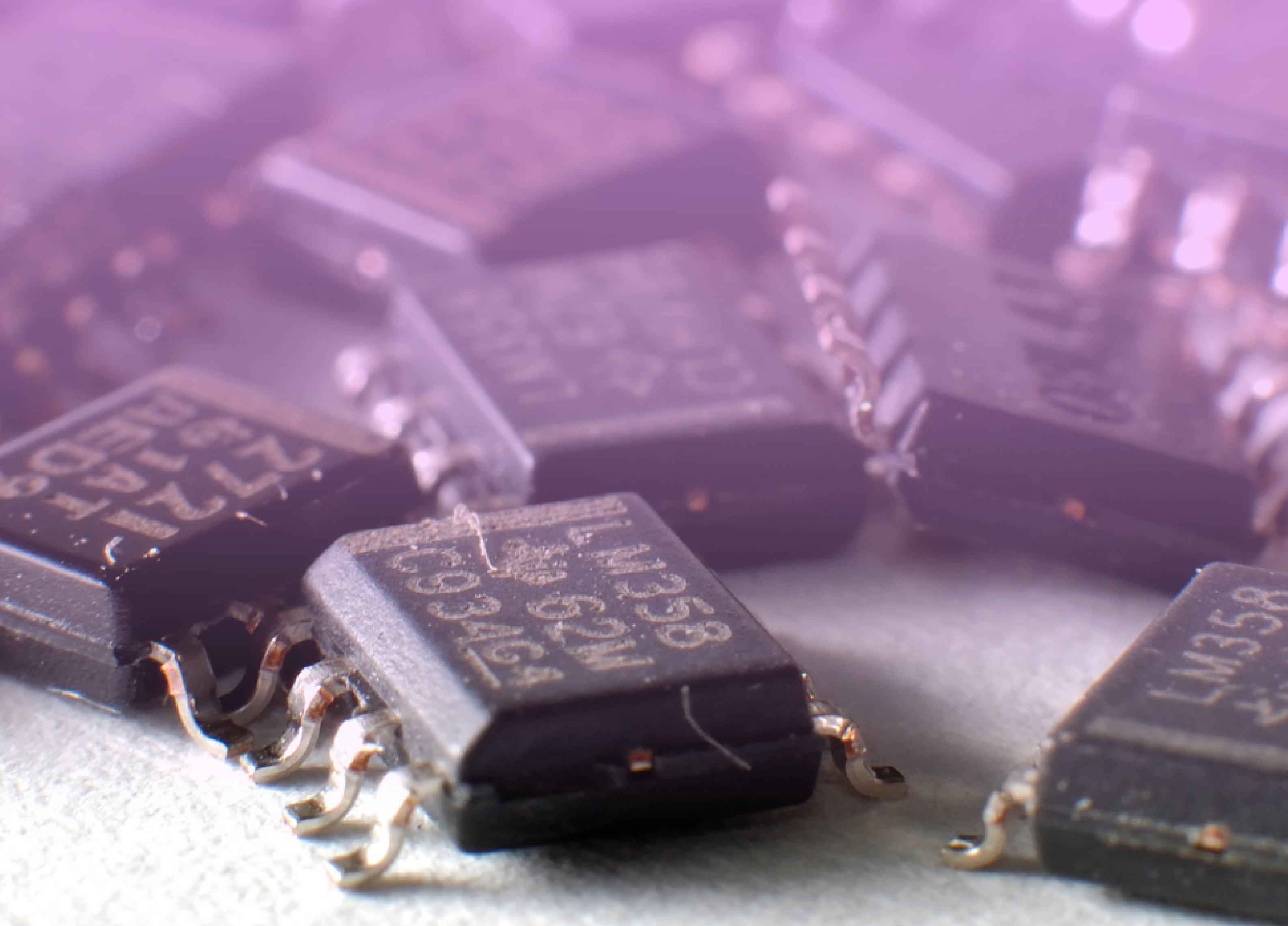
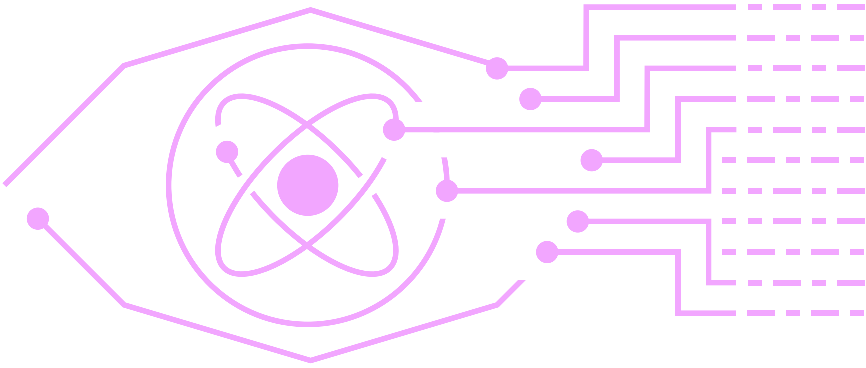
A Guide to Electronics Encapsulation

