# Application of the SOFT-Factor Concept to Metallic Materials

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## 1 Abstract

Reliable crash simulation depends on accurately predicting crack propagation in metallic materials – a task that remains particularly challenging for those exhibiting intermittent fracture behavior. This study investigates crack growth in various automotive metals through compact tension tests and finite element simulations. While conventional GISSMO-based models effectively capture continuous crack growth, they fail to reproduce abrupt propagation in press-hardened steels. To address this limitation, the SOFT-Factor is introduced as a softening mechanism within the GISSMO framework. Calibrated against experimental data, the SOFT-Factor significantly improves simulation accuracy for intermittent crack growth. Its successful application to sled test simulations confirms its potential to enhance predictive capabilities using standard crash meshes, offering a practical solution for industrial crash modeling.

## 2 Introduction

Accurate prediction of crack initiation and propagation in metallic materials remains a critical challenge in crash simulations. While material models in modern finite element solvers – such as those implemented in LS-DYNA using the GISSMO damage model – are effective in capturing damage evolution and crack initiation, they often fall short in accurately representing the full extent of crack propagation, particularly in press-hardened steels.
This study is motivated by a significant discrepancy observed between experimental results and simulation predictions in sled tests of side-impact structures. Specifically, the simulation fails to reproduce the crack path observed in the B-pillar, a component made of press-hardened steel, despite employing a state-of-the-art material card and standard crash mesh. This mismatch is illustrated in fig. 1, where the experimental crack path can only be sketched schematically due to company legacy restrictions. The discrepancy highlights the limitations of current modeling approaches and underscores the need for enhanced simulation techniques capable of reliably predicting crack growth behavior.

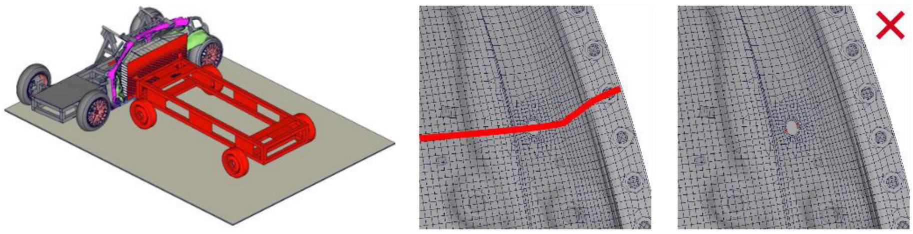

*Fig.1: Comparison of experimental and simulated crack behavior in a B-pillar during a side-impact sled test*

To address this challenge, a series of compact tension tests are conducted on various automotive metallic materials, including non-heat-treatable and heat-treatable aluminum alloys, high-strength steels, and press-hardened steels. This paper presents the experimental methodology and simulation setup used to study crack propagation behavior in these materials. Additionally, the SOFT-factor concept is introduced and successfully implemented, offering a practical solution for predicting intermittent crack growth.

## 3 Experimental Investigations on Crack Propagation

Understanding crack propagation behavior in metallic materials is essential for improving the predictive accuracy of crash simulations. To isolate and analyze this phenomenon, a series of controlled experiments are conducted using compact tension specimens. These tests provide valuable insight into the initiation and growth of cracks under tensile loading and serve as the basis for subsequent simulation and modeling efforts.

## 3.1 Compact Tension Test

To investigate crack propagation at the coupon level, compact tension specimens are employed because they effectively isolate crack behavior from other structural influences. Each specimen features a sharp notch to ensure consistent crack initiation under tensile loading, as illustrated in Fig. 2. After evaluating different notch radii, a radius of 0.2 mm is selected for all tests, as it provides the most reliable and reproducible results.

