

Conquering Material Deviations in Plastics Manufacturing

A Technical Guide

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Conquering Material Deviations in Plastics Manufacturing: A Technical Guide

In 2023, the global plastics industry reached a market value of 712 billion USD. The expanse of this industry is not only apparent in its economic value, but also in the number of sectors it serves. Automotive, aerospace, electronics, construction, healthcare, and packaging are but a few of those sectors.

The plastics industry is also undergoing swift transformation triggered by technological advancements, Industry 4.0, shifting market demands, customer preference realignment, and a heightening focus on sustainable manufacturing.

To keep up with the evolving dynamics of the plastics market, plastics manufacturers are zeroing in on and attempting to eliminate any production bottlenecks that deter their growth, competitiveness, and operational efficiency through automation, digitalization, and advanced process control techniques.

Material behavior deviations during plastics processing is one example of a common production bottleneck. Accordingly, this white paper will dive into the challenge of material deviations and offer a comprehensive exploration of:

- **Diverse Defects:** Understand the various types of material defects that can arise, affecting everything from dimensional accuracy to mechanical properties and surface finishes.
- **The Root Causes:** We examine the factors that contribute to material behavior deviations, including raw material inconsistencies, storage and handling procedures, process parameter fluctuations, and even human error.
- **Costly Consequences:** Uncover the consequences of material deviations, encompassing their impact on product quality, scrap generation, rework expenses, production delays, and ultimately, brand reputation.
- **Overcoming the Obstacles:** Discover preventive measures and control strategies to mitigate the risks of material deviations. Our focus goes beyond standard approaches, highlighting the importance of a process control system with material characterization capabilities and predictive algorithms.



What are Material Deviations?

What are Material Deviations?

In the plastics manufacturing environment, achieving consistent quality hinges on rigorously controlling various parameters. However, even with the most stringent measures, imperfections sometimes arise and pose significant challenges.

These imperfections are otherwise known as material deviations – unwanted variations in the properties or characteristics of the final product compared to its intended specifications.

Warping, discoloration, or unexpected cracks are just a few manifestations of material deviations. Their impact can be multifaceted, affecting aesthetics, functionality, and even safety.

The types of deviations encountered vary based on polymer type, processing methods, and intended application. However, their underlying attribute remains the same – a departure from the desired outcome.

This departure can present itself in various ways, including:

- Dimensional variations
- Surface imperfections
- Internal flaws
- Mechanical property deviations

In the following sections, we outline various material deviation classification perspectives and introduce the different types of defects that might arise during plastics processing.

Categorizing Material Deviations in Plastics Manufacturing

Classification Systems

To effectively combat material deviations and defects, it is crucial to first understand their nature by categorizing them.

One such category focuses on the **origins** of defects, revealing their root cause:

- **Processing-induced:** These defects arise from flaws within the manufacturing process itself, such as improper temperature or pressure control.
- **Material-induced:** Inherent inconsistencies in the raw material, like impurities or uneven mixing, can manifest as defects in the final product.
- **Design-induced:** Sometimes, even the design itself can harbor weaknesses, leading to stress concentrations and subsequent cracking or breakage.

Another category focuses on the **location** of the defect, pinpointing its physical manifestations:

- **Surface defects:** These mar the product's aesthetics, such as flow lines, scratches, or discoloration, impacting its visual appeal and potentially influencing functionality.
- **Internal defects:** Hidden beneath the surface, voids or cracks can compromise the product's structural integrity and performance.
- **Dimensional deviations:** Variations in size, shape, or thickness, like warpage or shrinkage, can lead to assembly issues and performance inconsistencies.

Finally, a third category emphasizes the **impact** of the defect, highlighting its practical consequences:

- **Aesthetic defects:** While impacting appearance, they may not affect functionality, like slight color variations or minor surface imperfections.
- **Functional defects:** These compromise the intended use of the product, such as dimensional inaccuracies hindering assembly or cracks weakening structural integrity.
- **Structural defects:** These pose safety hazards by affecting the product's ability to withstand intended loads or stresses. Think cracks in pressure vessels or weakened components in critical applications.