Optimizing Closed Mold Encapsulation Processes



sensXPERT

EXPAND your sense of the possible



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In our technology-driven world, there is an ever-increasing reliance on electronics; take smartphones and electric vehicles as examples. However, electronic components can be highly sensitive to various environmental factors, including but not limited to moisture, dust, corrosive chemicals, and physical stress.

Fortunately, a technique called encapsulation is applied to sensitive electronic components to shield them from these environmental challenges. Electronic encapsulation transforms vulnerable electronics into robust, resilient devices.
In this white paper, we will expand upon the definition of electronics encapsulation, relay the importance of encapsulating electronic components, and outline common processes and plastics materials used for encapsulation.

Additionally, we will navigate the material and process challenges that can arise in electronics encapsulation, as well as provide strategies and solutions to overcome those challenges.

Finally, we will present a case on two companies that encapsulate electrical components to illustrate how sensXPERT improves transparency in each molding cycle.

What is Electronics Encapsulation?

Electronics encapsulation is the process of creating a secure 'casing' or 'coating' over sensitive components to ensure their durability in the face of shock, corrosive chemicals, vibrations, and more. The materials constituting this protective layer are selected based on the electronic components' specific applications, but typical material choices include epoxy resins, polyurethanes, and silicone rubber.

Not to be confused with potting, which is the placement of a part in a container to partially or completely embed it with resinous material, encapsulation is a process that wields a reusable mold to coat components with the material.

Encapsulation is a crucial step in the manufacturing of electronic devices, as it ascertains the devices' effective operation under difficult conditions and long-term functionality. It is also a process that works in conjunction with other safeguarding measures like conformal coating and sealing and bonding.

Why Encapsulate Electronic Components?

- ·Environmental protection: sensitive electronic components are encapsulated to protect and insulate them against environmental conditions such as moisture, contamination, vibration, physical shock, harsh chemicals, and more.

- Electrical insulation: all materials used to encapsulate electronics must be electrically insulating, which prevents unintended electrical contact between different components and reduces the risk of short circuits.

- Thermal management: some encapsulation materials have properties that aid in thermal management by dissipating heat generated by electronic components.

- Security and tamper resistance: encapsulation can be used to enhance the security of electronic devices by making it more challenging for unauthorized individuals to access or tamper with sensitive components.

- Longevity and reliability: components that are encapsulated generally experience a longer service life than those that are not, making them more reliable for critical applications in which downtime or failure is unacceptable. Examples of such applications include the aerospace, automotive, and medical industries.

- Compliance with industry standards: The abovementioned industries also have very specific and rigorous standards and regulations that must be abided by, which will often include the reliable encapsulation of electronics.

Overall, encapsulating electronics is a significant process that not only protects electronic components from environmental factors but also enhances their durability, reliability, and performance. It is a necessary approach to maintaining the effective operation of electronic devices in a wide range of applications and conditions.

Prevalent Materials Used in Electronics Encapsulation

Formerly, electronics components were protected by materials such as metals, ceramics, and glass. These materials were eventually substituted with polymers, and the most preferred material choices for encapsulation today are epoxy resins, silicones, and polyurethanes.

These three materials have varying significant characteristics that make them suitable for different encapsulation applications.

Silicones have good heat resistance and can withstand temperatures from about -50°C to 200°C. Silicones are also self-extinguishing, making them the appropriate choice for applications requiring flame retardancy.

Silicones are moisture and UV resistant, which in combination with the previously mentioned characteristics, makes the material ideal for harsh environments.

