Analysis of CIPP Composites

By

Gravimetric Methods

By

Steven R. Leffler

Technical Director

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Scope:

Using a modified method of ASTM D-792, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement, and multi-component mixture diagrams, and/or the mathematical equivalent of them, quantitative values for the percentage of the components are obtained. Also, by calculating the theoretical values of specific gravity and listing the ideal ratio of the resin and felt, those values may be compared to the actual quantitative values to gauge the quality of the product and conformance to standards and specifications.

Method Summary:

The following is a modified ASTM D792 method. An electronic scale accurate to 0.01gram is used to weigh the specific gravity sample when the sample is suspended in air and when it is then submersed in tap water. Many electronic platform scales have a hook on the underside to facilitate suspending a sample by a string or wire. Using a bucket or deep tub, fill it with tap water and let it sit for a day to bring the water to room temperature and to let the dissolved air bubble out. The CIPP sample is weighted dry while suspended, and then submersed. If the sample floats, as occasionally happen, then you'll need to add lead fish weights to sink the sample.

A typical CIPP composite sample, as delivered from the field, is essentially comprised of three major components and one contaminate component, namely, entrained air in the presence of voids. The major components are the cured **resin** and PET **felt**, that are the medium that the air is entrained in, and a thermoplastic (TP) (usually polyurethane (**PU**) or polyethylene (PE)) coating that is bonded but essentially a homogenous layer typically covering one surface. The TP layer is separated from the resin/felt through mathematically calculating the approximate volume and weight based on the measured dimensions and the nominal specific gravity. The best way to get the dimensions of the TP layer, is to cut the sample to some easily calculated area, such as, a square or rectangle, a trapezoid or a circle as from a hole-saw core sample.

The specific gravity of the resin/felt/air composite is then calculated and that value is plotted at the two places on the frame of the ternary plot (a three component mixture diagram) that it is equal. A line, the "iso-specific gravity" line, is drawn onto the ternary plot connecting the two points that is the same specific gravity as the value of the sample (akin to contour line on a map). The felt is assigned a value of 13-15% (a reasonable estimate) and a line drawn on the ternary plot. The values of the resin and air, if it is present, are determined by where the iso-specific gravity line and the felt 15% lines intersect. A demonstration example ternary plot is included.

Apparatus:

The sample needs to be arranged to load the scale by tension so the buoyant weight of the sample can be measured. The scale comes with a tension-loading eye on the bottom of the housing that allows you to load the scale in tension. The Archimedes' principle, essentially states that the buoyed weight of a sample is the difference between the density of the sample and the volume of water it displaces. This principle is used to determine the specific gravity. You will need to have a support structure to hold the scale above a bucket or other basin of water. You'll also need a band saw or device to cut and trim the samples, rulers or other length measure, felt pens, and forms for data and information.

Test Specimen Preparation:

Field samples should be uniquely identified and labeled. Indelible felt pen markers work well. They should be trimmed with a saw to form either rectangular shapes, trapezoids or circles so the area of the PU could be reasonably calculated. Avoid areas that have over-lapped felt seams, or TP patches or seam tape or other areas that have multiple thickness of TP material, unless the entire sample has a double thick layer and the data is accounted for in the calculation. As a modification of the ASTM D792 Standard, sample sizes greater than 50 grams are acceptable in order to improve average. CIPP field samples tend to exhibit quite wide variation of resin saturation and air entrainment over small areas. Within reason, there is no fundamental size limit to the application of Archimedes's Principle.

Temperature Conditioning:

Unless there are legal issues, no special temperature controls are needed, as the variance in the lab temperature from the standard temperature, and the variance in the daily temperatures was not great enough to affect the accuracy needed for routine analysis.

Procedure:

1. The samples are labeled with the identification
2. The samples are cut from the larger sample, where appropriate, to make a regular shape that can easily provide a surface area calculation of the area of the TP layer. Make them as large as practical within the bounds of the size of the bucket. Larger samples can be tested provided the water basin is an adequate size.

