Basics of Plastic Shrinkage in Injection Molding: Causes, Solutions, and Case Studies

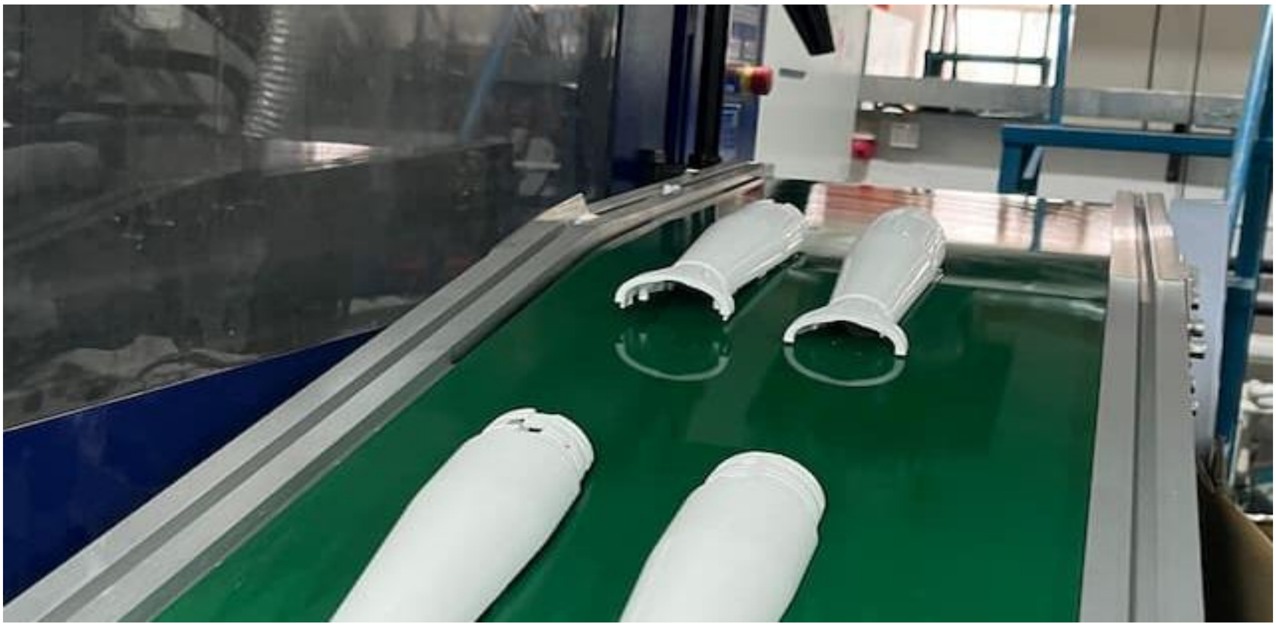
By GEMS-MFG Team

I. What is Plastic Shrinkage?

Plastic shrinkage refers to the reduction in size that occurs in plastics as they cool and solidify after the injection molding process. This phenomenon is primarily due to the contraction of polymer chains as the material transitions from a molten state to a solid state.

Shrinkage in injection molding is a critical factor influencing the dimensional accuracy and quality of molded parts. Variations in shrinkage can lead to defects such as warping, sink marks, voids, and dimensional inaccuracies, posing significant challenges for manufacturers. Controlling shrinkage is vital not only for ensuring product quality but also for reducing production costs and minimizing waste.

By understanding the shrinkage behavior of different plastics and implementing effective measures, manufacturers can achieve consistent, high-quality production. This article explores the shrinkage rates of common plastics, examines the causes of shrinkage-related defects, and outlines actionable strategies for prevention and resolution.



II. Key Factors Influencing Shrinkage in Injection Molding

Shrinkage in injection molding refers to the reduction in volume of a molded part as it cools and solidifies inside the mold. This occurs due to the thermal contraction of polymer chains and the phase transition from a molten to a solid state. Shrinkage is influenced by multiple factors, including material type, part geometry, and processing conditions.

