Improvement in predictive capability of smalloverlap crash simulation with emphasis on GISSMO material model, weld rupture and detailed modeling

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1 Abstract

CAE tools are one of the best techniques in the auto industry to drive design and help product development with minimal physical tests. Physical tests are very time consuming and expensive which is driving the auto industry towards virtual simulations to replace physical tests. CAE has become an integral part of product development to accurately predict physical testing and drive design direction. For CAE to accurately predict the physical test, it depends on details captured in the full vehicle model. In the small overlap load case, it is necessary to capture as much details as possible for the components engaged during the impact event. However, capturing too much detail leads to prohibitively large models with excessive computational time. So, it is important to understand the load path to decide the critical vehicle components which play a vital role in the crash event. This includes the sheet steel/aluminum stamped parts, aluminum extrusion, fasteners and welds. In this paper an attempt was made to revisit the modeling of these critical vehicle components and later confirm the performance with respect to the physical test.

The sheet steel/aluminum stamped parts and also the aluminum extrusions were finely meshed and GISSMO material models were implemented to define their rupture behavior. The fasteners (bolts) were modeled using solid elements. The spot welds were modeled as solid nuggets with damage material model MAT_SPOTWELD_DAIMLERCHRYSLER and a simple elegant technique was used to define aluminum MIG welds. The MIG welds join thick aluminum parts in the load path. MIG welds were represented by discrete beams with MAT119 material model. The stiffness, loads, and rupture displacement parameters were adjusted to match component tests and an envelope of rupture was created. This was carried on to the full vehicle as a predictive model and designs were iterated. All of the above modeling methods and techniques helped to accurately predict velocities, intrusion, wheel kinematics and a good correlation to the physical test was achieved.

2 Introduction

The small overlap Impact (SOI) test introduced by the Insurance Institute for Highway Safety (IIHS) in 2012 is a challenging load case for automakers. In this test, the vehicle impacts a rigid barrier at a speed of 64 KPH with 25% overlap in the front. This creates the most difficult scenario of managing the energy without engaging the front longitudinal rails. Hence the vehicle structure components lying in the load path requires a significant design development to reduce the load transfer to the occupant compartment.

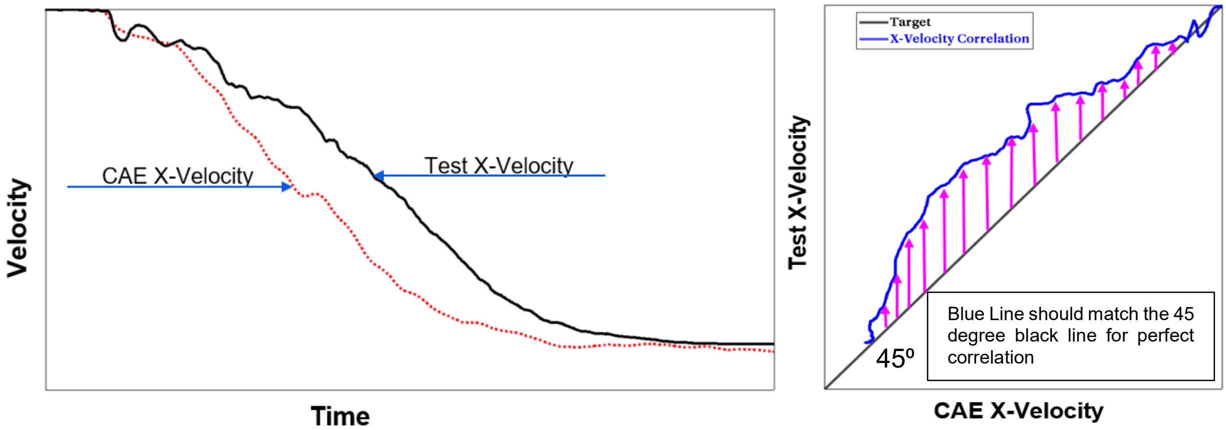
CAE plays a crucial role in this design development. It facilitates engineers to iterate different ideas in a short time span and optimize them. In order for CAE to accurately predict the events in the physical test it has to capture the details in the full vehicle model. At the same time there is a necessity to predict the rupture or detachment of critical joints and components. This paper describes the limitation of the traditional modeling methods and explains new modeling strategies implemented to get a good correlation to the physical test.

