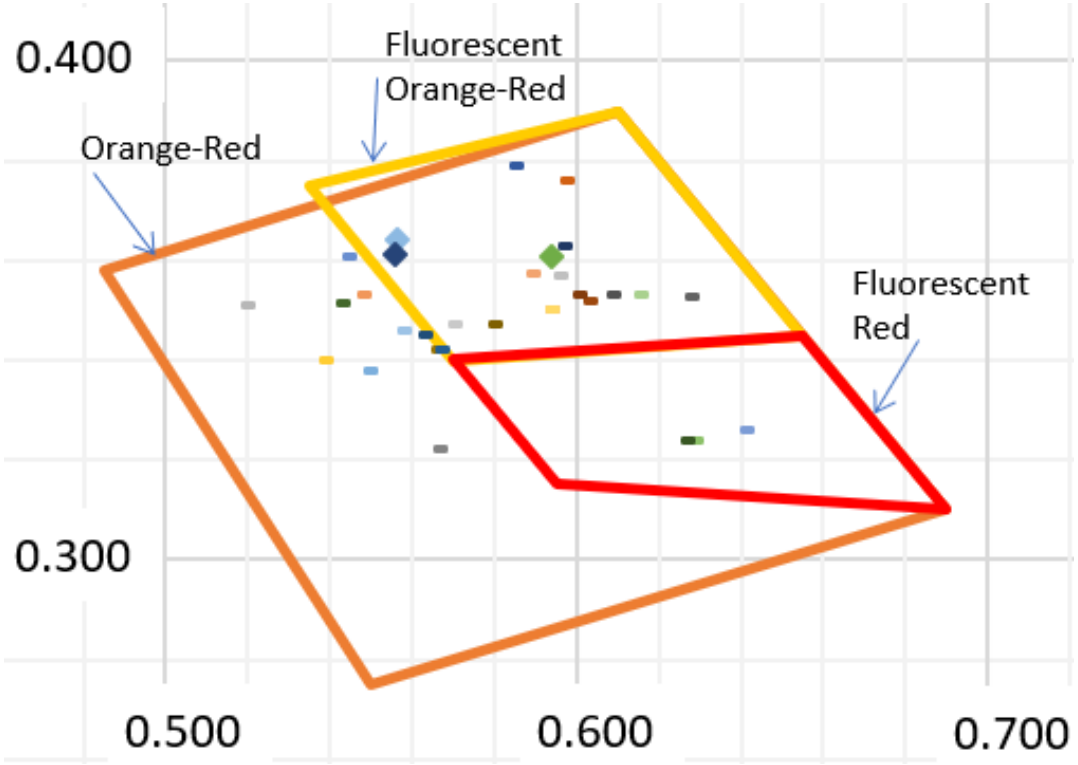


Figure 5 – Orange and Red Samples Plotted with Polygons from ISO 12402-7

Samples 0022, 0027A, 0027B, 0028A, and 0028B that fell within the yellow color range are shown here for reference only, since the scope of this project focuses on the orange color range.

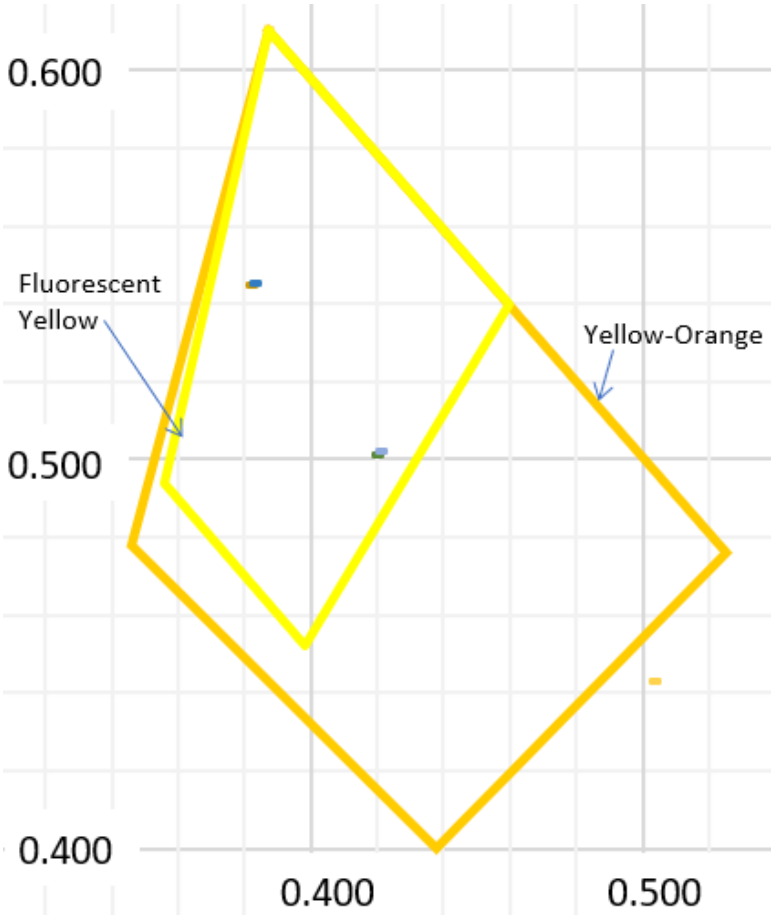


Figure 6 – Yellow Samples Plotted with Polygons from ISO 12402-7

Based on the chromaticity coordinates for the USCG Approved sample colors for Orange-Red, Fluorescent Orange-Red, and Fluorescent Red within the CIE coordinate spectrum, new polygons shown in Figure 7 were defined using the UL chromaticity coordinates shown in Tables 1 and 2 below. UL generated polygons by cutting away areas of the ISO defined polygons that were not populated with data points – primarily the left and lower regions of the ISO Orange-Red polygon – while maintaining similar clearance between the data points and polygons, the same color regions, and balancing the shape of the original ISO polygons.

Table 1 – Chromaticity Coordinates for Orange-Red

Color	ISO 12402-7 Table 3 Chromaticity Coordinates		UL Chromaticity Coordinate Result	
	x	*y*	*x*	*y*
Orange-Red	0.610	0.390	0.610	0.390
	0.690	0.310	0.680	0.320
	0.550	0.275	0.560	0.313
	0.485	0.358	0.485	0.358

Table 2 – Chromaticity Coordinates for Fluorescent Orange-Red and Fluorescent Red

Color	ISO 12402-7 Table 4 Chromaticity Coordinates		UL Chromaticity Coordinate Result	
	x	*y*	*x*	*y*
Fluorescent Orange-Red	0.61	0.39	0.61	0.39
	0.535	0.375	0.54	0.372
	0.57	0.34	0.57	0.34
	0.655	0.345	0.655	0.345
Fluorescent Red	0.655	0.345	0.655	0.345
	0.57	0.34	0.57	0.34
	0.595	0.315	0.595	0.315
	0.69	0.31	0.68	0.32

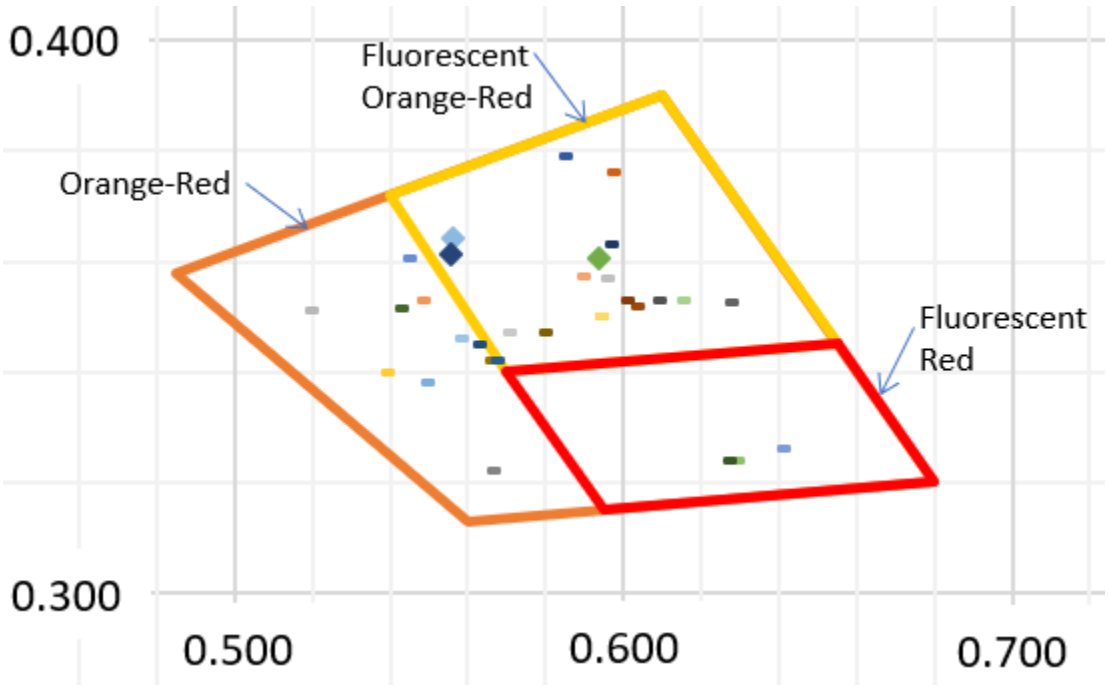


Figure 7 – Orange and Red Samples Plotted with UL Defined Polygons

DISCUSSION AND CONCLUSION

Quantifying the color of an object, in general, needs to account for several variables which continually interfere with measurement, such as the size of sample, light source, amount of light, surrounding color, angle of observation, sight quality of the observer, etc. Using instrumentation, instead of the human eye, provide standardized conditions that ensure color perception measurements that are consistent and repeatable. The equipment used for this project was a spectrophotometer, and as stated on Page 5 of this report, is an instrument designed for physical sample analysis via full spectrum color measurement. By providing wavelength-by-wavelength spectral analysis of a sample's reflectance, absorbance, or transmittance properties, it produces precise data beyond that observable by the human eye.

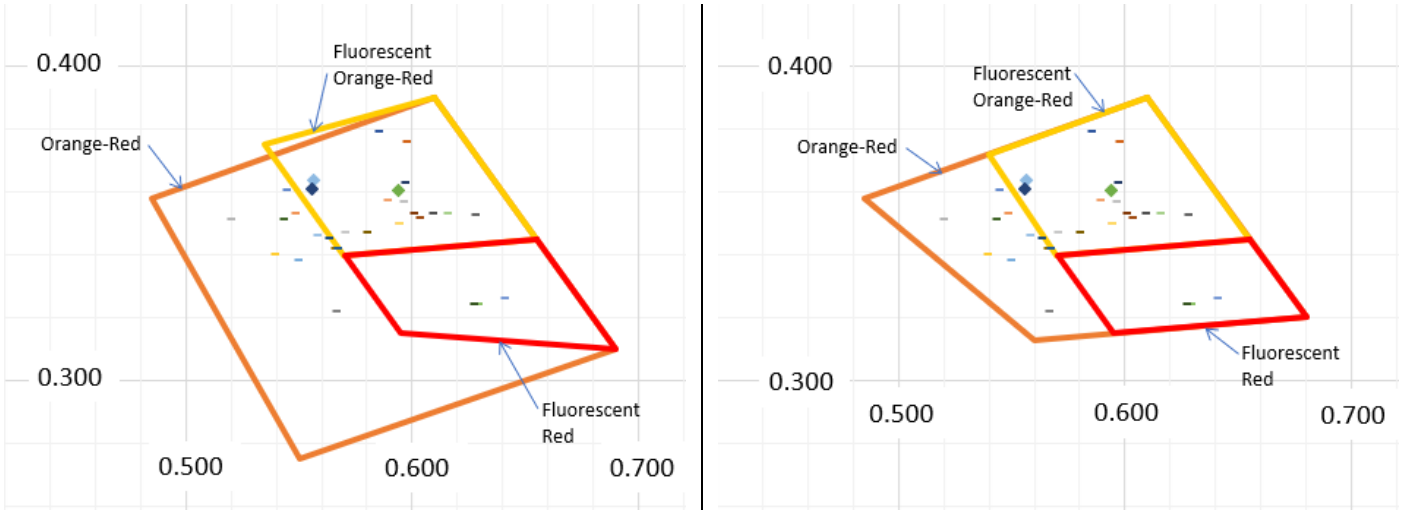
As documented on Page 13 of this report, the samples were tested in accordance with ISO 12402-7, Section 4.1.6.4 with the procedures defined in CIE publication No. 15.2 with polychromatic illumination D65, 45/0 geometry and 2° standard observer. It was determined that the repeatability of measurements was high as the average standard deviation for all samples tested was 0.001 when comparing each individual result to its respective mean.

There were no difficulties noted during the testing of the samples provided. There were also no deviations from the aforementioned test method regarding the measurement of colors, however the conditioning of the samples did differ from the requirements within ISO 12402-7, 4.3.3.2. ISO 12402-7 requires that the color of the samples be measured after accelerated weathering has occurred, however the samples were only tested in their as-received condition.

As seen in Figure 5 on page 13, the plotted average CIE coordinates for the reference color samples and USCG Approved color samples were found to be in compliance with the areas defined in Tables 3 and 4 of ISO 12402-7. It is important to note that the Fluorescent Orange-Red and Fluorescent Red polygons are sub-areas within the larger Orange-Red polygon. All data points for the reference colors (samples R1, R2A, and R2B shown with a diamond shape ♦) fell within the Fluorescent Orange-Red polygon. While several data points for the USCG color samples also fell within the Fluorescent Orange-Red polygon, others fell within the non-fluorescent area of Orange-Red polygon, and only three of the data points fell within the Fluorescent Red polygon.

Referring to Figure 8 for a side-by-side comparison view of the ISO defined polygons (from Figure 5) and UL defined polygons (from Figure 7), the polygons defined by UL more closely encompass the CIE coordinates of the color samples, and also stay within the color regions defined by the ISO 12402-7. Additionally, the alignment of the UL defined polygons are visually represented in Figures 9, 10, and 11.

To define allowable "orange" colors for lifesaving appliances, referring to CIE coordinates that define a polygon(s) that encloses chromaticity coordinates of acceptable colors was considered acceptable. Although it is important to note that testing for this project was done with samples in the as-received condition, without being subjected to accelerated weathering.



ISO Defined Polygons UL Defined Polygons

Figure 8 – Polygon Comparison View

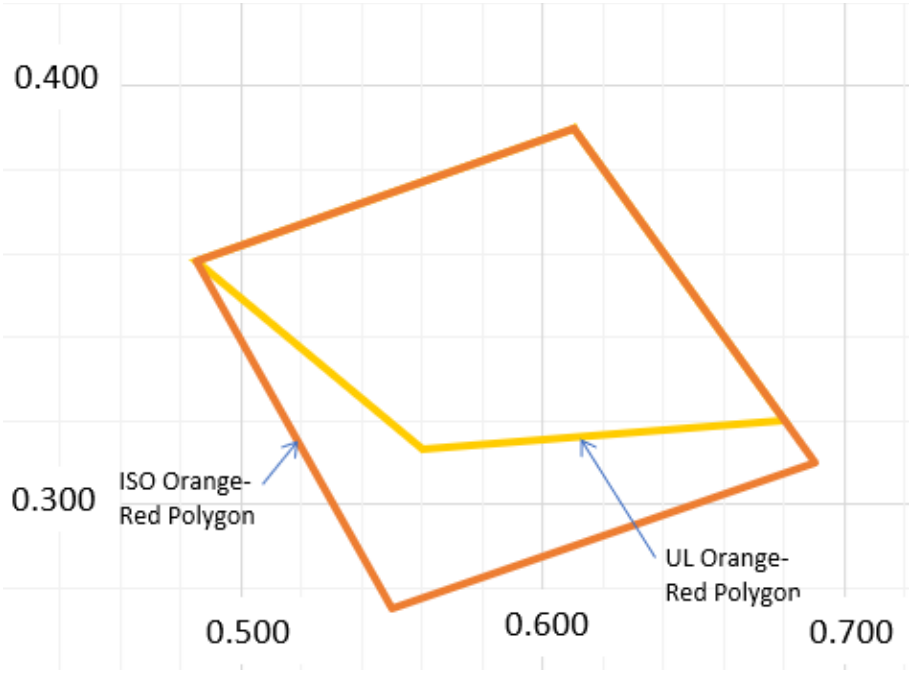


Figure 9 – Alignment of UL and ISO Defined Orange-Red Polygons

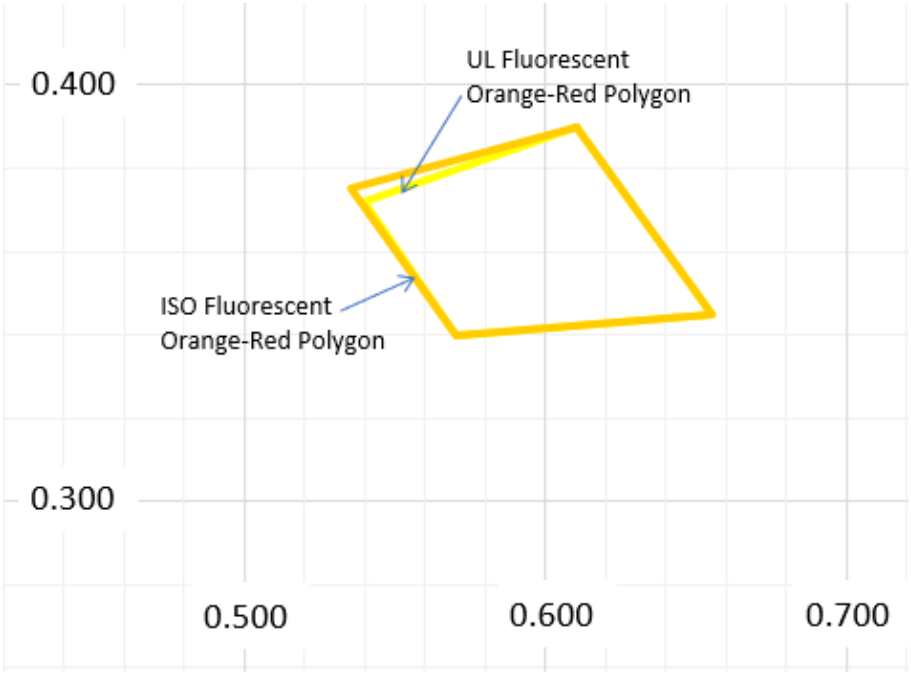


Figure 10 – Alignment of UL and ISO Defined Fluorescent Orange-Red Polygons

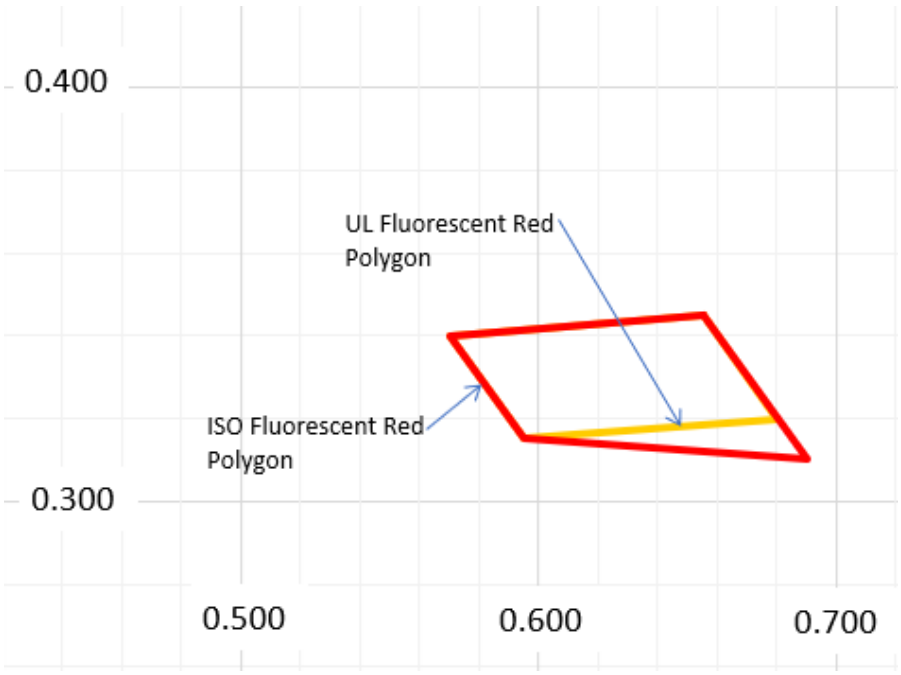


Figure 11 – Alignment of UL and ISO Defined Fluorescent Red Polygons

Samples received from USCG with multiple specimens of the same color, or having a coated and uncoated side, were assigned with an A or B suffix to represent the specimen number or coating as indicated in the sample information on pages 2 through 4. As shown on pages 11 and 12 (for samples 0017A and 0017B, 0019A and 0019B, 0032A1 and 0032B1, and 0032A2 and 0032B2, the measured average CIE chromaticity coordinates for a color with a coated and uncoated side did not yield a significant difference. These results indicate that the presence of a coating did not significantly change the chromaticity coordinates. This is consistent with UL's experience in dealing with coated and uncoated lifejacket textile materials. Textile materials such as woven and knitted fabrics, fabric laminated foams, and webbing are generally produced with various types of coatings and finishes. The typical coating weight for such specimens is usually lower than 2.0 oz/yd^2 which means that it becomes difficult to even distinguish the coated side versus the uncoated side on these types materials as the material can absorb the coating and it is not visibly detected. Although the coating weights and coating types for the submitted samples was not provided, UL noted that the uncoated side and coated side of the submitted samples was visibly the same and this is consistent with the data on pages 11 and 12.

In conclusion, as stated within this Report, the data provided validates that the Approved colors specified by the USCG were aligned within the polygons defined in ISO 12402-7, Tables 3 and 4. UL defined new polygons for Orange-Red, Fluorescent Orange-Red, and Fluorescent Red as modified per the aforementioned ISO 12402-7 polygons.

RECOMMENDATIONS FOR FUTURE WORK

This section of this Report will document UL's recommendations for additional variables that may be considered for studying the polygons for Orange-Red, Fluorescent Orange-Red, and Fluorescent Red. As described in this Report, variables such as the coating type, coating weight, material composition, etc. were not provided with the submitted USCG samples. UL has experience dealing with coated and uncoated textile materials and as noted on page 20, the results provided in this report indicate that coating did not significantly change the chromaticity results. With more information on the specimen, additional testing could be conducted to compare the CIE coordinates of test specimens that have known similar characteristics (including coating type, coating weight, and material composition). Additionally, the luminance factor was measured during testing but this parameter was not included in the data analysis as this project focused on defining a new polygon as modified per the aforementioned ISO 12402-7 polygons. The luminance is a parameter that is measured by the spectrophotometer with the CIE coordinates so further analysis of this parameter may yield additional findings.

REFERENCES

Bostick, M. (2018). What Goes On Inside a Spectrophotometer. Retrieved from https://www.carolina.com/teacher-resources/Interactive/what-goes-on-inside-a-spectrophotometer/tr41103.tr

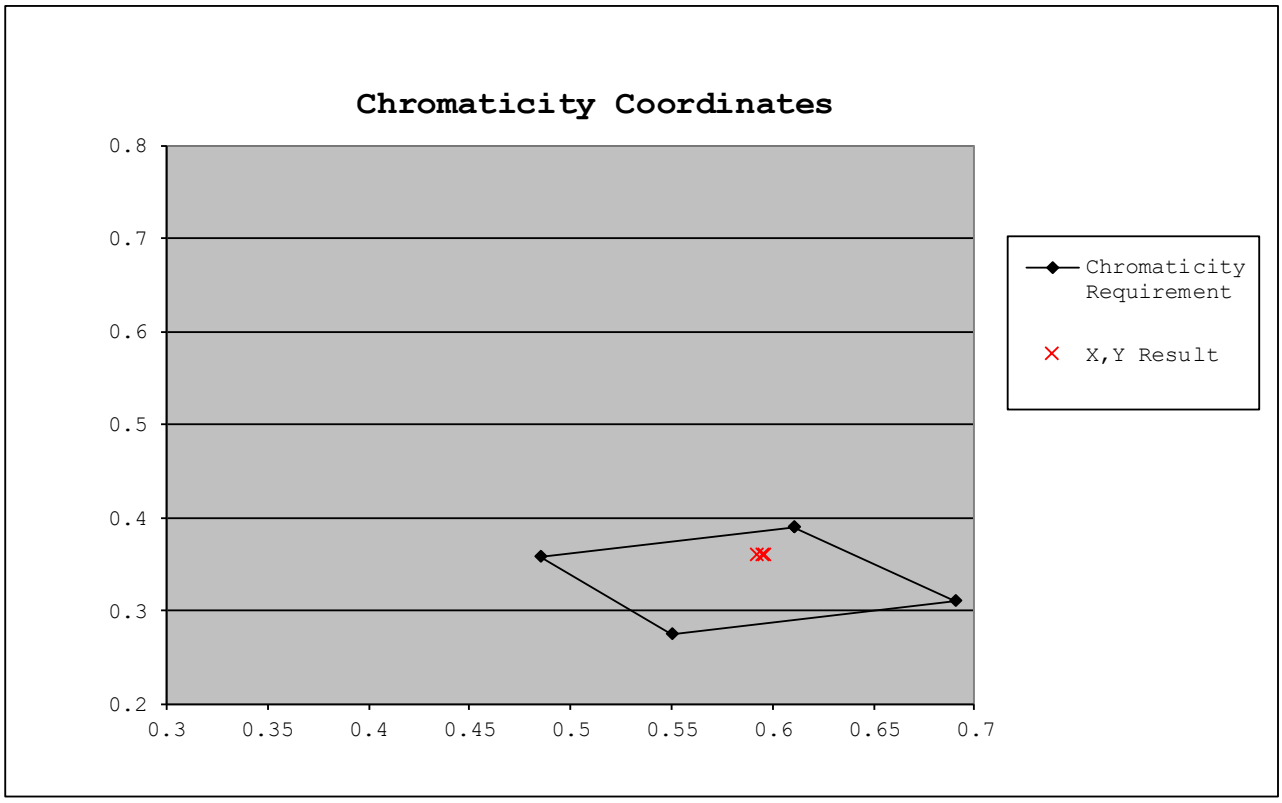
National Institute of Standards and Technology (NIST) (2009). Spectrophotometry. Retrieved from https://www.nist.gov/programs-projects/spectrophotometry

Zeiss. (n.d.). Color Measurement. Retrieved from https://www.zeiss.com/spectroscopy/solutions-applications/color-measurement.html#tristimulus-value

APPENDIX A – Individual CIE Plots for Reference Color Samples Against ISO 12402-7 Requirements

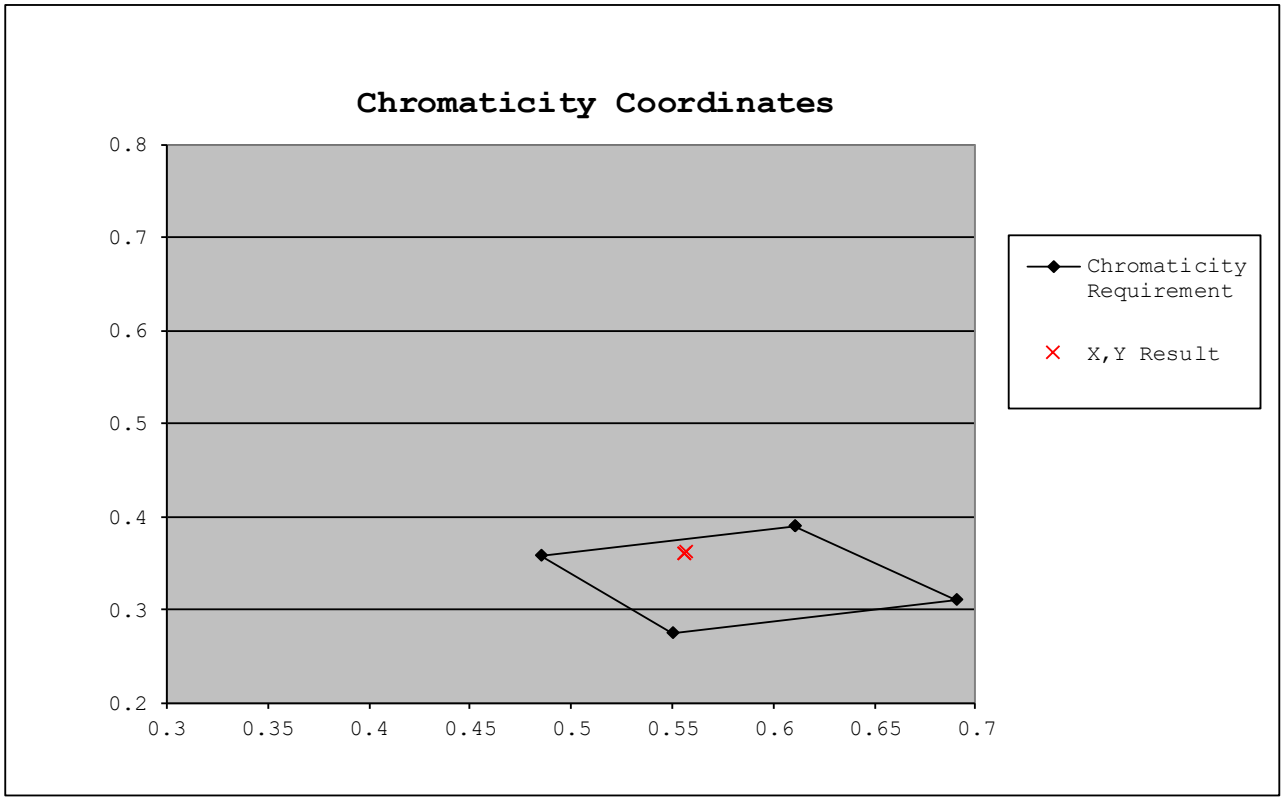
Sample #: R1
Sample Description: Vivid Reddish Orange/International Orange, FED-STD-595C No. 12197

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.595	0.361
2			0.595	0.361
3			0.592	0.361



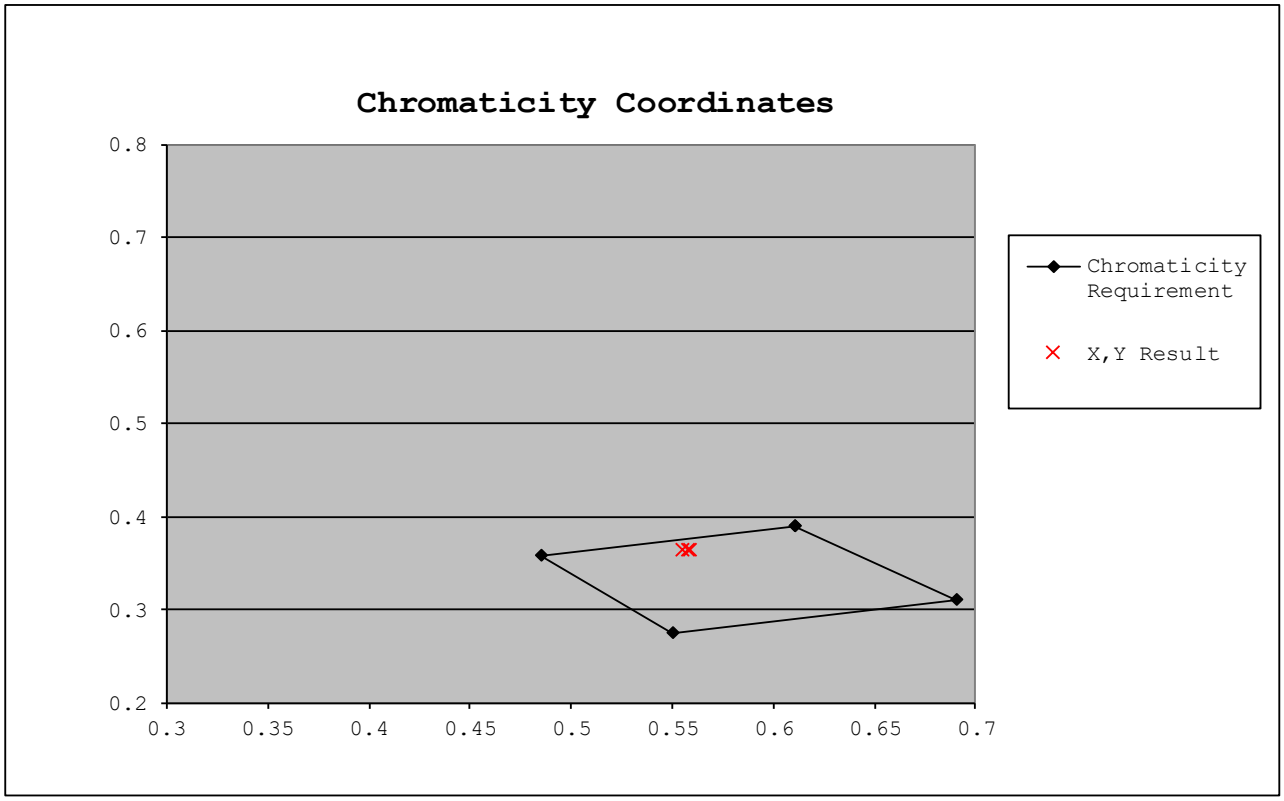
Sample #: R2A
Sample Description: Indian Orange, FED-STD-595C No. 70072 – Uncoated Side

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.555	0.361
2			0.555	0.361
3			0.557	0.362



Sample #: R2B
Sample Description: Indian Orange, FED-STD-595C No. 70072 – Coated Side

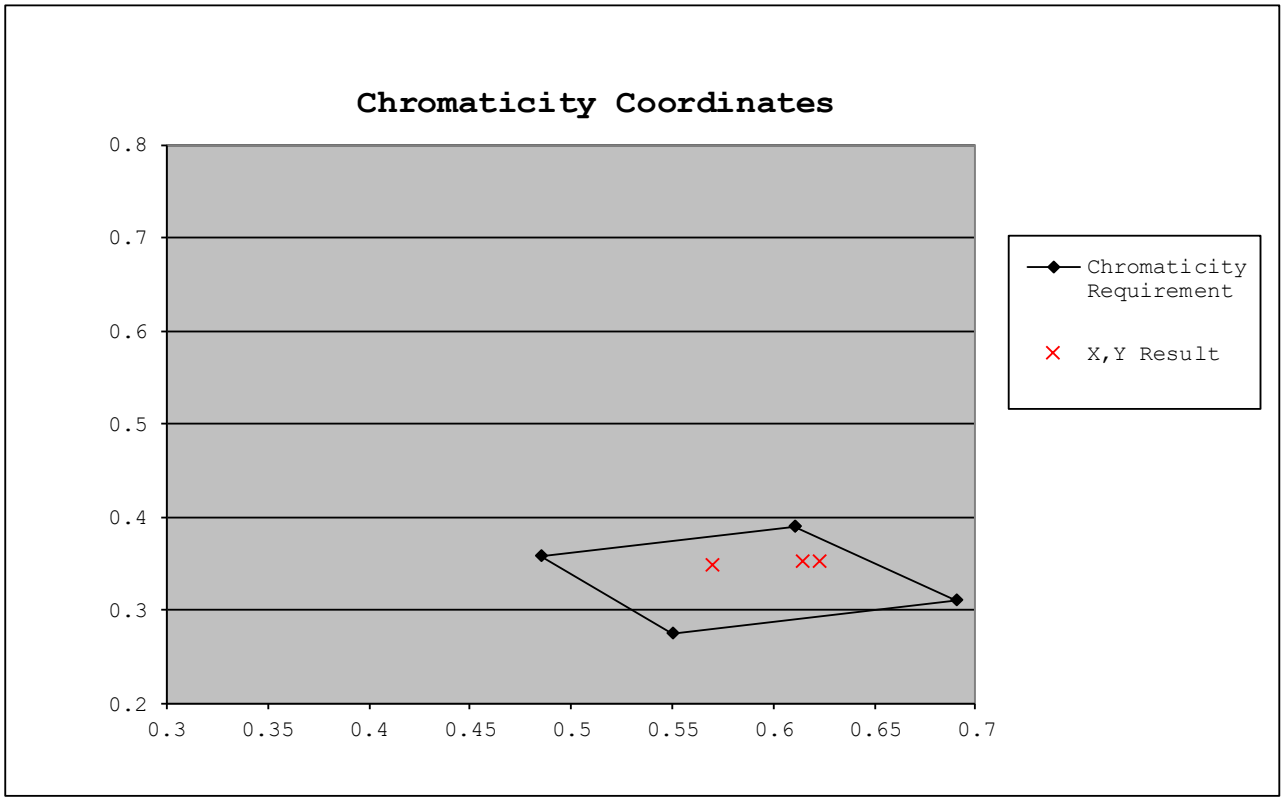
Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.557	0.364
2			0.555	0.364
3			0.558	0.364



APPENDIX B – Individual CIE Plots for USCG Color Samples Against ISO 12402-7 Requirements

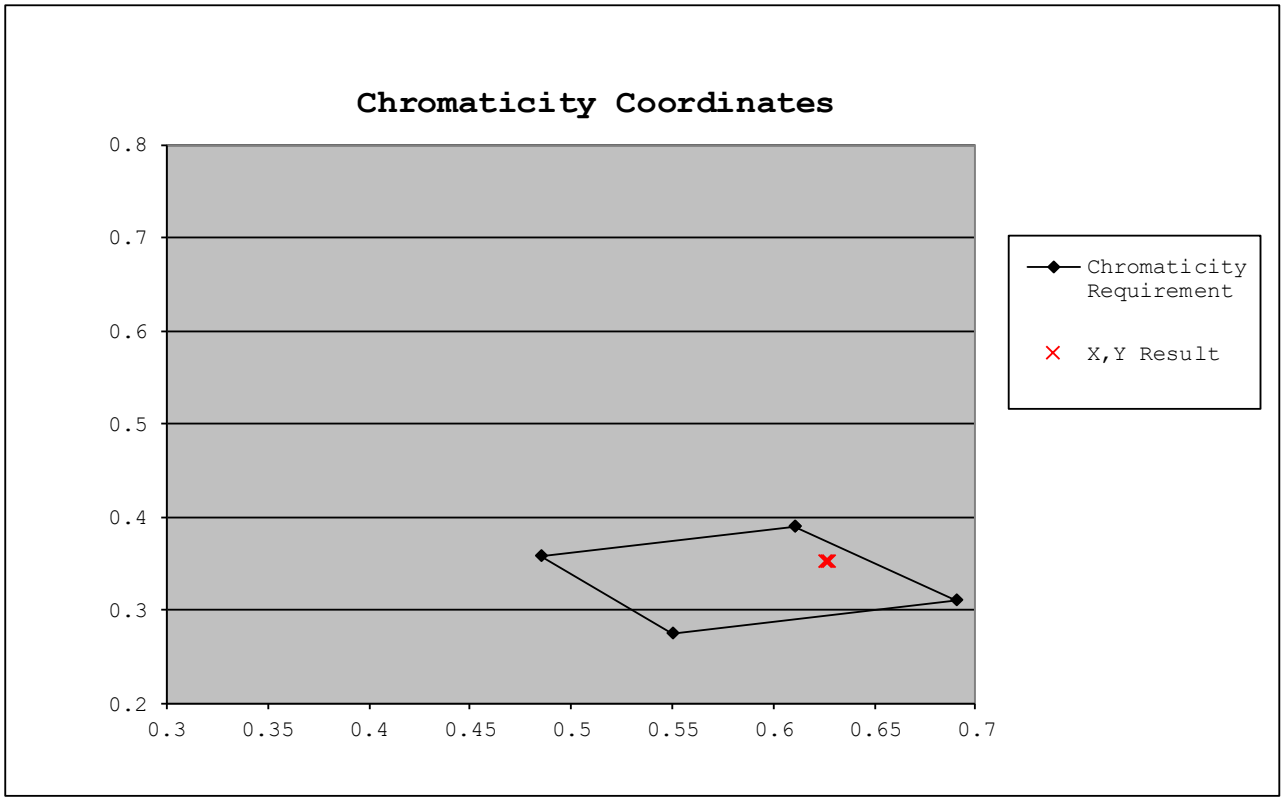
Sample #: 0003, specimen A
Sample Description: Orange Vinyl dipped PVC foam

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.623	0.353
2			0.614	0.353
3			0.570	0.349



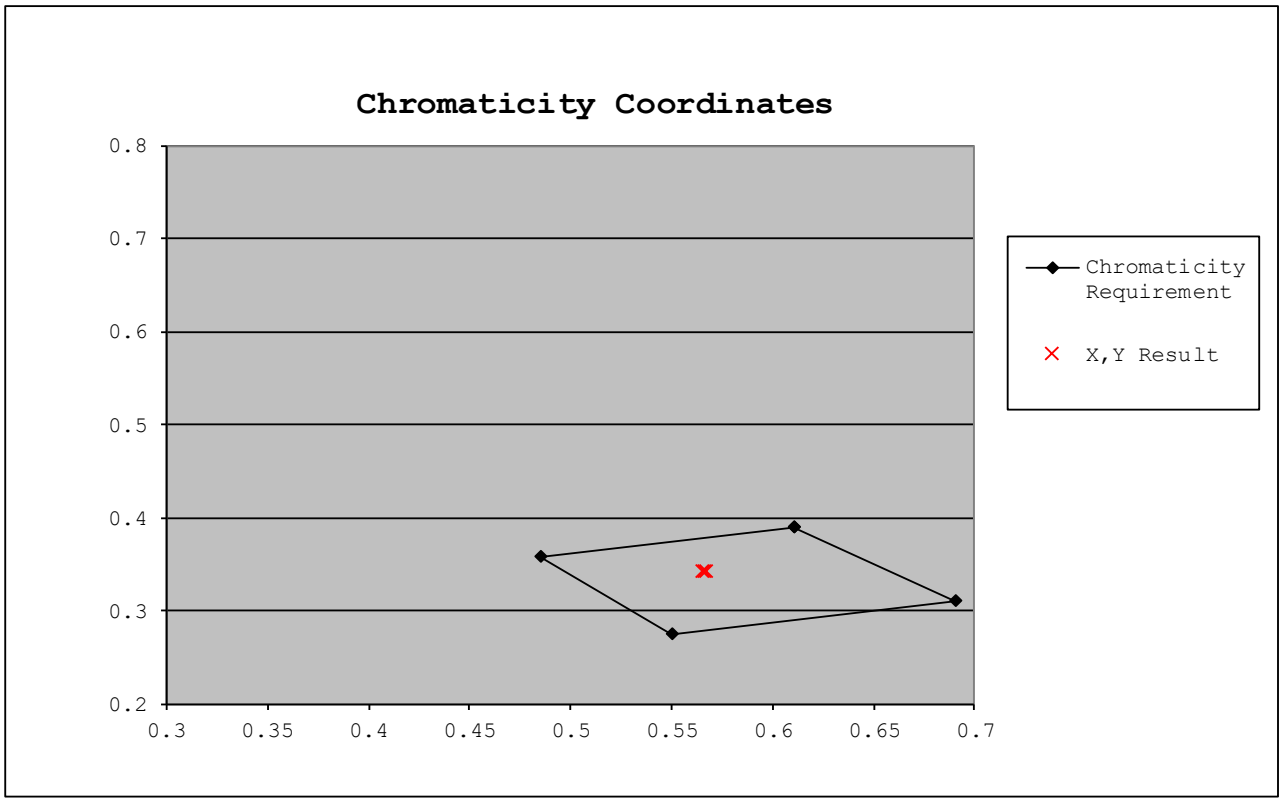
Sample #: 0003, specimen B
Sample Description: Orange Vinyl dipped PVC foam

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.628	0.353
2			0.626	0.352
3			0.626	0.353



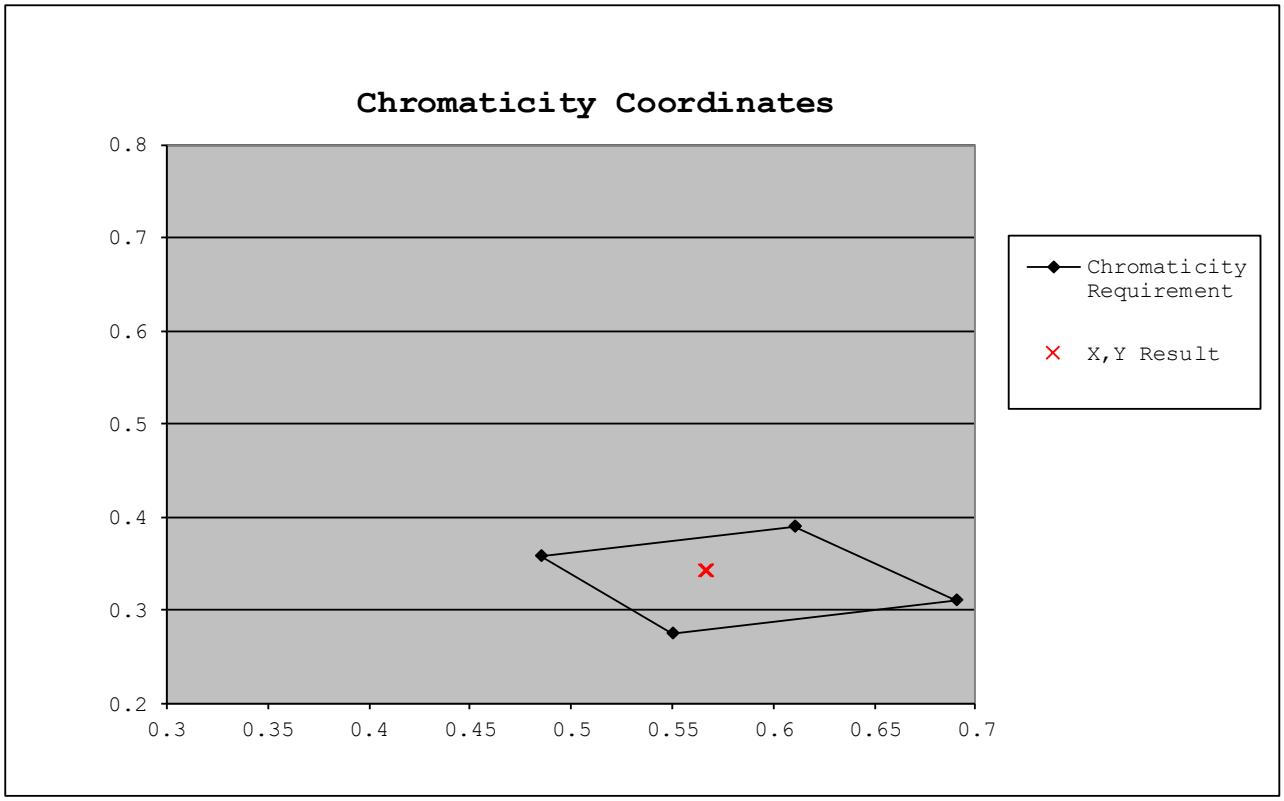
Sample #: 007, specimen A
Sample Description: Fluorescent Orange Fabric-laminated foam

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.565	0.342
2			0.565	0.342
3			0.566	0.342



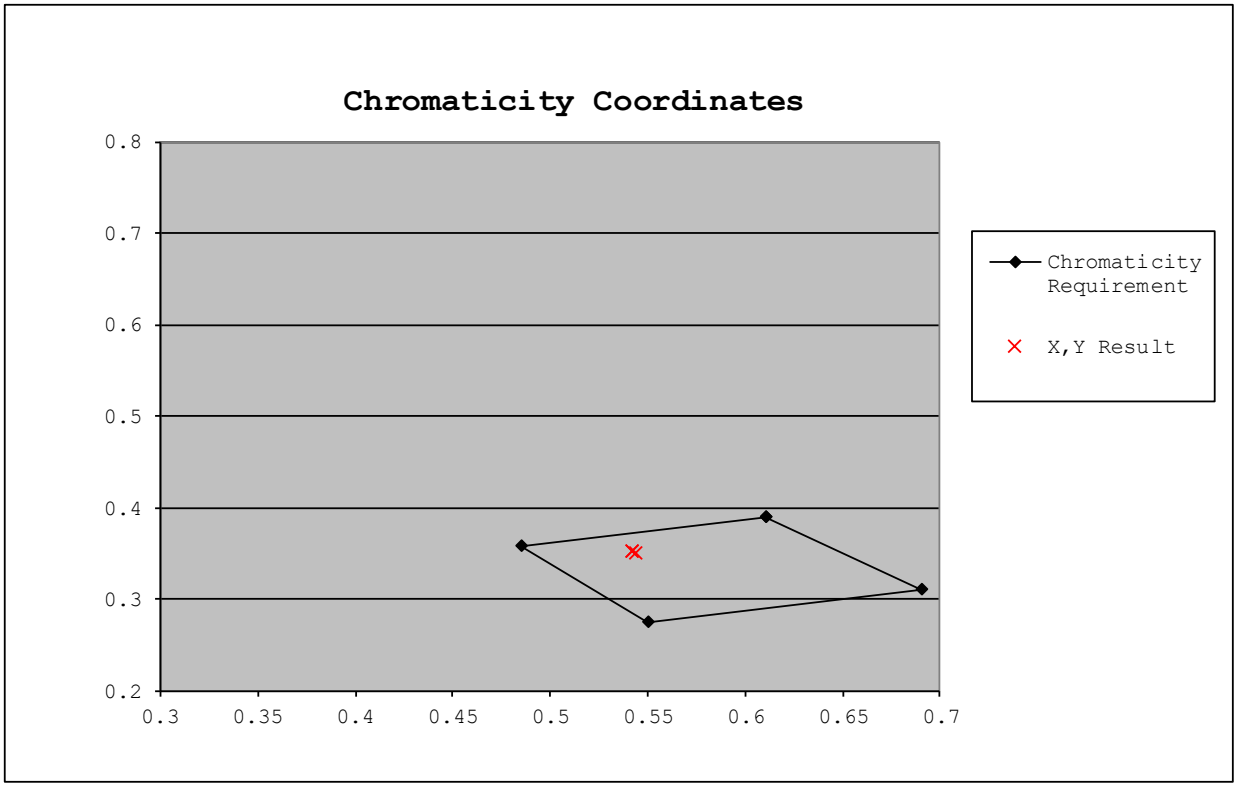
Sample #: 007, specimen B
Sample Description: Fluorescent Orange Fabric-laminated foam

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.566	0.342
2			0.566	0.342
3			0.567	0.342



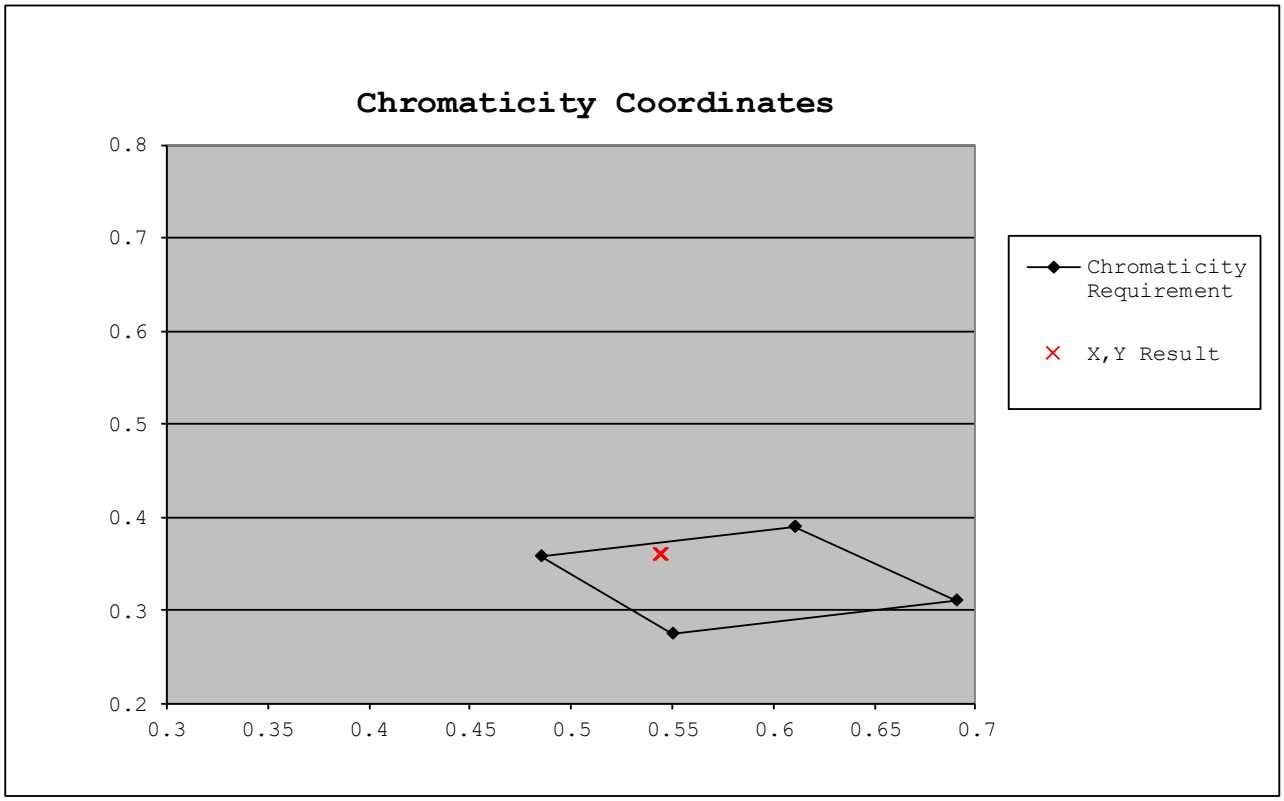
Sample #: 0012
Sample Description: Orange Woven fabric

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.542	0.352
2			0.541	0.351
3			0.543	0.351



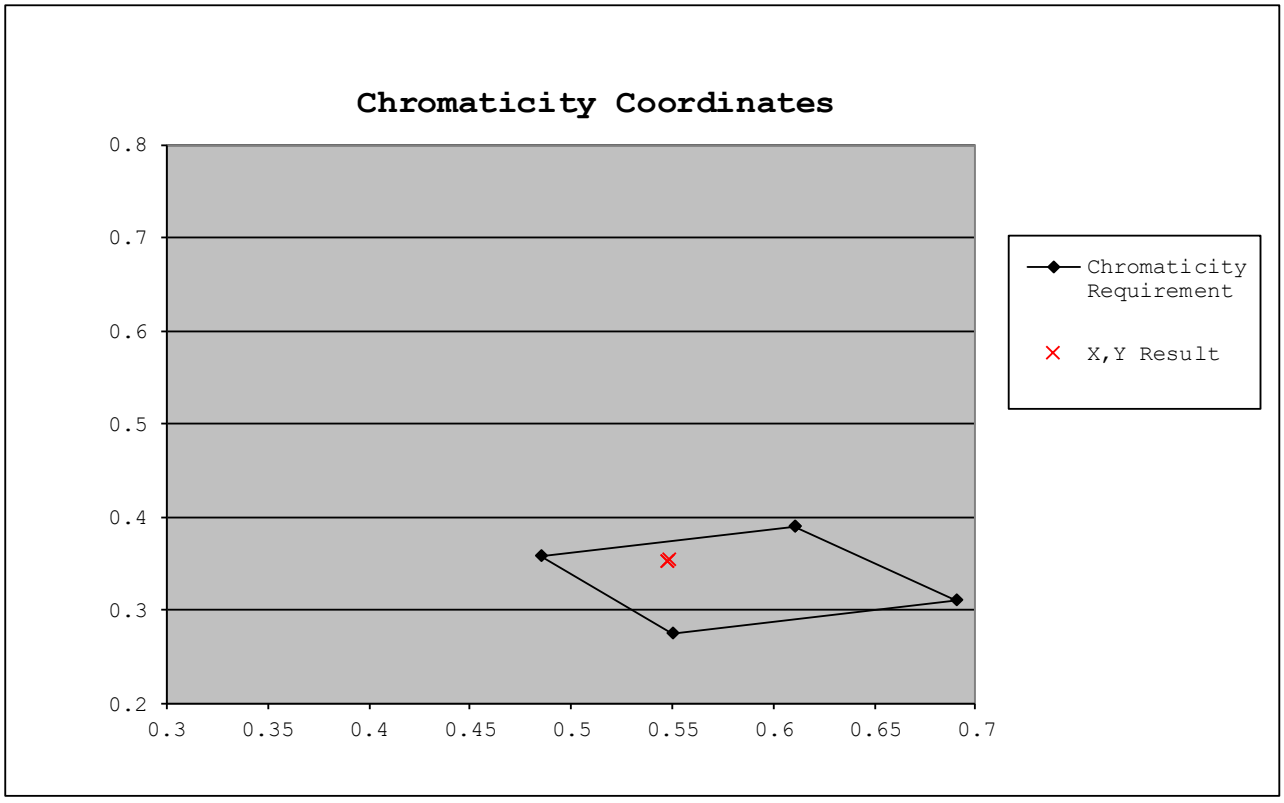
Sample #: 0015
Sample Description: Orange Woven fabric

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.544	0.361
2			0.544	0.361
3			0.543	0.361



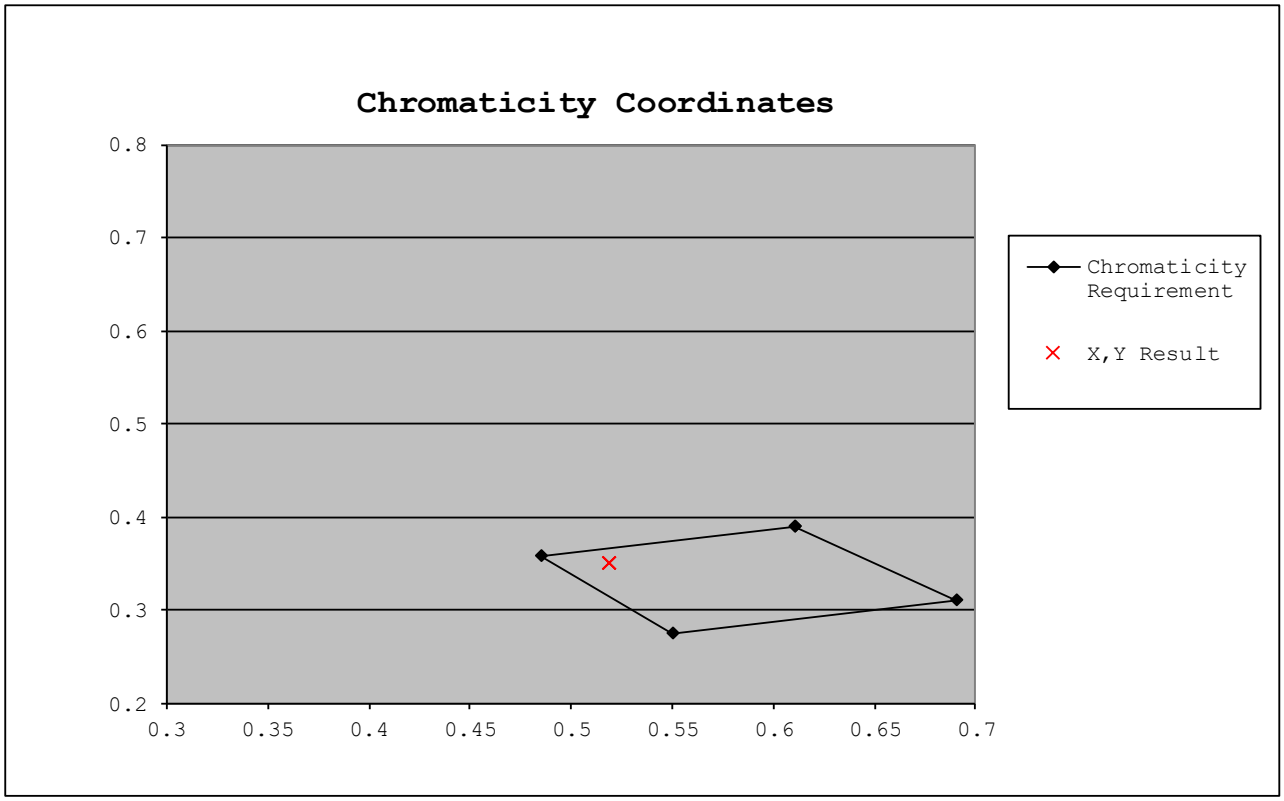
Sample #: 0017A, uncoated side
Sample Description: Orange Woven fabric

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.548	0.353
2			0.547	0.353
3			0.547	0.353



