Comparison of Calibration Strategies for Material Models of Polymers, Foam, and Composite Materials

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Abstract

The accurate calibration of materials models is crucial for simulating the behavior of materials across various industries, including automotive, aerospace, and consumer goods. With the increasing complexity of modern materials, particularly polymers, foams, and composite materials, developing reliable and efficient calibration strategies is more important than ever. This paper presents a comprehensive comparative analysis of calibration strategies for material models applied to these materials, focusing on the challenges and best practices for each material class. The study explores the calibration and validation of three specific models: the Fu Chang model for foams, the SAMP model for polymers, and composite damage models for continuous fiber-reinforced thermoplastic composites (CFRTPs). The research integrates experimental testing campaigns, such as tensile, shear, compression, and impact tests, under varying strain rates and environmental conditions, to collect detailed data that are essential for effective model fitting. For polymers, the semi-analytical SAMP model is calibrated using a combination of advanced testing techniques, including high-speed video analysis and digital image correlation (DIC), along with optimization algorithms. This approach allows for the precise characterization of strain-rate dependencies and the evolution of damage under different loading conditions. In foams, the calibration process focuses on the accurate representation of stress-strain curves and material rate sensitivity, providing valuable insight into robust calibration practices that account for dynamic loading and high-strain-rate phenomena. For CFRTPs, the study addresses material modeling at both macro and meso scales. At the laminate level, the study emphasizes the modeling of nonlinear behavior, including strain-rate effects, making the material models suitable for impact applications. At the lamina level, calibration highlights the importance of fiber orientation and interface modeling, which significantly influence the material's performance under complex loading conditions. This paper highlights the unique challenges posed by each material class, including strain-rate sensitivity, failure evolution, and the complexities involved in multi-scale modeling. It also discusses the importance of flexible calibration workflows that can adapt to different material behaviors and loading scenarios. The integration of advanced optimization tools is crucial for achieving reliable predictions in dynamic applications after the calibration process. The findings of this research offer valuable insights into the optimization of calibration

strategies and provide practical guidance for selecting the most suitable fitting processes.

1. Introduction

Material models serve as the foundational tools in simulating the behavior of materials under various loading conditions. In industries such as automotive, aerospace, and consumer goods, these models are indispensable for predicting how materials will respond to real-world stresses, strains, and environmental conditions. Accurate material modeling can help engineers make informed decisions about design, performance, and safety, reducing the need for expensive prototyping and physical testing. In particular, material models allow for the analysis of complex behaviors such as nonlinear deformation, strain-rate sensitivity, and damage progression, which are crucial for ensuring optimal material performance in dynamic applications. In computational engineering, material models are vital in ensuring that simulations reflect the real-world performance of materials, especially when subjected to extreme conditions like high strain rates, impact, or multi-axial loading. These models are utilized for structural simulations, safety analyses, and optimization tasks. For example, in the automotive industry, material models help predict how car parts will deform during a crash, providing insight into potential failure modes and energy absorption. In aerospace, they are used to simulate the impact behavior of lightweight materials in aircraft structures, while in consumer goods, material modeling aids in improving the durability and reliability of products under varying usage conditions. In the CAE sector, polymers, foams, and composites are among the most challenging and in-demand materials to simulate; therefore, this paper explores potential strategies for calibrating their models.

Polymers are widely used in many industries for their light weight, versatility, and ease of processing. However, their complex, nonlinear behavior, especially under varying strain rates and temperatures, poses significant challenges for accurate simulation. The semi-analytical SAMP model (LS-Dyna MAT187) is a powerful tool for characterizing the stress-strain relationships of polymers under dynamic loading, considering their strain-rate sensitivity and damage evolution. This paper presents a comprehensive comparative analysis of calibration strategies for these three material classes, emphasizing the integration of experimental testing, advanced data processing, and numerical optimization techniques. The research highlights the importance of flexible workflows capable of addressing diverse material behaviors and loading scenarios. By combining experimental data with robust modeling approaches, the study aims to provide practical guidance for developing accurate and reliable material models applicable to dynamic applications.

Foams, often used for energy absorption in automotive and aerospace applications, exhibit highly nonlinear behavior with unique compressive stress-strain responses. The Fu-Chang model (LS-Dyna MAT083) is tailored for simulating foam materials, capturing their rate-dependent deformation, stress plateau, and densification stages. Calibration of foam models is particularly challenging due to the complex cell structures and the rate-dependent behavior that foams exhibit under dynamic loading.

Composite materials, particularly Continuous Fiber-Reinforced Composites (CFRPs), are gaining prominence due to their excellent strength-to-weight ratio and high-performance capabilities. However, their anisotropic nature, fiber orientation, and complex failure modes—such as delamination and matrix cracking—require advanced modeling approaches. The LS-Dyna MAT058 model is specifically designed to simulate the behavior of composites, both at the lamina and laminate levels, considering their nonlinear response and failure mechanisms under different loading conditions.

