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АНАЛІЗ ТА ЗМЕНШЕННЯ УСАДКИ ТА КОРОБЛЕННЯ ДЕТАЛІ З ПЛАСТИЧНОГО МАТЕРІАЛУ, ЯКА ВИГОТОВЛЕНА МЕТОДОМ ЛИТТЯ ПІД ТИСКОМ

Виробництво деталей та виробів з пластичних матеріалів методом лиття під тиском в прес форми є найбільш поширенішим і найбільш продуктивнішим методом виробництва. Сучасний рівень розвитку науки і техніки висуває досить високі вимоги до якості виробів і деталей з пластичних матеріалів, підвищення якості виробу в умовах високої конкуренції є необхідною умовою для конкурування на ринку. Дефекти, які виникають в процесі лиття під тиском деталей з пластичних матеріалів мають негативний вплив на якість виробу. Досягнення високої якості виробів не можливе без використання систем інженерного аналізу. Сучасні програмні продукти дозволяють змоделювати процес лиття під тиском та прогнозувати можливі дефекти лиття. Зменшення дефектів усадки та коробления вимагає комплексного підходу до процесу лиття під тиском: розуміння властивостей матеріалів, проектування прес форм та параметрів процесу лиття. В роботі було проведено моделювання процесу лиття під тиском деталі з пластичного матеріалу та отримано результати усадки та коробления цієї деталі. Також запропоновано рішення, яке дозволило зменшити ці дефекти. Таким чином, проведений аналіз відкриває нові можливості для прогнозування можливих дефектів лиття,методів та підходів усунення дефектів на початкових етапах, що на сьогоднішній день відповідає загальноприйнятим підходам до процесу лиття та забезпечує високий рівень якості виробів та деталей.

Ключові слова
Лиття деталей під тиском, прес форми, SolidWorks Plastics, моделювання, аналіз процесу лиття.

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ANALYSIS AND DECREASING OF THESHRINKAGE AND WARPAGE OF INJECTION MOLDED PLASTIC PART

The production of parts and components from plastic materials by injection molding in a mold is the most extensive and most productive method of production. The current phase of development of science and technology is expected to reach a high level of availability of products and parts made from plastic materials. Improving product quality in conditions of high competition is a necessary requirement for staying competitive in the market. Defects that arise during the injection molding process of plastic parts negatively affect product quality. Mitigating warpage begins with addressing variances in temperature, materials, and improper tooling. You should work early with your manufacturer, as it's during the design phase that troubleshooting defects can have the lowest impact on your bottom line. During the prototyping phase, an engineer will ensure the proper materials, tool design, processes, and machine settings will work in conjunction to prevent warpage. However, should warpage occur despite the safeguards, engineers will inspect where and how much warpage is present and its effects on the part to isolate the culprit. Achieving high product quality is impossible without the use of engineering analysis systems. Modern software tools make it possible to simulate the injection molding process and predict potential molding defects. Iterating designs through manual or automated workflows enable engineers to change processing conditions or part design to identify a combination that produces an acceptable part. Moldflow's automated optimization analyses, provide straightforward feedback on the influence of design, material, and process changes toward part warpage. Reducing shrinkage and warpage defects requires a comprehensive approach to the injection molding process: understanding material properties, designing molds, and setting process parameters. In this work, the injection molding process of a plastic part was simulated, and results for the part's shrinkage and warpage were obtained. A solution was also proposed that helped reduce these defects. Thus, the analysis reveals new possibilities for predicting possible defects in injection molding, methods and approaches to eliminate defects at the primary stages, which today is widely accepted approaches to the injection molding process that will ensure a high level of quality of products and parts.

Keywords: Injection molding, SolidWorks Plastics, shrinkage, warpage, analysis of injection molding.

