

INTEGRATING PLASTICS MOLDING AND STRUCTURE DYNAMICS ANALYSIS BY LEVERAGING LS-DYNA, MOLDEX3D AND PRESYS

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Abstract

An increasing number of automotive or consumer electronics parts are made of engineering plastic for its low cost and superior material properties. The traditional structure analysis for injection-molded plastics part is to perform CAE analysis based on the assumption of one or several isotropic materials. However, the material characteristic of plastic part is extremely dependent on molding process. The process-induced properties, such as fiber-induced anisotropic mechanical properties or weld-line defects, might not be favorable to the structural requirement of final products. Besides, the mesh requirement for different analysis purposes might not be the same, either. In this topic, we integrate the CAE analysis of structure and plastics molding through the integration of LS-DYNA, Moldex3D, and PreSys. This approach shows the effects of mutually dependent analyses have been successfully examined in some injection-molded parts.

Introduction

An increasing number of automotive parts are made of engineering plastic for its low cost and superior material properties, such as fiber-reinforced plastic valve. Fiber-reinforced engineering plastic is used to substitute metal material in the manufacture of automotive products due to its superior mechanical properties and high heat distortion temperature. The traditional structure analysis for automotive part is to perform CAE analysis based on the assumption of one or several isotropic materials. However, the material characteristic of plastic part is extremely dependent on molding process. The process-induced properties, such as fiber-induced anisotropic mechanical properties, might not be favorable to the structural requirement of final products. Hence this traditional analysis procedure could neglect some molding-induced effects. Furthermore, the results of analysis could be incorrect.

The injection molding of fiber-reinforced thermoplastics is a complicated process. The reinforced composites don't possess isotropic material properties. The thermal and mechanics properties of the composite strongly depend on the fiber orientation pattern. The composite is stronger in the fiber orientation direction and weaker in the transverse direction. In this topic, we

integrate the CAE analysis of structure and plastics molding through the integration of LS-DYNA, Moldex3D, and PreSys. Also, PreSys will be the main platform to sequentially connect the analysis capabilities of Moldex3D and LS-DYNA.

Theory

Plastics Filling:

For the filling/packing process, the polymer melt is assumed to behave as Generalized Newtonian Fluid (GNF). Hence the non-isothermal 3D flow motion can be mathematically described by the followings.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0 \quad (1)$$

$$\frac{\partial}{\partial t} (\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u} \mathbf{u} - \boldsymbol{\sigma}) = \rho \mathbf{g} \quad (2)$$

$$\boldsymbol{\sigma} = -p \mathbf{I} + \eta (\nabla \mathbf{u} + \nabla \mathbf{u}^T) \quad (3)$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) = \nabla \cdot (\mathbf{k} \nabla T) + \eta \dot{\gamma}^2 \quad (4)$$

where \mathbf{u} is the velocity vector, T the temperature, t the time, p the pressure, $\boldsymbol{\sigma}$ the total stress tensor, ρ the density, η the viscosity, \mathbf{k} the thermal conductivity, C_p the specific heat and $\dot{\gamma}$ the shear rate. The FVM due to its robustness and efficiency is employed in this study to solve the transient flow field in complex three-dimensional geometry.

Fiber orientation:

The fiber orientation state at each point in the part is represented by a 2nd-order orientation vector \mathbf{A} ,

$$\mathbf{A}_{ij} = \int (p_i p_j) \phi(p) dp \quad (5)$$

The equation of orientation change for the orientation tensor proposed by Advani and Tucker is employed for the analysis,

$$\frac{\partial A_{ij}}{\partial t} + u_k \frac{\partial A_{ij}}{\partial x_k} = A_{ik} \Omega_{kj} - \Omega_{ik} A_{kj} + \lambda (A_{ik} E_{kj} + E_{ik} A_{kj} - 2A_{ijkl} E_{kl}) + 2C_I \dot{\gamma} (\delta_{ij} - 3A_{ij}) \quad (6)$$

where C_I is the interaction coefficient with the value ranged from 10^{-2} to 10^{-3} . For the fourth-order tensor A_{ijkl} , a closure approximation is needed.