Understanding these diverse classification categories empowers manufacturers to approach defect mitigation from various angles. Each perspective offers a unique lens through which to view and categorize the challenge of material defects, ultimately assisting in the development of targeted strategies for prevention and control.

Types of Material Deviations and Defects

Having established a few perspectives for classifying material deviations, we now examine the specific types of defects that might occur during plastics processing using the location classification perspective.

Dimensional Deviations

These deviations disrupt the intended geometry of products, leading to downstream challenges.

- **Warpage**, which is characterized by distortion or bending of the plastic, can arise from unfavorable temperature conditions, excessive cooling, or pronounced orientation of the fillers.
- **Shrinkage**, a natural tendency for plastics to decrease in size after processing, can lead to inaccurate dimensions if not properly accounted for.
- **Sink marks** are depressions on the surface that result from incomplete mold cavity filling or inconsistent shrinkage.
- **Flash** is when excess material overflows the mold, solidifies, and creates an extra layer on the surface of the plastic part.
- **Short shots** are incompletely filled molds and result in products that lack critical features.

Surface Defects

These imperfections impact the product's visual appeal and may even affect functionality.

- **Flow lines** are visible patterns caused by plastic flow during molding, and these can influence both aesthetics and, in some cases, strength.
- **Weld lines** form when separate molten plastic flows merge, which can create weak points or uneven surfaces.
- **Blisters** are raised bubbles on the surface that arise from trapped air or moisture.
- **Haze** is a cloudiness that reduces transparency and can occur due to chemical reactions or surface irregularities.
- **Scratches and discoloration**, although seemingly minor, can affect marketability and brand perception.

Internal Defects

These hidden blemishes compromise the product's structural integrity and performance.

- **Void**s are air pockets that get trapped within the plastics, weakening their internal structure.
- **Inclusions** are foreign particles like impurities or unmixed additives, which can create stress points and initiate cracks.
- **Porosity** is a network of small voids that compromises mechanical properties.
- **Delamination** occurs when layers of plastic separate, creating weak zones.
- **Cracks**, visible or microscopic, pose serious concerns as they can propagate under stress leading to product failure.

Mechanical Property Deviations

These deviations affect the material's intended performance characteristics.

- **Reduced strength or stiffness** can occur due to improper processing, material inconsistencies, or internal defects.
- **Impact resistance**, the ability to withstand sudden force, can be compromised by material flaws.
- Other properties, like **heat resistance**, can also deviate due to material or processing issues.

Material deviations can have a cascading effect, impacting various aspects of production and the final product. Some key consequences of deviations are reduced quality, increased costs, production inefficiencies, safety concerns, and damage to brand reputation.