Thus, this paper aims to present the calibration strategies for three LS-Dyna material models: MAT187 (SAMP) for Polymers, MAT083 (Fu Chang) for Foams, and MAT058 (Laminated Composite Fabric) for CFRPs.

2. Material Models

2.1.The Semi-Analytical Model for Polymers (MAT187)

The Semi-Analytical Model for Polymers (SAMP) is a robust constitutive material model designed to simulate the mechanical behavior of polymers under various loading conditions. Originally developed to address the complexities of polymeric material responses at DaimlerChrysler, Sindelfingen, in collaboration with Paul Du Bois and Dynamore, Stuttgart. It provides an accurate representation of the nonlinear, strain-rate-dependent, and damage-evolving behavior observed in these materials. This makes SAMP particularly suitable for dynamic applications, such as crash simulations, impact analysis, and high-strain-rate phenomena in industries like automotive and aerospace.

SAMP is built upon a semi-analytical framework, combining analytical and numerical approaches to describe polymer behavior with a balance of accuracy and computational efficiency. The model employs a isotropic C-1 smooth yield surface in the σVM-p stress space, where σVM represents the von Mises stress and p is the pressure. Key parameters of the model, are derived from experimental stress-strain data and define the yield surface's shape and size. These parameters allow the model to account for the material's dependency on hydrostatic stress, a critical factor in polymers.

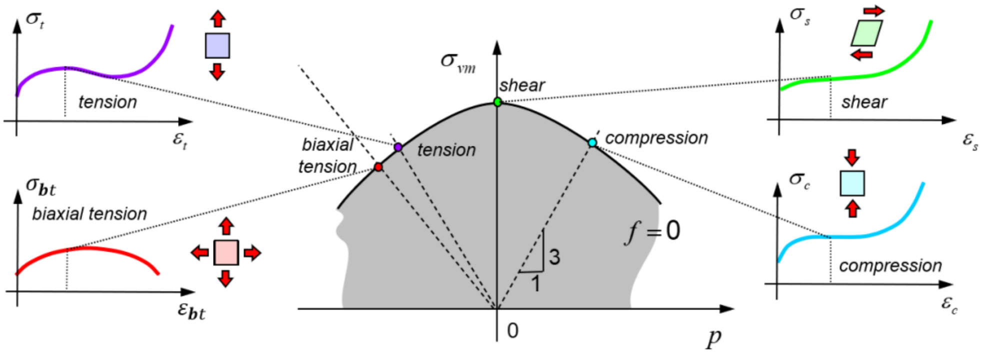

Figure 1: Von Mises stress as function of pressure. From reference [1]

The SAMP model integrates strain-rate effects through parameterized dependencies for tension, shear, and compression. This capability enables accurate simulation of polymer deformation under varying rates of strain, reflecting the material's viscoelastic nature. Additionally, SAMP incorporates a damage model to simulate material degradation and failure. The damage can be introduced via two approaches:

1. **Plastic Strain Thresholds**: Using critical plastic strain values ($\bar{\varepsilon}^p_{fail}$) to define the onset of damage and strain at element erosion ($\bar{\varepsilon}^p_{erode}$).

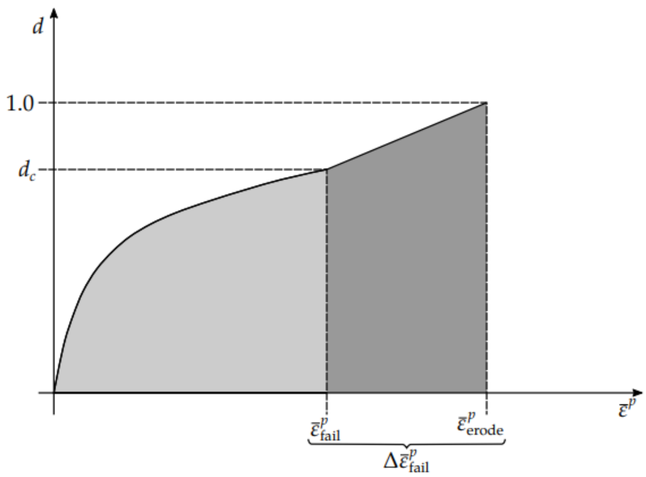

Figure 2: Plastic Strain threshold criteria for damage evolution. From reference [2]

2. **Damage Function**: A customizable function to capture more complex damage evolution mechanisms.

2.2.The Fu Chang Foam Model (MAT083)

The Fu-Chang model is a widely recognized constitutive material model designed to simulate the mechanical behavior of foam materials under various loading conditions. It is particularly effective for capturing the nonlinear, rate-sensitive, and compressive behavior typical of foam structures. Developed for applications where energy absorption and deformation are critical, the Fu-Chang model has become a cornerstone in the simulation of crash and impact scenarios, especially in industries such as automotive and aerospace.

