# Spotweld Failure Prediction using Solid Element Assemblies

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## Abstract:

One current methodology for spotweld modelling utilizes a tied contact to connect the weld elements to the components. In order for this contact to be robust and acceptably mesh independent, multiple solid elements are needed to represent a single weld. Several studies were conducted which concluded that a cluster of eight hex elements provides significantly improved performance over a single beam or hex element. However, ease of use is critical to the application of these spotwelds since thousands of welds can be present in a single full vehicle model. Therefore, a single output is generated for each weld assembly rather than on an element basis. The time step for these hex clusters is controlled by the smallest edge length so using multiple elements does not result in a time step penalty since the thickness of the weld is usually the smallest edge length.

This paper will present the development of the eight hex cluster weld, followed by the validation process of these cluster spotwelds. Failure parameters for the resultant-based Mat 100 Damage-Failure model were derived by simulating coupon tests of single welds in shear and tension failure. These failure parameters were then used in a component test model with dozens of welds, several of which failed under the applied load. Finally, these parameters were applied to a full vehicle model using automatic sorting of the welds by the pre-processing software. At both the component and full vehicle level, good agreement was found between simulation and test results. The additional mass scaling and run time penalties of the cluster spotwelds were not significant. Furthermore, the effort needed to apply automatic methods to organize the welds is small enough to be practical in the production CAE environment.

## Keywords:

Spot weld Modelling, constitutive model and failure, weld assembly, crashworthiness, connection Modelling, finite elements


## Introduction

The representation of the spotweld in finite element models has been problematic for a number of years. The simplest representation consists of a rigid link connecting two or more sheets represented with thin shell elements. This method requires the mesh of the different sheets to be aligned, and for complex models, this poses a very difficult logistical problem. This has been addressed by using beam elements using a tied contact to attach the beams representing the weld to the sheet. This opens up the opportunity to apply failure; however, upon closer inspection of the behaviour of the beam elements, and the output generated, mesh dependence is observed which negates the possibility of successfully applying weld failure to the model.

Solid hexahedral elements can also be used in the representation of spotwelds. In this paper, the development and methodology of applying hexahedral assemblies consisting of several elements will be presented. Weld assemblies provide the best results for mesh independence which leads to successful application of weld failure. Of course, as is always the case when refining a mesh, the time step must be observed. However, since the thicknesses of the welds are most often the smallest edge length, refining the mesh of the weld does not incur any time step penalties.

Finally, the user must be able to treat each weld assembly as a single entity rather than as a group of individual elements in order for the weld assemblies to be used practically in large models. *CONTROL_SPOTWELD_BEAM and *DEFINE_HEX_ SPOTWELD_ ASSEMBLY are features in LS-DYNA which allow the user to treat the weld assemblies as a single entity [1]. The outputs from these assemblies to the SWFORC file are on a weld basis rather than on an element basis. Weld failure can now be applied in a predictive sense which has greatly increased the usability of many production simulation models.

## Importance of Mesh Independence

The internal weld forces used as the weld failure criteria must remain consistent regardless of relative placement of the weld to the master segments in order to successfully apply predictive weld failure. In this study, the mesh of the weld is refined from a 1-Hex representation to a 16-Hex representation in order to determine the best weld configuration for the application of weld failure. The internal weld forces are then compared to the external forces of the model to confirm that they are in good agreement, and in order to evaluate the mesh independence of the weld [2].