Consequences of Material Deviations

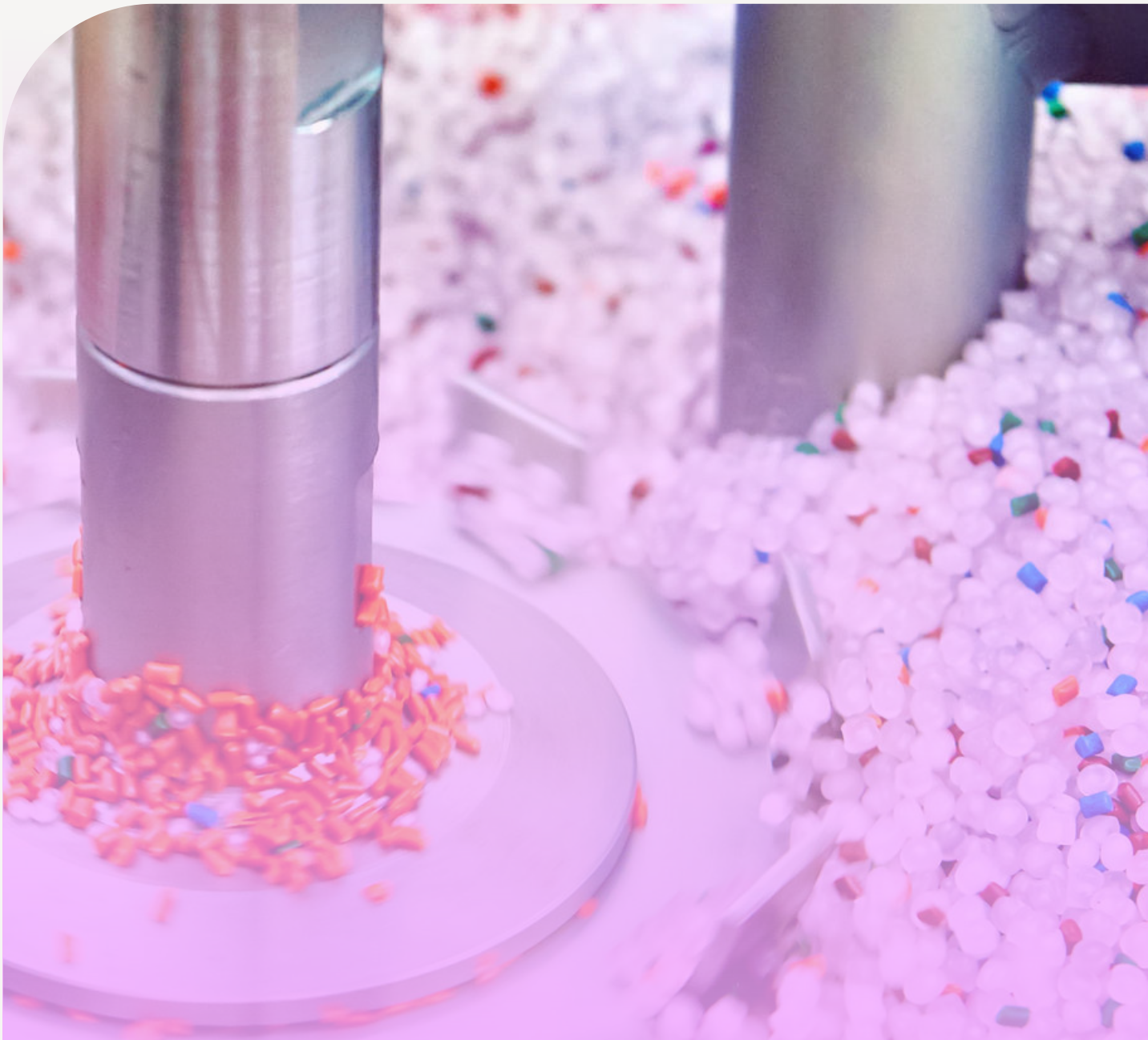
Reduced quality: Deviations can lead to inconsistent product dimensions, surface imperfections, compromised mechanical properties, falling short of quality standards and potentially causing product failure and scrap.

Increased costs: Scrap generation, rework, and production downtime due to deviations result in significant financial losses. Additionally, addressing customer complaints and warranty claims when defective products escape notice and reach customers adds a further strain on resources.

Production inefficiencies: Deviations disrupt production flow, leading to delays, increased cycle times, and reduced output. This can put manufacturers behind schedule and hamper their ability to meet customer demands.

Safety concerns: In extreme cases, deviations can cause product defects that pose safety hazards to workers or consumers.

Brand reputation damage: Inconsistent product quality and safety issues can damage a manufacturer's brand reputation, leading to distrust and potential market share decline.



Identifying the Root Causes of Material Deviations

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To understand and overcome the challenges posed by material deviations, pinpointing the root cause – the source of deviation – is critical. Beyond simply identifying the immediate outcome (e.g., warpage), a deeper investigation reveals the underlying factor that triggered it (e.g., uneven mold temperature).

Uncovering the root causes of material deviations encourages plastics processors to proactively prevent them, enhance their quality control methods, and save costs that would otherwise be spent on material waste, rework, and downtime.

Material deviations can come about due to different factors, including processing parameters, material properties, design considerations, human error, and equipment performance.

