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Characterization of dynamic hardening behavior using acceleration information

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Abstract

Crash analysis simulation is very important in automotive industry to assess automotive crashworthiness and safety. In the FE simulation, accurate dynamic hardening behavior should be used as input data to provide reliable results. But, it is difficult to obtain precise hardening properties at intermediate or high strain rates due to inaccurate measurement of load caused by the inertial effect. In this study, a new methodology was applied to retrieve dynamic strain hardening properties of sheet metal specimens. The virtual fields method (VFM) was adopted as an inverse method to identify hardening parameters without load information. As an initial study, Swift model for a rate independent hardening law was selected for an elasto-plastic constitutive model. In order to validate the proposed methodology in the experiments, a new type of high speed tensile tester for sheet metal specimens was built and high speed tensile tests were performed. Digital image correlation technique using a high-speed camera was utilized to measure strain and acceleration fields so that the identification is carried out from the measured quantities. The validation of the proposed VFM identification procedure using the acceleration will be performed by comparing with the conventional procedure using a load-cell.

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Keywords: dynamic hardening behavior; plasticity; sheet metal; virtual fields method; full-field measurements;

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1. Introduction

Crash analysis using finite element (FE) simulation is now essential in auto companies to evaluate automobile crashworthiness. In order to acquire reliable simulation results, precise material behaviors at intermediate or high strain rates should be fed as input. However, the dynamic hardening behavior of materials at high strain rates is not easily characterized because accurate measurement of load is difficult due to the inertial effect [1]. The aim of the present study is to characterize the dynamic strain hardening behavior of thin steel sheet specimens using the virtual fields method (VFM) [2]. The identification is carried out using the acceleration fields without utilizing load information. To determine the hardening parameters at high strain rates, high speed tensile tests are conducted on advanced high strength steel (AHSS) sheet specimens and full-field displacement fields are measured by a digital image correlation (DIC) technique using a high-speed camera. Then, a proper elasto-plastic constitutive model is chosen and the VFM is used as an inverse analytical tool to determine the constitutive parameters. In this study, the methodology is introduced and a wider validation of the proposed identification procedure against simulated and experimental data is presented.

2. Identification procedure

2.1. Logarithmic (true) strain

In order to simulate the measurement points from DIC, fine mesh size was employed first. Three nodes triangular shell elements were used. Reference (undeformed) and deformed coordinates of measurement points were recorded and the whole area of interest (AOI) was meshed using triangular elements.

The deformation gradient F for each triangle was calculated from the undeformed and deformed coordinates of measurement points using the analytical approach adopted in [3] and the theory of finite deformation [4]. A plane stress state and incompressibility (det(F)=1) in plasticity were assumed. Then the logarithmic strain tensor $\varepsilon_{\ln}$ was obtained from the deformation gradient F through the left stretch tensor V ($V^2=F^TF$) as in equation (1).

$$\varepsilon_{\ln} = \sum_{i=1}^{3} \ln(\lambda_i) r_i \otimes r_i \tag{1}$$

where λ_i and r_i are the eigenvalues and eigenvectors of the left stretch tensor V respectively.

2.2. Constitutive model

Choosing a constitutive model which can describe the dynamic strain hardening behavior properly is important. In this study, von Mises yield criterion for isotropic material and Swift model for a rate independent hardening law were chosen as an initial study. The associated flow rule was assumed.

Swift model: $$\sigma_s = K(\varepsilon_o + \varepsilon_p)^n \tag{2}$$

where σ_s is the current yield stress and ε_p the equivalent plastic strain. K, ε_0 and n are the material parameters to be identified.

2.3. The virtual fields method

In this study, the virtual fields method (VFM) was used for an inverse method to retrieve the constitutive parameters from the measured deformation fields. The VFM makes use of the principle of virtual work which describes the condition of global equilibrium. The equilibrium equation in the case of elasto-plasticity for dynamic loading, and in absence of body forces, can be written as follows: