Three -Dimensional Integrated Simulation for Composite Sheet Compression Molding

Jim Hsu[1], Srikar Vallury[1] and Anthony Yang[1]

[1]*Moldex3D Northern America Inc., MI*

Abstract

Sheet molded composite (SMC) or glass-mat-reinforced thermoplastic (GMT) material is widely used in the automotive industry with the compression molding process to achieve a higher residual length of the glass strands. In this work, an integrated simulation procedure is developed for SMC/GMT composite compression process. First, LS-DYNA® is used to conduct the draping analysis to predict the deformed shape of the initial charge before compression. The deformed shape and other data is then exported to Moldex3D to do the compression molding analysis to get the final part shape and fiber orientation. This work demonstrates a cost-effective analysis tool for sheet composite manufacturing.

Introduction

Compression molding is a processing method used for SMC materials. Compression molding enables the production of complex composite components at fast rates. For this reason, many industries are rapidly adopting SMC materials, to be incorporated to their products. Compression molding begins with several rectangular plies, known as a charge, being placed onto the bottom half of a pre-heated mold cavity. The charge must cover 60%-70% of the mold surface area, which sits on the bottom fixed mold half (Figure1.), in order to fill the cavity during the cure process.

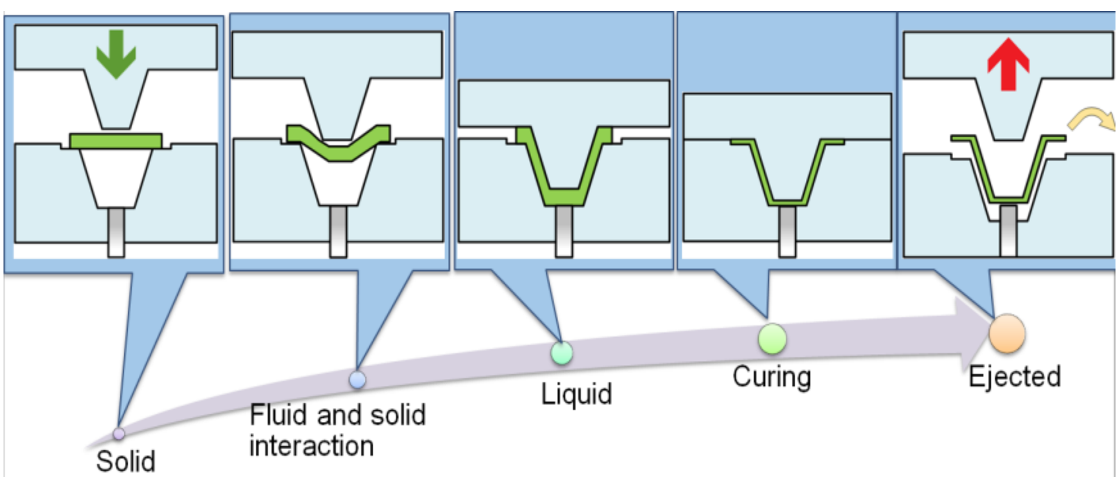

Figure 1: The compression molding process

SMC materials are beginning to see a wider range of applicability, especially in automotive industry. SMC materials are used for seat back, body, chassis, and engine components. They typically utilize chopped fibers that are randomly dispersed within a polyester or vinyl ester matrix. Two reasons for using SMC's over steel automotive components include not only significant weight reductions, but also lower tooling costs. Compression molded SMC components will typically have 40% - 60% lower tooling costs than steel stamping.

Compression molding/Glass mat thermoplastic process is commonly used for large scale production of fiber reinforced plastic parts, especially in automotive industry. This process is a forming process in which a pre-cut prepreg is placed within a heated mold and is first pressed into shape before being cured. In the first stage, no real material flow is expected to take place and it has plastic deformation for the case, especially with the deep cones. After the melt point, it begins to flow in the mold in the second stage. In order to implement the compression molding analysis for both solid deformation in the solid stage and flow behavior in the second stage, the integration of LS-DYNA and Moldex3D can be able to carry out the whole compression molding analysis from solid stage to fluid stage. As shown in Figure 2, the integration of LS-DYNA and Moldex3D simulates the entire compression molding process, allowing engineers to select the most appropriate material, the right tooling design, and the best process parameters.

