INVESTIGATION ON WARPAGE AND ITS BEHAVIOR IN SEQUENTIAL OVERMOLDING

Chao-Tsai Huang[1], Meng-Chih Chen[1], Wen-Li Yang[1], Kai-Jie Chang[2], and Shi-Chang Tseng [2]
1. CoreTech System Co., Ltd., Hsinchu, Taiwan.
2. Dept. of Mechanical Engineering, National Yunlin University of Science & Technology, Taiwan.

Abstract

Sequential overmolding is one of the great methods to fabricate the modern injection products. Due to its complicated nature and the unclear physical mechanism, trial-and-error method can not realize and manage the warpage and its mechanism effectively. In this study, various parameters including product geometrical effect and material selection have been conducted both theoretically and experimentally. Results showed that the product geometries and molded materials will affect the warpage of final products significantly. It can be the good guidelines to help people understand the mechanism and make the proper design for fabricating the modern multi-component molding products.

Introduction

In modern plastic molded product fabrication, sequential overmolding is one of the great methods to diversify the development. In fact, the fundamental idea of sequential overmolding or Multi-component molding (MCM) is not new. The first patent was announced in 1962 regarding the development of multiple material tailing light by G. Carozzo [1]. During the past decades, many new technologies, methods, and related material combination have been proposed [2-4]. However, how to handle this complicated process to be more understanding and forward the concept into more concrete development are still under endeavors.

Due to its complicated nature and the unclear physical mechanism for the sequential overmolding processes, a conventional trial-and-error method cannot catch the crucial factors effectively. To get better understanding, we have focused on product geometrical effects and material selection on sequential overmolding processes numerically and experimentally. Specifically, it covers 1^{st} shot constraint on the 2^{nd} shot injection molded products in an asymmetrical structure. In addition, the effects of width of 2^{nd} shot are also considered. Results showed that the product geometries and molded materials selection will affect the final products significantly. Also, when the geometry of the 1^{st} shot is fixed, the warpage behavior of final product highly depends on width of the 2^{nd} shot. This warpage mechanism is also conducted in this study. It can be the good guidelines to help people understand the mechanism and make the proper design to fabricate the modern sequential overmolding products.

Theory Approach and Assumption

The major analysis procedures for injection molding processes include filling, package, cooling, and warpage. In filling/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 mold base surfaces is involved [5-7]. In addition, to handle the sequential overmolding, the molded part (the previous shot) will be setup into the cavity to become the boundary for the next shot. The geometry of 1^{st} shot is assumed as a perfect U-type shape. The overall heat transfer phenomenon is governed by a three-dimensional Poisson equation. We assume there is a cycle-averaged mold temperature that is invariant with time. The warpage analysis assumes the mechanical properties are linear elasticity. The stress-strain equilibrium equations enable us to solve the problems. Also, the interfacial adhesion between sequential shots is assumed perfect.

Investigation Procedures

A. Numerical Study

To get better understanding of the sequential overmolding processes, we have conducted Moldex3D R8.0 software numerically. The geometrical model includes runner system and dimensions are shown in Fig. 1 and Table 1. The dimension of 1^{st} shot, or insert, is 19mm X 9.5mm X 2mm. To study the constraint effect, the materials arrangement of 1^{st} shot, or insert, can be a metal or a plastic. The dimension of 2^{nd} shot is (19+2**x**)mm X (9.5+2**x**)mm X 2mm, where **x** is from 0.25 to 2 mm. The materials of 1^{st} shot or 2^{nd} shot in this study are ABS, PC, or PMMA. Here, ABS is Chi-Mei Polylac PA-777D, PC is Teijin Panlite L-1250 Y, and PMMA is Chi-Mei CM-211. In this asymmetrical (U-type) structure, the solid constraints on the models with an insert (either in metal or plastic) or without an insert are displayed. Also, under different material combination of 1^{st} shot and 2^{nd} shot, when the width of 2^{nd} shot varies, the injection molding processing for 2^{nd} shot will be effected from filling to warpage performance.

B. Experimental Investigation

To catch the warpage behavior and its behavior, we also performed the experimental investigation. The testing model and its dimensions are described in Fig. 1 and Table 1. The main injection molding procedures are exactly same as those of numerical study described earlier. The only difference is that the sample of 1^{st} shot has slightly warped before installed into mold for the 2^{nd} shot.

