

FEA Development of Spot Weld Modeling with Fracture Forming Limit Diagram(FFLD) Failure Criteria and Its Application to Vehicle Body Structure

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ABSTRACT

Spot weld separation in vehicle development stage is one of the critical phenomena in structural analyses regarding quasi-static test condition, like roof strength or seat/belt pull. It directly reduces structural performance by losing connected load path and occasionally introduces tearing on surrounding sheet metals. Traditionally many efforts have been attempted to capture parent metal ductile fracture, but not applied to spot weld separations in automotive FEA simulations. [1,2,3]

This paper introduces how to develop FFLD failure criteria from a series of parametric study on ultra high strength sheet steel and deals with failure criteria around spot weld and parent metal. Once the fracture strains for sheet steels are determined, those developed values were applied to traditional spot weld coupon FEA simulations and tests. Full vehicle level roof strength FEA simulations on a typical automotive body structure were performed and verified to the physical tests.

Developed FFLD curves have been used for both spot weld and parent metal and good correlations have been achieved. Various mesh patterns and sizes around spot welds have been investigated. Finally, an optimized weld pattern and mesh size have been suggested for quasi static load cases and successfully applied to vehicle body structures.

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INTRODUCTION

There are two analytical methods that have been widely used in the automotive industry. One is force-based approach. This approach is represented by mesh-independent beam or hexahedral solid element representing the spot weld with contact definitions to sheet metal. Weld separation is predicted by utilizing developed force and moment criteria, but is limited to capturing interfacial weld fracture mode only. The other approach is strain-based spot weld. It is represented by mesh-dependent hexahedral elements with shared nodes to adjoining shell elements and captures both interfacial and button pullout weld separation modes. Spot weld in Interfacial failure mode fractures via crack propagation through the weld nugget. On the other hand, the weld nugget in the button pullout mode completely pulled out from one of the sheets. One advantage of this strain-based approach, is that it is applicable to both fracture on parent metal as well as HAZ (Heat Affected Zone). HAZ is not exclusively modeled in the force-based approach. It is one reason that the force-based approach makes it difficult to predict accurate spot weld separation through analytical simulations. It drives us to develop modeling of HAZ, FZ(Fusion Zone) and fracture criteria based on FFLD/FLD (Fracture Forming Limit Diagram) which is widely used in sheet steel manufacturing or forming process.

Traditional CT (Cross Tension), LS (Lap Shear) and CP (Coach Peel) spot weld simulations on various sheet steels, have been conducted utilizing LS-DYNA3D Explicit commercial code - a non-linear finite element based structural analysis solver[4] to determine maximum principal strain versus minimum principal strain, or FFLD, spot weld fracture criteria. Spot weld mesh patterns around HAZ were also investigated to determine the optimal mesh pattern which compares to the developed fracture criteria.

Parameter Study

Spot weld models in the automotive CAE community are represented by either a hexahedral solid element or a beam element with a tied contact to adjoining shell elements [5, 6]. The biggest disadvantage of this method is that the spot weld performance strongly depends upon mesh size and location of the hexahedral, or beam spot weld, to surrounding shell elements. [7] In order to evaluate mesh size effect and determine the most appropriate mesh pattern for spot weld modeling, a traditional spot weld coupon FEA simulations and CP(coach peel) tests have been carried out as shown on Fig. 1

Component A is constrained in x, y and z translation and rotation. B and C are only allowed to move in x translation. Load according to time variation is applied to Component C. A spherical joint between Component B and C is defined to measure a force at fracture.

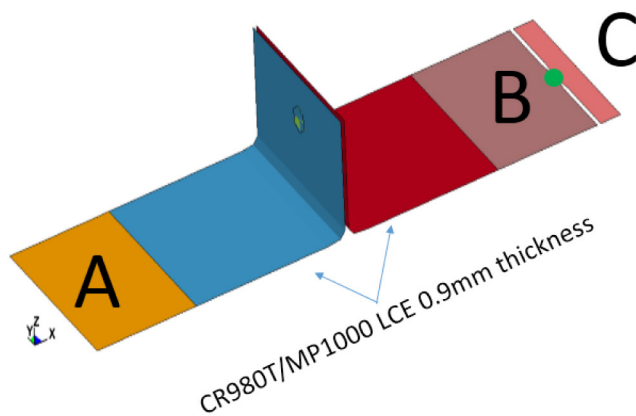


Fig. 1. Spot Weld CP(coach peel) Coupon FEA model

Ten(10) mesh independent and five(5) mesh dependent mesh patterns on CR980T/MP1000 LCE(Cold Rolled Hot Dipped Galvanized Grade MP1000 Multi-Phase Steel Low Carbon Equivalent) 0.9mm thickness have been investigated as shown on Fig. 2.

