FILM THICKNESS MEASUREMENT

TECHNICAL ARTICLE

Measuring coating thickness on heat-sensitive substrates

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This article describes technology available to measure the thickness of cured powder coatings on substrates other than metal, such as medium-density fiberboard (MDF) and plastics. It describes the working principle and benefits of ultrasonic coating thickness testing with handheld instruments.

Coating thickness gages that use ultrasonic measurement techniques are becoming increasingly popular in industries that work with heat-sensitive substrates such as wood, plastic, composites, and glass. These instruments support or replace destructive methods for measuring the thickness of cured powder coatings in a variety of industries including automotive, aerospace, manufacturing, and industrial finishing.

Coating thickness is an important variable that plays a role in product quality, process control, and cost control. Measurement of film thickness should be a routine event for all coaters. Understanding the equipment available for film thickness measurement and knowing how to use it properly are valuable to every coating operation.

Why measure thickness?

To begin, let's define the unit of thickness measurement. The normal standard used in powder thickness measurement is the mil, where 1 mil is equal to a thousandth of an inch (1/1,000 inch). So if the manufacturer's specified thickness is 2 mils to 5 mils, the final cured thickness of the powder should be between 0.002 inch and 0.005 inch. The metric unit of measurement is called the *micron*, where 25.4 microns is equal to 1 mil. Applicators must apply the powder evenly and according to the product specification sheet. This provides the maximum benefit from that particular powder specification.

Coatings are designed to perform their intended function best when applied within a tight thickness range as specified by the manufacturer. This ensures optimum product performance. Many physical and appearance properties of the finished coating are affected by the film thickness. Film thickness can affect the color, gloss, surface profile, adhesion, flexibility, impact resistance, and hardness of the coating. The fit of pieces assembled after coating can be affected when film thickness isn't within tolerance. Therefore, coatings must be applied within certain minimum and maximum film thickness specifications to optimize their intended use.

On medium-density fiberboard (MDF), for example, powder coating thicknesses typically range between 1 mil and 8 mils (25 to 200 microns) or even higher for thermoplastic coatings. (See Figure 1.) Usually the finish is made more durable with thicker mil coverage. Factory specifications often call for a stated ±1 mil tolerance. This level of quality can't be determined by just looking at it.

FIGURE 1

Testing powder coating thickness on a wood product

There are other benefits to precisely measuring finish thickness whether to meet International Organization for Standardization (ISO), quality and customer requirements for process control, or to control costs. When companies fail to check and verify coating quality of incoming material, they waste money reworking product. By checking their application equipment, they ensure the coating is being applied in compliance with the manufacturers' recommendations. Applying excessive film thickness risks the possibility of incomplete cure and can drastically reduce overall efficiency. Too much powder coating may result in poor adhesion and tends to peel or chip from the substrate. Regular testing can reduce the number of internal reworks and customer returns due to finishing defects.

How best to test

Measurements of powder coating thickness can be made by using different methods depending upon the substrate and whether the test is being performed before or after powder cure. The American Society for Testing and Materials (ASTM) has a series of documents describing these techniques.

- Practice D 7378 describes three measurement methods for the thickness of applied, pre-cured coating powders to predict cured thickness.
- Test Method D 4138 describes destructive measurements over rigid substrates made with cross-sectioning instruments.
- Practice D 7091 describes nondestructive measurements over metal substrates made with magnetic and eddy current coating thickness gages.
- Test Method D 6132 describes nondestructive measurements over nonmetal substrates made with ultrasonic coating thickness gages.

Pre-cured coating powder thickness testing

Most thickness testing specifications apply to the final cured thickness of powder. However, there are several methods available to measure powder coatings in the pre-cured, pre-gelled state. Because measurements made in the two different states are never the same, a relation between the two values must be determined. The purpose of pre-cured thickness measurement is to help ensure correct cured thickness the first time through the line. There are three common methods for measuring dry coating powders.