1. **Material Properties:**
   - **Amorphous Plastics (e.g., ABS, PC):** Tend to exhibit lower and more predictable shrinkage rates due to their random molecular structure.
   - **Semi-Crystalline Plastics (e.g., PE, PP):** Exhibit higher shrinkage rates due to the orderly arrangement of molecules during solidification.
2. **Thickness Variations:**
   - With thinner areas cooling more rapidly than thicker ones, this differential cooling can result in shrinkage and warping.
3. **Stress Level**:
   - Stress during injection molding affects shrinkage. Excessive stress can cause fluid excess, leading to shrinkage and brittleness.
4. **Cooling Dynamics:**
   - Rapid cooling can lead to uneven shrinkage and internal stresses.
   - Properly designed cooling channels can promote uniform shrinkage.
5. **Processing Parameters:**
   - Injection pressure, speed, and temperature directly affect material flow and shrinkage.
   - Packing and holding pressure play a critical role in reducing voids and controlling part dimensions.
6. **Mold Design:**
   - Uniform wall thickness reduces shrinkage variations.
   - Placement of gates and runners affects material flow and shrinkage distribution.

III. Shrinkage Rates of Common Plastics

Understanding the typical shrinkage rates of plastics helps engineers design molds and processes that account for material behavior. Below is a detailed table summarizing shrinkage rates and characteristics for common plastics:

Material	**Shrinkage Rate (%)**	**Characteristics**
Polypropylene (PP)	1.2 – 2.5	High shrinkage; suitable for lightweight, flexible parts.
Polyethylene (PE)	1.5 – 4.0	Semi-crystalline; used for containers, pipes, and packaging.

Acrylonitrile Butadiene Styrene (ABS)	0.4 – 0.8	Low shrinkage; excellent for precise and durable components.
Polycarbonate (PC)	0.5 – 0.7	High impact strength; used for optical and structural parts.
Polystyrene (PS)	0.3 – 0.7	Low shrinkage; commonly used in disposable and lightweight products.
Nylon (PA)	1.0 – 2.0	High shrinkage; excellent for wear-resistant and mechanical parts.
Polyethylene Terephthalate (PET)	0.2 – 2.5	Semi-crystalline; used in high-precision, transparent, and food-safe parts.
Polyvinyl Chloride (PVC)	0.1 – 0.5	Minimal shrinkage; widely used in pipes and profiles.
Thermoplastic Polyurethane (TPU)	0.8 – 1.5	Elastic and durable; commonly used in seals and flexible parts.

Additional Notes:

- Shrinkage rates vary with filler content. For example, glass-filled materials often exhibit reduced shrinkage compared to unfilled variants.
- Special grades of materials (e.g., flame-retardant, UV-resistant) may have unique shrinkage characteristics.

IV. Causes of Shrinkage-Related Defects in Injection Molding

Shrinkage is a natural result of polymer solidification, but when not managed correctly, it can lead to several defects like below:

1. Warping and Distortion:

- Uneven cooling or asymmetrical mold designs result in non-uniform shrinkage, causing parts to bend or twist.

2. Sink Marks:

- Formed in thick sections due to inadequate packing pressure or insufficient cooling.