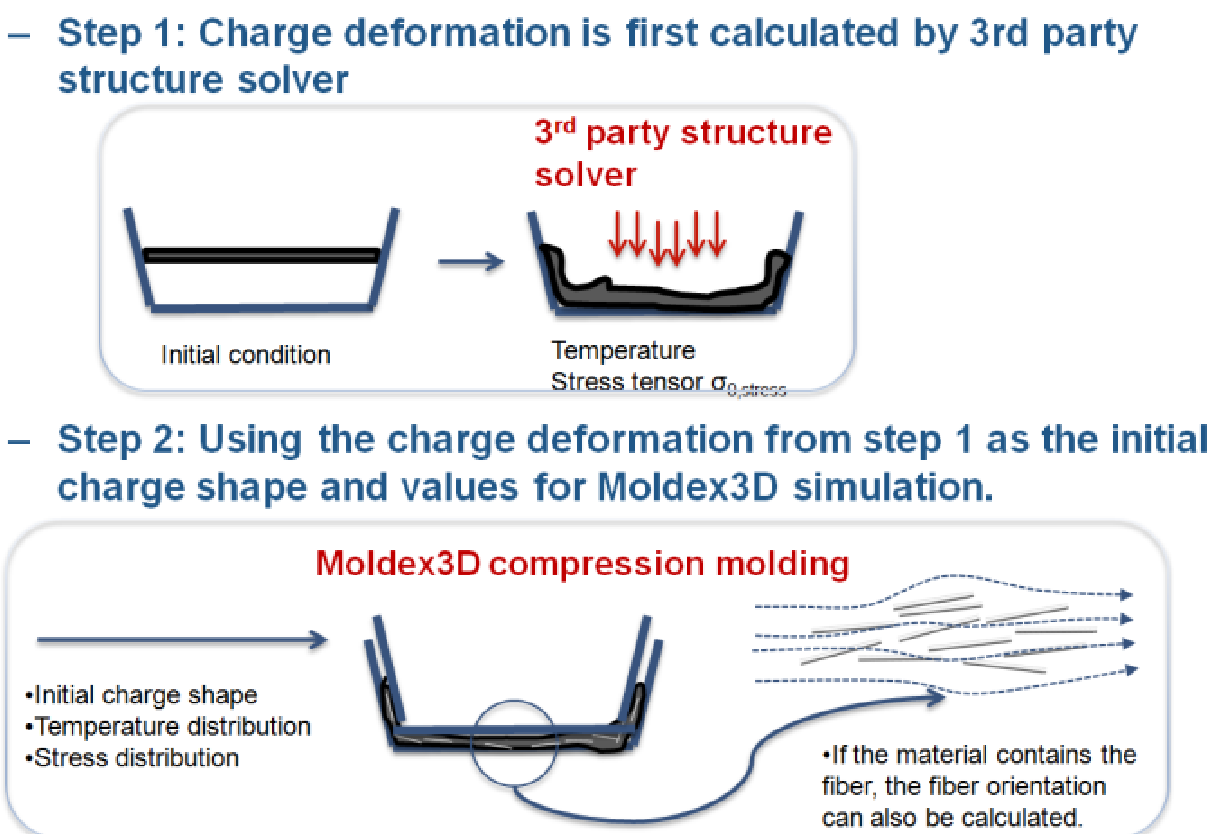

Figure 2. Integration analysis between Moldex3D and LS-DYNA

Forming analysis with LS-DYNA

The forming model was implemented in LS-DYNA FEA code. Several of the existing material models available in LS-DYNA were trialed including various formed models as well as available temperature and strain rate dependent material models. The material model which allowed the best representation of the observed behavior was elastic-plastic thermal material model MAT_004 available in LS-DYNA. The capability of MAT_004 can be that temperature dependent material coefficients can be defined and a maximum of eight temperatures with the corresponding data can be defined.

Figure 3 shows the geometry of the part and the simulation model for the initial charge and the part. In this figure, the yellow area is the final shape of the part to be molded, and the green area is the initial charge. The length of the part is about 200 mm, the width is 100 mm and the typical height of the final part is about 40 mm. The finite-element mesh has approximately 20,000 tetrahedral elements and 6,000 nodes. The thickness of the charge is 4 mm.