Furthermore, silicones have good vibration resistance, which is useful for applications like turbines or engine housings.

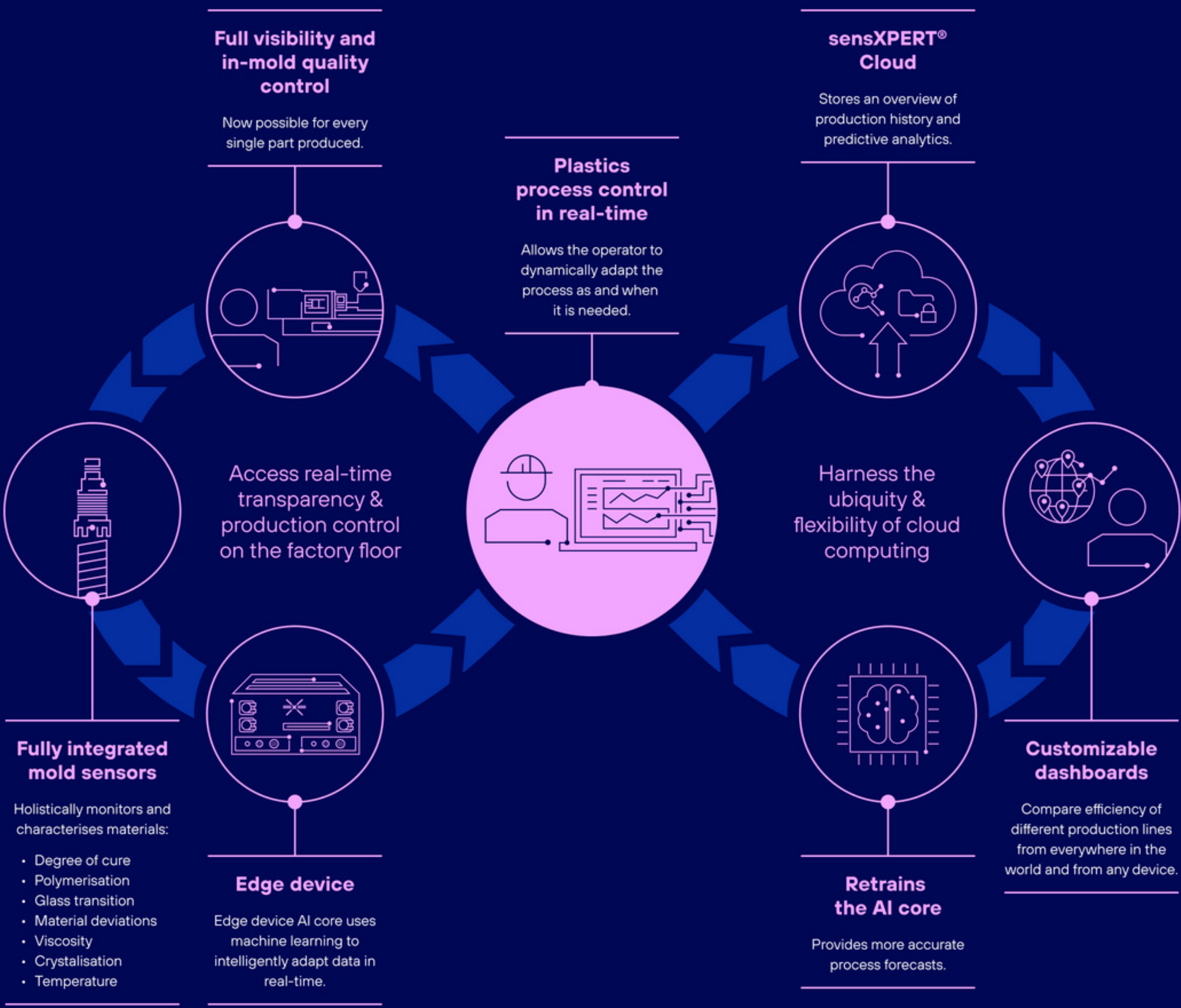
Epoxy resins present exceptional dielectric properties – thermal conductivity being one – as well as moisture and chemical resistance. Epoxy resins can also withstand temperatures from around -50°C to 200°C.

This material offers high adhesion and mechanical strength, and they are generally suited to high-voltage applications.

