

Application of Spot Weld and Sheet Metal Failure Prediction to Non-Linear Transient Finite Element Analysis of Automotive Structures

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ABSTRACT

In early design phases vehicle safety testing has revealed the occurrence of both spot weld failure and sheet metal tearing that contributed to below specification performance. This would require redesign and additional testing to meet the specification. Because of cost and weight requirements in vehicle development, it is desirable to create efficient body designs for vehicle safety performance.

To develop more efficient structures, it is useful to be able to predict both connection and material failure in a variety of loading conditions using finite element (FE) models. Two new FE methodologies were developed separately to aid in predicting these phenomena. Since it is a widely used explicit FE code, LS-DYNA™ was chosen as the program with which to implement the new material and spot weld models. One methodology uses a force based failure criteria to model failure in, and next to, spot welds. A second methodology was developed to predict sheet material failure using the Forming Limit Diagram (FLD) for ferrous materials. These methodologies were confirmed separately using simple FE models and compared to actual test results.

After each methodology was confirmed separately, the two new FE techniques were used in concert to predict automotive structural behavior with combined spot weld failure and sheet metal tearing present.

INTRODUCTION

Why is it necessary to attempt to predict spot weld and sheet metal failure using finite element analysis (FEA)? We can agree that the customer has multiple requirements including vehicle safety, fuel economy, passenger space, and driving performance to name but a few. We therefore strive to design vehicles which provide good vehicle safety performance at the lightest possible mass and with the most efficient design.

The lighter weight of vehicle structures may lead to an increased concern for spot weld and sheet metal performance during a physical crashworthiness test. Even small numbers of weld separations or sheet metal tears might result in a test that does not meet the target performance. Therefore, it is helpful to evaluate a design's performance using FEA before prototype production and testing occurs.

SPOT WELD FAILURE PREDICTION

In vehicle safety simulations one common method for representing a single spot weld has been to use a single one dimensional beam element connected to the adjacent sheet metal represented by two dimensional sheet elements. In recent years the common method to connect the beam to the shells has been with a mesh-independent tied contact algorithm. However, depending on the relative size of the shell mesh and the beam diameter, the assumption that these beams behave in a truly mesh-independent manner could cease to be true under certain conditions. If this mesh independence is not reliable, then the forces through the

weld might not be reliable and so too would any failure criteria applied to such a spot weld. One method that was shown by Nutwell et al. [1] to make the force through the weld more mesh-independent was to change the weld model from a single beam to an assembly of solid elements with multiple nodes in contact with the shells.

The method used to evaluate each spot weld is based on the resultant forces and moments as described in Figure 1. The spot weld that is subjected to forces beyond its capacity will be deleted from the calculations once the Failure Criteria (FC) equals unity. By assumptions of symmetry, the six terms can be reduced to four distinct terms. These terms are functions of properties of the sheet metal and weld nugget. Specifically, NRR (Tension) is a function of thickness and nugget diameter (failure by compression is not allowed by the equation). 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.

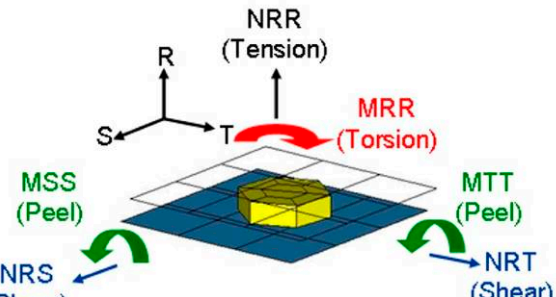
$$FC = \sqrt{\left(\frac{\max(N_{rr}, 0)}{N_{n_y}}\right)^2 + \left(\frac{N_{rz}}{N_{n_y}}\right)^2 + \left(\frac{N_{ry}}{N_{n_y}}\right)^2 + \left(\frac{M_{rr}}{M_{n_y}}\right)^2 + \left(\frac{M_{rz}}{M_{n_y}}\right)^2 + \left(\frac{M_{ry}}{M_{n_y}}\right)^2}$$


Figure 1 - Spot Weld Failure Criteria.

This method is available as an option in the widely used non-linear explicit finite element analysis code LS-DYNA™ made by Livermore Software Technology Corporation. This particular failure method is available in *MAT_SPOTWELD_DAMAGE-FAILURE with the option flag set to zero.

One assumption of this work is that there exists a database of spot weld strengths for the entire matrix of spot welds. These strengths depend on the thickness and material of each sheet in the weld, the number of sheets and the nugget diameter (which itself depends on the welding schedule).

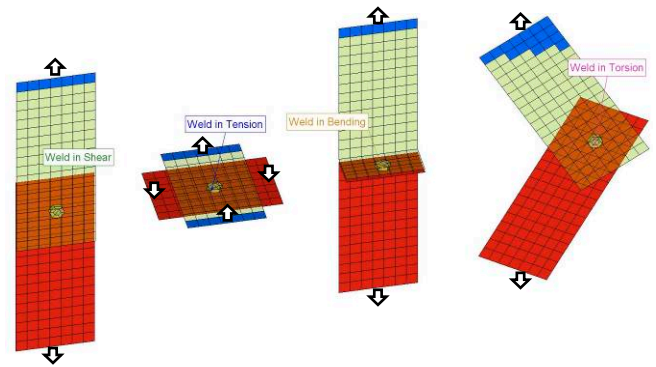


Figure 2 - Spot Weld Coupon Simulations

From an iterative routine using commercially available optimization software the correct values for the failure parameters NRR, NRS/NRT, MRR, and MSS/MTT were reverse engineered. The weld coupon simulation models used for this correlation are shown in Figure 2.

It should be noted that there is no strain rate component to the weld evaluation data or criteria. The basis for this omission is the research from Madasamy et al. [1] as well as Lin et al. [2]. In both these studies, spot weld coupon tests using mild and high strength steels in hundreds of thickness and material combinations showed insignificant strain rate dependence.

SHEET METAL FAILURE PREDICTION

During vehicle prototype safety testing and development, sheet metal tearing may be present despite prior finite element (FE) analysis. The presence of the tearing is often unexpected; and recovery from an unacceptable test result may require significant resources and time. Prediction of sheet metal tearing in the FE environment is highly desirable because it allows development of an alternative design before actual prototype production takes place. In addition, the FE analyst, designer and test engineer are given the opportunity to develop a robust solution while minimizing cost and weight.

A number of methods are currently available to help predict sheet metal tearing in the FE environment. Some of these methods are simple in terms of material parameter definition, while others are more complex requiring significant material testing to develop an accurate failure model. In some cases, the simplified methods may provide accurate results but may tend to over- or under-predict tearing if the load case is not suitable to the failure parameters. In the case of the complex sheet metal tearing models, it is prohibitive to perform the testing to obtain the failure parameters for all of the steels used in a modern automotive body. Because of the limitations on the current predictive