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Foaming Prediction Technology for Automotive Polyurethane Using a Model-Based Approach

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This study developed a foaming simulation model for automotive polyurethane foam to predict cell-structure formation during chemical foaming and to clarify the relationship between molding conditions and the final microstructure. In automotive sound-insulation and thermal-management parts, performance is strongly influenced by bubble diameter, throat diameter, bubble number density, and the transition from closed cells to interconnected cells. However, these structures are formed through coupled phenomena such as heat generation, gas generation, viscosity increase, and bubble–bubble interaction. As a result, conventional process design has largely depended on empirical know-how.

The developed simulator, RYUSI-Foam, treats individual bubbles as discrete elements and sequentially calculates bubble generation, growth, contact, coalescence, and throat opening. The initial bubble number density and bubble generation rate were defined based on visualization experiments, while the time histories of temperature, pressure, and viscosity obtained by measurement were used as time-dependent inputs. In addition, by incorporating gas mass transfer into the model, the simulator can predict cell-structure parameters during foaming, including average bubble diameter, average throat diameter, and bubble number density.

The predictive accuracy of the model was validated by comparison with in-situ visualization observations during foaming and CT-based cell-structure analysis after foaming.(Fig.1,2) The results showed that the simulation reproduced the time evolution of bubble growth and captured the final trends in average bubble diameter, average throat diameter, and bubble-diameter distribution. Furthermore, even when practical molding history conditions were applied, the model reproduced the injection-density dependence of average bubble diameter and average throat diameter with overall good agreement with the experimental results.(Fig.3,4) These findings indicate that the present model is applicable to predicting the microstructure of polyurethane foam under actual molding conditions.

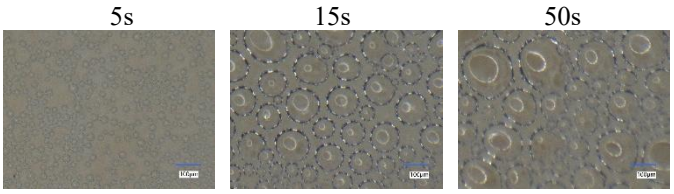

Fig.1　Visualization results during foaming at 5 s, 15 s, and 50 s after the start of discharge.

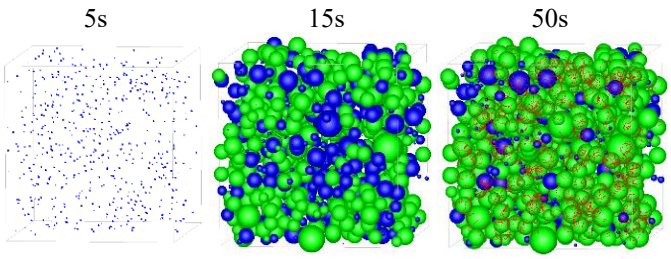

Fig.2　3D simulation results during foaming at 5 s, 15 s, and 50 s after the start of calculation. These results are compared with visualization images taken at the corresponding times after the start of discharge.

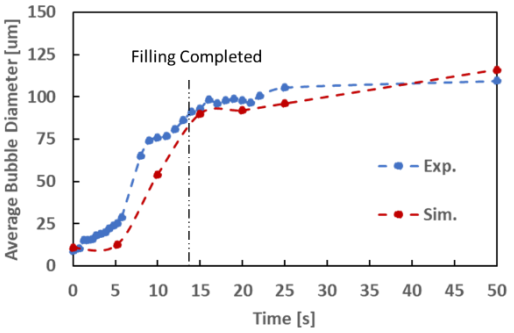

Fig.3　Comparison of the change in average bubble diameter over time between experimental and calculated results

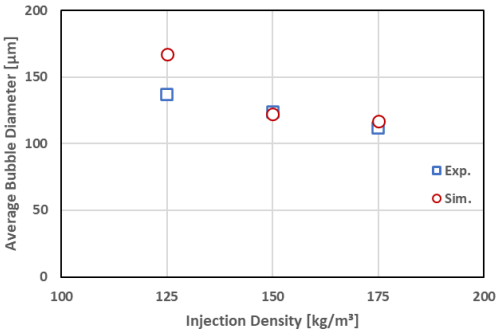

Fig.4　Comparison of cell structure prediction accuracy at different injection densities.