In comparison to epoxy resins, which become hard and rigid when cured, polyurethanes typically become slightly more flexible than the average epoxy, but polyurethane properties can be extremely widespread. This is especially practical when dealing with delicate components.

Similar to epoxy resins, this material is also chemical and moisture resistant and provides great electrical insulation.

However, when comparing polyurethanes to silicones and epoxy resins, polyurethanes can withstand a smaller temperature range of about -40 °C to 150°C.


Full visibility and in-mold quality control
Now possible for every single part produced.
Plastics process control in real-time
Allows the operator to dynamically adapt the process as and when it is needed.
sensXPERT® Cloud
Stores an overview of production history and predictive analytics.
Access real-time transparency & production control on the factory floor
Harness the ubiquity & flexibility of cloud computing
Fully integrated mold sensors
Holistically monitors and characterises materials:
• Degree of cure
• Polymerisation
• Glass transition
• Material deviations
• Viscosity
• Crystalisation
• Temperature
Edge device
Edge device AI core uses machine learning to intelligently adapt data in real-time.
Retrains the AI core
Provides more accurate process forecasts.
Customizable dashboards
Compare efficiency of different production lines from everywhere in the world and from any device.

Three Encapsulation Processes and How They Work

In this section, we will be exploring three common closed mold processes used to encapsulate electronics in manufacturing environments.

Injection Molding

Injection molding is one of the most widely used manufacturing processes for the production of plastic parts and products. It is an efficient, cost-effective process for the mass-production of components with complex shapes and precise dimensions.

The mold in an injection molding machine is typically composed of steel or aluminum and consists of two halves; a core and a cavity. These two halves are designed to match the intended shape of the final product.

The process begins by feeding raw plastic materials, in the form of pellets or granules, into a heated barrel. The material moves through a screw and is then injected into the mold cavity and held under pressure for a period of time. Finally, the part is cooled and ejected from the machine.

Transfer Molding

Another process that can be used to encapsulate electronics is transfer molding. This process is relatively similar to injection molding but differs in that the transfer molding machine includes a plunger and transfer pot – instead of an injector screw - to force the raw material into the mold cavity.

To encapsulate electronics, transfer molding is carried out by placing the component that will be encapsulated into the mold cavity. Resin is forced into the mold cavity and encapsulates the component already held within the mold.

In the next section, we will navigate the challenges of electronics encapsulation, including material variability, electronic vulnerability, high material costs, and location-to-location inconsistencies, and provide insight on a technology-based solution that addresses these challenges.

Over molding

Over molding is a molding process used to mold one or more components over another component. In this process, a pre-formed part or, in the case of electronics encapsulation, an electronic component is placed within the mold and the heated raw material is injected into the mold to form a protective layer around the electronic component.

Electronics encapsulation is a pivotal process in the safeguarding of electronic components to ensure their longevity, functionality and their protection from the environment.

However, manufacturing encapsulated electronics components can come with a number of challenges, including material variability and electronic vulnerability.

Furthermore, striking a balance between quality and cost, while simultaneously addressing location-to-location process inconsistencies, presents its own set of difficulties.

In the previous section, we discussed the essentials of manufacturing encapsulated electronics by identifying the importance of encapsulation, introducing prevalent materials used for encapsulation, and detailing a couple common closed mold encapsulation processes.

Challenges in Electronics Encapsulation

As previously mentioned, processes that encapsulate electronics can encounter several challenges. Batch-to-batch material differences and in-process material behavior deviations can lead to quality fluctuations, defective parts, and increased scrap rates.

Additionally, the lack of transparency in closed mold processes creates a manufacturing 'black box' that prevents manufacturers from knowing whether a component has been properly and reliably encapsulated, or if the electronic component has been damaged during molding, until post-process quality assurance testing.

Moreover, the plastics encapsulation of electronics relies on specialized polymers that can prove to be very costly, especially when processes are producing defective or unreliable final parts.

Another challenge is the variation or deviation between processes occurring in different manufacturing locations.

Fortunately, there are certain strategies and solutions in place that can aid manufacturers in combatting or avoiding these challenges altogether. sensXPERT Digital Mold is a solution that combines several hardware and software features to enable real-time process control, quality assurance (QA), and stability, as well as in-mold transparency and remote process tracking.

You can learn more about sensXPERT Digital Mold here.