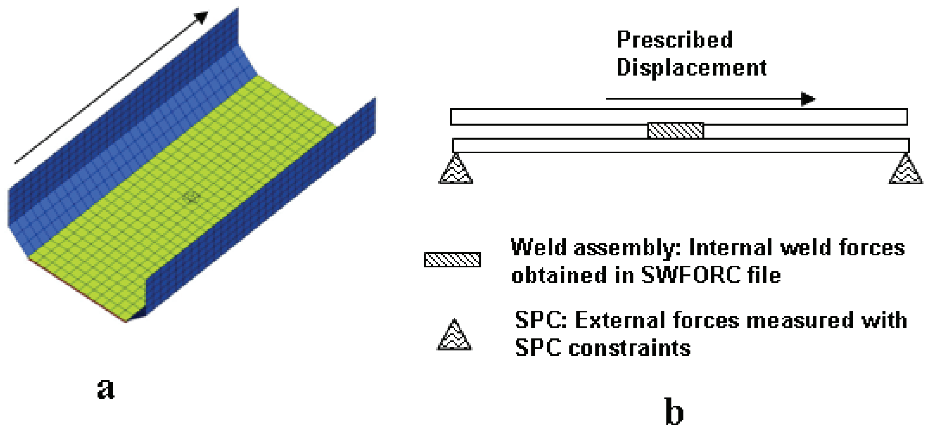



Figure 1a: Simple test model to evaluate mesh independence within LS-DYNA. Figure 1b: Schematic diagram showing a side view of the test model.

The mesh size of the master segment is set to 5mm, which is an appropriate mesh size for full vehicle crash models, while the diameter of the weld is 8mm, which is an average size of a spotweld applied to the vehicles. The effect of refining the mesh of the weld assembly is studied in order to determine the minimum number of elements required to represent the weld. Four cases are considered as shown in Figure 2.

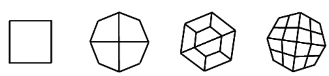
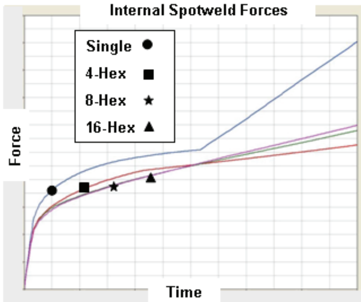


Figure 2: Hex weld mesh refinement ranging from 1-Hex to 16-Hex configurations.

Comparing the internal weld forces in Figure 3a, the single hex weld is clearly an inadequate representation of the weld, particularly for this case where the weld is larger than the mesh of the master segment. The weld forces are comparatively very stiff, and it is subject to spurious weld forces due to the master segment passing through the weld. The 4-Hex assembly compares reasonably well to the more detailed weld representations. There is a minimal difference between the 8-Hex and 16-Hex configurations indicating that further mesh refinement beyond eight elements is unnecessary. By taking a cross section cut view of the model through the weld in the deformed shape, the importance of the mesh refinement becomes clear (Figure 3b). As the number of nodes is increased on the slave side of the weld contact, the contact becomes more robust; therefore, it becomes a more stable representation of the weld connection.

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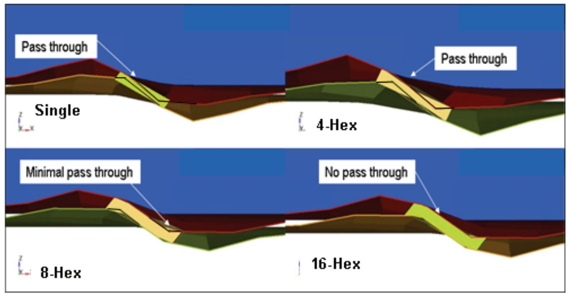


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Figure 3a: Internal weld forces comparing the effects of mesh refinement of the weld. Figure 3b: A cross sectional view of the deformed shape for various weld mesh densities.

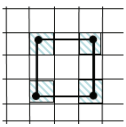


**Figure 4a:** The tied contact for a single hex weld. The center element of the master segment is not included in the tied contact because the weld element is larger than the master segment mesh. This allows the master segment to pass through the weld. This results in a non physical representation of the weld.