3 Motivation of This Study

3.1 Limitations of non-GISSMO Material Models

The traditional modeling methods generally consists of non-GISSMO (Generalized Incremental Stress State Models) material models. And hence the mesh size is made up of average 5mm or 8mm. Only intricate areas are modeled with small mesh size of around 3mm. The objective is to reduce the CPU time by keeping the mesh as coarse as and wherever possible. To incorporate rupture or detachments, strain based assumptions were used. These assumptions were either based on experience or component test data. In small overlap impact, with traditional method of CAE modeling, it is very difficult to achieve a good correlation with the physical test. The non-GISSMO material models limit the timing of the events like rupture or detachment of the components and hence it affects the overall simulation performance of the vehicle. For example, the Fig.1 shows the comparison of the Vehicle's X velocity between the CAE using traditional methods and physical test. On the right is shown the amount of error/difference in correlation. An ideal correlation should match the 45-degree line. Models with such low level correlation, limit their use for design direction in the process of vehicle development.

Fig.1: X (Longitudinal) Velocity Comparison between CAE (traditional method -left) and graph

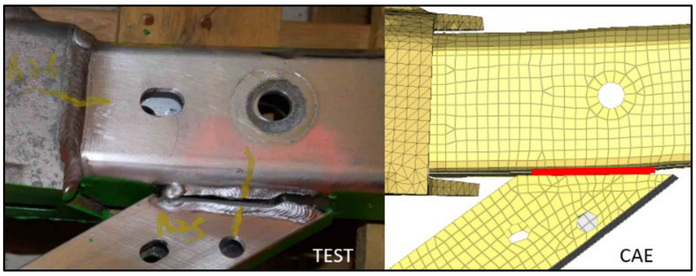


showing the amount of error or difference in correlation (right)

3.2 Challenges in Aluminum MIG Weld Modeling

Aluminum is now a widely used material in the car industry. To achieve good fuel economy all automakers are replacing heavy steel parts with lighter aluminum material. When it comes to CAE, the biggest challenge is to predict the rupture or detachment of the aluminum MIG welds. The timing of rupture of these MIG welds play a significant role in determining the load transfer and hence their rupture prediction is very important to develop a better design. For simplicity and faster turnaround times Nodal Rigid Body (NRB) connections were used to represent the MIG welds. For example, Fig. 2 shows the comparison between the CAE and Test. The CAE shows no rupture of the Al MIG weld at the end of the event.

Fig.2: Aluminum MIG Weld rupture comparison Test Vs CAE(NRB).



3.3 Requirement of Detailed Fastener Modeling

An often used method to represent a bolt in CAE is with a beam element and Nodal Rigid body (NRB) at each end of the beam connecting it to the mating parts. An example of this is shown in Fig.3, with the CAD on the left along with the CAE representation on the right. This method offers a quick and computationally inexpensive way to model a bolt. Additionally, it can monitor force in the joint and add fracture if needed.

There are several drawbacks to using a beam element and NRBs to model a bolt. In the example of Fig. 3. the NRBs distribute the load evenly around the holes it is attached to. This will incorrectly load the joint in the case of shear loading. The model is less likely to predict the bolt tearing through the parent material in shear. Another downside to this technique is that it doesn't capture the bending of the bolt as it's loaded in shear. This again can lead to inaccurate prediction of the joint behavior. Mesh refinement of the beam elements to capture this bending can introduce a new challenge when considering contact. A well-defined contact with appropriately small elements would need to be defined to prevent the bent bolt from passing through any shell elements it comes into contact with.