Foam materials exhibit unique mechanical properties, including:

- A highly nonlinear stress-strain response.
- Distinct deformation plateaus during compression.
- Rate-dependent behavior.
- Low or negligible Poisson’s ratios under compressive loads.

The Fu-Chang model accounts for these characteristics through a carefully parameterized framework. Its constitutive equations define the material's behavior in terms of stress-strain relationships under compression, tension, and shear, while also incorporating strain-rate sensitivity. The model uses distinct stages to represent foam deformation:

1. **Elastic Response**: Initial linear behavior at low strains, governed by the foam's density and cell structure.
2. **Plastic Plateau**: A region of nearly constant stress as the foam cells collapse under load.
3. **Densification**: A steep rise in stress as the foam material becomes fully compacted.

The model incorporates viscoelastic and strain-rate-dependent terms to simulate the dynamic response of foam materials. These terms ensure accurate predictions of the foam’s mechanical behavior under high-speed loading.

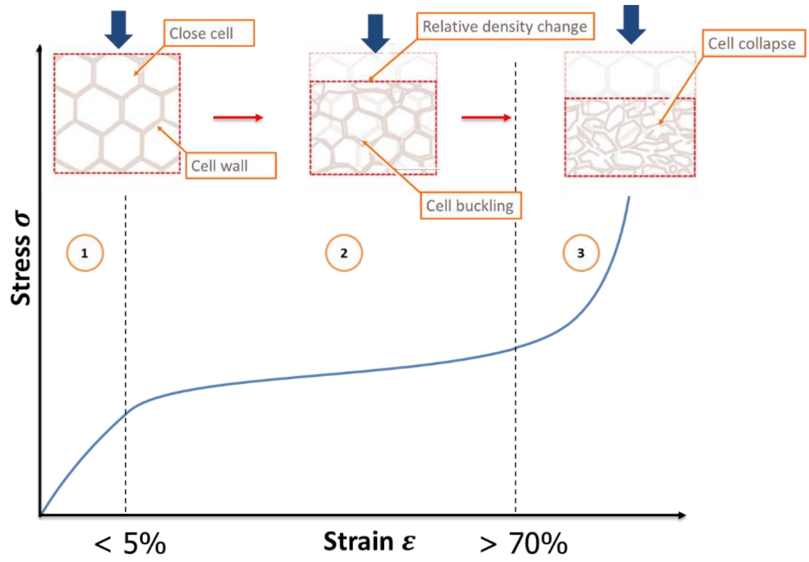

Figure 3: Compression response of foam materials. Reproduced from [3]

2.3.The Laminated Composite Fabric model for CFRP Materials (MAT058)

Continuous fiber-reinforced composites (CFRPs) are advanced materials valued for their lightweight, high-strength properties, and sustainability, making them increasingly important in automotive, aerospace, and consumer goods industries. The MAT058 model in LS-DYNA provides a robust framework for accurately simulating the mechanical behavior of CFRTPs, particularly under dynamic and multi-axial loading conditions.

MAT058 is a damage mechanics-based material model tailored for laminated composite materials, including unidirectional (UD) fiber-reinforced layers and woven fabrics. The model captures the nonlinear elastic stiffness of CFRPs, incorporating both pre-peak and post-peak behavior, as well as strain-rate effects. Its formulation includes multiple failure surfaces to address the diverse failure mechanisms in composite materials, such as fiber rupture, matrix cracking, and interfacial delamination. Key features of the model include:

1. **Nonlinear Elastic Response**:

    - The model accounts for anisotropic stiffness, representing the material's distinct behavior in longitudinal, transverse, and shear directions.

    - Strain-rate dependency is incorporated to simulate dynamic loading scenarios accurately.

2. **Damage Evolution**:

   - MAT058 integrates progressive damage mechanisms for each failure mode (e.g., fiber tension/compression, matrix tension/compression, and shear failure).
   - Post-peak softening is included, enabling the model to simulate the gradual degradation of mechanical properties as damage accumulates.

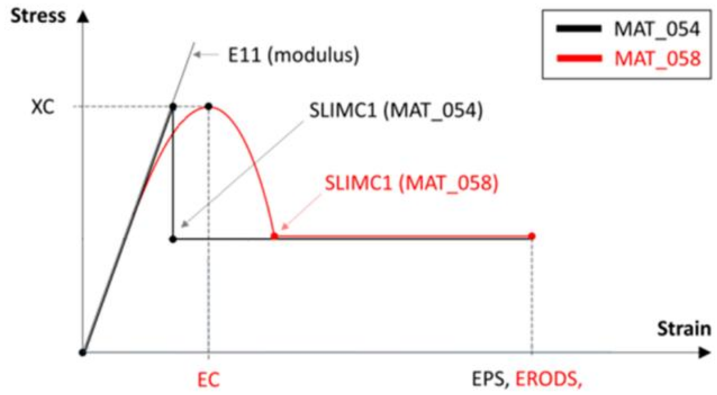

Figure 4: Damage evolution of MAT058 vs MAT054. Reproduced from [4]

3. **Element Flexibility**:

   - The model supports shell elements, thick shell elements, and solid elements, allowing for flexibility in simulating different composite structures and component geometries.