Results and Discussions

Fig. 2 shows the filling behaviors of 2^{nd} shot in the sequential overmolding. It looks not very different from a single shot system. However, in the presence of 1^{st} shot, the temperature distribution is significant different from that in a single shot system during cooling phase. In Fig. 3, the inner portion of the 2^{nd} shot with 2mm width structure, adjacent to the 1^{st} interface, has high temperature at the end of cooling. Fig. 4(a) displays the warpage behavior of 2^{nd} shot. Obviously, during the injection process, the presence of 1^{st} shot will affect the performance of the 2^{nd} shot. At the same time, the status of the 1^{st} shot, which is inserted into the mold before the 2^{nd} shot, is also affected by the 2^{nd} shot as shown in Fig. 4(b). Since the temperature distribution is asymmetrical, it will induce the imbalanced thermal stresses. These stresses will affect both 1^{st} shot and 2^{nd} shot simultaneously. Furthermore, to conduct the runner constraint effect, we also perform simulation without runner in Fig. 5. In the absence of runner system, the shrinkage and warpage go inward and more symmetrically. When 1^{st} shot is inserted before 2^{nd} shot, the shrinkage and warpage go outward. Fig 5(b) and (c) showed the metal constraint is better than plastic one.

Sequential overmolding and its warpage behavior are also conducted experimentally here. Firstly, we defined the **inward** and **outward** phenomena as shown in Fig. 6. It defines the length of one side as A and of the other side as B. The warge is regarded as **outward** when A is greater B and contrarily regarded as **inward** when B is greater than A. For example, in the presence of runner system, after completed injection molding, the U-type parts can be examined. The single shot shows inward warpage in Fig. 7, while the two-shot sequential overmolding is also completed and measured as shown in Fig. 8. Obviously, when the width of 2^{nd} shot is 2 mm, the warpage of the whole part displays outward.

Keeping the 1^{st} shot fixed dimension and following the previous procedures, we have done various material combination for both 1^{st} shot and 2^{nd} shot as listed in Table 1. Fig. 9 shows the warpage tendency from numerical analyses and experimental studies for (1^{st} shot PC +2^{nd} shot PC) materials. Clearly, when the width of 2^{nd} shot keeps increased, the outward warpage tendency is increased. Both of numerical and experimental studies are in a good agreement. Furthermore, the warpage tendency for (1^{st} shot PMMA +2^{nd} shot PC) materials is also shown in Fig. 10. It is similar as (1^{st} shot PC +2^{nd} shot PC) case.

The warpage behavior in this sequential overmolding probably results from thermal residual stresses. In Fig. 11(a), when the width of 2^{nd} shot is small (say 0.25 mm), the inner portion of 2^{nd} shot is not hot. The asymmetrical temperature distribution causes a minor effect with small thermal residual stresses along 2^{nd} shot to cause tiny warpage. Alternatively, when the width of 2^{nd} shot is increased to 2mm, the thermal residual stresses have been accumulated along 2^{nd} shot. This imbalanced residual stresses result in the outward tendency of the warpge for final parts. This phenomenon is also expressed in Fig. 12. When the width of the 2^{nd} shot is increased, the imbalanced heat accumulated in the inner portion of 2^{nd} shot rises. This gives the potential to parts having the tendency of outward warpage.

Finally, the physical mechanism of warpage in a sequential overmolded part as described above is more complicated than that in a single injected part. Basically, the filling/packing history will introduce the volumetric shrinkage. Then cooling stage will introduce the thermal unbalance phenomena to the final product. In addition, in consideration of the combination of the material selections for 1^{st} shot and 2^{nd} shot, and the geometrical effects of designs, the parameter space will become very huge and complicated.

Conclusion

In this study, we have systematically shown that the importance of the geometrical effect and material combination in sequential overmolding development both numerically and experimentally. The warpage of final injected products not only results from the injection history but also are affected by geometries and material selections. The warpage tendencies of sequential overmolded parts in different materials combination are also conducted. No matter which material is applied for the 2^{nd} shot, when the geometry of 1^{st} shot is fixed and the width of the 2^{nd} shot is increased, the outward tendency of warpage is larger. Both numerical and experimental results could catch this behavior in a very good agreement. Also, this warpage mechanism is also disclosed.

