Development Of LS Dyna Materials to Predict Failure

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Abstract- In the Automotive industry there is a need for weight reduction in order to reduce the Energy consumption, $Co2$ emissions and also the need for high safety, which has led to the use of high strength steels because of their light weight and high strength properties. The increasing demand of high strength steels and short development time has led to the requirement of improved predictions of the actual crash behavior in the automotive industry because a full-scale crash test is both expensive and time consuming.

The models used for crash simulations are usually isotropic and is based on the Gurson, Tvergaard & Needleman or the von Mises flow rule. GISSMO is the damage model has been developed at Daimler and DYNAmore used in such crashworthiness simulations. This paper is mostly based on the reference of various LS-DYNA

User conferences. GISSMO damage model has a number of parameters and curves that defines when necking and failure occurs. GISSMO is a phenomenological damage mechanics model which is based on experimental results and does not consider voids and cracks

I. INTRODUCTION

In the automotive industry the demand for accurate predictions regarding material be- haviour and material failure has increased in the recent years and due to less time the Crash- worthiness simulations are used to develop the safety components. Crashworthiness simulations of the car body is an important part of the CAE development for car design. The simulations can also give information about different phenomenon in a car crash since it is very expensive to crash a car in the real environment and also due to variations in manufacturing.

A generalized scalar damage model (GISSMO) can be made with these parameters. In GISSMO, the different load cases are represented by the triaxiality which is the ratio between the mean stress and the von Mises stress. In GISSMO, separate treatment of plasticity formulation and failure prediction can be done. Both the failure/fracture limit criteria and instability/localization criterion exist in GISSMO and also an equation that is used to find the total amount of energy absorbed by the material during a crash simulation [5]. The main advantage of GISSMO is the possibility to include more fracture criterion like Wilkins (W) model, Cockroft-Latham, Johnson Cook, Bao Wierzbicki etc. which are focused on different parameters to find failure in a material [7].

II. DAMAGE MECHANICS

Damage occurs when a material is subjected to mechanical loading and increases with in- creasing load resulting voids and micro cracks. Damage mechanics itself is a specific field of research that is active to incorporate damage in various constitutive model for materials. [1].

Damage mechanisms based on micro level such as voids and micro cracks and have a defined micromechanical criterion for damage growth are called Micromechanical damage mechanics models. This model can be derived to macroscopic models later

Phenomenological damage mechanics models are based on actual experiments. The selected material is subjected to different load cases and their respective stresses and strains or forces and displacements are recorded [1].

The damage is hard to measure often, and it is an estimation done from changes in mate- rial properties like for example changes in stiffness. Therefore, these types of models should be used with extra attention when tested for other load cases [1].

One common way to describe the damage is to compare the cross-sectional area of the material, $A0$ with the effective area, Ar . Ac is the effective area due to voids and micro cracks of a certain area [1].

III. GENERALIZED SCALAR DAMAGE MODEL

GISSMO is a combination of the proven features of failure description provided by damage models and also instability/localization description. With the help of phenomenological formulation of ductile damage, the simple inputs of material parameters are achieved [5].

IV. STRESS AND STRAIN MEASURES

The usual way to treat instability/localization in sheet metal forming process is by comparing resulting strains in the final stage with a fixed curve of principal strain values. The forming limit curve considers only the final stage of deformation and doesn't consider the changes in the strain path [4].

The FLC from principal strain ($\varepsilon\varepsilon 1$, $\varepsilon\varepsilon 2$) space is transformed to a notation using the equivalent plastic strain $\varepsilon\varepsilon p$. Which was initially proposed by Muschenborn and Sonne (1975), is a practical approach for a strain-path dependent forming limit determination In isotropic material models, the usual notation for crashworthiness purposes is a characterization of load state using the invariants of the stress tensor. The invariant notation is independent of the respective material direction [5].

The strain increments are related to stress values by a 2D constitutive model considering plane stress case as a common assumption. The strain-based notation can be transformed into a notation in invariant of the stress tensor [5].

V. PATH DEPENDENT FAILURE CRITERION

To allow the treatment of arbitrary strain paths to predict failure, an incremental formulation has been chosen to measure damage

$$\Delta D = \frac{n}{\varepsilon\varepsilon_{ff}(\eta)} D^{(1-\frac{1}{nn})} \Delta\varepsilon\varepsilon_p$$

This equation represents linear accumulation rule for damage as proposed by Johnson and cook (1985). If GISSMO is active, equation is evaluated at every time step in LS- DYNA using the current values of damage(D), triaxiality(η) and increment of plastic strain($\Delta\varepsilon\varepsilon p$)

In equation 9, n is a damage exponent and allows for a non-linear accumulation of dam- age until failure and creates a possibility to fit the model to data of multi-stage material tests, and $\varepsilon\varepsilon ff(\eta)$ is the fracture strain as a function of triaxiality [5].