4. **Failure Criteria**:

   - MAT058 employs advanced criteria such as Chang-Chang and Tsai-Wu to predict damage initiation and evolution. These criteria ensure the accurate representation of the composite's behavior at both lamina (ply) and laminate (stacked layers) levels.

3. Calibration Processes

Calibration involves systematically adjusting model parameters to align numerical predictions with experimental data, thereby improving the accuracy of simulations under various loading conditions. Given the distinct mechanical behaviors of these material classes—ranging from the strain-rate sensitivity of polymers to the energy absorption characteristics of foams and the anisotropic nature of composites—each requires a tailored calibration approach.

3.1.The Semi-Analytical Model for Polymers (MAT187)

Experimental Data

The calibration of SAMP requires high-quality experimental data to capture the nonlinear, strain-rate-dependent behavior of polymers. The test campaign usually includes tensile, small and large notched tensile, shear, and compression experiments performed under both quasi-static and dynamic conditions. It also includes validation test such as punch or impact test and three-point bending.

To ensure accuracy, Digital Image Correlation (DIC) is employed for full-field strain measurement, while high-speed video analysis is used in dynamic testing to capture rapid deformation and failure events. Environmental conditions such as temperature and humidity may also be controlled to evaluate their influence on polymer behavior. The gathered data serves as the foundation for the subsequent model calibration, ensuring a precise representation of the material's mechanical response.

Table 1: Typical test campaign for the calibration of SAMP model.

Test Type	**Description**	**Extracted Parameters**	**Test Standard**
Tensile Test (Quasi-static & Dynamic)	Uniaxial tension test performed at different strain rates to determine stress-strain behavior	Yield stress, strain at failure, strain-rate sensitivity, modulus of elasticity	ASTM D638 (quasi-static), ISO 527-2 (dynamic)
Large-Notched Test	A notched specimen subjected to tensile or	Stress-state dependence, yield surface calibration	No universal standard, often customized

	compression loading to capture material behavior in higher triaxiality stress states	at high hydrostatic pressure	based on ASTM D638 or ISO 527
Small-Notched Test	Similar to the large-notched test but with a smaller notch radius, creating a more localized high-triaxiality stress state	Yield surface data in a wider range of stress triaxialities, failure strain at different stress states	No universal standard, often customized based on ASTM D638 or ISO 527
Shear Test	Test to evaluate shear response under different strain rates using a specimen with notches or V-grooves	Shear modulus, shear strength, strain-rate effects in shear	ASTM D5379 (Iosipescu), ASTM D7078 (V-notched)
Compression Test	Uniaxial compression to analyze polymer behavior under compressive loads at different strain rates	Compressive yield stress, modulus, strain-rate sensitivity	ASTM D695, ISO 604
Impact Test	High-speed test to assess polymer response under rapid loading, typically using drop weight or split-Hopkinson pressure bar (SHPB)	Failure characteristics and validation of model predictions	Custom test

Three-Point Bending Test	A flexural test where a polymer specimen is supported at two points and loaded at the center. Evaluates bending stiffness and failure modes	Validation of model predictions	ASTM D790, ISO 178

Calibration process

Once experimental data is collected, the next step is processing and fitting this data to construct the yield surface and define the material's strain-rate dependence. The SAMP model uses a quadratic yield surface in the $\sigma VM - p$ stress space, where σVM. The key steps in data fitting:

1. **Filtering and Smoothing**: Raw stress-strain curves are preprocessed to remove noise and ensure smooth, monotonic behavior for numerical stability.

2. **Strain-Rate Dependency Modeling**: The variation of the plastic behavior and yield stress with strain rate is captured by defining strain-rate scaling functions, typically using a power-law or logarithmic relationship.

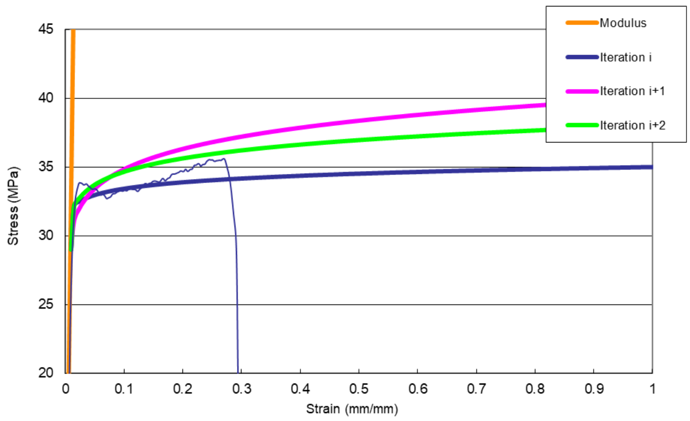

Figure 5: Iterations of the strain-rate dependency fitting process.