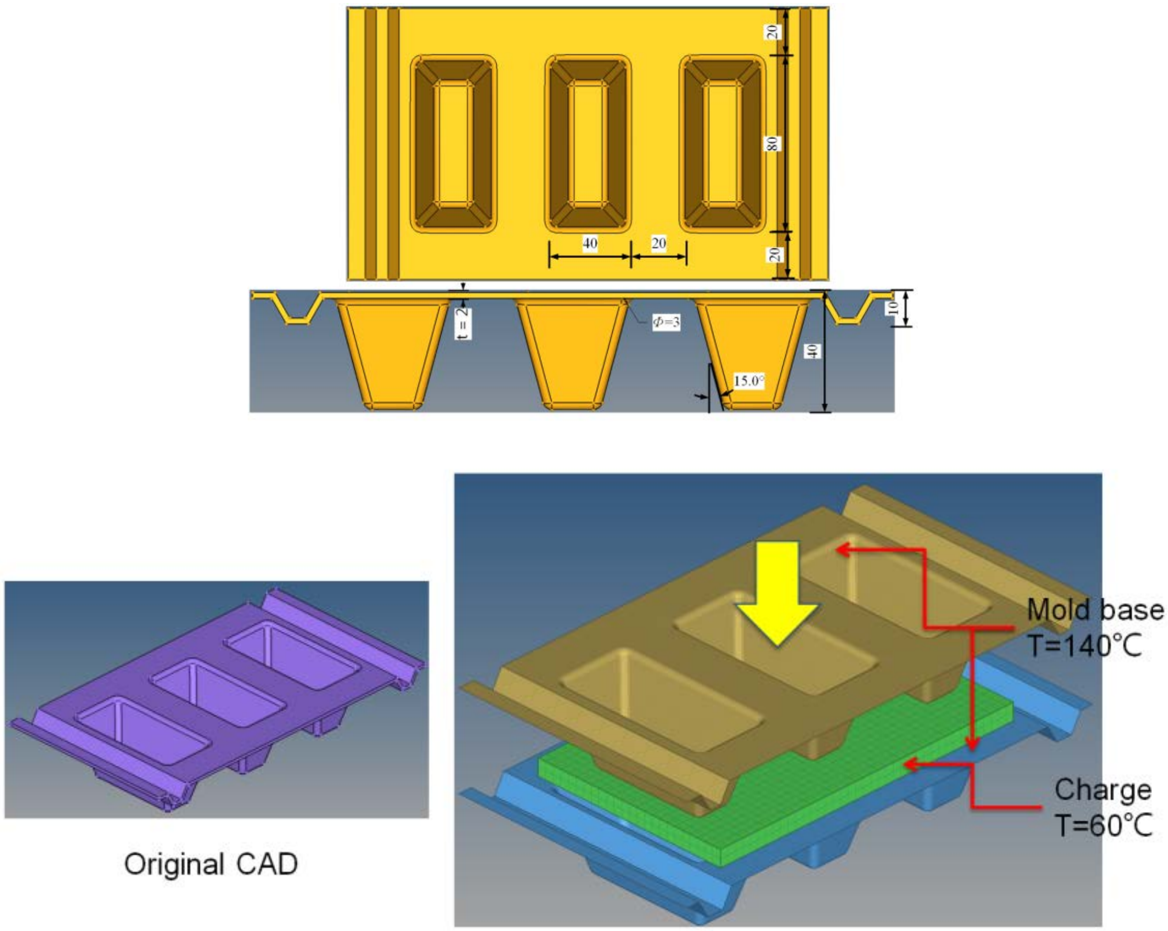

Figure 3. Compression molding model

Figure 4 shows the initial, intermediate, and final simulated deformation states of the SMC material. In this stage, the initial charge shape, temperature, stress tensor, and anisotropic material property which are obtained from LS-DYNA can be taken into next stage for compression molding simulation. In the compression molding process, the charge placement and molding conditions have a great influence on the mold filling and fiber orientation of the part.