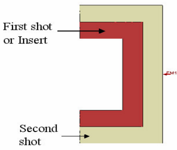
References

1. US patent #3,051,994.
2. Multi-material Technology, Battenfeld.
3. Web source http://www.engelmachinery.com
4. "Geometrical Effect and Material Selection in Multi-Component Molding (MCM) Development", Chao-Tsai Huang et al, ANTEC2006.
5. "The warpage simulation with in-mould constraint", Yi-Hui Peng et al, ANTEC 2004.
6. "The warpage simulation with in-mould constraint effect in injection moulding", Yi-Hui Peng et al, Moldex3D paper.
7. "Three-Dimensional Insert molding simulation", Rong-Yeu Chang et al, ANTEC 2004.

Key Words

Sequential overmolding, geometrical effect, warpage.

Table 1 Different geometrical dimension effects in sequential overmolding development.

Geometrical Structure	Dimension in shot$^{\alpha}$		Material in shot		Injection process focused$^{\beta}$
	1st	2nd	1st	2nd	2nd shot
U type 	L=19 W=9.5 T=2 (mm)	L=19+2**x** W=9.5+**x** T=2 **x=0.25~2** (mm)	ABS	ABS	F/P/C/W
			PC		
			PMMA		
			ABS	PC	F/P/C/W
			PC		
			PMMA		
			ABS	PMMA	F/P/C/W
			PC		
			PMMA		

α: L is length, W is width, and T is thickness.
β: F is filling; P is packing; C is cooling; W is warpage.
x: demonstrates the variable width of 2nd shot in U type geometry.
ABS is CHI-MEI POLYLAC PA-777D; PC is TEIJIN Panlite L-1250Y;
PMMA is CHI-MEI CM-211

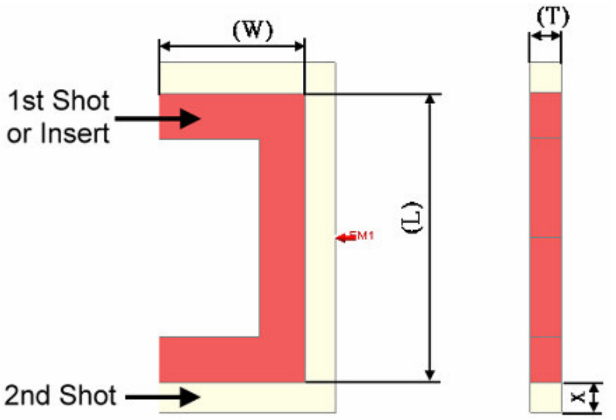


Fig. 1 (a). The model structure and dimension: it includes the dimension and geometrical structures for 1st shot and 2nd shot, and the details have been described in Table 1.

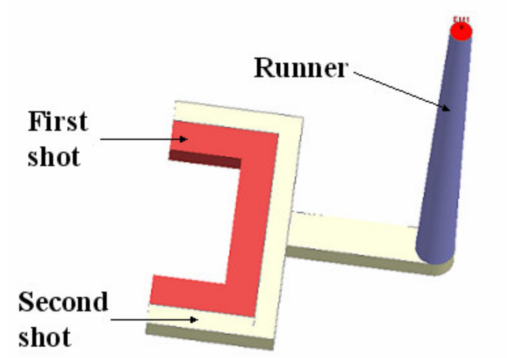


Fig. 1 (b). The model includes the runner system.

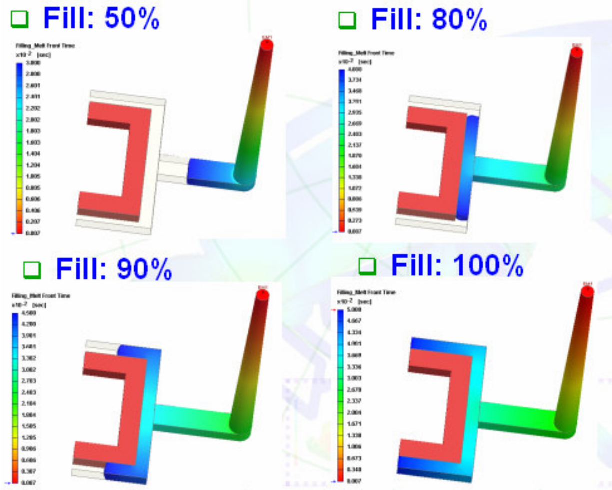


Fig. 2. The filling behaviors of the 2nd shot in sequential overmoding. (width of 2nd shot **x**=2 mm)