3. **Yield Surface Approximation**: Data from tensile, compression, shear, and notched tests is used to construct the yield surface by defining its shape in different stress states.

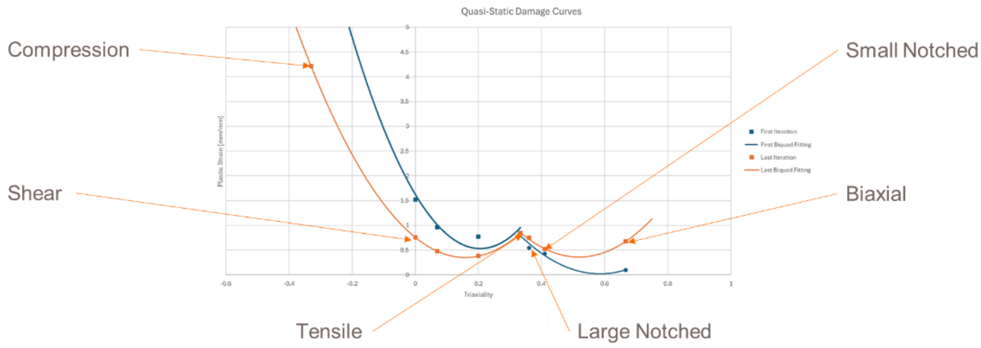

Figure 6: Iterations of the yield-surface fitting process.

4. **Failure Criteria Fitting**: Damage thresholds are determined by matching failure strains observed in experiments to model predictions.

Optimization techniques, such as least-squares regression or inverse modeling approaches, are used to iteratively refine the yield surface until simulation results match experimental data.

3.2.The Fu Chang Foam Model (MAT083)

Experimental Data

To construct an accurate foam material model, a combination of quasi-static, dynamic, and multi-axial tests is necessary to characterize the foam's mechanical response under various loading conditions. These tests ensure that the Fu-Chang model correctly simulates the foam's compressibility, energy absorption properties, and strain-rate effects. The test campaign usually includes tensile, shear, and compression experiments performed under both quasi-static and dynamic conditions. It also includes a ball drop impact test for validation.

The table below summarizes the key experimental tests required for Fu-Chang model calibration:

Table 2: Typical test campaign for the calibration of the Fu Chang Foam model.

Test Type	Description	Extracted Parameters	Test Standard

Compression Test (Quasi-Static & Dynamic)	Uniaxial compression at multiple strain rates to capture foam's stress-strain response. Identifies elastic, plateau, and densification phases	Elastic modulus, plateau stress, densification strain, strain-rate sensitivity	ASTM D575-91
Tensile Test	Uniaxial tension test performed at quasi-static strain rate to determine stress-strain behavior	Elastic modulus	ASTM D412-16
Drop Tower Impact Test	Evaluates foam's energy absorption capabilities under high-speed loading conditions.	Energy absorption, peak force, impact resistance	Custom test

<u>Calibration process</u>

Once experimental data is collected, the next step is to process and fit the data to ensure smooth, monotonic behavior for model calibration. Key steps in data fitting:

1. **Data Smoothing and Noise Reduction**: Raw experimental curves are filtered to remove noise while preserving key deformation characteristics.

2. **Strain-Rate Dependency Approximation**: A power-law or exponential function is fitted to the stress-strain data at different strain rates.

3. **Data extrapolation**: The compression curves are extrapolated linearly for tension behavior, and hyperbolically for compressive behavior.

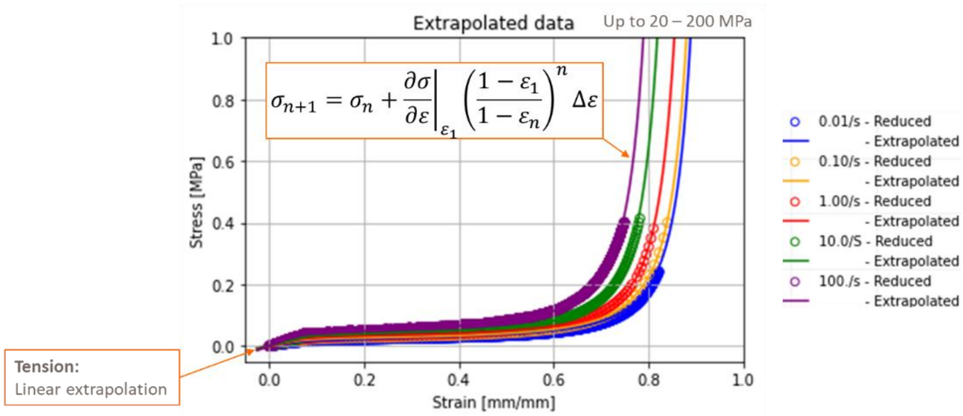

Figure 7: Extrapolation of curves during the Fu Chang model calibration.