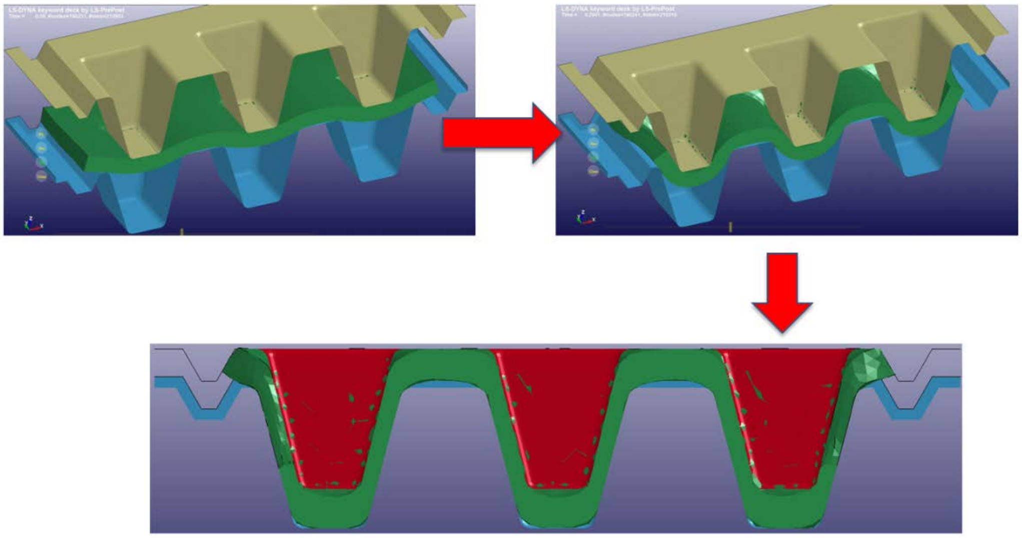

Figure 4. The deformation of the cross-section of the model during forming analysis

Figure 5 shows the deformation of the charge during forming process.

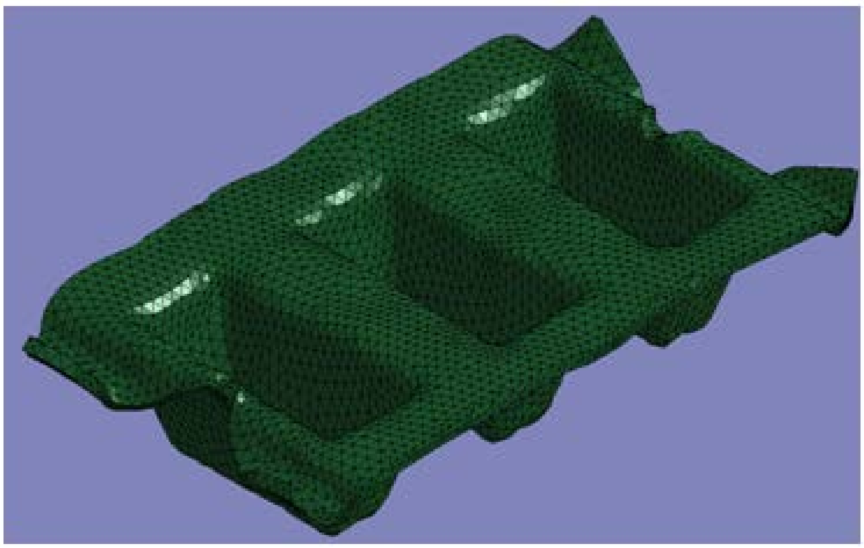

Figure 5. The deformation of the charge during forming process

Compression molding analysis with Moldex3D

Mold filling is used to study the advancement of material inside the mold cavity starting with the initial charge shape or injection point and finishing with the full mold. This information is used to predict cycle times, compute pressure balance, ensure complete filling of the mold, predict knit lines and detect air entrapment. Before the mold design is finalized the engineer can avoid future operating problems by simulating mold filling for varying molding conditions, mold thickness and for a series of charge configurations or injection gates. In the second stage, this compression molding process is implemented in Moldex3D.

To bridge the gap of forming analysis in LS-DYNA and compression molding analysis in Moldex3D, Moldex3D provides access to take the charge shape from forming stage, and redistributed the anisotropic material property, into the second stage. As shown in Figure 6, the fiber will display its corresponding direction once the initial fiber setting is finished. The data will be stored in the *.cmbc file under the run folder.