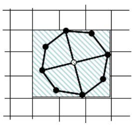


**Figure 4b**: The 4-Hex configuration shows a dramatic improvement over the single hex-weld. As the master segment deforms, there remains some pass through with the tied contact because the mesh of the weld continues to be coarse. This is accounted for to a point by using the SPOTHIN parameter. This results in a softening of the weld internal forces because it allows the master sheets to move closer together inside the weld which is not physical.

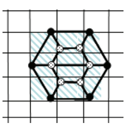


**Figure 4c:** The contact patch for the 8-Hex configuration is similar to that of the 4-Hex weld. The tied contact is more robust due to the weld consisting of an inner ring of nodes, rather than a single node for the 4-Hex assembly. The internal weld force is within 1% of the 16-Hex configuration indicating that the refinement of eight elements for the weld is sufficient.

Figure 4: Schematic of tied contact patch for 1-Hex (a), 4-Hex (b), and 8-Hex (c).

Mesh dependence was considered for the case of changing the relative position of the weld to the master segment as shown in Figure 5. The mesh density of the master segment was slightly altered in order to avoid moving the weld which would change the physicality of the model.

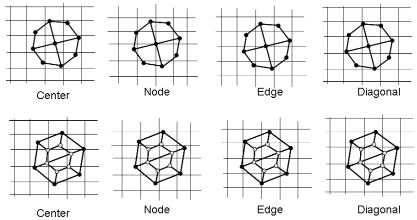



Figure 5: Positional cases evaluating mesh dependence for 4-Hex and 8-Hex weld assemblies.

The internal and external forces compare well for both the 4-Hex and 8-Hex welds (Figure 6). However, there are spurious weld forces in the 4-Hex case due to the contact not being as robust and allowing the master segment to pass through the weld. The severity of this pass through is dependent on the location of the weld relative to the master segment. This issue does not present itself in the case of the 8-Hex weld assembly.

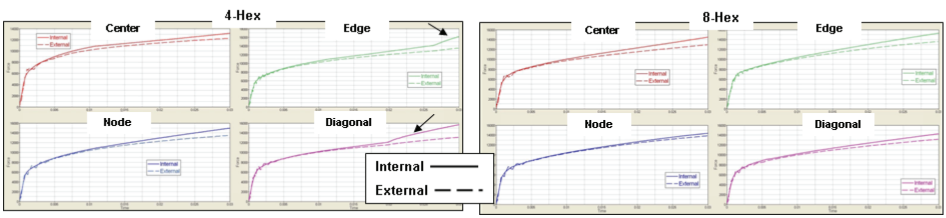



Figure 6: Comparison of internal weld forces to external forces of 4-Hex and 8-Hex welds.

Mesh dependence was then considered for the case of rotating the weld relative to the master segment as shown in Figure 7.

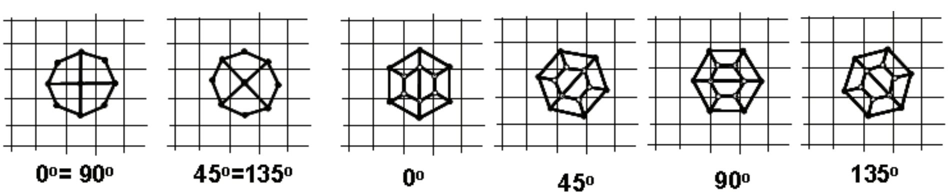
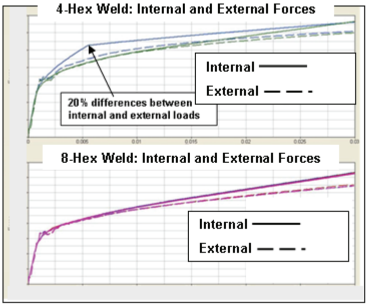



Figure 7: Rotational cases evaluating mesh dependence for 4-Hex and 8-Hex weld assemblies.