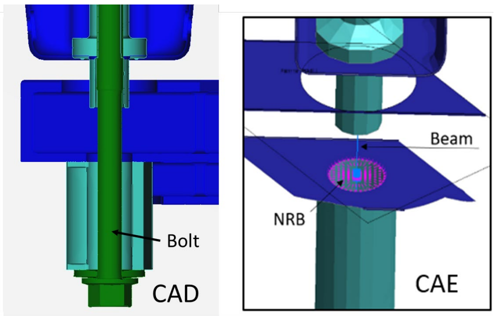


Fig.3: Fastener CAD representation (on left) & CAE representation (on right)

4 Objective of This Study

There are 5 main objectives of this study

1. Implement GISSMO Material Models to all critical components in the small overlap impact load path.
2. Establish a modeling method for Aluminum MIG welds to predict rupture.
3. Use the MAT_SPOTWELD_DIAMLERCHRYSLER damage material model to model the spot welds between sheet metal parts.
4. Establish a modeling method to model the fasteners to overcome the variation in the CAE with respect to test due to the play in linkages.
5. To accurately predict the velocities, intrusion and wheel kinematics of the overall vehicle performance.

5 New Modeling Method

5.1 Application of GISSMO Material Models

GISSMO material models (*MAT_PIECEWISE_LINEAR_PLASTICITY + *MAT_ADD_EROSION) are state of the art LS-Dyna rupture models for sheet metals, extrusions and solid cast parts. To generate such a model, coupon tests need to be carried out in tensile, shear, plane-strain and biaxial stress-state modes and local rupture strains were measured through Digital Image Correlation (DIC). These tests were simulated and the GISSMO models were developed and calibrated with regularization so that they work with mesh sizes from 1 to 4mm in size. The process of obtaining such a GISSMO model which is a CAE material separation prediction tool is shown in Fig.4. A database of the steel and aluminum sheet/extrusion/cast materials was developed. All the critical components playing crucial role in the small overlap mode were re-meshed to an average 3mm and a minimum of 1mm element size and defined with its respective GISSMO material model.

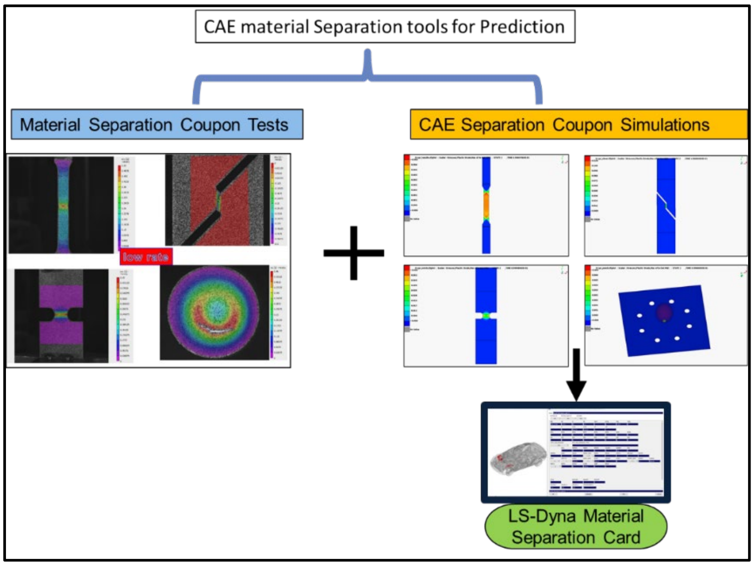
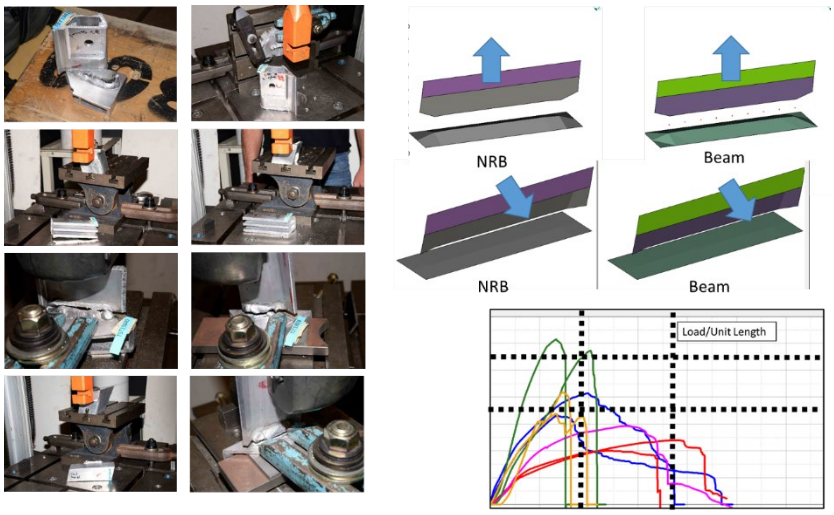