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Introduction

Shrinkage, which is part and parcel of polymer processing, occurs when the part reaches from molding temperatures to the point where the temperature crosses the glass transition temperature. It is a phenomenon which although cannot be avoided but can be controlled. Warpage on the other hand is a result of differential shrinkage. In injection molding shrinkage takes place in three types: shrinkage during processing which occurs under extreme conditions which is known as "in-mold shrinkage"; "as-molded shrinkage" which occurs just after the mold opens; and "post-molding shrinkage" which occurs during storage of the part molded. This report will talk about the "as-molded shrinkage"; the "post-molding shrinkage" and the effects of molding conditions. The "as-molded shrinkage" occurs as a result of processing conditions and the geometry of the mould. Holding pressure is known to be the most influential process parameter which affects shrinkage; higher the holding pressure, lower is the shrinkage. In case of the experiments carried out for this study, the selected holding pressure was approximately80% of the injection pressure. Another important processing parameter is the injection temperature which in this case was set as recommended by the material MSDS. Gate freezing time is also important which also has an impact on shrinkage. [1]

Warpage is one of the most common and frustrating defects in injection molding. It occurs when a molded plastic part doesn't maintain its intended shape after being ejected from the mold, leading to issues like bending, twisting, or uneven surfaces. In plastic production, warpage can compromise both the aesthetic appeal and the functional quality of the final product, making it a critical issue to address. Ensuring that parts retain their precise shape is essential not only for product performance but also for maintaining efficiency in the manufacturing process.
Warpage in injection molding refers to the distortion or deformation of a plastic part after it has been ejected from the mold. This defect occurs when different areas of the part cool and shrink at uneven rates, causing the part to change shape. There are several types of warpage, including bending, twisting, bowing, or general uneven shrinkage.
These deformations can result in visible defects or functional issues, such as parts not fitting together correctly or not performing as intended. Warpage is a critical problem because it compromises both the structural integrity and aesthetic appeal of the molded part. [2]

Avoiding warping and shrinkage in injection mold design requires a comprehensive understanding of material properties, mold design and processing conditions. By adhering to best practices such as maintaining uniform wall thickness, optimizing gate placement and controlling cooling rates, manufacturers can minimize these defects and ensure the production of high-quality parts. While shrinkage cannot be eliminated entirely, careful planning and attention to detail can help mitigate its effects and reduce the risk of warping. Proper collaboration between design engineers, material scientists and process technicians is essential to achieving optimal results. [3]

Injection molding simulation

Plastic parts that are thin (< 1.5 mm) and feature a high ratio of flow length to thickness (> 100) form quickly solid layers when molten polymer enters mold cavities, thereby facilitating a short shot caused by the sharp decrease in the flowing channel. Thus, a high injection speed is required to complete filling and packing during the injection molding process. This high-speed injection molding requires using high injection pressure to force molten polymer into mold cavities and overcome flowing resistance, and thus considerable changes inner pressures, particularly those of polymeric materials located near and far from the gates. This phenomenon may induce uneven shrinkage of plastic parts that warp easily after mold release. Thin-walled plastic parts are particularly prone to severe warping because of their weak mechanical structures; nevertheless, the effects of improper molding condition settings and uneven cooling result in sectional shrinkage variations. Therefore, warpage control is crucial in manufacturing industries to prevent quality problems during the successive assembly process, and warpage must be minimized within dimensional tolerance. [4]

Managing warpage is a complicated task, given the number of factors involved and how each one can affect the others. Simulation software can make this work easier by allowing engineers to address the problem earlier in the product design cycle.

Using simulation tools allows engineers to set up and run analyses to visualize how much shrinkage and warpage to expect, given the current part material, design, and expected processing conditions. Through the visualization tools, results can be scaled and anchored for easier interpretation and comparison to other simulations.

Iterating designs through manual or automated workflows enables engineers to adjust processing conditions or modify part designs to identify a combination that yields an acceptable part. Moldflow's automated optimization analyses provide clear feedback on how changes in design, material, and processing parameters influence part warpage. These simulations also make it faster and easier to explore a broader range of potential solutions—such as changing materials or adjusting mold cooling—offering a more efficient approach than addressing warpage after molding. [5]

In this research we use SolidWorks Plastics to simulate of injection molding process to determine the shrinkage and warpage in the injection molded part and decrease it.

We used the following dataset for modeling:

- Part material - HDPE;
- Part weight – 63 grams.

Set the hot-runner system to use. According to[6]set the injection pointer diameter equal 2.7 mm.

Create new study in the SolidWorks Plastics and set the following parameters:

- Injection process - Single material;
- Analysis procedure – Shell;
- Set a material – HDPE.
- Set the injection point location (injection diameter is defined automatically according to a hole diameter set in a sketch).
- Create the mesh, type – Curvature-based shell.

On picture 1 is showed the 3D model of the mesh and other parameters described above.