Processing Parameters

At the heart of the manufacturing process lies a combination of parameters that directly influence a material's behavior and final properties. In essence, these parameters guide the manufacturing process, and any inconsistencies or deviations can lead to defects.

- **Temperature Control:** Inaccurate or fluctuating temperatures during melting, molding, or cooling can lead to warpage, shrinkage, or surface imperfections.

- **Pressure Settings:** Improper pressure settings can cause flow lines, weld lines, flash, or incomplete filling compromising both aesthetics and functionality.
- **Injection Speed and Cycle Time:** It is crucial to balance these parameters to avoid internal stresses, voids, and dimensional inconsistencies.
- **Mold Design and Cleanliness:** Poor mold design can trap air or create uneven flow, while inadequate mold cleaning can introduce contaminants leading to surface defects.

Material Properties

Inconsistency in the inherent properties and quality of raw materials used in plastics processing can lead to unpredictable behavior and deviations. Material property inconsistencies include variations in factors like molecular weight, crystallinity, or moisture content.

Additionally, the presence of impurities and contaminants can create stress points, initiate cracks, or disrupt the material's homogeneity, thus impacting performance. Furthermore, choosing a material that is unsuited for the intended processing conditions or applications can lead to unexpected issues like cracking or discoloration.

Design Considerations

Sometimes the design itself may pose challenges. For instance, geometrically complex parts with sharp corners, thin walls, or intricate features can create difficulties during processing, leading to flow issues, stress concentrations, and potential breakage.

Another design consideration that might prompt deviations is inadequate stress analysis. Failing to account for expected loads and stresses during use can result in premature failure or unforeseen deformations.

Human Error

While automation plays an increasingly important role, human involvement remains crucial. Unintentional mistakes or lack of training can have significant consequences.

- **Incorrect Settings:** Entering the wrong parameters into control systems can have significant consequences for the material and final product.
- **Improper Handling:** Rough handling of materials or molds can introduce scratches, nicks, or contamination, impacting aesthetics and, potentially, performance.
- **Inadequate training:** Insufficient knowledge of proper procedures or safety protocols can lead to operational errors and deviations.

Equipment Performance

Even the most reliable tools can wear down or malfunction, and resulting equipment issues can significantly impact process outcomes. Worn-out molds, nozzles, or other components can create inconsistencies in flow, pressure, or temperature. Additionally, improperly calibrated equipment can provide inaccurate measurements and readings, hindering effective process control.

Processing parameters, material properties, design considerations, human error, and equipment performance are not mutually exclusive causes of deviations. A process that sees a lot of defects and deviations will often have multiple factors interacting and contributing to a single deviation.

Even when understanding the root causes that might bring about material deviations in a plastics production process, manufacturers can still be challenged by deviations.

After detecting a part defect during downstream quality assurance tests, locating the precise origin of the defect or deviation can prove difficult. Numerous interacting parameters, including temperature profiles, pressure settings, material properties, and mold design, influence final product outcomes.

Traditional root cause analysis tools often focus on singular factors, making it difficult to disentangle the complex interactions that contribute to a specific deviation. Additionally, limited physical access to certain areas during the process, such as mold interiors, further hinders the precise localization of the error.

Subtle variations in material properties and batch-to-batch inconsistencies add another layer of complexity, requiring advanced statistical analysis and process monitoring techniques to identify subtle deviations masked by inherent material variability.

Moreover, the very nature of closed-mold processes presents the challenge of limited visibility. Once the mold closes, a “black box” forms, obscuring the material’s behavior and potential deviations from view. This lack of real-time visibility makes it difficult to pinpoint the exact moment and location of a deviation or predict its impact on the final product quality.

sensXPERT Digital Mold: A Process Control Solution to Combat Material Deviations

Traditional approaches to material deviation mitigation in plastics manufacturing often suffer from limitations in post-production testing, static process control, and limited in-mold visibility. These limitations leave manufacturers vulnerable to recurring defects, inconsistent quality, and reactive troubleshooting.

sensXPERT Digital Mold presents a transformative solution by employing a sophisticated dielectric sensor system embedded directly within the mold itself and in direct contact with the processed material. This system acts as a real-time data acquisition and analysis tool, capturing critical material properties like viscosity, degree of cure or crystallization, glass transition temperature, flow, and more throughout the entire molding cycle.