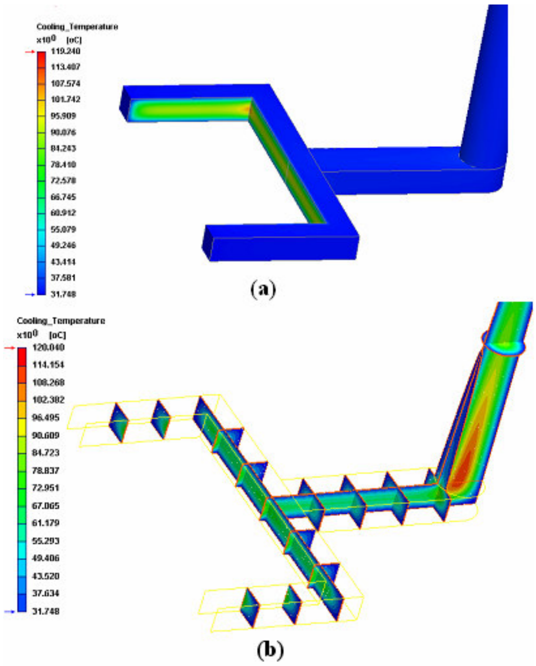


Fig. 3. The cooling temperature distribution for 2nd shot: (a) 3D structure, (b) slicing display helps to realize inner portion. (width of 2nd shot **x**=2 mm)

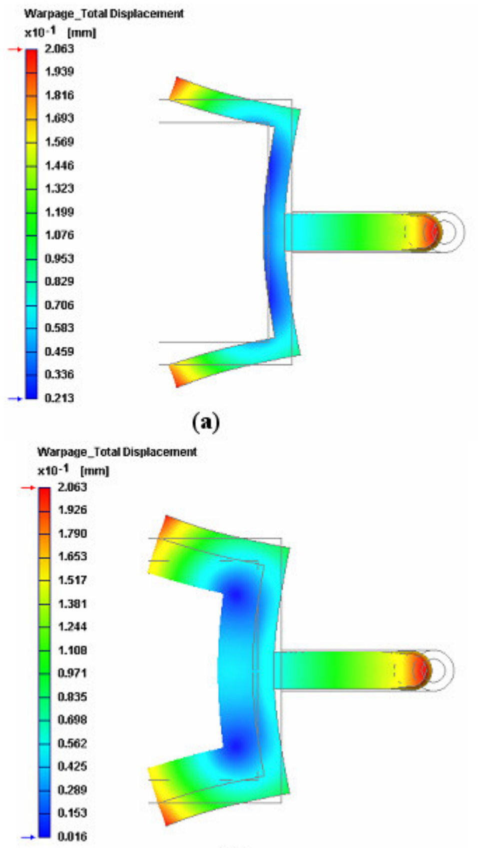
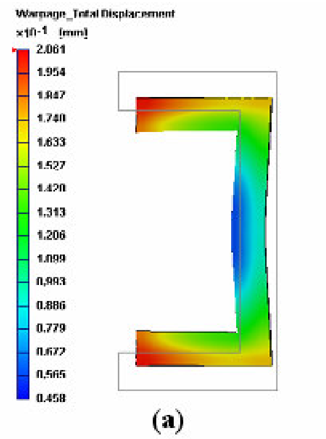


Fig. 4. Warpage behavior of 2nd shot with a plastic 1st shot in the presence of a runner system: (a) display the 2nd shot only, (b) display 1st and 2nd shots simultaneously (width of 2nd shot **x**=2 mm, Enlarge 12 times)