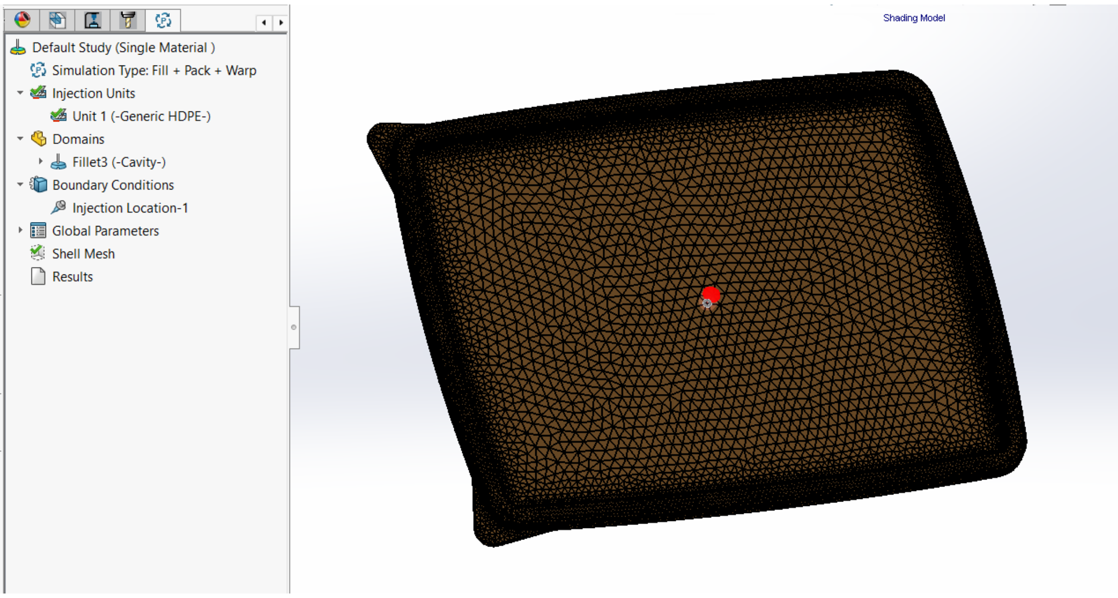

Fig.1. 3D model of the mesh

Run the Fill+Pack+Warp analysis and get the following results:

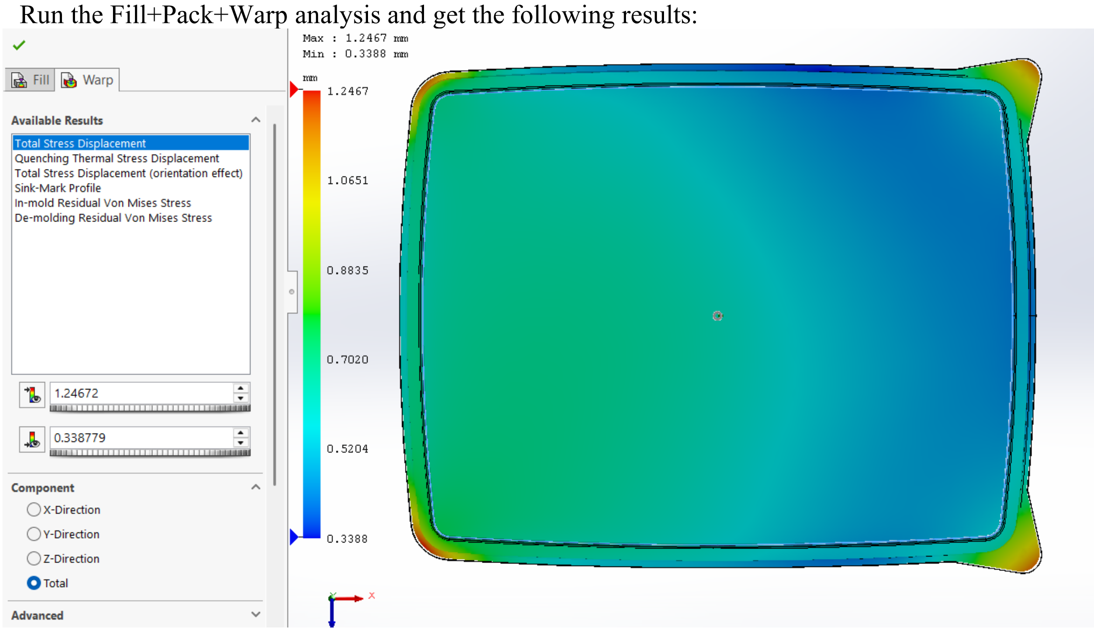

Fig.2. Total stress displacement

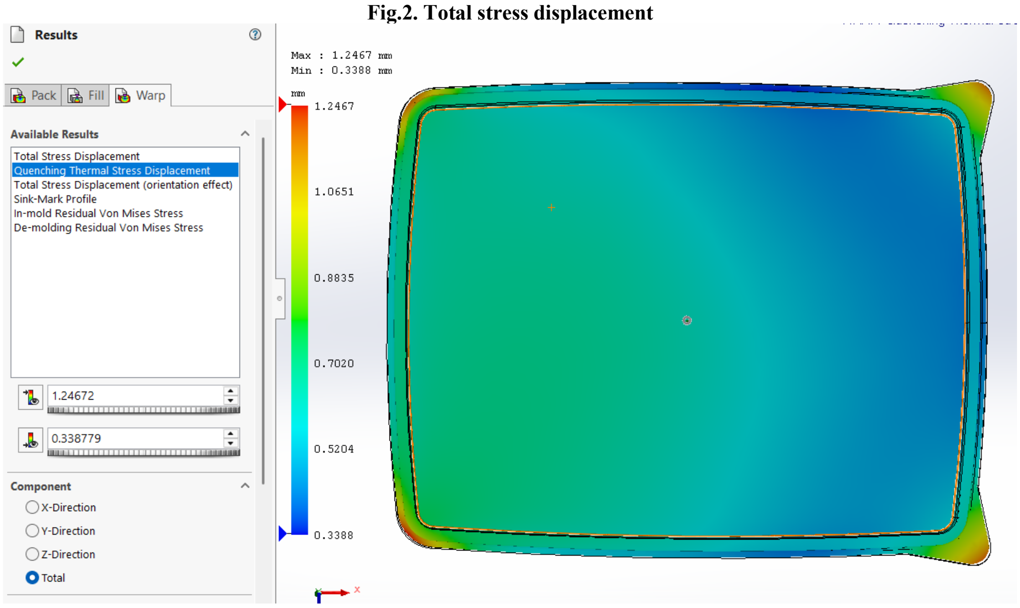

Fig.3. Quenching thermal stress displacement

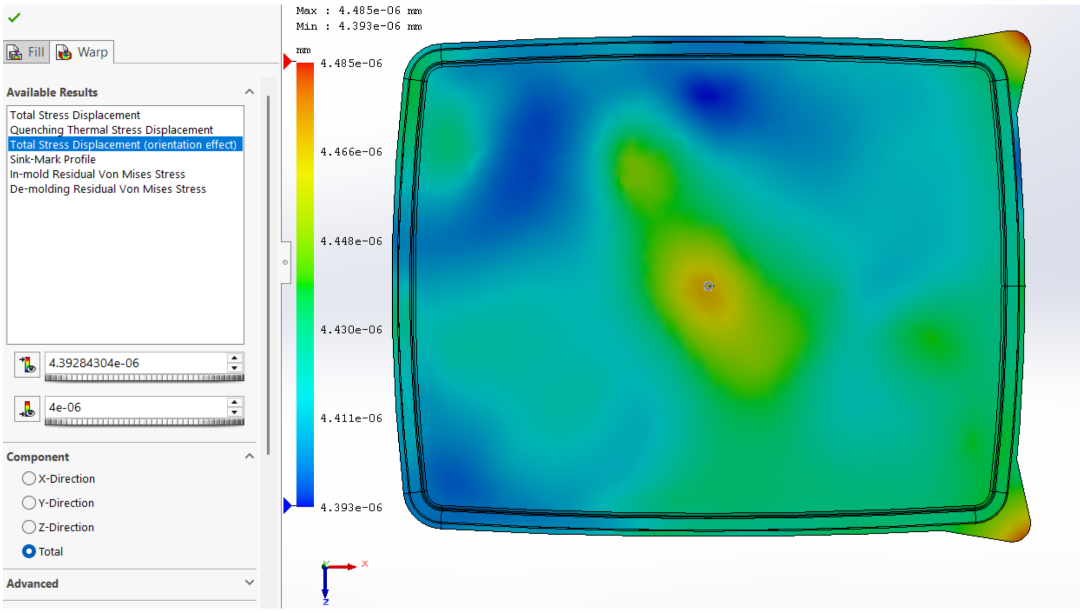

Fig.4. Total stress displacement (orientation effect)