3. Voids:

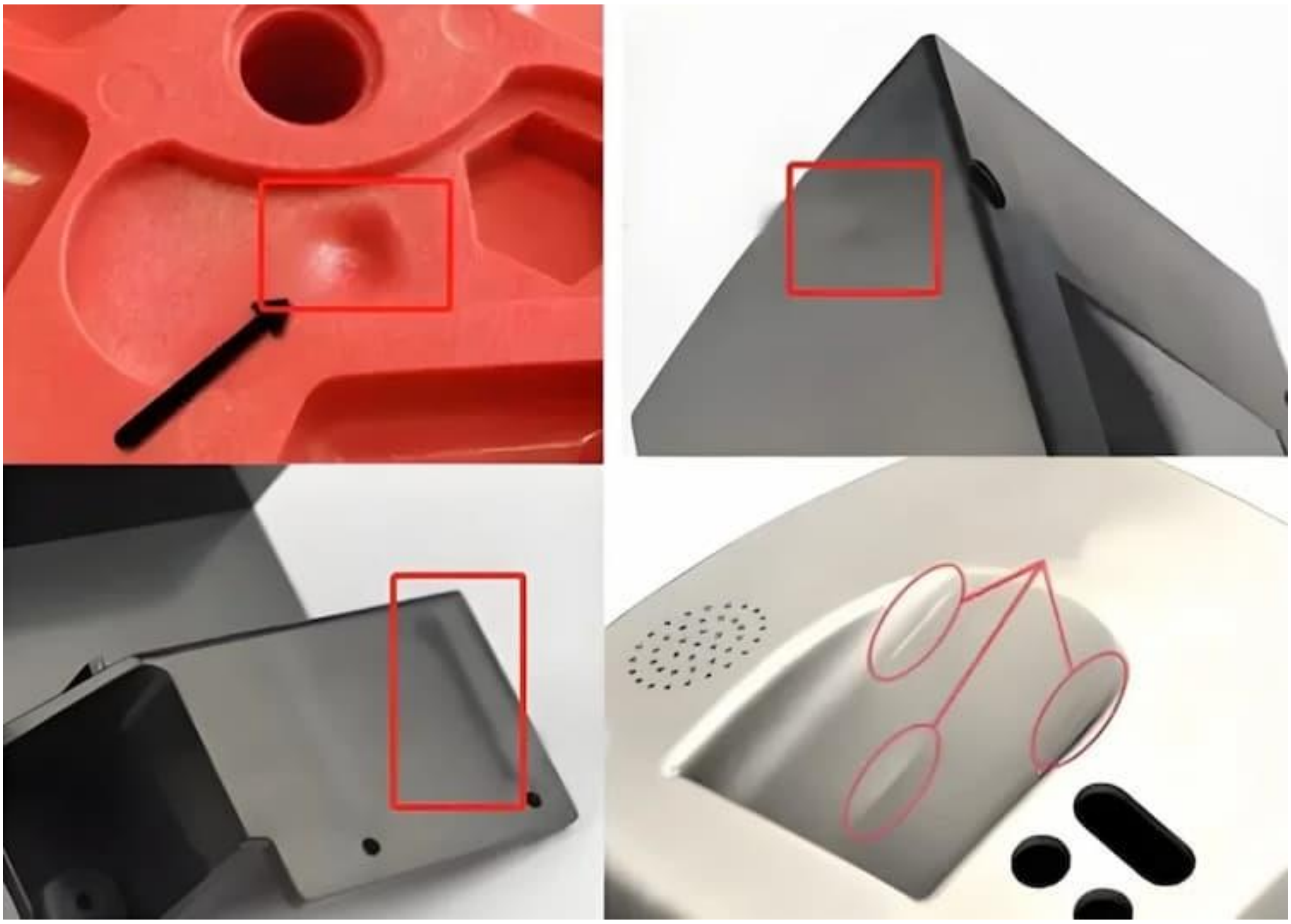
- Air pockets trapped within the part due to excessive shrinkage or improper packing.

4. **Dimensional Inaccuracies:**

- Variations in shrinkage rates lead to mismatched dimensions, especially in multi-cavity molds or assemblies.

5. **Surface Defects:**

- Uneven shrinkage can cause surface irregularities such as ripples or waviness.



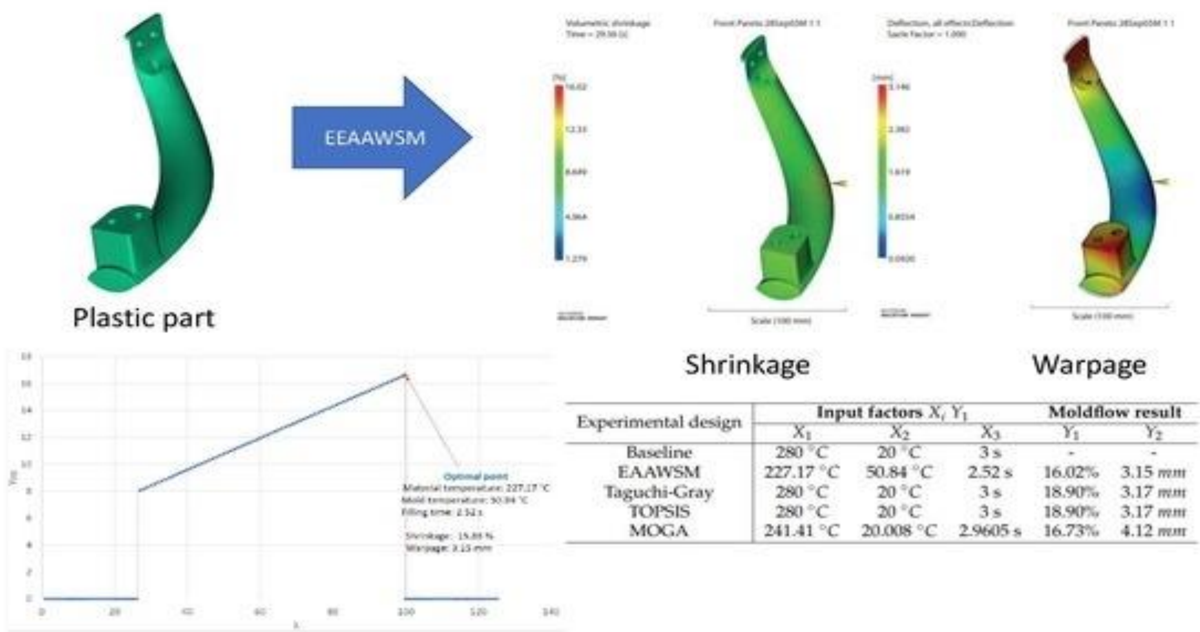
V. Preventive Measures for Managing Shrinkage in Injection Molding

