PPG Powder Coatings

What is a cure curve?

A cure curve is a graphical representation of the thermal conditions required to insure that an applied thermoset powder coating is completely cured, i.e. essentially all available resin and curing agent reactive groups are chemically reacted together.

Do all products from the same chemistry follow the same cure curve?

No, each powder product manufactured by PPG has a cure curve associated with it, the specification of which is primarily determined by the formulation of its resin and curing agent system. However, there are commonalities between technologies, so it's not unusual to see a family of related powder products sharing a single cure curve.

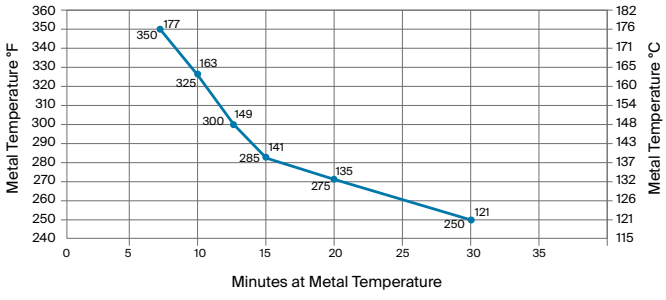
Are there different types of cure curves?

Yes. The simplest cure curve is one that specifies the minimum thermal conditions that must be provided to cure a powder during its baking process. Graphically, it is a single line or curve. Conditions of shorter time or lower temperature, i.e. those which fall below the cure curve line, are not recommended due to the likelihood of less than optimal cured film performance.

The temperature represented in cure curve is substrate temperature, not air temperature. It may take several minutes for the substrate to reach the scheduled temperature.

The following minimum (simple) cure curve is for a low-temperature cure polyester TGIC product line.

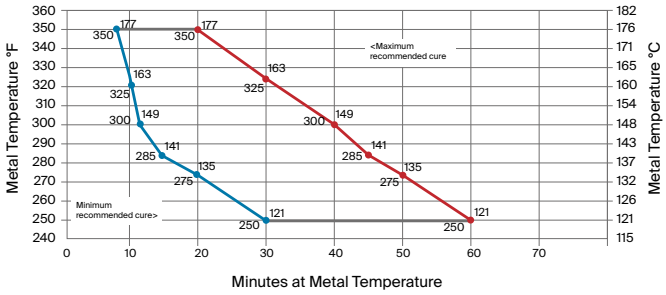
ENVIROCRON® LOW CURE PCT RECOMMENDED BAKE



A more complex cure curve will graphically represent both minimum and maximum thermal conditions, and thus is a two-dimensional area, rather than a line.

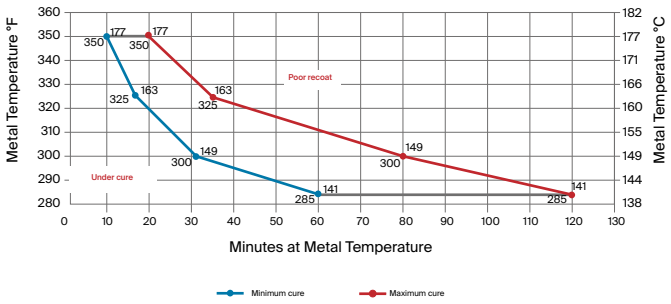
The complex (area) cure curve below is for the same low-temperature cure polyester TGIC product line as shown above, and has identical minimum cure data points (blue line), but with the addition of a maximum cure conditions line (red).

ENVIROCRON® PCT RECOMMENDED MINIMUM/MAXIMUM CURE



Annotations can be added to complex cure curves indicating details of how they were determined or displaying the powder film properties or potential failure modes that are associated with various cure chart areas.

ENVIRACRYL® POWDER PCC10103S PCT RECOMMENDED MINIMUM/MAXIMUM CURE CURVE



In the case of multi-film coating systems that undergo two or more heat-curing processes, cure curves for each applied coating layer need to be cross-referenced to account for the cumulative thermal experience of the system.

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Why are so many of PPG's recommended cure curves just a single simple line?

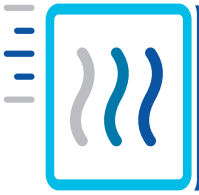
Historically, the laboratory determination of minimum bake time and temperature using standard pretreated metal test panels has been found to correlate well with customer experience. Often film flexibility or chemical resistance falls off dramatically once baking conditions fall below a certain point.

