# WARPAGE MANAGEMENT USING THREE DIMENSIONAL THICKNESS CONTROL METHOD IN INJECTION MOLDING

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## Abstract

Warpage is one of the most crucial problems in injection molding quality control. Since many factors will cause shrinkage and warpage, it is very difficult to distinguish which factor always dominates warpage. In this study, we have developed Three Dimensional Thickness Control Method (3DTCM) to manage the warpage of the injected parts. Using this method, we will specify the geometry of parts with non-uniform three dimensional structures. After integrated with special gate design, material selection, various operation conditions, warpage of injected parts can be managed significantly. Also, to verify our results, both numerical and experimental investigation will be performed in this study.

## Introduction

Due to their light weight and easy to be molded, injection products have been applied in various fields, including computer, telecommunication, automobile, housing, precision industries, and many others. During the development of injection molding products, there are many defects which people often meet in every day fabrication, such as warpage, short shot, sink mark, weld line, air trap, and so on. Among them, warpage is one of the most crucial problems in quality control. Since many factors will cause shrinkage and warpage, it is very difficult to distinguish which factor always dominates warpage. For example, for one certain geometry design and selected some polymer material, different process condition setting will result in different shrinkage and warpage. People often try to think about how to manage and control warpage of injection molding, but it is not so easy [1-4].

In this study, we have proposed Three Dimensional Thickness Control Method (3DTCM) to manage the warpage of the injected parts. Through the non-uniform thickness geometry, it can influence the product from the early filling stage till the final warpage stage. To illustrate this method, various geometry structures have been proposed. Also, both numerical simulation and experimental study have been applied to demonstrate and verify. Using the specified geometry model, the flow pattern can be governed. It can further manage the shrinkage and warpage to maintain the quality of product. To get better understanding, both numerical simulation and experimental studies have been performed. Through the comparison of warpage behavior and deformation prediction, both numerical simulation and experimental results are in a good agreement. Using this method, we can integrate part design, mold design, material, and process conditions at the same time, and then further manage the quality of injection parts.

## Three Dimensional Thickness Control Method (3DTCM)

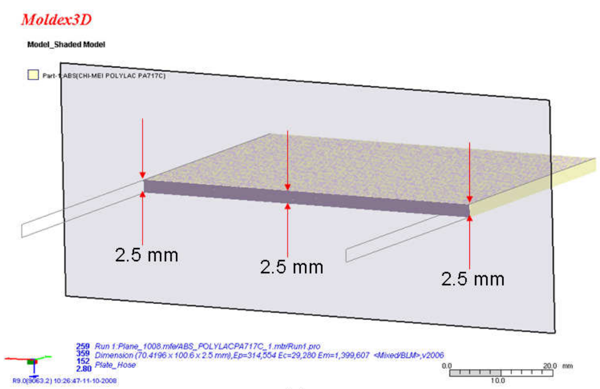
As mentioned earlier, injection molding process is a very complicated system. How to handle this system with a good quality product by integration part design, mold design, material, and process conditions is the key. Here, we try to manage and control the warpage of injection molding product from very early stage by using 3DTCM. Briefly to say, this method proposed some three dimensional geometry structures, such as U-shape, and many others, which utilize the geometrical features to control the flow field during the filling stage. It then influences the injection parts during packing and cooling stages. Finally, it can further compensate the shrinkage and warpage problems. To give better understanding this method, we are going to demonstrate and verify from both numerical and experimental studies as shown in the following sections.

