Thermoset Compression, Transfer, and Injection Molding:
A new Intelligent Cure Control Tool for Improved Productivity and Quality

Signature Control Systems, Inc.
Industry White Paper

A new Intelligent Cure Control Tool for Improved Productivity and Quality

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Signature Control Systems, Inc.
Contact:
Tom Trexler
720.963.6515
tom.trexler@signaturecontrol.com
www.signaturecontrol.com
Thermoset Molding: 
The Case for Intelligent Cure Control

Introduction

Thermoset polymers such as polyester, vinylester, epoxy, and phenolic are typically molded in high to moderate quantities using compression, transfer, and injection molding processes. Using matched steel molds and presses as large as 4,000-ton, processors use Sheet Molding Compound [SMC], Bulk Molding Compound [BMC], granulated compounds, and in some cases pre-preg to mold complex parts with cure times typically ranging from 30-seconds to several minutes. Applications vary across a broad range of industries, but automotive and electronics dominate when measured by volume.

In today's global economy, thermoset processors are under constant pressure from shareholders and customers to reduce costs and improve quality. Intelligent Cure Control provides the thermoset industry with an urgently needed tool to satisfy customer needs, increase productivity and profitability, and take molding technology to the next level of excellence.

The Current Molding Paradigm

The current manufacturing paradigm for the molding of thermoset plastic materials is a compromise in processing time, cost, and quality. Because there is simply no way to "see" the chemical and physical changes in any thermoset plastic as it is being cured, manufacturers are forced to create fixed process specifications, or "recipes," for their molding operations. These recipes are typically developed using empirical testing, indirect laboratory measurements, engineering calculations, and operational trial and error. In addition, predictions of cure times must take into account processing variations induced by molding equipment, mold heat controls, the plant environment, and press operators, as well as charge weight variations, batch variations, out-time and compound aging.

As a result, safety margins must to added to cure times and introduced into the processing specifications in an attempt to account for inherent raw material and processing variations. The end result is an unnecessary compromise in quality and productivity.
Intelligent Cure Control: A New Manufacturing Tool for Improved Productivity and Quality

Signature Control Systems’ Intelligent Cure Control technology (SmartTrac®) allows manufacturers to “see” the rate, and state-of-cure thermoset plastics in real-time during the molding process. Sensors mounted directly in the mold detect subtle changes in the electrical impedance of the resins as they react and form cross-linked polymer structures. Changes in impedance readings generate a unique thermoset “fingerprint” or signature, which correlates directly with rheological and chemical changes in the material such as melt/soften, , minimum viscosity, gelation, and polymerization.

Using this new technology, manufacturers are now able to monitor and control their molding process using the optimum processing time for each cure cycle. As a result, safety margins can be eliminated, productivity can be dramatically increased, and product uniformity is more tightly controlled.

Compression Molding with Polyester SMC

The graph below shows a typical polyester/styrene SMC impedance signature with the time in seconds shown on the x-axis and conductance (an element of impedance) shown on the y-axis.
Initially the signature rises as the press closes, the molding compound comes into contact with the sensor, and the sensor couples with the opposing ground plane. The signature continues to rise as the compound begins to soften and ionic and molecular entities within the compound are more capable of moving within the sensor’s electric field. The signature “peaks” as the compound reaches the point of minimum viscosity and rapidly decays as the polyester and styrene react and cross-link restricting the motion of ionic and molecular entities within the sensor’s electric field. The signature then “tails” to a flat-line condition as the remaining styrene-styrene reaction takes place.

The ability to “see” these rheological and chemical changes in the mold in real time has important implications for molders for both quality and productivity. Since mold filling must be complete before the resin gels, the ability to “see” the onset of polymerization and gelation allows molders to adjust closing rates, molding temperatures, and compound formulations to optimize or troubleshoot molding parameters for a given molded part. More importantly, the ability to see the cross-linking reactions allows the molder to open the press at the optimum demolding time (time to attain sufficient degree of cure to demold the part). This eliminates the need for cure-time safety factors and can improve productivity by decreasing average cure times by 10 to 30% or more. In addition, *Intelligent Cure Control* prevents the premature mold opening on batches of material whose cure rate, for any number of reasons, falls outside of the built-in safety factor.

**Injection Molding with Phenolic BMC**

This example describes data collected from a SmartTrac system connected to an injection press molding an automotive brake piston using mineral filled phenolic. An impedance sensor was mounted in the cavity side of the mold. SmartTrac impedance data was collected while inducing mold and barrel temperature variations.

The graph below displays impedance data for three different processing conditions. The data with the latest peak (triangle shaped data points) was from the slowest curing condition (lower pre-form and mold temperatures). The impedance data with the earliest peak (black diamond data points) was from the fastest curing condition (higher pre-form and mold temperatures).

The slowest curing part (triangles) exhibited a surface blister due to under cure. The part fabricated with an intermediate cure rate (squares) exhibited porosity but no surface blisters, indicating it
was more cured, but not fully cured. The fasted curing part (diamonds) had no defects and was fully cured. Note that thermoset polymers exhibit a common data signature and that, as with the previous polyester SMC example, the graph illustrates the relationship between the flat portion (tail) of the impedance curve and the time necessary to reach adequate cure.

Molding with Advanced Composite Pre-Pregs

For certain high performance aerospace and military applications, unidirectional and woven carbon fiber pre-preg are sometimes compression molded into complex shapes using matched metal molds. This applications use longer curing epoxy and BMI resin systems and require that the polymeric material be staged in the mold and coordinated with the timing of mold pressure and the final closing to mold stops. If the dynamic rheology of the resin being processed is not properly coordinated with the closing of the mold, scrap will often be the result in the form of fiber wash or excess porosity.

In this case, Intelligent Cure Control provides the only known method of managing batch-to-batch variations and the timing of this compression molding process.

Conclusion

Intelligent Cure Control is providing molders with a new tool to increase productivity, improve yield, reduce scrap, and increase operating margins and customer satisfaction.