Unfortunately, the determination of maximum time and temperature bake schedules for curing powder coating products does not always correlate well between PPG's laboratory experiments and customer experience due to the fact that:

1. Powder coatings are remarkably heat resistant at common baking temperatures. They do not typically undergo embrittlement or chemical decomposition when exposed to 100% or even 200% of their standard baking times at a recommended temperature. Those properties of a powder coating that are significant for defining an overbake condition can be highly application-specific (e.g. recoat, touch-up repair, silk screening, pinstriping, decal application, etc.), and different customers will evaluate the various properties in different ways (e.g. color and gloss tolerances vary widely across applications and industries).
2. Many application factors can determine the exact point at which the product begins to lose some of its performance properties because of excess heat exposure. Among these factors, which are specific to each customer's application and production environment, are:
    - Type of gas used in the oven
    - Oven gas burner flame efficiency
    - Airflow speed and makeup air turnover rates in the oven
    - Presence of hot or cold spots in the oven
    - Size of the oven relative to the metal mass of parts that are run through the oven
    - Presence of chemicals or curing byproducts from other coating materials that may be used in the same oven or in areas of the production plant near the powder curing oven

How would a customer determine a maximum bake cure curve line?

Fortunately, although each customer has their own unique application and baking equipment situation, making it difficult for PPG to determine a maximum time-temperature cure chart line with great precision, most customers have relatively tight process controls and do not typically experience wide variation in bake times or temperatures.



Atypical circumstances might arise from conveyor line stoppages or from the differential heat profiles of parts that vary widely in substrate thickness but must be processed under a single set of baking conditions.

Often it is sufficient for a customer to simulate, perhaps in a validation or PPAP trial, just a few of the "worst case" combinations of time and temperature their "worst case" parts are likely to experience.

A maximum cure curve line constructed from such data points is likely to be conservative relative to the product's inherent capability, but it is often sufficient for practical, day-to-day process control purposes.
Some customers utilize thermal data acquisition hardware ("oven logger ") and its associated software (e.g. Datapaq® & Insight; Computer Aided Solutions Grant® & PaintView, etc.) to generate numerical analyses of thermal history for a part, including one or more "%-of-cure" parameters. Such theoretical indices may provide reassurance to a customer who is working only with a minimum recommended bake time/temperature cure curve that a detrimental overbake condition has not been experienced.

Are there any generalizations that can be made for customers who are working with a minimum recommended bake (single line) cure curve?

Many powder products show degradation of properties in the temperature range of 425-475°F (218-246°C). This is why all powder coating products should be tested carefully.

- Many PPG powder products are able to tolerate 100% overbake based on time, using the minimum time as a starting point. For example, a product with recommended minimum bake of 15 minutes at 375°F (191°C) would be expected to fully perform with a bake of 30 minutes at 375°F (191°C).
- In general, dark color products should be studied through testing of several key properties (for example, adhesion, gloss, and topcoat-ability) for overbake resistance properties when peak part metal temperature in the production oven reaches a temperature of 425°F (218°C).
- In general, light color products should be studied through testing of several key properties for overbake resistance properties when peak part metal temperature in the production oven reaches 400°F (204°C). In particular, color should be monitored for overbake yellowing.
- PPG does not recommend baking of typical powder coating products at temperatures of 500°F (260°C) or more.

Doesn't baking at conditions of the minimum cure curve line help detect marginal or poor quality product batches?

No. Many PPG powder products are tested for routine quality control purposes or for performance test specification compliance at conditions of slightly longer baking time and slightly higher bake temperature than the bare minimum.

A PPG powder production plant has multiple quality control parameters at its disposal to insure that product being made is consistent with past batches and with the formulation that was initially approved by the customer.

Does PPG recommend that customers bake parts at the recommended minimum time and temperature conditions as specified by the cure curve referenced on its product data sheet?

No. The customer must assume responsibility for verifying that proper cure is applied to the powder product under production conditions. PPG is unable to assess the degree of risk that a customer should assume, in light of the variability that characterizes its baking process. For most powders, there is seldom a problem with baking “above” the cure curve minimum. If anything goes slightly wrong, like cold spots in the oven, racking issues or variations in metal thickness, some parts will have an under cured coating.

Many PPG powder customers deliberately set oven conditions so that there is a comfortable safety margin between the minimum conditions specified in the cure curve and actual. For example, with a specified minimum of 15 minutes at 375°F (191°C), a customer might choose to adjust the oven burners settings so that every part’s temperature profile, measured with an oven recorder, at all positions on the racking system shows at least 21 minutes at 380°F (193°C).

To save time, and thus maximize productivity, many customers set their ovens higher than the maximum peak metal temperature achieved by the parts. For example, a set point of 425°F (218°C) may result in parts reaching a peak metal temperature of 395°F (202°C) just before they come out of the oven. But this approach carries the risk that if there is a conveyor line stoppage, unusually thin gauge metal, or oven “hot spots,” some parts might see the temperature as high as the oven set point.

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