## Numerical Study

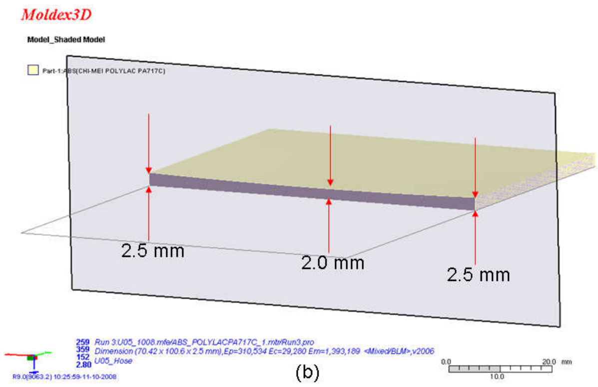
In numerical study, we have applied Moldex3D software to simulate all possible systems. To catch the warpage behavior, the major analysis procedures for injection molding processes include filling, package, cooling, and warpage. In filling and packing stages, the polymer melt is assumed to behave as Generalized Newtonian Fluid (GNF). Hence the non-isothermal 3D flow motion can be mathematically described. The FVM (finite volume method), due to its robustness and efficiency, is employed in this study to solve the transient flow field in complex three-dimensional geometries. During the molding cooling stage, a three-dimensional, cyclic, transient heat conduction problem with convective boundary conditions on the cooling channel and moldbase surfaces is involved. After the part is ejected from the mold, a free shrinkage happens due to the complicated interactions among temperature, pressure and specific volume. The mechanical properties are assumed as elastic for warpage analysis [2-4].

The geometry models are shown in Fig. 1. The basic geometry of Plate structure with the uniform thickness of 2.5 mm is in Fig. 1(a). To visualize the melt behavior, the hexahedral meshes has been applied with 10 layers in thickness direction. Fig. 1(b) and (c) show the U-shape structures. In Fig. 1(c) the center portion is thinner than that of Fig. 1(b). The detailed information about U – shape structures is illustrated in Fig. 2. In Fig. 2(a) for U05 model, the thinner portion is in the center of the plate with 2.0 mm. It is cored out with 0.5 mm. Similarly, Fig. 2(b) shows U10 model with the thinner portion of 1.5 mm in the center.

Fig. 3 demonstrates runner and cooling channel layout. In Fig. 3(a), it shows the size and dimension for sprue, runner and gate. Fig. 3(b) expresses the cooling channels. In order to make the better mold temperature control, the core side and cavity side have separate cooling pipe control. In addition, to make quantitatively measurement of warpage, the location of measuring nodes is listed in Fig. 4 for data collection.




(a)

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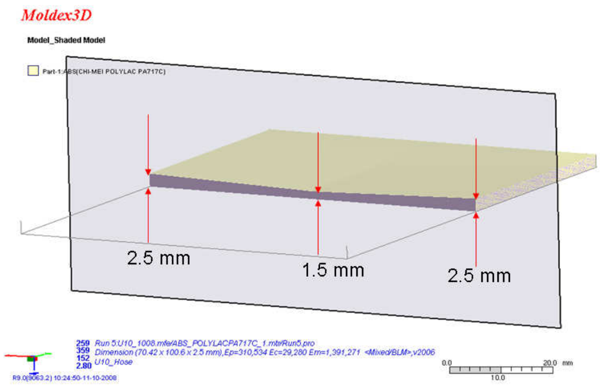
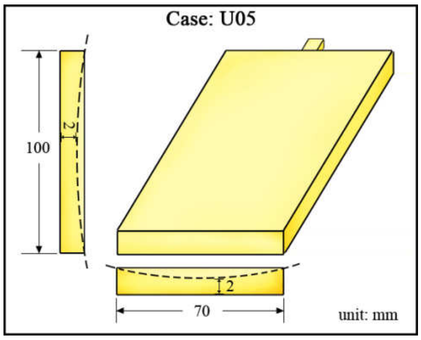
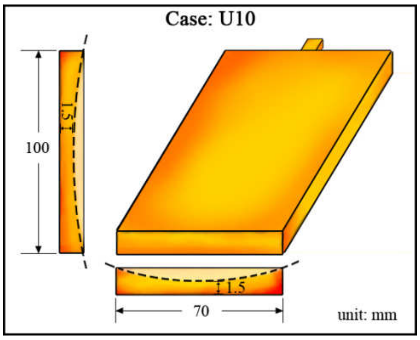



(c)

Figure 1. Geometry models: (a) Plate model with uniform thickness of 2.5 mm; (b) U05 model with the thinnest portion in the center of 2.0 mm; (c) U10 model with the thinnest portion in the center of 1.5 mm.