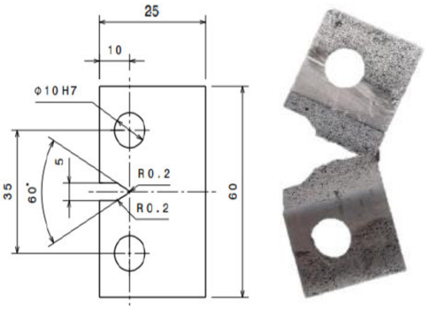


*Fig.2: Geometry of the compact tension specimen and the deformed sample used in crack propagation studies*

During testing, the specimens are subjected to tensile loading until crack initiation occurs. Two key response curves are recorded: the force–displacement curve, which indicates the load level at crack onset, and the crack length–displacement curve, which characterizes the crack growth behavior after initiation. These data enable a detailed assessment of whether crack propagation occurs in a continuous or intermittent manner—a distinction that is critical for subsequent simulation modeling.

## 3.2 Experimental Results

Six metallic materials commonly used in automotive applications are examined in this study: the non-heat-treatable aluminum alloy AL5083, the heat-treatable aluminum alloy TL116-N24, the high-strength steel DP600, and the press-hardened steels MBW1500-HV240, MBW1500-HV490, and MBW1900. The experimental results, illustrated in fig. 3, present force-displacement and crack-length-displacement curves for all tested materials.
The tests reveal two distinct types of crack propagation behavior. Materials such as the non-heat-treatable aluminum alloy AL5083 exhibit continuous crack growth, characterized by a smooth and gradual crack extension. In contrast, materials like the press-hardened steel MBW1900 display intermittent crack growth, where the crack length increases abruptly after initiation. This classification is visualized in fig. 4 by plotting curves with intermittent crack growth in red and those with continuous growth in gray.

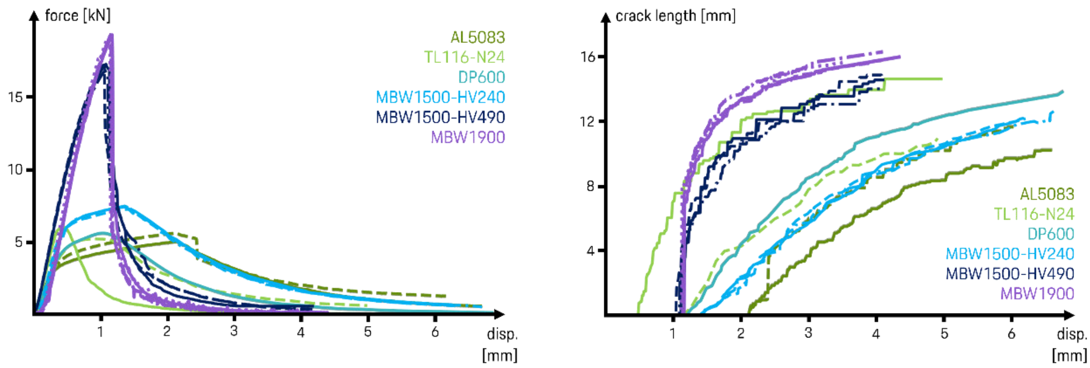


*Fig.3: Comparison of compact tension test results for non-heat-treatable and heat-treatable aluminum alloys, high-strength steel and press-hardened steels*

