# Sonic weld characterization and FEA modeling method development for automotive applications

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## 1 Introduction

Joining is a critical part of any structure for transferring load and maintaining integrity for the product. Ultrasonic weld is one of the popular methods for joining plastic parts in automotive industry. Along with providing a visually demanding finish, the method has been established for tight, strong, and dimensionally accurate joints. With the increase of complexity and integration of electrical and sensing instrumentation in autonomous and electric vehicles, sonic weld provides a necessary means of attaching plastic parts without compromising visual impact. However, the sonic weld performance is yet to be quantified, and the criteria for capturing weld separation, and losing this connected load path during structural vehicle analysis, has not been studied extensively. Sonic welds, even though it is a very effective joining method, the whole tooling process is expensive and time consuming. Ideally, to optimize the welding spot number and develop future cost-effective welding methods, it is crucial to understand the actual weld performance under several variables such as material type, temperature, strain rates, etc.

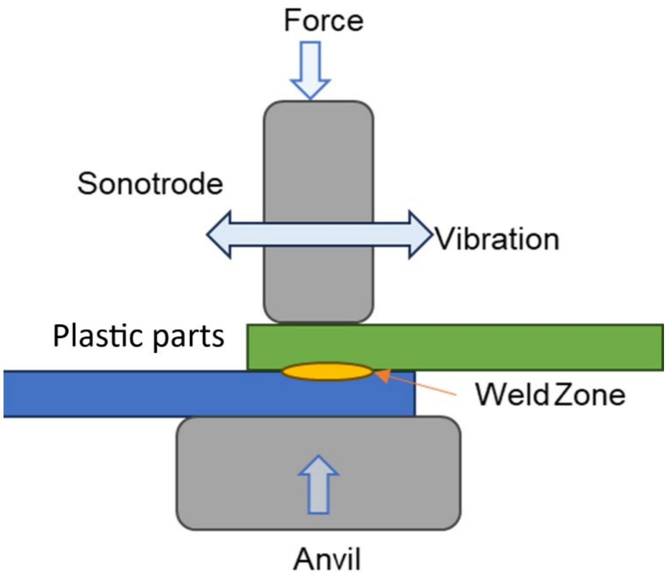


*Fig.1: Sonic welding setup schematic*

To join a plastic part such as brackets to the back of A-surface components like facias, spoilers, and exterior trim components, sonic welding is one of the most important joining processes. In this method, a sonotrode with some needles at the end is vibrated with frequencies between 20 to 40 KHz. Unlike regular ultrasonic welding, this method does not create any marks on the A-Surface. Therefore, the application of this method is growing very fast with the developments in autonomous and electric vehicles. However, predicting the sonic weld behavior under various loading like, thermo-mechanical loading in spoilers and impact loading in bumper fascia assembly has been challenging. This is due to the lack of accurate finite element analysis (FEA) techniques for sonic welds in plastic components and is the main purpose behind this project. In the spoiler applications, thermal expansion of joint materials affects the stresses around the sonic welds. In the impact loading for bumper fascia, the brackets welded to the fascia undergo a large deformation which may result in separation of sonic welded joints. Accurate modeling of these sonic weld joints will help better predict the stress and resulting failure modes in these components. This study is aimed to develop a correlation between test and finite element-based predictions.

## 2 Physical test

Understanding the behavior of joints and developing respective failure criteria is challenging. It becomes more challenging in the case of sonic welding since the method changes the parent material properties as the localized high temperatures affects the corresponding phase or/and crystal structure. The redistribution of material property in micro level due to the temperature distribution. The mechanical property of welding is highly process parameter dependent [1].
To characterize the physical performance, two lap shear configurations have been studied (Fig.2). The coupon geometries for testing strength of sonic welds in lap shear vertical (LSV), and lap shear parallel (LSP) were tested at three different temperature levels were. Three major exterior materials (ABS, ASA, TPO) have been studied with three different temperatures (-35˚ C, 23˚ C and 85˚) C and with three strain rates (10 mm/min, 100 mm/min, 750 mm/min) for each respective combination. The variation of the peak load and the ultimate displacement have been studied and compared.