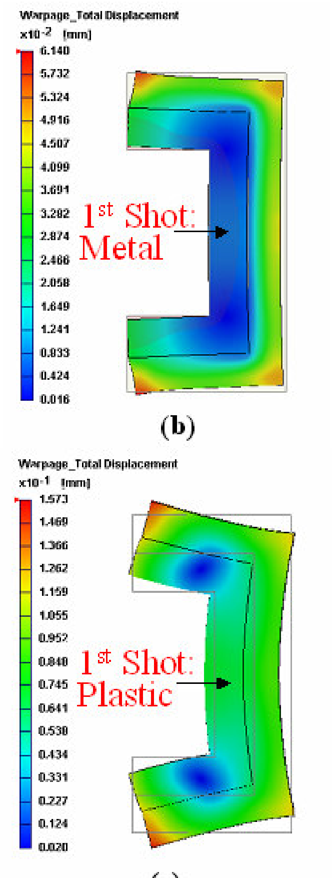


Fig. 5. Warpage behaviors in U-type structure without runner under considering the 2nd shot in sequential overmolding: (a) without insert, (b) with metal insert. (c) with plastic 1st shot (width of 2nd shot **x**=2 mm, Enlarge 12 times).

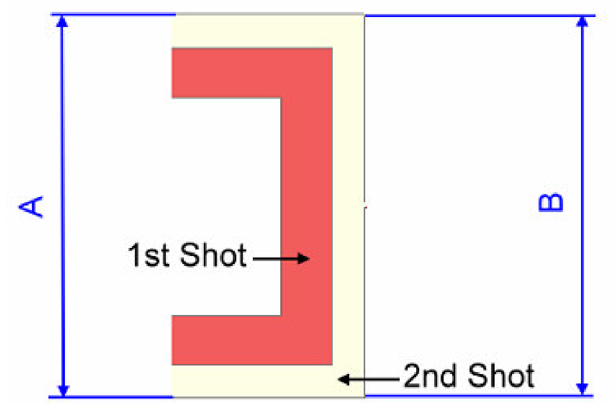


Fig. 6. Warpage behaviors definition for Inward or Outward from experimental study: (a) A>B is Outward, (b) A<B is Inward.

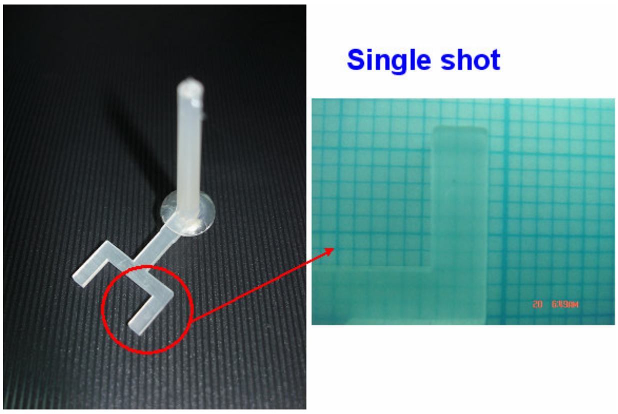


Fig. 7. Warpage behavior for a single shot: experimental result shows it is inward.

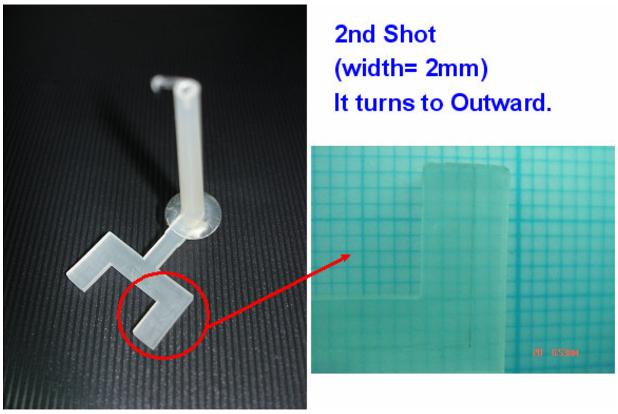


Fig. 8. Warpage behavior for a sequential overmolding with two shots: after two shots, experimental result shows it is outward.

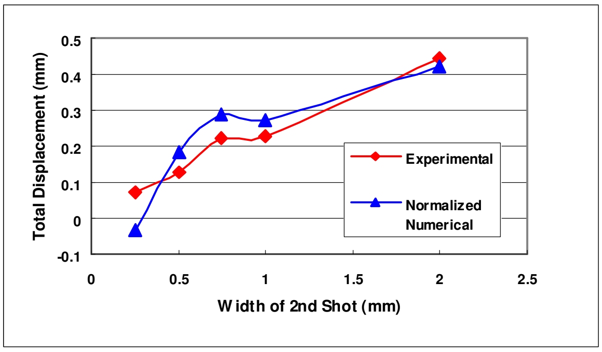


Fig. 9. Warpage tendency investigation using numerical analysis and experimental study in different 2nd shot width in the 1st shot material: 1st shot material is PC, and 2nd shot is PC.