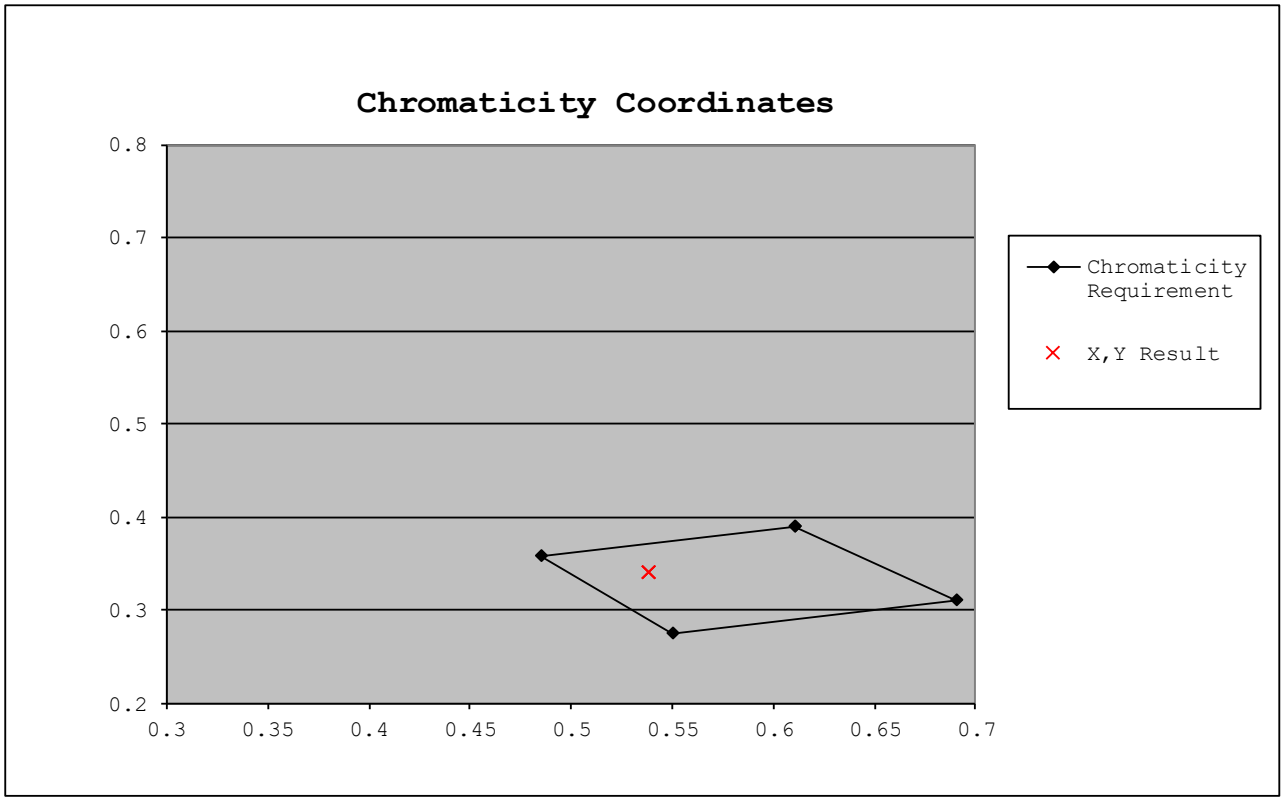
Sample #: 0017B, coated side
Sample Description: Orange Woven fabric

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.518	0.351
2			0.519	0.351
3			0.519	0.351



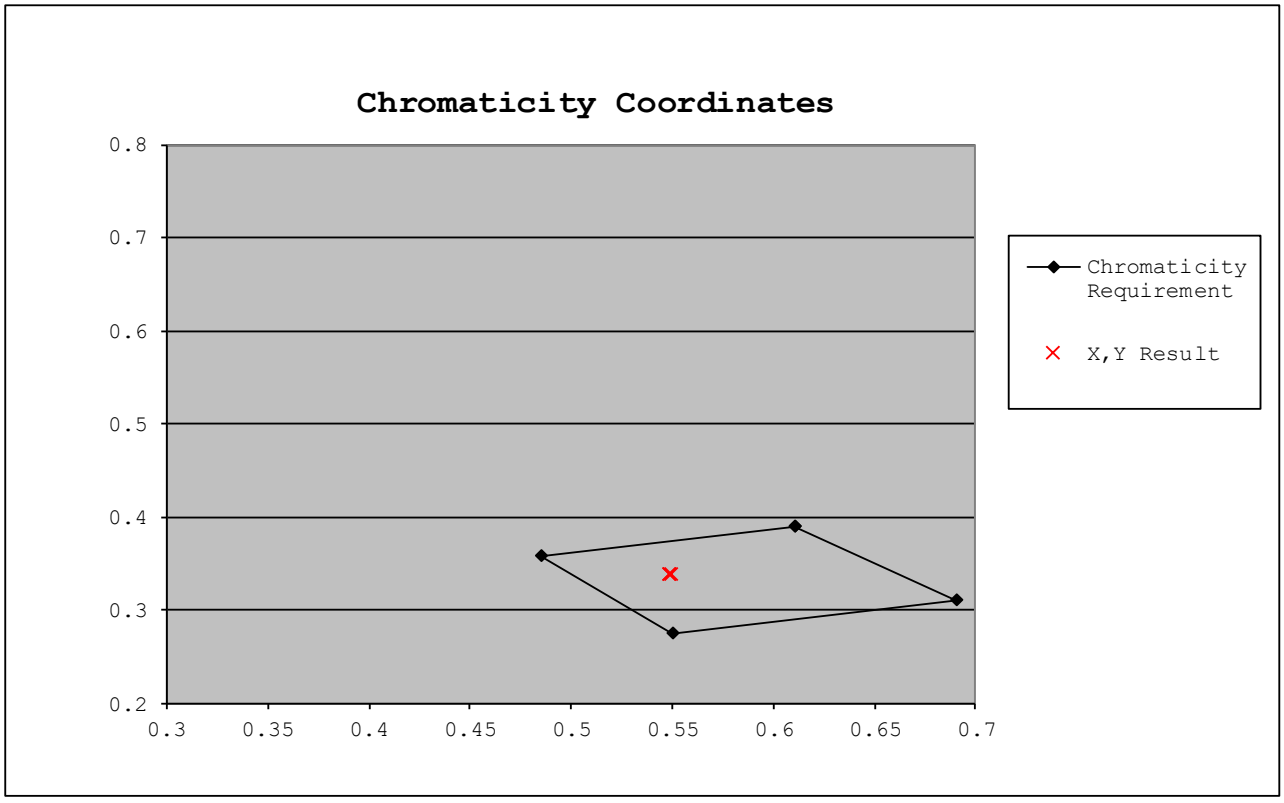
Sample #: 0019A, uncoated side
Sample Description: Reddish-Orange Woven fabric

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.538	0.340
2			0.538	0.340
3			0.538	0.340



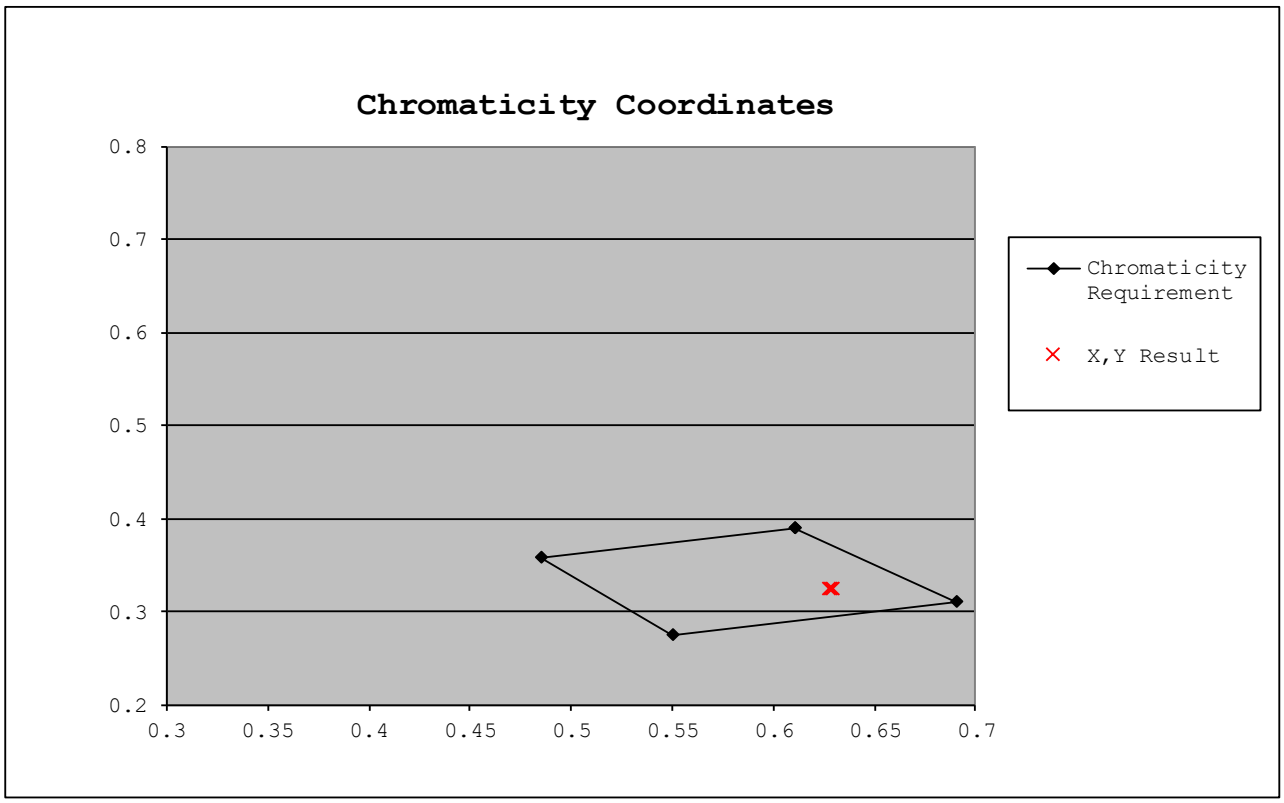
Sample #: 0019B, coated side
Sample Description: Reddish-Orange Woven fabric

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.548	0.338
2			0.549	0.338
3			0.549	0.338



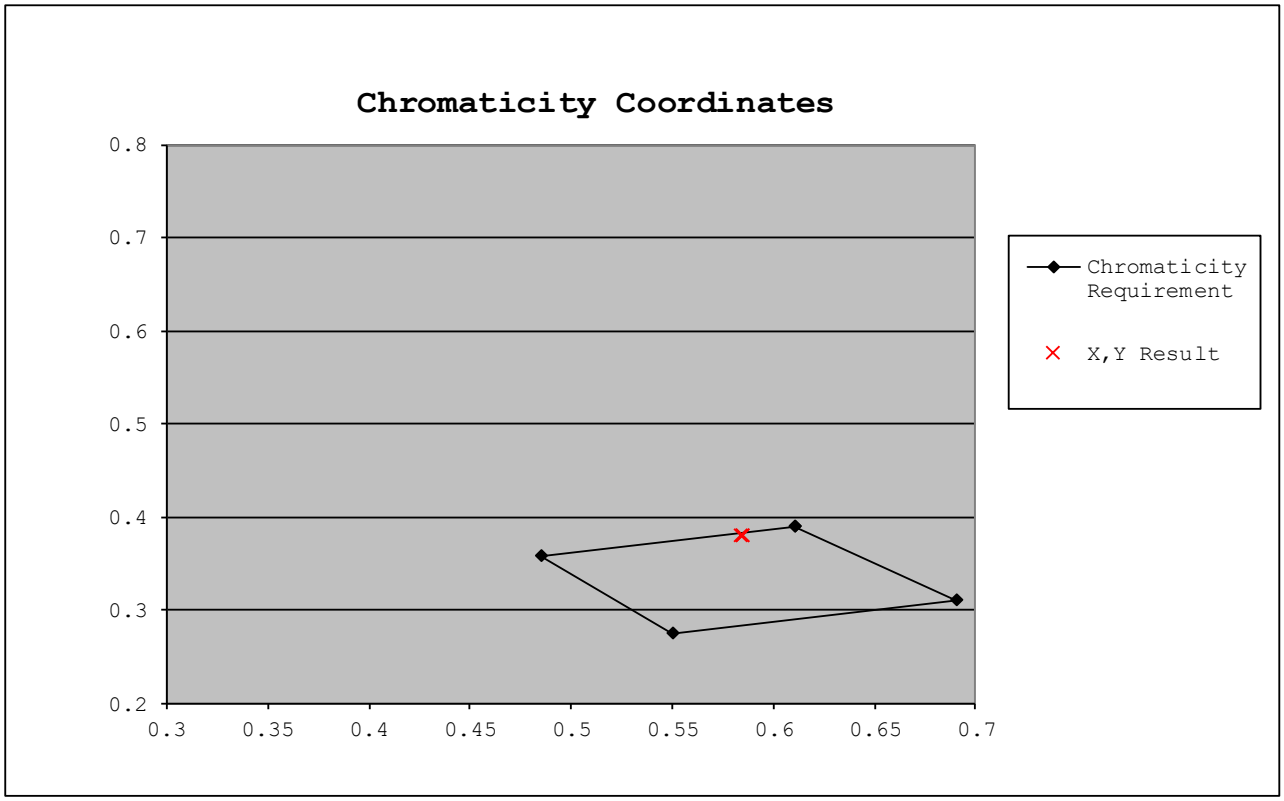
Sample #: 0020
Sample Description: Red Tile

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.628	0.324
2			0.627	0.324
3			0.629	0.324

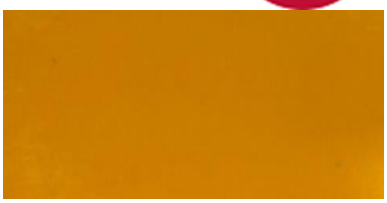


Sample #: 0021
Sample Description: Orange Tile

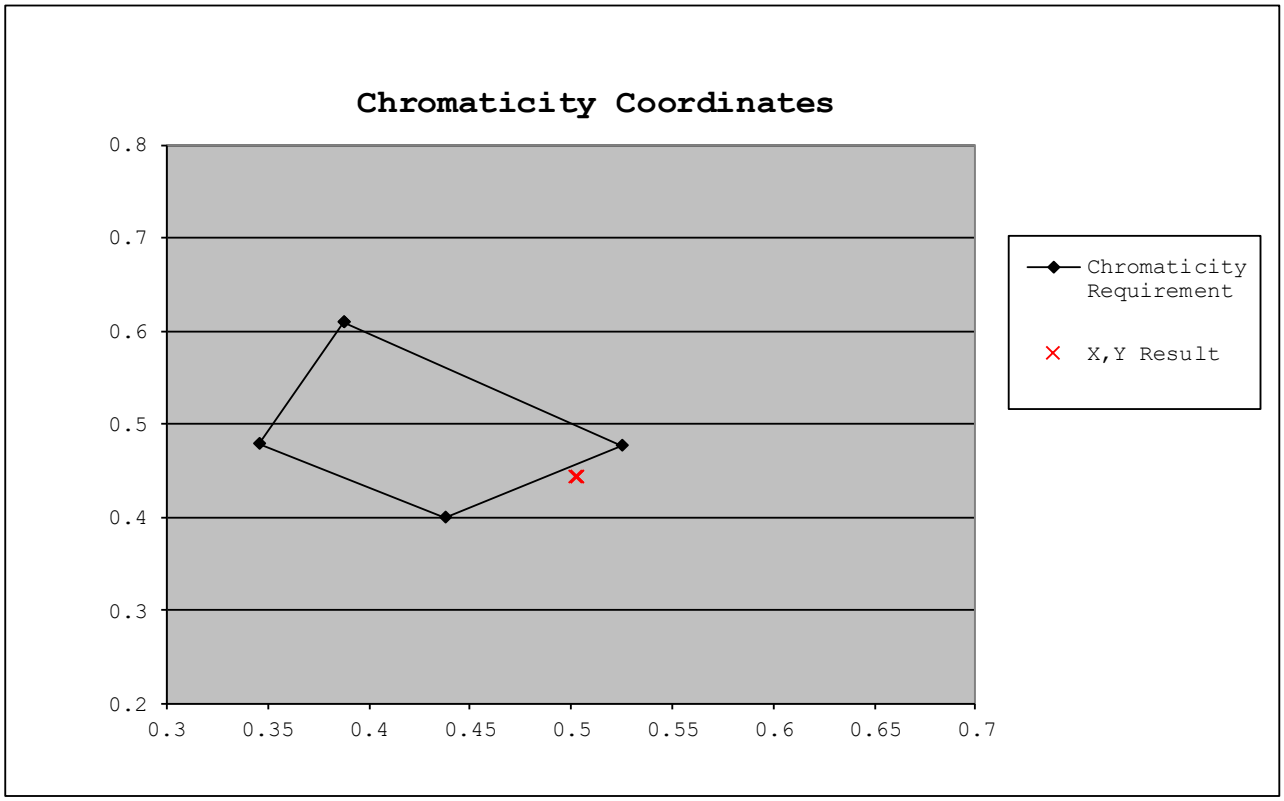
Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.584	0.379
2			0.584	0.379
3			0.584	0.379



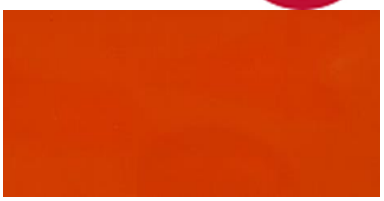
Sample #: 0022
Sample Description: Yellow-Orange Tile



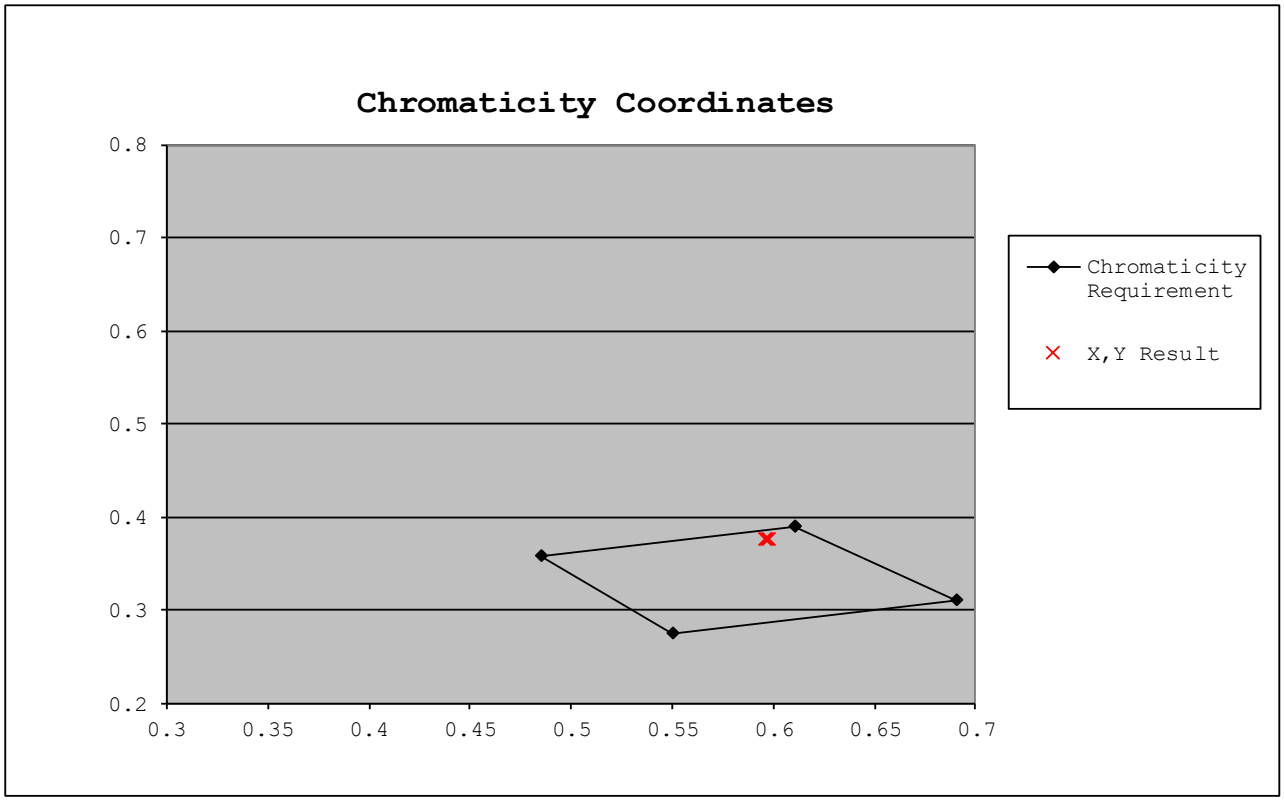
Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Yellow-Orange	0.502	0.443
2			0.503	0.443
3			0.503	0.443