3. Measure the dimensions and record the data. (In the case of trapezoids and circles, calculate the area and convert to an equivalent square by taking the square root of the area.)
4. Tare-out the combined rigging weight.
5. Attach the sample to the rigging and take the suspended dry sample and record the weight
6. Lift the suspended sample and place the bucket of water centered under the sample.
7. Lower the sample into the water, making sure it is totally submersed and it does not touch any sides or the bottom of the bucket.
8. Let the scale reading stabilize and record the weight of the submersed sample. You may need take a probe or rod and get rid of any bubbles that form on the sample.
9. Remove the sample and make the rigging ready for the next sample and repeat procedures 1-8 if more samples are to be tested.

<u>Calculations:</u>

1. Subtract the submersed weight from the dry weight and this yields the weight of water displaced which by the definition of specific gravity, water is the standard, this equals the volume of water displaced which equals the volume of the sample.
   Example:

Sample Dry Wt.	46.25g
Submersed Wt.	<u>- 6.31g</u>
	39.94g = 39.94 ml = Sample Volume

2. Divide the composite dry weight by the volume calculated in Step 1., above, which will yield the sample density or specific gravity, as they are equal:

$$\frac{46.25g}{39.94ml} = 1.158g/ml = 1.158 sp.gr.$$

3. Calculate the area of the TP layer. The felt and felt-tube manufacturer has given the coating specifications as 400g/m^2 at a sp. gr. of 1.22 for the PU polymer. This calculates out to an average thickness of 0.33 mm. They have also given a figure of 440 grams-per-square-meter and that is effectively 0.361mm. The later value is the value we use to calculate the volume and weight of the PU on the sample.

   135mm * 56mm = 7,560 mm^2

4. Calculate the volume of the PU coating:

   7,560 mm^2 * 0.361mm = 2,729mm^3 = 2.73ml

5. Calculate the weight of the PU coating:

   2.73 ml * 1.22 g/ml = 3.33g

6. Subtract the calculated volume of the PU layer from Step 4., from the volume of the field sample from Step 1., to get a value for the volume of only the resin and felt:

Sample Volume	39.94ml
PU Volume	- 2.73ml
	37.21ml = volume of resin/felt

7. Subtract the calculated weight of the PU from Step 5., from the measured weight of the of the dry sample from Step 1., to get a calculated value for the weight of the resin and felt:

Sample Dry Wt.	46.25g
PU Wt.	- 3.33g
	42.92g = weight of the resin/felt

8. Divide the weight of the resin/felt from Step 7., by the volume of the resin/felt in Step 6., to get a value for the *Specific Gravity* of the resin/felt composite which is the result we are after:

$$\frac{42.92g}{37.21ml} = 1.153g/ml = 1.153sp.gr \text{ of the resin/felt}$$

9. Calculate the average thickness by dividing the volume from Step 6. (convert to like units), by the surface area from Step 4., :

$$\frac{37.21ml}{7{,}560mm^2} = 4.9mm$$

10. We can calculate the percent of felt in the CIPP composite sample without the TP layer, by dividing the nominal specified thickness, in this case 6mm, by the average thickness found in Step 9., and then multiplying that by the nominal specified felt percentage (13% in this case):

$$0.13 \times \frac{6mm}{4.9mm} = 0.159 = 15.9\%$$

11. And finally, we calculate the ideal specific gravity of the resin and felt, a two component mixture. This would be arrived at by multiplying the percentage

of each part by the specific gravity value of each accordingly, then adding the two products:

$$(0.13 \times 1.38) + (0.87 \times 1.19) = 1.25$$

Ternary Plot Analysis:

The ternary plot and the following analysis can be done mathematically using planar geometry and 3-D vectors, and that is done that in an EXCEL spreadsheet model as shown in Attachment 1, Figure 1.

It however it is somewhat complex and beyond the scope of a paper such as this one, and the analysis can be more effectively demonstrated graphically as in Figure 2.