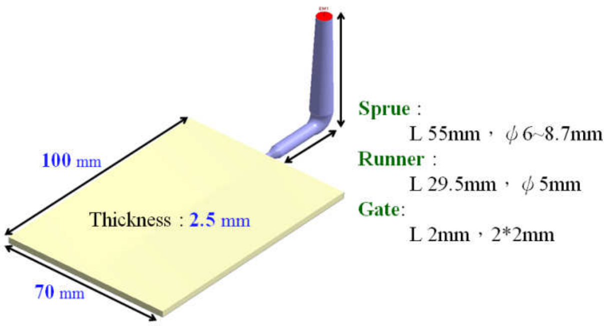



(a) U05

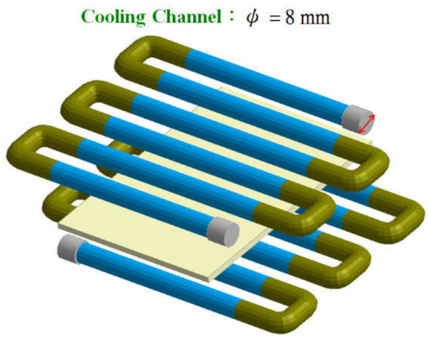



(b) U10

Figure 2. The geometry structures based on 3DTCM: (a) U05 model has the thinner portion in the center with 2.0 mm; (b) U10 model has the thinner portion in the center with 1.5 mm.




(a) Part and Runner system




(b) Cooling system

Figure 3. The dimensions for the plate model and its mold design: (a) the dimensions for part and melt delivery system; (b) the cooling channel layout.

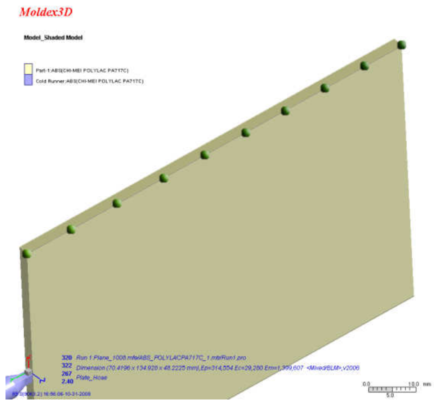



Figure 4. The location of the measuring nodes. The data collected will be used for warpage study.

Besides, the process condition settings are listed in Table 1 and 2. In Table 1 for symmetry mold temperature setting, we have considered the system with core side and cavity side of 50°C. In Table 2 for non-symmetry mold temperature setting, the mold temperature system with core side of 50°C and cavity side of 60°C. The material is Chi-Mei ABS-717C. Its viscosity property and PVT features are displayed in Fig. 5.

Table 1. Symmetry Mold Surface Temperature Parameters

| | |
|---|---|
| Mold Temperature ( ℃ ) | 50 (Core & Cavity) |
| Melt Temperature ( ℃ ) | 200 |
| Filling Time (sec) | 1 |
| Injection Ram (mm/s) | 32 |
| Packing Pressure (MPa) | 50 |
| Packing Time (sec) | 5 |

Table 2. Non-symmetry Mold Surface Temperature Parameters

| | |
|---|---|
| Mold Temperature ( ℃ ) | 50 (Core)<br>60 (Cavity) |
| Melt Temperature ( ℃ ) | 200 |
| Filling Time (sec) | 1 |
| Injection Ram (mm/s) | 32 |
| Packing Pressure (MPa) | 60 |
| Packing Time (sec) | 5 |