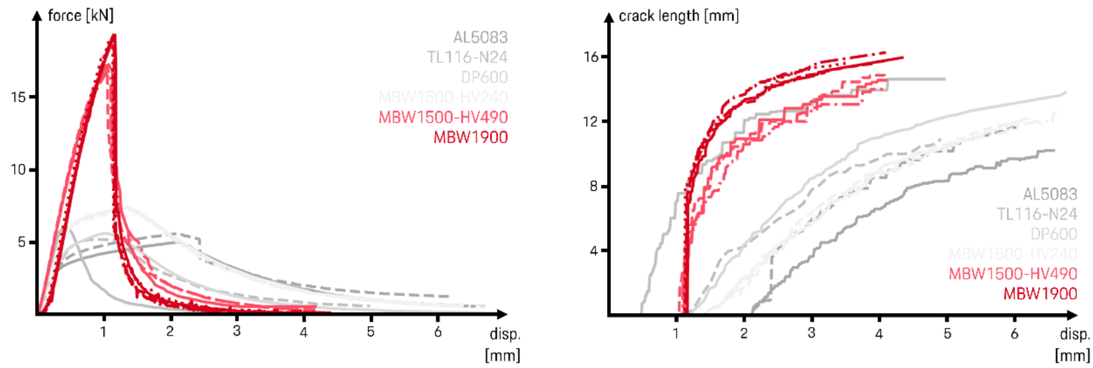


*Fig.4: Test result classification according to crack propagation behavior*

To further analyze these behaviors, the materials are plotted in a tensile-strength-versus-uniform-elongation diagram. This representation confirms that materials with higher tensile strength and lower ductility tend to exhibit intermittent crack growth, whereas softer and more ductile materials show continuous crack propagation. These observations are consistent with engineering intuition and provide a valuable basis for distinguishing material behavior in subsequent simulations.

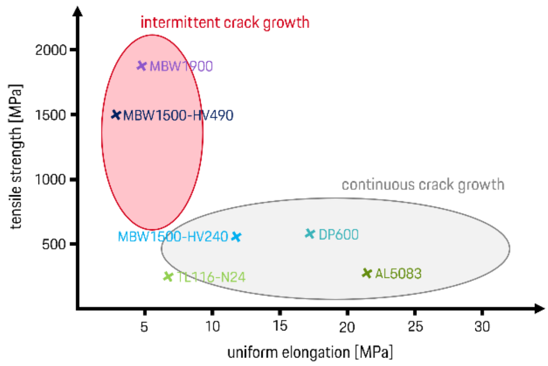


*Fig.5: Classification of metallic materials with intermittent and continuous crack growth behavior*

## 4 Crack Propagation in Finite Element Simulations

To complement the experimental investigations, finite element simulations are conducted to replicate the crack propagation behavior observed in compact tension tests. These simulations aim to evaluate the predictive capabilities of existing material models and identify limitations in modeling intermittent crack growth.

### 4.1 Finite Element Model of the Compact Tension Test

A detailed finite element model of the compact tension specimen is developed to accurately represent the experimental setup, as illustrated in Fig. 6.

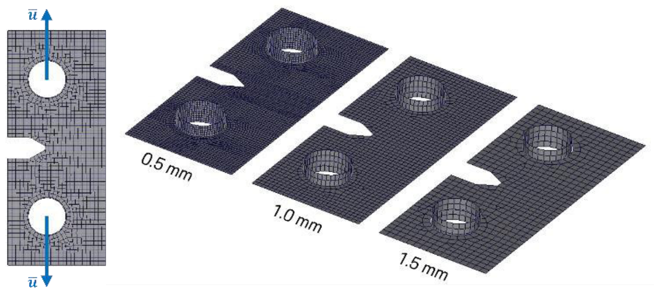


*Fig.6: Finite element model of the compact tension test with mesh sizes of 0.5 mm, 1.0 mm and 1.5 mm*

The specimen geometry, including the 0.2 mm notch radius, is modeled with high precision. Boundary conditions are defined to replicate the tensile loading applied during the experiments, and particular attention is paid to the contact interactions between the specimen and the fixture, which are critical for ensuring simulation accuracy.

## 4.2 Material Modelling for Metallic Materials

The material behavior is modeled using standard LS-DYNA material models for metallic materials. The **`*MAT_PIECEWISE_LINEAR_PLASTICITY`** model describes the elastic–plastic response based on isotropic Von Mises plasticity, while the **`*MAT_ADD_DAMAGE_GISSMO`** model captures damage evolution and failure, incorporating features such as instability curves, failure curves, and regularization. All material parameters are calibrated through an in-house parameter identification procedure, resulting in material cards that belong to a state-of-the-art database employed in all full-car crash simulations.