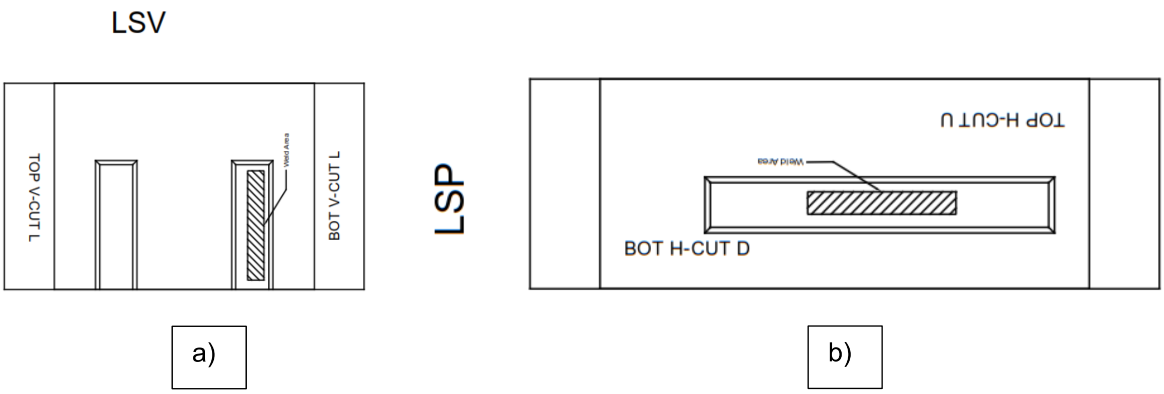


*Fig.2: Geometric configurations for sonic weld coupons a) Lap Shear Vertical, b) Lap shear Horizontal*

## 3 Joint characteristics

The peak load and the displacement at failure are two important information for joint characterization. The sensistvity study of this data on different parameters is necessary to understand the joint response on various loading and is an important input for the traction calculation. From Fig.3 it can be observed clearly that, the displacement at peak load was mostly found very close to the displacement at failure which indicates linear traction separation joint characteristics .

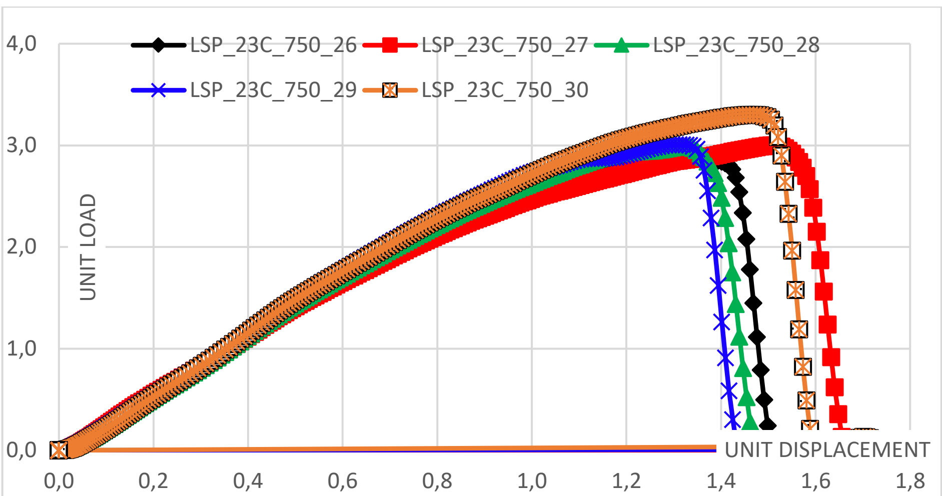


*Fig.3: Load Vs. displacement profile for lap shear parallel loading for ABS-ABS sonic weld joint (at room temperature at 750-unit test speed)*

Generally, materials with less than 5% elongation, is considered as brittle [2]. All the joint tests displayed a failure that was within the brittle domain as shown by the small displacements at peak value loads.