Sample #: 0025
Sample Description: Orange Tile

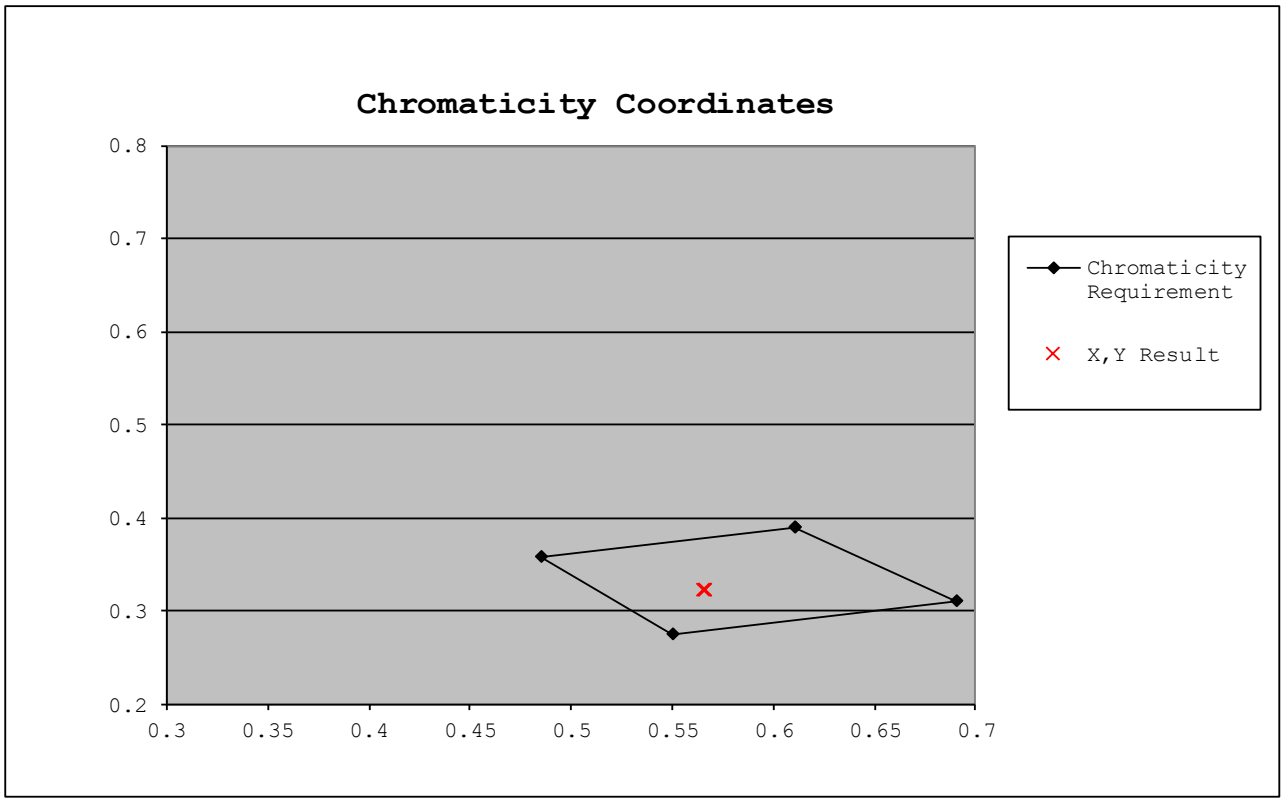


Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.596	0.376
2			0.596	0.376
3			0.597	0.376



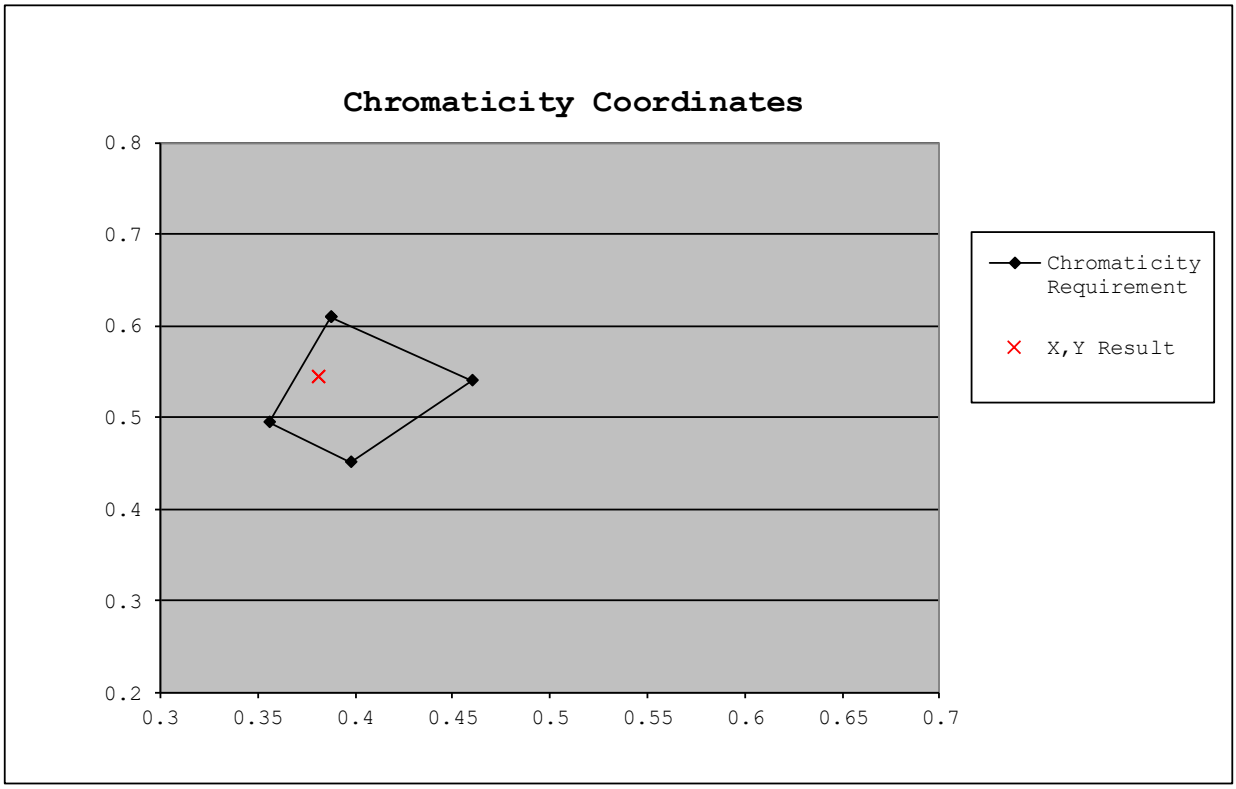
Sample #: 0026
Sample Description: Red Fabric-laminated foam

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.565	0.322
2			0.566	0.322
3			0.566	0.322



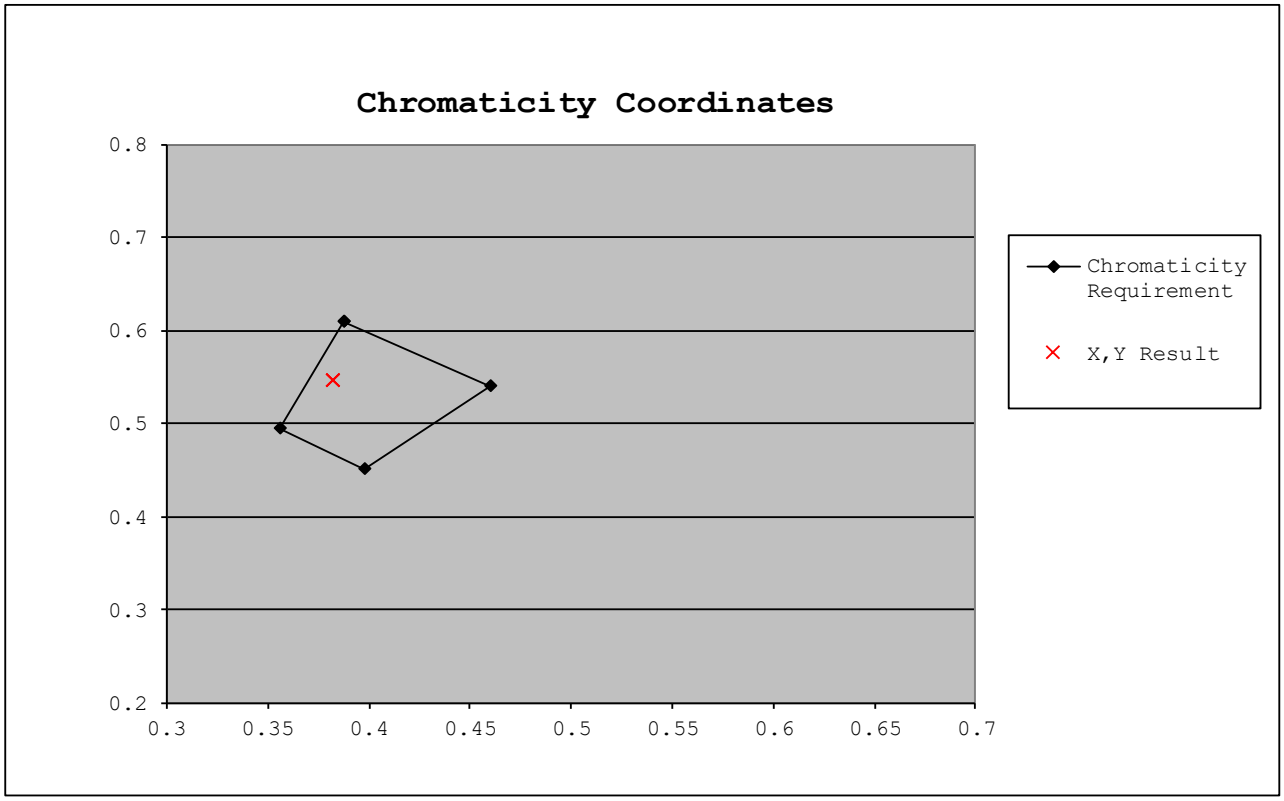
Sample #: 0027, specimen A
Sample Description: Fluorescent Yellow Woven fabric (FA1723-45)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Fluorescent Yellow	0.381	0.545
2			0.381	0.545
3			0.381	0.545



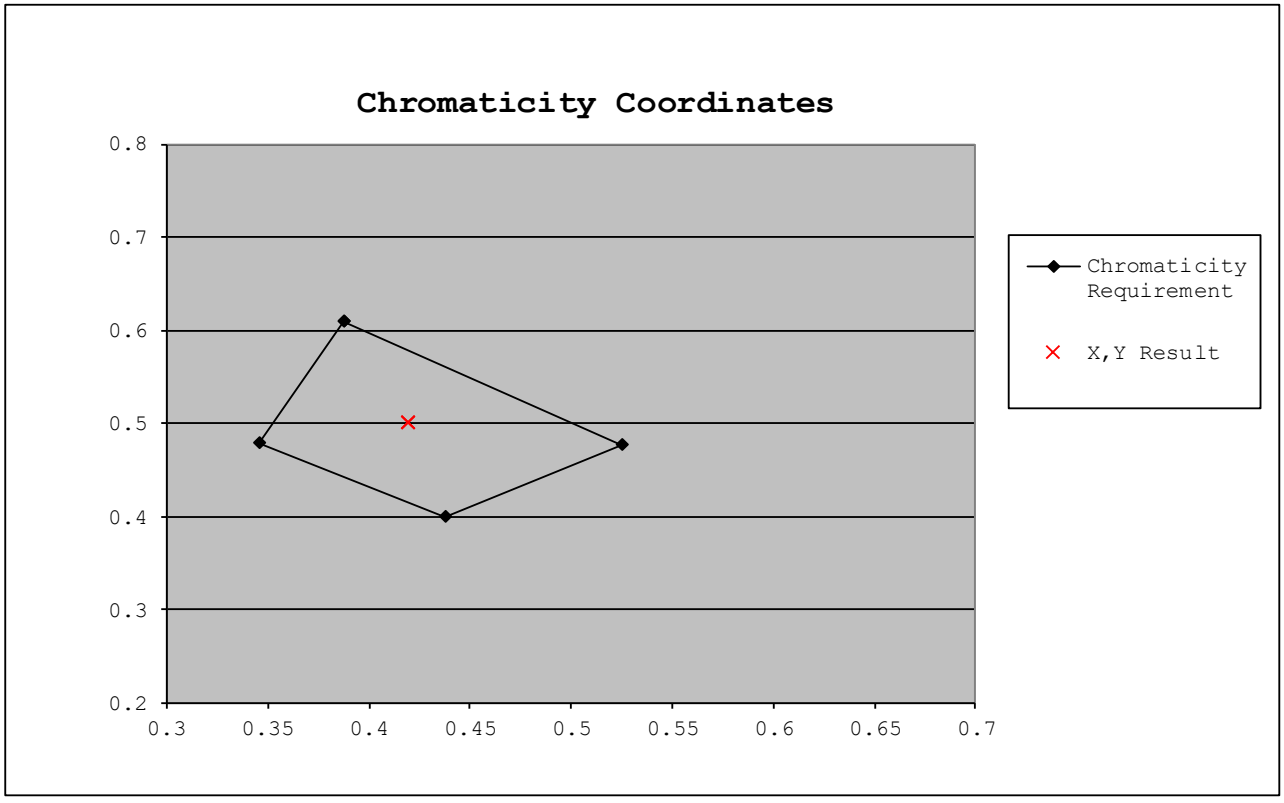
Sample #: 0027, specimen B
Sample Description: Fluorescent Yellow Woven fabric (FA1723-45)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Fluorescent Yellow	0.382	0.546
2			0.382	0.545
3			0.382	0.545



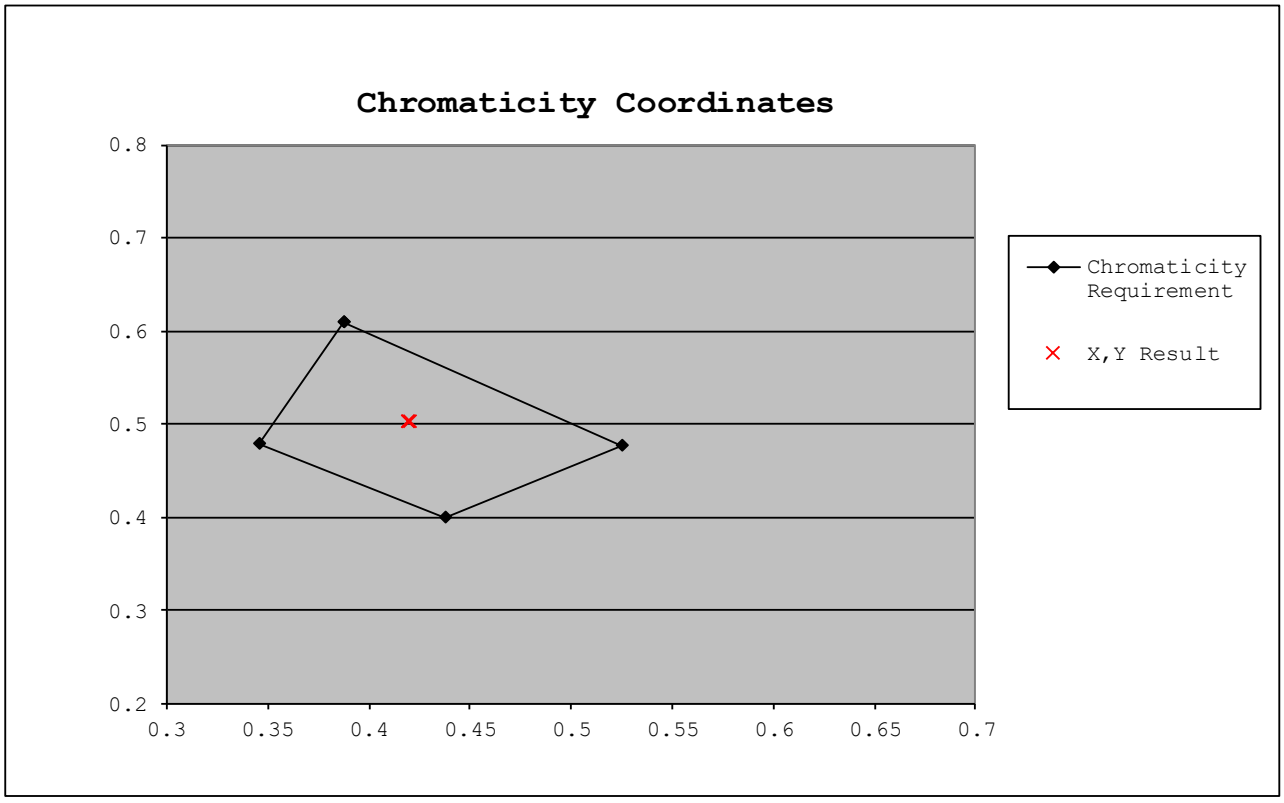
Sample #: 0028, specimen A
Sample Description: Yellow Woven fabric (FA1791-193)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Yellow-Orange	0.419	0.501
2			0.419	0.501
3			0.419	0.501



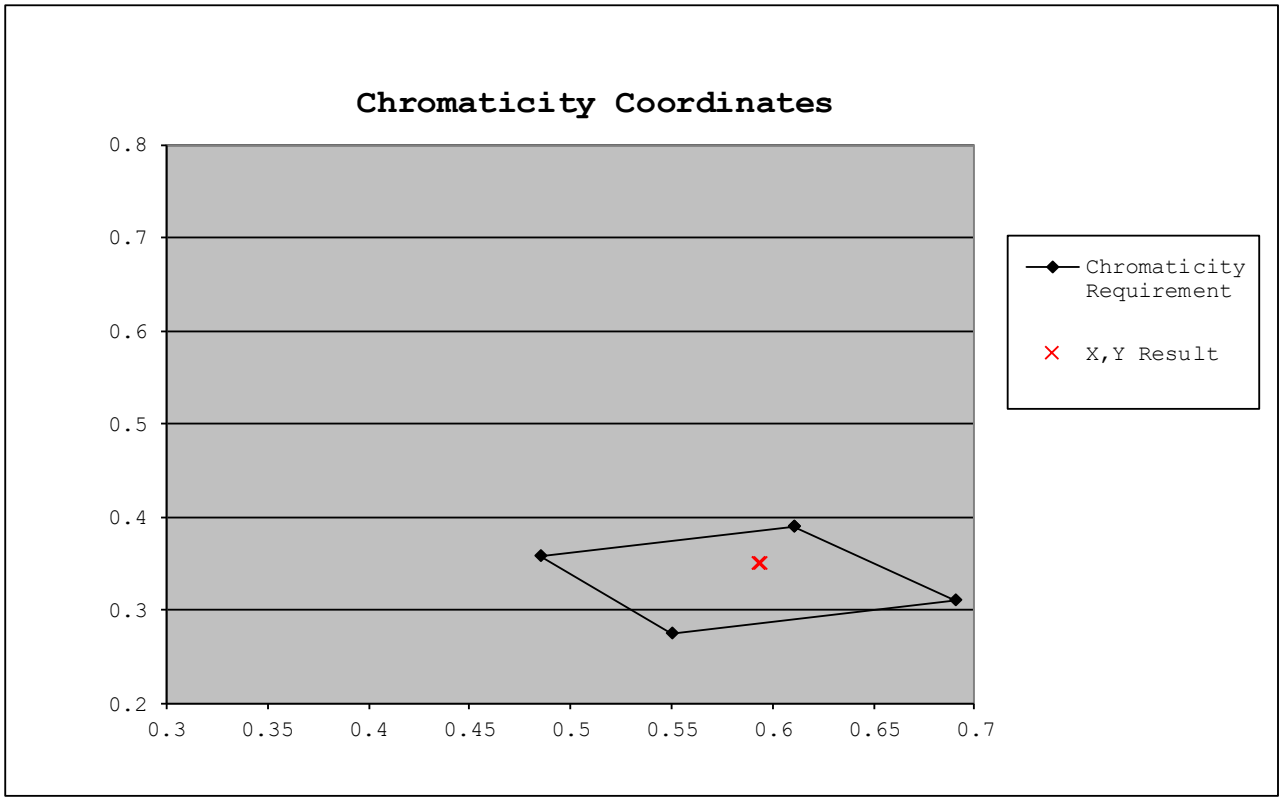
Sample #: 0028, specimen B
Sample Description: Yellow Woven fabric (FA1791-193)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Yellow-Orange	0.419	0.502
2			0.420	0.502
3			0.420	0.502