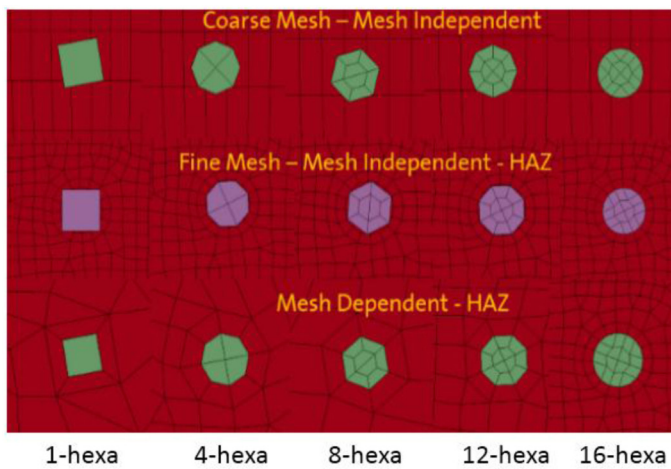


Fig. 2. Investigated Spot Weld Patterns

Fig. 3 indicates Force vs. Displacement curves for Mesh Independent mesh patterns and Fig 4 for Mesh Dependent patterns. None of the coarse meshed mesh independent spot welds correlate to the tests as shown on Fig.3. 16-hexa mesh dependent spot weld with FFLD(Fracture Forming Limit Diagram) curves falls into the minimum and maximum test results, and the other cases over-predict as shown on Fig. 4.

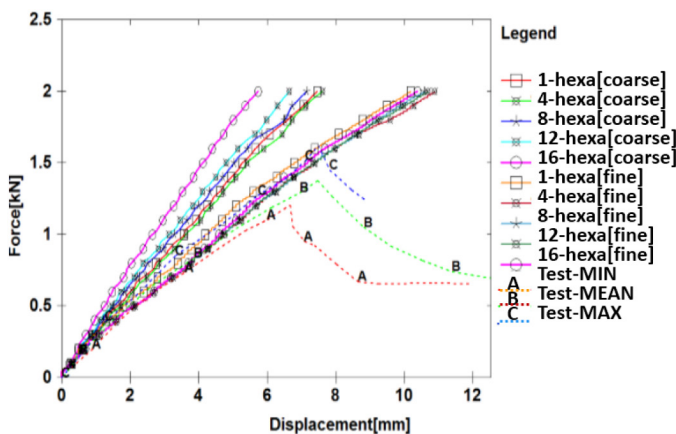


Fig. 3. CP - Mesh Independent : Force vs. Displacement

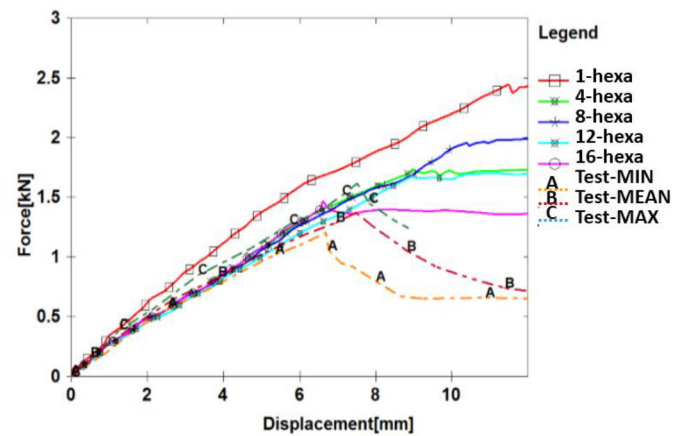


Fig. 4. CP - Mesh Dependent : Force vs. Displacement

It can be concluded that the differences are coming from element size around weld nugget. FFLD spot weld criteria are discussed in the later part of this paper. To eliminate this effect, mesh size regularization factor curve is introduced in each load cases and resulted to the same performances as the case of 16-hexa except 1-hexa. 1-hexa element size is too big to capture circular spot weld behavior.(See Fig. 5)

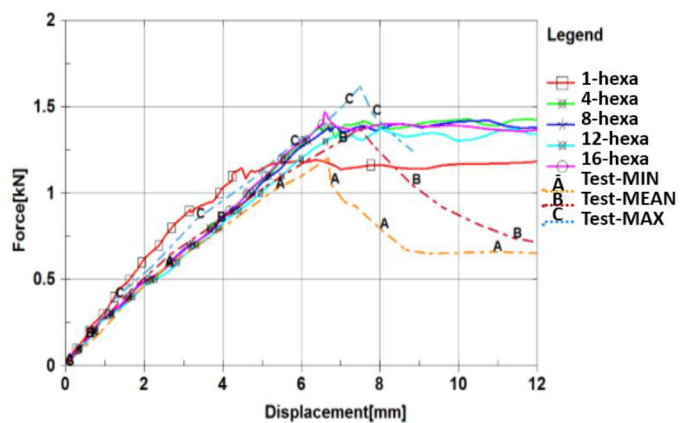


Fig. 5. CP Mesh Dependent : Force vs. Displacement with Mesh Size Regularization curve

The conclusion is to choose 16-hexahedral mesh dependent spot weld pattern for the reference mesh size and for the subsequent spot weld simulations considering both Mesh Independent and Mesh Dependent cases mentioned above.

Further parametric study on LS(Lap-Shear) and CT(Cross tension) load cases were performed on the same material and same mesh pattern(16-hexahedral) and discussed later part of this study.

Development of FFLD Curves

1. Effective Plastic Strain vs. FFLD

To capture button pullout failure mode during quasi-static load event, the strain based spot weld approach has been introduced by Lee et al [6]. It uses the effective plastic strain as the failure option, however it couldn't cover different strain paths as indicated in Fig. 6