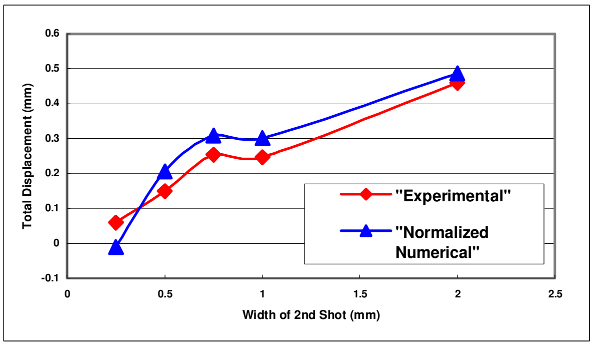


Fig. 10. Warpage behavior in different 2nd shot width in the 1st shot material: 1st shot material is PMMA, and 2nd shot is PC.

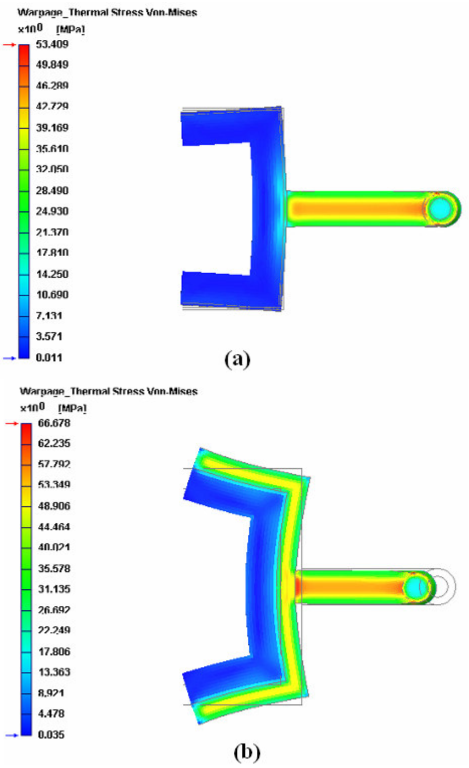


Fig. 11. Thermal residual stresses after 2nd shot: Warpage behavior in different 1st shot thickness: (a)1st shot is ABS width=2.0 mm, 2nd shot is PC with width=0.25 mm, (b) 1st shot is ABS width=2.0 mm, 2nd shot is PC with width=2.0 mm,

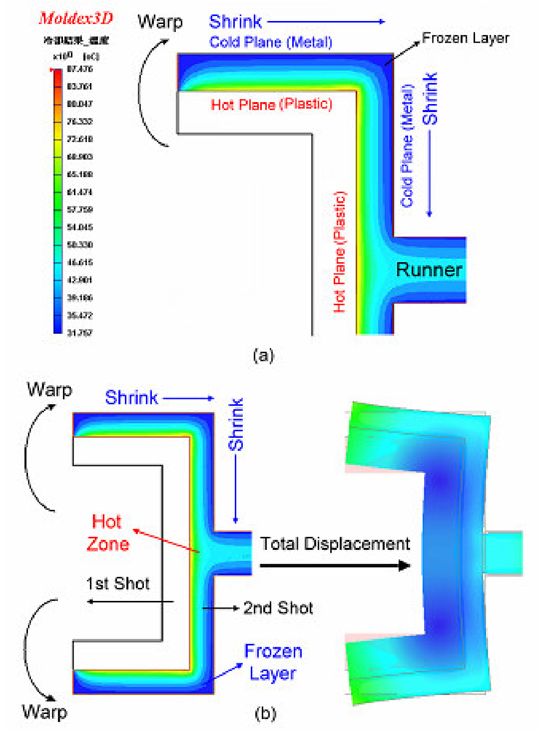


Fig. 12. Warpage mechanism prediction in a sequential overmolding.