Fig.4: CAE material separation tools for prediction

5.2 Aluminum MIG weld Modeling Method

Thick aluminum components are MIG welded and their behavior during the crash event is very important. Traditionally Nodal Rigid Body (NRB) connections were used to represent the MIG welds. These NRBs, when used with force based separations, do not work well in full vehicle simulations due to premature separation. There are different cards for defining load based rupture of constrained rigid entities, but they inherently have a lot of noise and are not consistent. For the current study the thick aluminum components were cut to make small aluminum coupons with their MIG welds. The coupons were loaded in different directions and their load-displacements and rupture was recorded. In Fig.5 the left side picture shows the different loading conditions and the right side shows its LS-Dyna simulations.

Fig.5: Coupon tests and their simulations.



The NRBs were replaced by elform-6 discrete beams and the material model of the beam was defined as *MAT_GENERAL_NONLINEAR_6DOF_DISCRETE_BEAM (*MAT_119). The beam model stiffness and moments were adapted such that the beam coupon response was similar to the coupon model of NRB as shown in Fig.6 below. The stiffness was adjusted per unit length and hence the same beam material model can be carried on to any mesh size and any MIG weld length. *MAT_119 has the capability to have displacement rupture values in normal (n), shear (t) and shear (s) directions. From the array of coupon tests, a window of loads and their corresponding displacements were created. The window of load carrying capacity of these welds with respect to their weld lengths was understood.

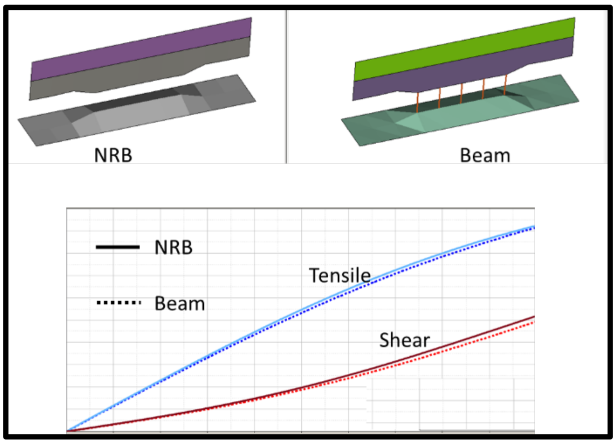


Fig.6: NRB Vs Beam Model – FD comparison.

Below is the picture (Fig.7) of a correlation of a component test. The left side picture shows the MIG welds ruptured in CAE very similar to the component test. The blue curve shows performance of the model with NRB (without rupture) and the red curve shows performance with beam rupture. The correlated beam material model was carried on to the full vehicle for predicting the crash responses.