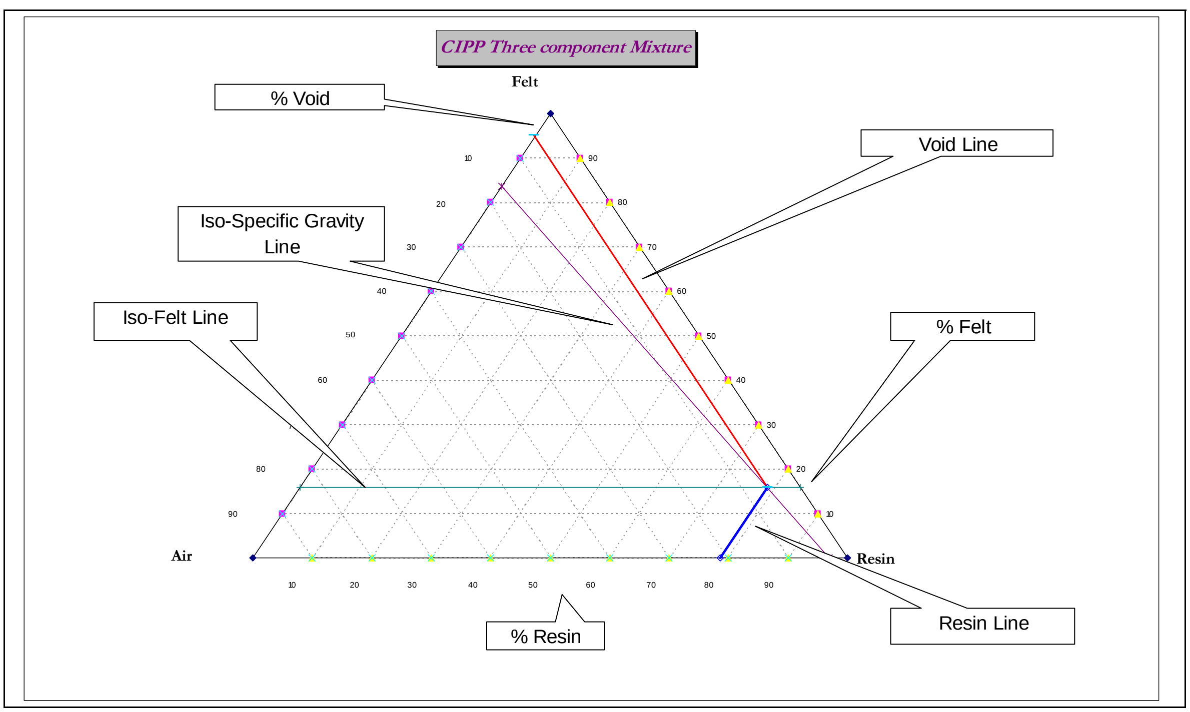

Figure 2: Ternary Plot – Resin/Felt/& Air (voids)