3.3. The Laminated Composite Fabric model for CFRP Materials (MAT058)

Experimental Data

To fully characterize the composite's stiffness, strength, damage evolution, and failure criteria, a range of mechanical tests is performed on either at lamina (single ply) and/or laminate (stacked layers) levels. These tests provide key input parameters such as longitudinal and transverse moduli, shear response, strain-rate sensitivity, and damage initiation thresholds. The experimental data ensures that the MAT058 model correctly predicts fiber failure, matrix cracking, delamination, and strain-rate effects in real-world applications.

Table 3: Typical test campaign for the calibration of Laminated Composite Fabric model.

Test Type	**Description**	**Extracted Parameters**	**Test Standard**
Tensile Test (0°, 90°, ±45°)	Uniaxial loading applied in multiple fiber orientations to capture in-plane stiffness and strength.	Longitudinal and transverse Young's modulus, Poisson's ratio, tensile strength.	ASTM D3039, ISO 527-4/5

Compression Test (0°, 90°)	Uniaxial compression to evaluate fiber and matrix behavior under compressive loads.	Compressive modulus, compressive strength, failure strain.	ASTM D6641, ISO 14126
In-Plane Shear Test (±45° Tension Test)	Tension applied to a ±45° specimen to measure in-plane shear response.	Shear modulus, shear strength.	ASTM D3518, ISO 14129
V-Notched Shear Test (Iosipescu or V-Notched Rail Shear Test)	Measures in-plane shear properties of composites using a notched specimen.	In-plane shear modulus and strength.	ASTM D5379, ASTM D7078
Drop Tower Test	High-strain-rate testing to evaluate impact resistance and strain-rate sensitivity.	Dynamic stress-strain response, energy absorption, rate effects.	Custom Test
Flexural Test (3-Point & 4-Point Bending)	Measures bending stiffness and failure under flexural loads.	Flexural modulus, flexural strength.	ASTM D790, ISO 14125

Calibration process

The calibration of the MAT058 composite model requires a multi-step approach involving directional mechanical testing, advanced data fitting, and iterative parameter optimization. Key steps in data fitting:

1. **Data Smoothing and Noise Reduction**: Stress-strain curves are filtered to remove noise while maintaining key deformation characteristics.

2. **Anisotropic Stiffness Approximation**: Unlike isotropic materials, composites require stiffness characterization along different principal

directions. The elastic properties (E_1, E_2, E_3, ν_{12}, G_{12}, etc.) are determined from experimental stress-strain curves and are used to populate the stiffness matrix in the material model. Some of these parameters need to be obtained through approximations, involving iteratives processes.

3. **Failure Surface Construction**: Experimental failure stress data is used to build Tsai-Wu and Chang-Chang failure surfaces, which define fiber rupture, matrix cracking, and shear failure. Failure envelopes are constructed by plotting stress combinations from multiple test configurations and fitting them to analytical failure criteria such as Tsai-Wu, Hashin, or Puck's failure theory

Regression techniques and inverse modeling approaches are used to iteratively adjust material parameters until the numerical model aligns with experimental results.

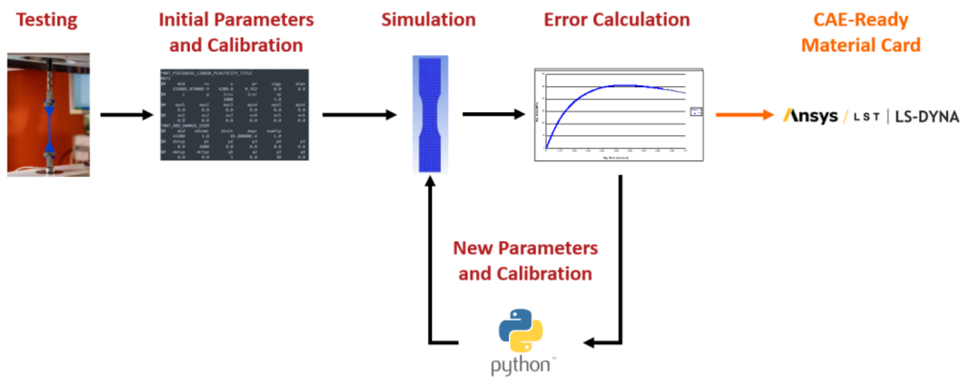

Figure 8: Iterative process for calibrating LS-Dyna MAT058.

4. Validation Process

The validation process for the SAMP model (polymers), Fu-Chang model (foams), and MAT058 model (composites) aims to verify that the calibrated material parameters allow the models to accurately predict the mechanical response of the material under various loading conditions. Each validation test is designed to challenge key aspects of the material model, ensuring its reliability in real-world applications.

4.1. The Semi-Analytical Model for Polymers (MAT187)

For the SAMP model, validation is typically performed using two key tests:

1. **Drop Test**: Evaluates the polymer's response under high-strain-rate dynamic impact.
2. **Three-Point Bending Test**: Assesses the model's ability to predict failure under multi-modal deformation states.