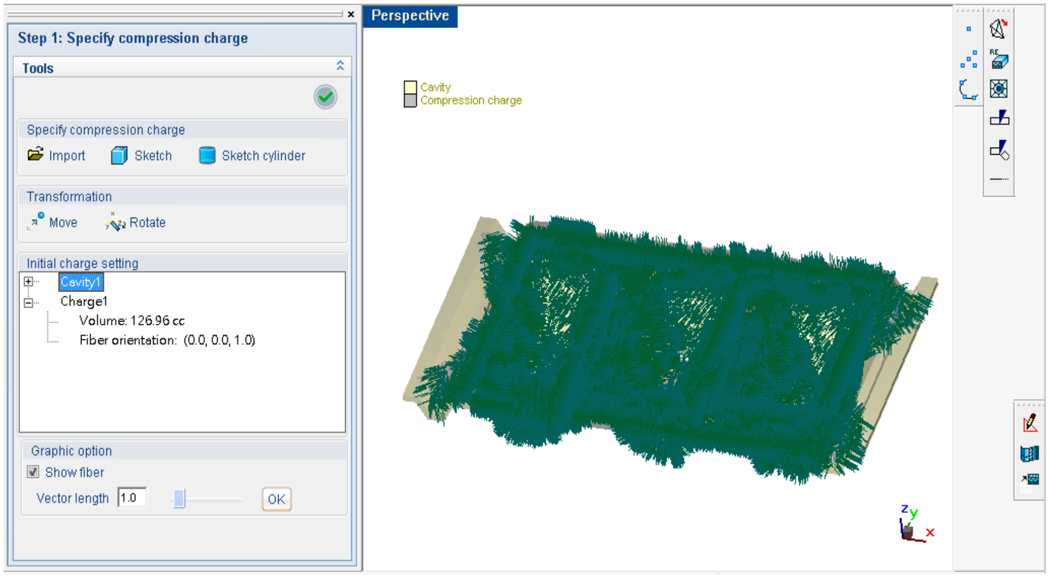

Figure 6. The setting of initial charge shape and initial fiber orientation in Moldex3D

Figure 7 shows initial fiber orientation at the first time step. The fiber orientation vector may change its direction in the X-Y plane due to the charge shape. If we choose a smooth charge shape, the transformation will still keep the Eigvenvalue=0.5 for both the X and Y direction.

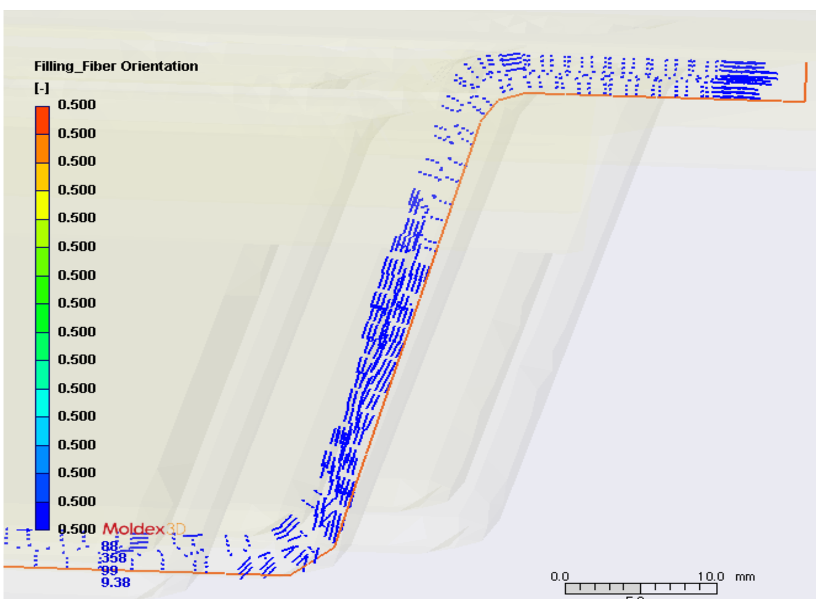

Figure 7. Initial fiber orientation in Moldex3D

Figure 8 shows the filling simulation at different melt front.