Mesh dependence of the 4-Hex assembly is noted when comparing the internal and external forces (Figure 8a). The 8-Hex weld assembly has a much greater internal energy since the tied contact is much more robust and the mesh is fine enough to capture the deformed shape of the weld (Figure 8b). This results in the internal forces of the weld to be very stable and in good agreement with the external forces. However, the 4-Hex weld assembly exhibits severe hourglassing, indicating a lack of robustness with the tied contact, and that the mesh is too coarse to capture physical behaviour of the weld. This results in measurable mesh dependence, and a lack of agreement between the internal weld forces and the external forces.

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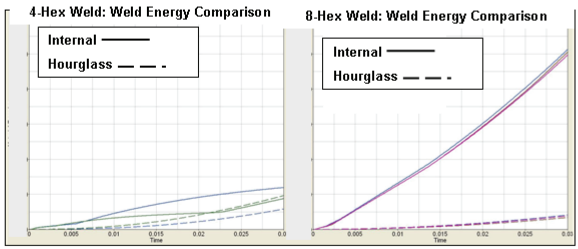


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Figure 8a: Comparison of internal weld forces to external forces of 4-Hex and 8-Hex welds for each rotational case. Figure 8b: Internal and hourglass energy for 4-Hex and 8-Hex weld assemblies for each rotational case.

Based on these results, the best weld configuration is an 8-Hex weld assembly in order to successfully apply weld failure in a predictive manner. Internal weld forces, which are used as the criteria for the failure model, are stable. No error will be introduced as a result of any mesh dependence of the weld.

## Spotweld Failure Method

The method used to fail each spotweld is the resultant force based failure method available in *MAT_SPOTWELD_DAMAGE-FAILURE with the option flag set to zero. This method takes into account forces and moments in three axes for a total of six failure criteria as shown in Figure 9 and Equation 1[1].

$$FC=\sqrt{\left(\frac{max(N_{rr},0)}{N_{rr_F}}\right)^2+\left(\frac{N_{rs}}{N_{rs_F}}\right)^2+\left(\frac{N_{rt}}{N_{rt_F}}\right)^2+\left(\frac{M_{rr}}{M_{rr_F}}\right)^2+\left(\frac{M_{ss}}{M_{ss_F}}\right)^2+\left(\frac{M_{tt}}{M_{tt_F}}\right)^2} \quad \text{(Eq. 1)}$$

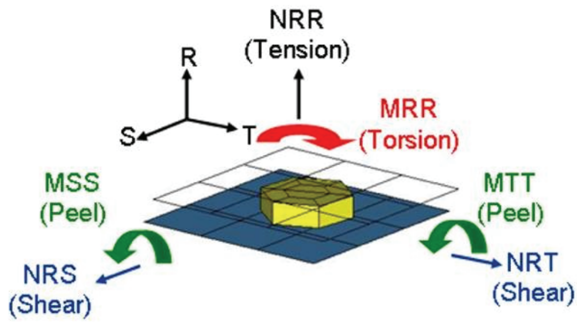


Figure 9: A single weld assembly illustrating the directions of the failure criteria.

NRR (Tension) is a function of thickness and nugget diameter. NRS = NRT (Shear) are a function of thickness, nugget diameter and material grade. MRR (Torsion) is a function of thickness, and nugget diameter. MSS = MTT (Peel) are a function of thickness, nugget diameter, and material grade.

## Determination of Failure Parameters from Coupon Tests

An existing series of spot weld coupon tests of various geometry was the basis for determining the strength values (Figure 10). Using a matrix of test data as the basis of comparison, failure parameters were varied until the coupon simulations correlated with the tests. This is done using a design of experiments methodology via a commercially available optimization code by treating each thickness and material grade combination as a separate experiment. Thus established, these failure parameter values are used in subsequent component and vehicle simulations.