Integration approach:

This approach is to link the data between Moldex3D mold-filling analysis and LS-DYNA structure analysis through PreSys software. The anisotropy moduli and thermal expansion coefficients of the fiber-reinforced polymer can be determined using the fiber orientation and mechanical properties of composite material. These anisotropy mechanical properties will be put into structural elements for later structure analysis. The molding-induced material properties will be taken into account in structure analysis.

Besides, the mesh requirement might be not the same for mold-filling analysis and structure analysis. The mesh of structure analysis could be focused on the area of stress concentration. However, the mesh of mold-filling analysis is stressed on the higher element resolution across the thickness direction. This approach further develops the mapping function to map the element properties from mold-filling-specified mesh to structure-specified mesh. It can correctly matches the elements and maps the material properties even though the mesh characteristics are totally different, as shown in Fig. 1.

Results and discussions

A rectangular plate of 100x50x1 mm molded with glass-fiber reinforced PET is simulated to validate the prediction of fiber orientation. Fig.2 shows the part geometry and the filling pattern. The gate is located in the center of the plate. Fig.3 displays the fiber orientation on the different cut planes. The orientation of the lines indicates the most favorable orientation direction and the color of each line represents the degree of orientation. In the vicinity of mold wall, we can see that the shearing flow tends to align the fibers along the flow. In the center cut plane, the flow is shear free and hence the fiber orientation is perpendicular to the flow direction. In Fig.4, the prediction shows the fiber alignment along the welding line. These analysis results agree well with the experimental observation.

A bumper case is shown in Fig. 5(a) and Fig. 5(b). This model is a typical thin-walled part with main wall thickness of 3.0 mm. The traditional 2.5D approach is enough to obtain good analysis results. 11,942 3-node triangular plate element are created for Moldex3D injection molding analysis. The resin is PP with 20% glass-fiber. Moldex3D analysis results show fiber orientations are mainly depended on melt flow behaviors, as shown in Fig. 6(a) and Fig. 6(b). This fiber orientatoin phenomenon will further result anisotropic machanical propoerties, and those properties will be taked into account in further LS-DYNA analysis. Besides, the mesh requirement might be not the same for mold-filling analysis and structure analysis. The mesh of structure analysis could be focused on the area of stress concentration. Therefore, we prepare a mesh composed of 4-node quadrilateral plate elements and 3-node

triangular plate elements for LS-DYNA is created in PreSys to increase the analysis accuracy and reduce the computational loading, as shown in Fig. 7. Through the proposed mapping approach, the fiber-induced anisotropic properties is mapped correctly to this specified mesh. LS-DYNA is adopted to perform the impact analysis of bumper. We assume the weight of imaginary vehicle behind the bumper is 1200.0 kgw and impact a rigid column with the rate of 4.0 km/hour. The fixed constraints on bolts are also shown in Fig. 8. The period of time is 0.15 sec. The results of model deflection is shown in Fig. 9. Fig. 10 and Fig. 11 show the histroy curves of internal energy and impact force between isotropic material and fiber-induced anisotropic materials. Results clearly illustrate the effects of fiber orientation on structure performance. Besides, to further compare the stress histroy of specified element between isotropic material and fiber-induced anisotropic materials, as shown in Fig. 12. All these results show the structure analysis of injection-molded plastic part depends heavily on molding process.

Conclusions

In this paper, we propose an integrated CAE solution for injection-molded automotive part. The results from several demonstrations show the structure analyses of fiber-reinforced plastic parts depend heavily on the molding process. Part designers are recommended to use this approach for evaluating the part design and mold design. It will be a cost-effect tool for the study of plastic part from design phase to manufacturing phase.