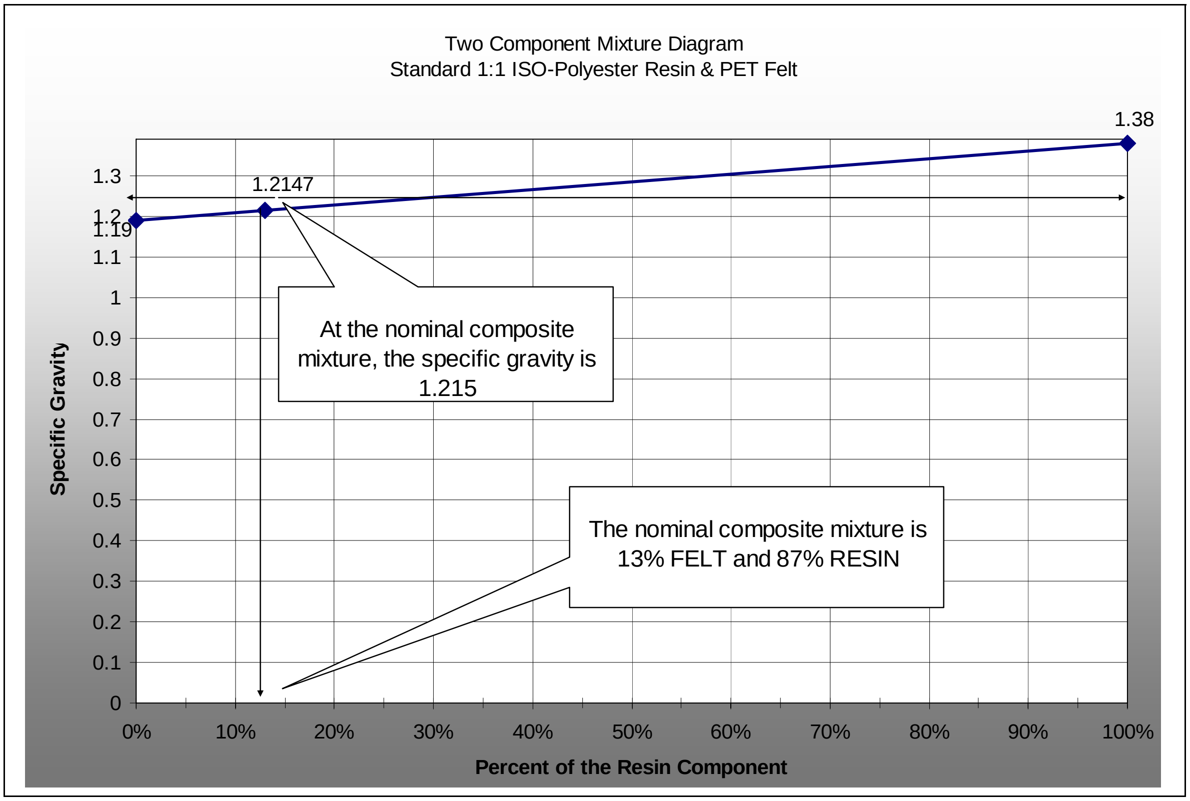

Figure 3: Two Component Mixture Plot, Nominal Resin/Felt

The ideal resin/felt composite is a two component mixture of just resin and felt. The proportions of each in a mixture can be analyzed using a two component mixture diagram, see Figure 3, and easily calculated as in Step 11., above. By measuring the density of the mixture and knowing the specific gravities (or densities) of each individual component, then by locating the specific gravity of the mixture on the diagonal line that connects the two pure components on a base scale of 0 – 100%, the percent of each component will be the base scale directly below the point on the line.

When we have a three component mixture, the mixture diagram is graphically a ternary plot (an equilateral triangular surface) with the scale on each side running from 0 – 100% for each component along one of the sides of the triangle, see Attachment 2. In the limit that one of the components of the mixture goes to 0%, then the mixture diagram is effectively a two component diagram as in attachment 1, only it is one edge of the equilateral triangle. The specific gravity of a mixture will always be less than the specific gravity of the heaviest component. The specific gravity of the sample will be a value point on two of the three sides of the triangle so we calculate the points and mark them on the base lines. For the sample we've been using above,:

$$\text{Sample sp.gr/Resin sp.gr.} = \frac{1.158}{1.19} = 0.9731$$

$$\text{Sample sp.gr/Felt sp.gr} = \frac{1.158}{1.38} = 0.8391$$

Then we need to draw a line connecting those two points and this defines all the possible mixtures with the specific gravity of that the sample was measured to have, in other words, an "iso-specific gravity" line. Think of it as the same as an "iso-bar" on a weather map or a "contour line" on a map.

This "iso-specific gravity" line is not of much value to us at this point, so we will need to estimate the approximate value of one of the components. In this case, we know the approximate amount of felt in the felt-tube, the specifications state that it was 13% felt and 87% nominal void by volume.

Having "fixed" the felt from Step 11., at 15.8%, we draw a line across the triangle between 15.8% on the felt side and the 84.2% on the void side. This is the "iso-felt" content line where all mixture along that line has 15.8% felt and varying amount of the other two components.

That point where the "iso-felt" line and the "iso-specific gravity" line intersect is the point we are interested in. We follow the lines up and left to pinpoint the void (air) content, in percent, and we follow the line down and to the left to pinpoint the resin content, in percent. For the example in attachment 2, the void is 5.1% of the composite and the resin is 82%.