Traditional Approaches to Material Deviation Mitigation

- **Post-production testing:** This reactive approach involves inspecting finished products to ensure they meet performance requirements and are not marred by defects like warpage, surface imperfections, or cracks. While valuable for identifying deviations, subtle defects might be overlooked.
- **Statistical process control (SPC):** This method involves monitoring key process parameters like temperature and pressure during production and statistically analyzing data for trends or deviations. SPC can identify potential issues before they manifest as defects, but its effectiveness relies on well-defined control limits and accurate data collection.
- **Mold design optimization:** Traditional methods involve analyzing mold design for potential flow issues, stress concentrations, or uneven cooling, often through simulation software or physical prototyping. While effective for addressing design-related deviations, it can be time-consuming and may not capture dynamic process variations.

By piercing the “black box” of the mold, sensXPERT offers unprecedented visibility into the dynamic interplay of process parameters and material properties. This data is then analyzed using advanced machine learning algorithms, enabling the precise identification of deviations in real-time.

Moving beyond traditional troubleshooting, sensXPERT Digital Mold’s predictive capabilities anticipate potential deviations before they occur. This allows for proactive fine-tuning of process parameters, including cycle times and temperature profiles, optimizing production runs and minimizing material waste.

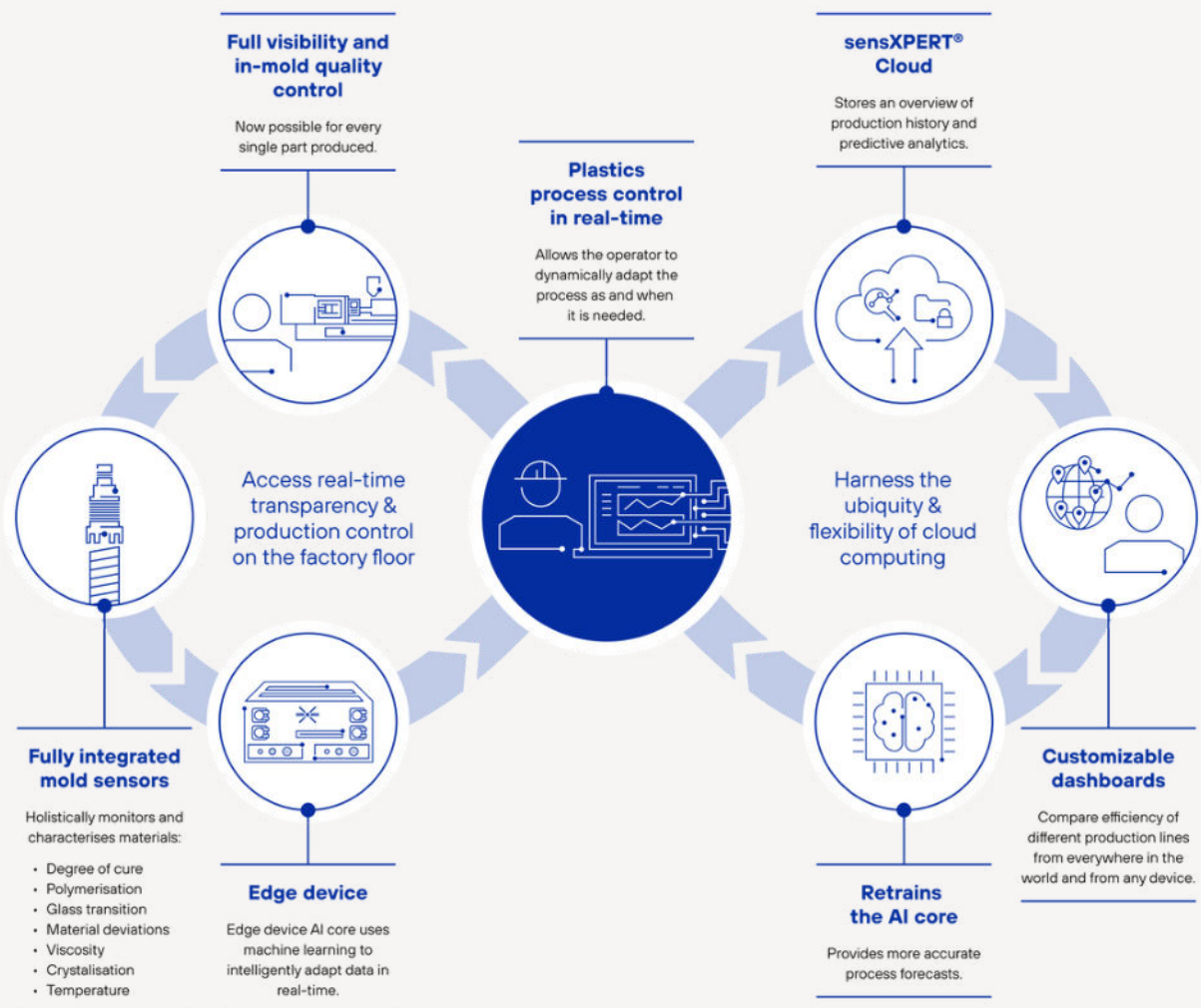
Additionally, the comprehensive data collection on each part produced allows for the identification of subtle defects that might otherwise be missed, ensuring consistent quality across the entire production batch.

