# Software for Creating LS-DYNA® Material Model Parameters from Test Data

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## Abstract

*LS-DYNA contains a wealth of material models that allow for the simulation of transient phenomena. CAE Modeler is a generalized pre-processor software used to convert material property data into material parameters for different material models used in CAE. In a continuation of previously presented work, we discuss the extension of the CAE Modeler software to commonly used material models beyond MAT_024. Software enhancements include advanced point picking to perform extrapolations beyond the tested data, as well as the ability to fine-tune the material models while scrutinizing the trends shown in the underlying raw data. Advanced modeling features include the ability to tune the rate dependency, as well as the initial response. Additional material models that are quite complex and difficult to calibrate are supported, including those for hyperelastic and viscoelastic behavior. As before, the written material cards are directly readable into the LS-DYNA software, but now these can also be stored and cataloged in a material card library for later reuse.*

## Introduction

A significant feature of the LS-DYNA software is its large library of material models for many diverse materials[1]. A requirement to use these material models is to obtain model coefficients or parameters, where material properties are converted into the values required by the constitutive equations. While some models are simple, most are of significant complexity and require some skill to understand how to obtain model parameters. The material properties come from performing a certain specified tests on the target material. The data is then subjected to a series of conversions to create the values or material parameters that feed the material model. When correctly identified, the material model uses these parameters to numerically re-constitute the desired material behaviors for use in the software calculations. Proper parameter identification is therefore crucial to the success of the simulation; significant error or failure of the simulation can otherwise result.

It is not our aim to cover test methods for the generation of data for different material models. Many excellent papers provide useful guidelines and reference to standard quasi-static test protocols that can be adapted for use in dynamic applications. Our intent is to cover the next step, the manner in which the test data is converted into material parameters. This process may be accomplished using direct conversion or general optimization methods. In the former, a series of mathematical transforms are used to calculate the desired parameters. The calculations are based upon established theory and serve a well-reasoned pathway to the required material parameters. Linear or multivariate non-linear regression can be layered on to fit specific parts of the material model. In all cases, the goodness of fit of each part of the material model can be assessed against raw data.

An alternate method floats all the parameters of the material model against the material property data and uses a global optimization program to arrive at the parameters. This approach is essential in cases where well-reasoned experiments cannot be created to tease out each aspect of the material model behavior. While optimization methods can yield apparently acceptable results, they carry a risk that the parameters do not have physical significance. Such models can produce non-physical results or fail when used in conditions outside the range over which the data were measured. Validation and tuning of such models against other test cases would be an essential confidence building measure.

While direct conversion cannot be used to parameterize all material models, we have found it to be the method of choice for most cases, yielding models that validate well in simulation at least against the original test data. In our initial work [2], the direct conversion approach was applied to the MAT 024 material model with good success, permitting the correct capture of plasticity and rate dependency from raw material data and the subsequent automated creation of properly formatted input files for LS-DYNA. Based upon user feedback, work on a second generation of the CAE Modeler software commenced to add capabilities for more advanced modeling. These new features make it possible to extend the software to additional commonly used LS-DYNA material models.

## Process

Because detailed guidance is often not available for parameter identification, the process becomes a subject of individual interpretation. The same input test data can sometimes be processed in different ways resulting in a variety of outcomes, some of which are equivalent. An incorrect conversion can result in lost time and debugging effort on the part of the crash analyst.

An important step prior to the parameter identification process is the measurement of relevant material data. This requires a proper understanding of the data requirements of the material model, the behavior of the material and the physical limitations of the testing process.

The input data required for the material model is usually specified in the material model documentation and in the software. As the materials get more complex, so do the difficulties associated with obtaining the right data. Many papers provide guidance on testing for various material models.

The materials being modeled by the material model are often complex and multivariate in nature, and some form of approximation is needed to correlate real life to the mathematics. These factors can have an impact on the fidelity of the simulation. A classic example of a behavioral mismatch occurs with the common use of MAT_024, a metal elasto-plasticity model, for plastics. Careful consideration must be given to quantify the errors, so that they do not mar the simulation result. Advanced material models must then be used.

Testing is often subject to physical limitations in that it is often not practical or possible to perform the tests in the manner expected from the model theory. Matters of instrument precision and traceability also come into consideration.