When the damage (D) reaches 1.0, it is assumed that fracture had taken place and the integration point can no longer be able to bear any external loadings. Equation is important for accurate depiction of fracture when the triaxiality is not constant over deformation (i.e., non-proportional strain paths) [5].

Non-proportionality is an issue in the prediction of localization/instability and failure. FLC based approaches are popular and effective in forming analysis but have been struggling for years to find suitable methods for strain path independent forming limit diagrams (FLD). Damage accumulations like in equation is simple and elegant way to deal with the problem. Equation can provide results that are satisfactory in many practical applications Even though there are many issues regarding damage accumulation [7].

VI. PATH DEPENDENT LOCALIZATION

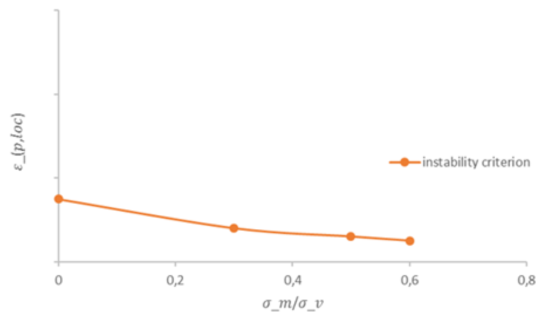
In this section, the methods that are used in GISSMO for treating localized deformation instability are described. The strains are noted at the onset of localization from tests under constant stress state. The tests include tensile tests with various hole radii, notch radii, biaxial tests and shear tests which can result a forming limit curve. This curve is used as an input for the constitutive model and is also used as a weighting function for the path de- pendent accumulation of necking intensity up to the expected point of instability [5]. Like proposal of Bai and Wierzbicki method (2008).

Generally, in numerical simulations, the localization behavior of materials depends on yield locus and evolution of the flow/yield stress. Instability starts from the post critical range of deformation and the determination of yield curves from the specimen tests is not possible for this range, therefore stress extrapolation based on engineering assumptions or models is used. Due to the mesh size dependency of results in the post-critical range, the used parameters of an extrapolation would determine the material properties in the post-critical range, and lead to mesh dependent results and therefore, a damage-based regularization for the post-critical range is proposed in the present contribution [5].

One of the reasons for the treatment of localization is to determine the beginning of material softening which is used as a damage threshold for the coupling of damage to flow/yield stress in crashworthiness applications [4].

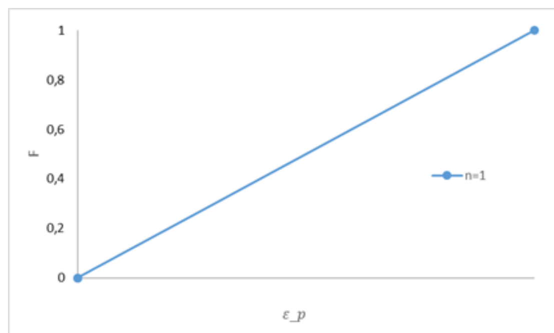
VII. NONLINEAR ACCUMULATION OF LOCALIZATION/INSTABILITY CRITERION

A nonlinear equation for accumulation is introduced to the GISSMO model by using the same relation as for the accumulation of ductile damage to failure. The parameters identification for this relation is difficult to obtain from direct tests and it is done rather by the means of reverse engineering simulations of multi-stage forming processes. The introduction of an additional parameter "n" should allow the fitting of the model to existing test data [5].

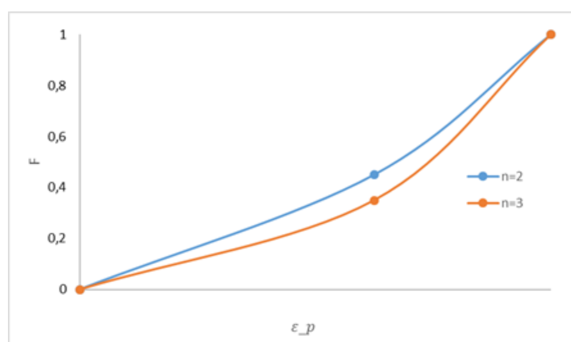


$$\Delta F = \frac{n}{\varepsilon_{p,loc}(\eta)} F^{(1-\frac{1}{n})} \Delta\varepsilon_p \qquad n > 1$$

Here, "n" is the accumulating exponent. If n=1, Equation 11 reduces to linear form. For proportional loading ($\varepsilon\varepsilon p,loc$ =constant) the equation can be inte- grated to yield a relation between the "forming intensity" F and the equivalent plastic strain [4]:



Graph showing linear accumulation.



