

# Ensuring Adequate Curing of Paint and Powder Coatings

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The basic curing process (cure schedule) for powder coatings consists of four stages: melt the powder, flow out the powder, crosslink and cure the powder, and achieve satisfactory crosslinking. All of these stages are critically affected by temperature, time at temperature and, in some cases, the rate of temperature change. Most powder coating final properties are controlled by these stages and, therefore, are temperature critical as well (table 1). Without adequate control of the curing process, the part being heated can experience under or over cure conditions that will deteriorate the coating quality (table 2).

**Table 1. Powder Properties Affected by Temperature**

Physical	Other
Hardness	Texture
Flexibility	Color Stability
Impact Resistance	Flow Properties
Adherence	Chemical Resistance
Gloss Retention	Service Life

Table 1. Several powder coating properties are affected by the cure schedule employed.

In most situations, confirmation of cure quality is performed by physical testing of the product after the cure schedule is completed. This approach is time consuming and tedious, and at best, it only highlights problems well after the damage has been caused. Physical examinations such as differential scanning calorimetry (DSC), rub, impact and gloss inspection tests may suggest the potential cause of cure problems, but often they do not provide sufficient information to allow rapid, accurate corrective action.

To guarantee finish quality, it is necessary to obtain accurate, specific knowledge about the temperatures experienced by a coated product throughout the curing process. Each coating has a specific cure schedule, provided by the coating manufacturer, using time and temperature values. For example, the cure schedule for a typical polyester powder coating is 10 min at 390°F (200°C). To achieve optimum curing of this powder, the coated component must be heated to 390°F (200°C) and held at that temperature for 10 min (dwell time). Due to the interdependency of time and temperature, however, coatings may have a series of possible cure schedules - for example, 10 min at 390°F (200°C), 8 min at 410°F (210°C), or 12 min at 375°F (190°C). Each will provide the same degree of cure.

A generic cure schedule is summarized in figure 1. From the temperature profile, it can be seen that to achieve optimal cure, the powder must be heated within the cure window. Temperature excursions above or below the cure window will result in inadequate curing and potential for coating failure.

When employing the cure schedule, the critical temperature quoted is component temperature, not air or oven temperature. Because the heating rate of any component is affected by many factors other than the oven settings (thermal mass, for instance), component temperature must be measured directly and accurately. At a fixed oven temperature, a part with low thermal mass (say a 2 mm thick aluminum sheet) will reach the cure temperature significantly faster than a part with higher thermal mass (a 10 mm dia. steel rod, for example). Other parameters that affect a component's heating include:

**Table 2. Effects of Under or Over Cure**

Under Cure	Over Cure
Brittle	Reduced Coating Life
Solvent Attack	Scorching
Poor Adhesion	Discoloration (Yellowing)
Too High Gloss	Too Low Gloss
Gloss Variability	Substrate Damage
Orange Peel (Poor Flow)	
Poor Weathering	

Table 2. Using the incorrect cure schedule can lead to under or over cure of the finish.

- Oven starting temperature. For example, with a box oven, temperature drops during

- loading.
- Conveyor track speed.
- Substrate thickness, weight and shape.
- Mix of components.
- Pattern of oven loading.
- Oven design (infrared vs. convection).
- Oven temperature recovery rate.
- Thermal uniformity in oven.

Static and remote temperature sensors used in ovens provide some temperature information, but they have weaknesses. One drawback is that the product's temperature measurement is estimated from oven temperature; therefore, the effects of the variables noted above on the component heating rate are not taken into consideration. From such estimates, product temperature often is quoted too high. Another drawback is that temperature information is provided only at discrete points in the process - where the sensors are located. Without a comprehensive temperature history of the product, an accurate confirmation of cure schedule may not be possible.

To prove that a paint- or powder-coated product is experiencing the optimum cure schedule, more temperature data is needed. Travelling through the oven with the product, an in-process temperature profiling system provides an accurate, comprehensive temperature profile of the product throughout the cure process.

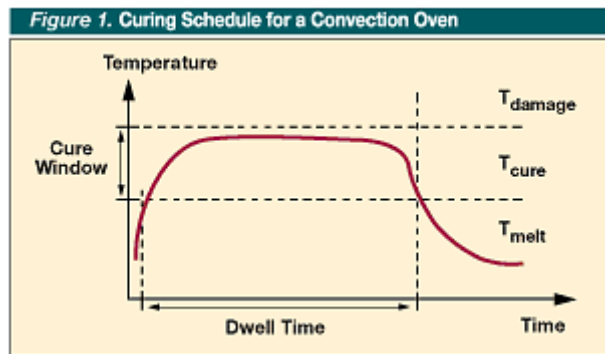


Figure 1. Each paint and powder coating has a specific cure schedule. This is a sample cure schedule for a coating cure in a convection oven.