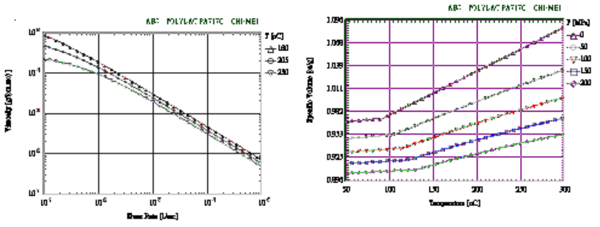
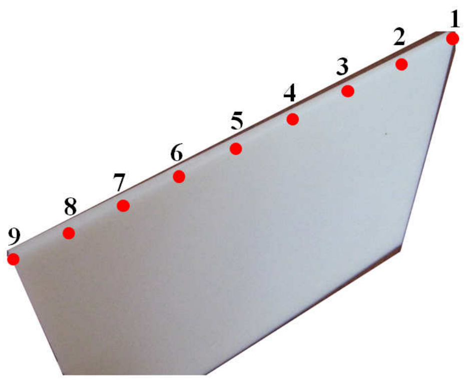

(a) (b)

Figure 5. Material properties of Chi-Mei ABS-717C: (a) viscosity property; (b) PVT feature.

## Experimental Study

On the other hand, in experimental study, the geometry models (including plate, U05, and U10), the runner and cooling channel layout, are the same as described in Fig. 1 to 3. The process condition settings are same as mentioned earlier in Table 1 and 2. Injection machine is Sodick HSP100EH2 with mixture of hydraulic and electronic type functions. Moreover, to evaluate the magnitude of warpage, the optical equipment of Micro-Vu with non-contact feature is used. In practice, among 9 measuring nodes, the No. 9 is close to gate, and No. 1 is next to the end of filling portion. The warpage is evaluated based on the deviation from the original straight line of the measuring points as shown in Fig.7.

Figure 6. Micro-Vu with non-contact feature for warpage measurement.



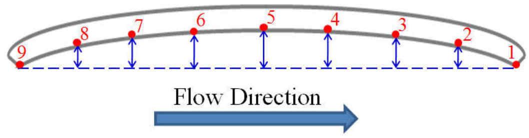
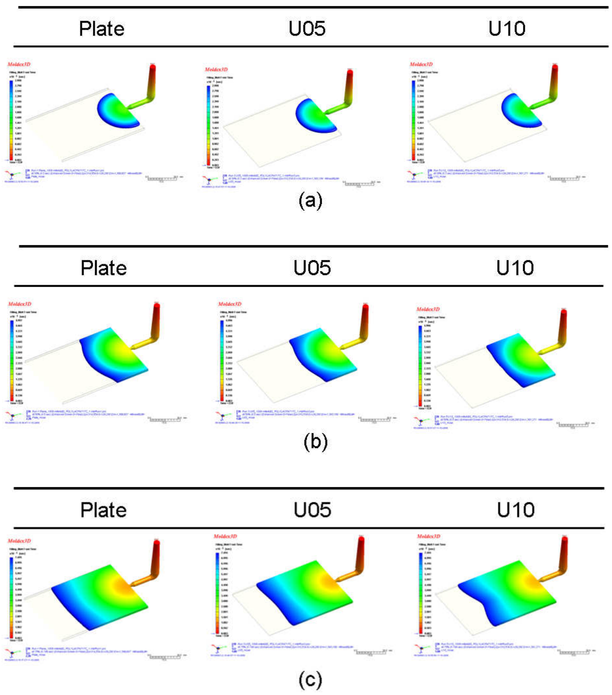




Figure 7. The method to evaluate the warpage magnitude from the original straight line of the measuring points.

## Results and Discussions

Fig. 8 displays the filling simulation results. During the short shot testing, when the geometry has been revised from plate to U05 or U10, the filling behaviors are changed significantly. During the early stage (say 30% filled), the flow patterns look similar for all geometry models. However, when the filling keeps going, such as 75% filled, the flow pattern can be varied from plate to U10. Especially, when the center portion is thinner (U10), the ear-flow phenomenon happens more significantly. Hence, it will further affect the packing, cooling, and warpage. It is the key issue that 3DTCM can integrate product design, mold design, material, and process conditions to manage and control the quality of product.