## 4.3 Comparison of Experiments and Simulations

Simulation results are compared with experimental data for all six tested materials. For ductile materials such as AL5083, the simulations show strong agreement with the experimental force–displacement and crack length–displacement curves, accurately capturing both the onset of cracking and the subsequent propagation behavior (see fig. 7).

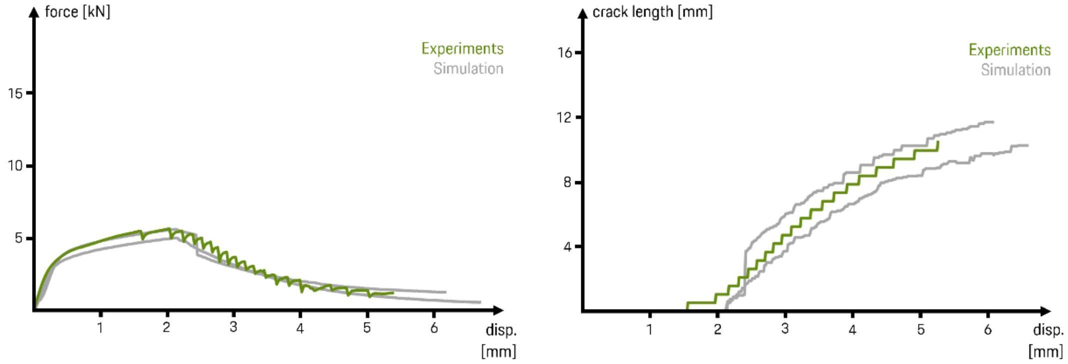


*Fig.7: Comparison of experimental and simulated compact tension test results for AL5083 non-heat-treatable aluminum alloy*

In contrast, for brittle materials such as MBW1900, the simulations fail to reproduce the abrupt crack growth observed experimentally. Although the force level at crack initiation is correctly predicted, the evolution of crack length deviates significantly, particularly during the early stages of propagation (see Fig. 8).

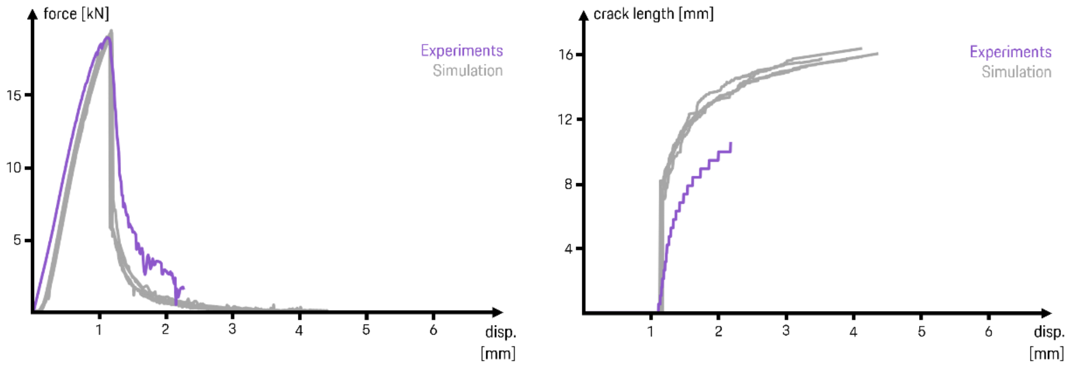


*Fig.8: Comparison of experimental and simulated compact tension test results for MBW1900 press-hardened steel*

This discrepancy highlights a fundamental limitation of the standard GISSMO-based modeling approach: while continuous crack growth can be simulated effectively, intermittent crack propagation remains challenging to capture.

## 5 Enhanced Material Modelling with the SOFT-Factor

The simulation results reveal a clear limitation in modeling crack propagation for materials that exhibit intermittent fracture behavior. To overcome this, the SOFT-factor is introduced as an extension within the GISSMO framework, offering a mechanism to enhance damage evolution in finite element simulations.