We know from the ideal two component mixture of resin and felt that the resin should make up 87% of the composite. If we have 82% resin, then we can divide 0.82 by 0.85 and find that we have approximately only 95% of the resin of the void free composite at the tested thickness. The question that can not be answered here is – why. If the resin was placed into the tube at the time of the wetout, by virtue of the proper gap setting for the thickness of the felt and the cut percentage of the felt-tube, and verified by a yield calculation, then it migrated out of the felt during installation and cure. There is also the possibility that the proper amount of resin was not placed in the felt at the time of wetout.

This brings us to an important point of analysis. We saw from Step 9., above, that the average thickness was only 4.9mm of the nominal 6mm. The sample is only 82% of the nominal thickness. Further, we need to calculate the amount of resin by weight in the CIPP sample, and compare (by dividing) that to the amount of resin in the ideal to get a percent of ideal. In condensed form:

$$\text{Sample Resin/Ideal Resin} = \frac{35.39}{46.96} = 0.7536 = 75\%$$

This figure, 75% of ideal resin, indicates a serious short fall of resin, and along with the 4.9mm thickness, that this would be a product likely not meeting specifications, and certainly not a CIPP composite not being made according to the industry standard, ASTM F1216 for example.

Conclusion:

Cured CIPP samples, through gravimetric analysis and product data provided by the material suppliers, can yield quantitative numbers to gauge quality and conformance of the installed and cured CIPP product that augments the standard physical properties testing.

It further enables the astute investigator highly technical diagnostics in the event of problems. It can provide insight to wetout practices such as roller gap setting and resin yields. These insights can be useful in performing root cause analysis.

Attachment 1.

Resin/Felt CIPP Composite Specific Gravity

Project : Example

Sample ID:

Sample Data		
Sample Width	135	mm
Sample Length	56	mm
Sample Area	7560	mm2
Composite Dry Wt.	46.25	g
Submersed Wt.	6.31	g
Cured Resin sp.gr. =	1.19	
Air sp.gr. =	0.0012	

Felt & Tube Specification Data		
diameter =	8	in.
thickness =	6	mm
Felt sp.gr. =	1.38	
Nominal Felt Volume =	13%	
Coating Thickness	0.36	mm
Coating sp.gr.	1.22	
Theoretical Liner wt =	0.001436	g/mm2
Theoretical Resin wt =	0.006212	g/mm2
Theoretical Volume =	45.36	ml
Coating Volume =	2.72	ml
Coating Wt.	3.32	g

Combined Resin/Felt (and Coating) sp.gr. = 1.158

Water Displaced 39.94 g. = 39.94 ml

Resin/Felt wt.,w/o Coating =	42.93	g
Resin/Felt vol., w/o Coating =	37.22	ml

Percentage of Theoretical Volume

82% = 4.9 mm ave. thickness

Resin/Felt sp.gr. =	1.153	
% Felt in the CIPP Compsite =	15.8%	
% Resin in the Composite =	78.6%	
% Void in the Composite =	5.6%	

Dry Liner (Felt+Coating) Wt =	10.86	g
Net Resin Wt. =	35.39	g
Theoretical Resin Wt. =	46.96	g
% of Theoretical Resin =	75%	

REPORT of ANALYTICAL FINDINGS

The CIPP composite is found to have a specific gravity of ------------------------------------ **1.158**

The ideal nominal specific gravity if a resin/felt composite is ---------------------------------- 1.2147

The composite has been found to be **15.8%** felt, by volume

It has been found to contain **79%** resin by volume, or **91.3%** of the resin required for a void free composite, and **75%** of the theoretical amount of resin to make a solid composite of nominal thickness.

Based on the volume of water displaced divided by the surface area of the sample, the resulting average thickness of the sample is found to be **4.9 mm, or** **82%** of theoretical.

Note: Although we believe this spreadsheet model to be accurate and rigorous within the bounds of certain assumptions, we take no responsibilty for its use, or the results.

Figure 1: EXCEL Spreadsheet Example