Electronic Vulnerability

Electronic components are vulnerable to external threats like moisture, mechanical stress, and environmental factors. Moisture can infiltrate electronic components, thus causing short circuits and corrosion.

This vulnerability is especially pertinent in outdoor or humid environments. At the same time, temperature fluctuations, radiation exposure, and chemical contaminants can lead to performance degradation or failure.

In a manufacturing environment, electronic components can be subject to mechanical stress through their assembly, processing, or encapsulation, which would potentially lead to physical damage or misalignment.

Therefore, it is crucial to ensure the adequate and reliable encapsulation of electronic components through a combination of material characterization, process monitoring, and predictive algorithms.

sensXPERT Digital Mold is a solution that monitors processes and makes them transparent, but, at the same time, the solution predicts the outcome of the process.

sensXPERT does this through predictive algorithms that utilize machine learning to forecast the optimal point to demold a final part.

Additionally, this solution can help identify 'harmful' cycles to prevent damaging the electronic components, or to determine that a specific part might need additional quality assurance scrutiny.

The Digital Mold also ensures that the encapsulated part will be cured or vulcanized enough to provide optimum protection of the electronic component.

High Material Costs

As previously mentioned, the high-performance, specialized polymers required in the encapsulation of electronic components can be costly. This challenge is proliferated by the need for consistent quality and reliability.

Process efficiency is one way of managing high material costs without compromising quality. Optimizing workflows is a method of improving process efficiency and can help minimize material waste and reduce processing time.

Additionally, sensXPERT's solution can help cut down cycle times with its predictive capabilities, thus making a process more efficient to minimize production costs. The solution's ability to monitor material behavior and forecast process outcomes also greatly reduces final part defects and the scrapping of costly materials, all while preserving or improving quality.

Location-to-Location Inconsistencies

Manufacturing locations in diverse geographic areas can exhibit variations in their environmental and seasonal conditions, such as temperature, humidity, and air quality, which can affect materials in storage prior to processing and their behavior within a mold.

In cases such as these, dynamic process adaptation is a solution that accounts for material behavior deviations and halts the process once a part has reached optimum cure or vulcanization, regardless of a material's reaction to fluctuating environmental conditions.

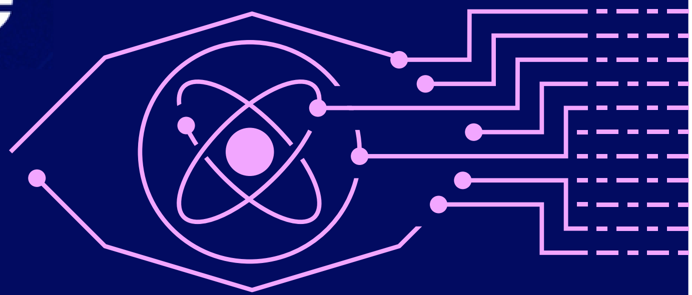
Simultaneously, sensXPERT provides remote process tracking through the sensXPERT Digital Cloud service. Therefore, manufacturers can monitor their processes across all locations and visualize the outcomes to verify that all processes are resulting in the same quality-assured, reliably encapsulated products.

In this section, we discussed several of the challenges that could affect electronic encapsulation processes, along with solutions to tackle them.

Material variability, electronic vulnerability, high material costs, and location-to-location inconsistencies can all impact process outcomes and productive manufacturing.

sensXPERT Digital Mold addresses these concerns before they can occur through material behavior characterization, predictive capabilities, in-mold transparency and monitoring, dynamic process control, and remote tracking.

What happens in the mold is invisible



Case: How sensXPERT Improves Transparency in Each Molding Cycle

Plastic processors, especially those working with thermoset materials, generally lack transparency as to what actually occurs in the mold during each processing cycle. Even processors who over mold a part with a thermoset protective layer face this challenge.

That makes it difficult to determine if the produced parts are in spec without conducting downstream quality assurance (QA) tests. Without little insight on the impact of in-mold material behavior on final part performance, molders struggle to control their processes and react to process drift in real-time.

This can lead to exceedingly long cycle times, high energy usage, high scrap rates, and high cost of quality.

However, sensXPERT Digital Mold offers real-time process transparency. By adopting machine learning (ML) algorithms, sensXPERT can accurately predict material behavior, which can then be used to aid manufacturers in dynamically controlling their processes and guaranteeing constant part quality.

