Madewell Products Corporation Technical Bulletin:

Controlling and Verifying Coating Film Thickness Over Non-Metallic Substrates

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Table of Contents

SECTION 1: INTRODUCTION

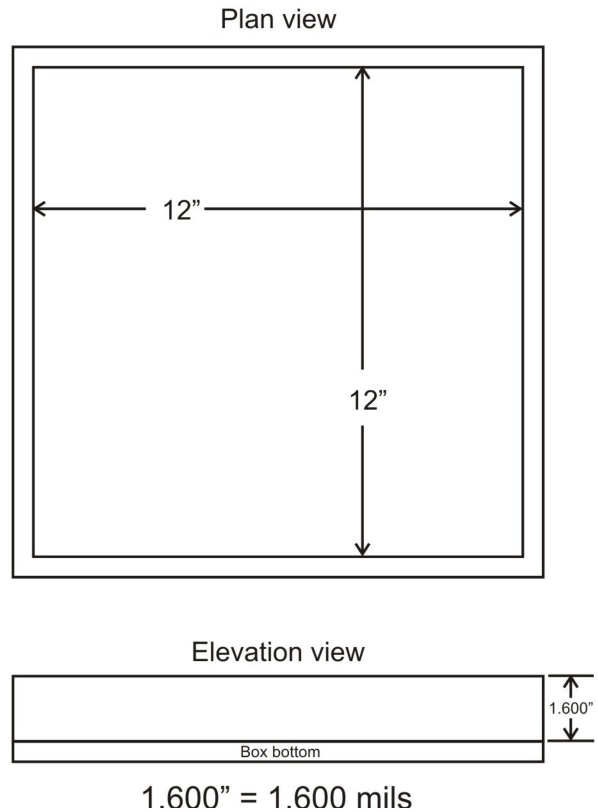
To perform in aggressive atmospheric or immersion service, coatings must be applied at the correct thickness. Measuring the thickness of coatings applied to smooth metallic substrates like steel is very simple and straightforward. In contrast, measuring the thickness of coatings applied to non-metallic substrates is substantially more complicated. In this Technical Bulletin, we will discuss four methods of measuring and controlling coating film thickness over non metallic substrates: By calculating the volume of coating in relation to surface area, by the use of a wet film gauge, by destructive testing, and by the use of ultrasonic instruments.

SECTION 2: CONTROLLING COATING FILM THICKNESS BY VOLUME

In the United States, we still use the British Imperial system of measurement which includes gallons and square feet. As such, the first set of calculations to be considered are based on this measurement system (metric calculations are included in Appendix A). First of all, under this system coating film thickness is expressed in "mils". There are 1,000 mils in an inch. Expressed in decimal form, 0.001" is **one mil**, 0.010" is **ten mils** and 0.100" is **one hundred mils**.

Although we commonly use gallons as a measure of volume, it is also possible to measure volume in **mil square feet**. You **must memorize** the fact that there are 1,600 mil square feet in a gallon (there are actually 1,604 mil square feet in a gallon, but it is simpler to round to 1,600). Let's start by imagining a "one square foot, one gallon box." It would look something like Figure 1.

Figure 1: Calculating Coating Film Thickness By Volume, "A One Square Foot One Gallon Box"



Now imagine a wall that is 8 feet tall and 200 feet long. This wall would have a surface area of 1,600 square feet. If you wanted to apply 1 mil of epoxy to this wall, it would theoretically require one gallon. If you wanted to apply 125 mils to this wall, it would require 125 gallons. So, it is simply a matter of figuring out the surface area that you want to coat (in square feet) and multiplying that area by the thickness you want (in mils). This gives you the number of **mil square feet** that you need. Because companies don't sell epoxy coatings in **mil square feet**, you must divide this number by 1,600 to get the number of gallons required.

Let's take another example. Let's say you have a 4 foot diameter manhole 10 feet deep. These structures are typically estimated by assuming the manhole is a simple 4 foot diameter cylinder with no top or bottom. Although the cone and chimney are smaller than 4 feet diameter, the base of the manhole must also be coated, so this estimating convention works pretty well. So, to calculate the amount of epoxy required, you must first calculate the surface area of a 4 foot diameter cylinder that is 10 feet long.

To calculate the surface area of a cylinder, you multiply its circumference (the distance around the edge of a circle) by its length. Circumference is calculated by multiplying the diameter times Pi, which is typically rounded to the number 3.14. Imagine you have a cardboard cylinder 4 feet in diameter and 10 feet long. Then imagine you took a razor knife and cut the cardboard tube in a straight line down its length. If you then opened up the cardboard cylinder and laid it flat on the ground, it would form a rectangle 12.56 feet long by 10 feet wide. We know the rectangle would be this size because the diameter (4 feet) multiplied by Pi (3.14) is 12.56 feet and the cylinder is 10 feet long. If you multiply the length of the rectangle by the width, you would find this rectangle has a surface area of 125.7 square feet. If you want to apply the epoxy at a thickness of 125 mils, you would multiply the area (125.7 square feet) times the thickness (125 mils) and you would find that you need 15,962.5 **mil square feet**. To get gallons, divide this number by 1,600 (the number of **mil square feet** in a gallon) and you would find that you need 9.98 gallons of epoxy (theoretically).