Acknowledgement

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Key Words

Enhance structure analysis, injection molded automotive part, Integration solution, LS-DYNA, Moldex3D, PreSys

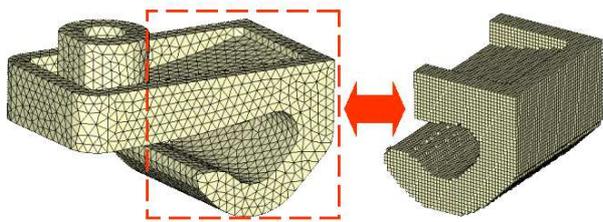
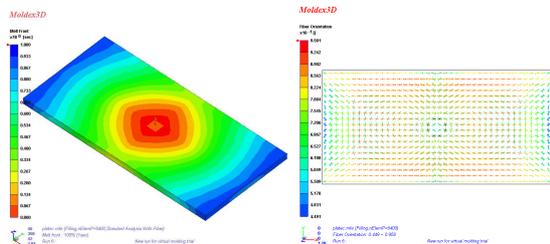
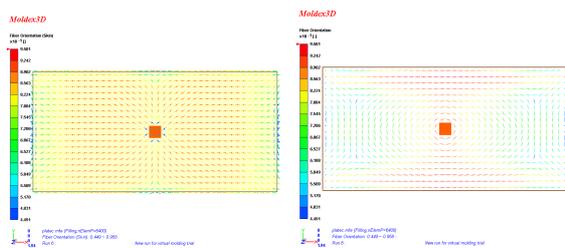


Fig. 1 Map element properties between different meshes



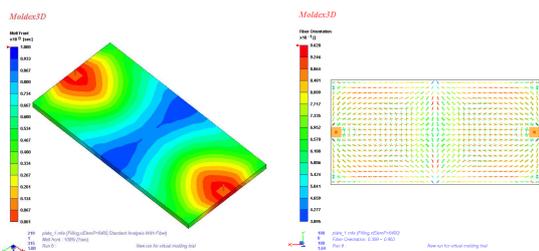
(a) Melt front (b) Fiber orientation

Fig. 2 Filling results of center-gate plate



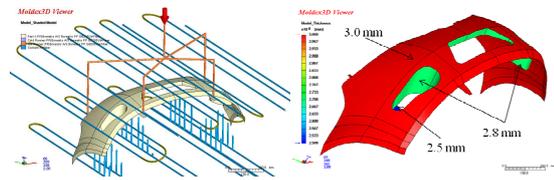
(a) On the wall (b) In the center cut plane

