Digital Prediction of Polyurethane Foam Expansion

Using the FOAM Software Package

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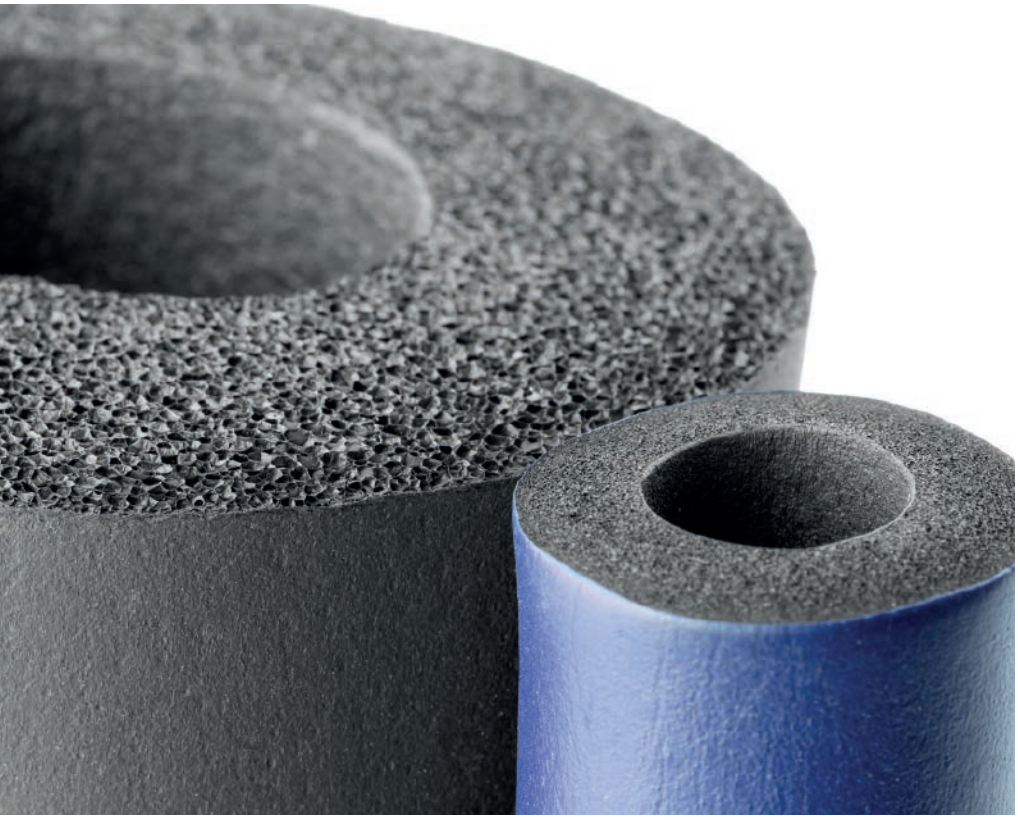
Polyurethane (PU) foam products possess inherent physical attributes that makes them quite attractive for various industrial and domestic applications. Their good thermal resistance, energy absorbing ability, and thermo-setting nature makes them very useful in shock application, acoustics, and thermal insulations. Industries including the automotive, aircraft, refrigerating, building, and packaging industries explore these properties to achieve enhanced cost-effective end products.



