Influence of Mold Wall Temperature on Surface Replication in Thermoplastic Injection Molded Parts

Abstract

The surface quality of injection molded plastic components is significantly influenced by the mold wall temperature. This work investigates the physical mechanisms of surface replication and their dependence on thermal conditions during the injection molding process. Both the theoretical fundamentals of light scattering effects and practical impacts of inhomogeneous temperature distributions are analyzed. The considerations are made under the assumption of professionally correct surface treatment in each case.

1. Introduction

Surface replication describes the ability of a thermoplastic material to reproduce the (micro)structures of the mold surface during the injection molding process.

The essential properties influenced by mold wall temperature are:

- Surface quality or replication accuracy
- Molecular structure
- Residual stresses
- Tolerances
- Component warpage

On the following pages, exclusively the fundamental relationships between **surface quality** and mold wall temperature will be discussed.

2. Theoretical Fundamentals of Visual Effects

2.1 Physical Explanation of Light Scattering

The optical properties of plastic surfaces can be classified through the underlying geometry and the resulting light scattering effects.

Table 1 shows the essential physical relationships.

	Geometric origin	Light scattering effect	Typical characteristics
	***Flat*** High gloss polished	The incident light is reflected at a defined angle - the angle of reflection equals the angle of incidence.	- Clear, sharp mirror images
	***Step*** (mostly linear) Change in profile / height level	Change in direction of (direct) light scattering Change in ratio of direct / diffuse scattering	- Brighter or darker line - Often correlated to flow front - Visibility / color can depend on inspection direction
	***Bump*** Punctual profile variation with positive height, i.e. above normal surface level	(see above)	- Punctual defect - Dark point in side view against light
	***Notch*** (mostly linear) Profile variation with negative height, i.e. below normal surface level	(see above)	- Brighter or darker lines - Often located between gates - Impression often depends on inspection direction
	***Roughness*** Combination of alternating positive and negative height variations	(see above)	- Area of low gloss / matt surface - (More or less) independent on inspection angle

Table 1

Flat surfaces ("Flat"): The incident light is reflected at a defined angle, where the reflection angle corresponds to the angle of incidence. This leads to clear, sharp mirror images.

Step structures ("Step"): Directional changes in direct light scattering create brighter or darker lines in the optical appearance.

Elevations ("Bump"): Point defects cause local light scattering anomalies.

Depressions ("Notch"): Similar to step structures, brighter or darker line effects occur.

Surface roughness ("Roughness"): Diffuse light scattering leads to areas with low gloss or matte surface appearance.

2.2 Surface Structures in Practice

In real applications, combinations of different surface structures frequently occur:

- Completely high-gloss surfaces (exclusively flat structures)
- Combinations of structured and high-gloss areas
- Completely structured, matte surfaces

Figure 1 shows typical effects of different surfaces

Completely high-gloss "flat" | Combination of structure and high-gloss "flat" and "roughness" | Completely structured "roughness"

Figure 1

The relationships shown under point 2 explain the fundamental effects. The question remains why there are different surface effects in injection molded parts, even though the mold surface itself is homogeneous.

A key factor here is the mold wall temperature.

3. Influence of Mold Wall Temperature on Surface Replication in Structured/Textured Mold Surfaces

3.1 Mechanism at High Mold Wall Temperatures

At elevated mold wall temperatures, the outer skin of the melt remains low-viscosity and flowable for a longer period. The frozen boundary layers are thinner. This effect enables better penetration of the melt into the mold surface.

Result: Complete reproduction of even the finest surface structures becomes possible, leading to a rougher, matte surface appearance.

3.2 Mechanism at Low Mold Wall Temperatures

At reduced mold wall temperatures, accelerated cooling of the plastic occurs at the mold surface. The frozen boundary layers are thicker. This effect prevents the penetration of the melt into the structures of the mold surface.

Result: The material cannot completely fill the (micro)structures of the mold surface, leading to incomplete replication and a glossier surface appearance.