Also, the toughness was found to be lower than the parent material. The trend is unlike to the original parent materials which show significant elongation before reaching to ultimate failure plastic strains. The brittleness indicates a significant change in material properties due to the sonic welding process. From the physical test data, for the majority of the lap shear coupons in different materials, it has been observed that the peak load increases slightly with the increase of test speed (Fig.4 to Fig.7).

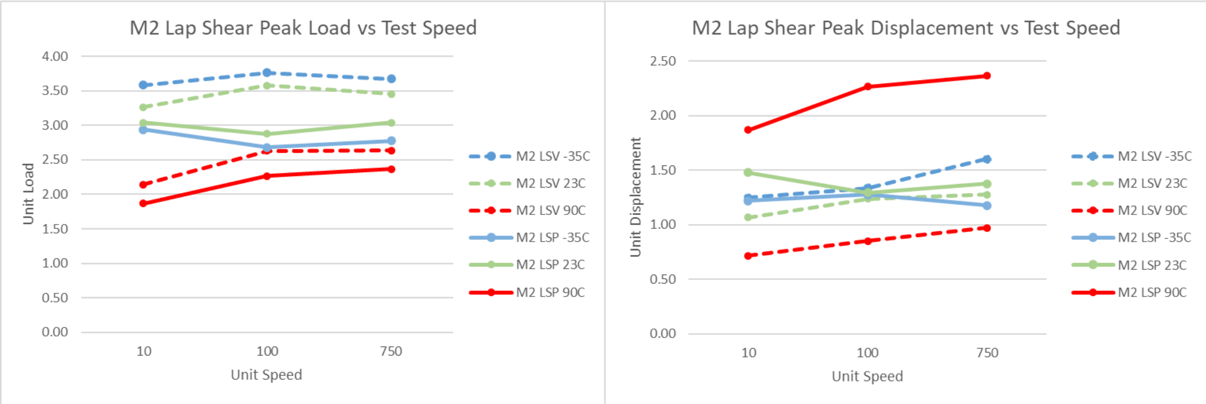


*Fig.4: M 2 – ABS- ABS Peak Load vs. Test Speed*

For different temperature conditions, it is observed that the sonic weld lap shear peak load and displacement values are different. The changes in displacement values in the coupons are small and indifferent of the material type (Fig 4 to 7). However, the peak force values across different material combination of sonic weld joints are different which indicates the need of seperate material cards for temperature variations.