1. **Material Selection:**
   - Low-Shrinkage Materials: Use materials like ABS or PC for applications requiring high dimensional stability.
   - Additives and Fillers: Reinforcements like glass fibers can reduce shrinkage while enhancing mechanical

properties.

2. **Optimized Mold Design:**
   - Uniform Wall Thickness: Prevents differential cooling and ensures consistent shrinkage.
   - Cooling Channel Placement: Strategically placed channels promote even cooling and reduce warping.
   - Gate Design: Proper gate size and location minimize flow restrictions and packing inconsistencies.
3. **Processing Optimization:**
   - Injection Parameters: Adjust injection speed and pressure for uniform material flow.
   - Packing Pressure: Increase packing pressure and duration to compensate for material contraction.
   - Cooling Time: Optimize cooling cycles to ensure parts solidify uniformly without overcooling.
4. **Post-Molding Treatments:**
   - Annealing: Heat treatment to relieve internal stresses and stabilize dimensions.
   - Stress Relief: Techniques like ultrasonic vibration or thermal cycling can improve dimensional accuracy.

Optimization of the reduction of shrinkage and warpage



Experimental design	Input factors X_i Y_1			Moldflow result	
	X_1	X_2	X_3	Y_1	Y_2
Baseline	280 °C	20 °C	3 s	-	-
EAAWSM	227.17 °C	50.84 °C	2.52 s	16.02%	3.15 *mm*
Taguchi-Gray	280 °C	20 °C	3 s	18.90%	3.17 *mm*
TOPSIS	280 °C	20 °C	3 s	18.90%	3.17 *mm*
MOGA	241.41 °C	20.008 °C	2.9605 s	16.73%	4.12 *mm*

VI. Troubleshooting Techniques for Resolving Shrinkage-Related Molding Defects

1. **Sink Marks**
   1) **Definition:**

- Depressions or dimples on the surface of a molded part, typically appearing in areas with greater material thickness.

2) Causes:

- Varying wall thicknesses leading to uneven cooling and shrinkage.
- Insufficient injection pressure failing to fill the mold completely.
- Inadequate cooling time or improper cooling system settings.

3) Solutions:

- Design parts with uniform wall thickness to ensure even cooling.
- Increase injection and packing pressure to ensure the mold is fully filled.
- Extend cooling time and optimize the cooling system to allow for gradual, even cooling.
- Use materials with lower shrinkage rates.

2. Voids

1) Definition:

- Internal cavities or hollow spaces within the molded part, often appearing in thick sections.

2) Causes:

- Insufficient material to fill the mold cavity completely.
- Trapped air or gases within the mold.

3) Solutions:

- Increase injection speed and pressure to ensure complete filling of the mold.
- Optimize gate location and size to improve material flow and reduce the risk of trapped air.
- Implement vacuum-assisted molding to remove trapped gases.

3. Warpage

1) Definition:

- Distortion or bending of the molded part due to uneven shrinkage rates during cooling.

2) Causes:

- Uneven cooling rates across different areas of the mold.
- Differential shrinkage due to varying wall thicknesses.

3) Solutions:

- Optimize cooling system design to ensure uniform cooling across the part.
- Adjust processing temperatures to reduce thermal gradients.
- Modify part design to have uniform wall thickness and reduce differential shrinkage.
- Use post-molding treatments like annealing to relieve internal stresses.

4. Dimensional Inaccuracies

1) Definition:

- Deviations from the intended dimensions of the molded part due to inconsistent shrinkage rates.

