Step of the vertical walls for warpage compensation on plastic housings

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Abstract. All plastic parts suffer deformations during cooling of the material after the injection process. The effect is called warpage. This problem is known by all mechanical design engineers and in development, each engineer tries to compensate this warpage using different design solutions. In this article we are analyzing one important solution for warpage compensation and we will present our results and the optimization steps that led us to the results. The solution is a step for a vertical wall of the housings. For this step we analyzed different dimensions and combinations to provide the best solution.

1. Introduction
The effect of warpage on plastic parts is almost impossible to avoid. For receiving the closest results to the CAD data, there are several optimization steps and solutions that need to be considered. Starting with the material choice and continuing with the design solutions, all mechanical engineers try to compensate the warpage behavior on their plastic parts. Here is the definition of warpage according to official sources: Warpage is a distortion where the surfaces of the molded part do not follow the intended shape of the design. Part warpage results from molded-in residual stresses, which, in turn, is caused by differential shrinkage of material in the molded part. If the shrinkage throughout the part is uniform, the molding will not deform or warp, it simply becomes smaller. However, achieving low and uniform shrinkage is a complicated task due to the presence and interaction of many factors such as molecular and fiber orientations, mold cooling, part and mold designs, and process conditions. (University, 2006)

2. Tools and inputs
The study was made on a square housing with 100 mm length, 100 mm width and 20 mm height. The design of different variants of housings were made with Catia V5 software provided by Dassault and for simulation of the warp of the plastic parts we used Simulation Moldflow Insight 2013 provided by Autodesk. The file format used to transfer data between Catia V5 and Simulation Moldflow Insight 2013 was STP file.

The thickness of the housing is 1.4 mm and the material that was considered for this design was a generic polypropylene without any fibers or fillers. The initial deflection that we want to optimize is 1,025 mm (see Figure 1).
3. Simulation plan
The purpose of the study is to improve the warpage on our housing. We will add a parametrized step of the vertical wall. The deflection of the vertical walls can be seen in Figure 1 that is pretty far from the initial design (grey exterior contour is the initial design). In order to highlight the warp, we increased the scale factor to 5.

We will simulate the warpage of different variants of steps for our housing varying the A and B parameters. The following parameters will be considered constant for all simulations:
- Wall thickness.
- Material.
- Injection point (see Figure 3).
- Draft angles.
- Radiiuses.
- Mesh global edge length and merge tolerance (see Figure 3).
Figure 3. Mesh inputs and injection point (gate) position.

The inputs for the mesh were chosen in order to reduce the number of nodes and the time for each simulation. Smaller values would lead to high load for computer resources and longer time for each simulation result.

The injection point is placed in the middle of the housing for each housing variant to have a proper material flow, fill and time. Since the housing is square, this is the best solution for placing the gate. Material is a generic PP without any fibers or fillers to study the behavior of the warpage on a non-improved housing and to see only the results of the design solutions. For sure for a housing of this dimensions (100x100mm) would fit better a material with glass fiber but this is not in our focus.

The simulation plan is to simulate different variants of steps for the vertical walls and optimizing the combinations of A and B parameters till we will obtain the best effect of warpage compared with the initial case. We will start with constant steps where A and B parameters are equal to find out where the warpage is compensated better and after that we will try to play with the parameters in that area.

4. Initial results and optimization steps for step of the vertical walls solution

Table 1. Initial results for the constant step of the vertical walls.

| Parameter A | Parameter B | Maximum deflection |
|-------------|-------------|--------------------|
| 2 mm        | 2 mm        | 0.7686 mm          |
| 3 mm        | 3 mm        | 0.7370 mm          |
| 4 mm        | 4 mm        | 0.7417 mm          |
| 5 mm        | 5 mm        | 0.7302 mm          |
| 6 mm        | 6 mm        | 0.7141 mm          |
| 7 mm        | 7 mm        | 0.7199 mm          |
| 8 mm        | 8 mm        | 0.6967 mm          |
| 9 mm        | 9 mm        | 0.6925 mm          |
| 10 mm       | 10 mm       | 0.6930 mm          |
| 11 mm       | 11 mm       | 0.6886 mm          |
| 12 mm       | 12 mm       | 0.6823 mm          |
| 13 mm       | 13 mm       | 0.6803 mm          |
There can be saw a progress from the initial deformation of 1.025 mm to 0.6803 mm around 13x13 mm step for the vertical wall. But when the step is increased, the effect for warpage compensation is reversed and we obtain again big values for the maximum deformation. The next steps are to create combination of values around the optimum cases and to try to obtain better values with asymmetric step.