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However, during their production phase, PU foams exhibit complex dynamics with evolving material properties which makes them quite difficult to study. However, a good understanding and prediction of the foam formation process would permit easier design and optimize the foam production process. The prevalent flow of complex fluids in industrial processes motivates several theoretical and experimental studies aimed at understanding and possibly predicting the complex dynamics exhibited by such fluids. Inspired by the vast industrial application of polyurethane (PU) foams in the aerospace, automobile, packaging, and refrigerating industries, with extended application in structural and construction industries as well as domestic (home) appliances, the authors are currently and actively engaged in research activities focused on understanding some of the physical complexities that occur in reaction injection molding (RIM) processes of expanding PU foams. This understanding will enhance the existing practical applications of these foams. In addition, it will promote cost effectiveness both in the process design stage and material fabrication stage of the RIM processes. In the RIM process of PU foams, shear thinned reacting polymer mixture of adequate isocyanate and polyol group is injected into a mold where after a few seconds the material evolves from a low molecular weight emulsion (through polymerization with the evolution of heat and CO_2 gas) to a complex polymer network via chain-linking and polymer entanglement. Generally, the final structure and attributes of expanding PU foams depends strongly on the evolving material properties of the reactant mixture used in producing them. For instance, the mixture viscosity exhibits chemo-rheological behavior, thus, changing in space and time with the degree of cure and temperature of the foaming system. In the mathematical framework, this behavior initiates a coupling between viscosity, degree of polymerization and temperature. With this form of coupling in the state variables it becomes very difficult to estimate associated model parameters analytically. Although the chemistry of reactive blown PU foams has a well-documented history, however, obtaining adequate mathematical description of the complex dynamics which occurs in the RIM process still remains an issue of current research. Even though the expansion of polyurethane foams is a very complex process, we can start our simulations with only a small amount of information from simple foaming experiments per-

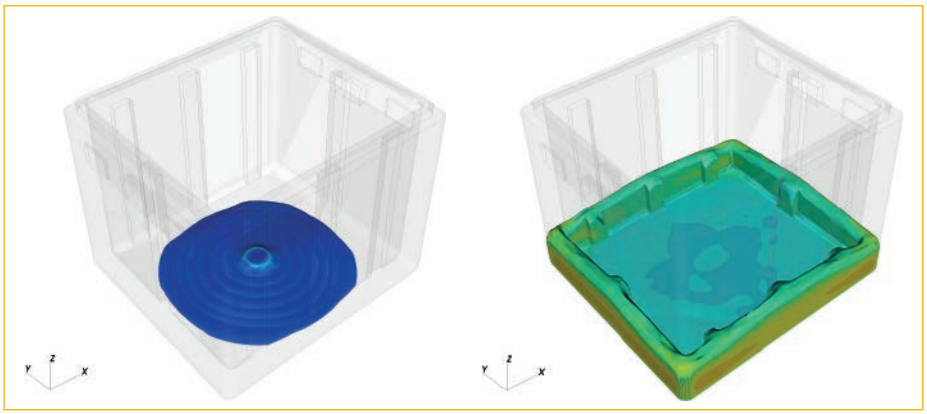

Fig.1 PU foam expansion in time – refrigerator geometry. Colors show foam temperature during expansion between 25 °C (dark blue color) and 80 °C (red color). Point inlet position and 2000 g of the injected material.

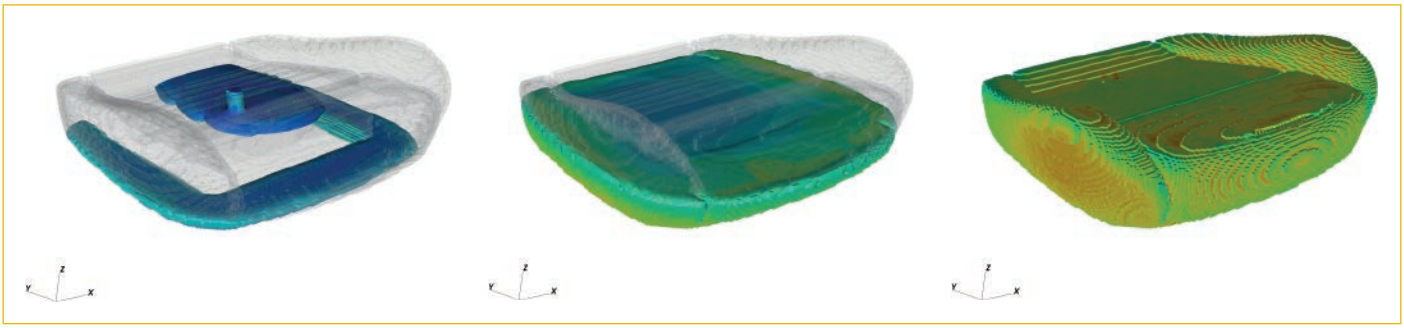

Fig.2 PU foam expansion in time – car seat geometry. Colors show foam temperature during expansion between 40 °C (dark blue color) and 80 °C (red color). Line inlet position and 1600 g of the injected material.