If you applied 9.98 gallons of epoxy to this manhole with perfect uniformity, the coating thickness would be exactly 125 mils thick. Unfortunately, it is not possible to apply the epoxy with perfect uniformity, so a waste factor is typically added (usually anywhere from 5% to 15%) to assure proper thickness throughout. So instead of 9.98 gallons you would probably apply more like 11 gallons (a waste factor of approximately 10%).

Section 3: "We Use Plural Component Pumps. How Do I Know When I Have Applied 11 Gallons?"

One way to do this is to count the pump cycles. The Graco plural component pump that most Mainstay applicators use is an XP70 or XP50 air motor with 2:1 ratio bottom pumps (one each 180cc and 90cc Xtreme legs). This pumping setup dispenses 270 milliliters per cycle (one stroke up, one stroke down). Because one gallon contains 3,784 milliliters, this pump must cycle 14 times to deliver a gallon. To deliver 11 gallons, this pump must cycle 154 times. Obviously, this is a lot of counting. So from a practical standpoint, there would need to be some method of counting this either mechanically or electronically.

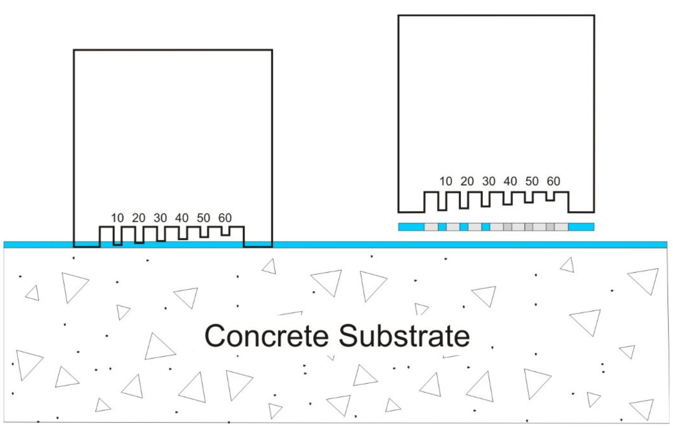
Section 4: Measuring Wet Film Thickness Using Notch Gauges

ASTM D 4414 Standard Practice for Measurement of Wet Film Thickness by Notch Gauges details the use of a wet film thickness gauge. There is a direct relationship between wet film thickness and dry film thickness. When measuring the wet film thickness of 100% solids epoxy materials, the relationship is very simple: Wet Film Thickness = Dry Film Thickness (WFT=DFT).

To perform the test, push the gauge into the wet film perpendicular to the wet film so that the two end tabs rest firmly on the substrate at the same time. Next, remove the gauge from the surface and examine the notched tabs. The film thickness is determined as being somewhere between the shortest tab wetted by the paint and the next shorter tab not wetted by the film.

Generally speaking, a wet film gauge is a painter's tool. It is used to determine the thickness of the coating as it is being applied. After measuring the film thickness, the painter will typically apply another pass or two to close up the marks left in the paint film by the wet film thickness gauge. For example, assume the painter is trying to achieve 125 mils. If the painter applies eight passes (typically four each in two directions), and he or she finds that this results in a thickness of 100 mils, the painter can reasonably assume that two more passes will result in a film thickness of 125 mils. In other words, a wet film thickness gauge provides feedback so that the painter knows how thickly the coating is being applied.

Figure 2: Wet Film Thickness Gauge



In Figure 2 above, the wet mil gauge on the left has been placed into a wet coating film (blue) so that the outside two end tabs touch the substrate. Note that the 10 mil, 20 mil, and 30 mil tabs touch the wet coating film. When the gauge is removed and the tips of the tabs are examined, note that the 10 mil, 20 mil and 30 mil tabs are covered with blue paint. Also note that the 40 mil, 50 mil and 60 mil tabs are not covered in paint. From this, we know that the wet film thickness is greater than 30 mils and less than 40 mils.

Section 5: Destructive Dry Film Thickness Testing

ASTM D 4138 is titled *Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means*. This test method outlines three methods of performing this test. Method A uses a cutting knife and is suitable for coatings less than 50 mils. Method B uses grinding instruments and is seldom used. Method C uses a drill bit. We will be discussing method C.

To perform this test, mark the surface with a felt tip marker and drill a hole through this mark and through the coating film into the substrate using a 90º countersink bit (hence the term “destructive”) and a battery powered drill. Because this hole must be drilled perpendicular to the plane of the coating film surface, a “holding block” is used to guide the bit. Figures 3 and 4 provide an elevation and plan view of what the completed hole looks like.