Correspondingly, sensXPERT supports molders in reducing cycle times, energy usage, scrap rates, and costs.

To illustrate sensXPERT's value in addressing the abovementioned challenges, you will read about two comparable companies (Company A & Company B) working with sensXPERT Digital Mold.

Both companies encapsulate high-voltage electrical components using a reaction injection molding (RIM) process. They differ in the polymers they use and the final parts they produce. However, they both face similar challenges with high scrap rates and high cost of quality owing to a lack of transparency during the molding process.

This case will highlight sensXPERT's ability to increase transparency and improve processes, even before full technical integration of the system.

Material Insights

Company A and Company B make functional parts in high-voltage applications like power grid solutions. More specifically, Company A produces connectors, while Company B produces bushings. Using a RIM process, Company A over molds ethylene propylene diene monomer (EPDM) rubber. This synthetic rubber is known for its durability, abrasion, tear resistance, excellent metal adhesion, and flexibility.

Additionally, EPDM is resistant to most water-based chemicals, polar solvents, and solvents at elevated temperatures. Owing to a saturated backbone, EPDM provides excellent resistance to aging caused by heat exposure, UV radiation, weathering, and ozone. It can produce a very smooth molded surface. The material is especially suitable for electrical insulation due to its low electrical conductivity.

On the other hand, while Company B uses a RIM process, they differ in using epoxies to produce their parts. Epoxies are known for their excellent tensile, compressive, and flexural strength. They are also resistant to impact, abrasion, fatigue, high moisture and steam, broad chemical, radiation, and corrosion.

Furthermore, the material has low post-cure shrinkage (1%) and a broad thermal performance (up to 190°C). Epoxies offer excellent adhesion to various fillers, reinforcements, and substrates. Similar to EPDM, epoxies also provide high electrical insulation.

This facilitates their use in motors, generators, transformers, gear switches, bushings, insulators, printed circuit boards, pottants, and semiconductor encapsulants.

Common Challenges

Regardless of the material difference, both companies face similar challenges in requiring more transparency during the RIM process. The lack of transparency makes it impossible for both companies to know whether they produce good or bad parts during each molding cycle.

On that account, it becomes difficult to understand the correlation between material behavior during molding and the defects detected in a part during post-mold QA tests. In the cases at hand, a defective part is one that might fail to pass an electrical discharge or a high-voltage penetration test. An added concern is the ability to detect contamination of a material during processing.

Difficulties in transparency and post-processing QA can lead to high and costly scrap. To anticipate and reduce such scrap would improve manufacturing sustainability.

The ultimate goal for both companies is to gain process transparency, improve process stability, boost quality, and reduce costs.

How Can sensXPERT Help?

The companies consulted the sensXPERT team to see if our in-mold process monitoring system could improve quality control, reduce scrap, and better understand the effects of processing on final part performance.

They also sought the sensXPERT technology to see whether the system could detect and reduce defects in completed parts. While the system does not directly track or measure defects, it does map out material behavior and transformation during cure.

The resulting insight can help processors understand what occurs inside a mold, more quickly discover the cause of failures, and optimize their processes to account for material deviation, thus ensuring consistent quality outcomes.

The sensXPERT system includes specially designed and manufactured hardened dielectric sensors that are mounted in a mold at the very start of flow, near or at the gate, and at the end of flow. The system measures critical material and process parameters that occur in the mold during the entire molding cycle, including:

- Degree of Cure (DoC)
- Percent polymerization
- Glass transition temperature (Tg)
- Viscosity and flow-front position
- Temperature inside the mold
- Material deviations (e.g. those caused by aging, out-of-spec material, or in the presence of contaminants).

The sensXPERT Edge Device, a hardened personal computer without a keyboard or monitor, sits outside the mold but very close to the press and is hardwired to the dielectric sensors. An edge device interface empowers manufacturers to adjust their process parameters in real-time effectively.

This interface visualizes running processes and, using predictive algorithms, provides operators with an optimal point of cure. The data on the edge device is transmitted to a customer's account in the sensXPERT Digital Cloud Service following a production cycle. In the Cloud Service, the data is parsed and compared with all previously collected data to evaluate specific quality indicators.

To help dynamically control processes and ensure part quality, historical data on the Cloud Service is used to train ML algorithms. The sensXPERT system can also take third-party sensor data - such as mold temperature, pressure, and humidity - into account, which can be integrated into the ML models as well.