### 5.1 SOFT-Factor Concept

The SOFT-factor functions as a softening reduction coefficient that scales the failure strain of so-called crashfront elements – those directly neighboring elements that have already failed. By locally reducing the failure strain, the SOFT-factor facilitates additional damage accumulation, ultimately leading to earlier element failure without affecting the onset of cracking. In its standard configuration, the SOFT-factor is defined as a scalar value between 0 and 1, where a value of 1.0 represents an inactive state with no scaling applied. Lower values increase the degree of softening, thereby accelerating damage accumulation in neighboring elements. The factor can be applied uniformly or made dependent on parameters such as triaxiality and element size using the LCSOFT keyword.

### 5.2 Calibration and Application of the SOFT-Factor

To ensure the SOFT-factor contributes meaningfully to crack propagation modeling, its calibration relies on experimental data obtained from compact tension tests. The process involves adjusting the factor iteratively until the simulation reproduces the distinct jump in crack length observed in brittle materials. Fig. 9 illustrates this calibration for the press-hardened steel MBW1900. A SOFT-factor value of 0.3 provides the closest match between simulation and experiment.

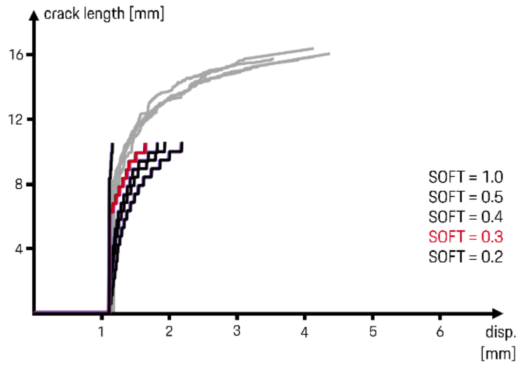


*Fig.9: Iterative SOFT-factor calibration process for MBW1900 press-hardened steel*

Once calibrated, the SOFT-factor is applied to sled test simulations. The previously observed discrepancy between experimental crack paths and simulation results disappears. As shown in fig. 10, the predicted crack path now closely mirrors the experimental outcome, even when using a standard crash mesh. This confirms that the SOFT-factor significantly enhances the material model's ability to simulate crack propagation and improves the overall reliability of crash simulation predictions.

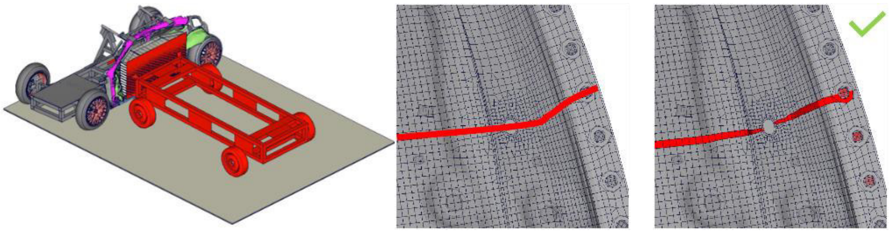

*Fig.10: Comparison of experimental and SOFT-factor-enhanced simulated crack behavior in a B-pillar during a side-impact sled test*

## 6 Conclusion

By introducing and calibrating the SOFT-Factor within the GISSMO framework, the limitations of conventional modeling in predicting crack growth are effectively overcome. The SOFT-Factor enables localized softening in crashfront elements, thereby accelerating damage accumulation and promoting realistic crack propagation. For the press-hardened steel MBW1900, a SOFT-Factor value of 0.3 provides the best agreement with experimental results from compact tension tests. The successful application of this calibrated SOFT-Factor to sled test simulations further confirms its effectiveness, as the enhanced model accurately reproduces experimental crack growth using a standard crash mesh. This approach significantly improves the reliability of finite element predictions in crash scenarios and provides a practical solution for integrating more realistic fracture behavior into industrial crash simulation workflows.

## 7 Literature

[1] LS-DYNA Keyword User’s Manual Volume II, R12, Livermore Software Technology, 2020