Figure 3: Cross Section of Counter Sunk Hole

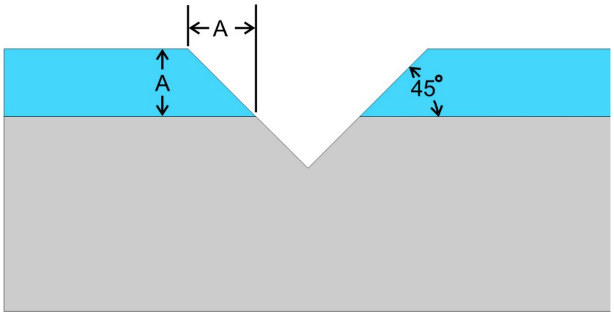
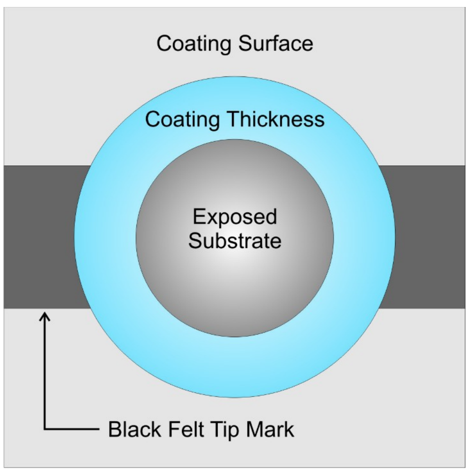


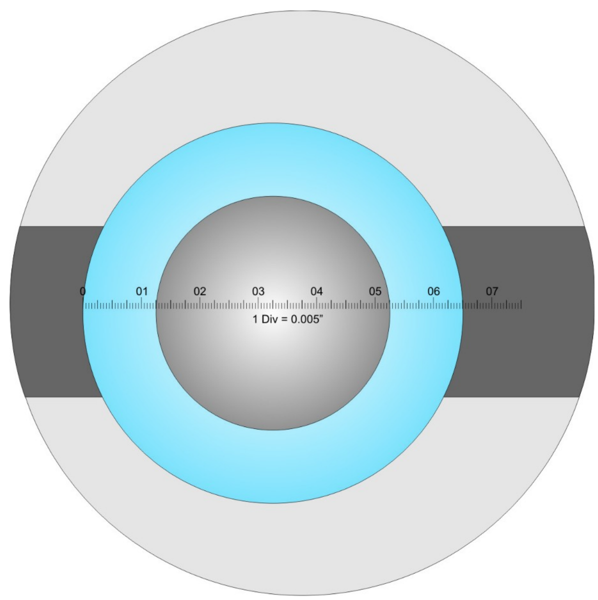
Figure 4: Counter Sunk Hole in Plan View



As you can see in Figure 3, the horizontal distance “A” from the upper cut edge of the coating to the lower cut edge of the coating is the same as the coating film thickness “A”. This is because the cut is at a 45º angle to the plane of the coating film surface, and every mil of rise is equal to a mil of run. When you look down on this hole in plan view (Figure 4), the hole looks like the graphic to the right. Notice that the black felt tip marker applied to the coating surface PRIOR to the hole being drilled helps define the upper edge of the cut from the surface of the coating.

Figure 5: View Through a 7x Loupe with Measuring Reticle

Figure 6: View of Countersunk Hole with Measuring Reticle



Coating film thickness is measured using a magnifier with a measuring reticle (Figure 5). In Figure 6, we are using a 7x loupe with a reticle capable of measuring ¾ of an inch in .005” divisions (5 mils per hash mark). Note that when the measuring loupe is placed on top of the drilled hole, it is possible to measure the distance between the upper edge of the coating (zero) and the coating/substrate interface.

The coating film in this case is exactly 125 mils thick.

Section 6: Ultrasonic Film Thickness Testing

ASTM D 6132 titled *Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Coating Thickness Gage* outlines the process of non destructive measurement of the dry film thickness of coatings applied to non metallic substrates. According to the standard, "Instruments complying with this test method measure thickness by emitting an ultrasonic pulse into the coating that is reflected back from the substrate to the probe". The time it takes for the ultrasonic pulse to reach the substrate and return to the probe is converted by the instrument into a thickness reading.

It should be noted that this instrument might not be able to measure all coatings applied to all substrates. Coatings containing fiber or flake reinforcement may be difficult to measure because these fillers reflect sound waves in an unpredictable manner. Any substrate with an acoustical signature similar to the coating film or substrates with significant profile may also be difficult to measure.

Electronic instruments of this type are typically not calibrated by the user in the field. Instead, calibration is performed by the instrument manufacturer or an authorized laboratory in a controlled environment using a documented process. These instruments are, however, adjusted for accuracy in the field. According to this standard, "the user should measure a known thickness of the coating by (among other methods) using a destructive, cross sectioning method such as ASTM D 4138." Most instruments will also require that the user "zero" the probe prior to use.

Ultrasonic gauges require the use of a couplant such as oil, water or a propylene glycol gel that transfers the ultrasonic pulses generated by the probe into the coating film. If the surface of the coating being measured is rough, the instrument may try to measure the thickness of the couplant over the surface of the coating. For this reason, it is common practice to adjust the gauge so that it ignores low readings that might cause this error.

Photo 1: Probe and Couplant (blue gel)

Photo 2: Ultrasonic Film Thickness Measurement