Fig. 3 Fiber orientations distribution of center-gate plate



(a) Melt front (b) Fiber orientation

Fig. 4 Filling results of side-gate plate



(a) Model design (b) thickness distribution

Fig. 5 Bumper model layout

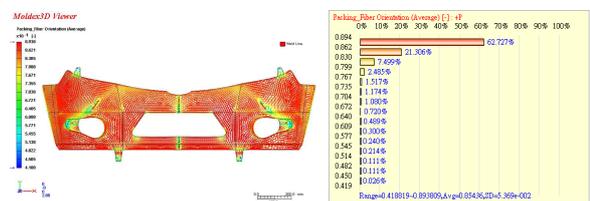


Fig. 6 Average fiber orientation distribution

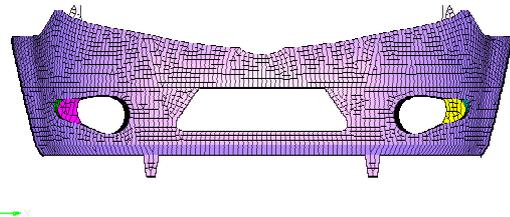


Fig. 7 Specified mesh for impact analysis

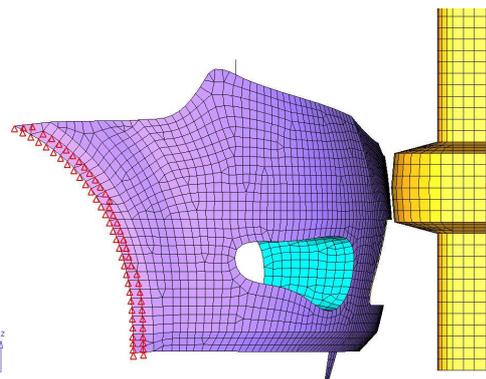


Fig. 8 Models and constraints for impact analysis

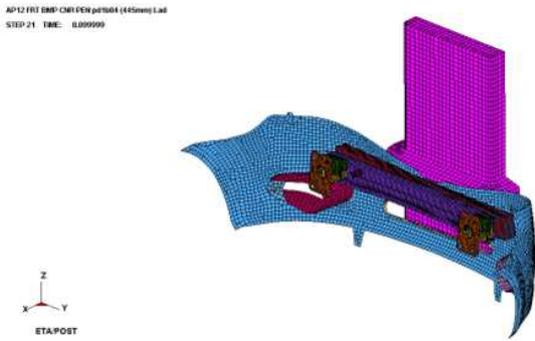
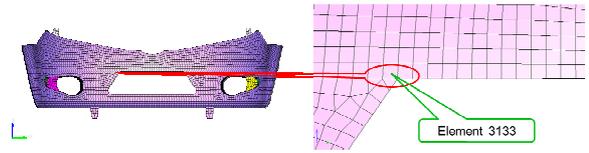


Fig. 9 Model deflection induced by dynamic impact



(a) Location of specified element (element #3133)

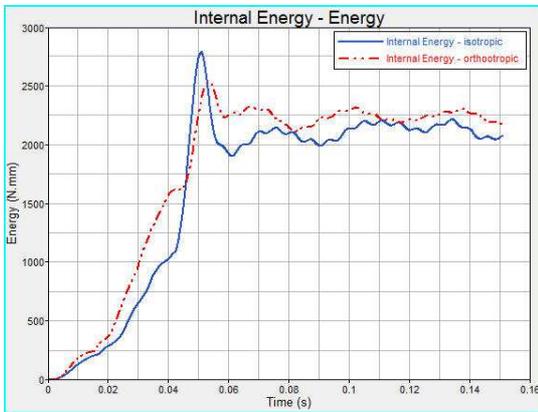
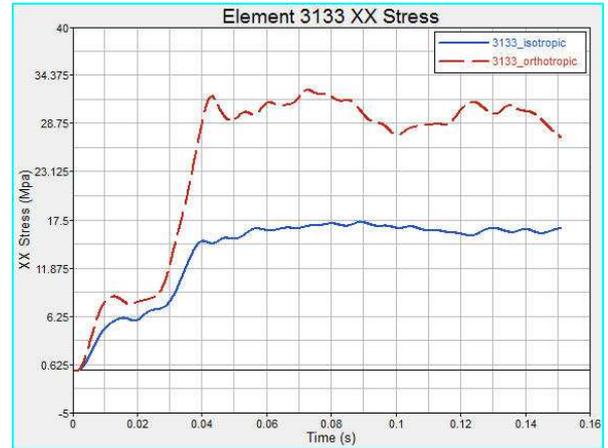


Fig. 10 Internal energy history curve



(b) XX stress history curve at element #3133

Fig. 12 XX stress history curve at specified element

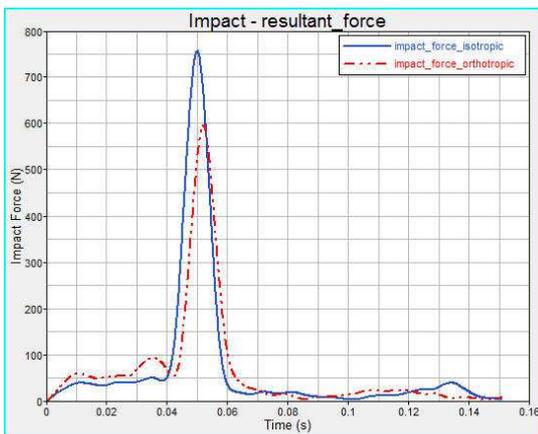


Fig. 11 Impact force history curve