The trained and retrained algorithms are applied to the edge device so that the predictions of process outcomes are constantly refined. Based on the predictions, a technician can determine whether they should act and modify a process setting.

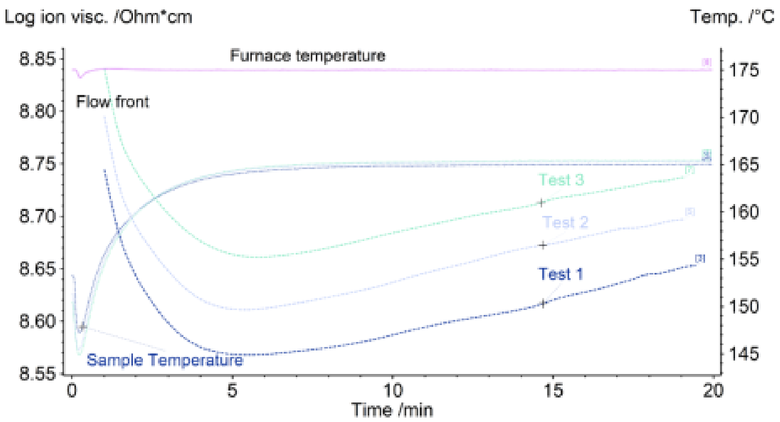
After fully installing sensXPERT Digital Mold, the companies can better understand whether pre-process material handling contributes to deviations during manufacturing. They will also gain more insight into how the curing mechanism affects final part properties and how that may contribute to failed post-process QA tests.

Preliminary Results

Based on laboratory characterization of EPDM rubber, the preliminary results above help explain what occurs during molding. As the material is heated, its viscosity lowers and flow increases, which is indicated by ion viscosity (in Ohm-cm).

This represents the movement of the material. However, as the temperature continues to rise, crosslinking begins to occur. This increases viscosity and decreases the mobility of the ions, which suggests that flow is slowing. As follows, measuring a process parameter like ion viscosity can indicate the degree of cure and how the material fills the mold.

When the companies produce parts, further material characterization and encapsulation experiments will be conducted in an instrumented mold to test the hypothesis that the degree of cure is the critical property affecting whether encapsulated parts pass QA testing.



What's Next?

As depicted throughout this case, processors that encapsulate high-voltage electrical applications in thermoset polymers are confronted by the lack of in-mold transparency during each molding cycle.

They can achieve process stability only when they understand how material properties within the mold create deviations that lead to issues, such as scrap.

Once they have in-mold transparency, they can reliably and repeatedly produce in-spec parts using adaptive process control without costly and time-consuming post-processing QA testing.

At a time when manufacturers struggle to fill skilled positions, supply chain challenges and rising energy costs add pressure to the bottom line. Companies are also compelled to make their manufacturing footprint more sustainable. New ML-based tools, like sensXPERT Digital Mold, can improve profitability and facilitate entering new markets and applications.

sensXPERT's technology can enable companies to maintain a digital thread of their processes and enhance in-mold transparency, cost control, and overall sustainable production.

Learn more at www.sensxpert.com or contact the team at www.sensxpert.com/contact

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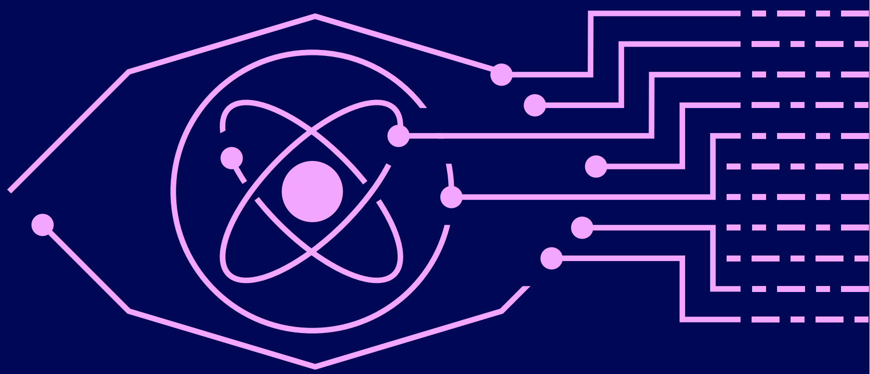

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