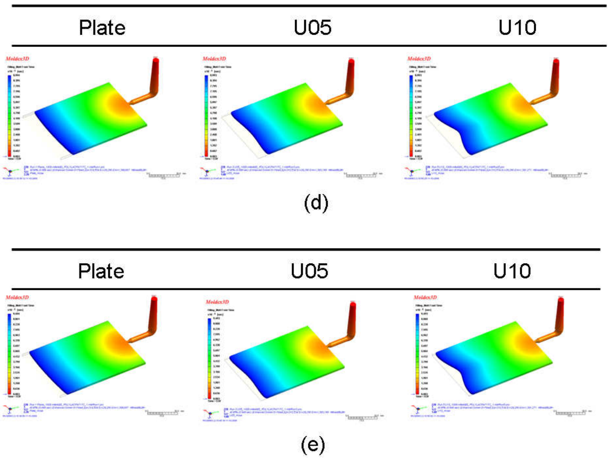
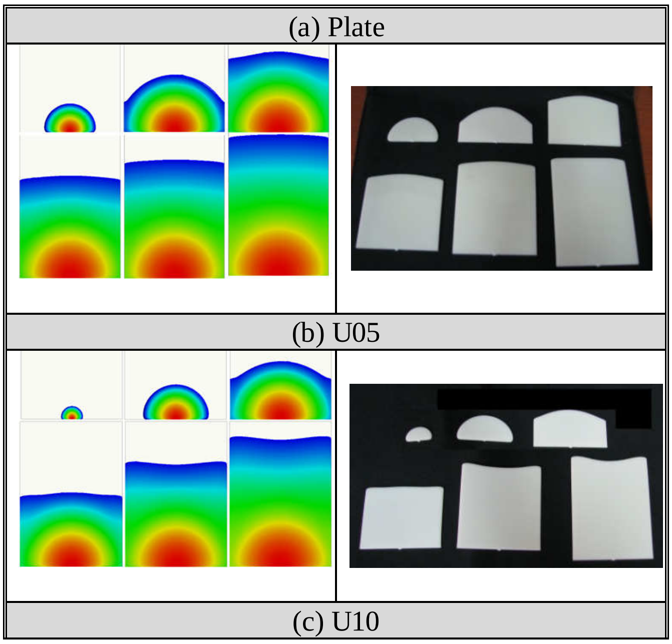



Figure 8. Short shot testing for all models during filling stage: (a) filling at 30%; (b) filling at 50%; (c) filling at 75%; (d) filling at 90%; (e) filling at 95%.

Fig. 9 illustrates the comparison between numerical simulation and experimental results. Clearly, for all models, both simulation and experimental results are in a very good agreement. In addition, when the geometry models have been modified by this 3DTCM (here applied U05 and U10), the flow front can be dramatically changed. Since the central portions of U05 and U10 models are thinner than that of Plate model, melt front from both sides are faster than that of central flow field.



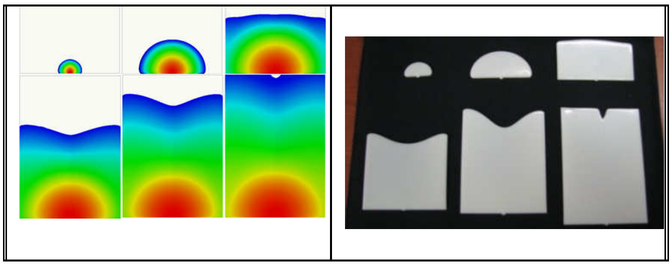



Figure 9. The comparison between simulation and experimental results: (a) plate model; (b) U05 model; (c) U10 model.