Graph showing nonlinear accumulation

VIII. POST CRITICAL BEHAVIOR

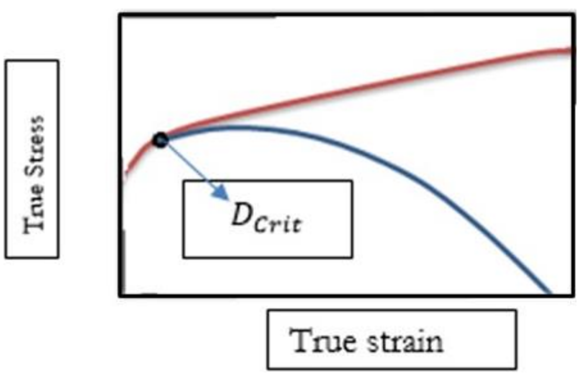
In the forming simulations the post critical range of deformation lacks interest because the formation of instability or necking is already considered as a failure.

But in crash simulations it is important to collect the post critical behavior because the maximum energy absorbed by the material can be found. Results based on the Mesh size dependency occurs while modelling of the post critical behavior of metals using Finite Element Method [4].

When the forming intensity measure F reaches unity, i.e. F= 1, a coupling of accumulated damage to the stress tensor using the effective stress concept (proposed by Lemaitre, 1985). A curve of material instability dependent on the triaxiality is used for the accumulation of forming intensity and this value represents the onset of material instability and ending of mesh-size convergence of results. For the practical application of the model to finite element simulations with limited mesh sizes requires regularization of different mesh sizes [4].

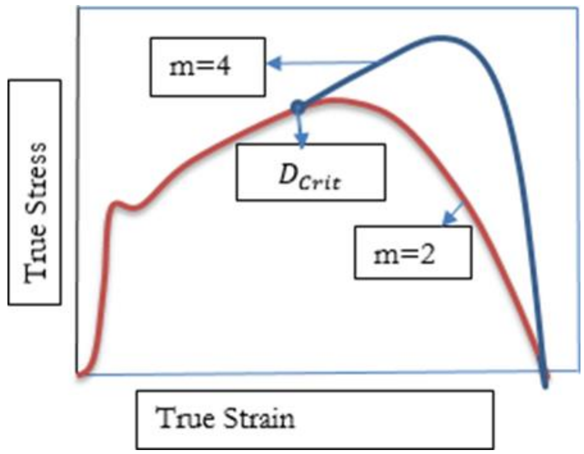
In the GISSMO model to regularize the amount of energy that is dissipated in the process of crack development and propagation the regularization treatment is combined with the damage model. For a finite element model this results in a variation of the rate of stress reduction through element fadeout [5].

Through a modification of Lemaitre's effective stress concept [4]:



Graph showing coupling of damage to stress in True Stress vs. True Strain.

A damage threshold can be defined in combination with the treatment of material instability. Damage and flow stress will be coupled as soon as the damage parameter D reaches this value. This allows a possibility to enter a damage threshold as a fixed input parameter or to use the damage value corresponding to the instability point [5]. As the post-critical range of deformation is reached a value of critical damage $Dcrcct$ is determined and used for the calculation of the effective stress tensor



Graph showing coupling of damage to stress with influence of fading exponent inTrue Stress vs. True Strain.

This procedure allows regularizing the energy consumed during the post-critical deformation the fracture strains, and also regularizes the resulting engineering stress-strain curves in tensile tests with different mesh sizes [5].

CONCLUSION AND DISCUSSION

In this paper, the GISSMO damage model has been described to capture the ductile damage and failure in different stress states for DOCOL 900M. The damage model is pre ferred based on the various LS-DYNA® conference proceeding papers which shows the potential of the model to predict the crashworthiness simulations. The damage model can be used for the simulation of shear, tensile and biaxial tests very effectively. This phenomenological damage model introduces many features suitable to describe ductile damage and failure in different stress states. The failure criterion and the instability criterion are both prescribed for DOCOL 900M. The major limitations for predictive performance occur from the deficiencies in material modelling and coarse discretization of the test specimens. The mesh size dependency plays an important role in finding the energy absorbed through element fadeout, so a fine mesh size is always preferred. The tests shall be performed on all the specimens along rolling direction and transverse direction to get better prediction of GISSMO.

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