2) **Causes:**

- Inconsistent shrinkage rates across different materials or sections of the part.
- Improper mold design leading to non-uniform cooling.

3) **Solutions:**

- Fine-tune processing parameters such as mold and melt temperatures.
- Use computer simulation for shrinkage prediction to optimize mold design.
- Implement statistical process control (SPC) to monitor and adjust the molding process.

5. **Internal Stress**

1) **Definition:**

- Residual stresses within the molded part due to uneven cooling and shrinkage, which can lead to warpage or cracking over time.

2) **Causes:**

- Rapid cooling of the outer layers while the inner layers remain molten, leading to differential shrinkage.

3) **Solutions:**

- Use slower mold cooling to increase the solidification rate of the core and minimize variation between sections.
- Select materials with lower shrinkage properties to avoid pulls and internal stresses.
- Modify mold design by coring out heavy walls to speed up external cooling of thick areas.

VII. Real-World Solutions to Common Shrinkage Challenges in Injection Molding

Case 1: Reducing Warping in Nylon Gears

Problem: A manufacturer producing nylon gears encountered significant warping issues, which affected the gear meshing performance. The primary cause was uneven cooling rates across different areas of the mold, leading to differential shrinkage.

Solution: The manufacturer redesigned the cooling channels in the mold to achieve uniform cooling. This involved:

- **Optimizing Cooling Channel Design**: The cooling channels were reconfigured to ensure even heat distribution across the entire mold. This included adding more channels and adjusting their placement to cover critical areas.
- **Material Selection**: The manufacturer chose a nylon material with lower shrinkage properties to reduce the likelihood of warping.
- **Process Parameter Adjustment**: Injection and holding pressures were increased to ensure the mold was

fully filled and to reduce the chances of warping during cooling.

Outcome: These changes resulted in a 40% reduction in warping, significantly improving the gear meshing performance and overall part quality.

Case 2: Eliminating Sink Marks in ABS Casings

Problem: A manufacturer producing ABS electronic casings faced persistent sink marks, particularly in areas with thicker sections. The sink marks not only affected the appearance but also compromised the structural integrity of the casings.

Solution: The manufacturer implemented several changes to address the sink marks:

- **Increased Packing Pressure**: The packing pressure was increased to ensure that the mold was fully packed, reducing the likelihood of sink marks due to material shrinkage.
- **Dual-Gate Design**: The mold was redesigned with a dual-gate system to improve material distribution. This ensured that thicker sections were filled more effectively, reducing the risk of sink marks.
- **Optimized Cooling Time**: The cooling time was extended to allow for more uniform cooling across the part, minimizing differential shrinkage.

Outcome: These adjustments effectively resolved the sink mark issue, resulting in casings with improved appearance and structural integrity.

Case Study 3: Improving Dimensional Accuracy in Medical Device Components

Problem: A medical device manufacturer was experiencing significant dimensional inaccuracies in a critical component used in disposable medical devices. These inaccuracies were primarily due to shrinkage variations during the injection molding process, which compromised the functionality and reliability of the devices.

Solution: The manufacturer implemented several targeted solutions to address the dimensional inaccuracies:

- **Advanced Software Simulation:** The company utilized advanced simulation software to predict shrinkage rates accurately. This allowed them to optimize the mold design and process parameters before production, reducing the likelihood of dimensional inaccuracies.
- **Mold Design Optimization:** The mold was redesigned to ensure uniform wall thickness and consistent cooling rates. This included adding more cooling channels and adjusting their placement to cover critical areas.
- **Temperature Control:** The manufacturer fine-tuned the mold and melt temperatures to ensure consistent material flow and cooling rates. This helped in reducing the shrinkage variations across different sections of the component.
- **Injection Pressure:** Injection and holding pressures were increased to ensure the mold was fully filled and

to reduce the chances of dimensional inaccuracies during cooling.

Outcome: These combined efforts resulted in achieving dimensional tolerances within ±0.05mm, ensuring the functionality and reliability of the medical devices. The manufacturer was able to meet the stringent quality standards required for medical applications, enhancing their market competitiveness.

VIII. Conclusion

Understanding and controlling shrinkage in injection molding is essential for producing parts with high precision and reliability. By combining material expertise, advanced mold design, and precise process control, manufacturers can effectively minimize shrinkage-related defects. A holistic approach to troubleshooting ensures cost-effective and high-quality production, meeting the ever-increasing demands of modern manufacturing.

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