The drop test consists of releasing a weighted striker onto a polymer specimen and measuring the force-displacement response, energy absorption, and failure progression. The test ensures that the strain-rate dependency incorporated into the model is correctly calibrated, as different regions of the specimen experience varying strain rates during impact.

The three-point bending test applies a combined stress state (tensile, compressive, and shear), requiring the yield surface of the model to accurately describe deformation behavior across multiple loading modes. This test provides an independent validation of the yield function, damage evolution, and stiffness predictions of the model.

Numerical simulations of both tests are performed in LS-DYNA and compared with experimental load-displacement curves, failure locations, and strain distributions obtained via Digital Image Correlation (DIC).

If discrepancies are observed, iterative parameter adjustments are performed to improve the correlation between experimental and simulated results.

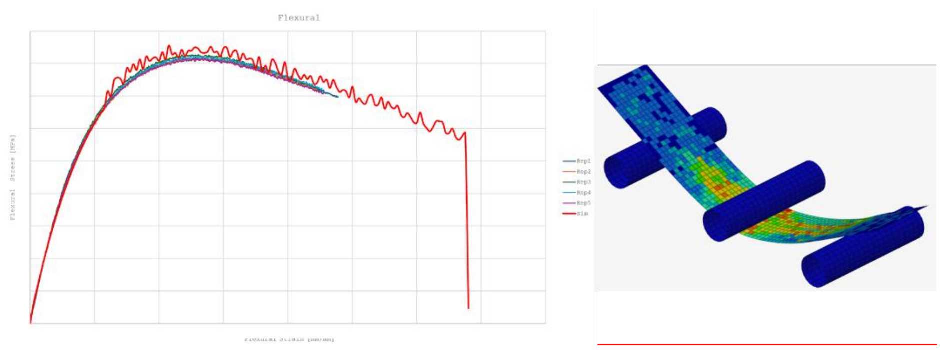

Figure 9: Validation test for the SAMP model.

4.2.The Fu Chang Foam Model (MAT083)

For foam materials, validation is typically carried out using an impact test, where a representative object size and impact energy are chosen based on the real-world application of the material. This single test effectively combines both key validation objectives:

1. **Ensuring correct strain-rate dependency**: Since foams undergo very high deformations, the strain rate varies significantly across different regions of the specimen. The model must accurately predict stress-strain response across this range of strain rates.
2. **Verifying large-strain deformation accuracy**: Foams exhibit complex stress-strain responses, transitioning from an elastic phase to a plastic plateau, and finally reaching densification. The model must correctly replicate these transitions under impact conditions.

The impact test consists of a drop-weight impactor striking the foam sample, while force, displacement, and energy absorption are recorded. The simulated response is compared with experimental results in terms of peak force, energy dissipation, deformation shape, and densification behavior.

If the model fails to capture key aspects (e.g. incorrect plateau stress or overestimated stiffness), strain-rate sensitivity parameters and densification strain values are fine-tuned.

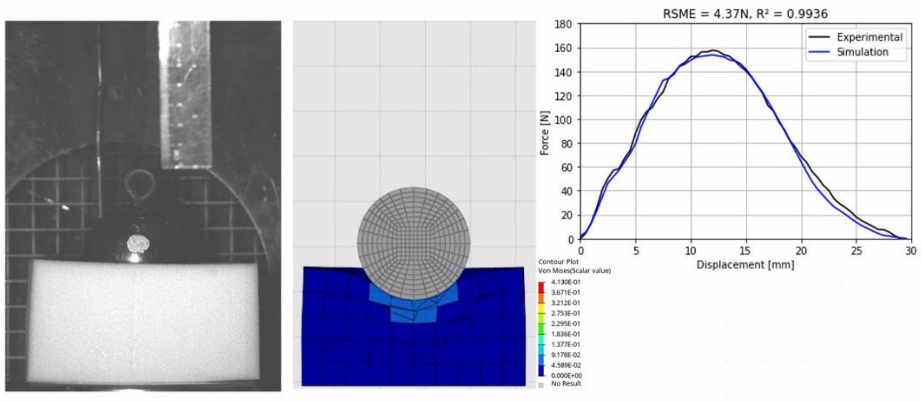

Figure 10: Validation test for the Fu Chang model.

4.3. The Laminated Composite Fabric model for CFRP Materials (MAT058)

To validate the MAT058 model, experimental results from tensile, shear, and impact tests are compared with simulation predictions. These tests cover different failure modes, including fiber rupture, matrix cracking, delamination, and interlaminar shear failure.

Tensile and shear tests are crucial in validating the stiffness, strength, and failure criteria of the MAT058 model. Whereas to validate the composite model under dynamic and high-strain-rate conditions, an impact test is conducted, typically using a drop-weight impactor or projectile test. This test is crucial because composites often exhibit brittle failure, delamination, and progressive damage under impact loads.