The material parameter conversion process follows; as described earlier as well as later on in this paper, direct conversion or general optimization methods are used. Some material models do exist that accept test data as a direct input, performing the necessary transformations within the model code; for example the work of DuBois on the Fu Chang foam model referenced in [3]. Such models are considerably easier to use. It is not always possible to have such a convenience for all material models because of the complexity and interplay that occurs between the different behaviors that the model is trying to replicate.

Many LS-DYNA material models contain options that turn on and off features of the material model. These features may be used individually or must be used in certain combinations in order to be effective. An understanding of when and how to use these options is essential to correctly model a material.

Writing the output file is a mechanical step that involves writing the data in correctly formatted manner. All required options and flags must be correctly set. LS-DYNA’s file format cascades using combinations of tables and curves to capture all the desired data. The resulting file, if correctly written will successfully read the material parameters into LS-DYNA.

Validation is s step whereby the material model is tested against the simulation. It can be performed at three levels. The unit element test runs the model against a single finite element and simply confirms that the model does not generate non-physical results. A closed-loop validation seeks to reproduce the original test that generated the material model. In the MAT-24 case, simulations of the tensile experiments would be performed to see if the original stress-strain curves are reproduced. An open-loop validation is the most difficult, where an alternate or multi-mode experiment is compared to simulation.

## Software

The CAE Modeler adopts a best practices approach based on developing an understanding of the mindset of the material model developer. Misunderstandings arising from differing use of terminology are eliminated, so that the correct material data enters the conversion process and is then processed using well-defined routines.

Based on this, the software is able to postulate a material model that expresses the underlying raw material data to the best of its ability. In the CAE Modeler user interface, the material model is presented as a mask over the underlying data so that the user can assess the goodness of fit between model and raw data. For example, in the case of the MAT_024 material model, the selected equivalent stress v. plastic strain data points are back-calculated to stress-strain so that everything can be viewed in the context of the familiar stress-strain curves.

The elastic part of the MAT_024 material model is handled via a single elastic modulus. This can be either a secant or a tangent modulus depending on how stiff a response the user requires. The software will smoothly scale the first plasticity point to be either on the stress strain curve (secant modulus calculation) or extrapolate the point of zero plasticity to the modulus line (tangent modulus calculation).

The initial fit of the modeler is limited to plasticity points up to the first maximum of the stress-strain curve with no attempt to handle regions of negative slope that can occur in the post-yield region. Using a simple point clicking process and the raw data background as a guide, the user adds additional plasticity points to the model. To account for the model requirement of a constant failure strain, extrapolation is now possible to add data points to the model that go beyond the tested data.

The MAT_024 model contains options for the modeling of rate dependency: individual plasticity curves, a quasi-static curve with a table of scale factors based upon the rate dependency of the yield stress or a Cowper-Symonds equation which describes this dependency. For each selected option, the software will compute rate-dependent stress-strain data to overlay on the raw data so that the user can obtain an estimation of goodness of fit. Error banding is now available allowing the user to visually quantify the error between the model and raw data.

Input files are written in the required formats using in the standard LS-DYNA unit systems so that the material model is now ready for use. Created files are also stored within a material card library that accompanies the software, where details of the modeling and the source material data are attached to properly document the material model for posterity.

## Conclusions

We present software for the conversion of raw material data into material parameters for LS-DYNA material models. A knowledge-based approach is used rather than a method of general optimization. The main benefit of the software is the reduction in effort of the data conversion process, eliminating errors in understanding and calculation, streamlining the creation of properly formatted material cards.

The software does not perform verification and validation (V&V), a step that can be quite beneficial in cases where the component is being subject to complex load cases. In these cases, performing a controlled experiment that accentuates the real-life deformation concerns of the project would be considered good practice and a logical step in material model parameter creation. Such experiments are not easy to perform, requiring the application of a carefully controlled load case which can be reproduced with fidelity in LS-DYNA. Digital image correlation (DIC) based surface strain measurements from the physical experiment must be compared to simulation to obtain an assessment of the fidelity of the simulation. The material model can be tuned at this stage to improve its fidelity to the real-life case. Care should be taken to note that while tuning may be beneficial to the special case, these steps may not improve the ability of the material model in the general framework.

## References

1. LS-DYNA Theory Manual (2007)
2. H. Lobo, 12th International LS-DYNA Users Conference Proceedings (2012)
3. B. Croop, H. Lobo, 7th European LS-DYNA Conference, Austria (2009).