After performed filling, packing, cooling, ejection, the warpage behaviors of simulation results for all models are shown in Fig. 10. In Fig. 10 (a), it shows the warpage behaviors with symmetry mold temperature setting. Clearly, when the center portion is thinner (say U10), the warpage is more effectively with bowl shape. The tendency of warpage is almost proportional to the cored out thickness in the center portion. Moreover, when the mold temperature setting is revised into non-symmetry with core side of 50°C and cavity side of 60°C, the warpage mechanism becomes a little bit complex. It might be due to the interaction between the structure constraint and thermal residual stresses.

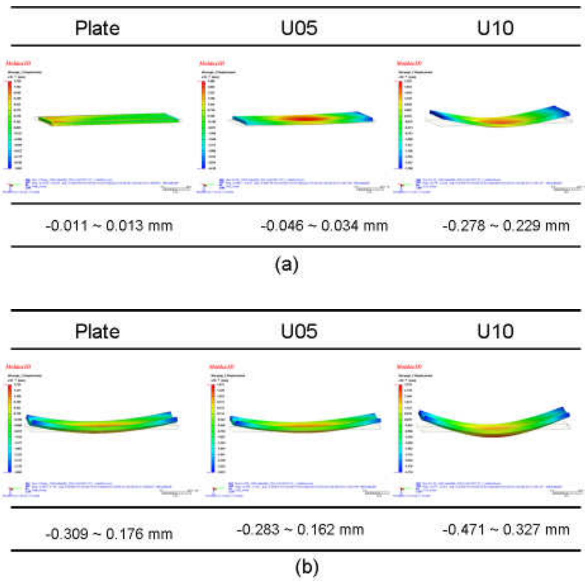
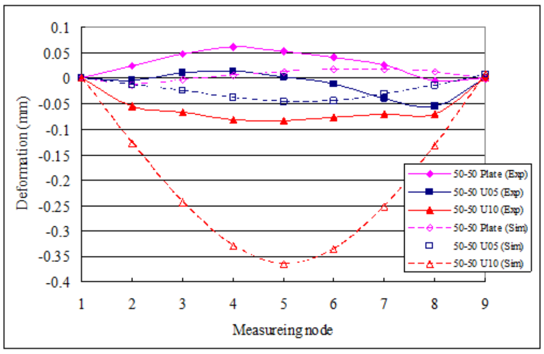


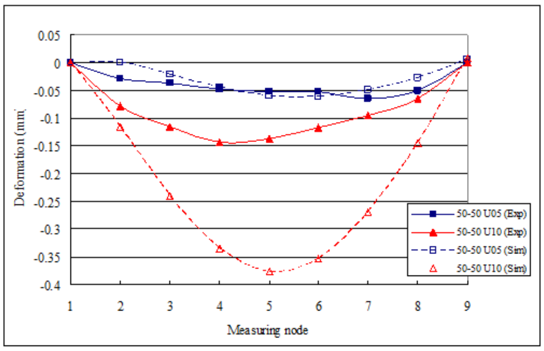

Figure 10. Simulation results of warpage: (a) with symmetry mold temperature setting: core side with 50°C, cavity side with 50°C; (b) with non-symmetry mold temperature setting: core side with 50°C, cavity side with 60°C.

Moreover, the warpage behaviors for all models are also investigated by experimental verification. Fig. 11 shows all models in symmetry mold temperature setting with core and cavity sides of 50$^{o}$C. In Fig. 11(a), when the Plate structure is modified with U-shape of U05 to U10, the deformation is increased. Both simulation and experimental results all display this tendency. Since the base system is Plate structure, to consider the U-shape geometry contribution, we further compute the difference deformation between U-shape and Plate as shown in Fig. 11 (b). Clearly, when moldbase has the uniform mold temperature setting, both U05 and U10 geometry designs will result in "Smile shape" warp generation. Also, through the comparison between simulation and experimental results, they are in a very agreement for the contribution prediction of U-shape.