Metal-notched gages. These manually determine thickness by being hand-dragged through the powder a short distance. Powder thickness is determined as being between the highest numbered tooth that made a mark and has powder clinging to it, and the next highest tooth that left no mark and has no powder clinging to it. These simple tools (Figure 2) are inexpensive but accurate only to within a few mils. Measurements can be made on a suitable rigid surface, metal or nonmetal, but marks will be made in the powder that may not be covered when the powder flows in the cure process.

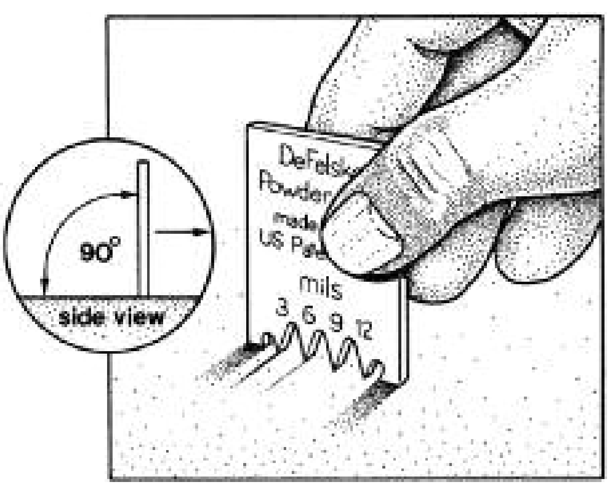
Electronic gages. By using magnetic or eddy current principles and a specially designed powder probe, these gages can be used to measure coating powder thickness. Micro pins, which are integrated into the probe, penetrate the coating powder down to the substrate. The probe is manually pressed down to the surface of the powder to effect a thickness measurement. This procedure is applicable to flat, metal substrates only. Marks made by the testing process may remain in the final product.

Noncontact ultrasonic gages. These measure the coating powder, then calculate and display a predicted cured thickness. While this is the most expensive solution, measurements can be made on any rigid surface, and there are no marks to affect the final finish.

The thickness of dry coating powder diminishes as much as 50 percent during the curing process depending upon the composition of the powder. To predict the final, cured powder thickness, a correlation, or reduction factor, must be made between pre-cured and post-cured thicknesses. This reduction factor is obtained by measuring the cured powder thickness at the same location where the uncured powder thickness measurement was taken. For best accuracy, measurements before and after curing should be taken for different thicknesses. When these values are plotted, a reduction factor can be determined and applied to all future dry coating powder thickness measurements to predict cured thickness.

FIGURE 2

A metal-notched gage



Cured powder coating thickness testing

Twenty years ago when powder coating revolutionized the metal finishing industry, thickness testing for quality control and inspection purposes was already commonplace. Handheld instruments were already in use nondestructively measuring coating thickness on products such as appliances, automotive parts, architectural components, and numerous other items.

Today, these methods continue to be used for powder-coated metal. When the base material is carbon steel, a magnetic method is used. On nonferrous metals such as aluminum, eddy current devices are used. There are many models to choose from among these handheld instruments. Some have built-in probes for easy one-handed measurement of large surfaces. Others have a small probe located at the end of a short cable to allow the operator to measure on small parts or on hard-to-reach areas. Many instruments have optional features to make the job of measurement easier, such as running average calculations and memory to download stored measurements to a printer or computer.

As popular as they are, instruments based on magnetic and eddy current principles can't directly measure the thickness of finishes over nonmetal substrates such as wood and plastic. So, before ultrasonic thickness testing, industries used alternate techniques including:

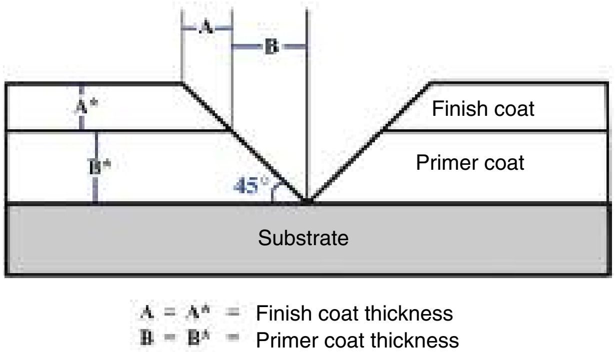
- Optical cross-sectioning (cutting the coated part and viewing the cut microscopically)
- Height measurement (measuring before and after with a micrometer)
- Gravimetric (measuring the mass and area of the coating to calculate thickness)
- Wet-gage dip (dipping a wet film thickness gage into the uncured coating)
- Substitution (placing a steel coupon alongside the part and coating it at the same time)

These tests are time-consuming, difficult to perform, and are subject to operator interpretation and other measurement errors. The gravimetric method, for example, will provide an average film build on the part, but will not provide a film thickness profile over specific areas.