formed in cylindrical tubes of different diameters. The minimum required information about the polymer foam includes the timing of the volume of expanding foam in each tube, the temperature of the expanding foam measured at a specific point in the containers and the viscosity of the polymer emulsion before expansion.

Better Design Through Modeling

Optimal product design and reduction of time in production is one major advantage of numerical simulation of industrial processes. More so, the advances in computing power and computer technology provides a platform to explore this capability extensively. Processes in automotive industries, refrigerating industries, furniture, and structural industries can be simulated for enhanced production of end products while minimizing wastage during production. To achieve that we have developed FOAM solver that is capable of simulating such PU foam expansion processes in industrial scale product designs. The solver also has the ability to predict PU foam expansion in continuous processes. As an example, we can mention the production of flexible mattresses or sandwich panels where rigid polyurethane foam is used as a core material and has very good insulation properties. FOAM solver based on relevant physical and mathematical arguments ([1] and references therein) successfully simulates the expansion process of PU foams in arbitrary geometries, thereby, offering the possibility to understand and predict PU foam expansion process in closed molds.

The reaction injection molding process is very similar to injection molding with the difference that in contrast to injection molding, RIM techniques use low viscosity liquid polymers in thermosetting processes rather than thermoplastics. As a result of various chemical reactions, these polymers expand, thicken, and cure only after being injected into a preheated mold. This property allows for the use of much more complex structures than in ordinary injection molding. In addition as a result of reaction heat and CO_2 gas are created. One of the main problems in RIM is the appropriate location of the vents, which enable the gas released during the chemical reaction to leave the mold. Another question that has to be asked is how to design injection positions in order to achieve full mold filling and the most uniform end product. All those aspects could be very time and cost consuming by a trial and error approach that would possibly require various experimental tests. However, with the help of an appropriate computer software, all the aspects mentioned above can be accelerated and the overall costs reduced. Already at the product planning level, a series of simulations can be carried out to narrow down the possible locations of injection points and vent positions while taking into account the constructional constraints and production process conditions.

Workflow

The workflow in FOAM starts by generating a volumetric grid from a technical drawing created in any Computer Aided Design (CAD) program. In the preparatory process, vent as well as injection positions are defined. The latter is either fixed or defined so that the injection follows any pre-defined curve (e.g. longitudinal line injection). After that follow specifications of PU foam material that cover foam density, viscosity, heat of reaction, degree of cure parameters, thermal conductivity and specific heat. To close up simulation specification boundary conditions are defined, e.g. mold temperature at wall, amount of material that has to be injected. From the simulation one gets foam front position in time, local foam density variations, gas volume fraction, foam temperature and degree of cure. In Figure 1 PU foam fronts together with foam temperature during expansion process are plotted. The foaming process takes about 40 seconds and fills the geometry, starting from the bottom where the injection point is located, and then fills the side walls. The vents have been placed in the upper parts of the side walls to avoid gas entrapment areas. The solver can also simulate multiple PU foams, e.g. hard and soft foams, giving the possibility of digital prediction of the RIM process involving multiple foams simultaneously. Such technology is used in production of car seats, for example.

Figure 2 presents foam expansion in car seat geometry. Here injection position is prescribed as a pre-defined curve. Injection takes about 10 seconds, while the chemical reaction of the foam starts 4 seconds after being injected. In order to reflect the fact that the foam exhibits a different reaction state in different areas of space, an additional equation for the residence time has been solved. In this example the total expansion time is about 40 seconds and the plots show PU foam temperature in range between 40 °C and 80 °C.

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