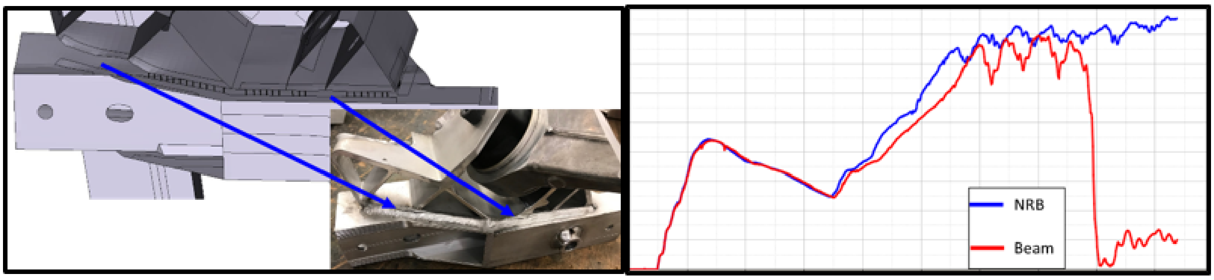


Fig.7: Component Test and CAE.

5.3 Spotweld Modeling Method.

The spotwelds were modeled in LS-Dyna as hexa elements and tied to their parent sheet metals through tied contact. The material card of the welds was assigned as MAT100 [1]. For the development of the material cards, Double U-type weld coupon tests comprising primarily of tensile, shear and peel modes of rupture of welds have been carried out (see Fig.8). Each of these test data was simulated in LS-Dyna and the material card *MAT_SPOTWELD_DAIMLERCHRYSLER was developed which is now being used in all the vehicle simulations.

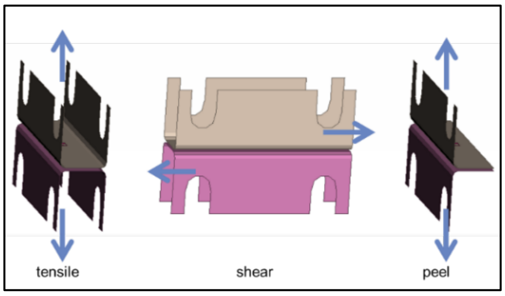


Fig.8: Double U-type coupons for weld coupon tests.

5.4 Fastener Modeling Method

Solid elements provide an accurate way to model bolted joints of particular interest. An example is shown in Fig.9. This method has several advantages over the beam element with NRB method shown in Fig.3. Solid element bolts ensure realistic load distribution compared to beam with NRB method. If shear loading is considered, the load will be concentrated at contact area with the surrounding surfaces. The capture of load concertation helps to predict tearing of the parent material or fracture of the bolt. It also accurately captures the bolt bending and therefore, the load transfers through the structure. Another advantage of relying on contact instead of a NRB is to capture the influence of gaps due to manufacturing tolerances. When gaps are accurately represented, the simulation can realistically predict the slippage of the joint.

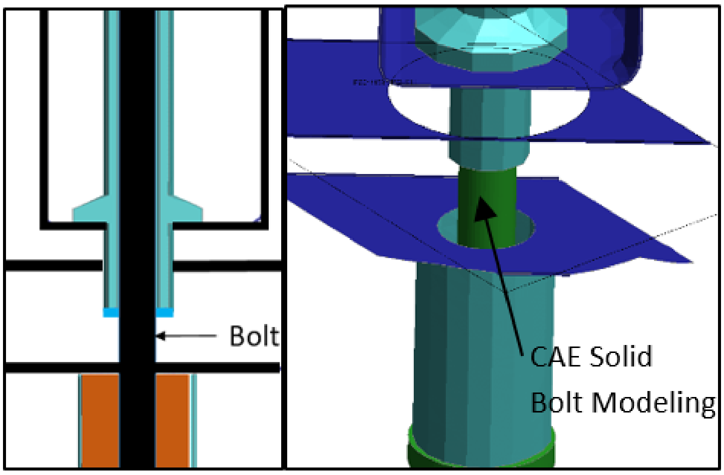


Fig.9: Fastener CAD representation (on left) & CAE representation (on right)

6 Application to Vehicle Model.

Techniques developed in Section 5 of this paper were implemented into a full vehicle impact model for validation.