A typical destructive technique requires cutting the coated part in a cross section and measuring the film thickness by microscopically viewing the cut. Another cross-sectioning technique uses a scaled microscope to view a geometric incision through the dry-film coating. To do this, a special cutting tool makes a small, precise V-groove cut through the coating and into the substrate. (See Figure 3.) Gages are available that come complete with cutting tips and illuminated scaled magnifiers.

FIGURE 3

A V-groove cut through a two-layer coating system



Although this method's principles are easy to understand, opportunities abound for introducing errors. It takes skill to prepare the sample and interpret the results. Adjusting the measurement reticule to a jagged or indistinct interface can create inaccuracies, particularly between different operators. To get a statistically representative sample, several products from a lot might need to be scrapped as part of the destructive testing process. Therefore, this method is most commonly used when inexpensive, nondestructive methods aren't possible, or as a means of confirming nondestructive test results.

Ultrasonic breakthrough

When technological advancements brought the advantages of powder coating to heat-sensitive substrates, concurrent advances were made in testing technology. With the arrival of ultrasonic instrumentation (Figure 4), many finishers have switched to nondestructive inspection of cured powder coating thickness.

Quality professionals are already familiar with various aspects of ultrasonic testing wherein high-frequency sound energy is used to conduct examinations and make measurements. Ultrasonic testing can detect and evaluate flaws in metal, measure dimensions, ascertain material characterization, and more.

Wall-thickness measurement is perhaps the most common and simple of ultrasonic tests. Precision ultrasonic wall-thickness gages permit quick testing of objects without requiring access to both sides. For coating measurement, however, these gages aren't ideal. They don't have sufficient sensitivity to measure the thickness of

FIGURE 4

An ultrasonic coating thickness gage

lacquers, ultraviolet (UV) finishes, powder coatings, and other materials used to finish nonmetal products.

The first handheld instrument designed specifically for coating thickness measurement appeared on the market 15 years ago and is now into its fourth generation. It uses a single-element transducer and advanced numerical techniques to filter and enhance digitized echoes. Today's handheld ultrasonic coating thickness gages are simple to operate, affordable, and reliable.

A sound measurement technique

Ultrasonic testing works by sending an ultrasonic vibration into a coating by using a probe (transducer) with the assistance of a couplant applied to the surface.

The instrument comprises a gage body and an ultrasonic probe. The body contains the alkaline batteries, the LCD (liquid crystal display), and operating buttons. The probe is typically connected to the body with a 3-foot (1-meter) cable and consists of a single-element transducer with a switch that initiates measurements.

To measure with ultrasound, a small drop of couplant is first applied to the surface of the cured coating. Couplant enables the ultrasonic sound pulse to travel from the probe into the coating. Water is a good couplant for smooth coatings, and glycol gel, usually supplied with the instrument, is required for rougher coatings. While it is unlikely that the couplant will damage the finish or leave a stain on the surface, it is a good idea to test the surface by using the couplant on a sample. If testing indicates that staining has occurred, a small amount of water can be used instead of couplant. Other liquids such as liquid soap may also be used.

Next, the probe is placed onto the surface and pressed down lightly to squeeze out excess couplant and to trigger a measurement. The resultant thickness calculation is then displayed within 1 second on the LCD in mils or in microns.

How is thickness calculated? During the measurement process, the probe emits a vibration that travels through the coating until it encounters a material with different mechanical properties—typically the substrate but perhaps a different coating layer. The vibration, partially reflected at this interface, travels back to the transducer. Meanwhile, a portion of the transmitted vibration continues to travel beyond that interface and experiences further reflections at any material interface it encounters (Figure 5).