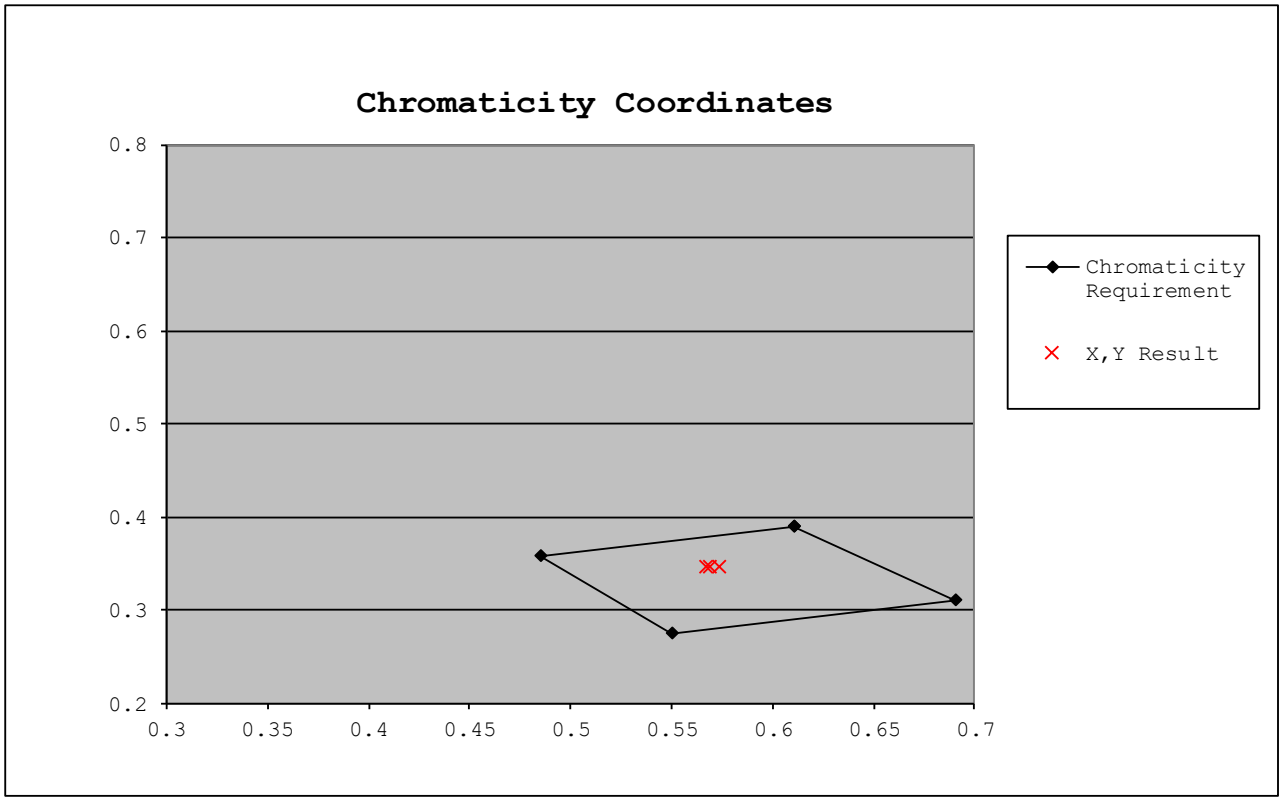
Sample #: 0032, specimen A uncoated side
Sample Description: Fluorescent Reddish-Orange Woven fabric (FA1281-46)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.592	0.350
2			0.592	0.350
3			0.594	0.350



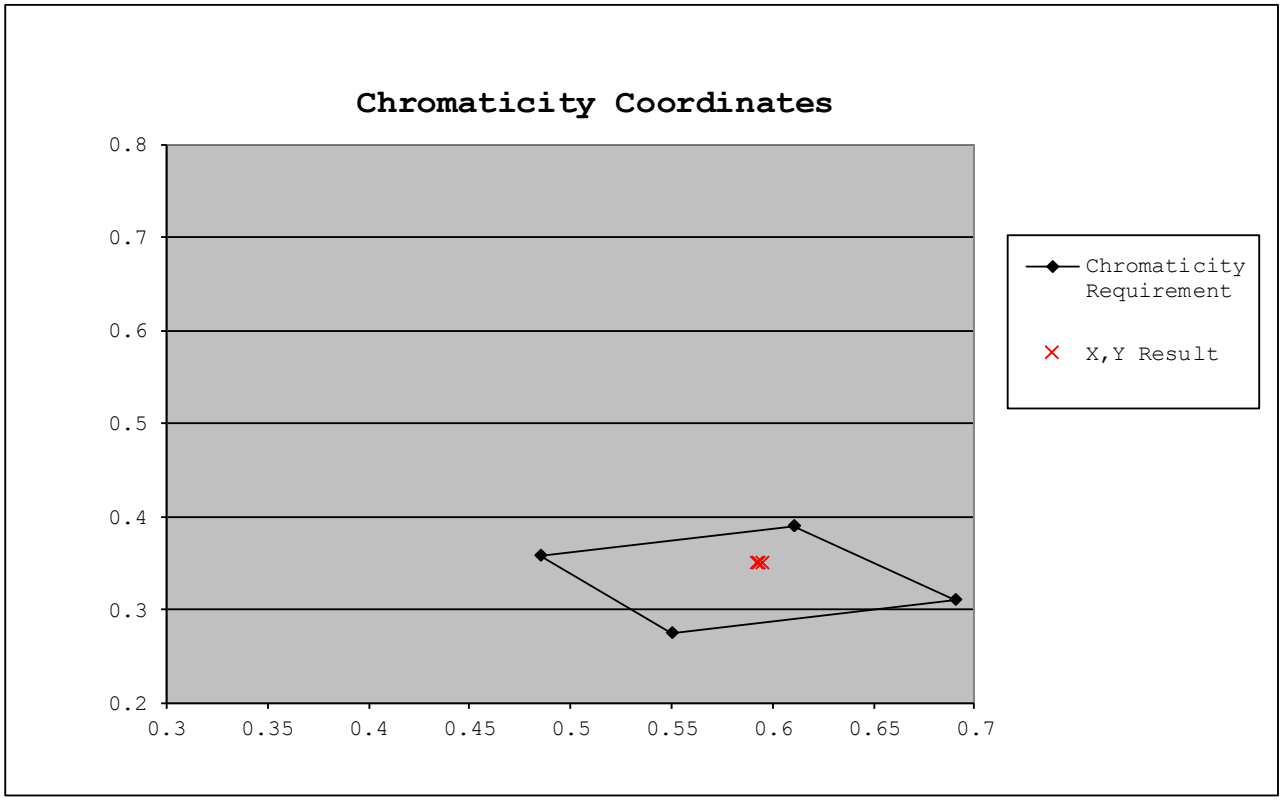
Sample #: 0032, specimen A coated side
Sample Description: Fluorescent Reddish-Orange Woven fabric (FA1281-46)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.567	0.347
2			0.573	0.347
3			0.568	0.347



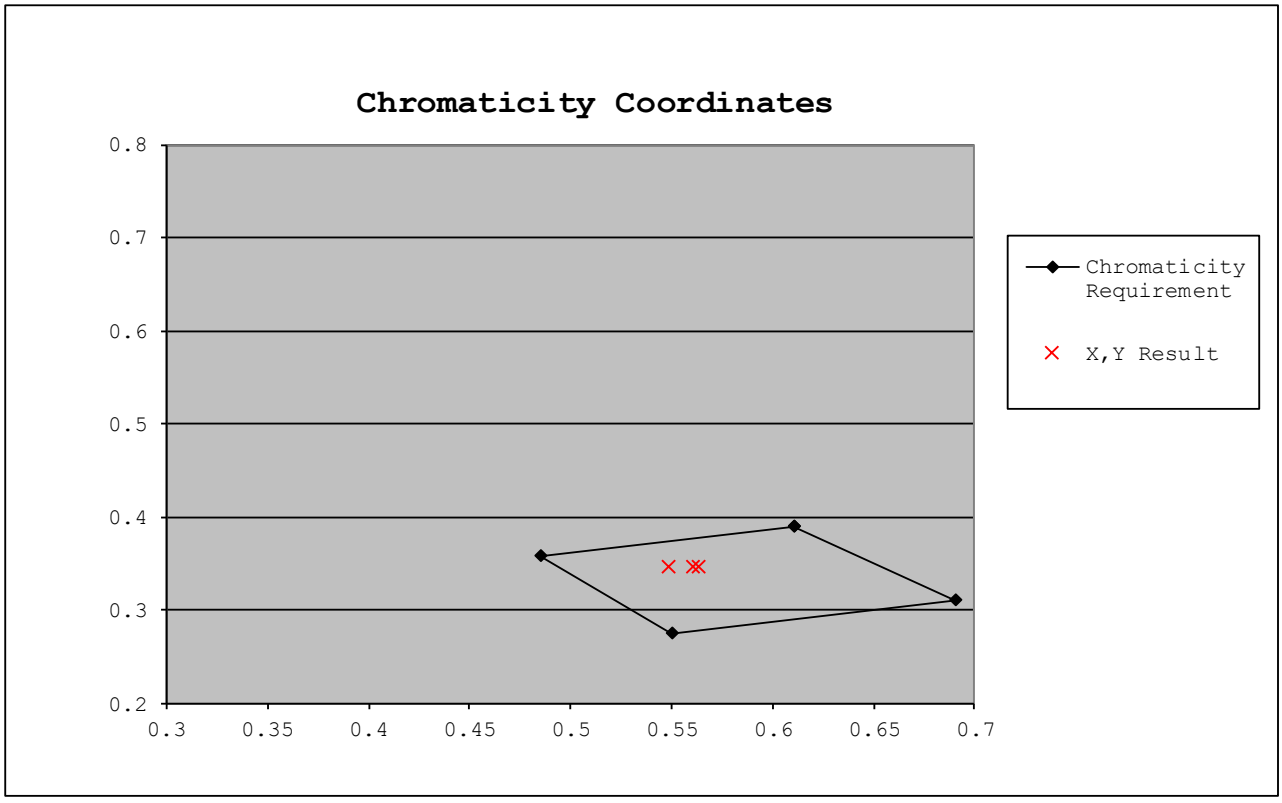
Sample #: 0032, specimen B uncoated side
Sample Description: Fluorescent Reddish-Orange Woven fabric (FA1281-46)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.595	0.350
2			0.593	0.350
3			0.591	0.350



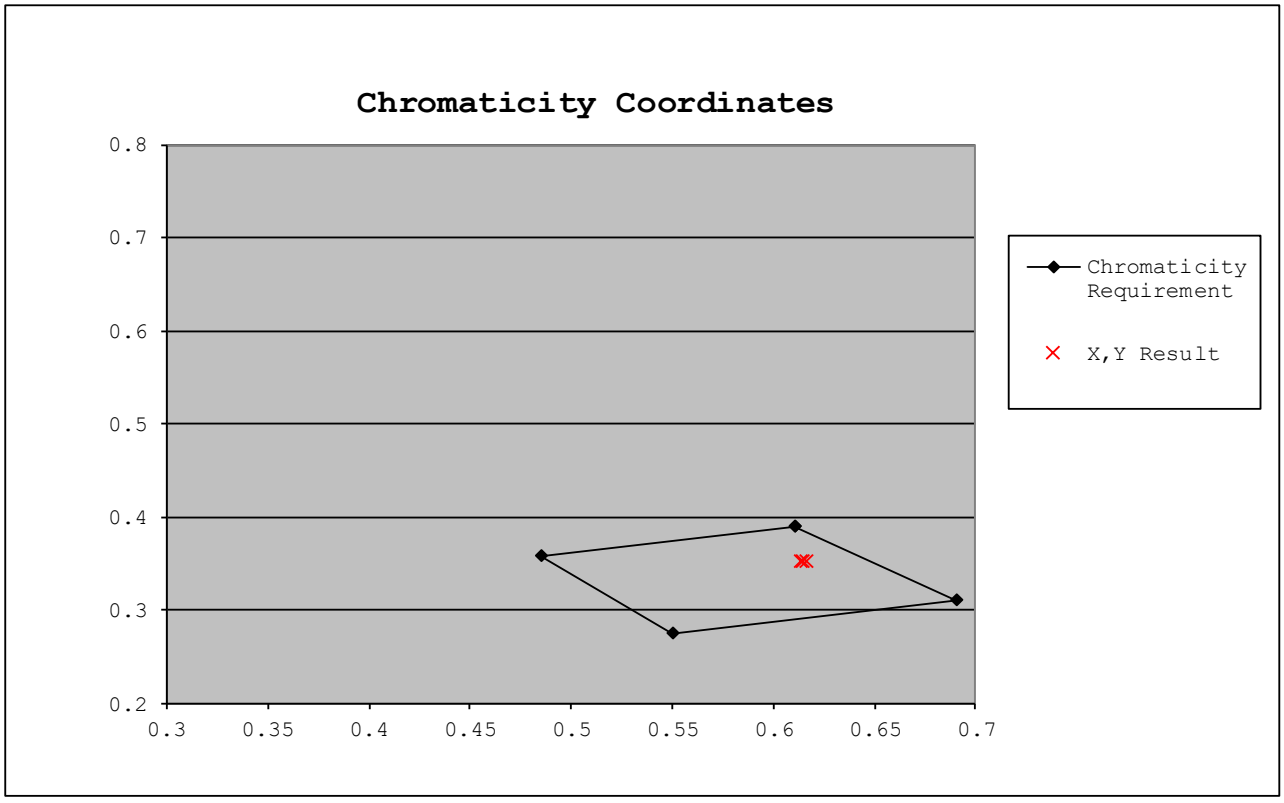
Sample #: 0032, specimen B coated side
Sample Description: Fluorescent Reddish-Orange Woven fabric (FA1281-46)

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.560	0.346
2			0.548	0.346
3			0.563	0.346

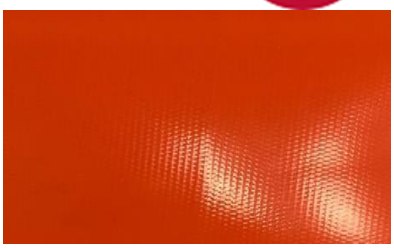


Sample #: 0033
Sample Description: Orange Tile

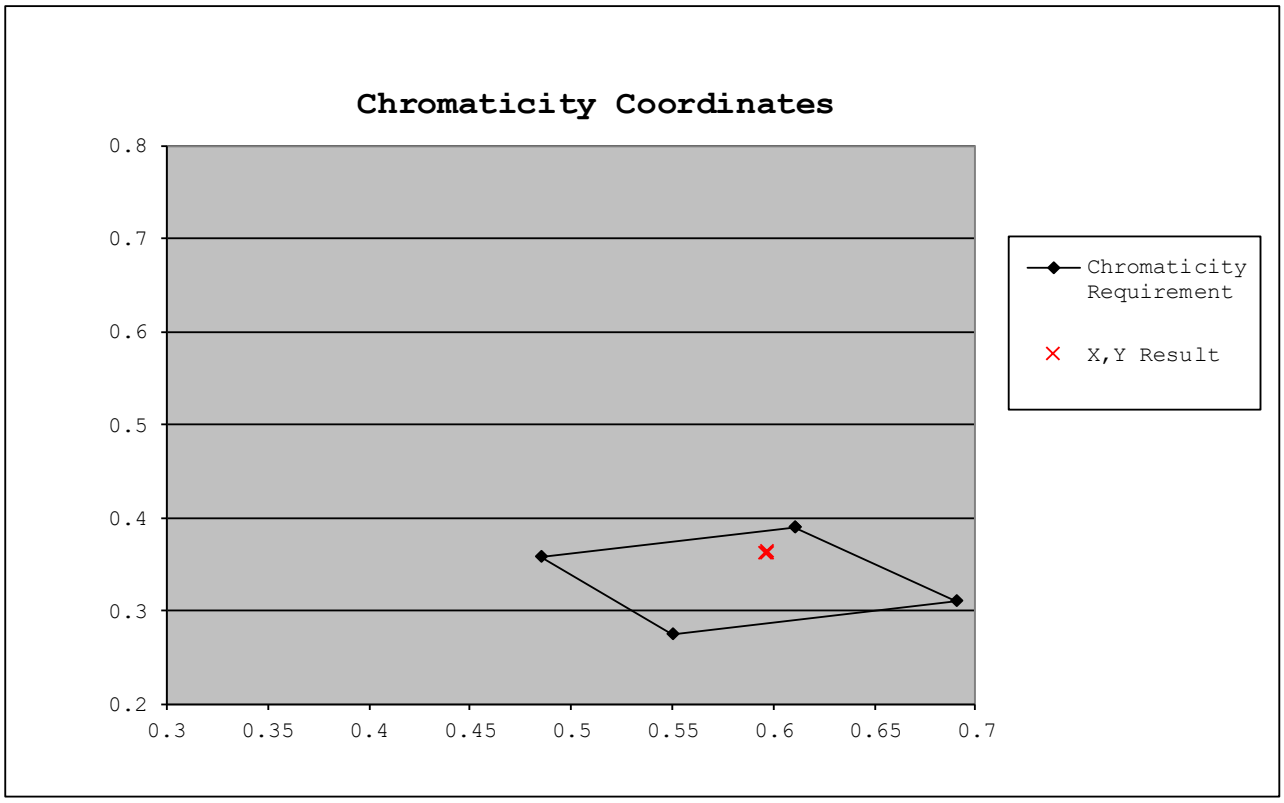
Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.616	0.353
2			0.614	0.353
3			0.613	0.353



Sample #: 0034
Sample Description: Orange Vinyl dipped fabric

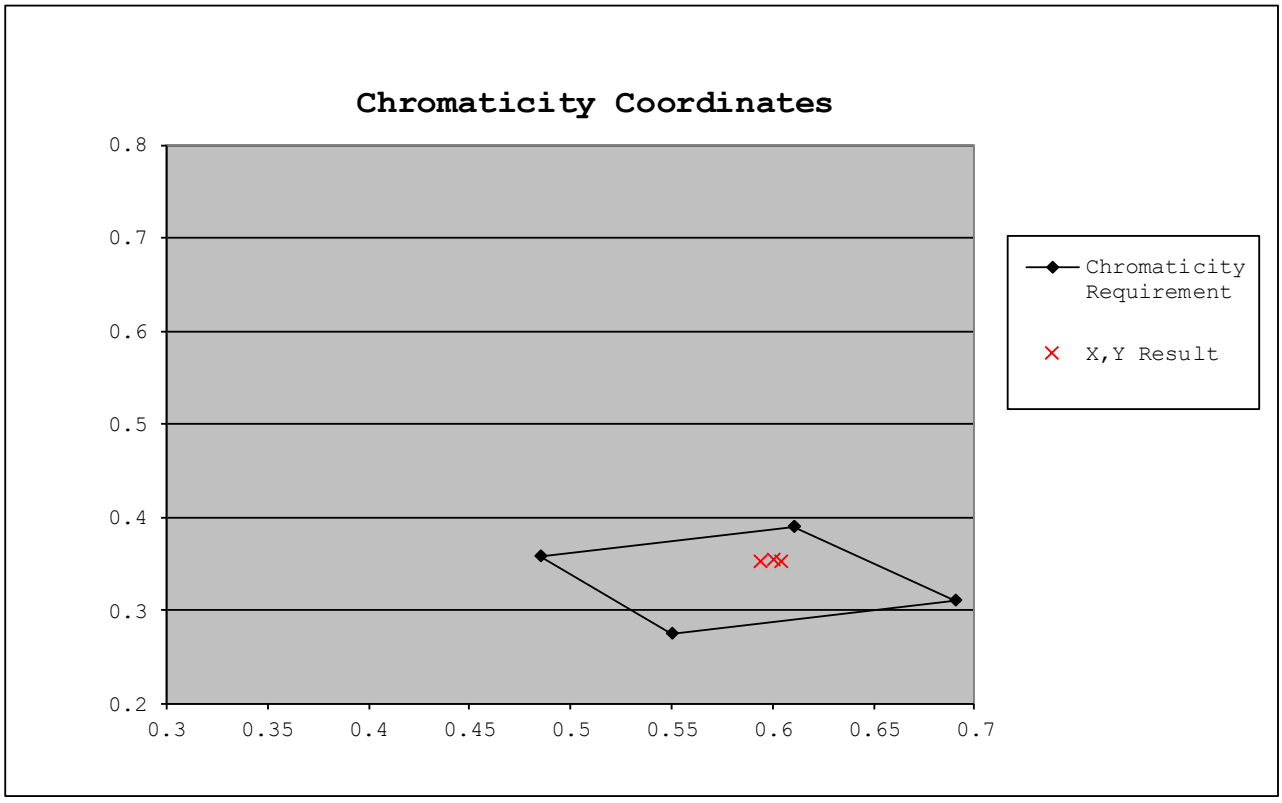


Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.596	0.363
2			0.596	0.363
3			0.596	0.363



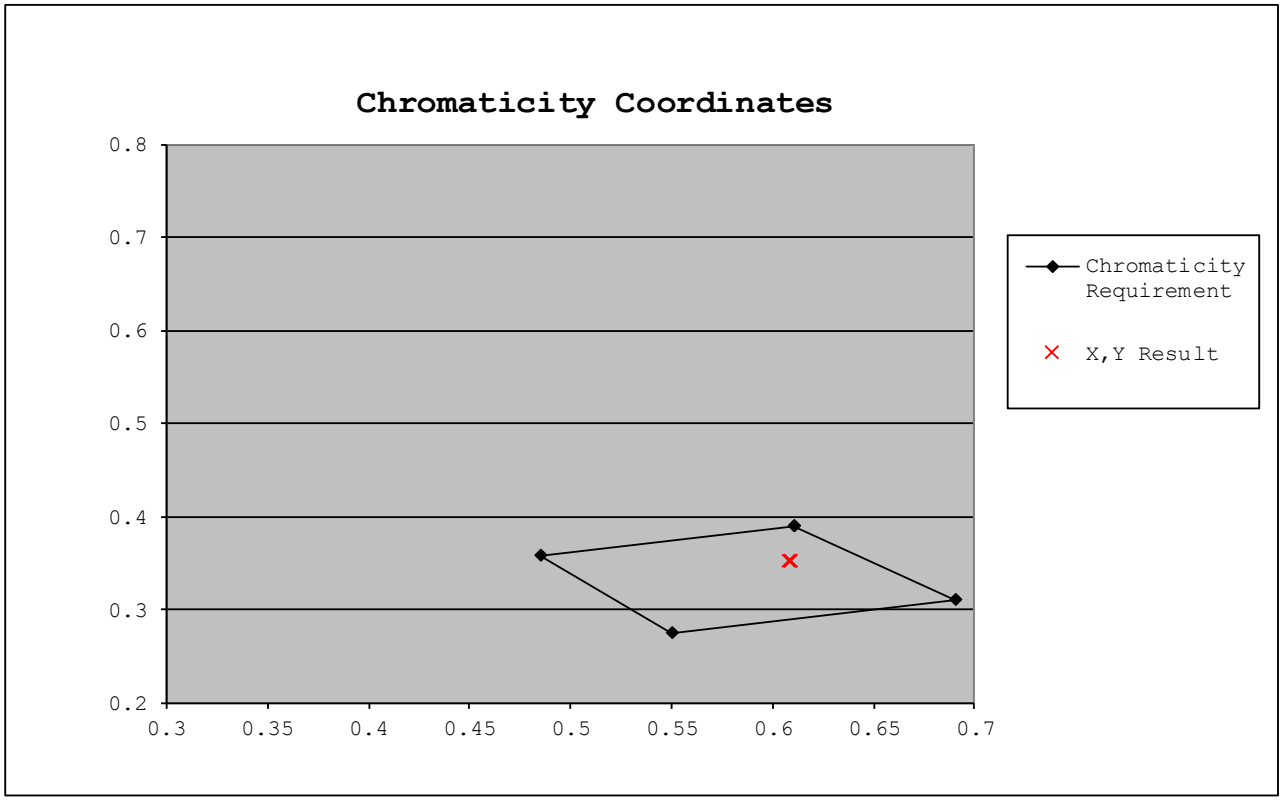
Sample #: 0001, specimen A
Sample Description: Orange Vinyl dipped PVC foam

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.601	0.354
2			0.594	0.352
3			0.604	0.353

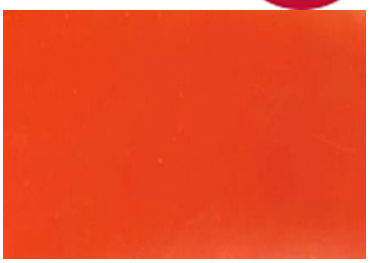


Sample #: 0001, specimen B
Sample Description: Orange Vinyl dipped PVC foam

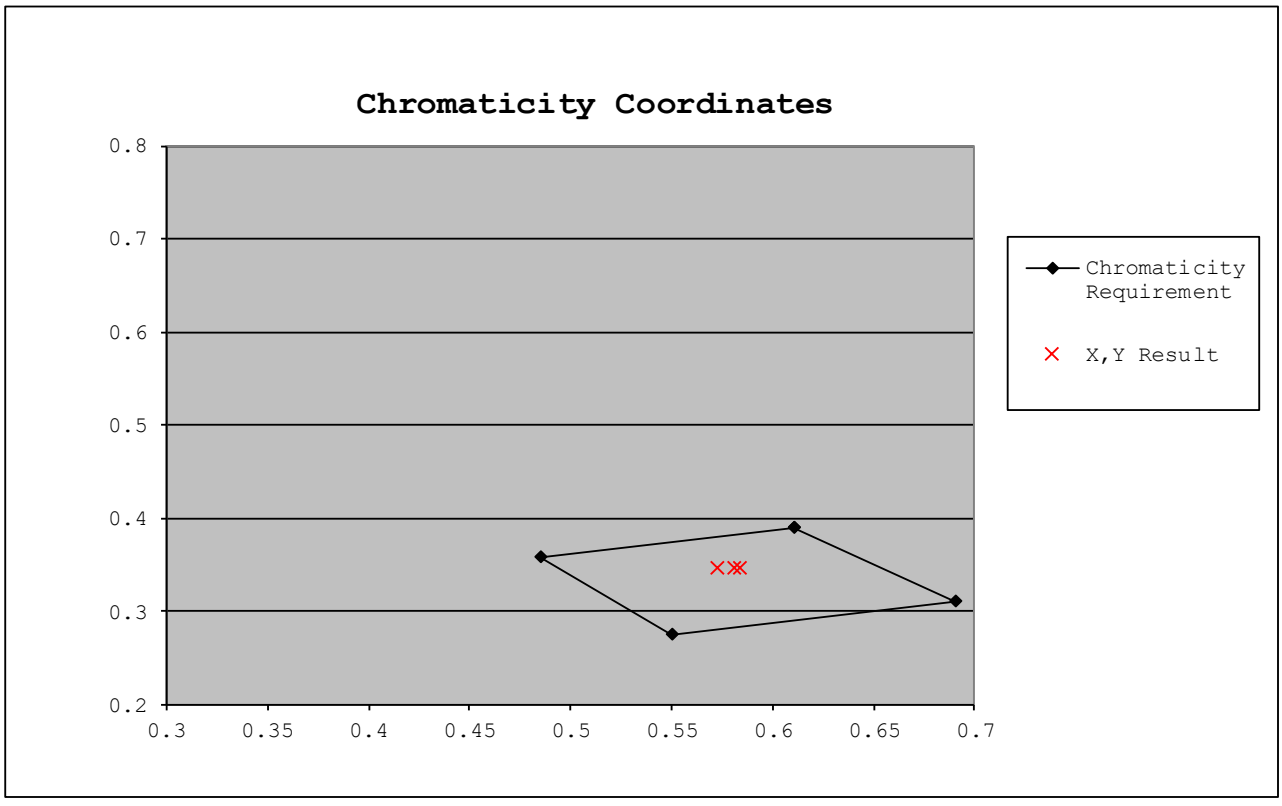
Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.608	0.353
2			0.608	0.353
3			0.608	0.353



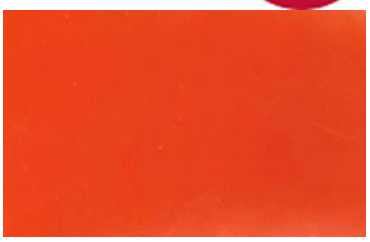
Sample #: 004, specimen A
Sample Description: Orange Hard-shell Ring Buoy Section



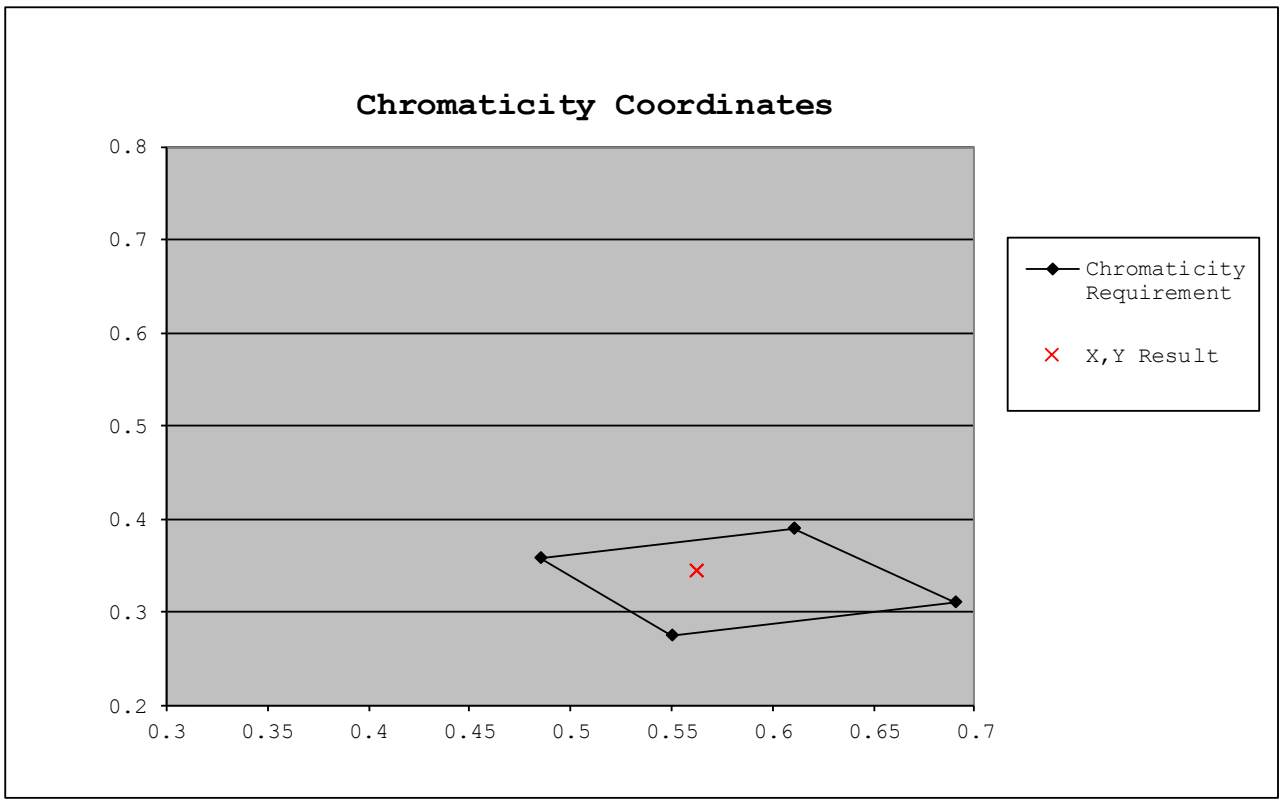
Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.584	0.347
2			0.581	0.347
3			0.572	0.347



Sample #: 004, specimen B
Sample Description: Orange Hard-shell Ring Buoy Section

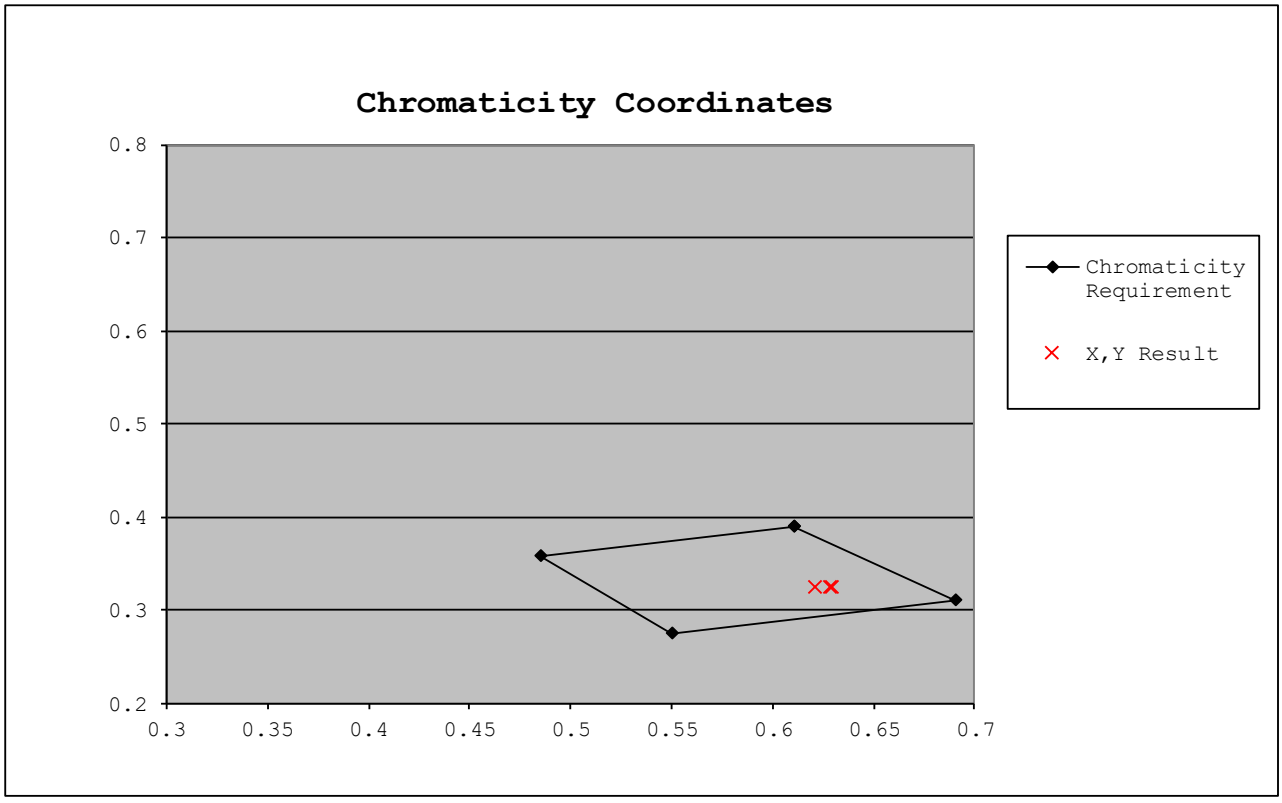


Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.562	0.345
2			0.562	0.345
3			0.562	0.345



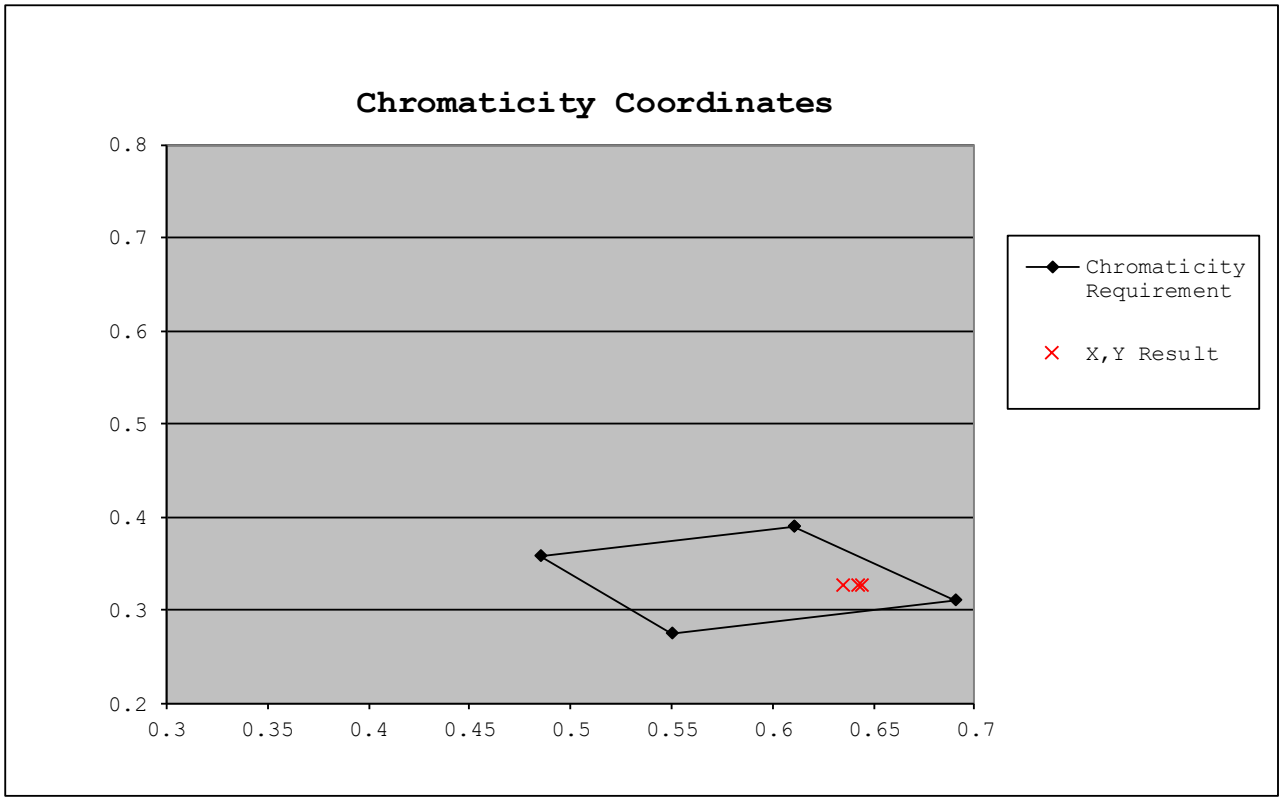
Sample #: 005, specimen A
Sample Description: Red Soft-shell Ring Buoy Section

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.629	0.324
2			0.621	0.324
3			0.628	0.324



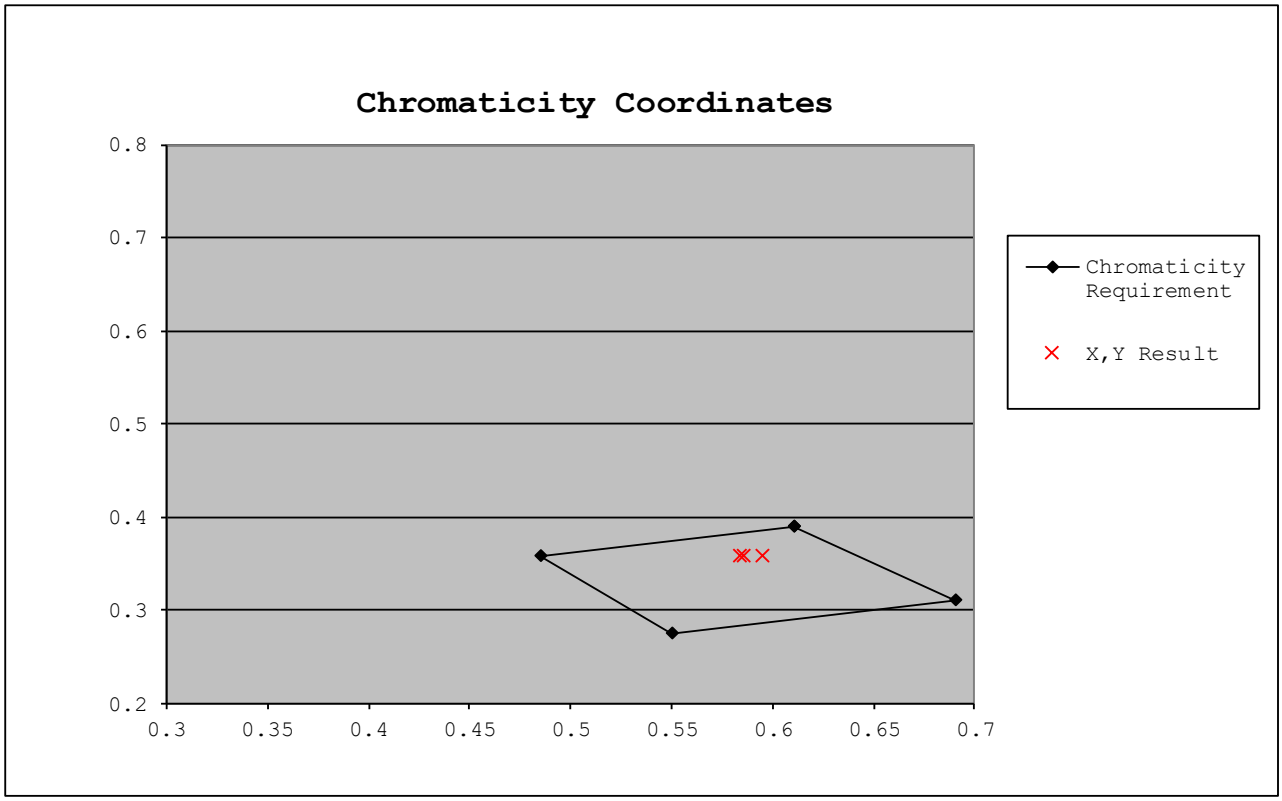
Sample #: 005, specimen B
Sample Description: Red Soft-shell Ring Buoy Section

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.644	0.327
2			0.642	0.326
3			0.634	0.326