Furthermore, we can study these behaviors for non-symmetry mold temperature setting with core side of 50$^{o}$C and cavity side of 60$^{o}$C. In Fig. 12 (a) and (b), some interesting phenomena happened, when the Plate structure is modified with U-shape of U05 to U10, the deformation is decreased first and then increased. Compared with Fig. 11, the same U-shape models, when the mold temperature setting is revised from symmetry to non-symmetry, the contribution of U05 can dramatically changed from "Smile shape" warpage to "Cry shape" warpage. At the same time, U10 shows the same contribution tendency for both symmetry and non-symmetry mold temperature settings. Also, in these non-symmetry mold temperature settings, through the comparison between simulation and experimental results, they are in a good agreement for the contribution prediction of U-shape.

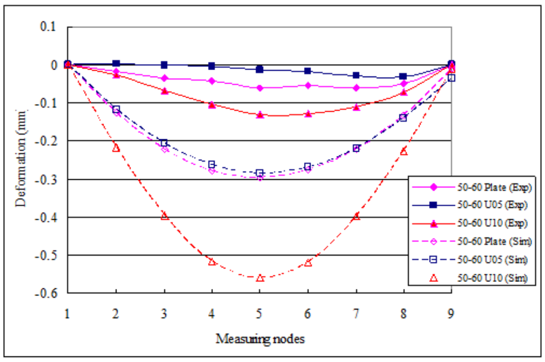



(a)

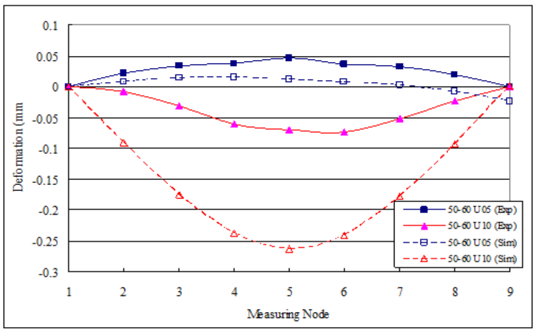



(b)

Figure 11. Comparison of warpage results for both numerical simulation and experimental study in the symmetry mold temperature setting with core and cavity sides of 50$^{o}$C: (a) individual deformation for Plate, U05, U10, where 50-50 means core and cavity sides with 50$^{o}$C; (b) contribution of U-shape for U05 and U10.




(a)




(b)

Figure 12. Comparison of warpage results for both numerical simulation and experimental study in the non-symmetry mold temperature setting with core and cavity sides of 50$^{o}$C : (a) individual deformation for Plate, U05, U10, where 50-60 means core side with 50$^{o}$C and cavity side with 60$^{o}$C; (b) contribution of U-shape for U05 and U10.

## Conclusions

In this study, we have proposed three dimensional thickness control method (3DTCM), which can integrate part design, mold design, material, and process conditions, to manage and control warpage behavior. Basically, it can influence the product from the early filling stage till the final warpage stage. To illustrate this method, various geometry structures have been proposed. Also, both numerical simulation and experimental study have been applied to demonstrate and verify. From the results, both numerical simulation and experimental study are in a reasonable agreement for warpage and deformation tendency prediction. The quantitative difference between simulation prediction and experimental study will be investigated in the future. Moreover, using the 3DTCM, we can further manage and control some quality of injection molding parts.

## Acknowledgement

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## References

1. Mathivanan D. and N.S.Parthasarathy, *SPE-ANTEC Tech. Papers,* **4**, 2126 (2008)
2. Rong-Yeu Chang, Yi-Hui Peng, David C.Hsu and Wen-Hsien Yang, *SPE-ANTEC Tech. Papers,* **1**, 496 (2004)
3. Yi-Hui Peng, David C.Hsu and Venny Yang , SPE-ANTEC *Tech. Papers,* **1**, 524 (2004)
4. Tyler Skiba and Nicholas Toomey, *SPE-ANTEC Tech. Papers,* **2**, 955 (2008)

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