Furthermore, sensXPERT Digital mold transcends localized quality control methods by providing a holistic overview of all a customer’s production processes through the sensXPERT Digital Cloud Service. Through the Digital Cloud Service, a manufacturer can remotely monitor each of their sensXPERT-equipped machines across all manufacturing locations. The Digital Cloud Service also stores all previous process data, creating a digital thread per part produced, and aligning with reporting regulations.

- **Material selection and characterization:** Choosing materials with suitable properties for the intended application and process conditions is crucial. However, relying solely on datasheet specifications may not account for batch-to-batch variations or complex material interactions.
- **Process parameter adjustments:** Based on experience or historical data, operators may manually adjust process parameters like pressure, cycle time, or temperature to address observed deviations. This approach can be effective for minor adjustments but lacks precision and may introduce unintended consequences.
- **Basic in-mold sensors:** Some molds utilize basic sensors for measuring cavity pressure or temperature and specific points. This offers localized data but fails to capture the complete picture of material behavior throughout the mold and lacks advanced analytical capabilities.

This deeper level of insights safeguards brand reputation and customer satisfaction by guaranteeing that every manufactured part meets the highest quality standards.

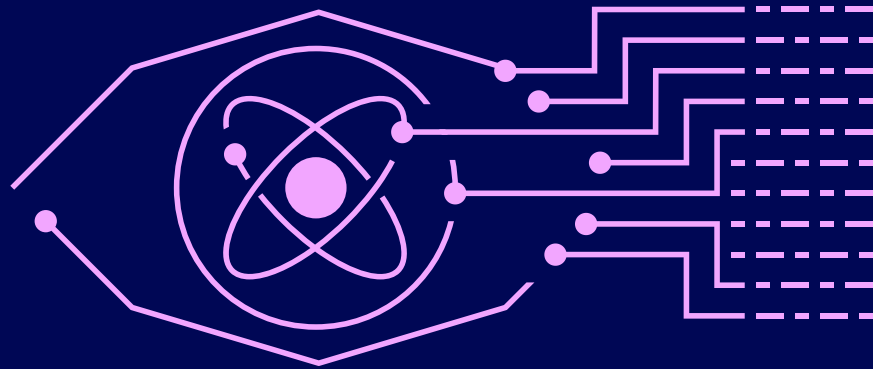
In conclusion, sensXPERT Digital Mold offers a technically innovative solution to the persistent challenge of material deviations in plastics manufacturing. By providing real-time data, in-depth material analysis, and predictive capabilities, it empowers manufacturers to take control of their processes, achieve consistent quality, reduce costs, and optimize production efficiency.



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