Most in-process temperature profilers consist of five parts: datalogger, transducer interface, temperature sensors, thermal barrier and analysis software (figure 2). The datalogger and transducer interface travel through the oven recording readings from the temperature sensors, which are attached to a sample part. The thermal barrier protects the datalogger and transducer interface's sophisticated electronics from the heat of the oven. Once the temperature profiling equipment and test part exit the oven, analysis software is used to transfer the collected data to a personal computer, where it converted into useful information that can be used to control and optimize the cure process.

## Temperature Profiling in Infrared Ovens

Use of infrared technology to cure paint and powder coatings is rapidly gaining popularity worldwide. But, with the introduction of infrared comes a new set of challenges for in-process temperature profiling.



Figure 2. Temperature profiling can be accomplished in four simple steps: connect datalogger and transducer, place in thermal barrier, send through oven, and analyze and report results.

The direct implications of infrared heating are speed, directionality and coating sensitivity. In direct comparison with convection, infrared heating provides a significantly more efficient heat transfer mechanism. Product temperatures can, therefore, be raised to the required cure schedules much more quickly. The typical temperature profile of a substrate heated with infrared energy differs significantly from that of a convection heated substrate (figure 3). To measure such rapid temperature increases, it is essential that both the measurement sensor and measurement device are capable of responding and logging quickly enough to accurately follow the temperature profile.

Heat transfer to the product in an infrared oven requires that the product is in the line of sight of the electromagnetic waves. Shaded areas of a part are heated via conduction through a part rather than the direct infrared. Therefore, when curing a paint or powder coating on products with complex geometries, it is essential that temperature measurements are made at carefully selected locations to discount differential heating of surfaces exposed to or shielded from the infrared radiation.

Remember that for curing, the critical temperature measurement is component temperature. In an infrared process, it is essential that direct radiative heating of the temperature sensor is eliminated. If the sensor is heated, it will report component temperature inaccurately. Effective protection should be given to the sensor so that it measures temperature changes of the substrate only.

To obtain accurate temperature profile information, it is critical that the temperature sensor is capable measuring changes in product temperature resulting from infrared absorption by the specific coating. Care also must be taken to prevent the thermocouple from altering the thermal mass or infrared absorption of that product.

## Profiling Methodology

Whether used in a convection or infrared oven, temperature profiling can be performed either directly or indirectly.

*Direct Profiling.* With this method, temperature measurements are taken directly from a standard coated product as it passes through the normal production cure process. Generally, direct profiling is performed in applications where it would be too expensive to use a test piece, and where thermocouples can be applied to the product without causing damage to the surface coating. As the method implies, thermocouples must be applied quickly and repeatably on a moving conveyerized line.

*Indirect Profiling.* With this method, temperature measurements are taken from a test piece designed to imitate a standard coated product. The test piece is inserted during the normal production run and is used repeatedly for profiling specifically, day after day.

Indirect profiling is performed where direct attachment of probes would cause coating damage and incur expensive scrap. Test pieces generally are employed where production is standard (one product line); therefore, only one test piece is necessary.

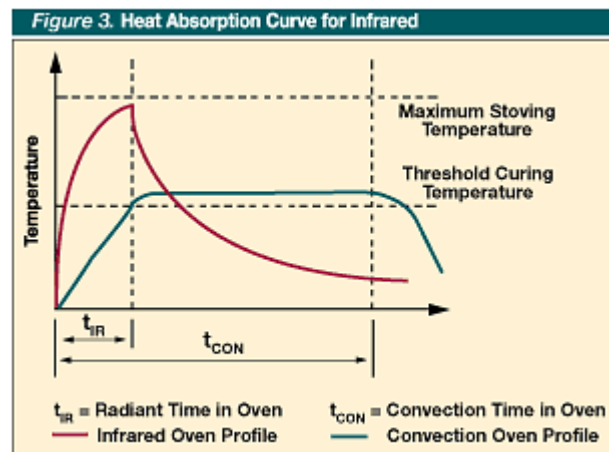


Figure 3. The typical temperature profile of a substrate heated with infrared energy differs significantly from that of a convection heated substrate.

## **Conclusion**

Using an in-process temperature profiling system, it is possible to generate the information needed to understand, control and enhance your process and provide four direct benefits: optimize product quality, increase productivity, perform rapid fault finding and prove system control.