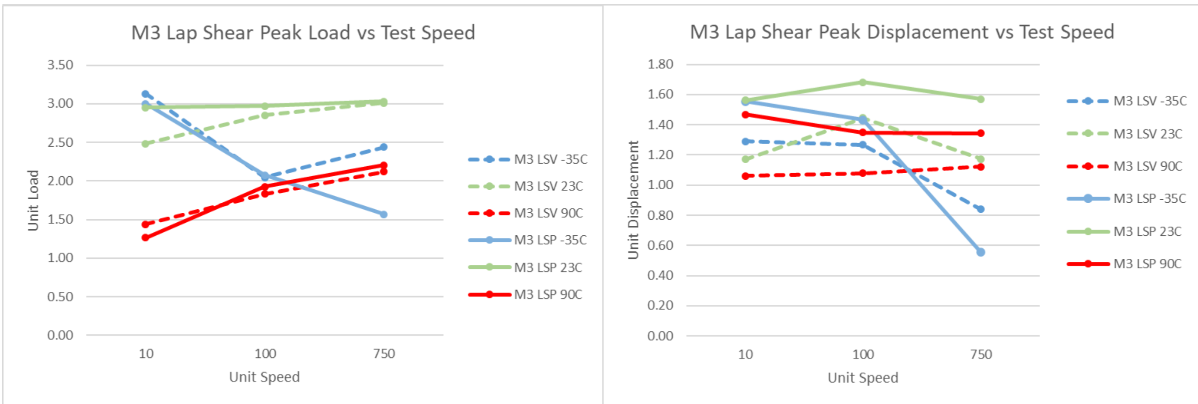


*Fig.5: M3 - ABS ASA Peak Load vs Test Speed*

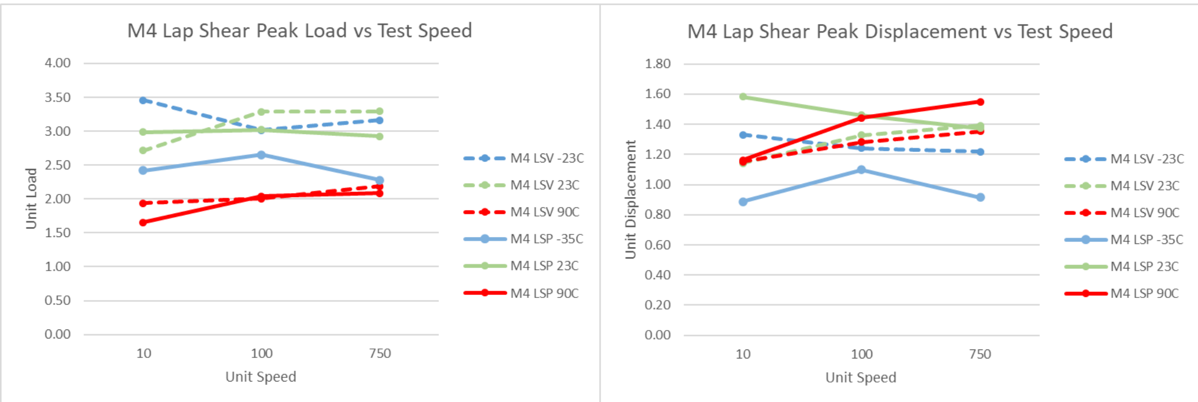


*Fig.6: M4 - ABS ASA Peak Load vs Test Speed*

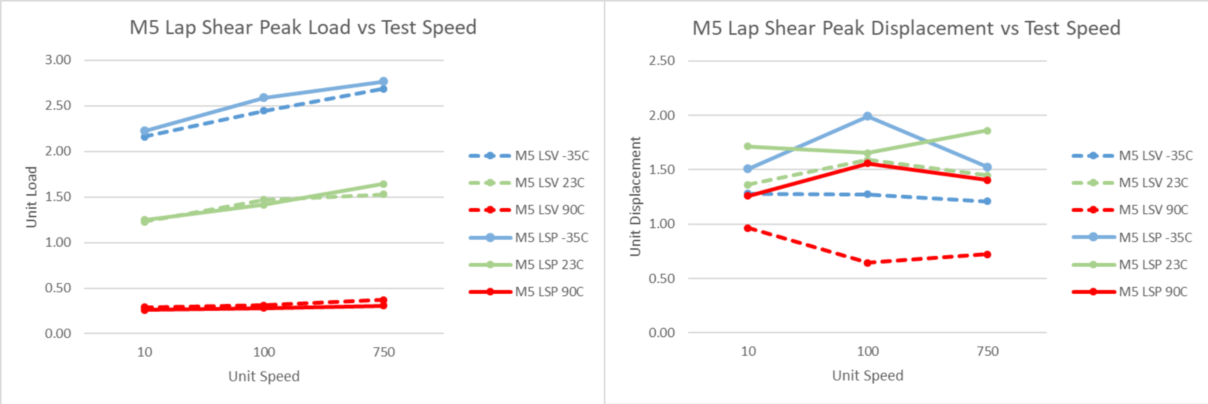


*Fig.7: M5 – TPO-TPO Peak Load vs Test Speed*

Fig.7 shows a typical TPO lap shear joint behavior and indicates relatively lower peak load than other joints. The difference in peak load at different temperatures are significantly different to other temperatures as well. However, the displacement at peak load is indifferent across the speed of test.

