Performance Evaluation of Fu Chang and Low Density Foam Model for Expanded Polypropylene

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ABSTRACT
Polymeric foams have several engineering and allied applications. Polymeric foam essentially being composites display complex mechanical properties and their behavior is widely affected by rate sensitivity, hysteresis, deviatoric and volumetric plasticity and stress softening (Mullins effect). Simulation based engineering and product development demands prediction of materials behavior accurately, which is quite a challenge for CAE engineers and scientists.

Increasing number of OEMs and suppliers are moving to computer simulations in the design phase to assess their future products. Hence different parameters with in FE package also play significant role and affect the results. Appropriate use of these parameters will narrow down error band and automatically reduce the cycle time and development cost. This research is focused on using simulation modeling to investigate the behavior of Expanded Polypropylene. FE Solver LS Dyna has different material models available to model the foams. Authors have selected two material models MAT57 and MAT83 and found considerable difference in output parameters. MAT83 found to be absorbing 27.83 percent more energy when compared to MAT57.

I. INTRODUCTION
Polymeric foams such as expanded polypropylene foams (EPP) are widely used in engineering and non-engineering application. Polymeric foams are lightweight and having higher energy absorbing capacity, good vibration attenuation, thermal and acoustic insulations and hence increasingly replacing the conventional materials in structural and non-structural applications like cushioning, packaging and insulation. Simulation driven product development demands for the accurate material characterization for predictable and correlated results. Extensive research work is available in terms of constitutive modeling of polymeric foams though there are many parameters involved in a simulation to achieve the correlated results and they are required to be dealt with case-to-case basis for a given material type.

Due to varied application from packaging to automobiles, there is keen interest in understanding the mechanical response when subjected to dynamic and crash loadings. Automobile OEMs have found a very attractive replacement of metal in Expanded Polypropylene (EPP). EPP is now being extensively used in bumpers and passenger safety application where material is expected to experience large multi-axial deformation at high strain rates. FE solvers are used on regular basis for product design and development. Model testing and correlation studies are performed to get suitable material models. There are so many models available yet complex behavior of foam makes the material selection a tough task. After selection of material models different option available in the FE solver, again makes it tough to get the desired results. In absence of any published result on this scenario the technique remains an individual’s skill only and demands repeated redundant effort to achieve same results. In current research authors have conducted a study showing the variation coming in results for two different material models for same material (MAT57 and MAT83 with-in LS-DYNA).

II. NUMERICAL SIMULATION
Reduced product development time and cost has always been prime mover in selection of numerical simulations. All numerical simulations were performed with LS-DYNA, a commercial nonlinear finite element analysis. Therefore in order to understand the implication of different material models on performance targets, it is necessary to quantify the difference coming in performance simulations. This in itself will automatically improve the numerical prediction for actual scenarios. The dynamic characterizations at high and medium strain rates [1] have to be investigated in experiments to provide reliable and realistic behavior laws for FEM codes. In the current research authors undertook the investigation of behavior of Expanded Polypropylene under different material models in explicit FE
Solver LS Dyna. Different output parameters like force, displacement and internal energy were observed.

A. FE Model
FE model consist of three components i.e. (a) cubic block (b) rigid floor (c) rigid impactor. Cubic block was meshed with tetrahedral solid elements of dimension 50 × 50 ×50 mm. Rigid floor and impactor were meshed with 2-D quadrilateral shell elements (Figure-1). *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_ID were used for interfacing and *CONTACT_FORCE_TRANSUDER_PENALITY_ID was used for extraction of force data.

B. Loading and Boundary Conditions
Floor is fully constrained in all degrees of freedom and made rigid hence shall not experience any deformation. Impactor was also modeled rigid and free to move in translational Z direction only. All other translational and rotational degrees of freedom were constrained. Impactor is ramped 0 to 1.35 kN (foot load) in 100msec and held constant for 25 msec. The load is applied via *LOAD_RIGID_BODY card.

C. Material Models
LS Dyna has a vast library of material models for each type of material though selection of material model largely depends on the material behavior observed during the test. Each material model was written for certain situation and one material model cannot represent all of the situations especially complex multi-dimensional loading occurring in large strain crash impact situations subjected to highly nonlinear material like cellular foam such as EPP. There are lot of material models aptly written for particular material are not used due to number of complex parameters required for modeling and calibration.