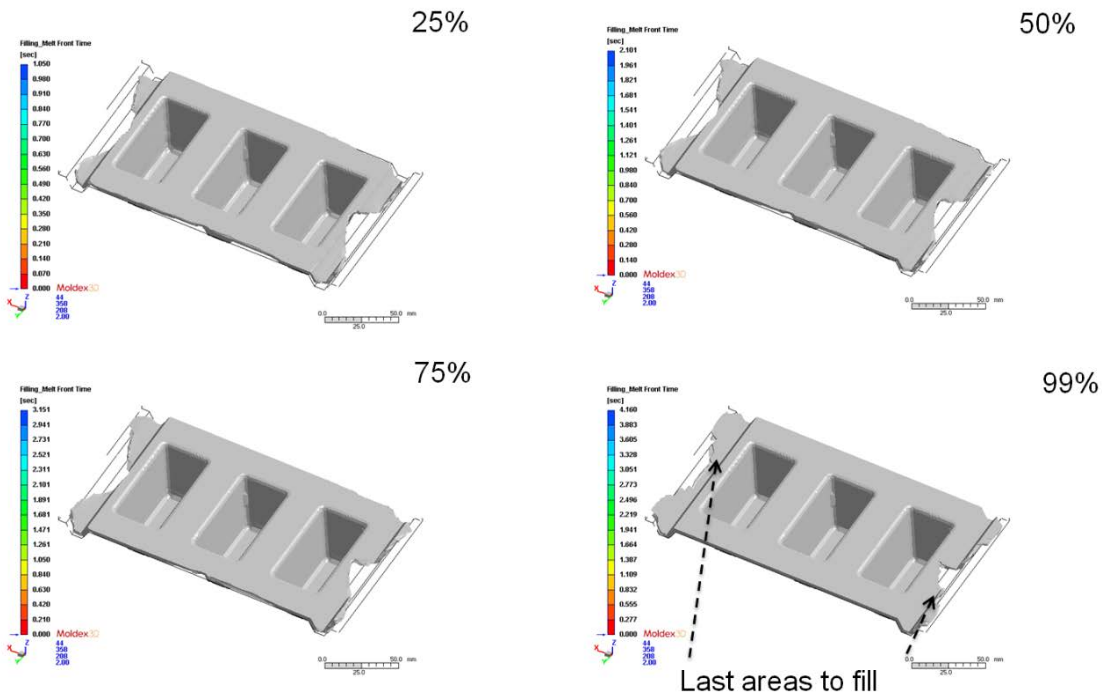

Figure 8. Melt front results

As depicted in Figure 9, material flow and deformation in the mold causes the reinforcing fibers to rotate and orient to create a part with anisotropic properties. This fiber orientation greatly affects stiffness and strength of the final part, and is the major cause for warpage after the part is cooled and removed from the mold. High degrees of fiber orientation become a problem in places where peak stresses are encountered such as around hinge or fastener attachments.

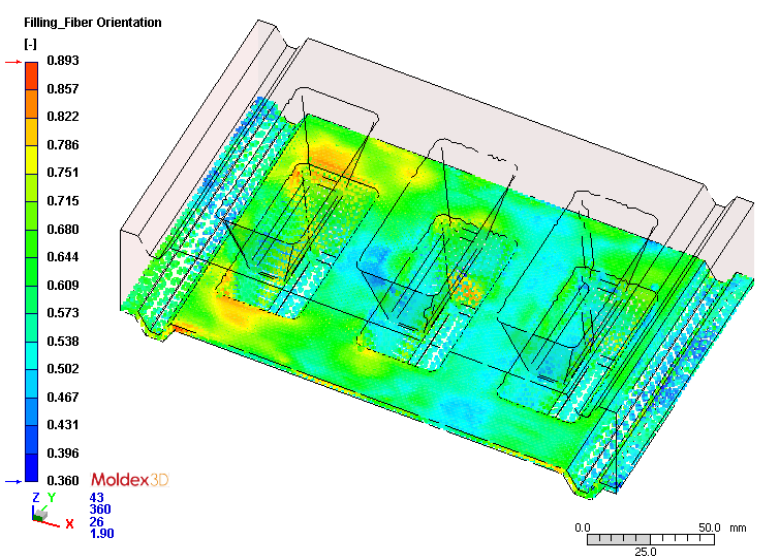

Figure 9. Fiber orientation at EOF

As shown in Figure 10, shrinkage and warpage of a compression molded part is a consequence of fiber orientation and residual stresses developed during compression molding processing. The formation of residual stress is attributed to two major coupled factors: curing and thermal history. Therefore, cure and temperature history along with fiber orientation are essential to understand and control the final shrinkage and warpage of the part.