Figure 2 shows the essential relationships

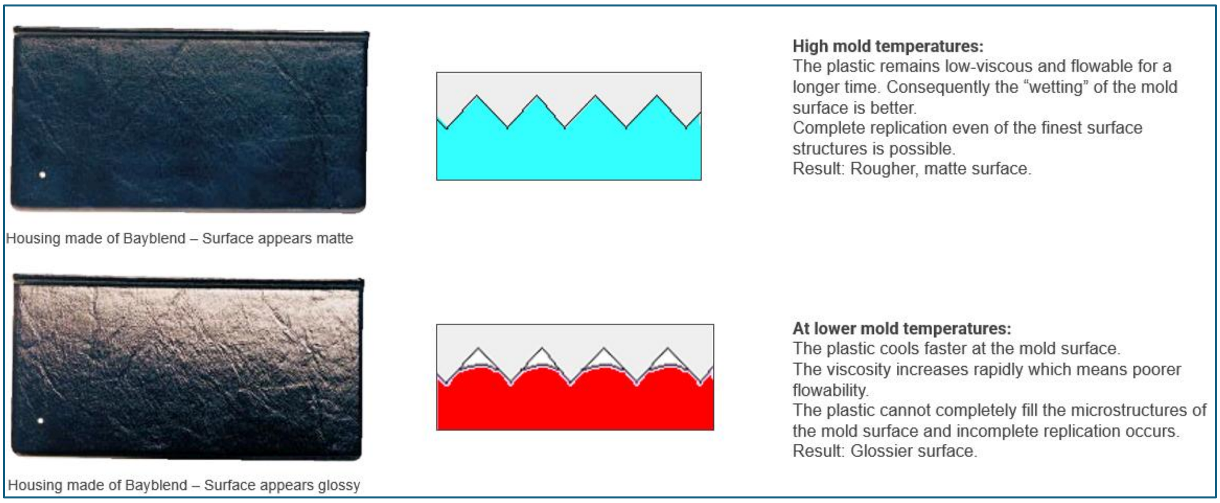
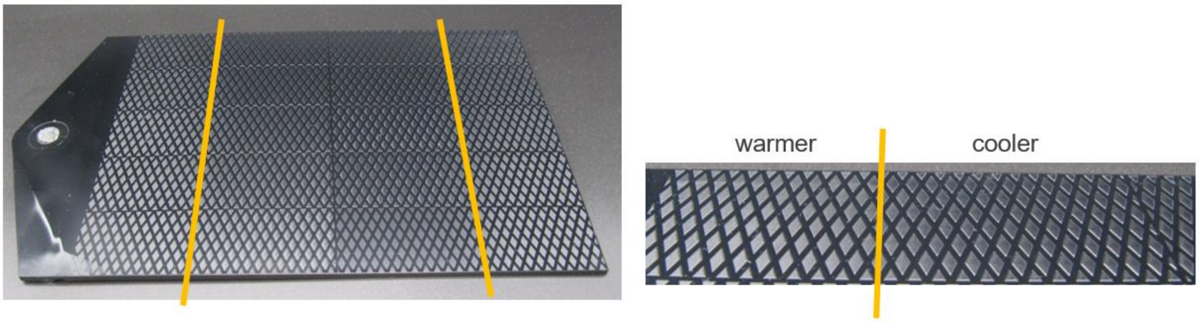


Figure 2

Figure 3 shows, using the example of a sample plate from the Covestro technical center, how different mold wall temperatures affect the surface replication.

The differences are very easily recognizable with the naked eye. Since a camera can only capture a static image at a fixed angle, the representation is difficult.



The area between the lines is cooler compared to the rest of the part.

Figure 3

4. Causes of Inhomogeneous Surface Temperatures

4.1 Technical Factors

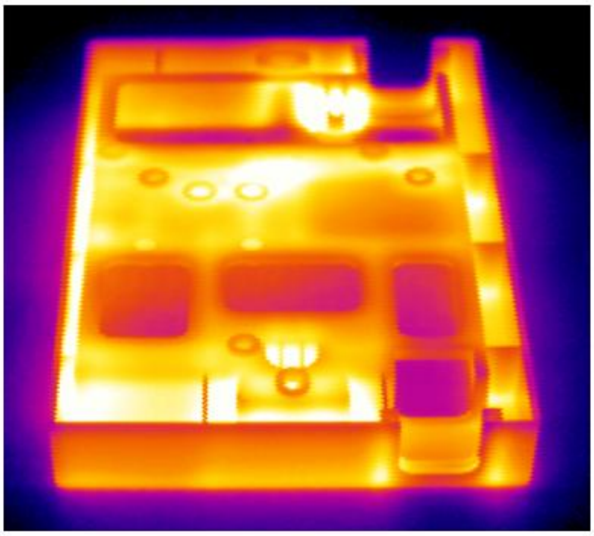
Inhomogeneous temperature distributions in molds arise from various design-related and process-related factors:

- Unfavorable cooling channel spacing: Excessive distances between cooling channels and mold surface or channel to channel distance
- Untempered areas: Areas without or with insufficient temperature control
- Blocked cooling channels: Blockages or deposits in the temperature control channels
- Unfavorable steel selection: Materials with unsuitable thermal properties
- Low flow rates: Insufficient coolant circulation
- Material accumulations: Local thickness variations in the mold
- Direct gating: Local overheating due to missing spot cooling

4.2 Effects on Component Quality

Excessive temperature differences impair both component quality and the economic efficiency of the production process.

Figure 4 shows the IR image of an injection-molded component immediately after demolding. Brighter areas indicate higher temperatures, and darker areas show cooler zones.



IR Picture of a molded part. Lighter areas indicate higher temperatures while darker areas are cooler.

Figure 4

5. Discussion and Conclusions

Mold wall temperature represents a critical process parameter for the surface quality of injection-molded plastic components. Understanding the underlying physical mechanisms enables targeted optimization of surface properties.

The selection of optimal mold wall temperature requires a trade-off between desired surface structure and other component properties. While higher temperatures enable complete surface replication, lower temperatures result in shorter cooling times.

For consistent surface quality, homogeneous temperature distribution in the mold is essential. This requires careful design of the temperature control system, considering all relevant design-related and process-related factors.