## 4 Joint modeling method

The effect of different parameters such as temperature, strain rate and material have been studied in terms of load and deflection values for same geometric configurations. In many literatures the energy approach for defining the failure criteria is common for joints [3]. In this specific sonic weld joint, as it is confined in some specific points, discontinuity is common and the empty space between the joining points can be considered as a crack (Fig. 8)

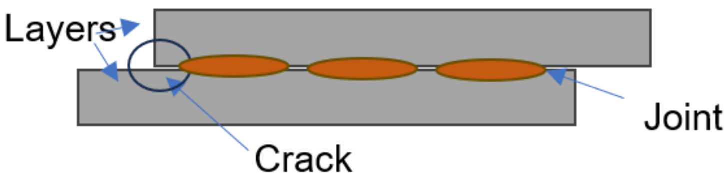


*Fig.8: Existing discontinuity in a joint*

In the proposed method, it has been hypothesized that the joint between two plastic plates can be addressed as separation of planes in a laminated setting. The separation of laminated layers is often characterized by modes in fracture mechanics in energy-based prediction method. Modes of fracture refers to the decomposition of crack tip stresses into three loading condition (tensile, shear and tear). However, before developing an energy-based prediction criteria addressing different loading modes, it is necessary to understand the traction and separation response type of the joint in each mode. There are different material models present in the commercial solvers such as: linear, bilinear, trilinear, trapezoidal, normalized traction separation laws etc., for describing the traction and separation. Based on the test data it was observed that the ductility portion after the peak load is less evident and the traction separation mostly followed linear pattern.

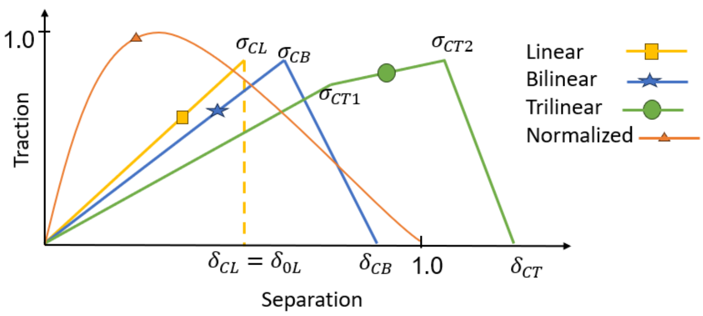


*Fig.9: Traction separation modeling laws for joint characterization*

### 4.1 The proposed FEA method for sonic weld

The actual sonic weld is basically realized into few electrode locations in an indented surface (Fig. 10). The weld features are tiny and inconvenient to be modelled in a real form for a production full vehicle model. To minimize the element modeling and computation cost, the detailed geometric and material modeling of sonic weld is inappropriate.