Coating thickness readings are obtained by measuring the time taken for the ultrasonic vibration to travel from the probe to the coating/substrate interface and back. The travel time is divided by two and multiplied by the velocity of sound of cured powder to obtain the thickness of the powder.

Because a potentially large number of echoes could occur, the gage is designed to select the maximum or "loudest" echo from which to calculate a thickness measurement. For most powder coating applications, this is the total thickness of the cured powder.

Instruments that measure individual layers in multilayered applications such as paint on plastic also favor the loudest echoes. The user simply enters the number of layers to measure, say three, and the gage measures

FIGURE 5

Ultrasonic vibrations reflect off coating interfaces. The instrument interprets the largest echo as the coating/substrate interface.

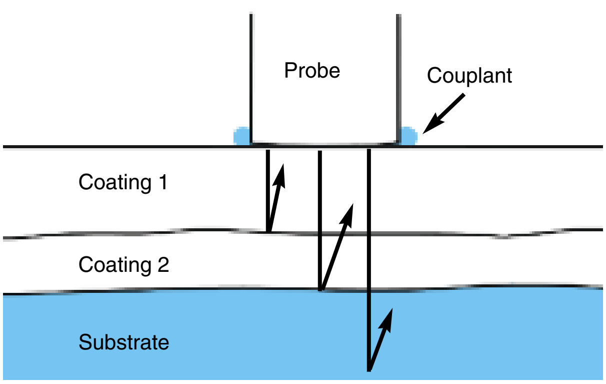
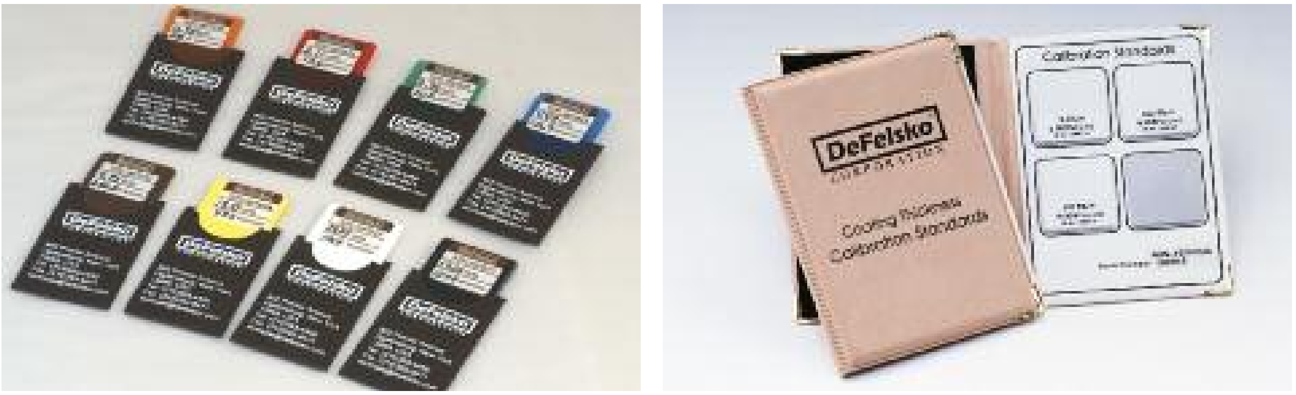


FIGURE 6

Thickness standards may be plastic shims (left) or coated plates (right).



the three loudest echoes. The gage ignores softer echoes from coating imperfections and substrate layers.

Measurement accuracy

The accuracy of any ultrasonic measurement directly corresponds to the sound velocity of the finish being measured. Because ultrasonic instruments measure the transit time of an ultrasonic pulse, they must be calibrated for the "speed of sound" in that particular material.

From a practical standpoint, sound velocity values don't vary greatly among coating powder materials. Therefore, ultrasonic coating thickness gages usually require no adjustment to factory calibration settings when measuring cured powder thicknesses.

FIGURE 7

An ultrasonic instrument being used to measure on textured surfaces.

As simple as these instruments are to operate, a prudent user should verify their operation on a regular basis, especially when conforming to an internal ISO procedure. Three steps ensure best accuracy.