The GISSMO material models were applied to the all critical components in the load path. Which included all High Strength Steel(HSS), AL sheet and cast parts. Application of the GISSMO material model required to change the existing average 5 mm mesh size to fine mesh of average 3 mm. The number of elements for small overlap CAE model increased by 50 percent compared to the traditional method. This increase in elements posed a challenge when considering the run time of the model but it was managed with help of higher core capacity.

AL MIG welds were modeled with discrete beams using MAT 116. Material model. MAT 116 required special node alignment which increased beam modeling process by 2 times compared to traditional NRB method.

All the spot welds from front bumper to B-pillar in the load path were modeled with hexa elements using MAT100 and separation criteria were applied as described in section 5.3.

Key bolts were modeled using solid elements with average mesh size 1 mm as described in section 5.4. These joints were extremely loaded and separation was of particular interest to overall performance of the vehicle.

7 Results

7.1 Fasteners Performance

The CAE result with beam/NRB model compared to a solid elemnt bolt model are shown in Fig.10. The joint was subjected to a shear load and plastic strain was plotted. The difference in modeling techniques is highlighted by observing the differnece in plastic strain. The plastic strain in the beam/NRB method is evenly distributed around the hole due to the NRB between the beam and hole circumference. For the solid element method strain is concentrated on one side due to contact. The plastic strain within the solid bolt and surrounding parent material is more accurately captured than in the beam/NRB method. Also the slippage in the joint due to manufacturing tolerances is captured in the solid bolt method. This ensures accurate deformation and load transfer through the joint. The end result of an accurately compliant joint is a better overall correlation to global measures such as the velocity correlation shown in Fig.12.

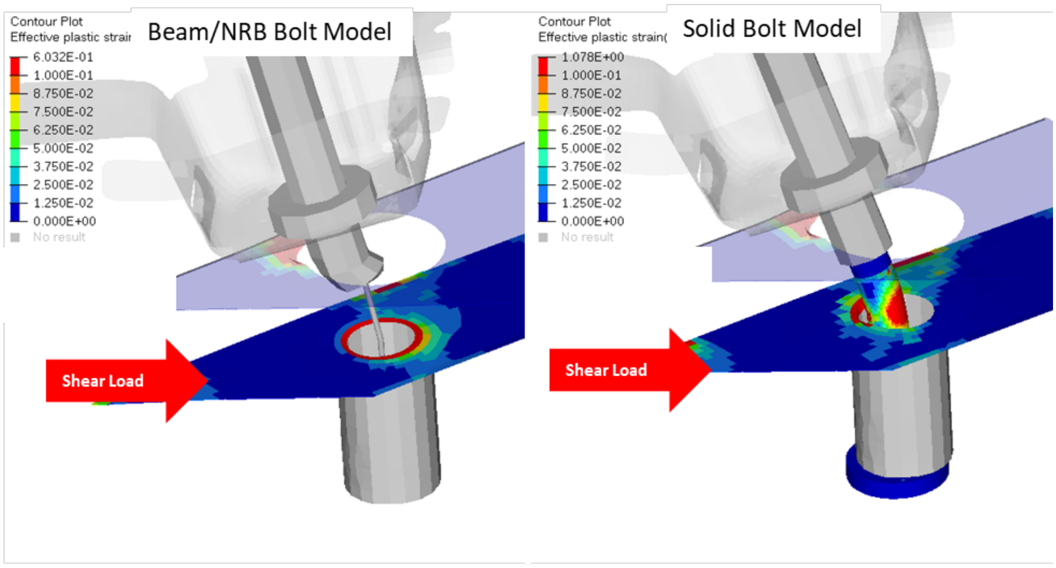


Fig.10: CAE results of two Bolt modeling techniques

7.2 AL MIG Weld Rupture – TEST Vs CAE

AL MIG weld prediction in CAE was one major road block to simulate vehicle response in this study. With application of new AL MIG modeling method, the model was able to predict weld separation similar to the test and achieved similar cross-member deformation.