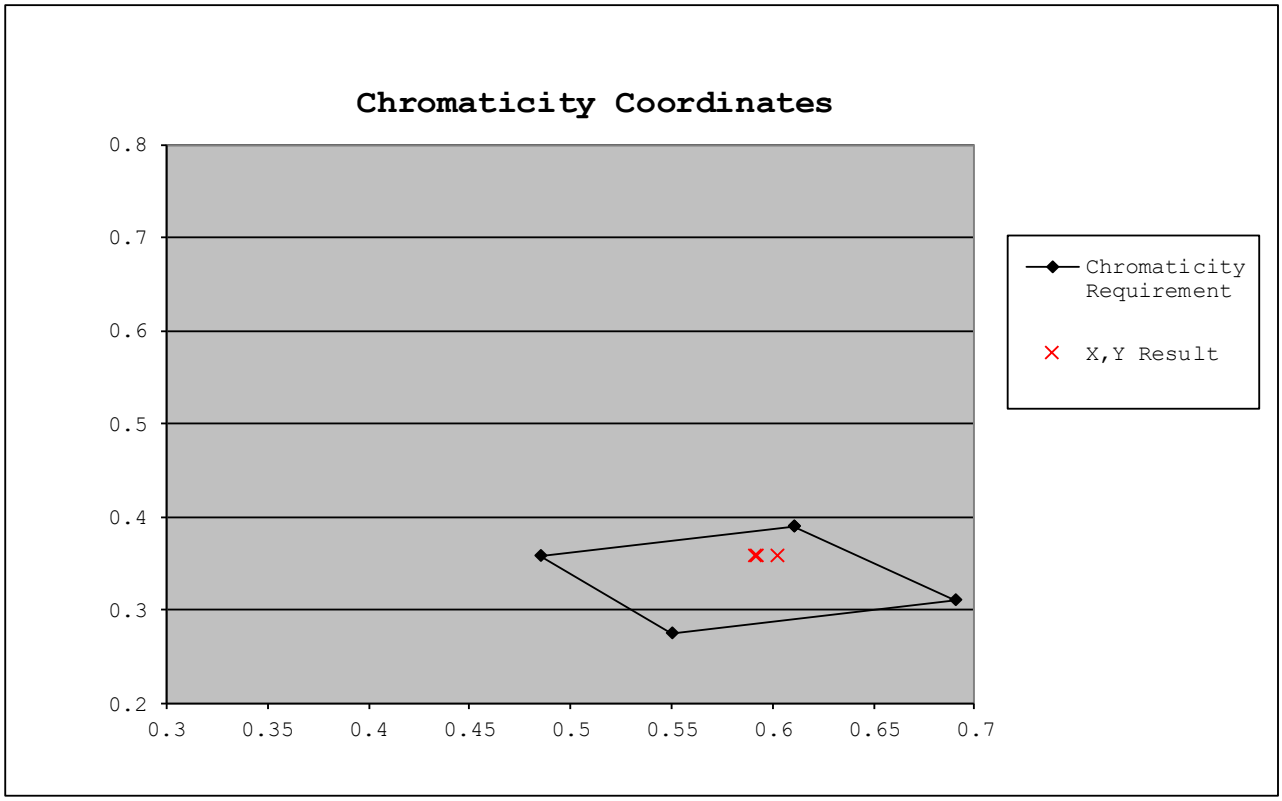
Sample #: 006, specimen A
Sample Description: Orange Soft-shell Ring Buoy Section

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.584	0.358
2			0.586	0.357
3			0.595	0.357



Sample #: 006, specimen B
Sample Description: Orange Soft-shell Ring Buoy Section

Location	Conditioning	Color	Chromaticity Result	
			x	y
1	As Received	Orange-Red	0.591	0.357
2			0.592	0.357
3			0.602	0.357



APPENDIX C – Equipment Calibration Certificate

Delta TRAC
A division of Delta Sales Associates
716-631-8103 • www.dsareps.com

Calibration Certificate #: 1569.01

8171 Main Street, Buffalo, NY 14221

STATEMENT OF CALIBRATION

Certificate #: MCD-071618-01

Company:	Underwriters Laboratories	**Reference PO#:**	CC
Address:	12 Laboratory Dr., Research Triangle Park, NC		

Instrument:	HunterLab ColorFlex	**Serial #:**	CX 1628/36801	**Condition:**	In Tolerance

The above instrument have been inspected and calibrated and was found to be in operable working condition. This determination was made with N.I.S.T. traceable white calibration tile standard, certified color difference (ΔE) standards and following ISO/IEC 17025:2005 and ANSI/NCSL Z540.1-1994 accredited procedures. The results below relate only to the instrument calibrated.

Date Calibrated:	7/16/2018	**Calibration Due Date:**	7/31/2019
Calibration Procedure:	Color Reflectance	**Procedure #:**	1028948

N.I.S.T. Traceable Color Standards Certification:

Standard	S/N	Acceptance Range ΔE	"As Found" ΔE	"As Left" ΔE	Tol*
L*a*b*	1.6G7.76/6.9SCE & 2.0G7.66/7.1SCE	1.96 - 2.36	2.26	2.20	±0.2 ΔE

Uncertainty Statement +/-0.2 Delta E with a Coverage Factor of k=2 and a Confidence Level of 95%

Temperature:	73 °F	**%RH:**	46%	**Location:**	Lab

Certified By: _____ **Issued:** 7/16/2018

PLEASE NOTE: Conditions affecting the calibration, such as standard wear, temperature, humidity, detector/electronic drift, etc., may affect the performance of this instrument during the recommended calibration interval, such that it may drift out of tolerance. It is recommended that the actual working calibration of this instrument be verified by the user on a regular basis according to manufacturer's specifications.

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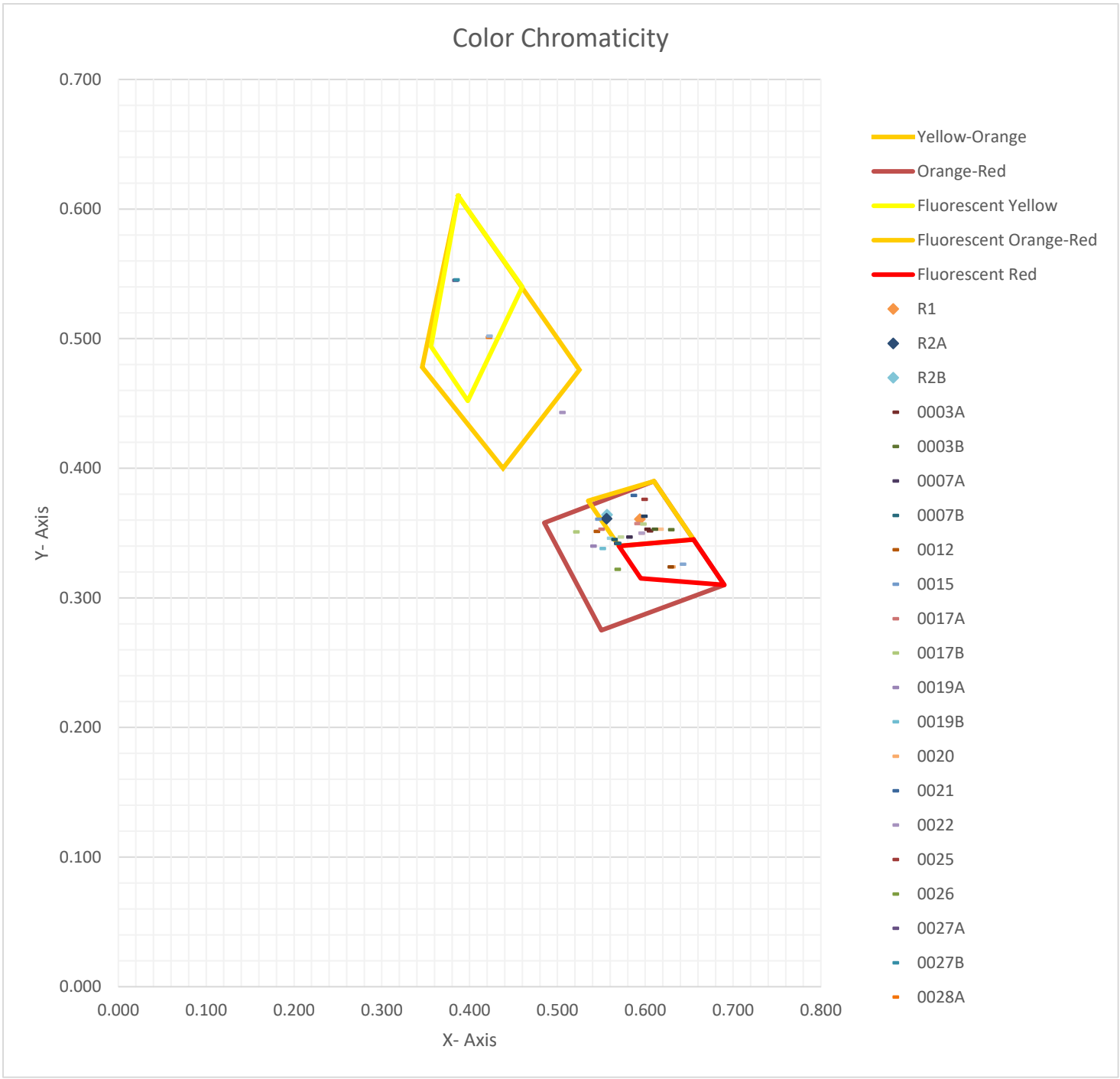
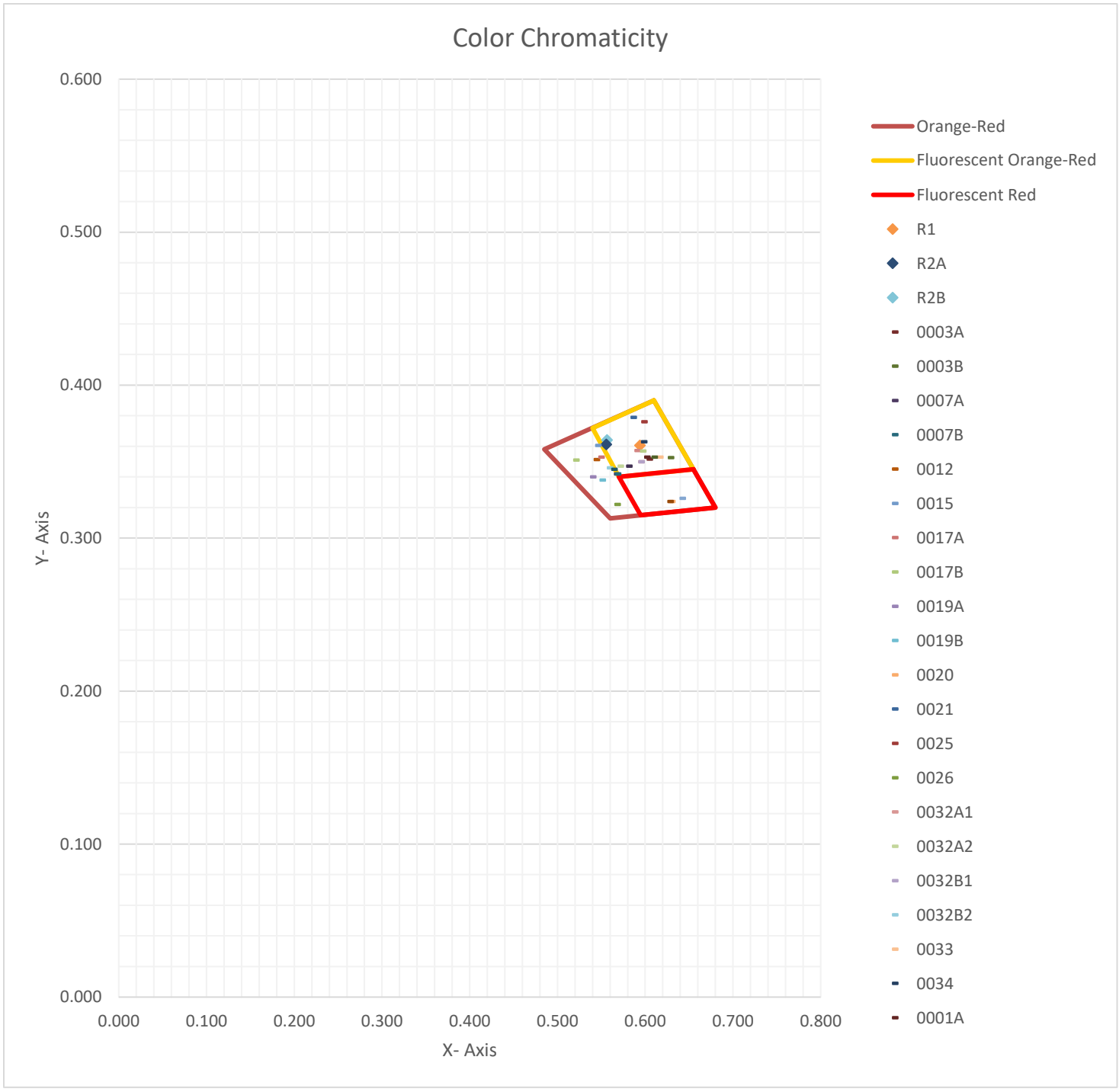
APPENDIX D – Color Chromaticity Results Summary

Color Chromaticity Results		Sample	Color
X	Y		
0.594	0.361	R1	Vivid Reddish Orange/International Orange, FED-STD-595C No. 12197
0.556	0.361	R2A	Indian Orange, FED-STD-595C No. 70072, uncoated side
0.557	0.364	R2B	Indian Orange, FED-STD-595C No. 70072, coated side
0.602	0.352	0003A	Orange Vinyl dipped PVC foam
0.627	0.353	0003B	Orange Vinyl dipped PVC foam
0.565	0.342	0007A	Orange Fabric-laminated foam
0.566	0.342	0007B	Orange Fabric-laminated foam
0.542	0.351	0012	Orange Woven fabric
0.544	0.361	0015	Orange Woven fabric
0.547	0.353	0017A	Orange Woven fabric, uncoated side
0.519	0.351	0017B	Orange Woven fabric, coated side
0.538	0.340	0019A	Reddish-Orange Woven fabric, uncoated side
0.549	0.338	0019B	Reddish-Orange Woven fabric, coated side
0.628	0.324	0020	Red Tile
0.584	0.379	0021	Orange Tile
0.503	0.443	0022	Yellow-Orange Tile
0.596	0.376	0025	Orange Tile
0.566	0.322	0026	Red Fabric-laminated foam
0.381	0.545	0027A	Yellow Woven fabric (FA1723-45)
0.382	0.545	0027B	Yellow Woven fabric (FA1723-45)
0.419	0.501	0028A	Yellow Woven fabric (FA1791-193)
0.420	0.502	0028B	Yellow Woven fabric (FA1791-193)
0.593	0.350	0032A1	Reddish-Orange Woven fabric (FA1281-46), uncoated side
0.569	0.347	0032A2	Reddish-Orange Woven fabric (FA1281-46), coated side
0.593	0.350	0032B1	Reddish-Orange Woven fabric (FA1281-46), uncoated side
0.557	0.346	0032B2	Reddish-Orange Woven fabric (FA1281-46), coated side
0.614	0.353	0033	Orange Tile
0.596	0.363	0034	Orange Vinyl dipped fabric
0.600	0.353	0001A	Orange Vinyl dipped PVC foam
0.608	0.353	0001B	Orange Vinyl dipped PVC foam
0.579	0.347	0004A	Orange Hard-shell Ring Buoy Section
0.562	0.345	0004B	Orange Hard-shell Ring Buoy Section
0.626	0.324	0005A	Red Soft-shell Ring Buoy Section
0.640	0.326	0005B	Red Soft-shell Ring Buoy Section
0.588	0.357	0006A	Orange Soft-shell Ring Buoy Section
0.595	0.357	0006B	Orange Soft-shell Ring Buoy Section

APPENDIX E – CIE Plots of Data Points with ISO 12402-7 Polygons



APPENDIX F – CIE Plots of Data Points with UL Defined Polygons



APPENDIX G – Individual Chromaticity Color Measurements

Sample ID	Chromaticity Result	
	x	y
R1	0.595	0.361
	0.595	0.361
	0.592	0.361
Avg.	0.594	0.361
Median	0.595	0.361
R2A	0.555	0.361
	0.555	0.361
	0.557	0.362
Avg.	0.556	0.361
Median	0.555	0.361
R2B	0.557	0.364
	0.555	0.364
	0.558	0.364
Avg.	0.557	0.364
Median	0.557	0.364
001B	0.608	0.353
	0.608	0.353
	0.608	0.353
Avg.	0.608	0.353
Median	0.608	0.353
003A	0.623	0.353
	0.614	0.353
	0.570	0.349
Avg.	0.602	0.352
Median	0.614	0.353
003B	0.628	0.353
	0.626	0.352
	0.626	0.353
Avg.	0.627	0.353
Median	0.626	0.353
004A	0.584	0.347
	0.581	0.347
	0.572	0.347
Avg.	0.579	0.347
Median	0.581	0.347
004B	0.562	0.345
	0.562	0.345
	0.562	0.345
Avg.	0.562	0.345
Median	0.562	0.345

Sample ID	Chromaticity Result	
	x	y
005A	0.629	0.324
	0.621	0.324
	0.628	0.324
Avg.	0.626	0.324
Median	0.628	0.324
005B	0.644	0.327
	0.642	0.326
	0.634	0.326
Avg.	0.640	0.326
Median	0.642	0.326
006A	0.584	0.358
	0.586	0.357
	0.595	0.357
Avg.	0.588	0.357
Median	0.586	0.357
006B	0.591	0.357
	0.592	0.357
	0.602	0.357
Avg.	0.595	0.357
Median	0.592	0.357
007A	0.565	0.342
	0.565	0.342
	0.565	0.342
Avg.	0.565	0.342
Median	0.565	0.342
007B	0.566	0.342
	0.566	0.342
	0.567	0.342
Avg.	0.566	0.342
Median	0.566	0.342
0012 fabric	0.542	0.352
	0.541	0.351
	0.543	0.351
Avg.	0.542	0.351
Median	0.542	0.351
0015 fabric	0.544	0.360
	0.544	0.361
	0.543	0.361
Avg.	0.544	0.361
Median	0.544	0.361

Sample ID	Chromaticity Result	
	x	y
0017A	0.548	0.353
	0.547	0.353
	0.547	0.353
Avg.	0.547	0.353
Median	0.547	0.353
0017B	0.518	0.351
	0.519	0.351
	0.519	0.351
Avg.	0.519	0.351
Median	0.519	0.351
0019A	0.538	0.340
	0.538	0.340
	0.538	0.340
Avg.	0.538	0.340
Median	0.538	0.340
0019B	0.548	0.338
	0.549	0.338
	0.549	0.338
Avg.	0.549	0.338
Median	0.549	0.338
0020, red tile	0.628	0.324
	0.627	0.324
	0.629	0.324
Avg.	0.628	0.324
Median	0.628	0.324
0021, orange tile	0.584	0.379
	0.584	0.379
	0.584	0.379
Avg.	0.584	0.379
Median	0.584	0.379
0022, yellow-orange tile	0.502	0.443
	0.503	0.443
	0.503	0.443
Avg.	0.503	0.443
Median	0.503	0.443
0025, orange tile	0.596	0.376
	0.596	0.376
	0.597	0.376
Avg.	0.596	0.376
Median	0.596	0.376

Sample ID	Chromaticity Result	
	x	y
6, red fabric-laminated fc	0.565	0.322
	0.566	0.322
	0.566	0.322
Avg.	0.566	0.322
Median	0.566	0.322
0027A	0.381	0.545
	0.381	0.545
	0.381	0.545
Avg.	0.381	0.545
Median	0.381	0.545
0027B	0.382	0.546
	0.382	0.545
	0.382	0.545
Avg.	0.382	0.545
Median	0.382	0.545
0028A	0.419	0.501
	0.419	0.501
	0.419	0.501
Avg.	0.419	0.501
Median	0.419	0.501
0028B	0.419	0.502
	0.420	0.502
	0.420	0.502
Avg.	0.420	0.502
Median	0.420	0.502
0032A1	0.593	0.350
	0.592	0.350
	0.594	0.350
Avg.	0.593	0.350
Median	0.593	0.350
0032A2	0.567	0.347
	0.573	0.347
	0.568	0.347
Avg.	0.569	0.347
Median	0.568	0.347
0032B1	0.595	0.350
	0.593	0.350
	0.591	0.350
Avg.	0.593	0.350
Median	0.593	0.350

Sample ID	Chromaticity Result	
	x	y
0032B2	0.560	0.346
	0.548	0.346
	0.563	0.346
Avg.	0.557	0.346
Median	0.560	0.346
0033, orange tile	0.616	0.353
	0.614	0.353
	0.613	0.353
Avg.	0.614	0.353
Median	0.614	0.353
4, orange vinyl dipped fa	0.596	0.363
	0.596	0.363
	0.596	0.363
Avg.	0.596	0.363
Median	0.596	0.363
001A	0.601	0.354
	0.594	0.352
	0.604	0.353
Avg.	0.600	0.353
Median	0.601	0.353