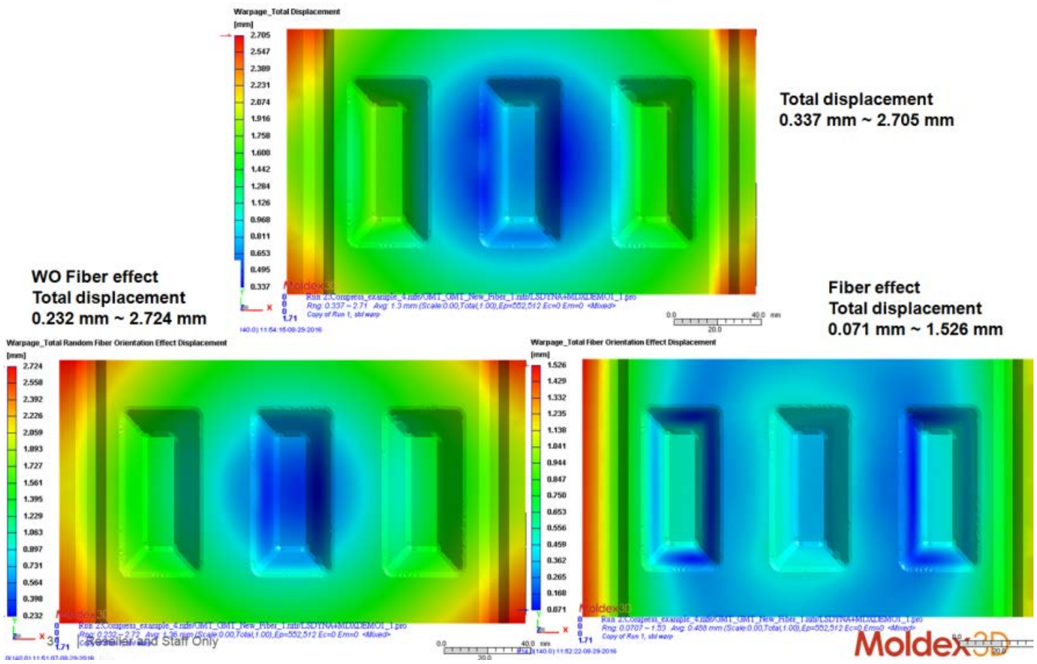

Figure 10.Warpage behavior

Conclusions

Using CAE tools properly can provide enormous cost savings and time savings for part design and manufacturing. CAE allows engineers to virtually test how the part will be processed and how it will perform during its operating life. To exploit the cost benefits of CAE, the material supplier, designer, molder and manufacturer should apply these tools concurrently early in the design cycle. Similarly, it is also very beneficial to the compression molding process. The rheological property of polymer has great influence on the filling, curing, warp behavior. Therefore, by only using LS-DYNA and elastic-plastic material model, it is not possible to reflect the right behavior and as complete as occurs in the real compression process. During the compression analysis, Moldex3D can provide the rheological property, which includes PVT relationship, viscosity property, viscoelasticity. Moldex3D showcase the full workflow of integration between Moldex3D and LS-DYNA : (1) run forming analysis on part in LS-DYNA, (2) Import draped form as charge into Moldex3D and run compression molding analysis.

References

1. B. A. Davis, R.P. Theriault, & T. A. Osswald, "Optimization of the compression(Injection-Compression) Molding Process Using Numerical Simulation," ASME Conference, (1997).
2. D-K Kim, H-Y Choi, and N. Kim, "Experimental investigation and numerical simulation of SMC in compression molding," Journal of Materials Processing Technology (1995), pp. 333-344.
3. D. Schommer, M. Duhovie, F. Gortner, M. Maier, "Advanced simulation of polymer composite SMC compression molding using fluid-structure interaction in LS-DYNA", 13th International LS-DYNA Users Conference, (2014).
4. Chih-Chung Hsu, Hsien-Sen Chiu, Chao-Tsai Huang, and Rong-Yeu Chang, "Through fiber orientation investigation to visualize compression molding", Proceedings of the Polymer Processing Society 29th Annual Meeting, (2013).