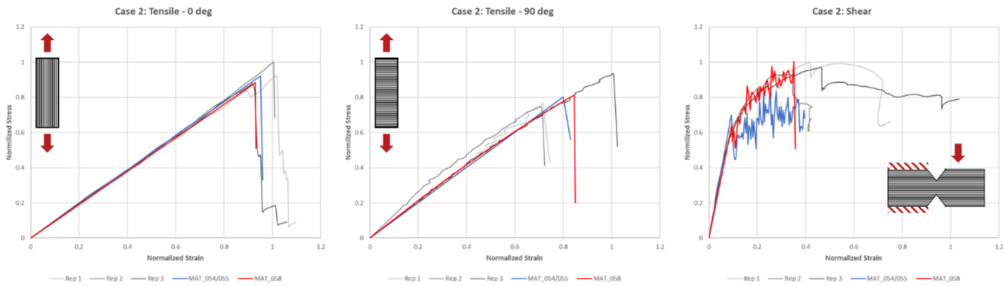

Figure 11: Validation test for CFRP models.

5. Discussions

The calibration methodologies for the SAMP model (polymers), Fu-Chang model (foams), and MAT058 model (composites) share the common objective of accurately defining material behavior for use in computational simulations. However, due to the unique mechanical characteristics of each material type, their calibration processes differ significantly in terms of experimental requirements, data fitting approaches, and parameter determination. These differences stem from the fundamental material responses to loading, requiring tailored approaches for capturing stress-strain relationships, strain-rate effects, and failure mechanisms.

One of the primary distinctions among the three methodologies lies in the experimental data collection process. Polymers, characterized by their nonlinear, viscoelastic, and strain-rate-dependent behavior, require an extensive testing campaign that includes tensile, shear, and compression tests performed at multiple strain rates. Notched specimen tests are necessary to define a more complete yield surface, ensuring that the model captures the influence of hydrostatic stress. Additionally, high-strain-rate tests, such as drop-weight impact, are essential to characterize the strain-rate sensitivity and dynamic failure mechanisms. In contrast, foams exhibit highly compressible behavior with a distinct plateau region in their stress-strain response, making compression testing the most critical component of calibration. While tensile and shear tests may be conducted, their role is secondary compared to impact tests, which provide insight into the foam's ability to absorb energy under dynamic loading conditions. Composites, on the other hand, require a completely different approach due to their anisotropic stiffness and progressive damage behavior. The MAT058 model is calibrated using tensile and compression tests in both the fiber and transverse directions, as well as in-plane and interlaminar shear tests. Impact testing is also used to evaluate strain-rate effects and dynamic failure progression, but it is primarily focused on validating the brittle fracture mechanisms and the material stiffness.

Another key difference between the three calibration methodologies lies in the data fitting process. The SAMP model, with its semi-analytical approach, requires careful yield surface construction in the von Mises stress–pressure space developed through an intensive iterative process. This process involves fitting stress-strain curves to define yield parameters while incorporating strain-rate dependency through power-law or exponential relationships. The iterative optimization process is critical in ensuring that the model correctly predicts multi-axial deformation, particularly under dynamic conditions. In contrast, the Fu-Chang model follows a different fitting approach based on defining the characteristic three-phase compression curve, including elastic deformation, the plateau region, and densification. Since foams experience significant geometric changes during deformation, data smoothing and strain-rate scaling functions are used to create a robust material representation. Unlike polymers and foams, composites require a failure surface definition using either Chang-Chang or Tsai-Wu criteria, making their data fitting process dependent on experimental failure thresholds and theoretical approximations. In addition to standard stress-strain curve fitting, delamination modeling and progressive damage evolution can be incorporated, increasing the complexity of the calibration process.

The validation stages also reveal significant contrasts in the methodologies. Polymers validation is typically conducted through a combination of drop tests, which assess the model's ability to capture strain-rate effects, and three-point bending tests, which validate multi-modal deformation response. Since foams undergo large deformations, validation is performed using an impact test with a representative sample size, ensuring that the model correctly predicts energy absorption and failure modes. Composites, on the other hand, require a more rigorous validation process, involving tensile, shear, and impact tests to confirm that the model correctly predicts fiber rupture, matrix cracking, and delamination progression.

Although each calibration methodology is distinct, they share common challenges, particularly in balancing computational efficiency with experimental accuracy. While the SAMP and Fu-Chang models require extensive experimental data to account for strain-rate effects, composites demand additional effort in modeling. In all three cases, achieving an accurate calibration requires an iterative approach, where simulation predictions are continuously compared against experimental results, and parameters are refined accordingly. The choice of validation tests is also critical in determining whether the calibrated model is robust enough to be used in practical simulations. Ultimately, the success of each calibration methodology depends on the ability to accurately replicate real-world material behavior across different loading conditions, ensuring that computational models can be effectively applied to engineering design and analysis.

6. Conclusions

This study highlights the distinct calibration methodologies required for polymers, foams, and composites, emphasizing their unique mechanical behaviors. Proper calibration enables reliable computational modeling for real-world applications such as impact resistance, crashworthiness, and structural analysis.

7. References

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