In the analysis 45g/l EPP was taken as the test material. To simulate this material two cards i.e. MAT57 (Low Density Foam) and MAT83 (Fu Chang Foam) were used. MAT57 is meant for modeling of highly compressible low density foams while MAT83 is meant for low and medium density foam with rate effects. MAT57 does not reflect any significant coupling in the transverse direction during uniaxial loading and similarly MAT83 assumes zero Poisson’s ratio and hence no coupling occurs in transverse direction. MAT57 has it origin from Storakers [2] work whereas MAT83 is the research work based on the unified constitutive equation of Fu Chang [3]. In MAT83 follows one dimensional material law where uniaxial experimental curve (compression, tension and hydro-static) can be directly used. It can be used for reversible foams without defining any complex parameters.

The material responses vary with fully integrated formulation or semi-reduced element formulation and may result in stiffer response or numerical instability. In order to avoid such issues single point element formulation with hourglass control was used.

III. RESULTS AND DISCUSSION
It is very important to carefully select and use material models implemented in FEA commercial codes. The prime challenge is to properly set parameters values and select correct material models to model material and to simulate the mechanical behavior. It must be also noted that the inherent numeric issues due to assumptions made in the implemented material model can get multiplied in the simulation and may result in large errors.
All these aspects are rarely discussed in the literature, as most of the research focuses on assuming that the cellular materials are isotropic [4-5] or focuses on developing new anisotropic material models [6-11] without concerning whether or not such a model is worthwhile applied and giving least importance to the error creeping in due to simulation parameters within the FE solver.

Displacement parameters were studied to understand the change caused by MAT57 and MAT83. These plots are shown in figure 1-3 for MAT57 and in figure 4-6 for MAT83. It can be clearly seen that MAT57 reflects higher displacement targets when compared to MAT83. While comparing the Force-Displacement and Internal Energy-Time parameters, we can see that MAT83 achieves higher values for F-D and Internal Energy-Time plots. These results were tabulated in Table 1, 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Per-cent Change</th>
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<tr>
<td>F-D</td>
<td>27.86</td>
</tr>
<tr>
<td>D-T</td>
<td>8.13</td>
</tr>
<tr>
<td>Internal Energy</td>
<td>26.50</td>
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Table 1. Percent Change Observed Between MAT57 and MAT83

Fig. 4. Force-Displacement Plot for MAT57

Fig. 5. Force-Time Plot for MAT57

Fig. 6. Displacement-Time Plot for MAT83

Fig. 7. Force-Time Plot for MAT83

Fig. 8. Force-Displacement Plots for MAT83

Fig. 9. D-T Plots for MAT83 & MAT57
MAT83 found to be experiencing 8.13 percent higher displacement during load while it absorbed 27.83 percent higher energy. Authors feel that there is a considerable difference between results obtained with two different material models for the same analysis. Among various material models available we need to carefully select the material model closer to physical scenario. Random selection of materials for foam may not yield results closer to reality and may result in stiffer response.

The flexibility of using engineering stain during material card input makes it better suited to most of the experiments as it is easier to keep engineering strain constant during an experiment. However unloading is slightly different as compared to loading as user cannot input the unloading curve and hence unloading response is appropriated from the loading curve and this makes unloading response stiffer when compared to test case. MAT57 uses only one loading curve though it can be used for loading and unloading as well. Unloading path curve is different and depends on shape parameter and hysteretic factor. MAT57 was found not so good in handling rate dependency when compared to the MAT83.

<table>
<thead>
<tr>
<th>Material Model</th>
<th>Max Displacement (mm)</th>
<th>Time (msec)</th>
<th>Max Internal Energy (J)</th>
<th>Time (msec)</th>
</tr>
</thead>
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<tr>
<td>MAT57</td>
<td>33.19</td>
<td>122</td>
<td>25.43</td>
<td>103</td>
</tr>
<tr>
<td>MAT83</td>
<td>35.89</td>
<td>125</td>
<td>32.17</td>
<td>125</td>
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</table>

Table No.-2 Maximum Displacement and Energy for MAT57 and MAT83

IV. FUTURE WORK

Correlation studies are very common though it is not easy to differentiate between the error due to wrong selection of simulation parameters and error due to experimental noise. This is largely due to lack of set procedures for characterization and which may lead to pragmatic choices rather than the factual scientific decision based on material and its behavioral characteristics. Future studies may focus on a DOE based study of simulation input parameters for different FE solvers like LS DYNA, ABAQUS, PAM-CRASH and RADIOS. This may further lead to correlation with physical results and cross correlation among the selected commercial FE solvers for development of unified product development approach.

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REFERENCES