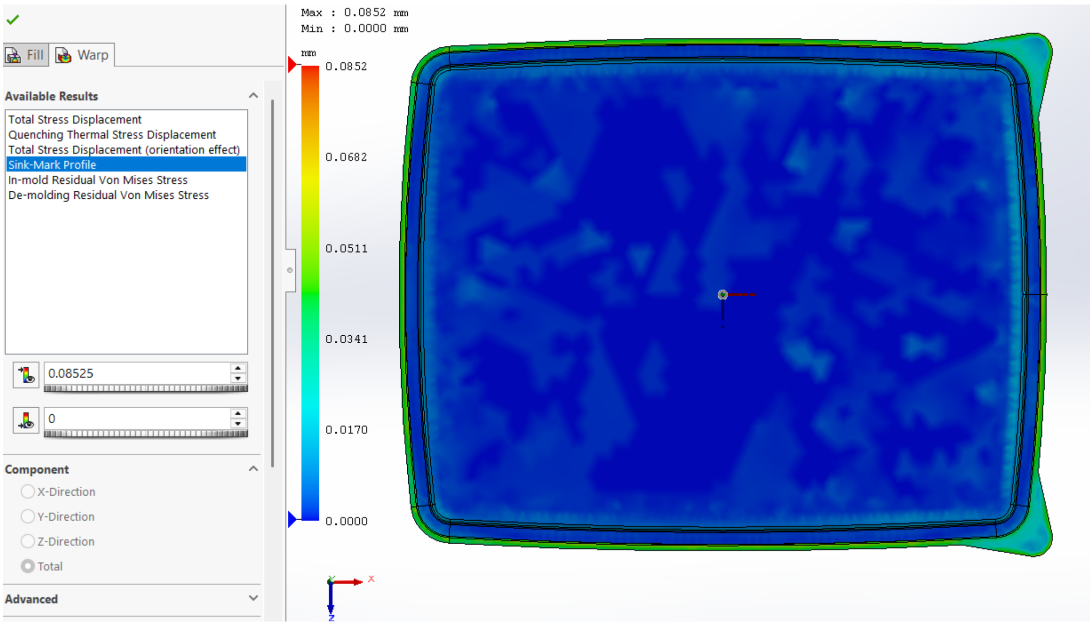

Fig.5. Sink mark profile

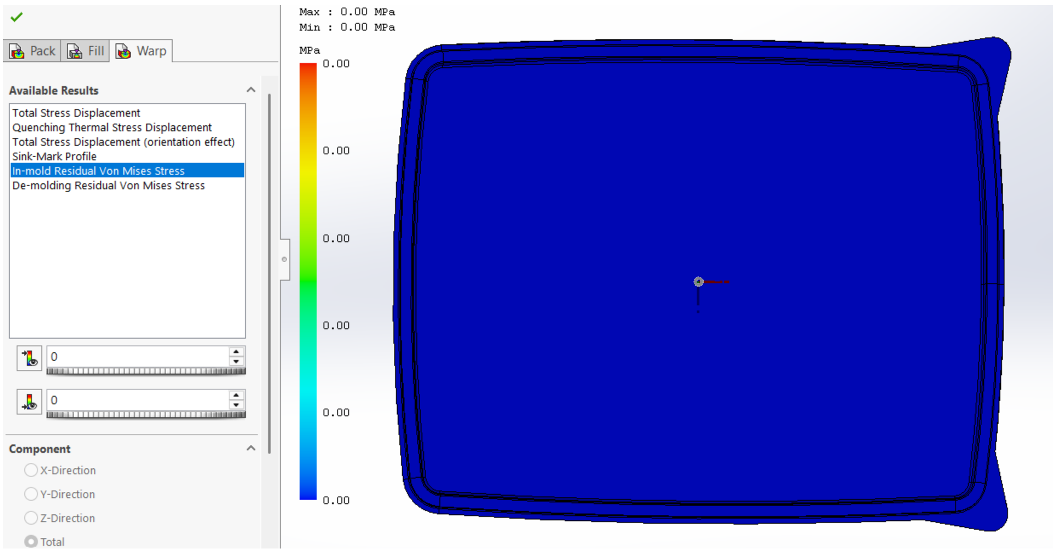

Fig.6. In-mold residual Von Mises Stress

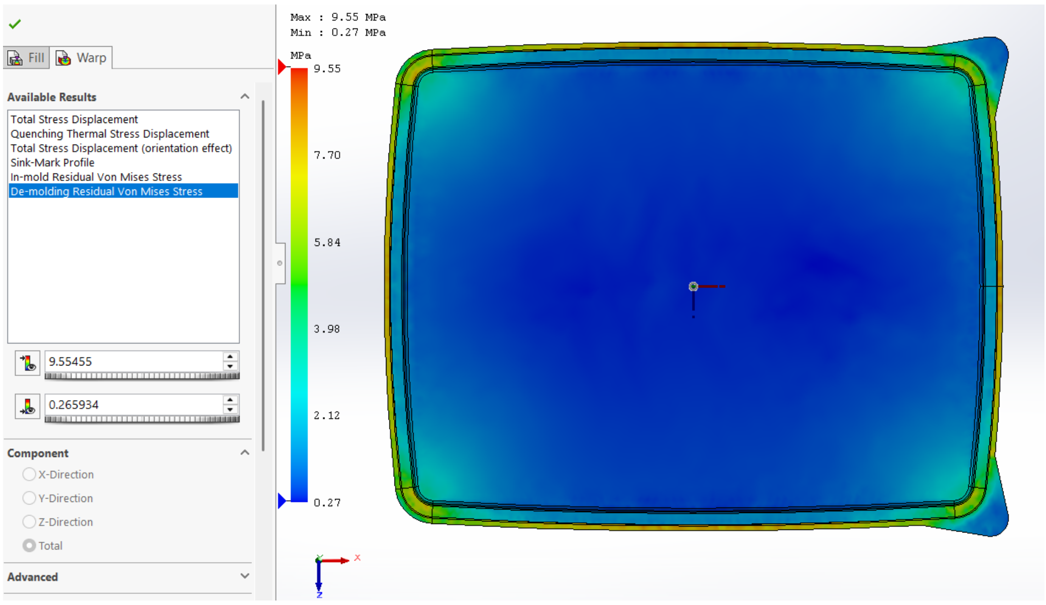

Fig.7. De-molding residual Von Mises Stress

Results and discussion

Total Stress Displacement - Shows the total deformation of the part after it is molded and cooled to room temperature. All simulated stresses and thermal effects are considered in this result. [7] It is showed on Fig.2. The maximum value of total stress displacement of our part is 1.25 mm.

Quenching Thermal Stress Displacement - Shows the portion of the deformation that develops after the de-molding stage, because of the stress associated with thermal contraction as the part is cooled to room temperature. [7] It is showed on Fig.3. As we can see the quenching thermal stress displacement plot is the same as the total stress displacement plot and the same maximum displacement value.

Sink-Mark Profile - Shows the depth of sink marks after the part has been ejected and cooled to room temperature. All thermal stresses and warping effects are included in this result. [7] It is showed on Fig.5. The maximum value of the depth of sink marks is 0.085 mm. It is acceptable for us.

In-mold Residual von Mises Stress - Shows the magnitude of the residual von Mises stress inside the part at the end of the in-mold cooling time. [7] It is showed on Fig.6. No residual stress inside of the part is present at the end of in-mold cooling phase.

De-molding Residual von Mises Stress - Shows the magnitude of the residual stress that remains after the part cools to room temperature, and allowed to deform freely. [7] It is showed on Fig.7. The plot shows significant de-molding residual stress. The maximum values are located on the edges of the part's castle.

Summing up the values of the total stress displacement and the sink mark profile are not acceptable for us. Let's change the material of part from HDPE to PP.