Calibration. Calibration of coating thickness instruments is usually a documented process performed by the equipment manufacturer in a controlled environment. A Certificate of Calibration showing traceability to a National Metrology Institution is often issued. There is no standard time interval for re-calibration, nor is one absolutely required, but a calibration interval can be established based on experience and the work environment. A 1-year calibration interval is a typical frequency suggested by many instrument manufacturers.

Verification. This is an accuracy check performed by the user with known reference standards. This quick check ensures the instrument is measuring properly and that the user is operating it correctly. Accuracy should be verified by measuring plastic shims or epoxy-coated standards with assigned values traceable to a national metrology institution.

Adjustment. Adjustment, or calibration adjustment, is the act of aligning the gage's thickness readings to match that of a known reference sample to improve the accuracy of the gage on a specific coating within a specific portion of its measurement range. As stated earlier, this operation is seldom required in the powder coating industry because sound velocity values don't vary greatly among coating powder materials. When new powders are used or greater thicknesses applied, prudent users verify ultrasonic results with known thickness values to determine if an adjustment is required.

Fortunately, measuring powder thickness on heat-sensitive substrates is a relatively easy matter for ultrasonic coating thickness gages. Most instruments include plastic shims (Figure 6) of known thicknesses that the operator measures before beginning each measurement session. From a practical standpoint, this quick check is usually all that is required before measuring.

Where the coating meets the substrate

Cured powders have surface irregularities, either at a microscopic level or with texturing large enough to be seen by the eye. On metal substrates, this causes measurements by magnetic and eddy current instruments to become less repeatable the more pronounced the surface texture. Industry test methods and recommended procedures therefore recommend that several measurements be taken and their results averaged to obtain a more meaningful thickness result.

Surface texture exists on heat-sensitive substrates too and ultrasonic gages (Figure 7) are inherently designed to average small irregularities to produce a meaningful result. On particularly rough surfaces or substrates where individual readings may not seem repeatable, comparing a series of averaged results provides acceptable repeatability, just like on metal.

On rough surfaces, ultrasonic testers typically identify thickness as the distance from the top of the coating peaks down to the substrate. This is represented by distance #1 in Figure 8. Couplant fills the voids between the probe and the coating to assist the ultrasonic pulse to enter the coating.

Severe roughness can cause the gage to display low thickness values (distance #2). While this estimate of surface roughness may be perceived by some as being beneficial, most would prefer the gage to measure total powder thickness only. Low results happen because echoes from the couplant/coating interface are stronger than the coating/substrate interface. To eliminate these low measurement results, ultrasonic testers have a

Figure 8

Couplant fills the voids between the ultrasonic probe and the textured powder coating.

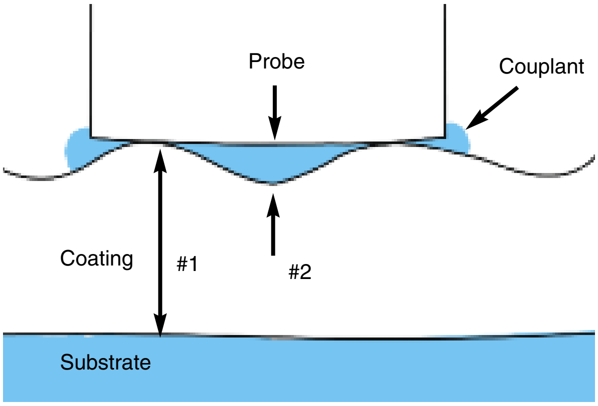
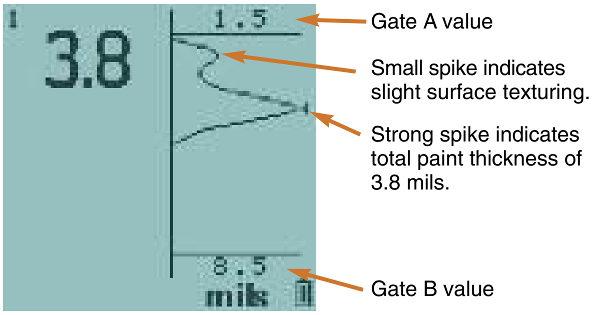


Figure 9

Some models have graphical displays to help the user interpret measurement results.



unique user-adjustable Gate feature to force the instrument to ignore surface roughness echoes as described in Figure 9.