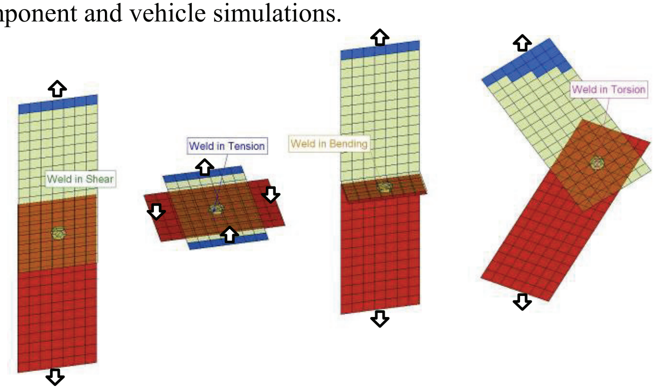


Figure 10: Spot weld coupon simulations used to correlate failure parameters.

## Practical Application to Large Models

Application of any theoretical method in large models can pose new challenges. In the case of spotweld failure prediction, each of the thousands of welds must have the correct failure parameters for that particular weld's circumstance. Other possible challenges to be considered and checked are solution run time and mass scaling.

With the Option 0 method in *MAT_SPOTWELD_DAMAGE-FAILURE this sorting must take place in the pre-processor. Custom macros were developed inside of two separate pre-processors. These macros search through the entire model and identify the parts attached by each weld. Based on the attached parts thickness and material, the weld is sorted into groups of welds with those same properties.

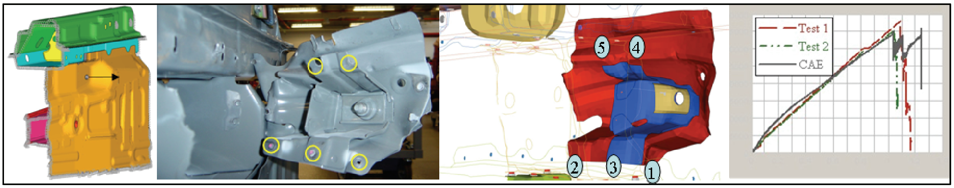


Figure 11: Boundary conditions and load, post test, post simulation, and graph of achieved load.

A quasi-static load was applied to a seat mounting point on a floor frame assembly in both the real world and by simulation as shown in Figure 11. Two tests achieve 103% and 110% of the load predicted by simulation. The failure order of the welds is also shown in Figure 11 and the test and simulation agree here as well. As a practical consideration it should be noted that the stability of the simulation under extensive spot weld failure was demonstrated, running without error termination far beyond the point necessary in practice.


Figure 12: Side Impact simulation, post test with weld failure circled, post simulation showing the order of failure for each spot weld.

A full vehicle side impact test reveals weld failure in the connection at the base of the B-Pillar pictured in Figure 12. Using the same 8 hex assembly spot welds throughout the model, a full vehicle simulation with approximately 2 million elements and 4 thousand weld assemblies was made. The same welds fail in the simulation as did fail in the test within 2ms time judging from accelerometers located in B-Pillar on the test vehicle. Practical considerations were confirmed. For instance using the pre-processor, the time required to organize all the welds in a vehicle takes about 1 hour. The run time with beam elements was 19 hours whereas the solution time with 8 hex element assembly welds was 19.5 hours. The added mass for the beam spot welds was 8.5 kg vs. 12.5 kg for the 8 hex element assembly welds.

## Summary and Conclusions

Beam and single hex element spot welds should not be thought of as mesh independent in terms of internal forces and displacement. Such elements should not be considered if a resultant force failure method is used due to the inconsistency caused by the relation of the welds to the shell elements. Implemented in LS-Dyna version 971, a new assembly of hex elements treated as a single spot weld entity is more accurate and consistent in comparison. The use of the new assembly weld entity in conjunction with the existing resultant force failure option is a practical methodology to predict spot weld failure in models as large as a full vehicle crash simulation. Assembly welds improve the mesh independence and accuracy of the forces measured in the weld. Negative effects on run time and mass scaling have not materialized.

## Acknowledgements

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