Table 2. Results for the asymmetric step of the vertical walls.

| Parameter A | Parameter B | Maximum deflection |
|-------------|-------------|--------------------|
| 12.8 mm     | 13 mm       | 0.6864 mm          |
| **12.5 mm** | **13.5 mm** | **0.6708 mm**      |
| 13 mm       | 13.5 mm     | 0.6738 mm          |
| 12 mm       | 13 mm       | 0.6780 mm          |
| 12.6 mm     | 13.4 mm     | 0.6906 mm          |
| 12.5 mm     | 13.6 mm     | 0.7005 mm          |
| 12.3 mm     | 13.5 mm     | 0.6861 mm          |
| 12.1 mm     | 13.7 mm     | 0.6787 mm          |
| 12.2 mm     | 13.4 mm     | 0.6916 mm          |
| 12 mm       | 5 mm        | 0.7403 mm          |
| 5 mm        | 12 mm       | 0.6929 mm          |
| 3 mm        | 12 mm       | 0.7037 mm          |
| 12 mm       | 3 mm        | 0.7256 mm          |
| 8 mm        | 12 mm       | 0.6913 mm          |
| 12 mm       | 8 mm        | 0.7177 mm          |
| 10 mm       | 12 mm       | 0.6933 mm          |
| 12 mm       | 10 mm       | 0.7162 mm          |
| 6 mm        | 12 mm       | 0.7061 mm          |
| 4 mm        | 10 mm       | 0.7146 mm          |
| 15 mm       | 12 mm       | 0.7086 mm          |
| 11 mm       | 12 mm       | 0.6920 mm          |
| 11.5 mm     | 12 mm       | 0.6888 mm          |
| 11.5 mm     | 12.5 mm     | 0.7087 mm          |
| 12 mm       | 12.5 mm     | 0.6823 mm          |
| 4 mm        | 6 mm        | 0.7198 mm          |
| 5 mm        | 10 mm       | 0.6989 mm          |
| 6 mm        | 11 mm       | 0.6837 mm          |
| 12.2 mm     | 12.2 mm     | 0.7130 mm          |
| 11.9 mm     | 12.1 mm     | 0.6962 mm          |
| 10.5 mm     | 12.5 mm     | 0.6925 mm          |
5. Best result for step of the vertical walls solution
During multiple simulations was observed that better values were obtained when parameter B was bigger than parameter A. The variation of warpage compensation was small from 0.1 mm difference but compared with the initial case we obtained an improvement of 0.3542 mm only with this solution. Was observed that the best results are obtained when parameters A and B are around 60% of the total height of the vertical wall.

![Figure 4](image)

**Figure 4.** Best result for the step of the vertical wall solution

6. Validation plan
For validation we will modify the housing vertical wall height to 10 mm and also the length and width to 70 mm x 70 mm. Without the step on the vertical wall we obtain after the simulation a maximum deflection of 0.5577 mm. See Figure 5.

![Figure 5](image)

**Figure 5.** Validation geometry

7. Results for the validation

| Parameter A | Parameter B | Maximum deflection |
|-------------|-------------|--------------------|
| 2 mm        | 2 mm        | 0.5458 mm          |
| 3 mm        | 3 mm        | 0.5388 mm          |
| 4 mm        | 4 mm        | 0.5137 mm          |
Was observed after multiple simulations and on different geometries that the best warpage compensation is obtained when parameter A and B are around 60% of the total height of the vertical wall. This proves that our theory is correct.

8. Comparison between results
Our study was made on a housing with 100 mm length, 100 mm width, 20 mm height of the vertical wall and a constant thickness of the wall of 1.4 mm. With our solution for warpage compensation we obtained a 0.3542 mm optimization on the deflection behavior which means 35% of improvement from the initial deflection (1.025 mm). For the validation we wanted to make sure that the best combination for parameters A and B is when they are around 60% from the total height of the vertical wall and we approved that. From an initial deflection of 0.5577 mm without deeper investigation for an asymmetric step. Is clear that for a higher wall height, the deflection will be bigger and also the compensation with this solution.

9. Conclusions
When designing a plastic part is particularly important to take measures for compensating the warpage from the beginning. This article is providing a good solution that can be combined with any other solutions to obtain the best design for your product.

10. References
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