Run the simulation again and get the following results:

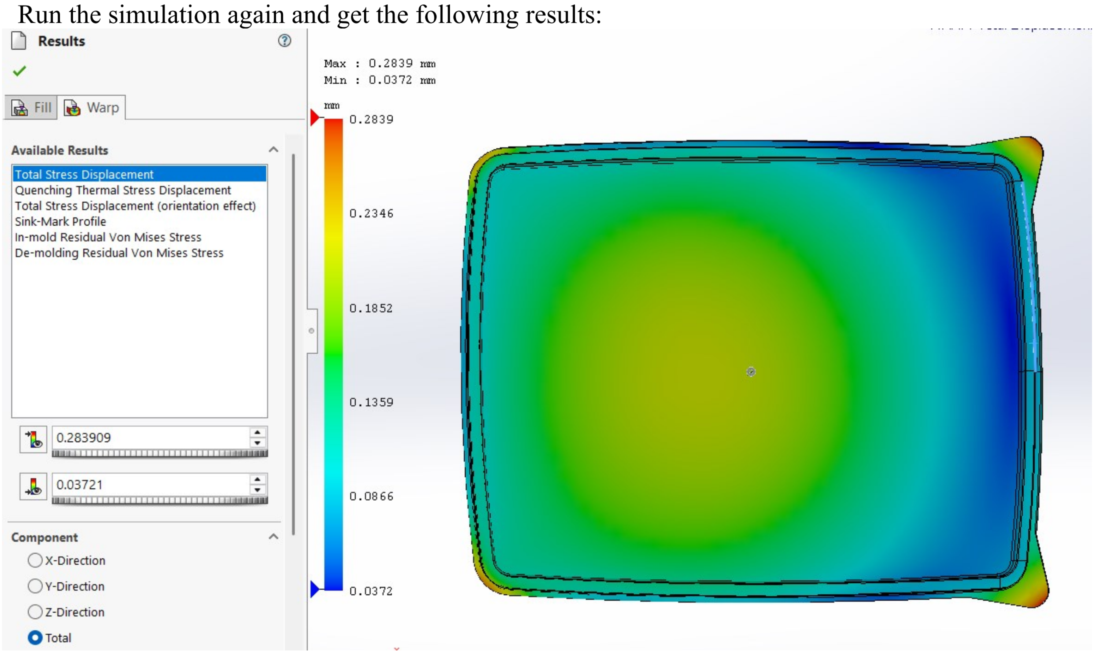

Fig.8. Total stress displacement after material change

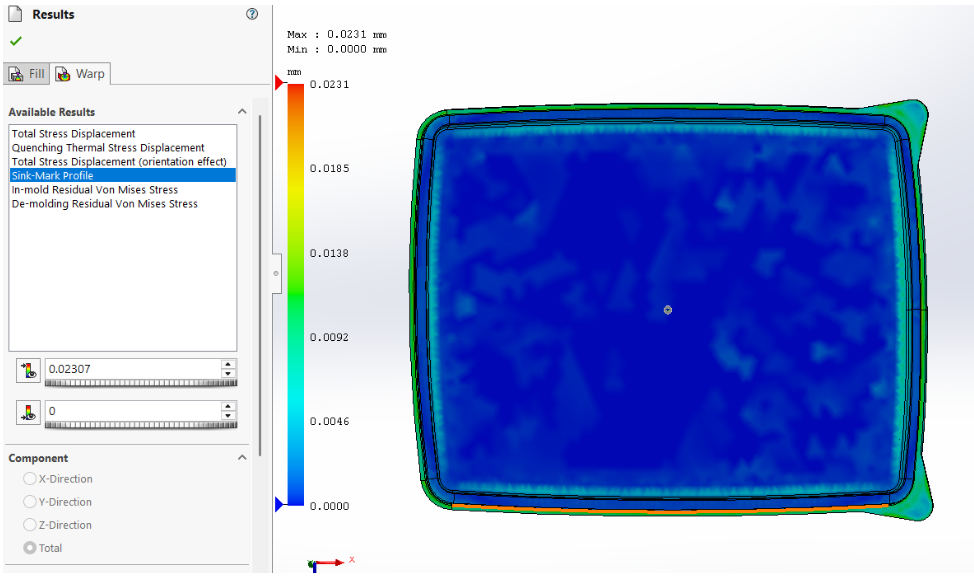

Fig.9. Sink mark profile after material change

Conclusion and further prospects for research in this direction

Analyzing the plots above we can conclude that changing the part material from HDPE to PP has allowed to decrease the total stress displacement approximately by 4.5 times and decrease the sink mark profile by 3.7 times. Also, it is essential during the production to use the packing phase to decrease the sink mark profile. Nonuniform cooling time of the part could be a reason of warpage. In order to check this, we need to design and simulate the cooling system.

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