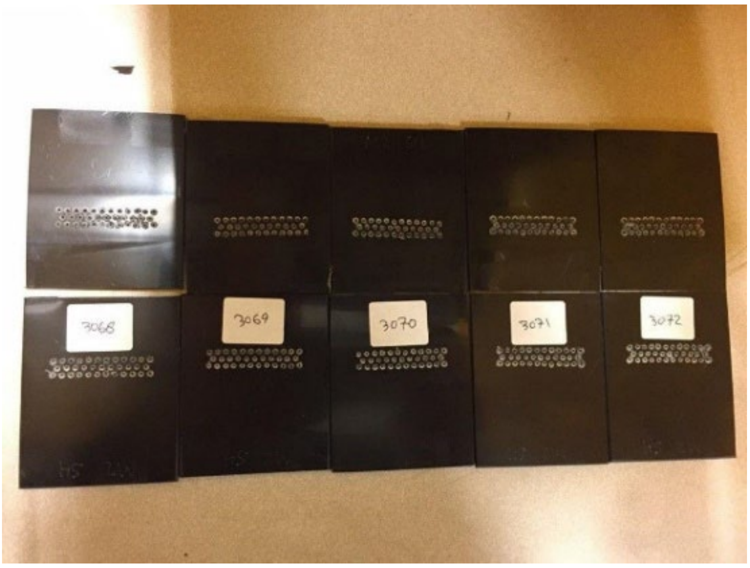


*Fig.10: Sonic weld in coupons after test*

In the proposed method, a layer of solid cohesive elements has been considered between two joining surfaces to represent joint. The explicit solver LS Dyna has been used for this study. Shell elements with a mesh size of 5 mm have been considered for parent material with regular MAT 24 definition. Additionally, the failure criteria were defined in the weld material instead of the contact. The material properties were estimated from the physical test data reflecting the joint behavior. The tied contact *CONTACT_TIED_SHELL_EDGE_TO_SURFACE_CONSTRAINED_OFFSET has been considered between weld and parent materials. The lap shear coupons were selected for the assessment. The loading point offset between two parallel plates was neglected, considering the loading mode as pure shear. The traction value in tangential direction was calculated from the test and was used in the material model accordingly. The geometry of the cohesive zone and the modulus of elasticity effectively contributes to the joint stiffness in the simulated structure. The stiffness of physical test joint data was used for estimation of the material stiffness of the cohesive elements.

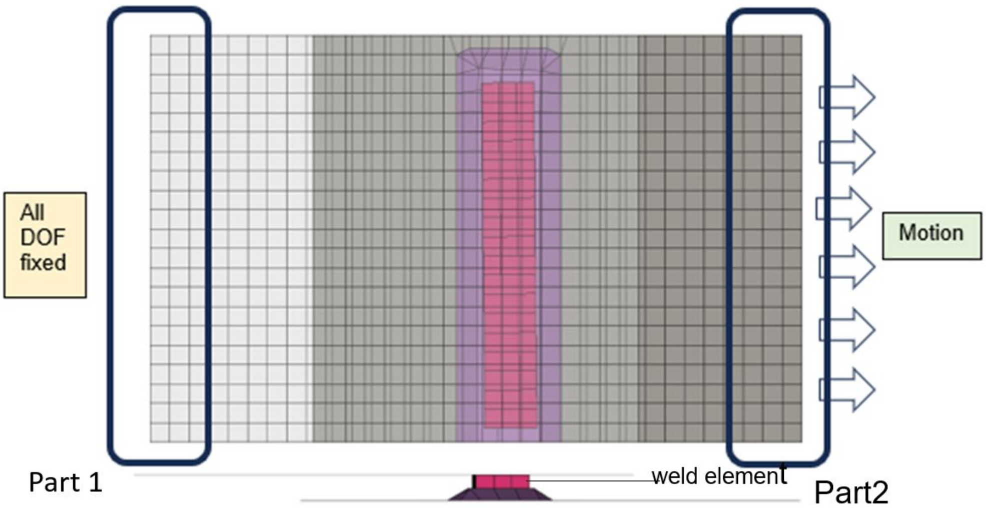


*Fig.11: LSV coupon FEA model*

### 4.2 Simulation results

Mat 138, Mat184 and Mat 186 [4] was studied for predicting the joint behavior of the sonic weld. The simulated load vs. deflection results are shown in Fig.12. It is evident that the finite element model is under-predicting peak force and slightly above average deflection values compared to the physical test values. The tangential traction value input for Mat 184 is one of the key parameters in this modeling approach that was used from the physical test data. Mat 138 was checked for predicting the joint behavior as well. The traction value calculated for lap shear parallel and lap shear vertical configurations are different. However, to minimize the variability and to apply the material card for any kind of loading the average value of the stiffness and traction is recommended to be used. The simulation model showed better predictability in the in terms of peak load observed in the physical test however the displacement at the peak load is slightly over predicted. The overall stiffness of the joint is predicted less than the actual stiffness. It indicates the joint behaved stiffer than the estimated cohesive material stiffness in the simulation.