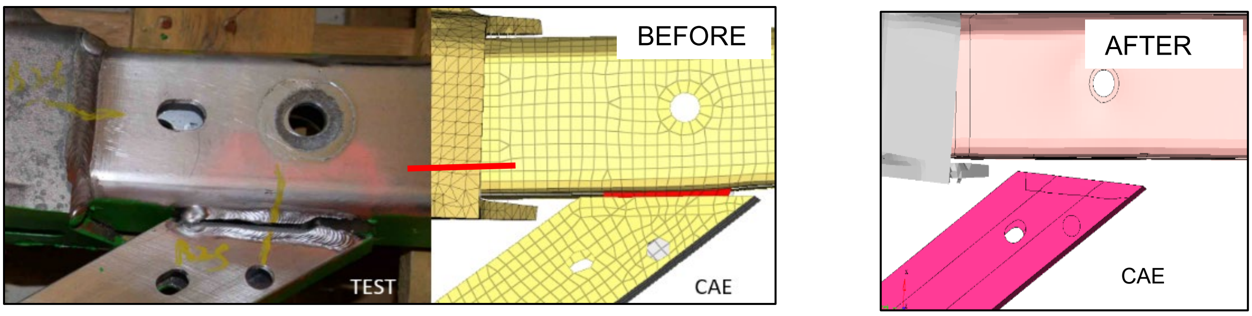


Fig.11: Al MIG weld rupture Test Vs CAE comparison

7.3 Vehicle X-velocity – Test Vs CAE Correlation

The variation observed in the vehicle X-velocity between traditional CAE method to physical test was undesirably high as shown in Fig.12 on the left. Hence, it is difficult to use such model for enabler development. After implementing improved CAE modeling methods, X-velocity response was close to the test as shown Fig.12 on the right. A more accurate CAE model allowed a greater amount of optimized enablers in shorter development time.