Another factor influencing the accuracy and repeatability of ultrasonic measurements is how these coatings interface with the substrate. Wood products, for example, can have both smooth and rough surfaces on which to test coating thickness. Figure 10 shows an example of coated wood. This photo, taken at higher resolution than most field destructive tests are capable of, shows the boundary between the powder coating and the wood. The coating may look smooth on top, but thickness may be inconsistent. Wood substrates often are grainy with varying degrees of surface roughness and primer penetration. Such porosity and roughness may promote adhesion but they make it difficult to obtain repeatable thickness measurements by any means. Again, averaging several thickness results is the best way to establish an overall thickness value.

A final echo

Most ultrasonic coating thickness gages are ready right out of the box to measure powder coating applications. They commonly have a measuring range of 0.5 mil to 40 mils (13 microns to 1,000 microns) and are ideal for measuring total coating system thickness. They often require no calibration adjustment, are mils/microns switchable, and are easy to operate. Models are available with advanced features, such as graphical display of the ultrasonic pulse as it passes through the coating system, memory for statistical calculations such as the average of a series of measurements (Figure 11), and downloading to a printer or PC for reporting and record keeping.

Ultrasonic coating thickness measurement is now an accepted and reliable testing routine used in powder coating industries working with heat-sensitive sub-

Figure 10

High-powered magnification reveals both coating and wood surface roughness.

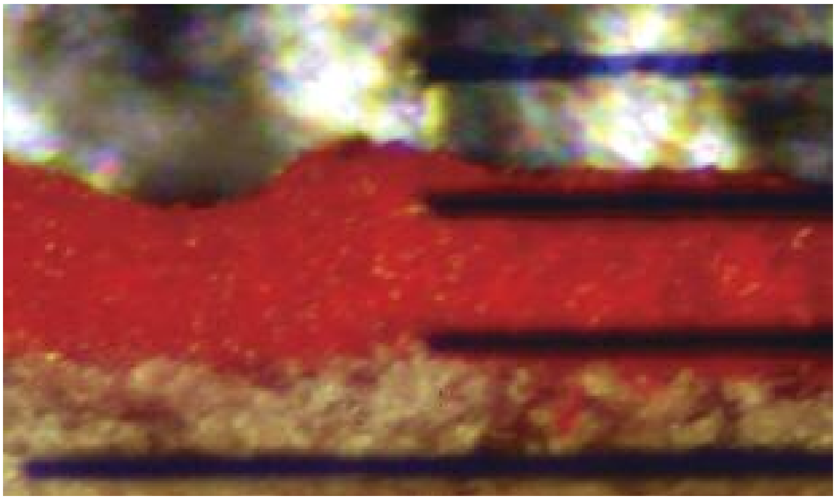
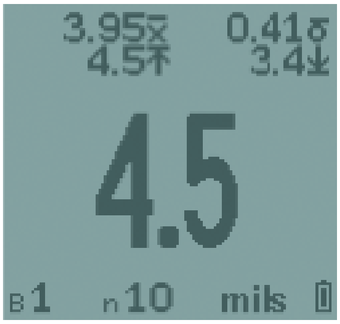


Figure 11

Some instruments provide statistical analysis. In this example, 10 measurements have been taken. The last measurement of 4.5 mils is displayed along with the average, standard deviation, and max/min values of all 10 readings.



strates. Quick, nondestructive thickness measurements can now be taken on materials that previously required destructive testing, lab analysis, or expensive nondestructive equipment. This advanced technology improves consistency and throughput in the finishing room. Potential cost reductions include

- Minimizing waste from over coating by controlling the thickness of the coating being applied
- Minimizing rework and repair through direct feedback to the operator and improved process control
- Eliminating the need to destroy or repair objects by taking destructive coating thickness measurements

Today, these instruments are simple to operate, affordable, and reliable. **PC**

Editor's note

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