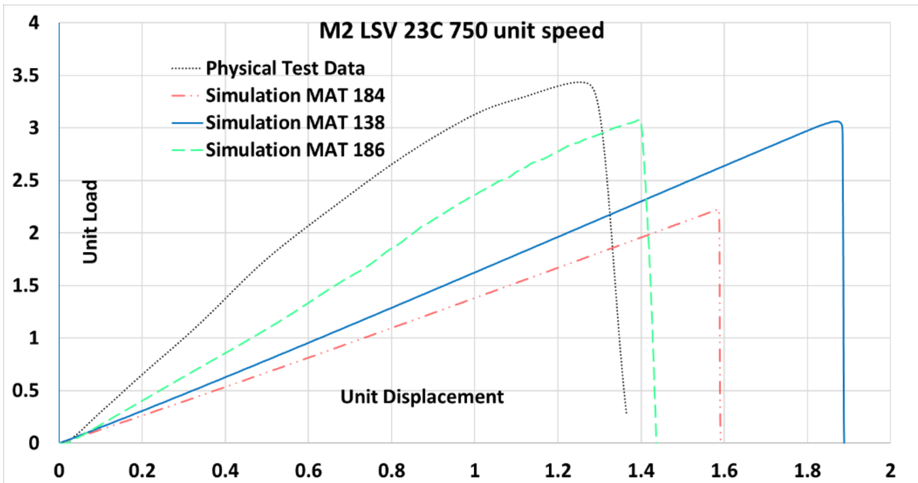


*Fig.12: Material 2 Lap Shear Vertical ABS - Test vs CAE correlation*

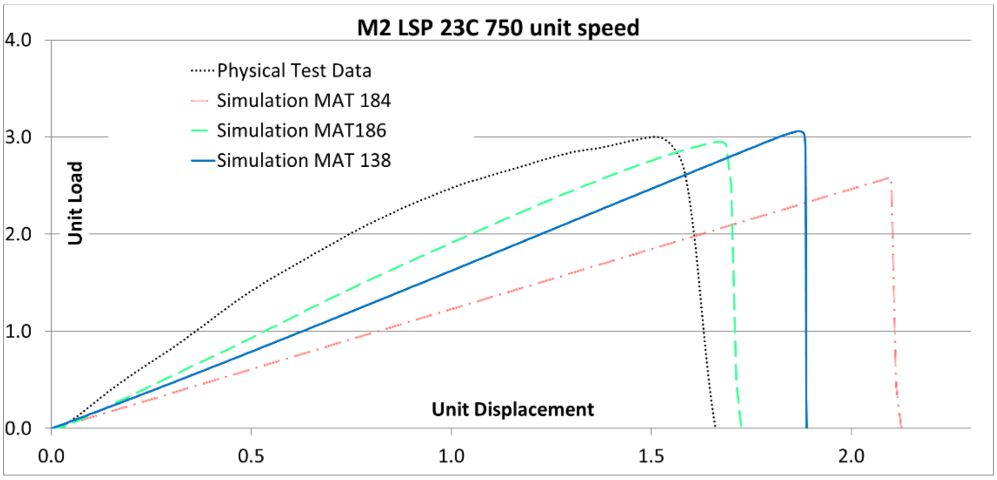


*Fig.13: Material 2 Lap Shear Parallel ABS - Test vs CAE correlation*

## 5 Summary

In this study, the sonic weld physical performance was evaluated for four different material combinations, three different strain rates and three different temperatures. Based on the analysis, a fully characterized FEA sonic weld modeling method was developed, which captures weld separation, for in-production parts joined with sonic weld failure criteria. The results show high fidelity of the model predicting the joint behavior at high speed and room temperatures. This method can be applied on full vehicle level analysis, like front and rear low speed, and enables for optimized design by determining an ideal number of sonic welds necessary for this type of structural loading. The future scope of this project is to implement the scheme into mixed-mode loading and verify the test CAE correlation. In the case of bilinear and trilinear joint behavior, a different material type will need to be utilized. Additionally, this project only investigated rectangular sonic welds, but it is recommended to study the behavior and prediction of circular sonic welds in future studies. This study mainly shows shear behavior of the sonic weld. For full characterization it is recommended to understand normal directional characteristics as well. Fatigue characteristics of the joint also need to be explored as well as the variation of the process conditions and their effect on the sonic weld performance.

## 6 Literature


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