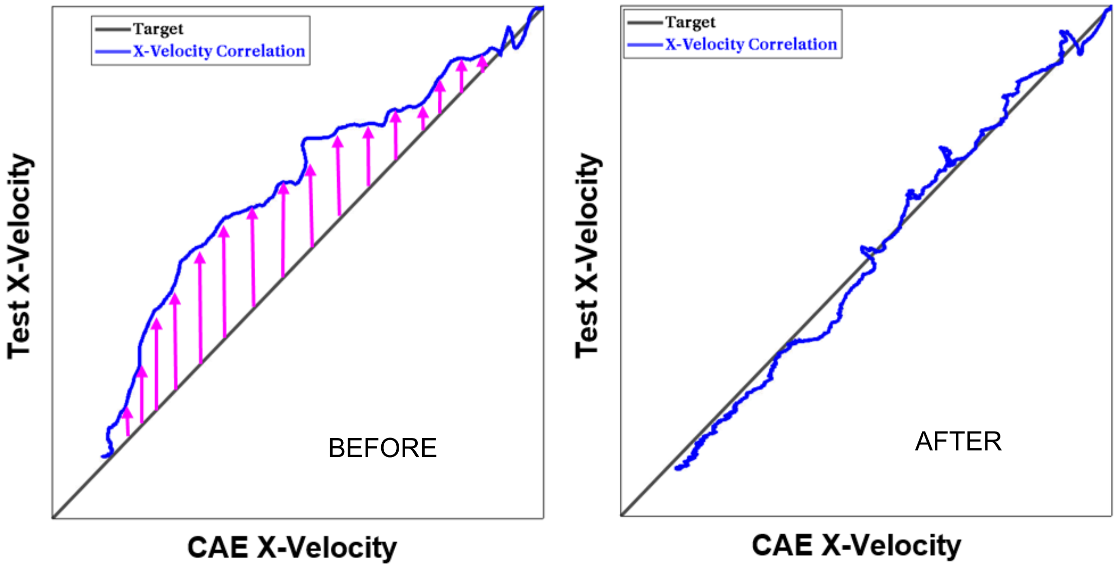


Fig.12: Correlation before Method application (on left) & Correlation after Method application (on right)

7.4 INTRUSION – TEST Vs CAE Correlation

Traditional CAE model intrusion prediction was far from the test measurements, especially last 3 measurement locations as shown in Fig.13. Improved CAE model shows close intrusion to test measurement. This gave high confidence in the CAE model and allowed for development of optimal enablers.

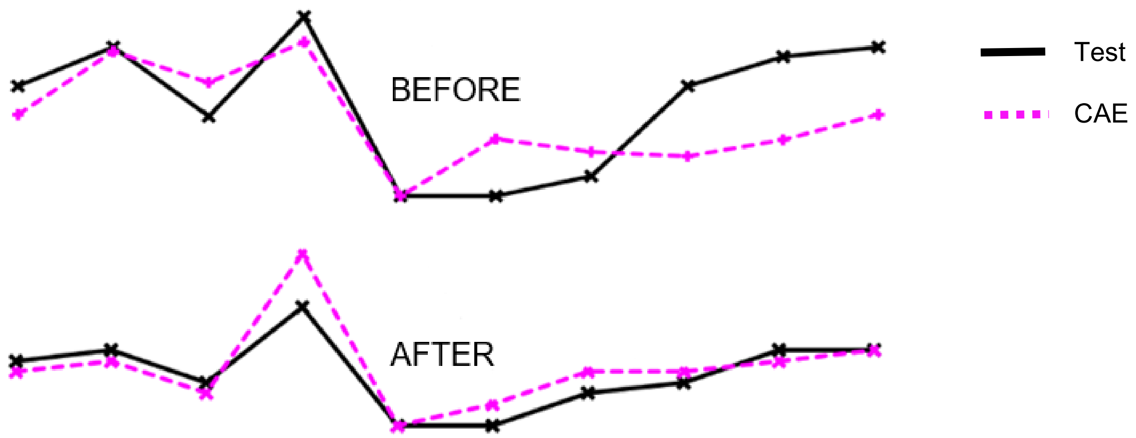


Fig.13: Intrusion comparison Test Vs CAE, before and after the new method application.

8 Summary and future scope of work

By applying all the new methods discussed above like the GISSMO material modeling, solid bolt modeling, new aluminum MIG welds method, and spotweld separation criteria helped to achieve an overall good level of correlation. A CAE model with this level of correlation will definitely help to give right design direction in the vehicle development process. The only limitation behind improving the predictive capability of the CAE model is increase in the model size and hence the solver run time.

For MIG welded sheet metals with upfront knowledge of hardness degradation of Heat Affected Zones (HAZ), HAZ separation methods have been used in other studies. When thick parts like castings are MIG welded, only discrete beams with separation criteria are used as descibed in this paper. The future scope will be to investigate combining the HAZ and discrete beam methodologies to develop common approach between sheet and thick parts.

9 Literature

[1] LS-DYNA keyword manual – R9.0/R10 – Livermore Software Technology, an Ansys/LST

[2] Dr. Anantharam Sheshadri, Hamid Keshtkar, Ashutosh Patil, Paul Dubois, “Experience with Material and Fracture Modeling at FCA US LLC”, Keynote lecture at 15th LS-Dyna Users Conference, Michigan USA

[3] Small Overlap Frontal Crashworthiness Evaluation Crash Test Protocol VersionVII, IIHS