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Modeling and numerical simulation of AA1050-O embossed sheet metal stamping

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Abstract

In this paper, a numerical methodology is presented for the stamping simulation of a embossed sheet. A large strains elastoplastic model based on Hill's anisotropic plasticity criteria and coupled with damage is presented and identified in the case of AA1050-O flat sheets. Finally the stamping of an industrial part is simulated and validate the proposed methodology.

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Keywords: elastoplasticity, ductile damage, AA1050-O sheet, embossed sheet, stamping operation

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1. Introduction

A lot of scientific and industrial works are mainly oriented towards stamping processes. These works are mainly based on behavior models that use a purely isotropic theory of plasticity with isotropic (von Mises type) or quadratic anisotropic (Hill 1948) or even non-quadratic anisotropic [1] criteria. Anisotropies induced by phenomena such as kinematic hardening, yield surfaces distortion or damage are rarely taken into account. Some works use the notion of materials local damage as rupture criterion but without any "strong" coupling between this damage and the other thermomechanical fields (stress, hardening, …). Moreover, the majority of the stamping simulations use laminated smooth sheets. Few studies have proposed solutions to model the deformation of initial complex shape of sheets [2]. In some cases, a rolling operation with shaped rolling mills allows initial embossing of aluminum alloy sheets. Embossed sheets make it possible to obtain complex stamped shapes which would be impossible to obtain from the same smooth sheet steel. In the research field, many approaches are adopted in order to simulate the mechanical behavior of corrugated sheets by using equivalent models, not so much for the doubly curved geometries. Among these efforts, the substitute model approach is strongly used especially for corrugated laminates [3]. Thus, the influence of embossed cross-section geometry on the substitute stiffness matrix of corrugated laminates is investigated. The geometry pattern constitutes then, a mean for tailoring the anisotropy and substitute stiffness modulus [4]. To overcome numerical difficulties, an equivalent classical plate model of corrugated structure is derived using a variational asymptotic method. Thanks to this method, the sets of effective plate stiffnesses and recovery relations are provided in order to obtain the local fields within the corrugated shell [5].
The present paper is based on the strong coupling between the behavior of metals and their ductile damage due to non-linear isotropic and kinematic hardening, anisotropy of plastic flow and anisotropies induced by kinematic hardening. Identification of the model parameters is based on tensile and bulging tests of AA-1050-O aluminum alloy plane sheets. The commercial software ABAQUS® was used as a support for the development of the model and for simulating both the characterization tests and the stamping operations. A c-program in addition to the ABAQUS® software has been developed to describe the mechanical state (deformed configurations, hardening, thickness variation, etc.) of an embossed sheet from a duplication operation of an embossed periodic cell. The effect of the embossing on sheet metal shaping has been studied by means of different types of experimental and numerical tests (tensile tests, Marciniak tests, etc.). The first results show that the modeling of the effect of sheet embossing affects the numerical results of stamping and the vibration behavior of the automotive part. The introduction of the embossing geometry and the variation of thicknesses influence the prediction of the numerical model and more particularly the prediction of severe folds.

2. Modelisation of the AA1050-O embossed sheet

2.1. Elastoplactic model with isotropic ductile damage

This model has been developed in the framework of thermodynamics of irreversible processes with state variables, assuming large plastic strains and small elastic strains and taking into account an initial plastic anisotropy of Hill 1948 type. In this framework, the main constitutive equations used in this study are detailed. The following couples of state variables are used: $(\underline{\varepsilon}^e, \underline{\sigma})$ represents the elastoplastic flow; $(\underline{\alpha}, \underline{X})$ represents the kinematic hardening; *(r, R)* represents the isotropic hardening, and *(d, Y)* represents the isotropic ductile damage [6] and [7]. The strong coupling between the plastic flow with hardening and the ductile damage is performed in the framework of the total energy equivalence assumption, leading to the definition of the effective state variables $(\underline{\tilde{\varepsilon}}^e, \underline{\tilde{\sigma}})$, $(\underline{\tilde{\alpha}}, \underline{\tilde{X}})$ and $(\tilde{r}, \tilde{R})$ through the use of damage-effect functions, see reference [6], [8] and [9] for more detail.

By using the effective strain-like variables defined above in the Helmholtz free energy taken as a state potential, the following state relationships can be easily obtained [4]:

$$\underline{\sigma} = 2\mu_e\left[(1-d)\left\langle \underline{e}^e \right\rangle_+ + (1-hd)\left\langle \underline{e}^e \right\rangle_-\right] + k_e\left[(1-d)\left\langle tr(\underline{\varepsilon}^e)\right\rangle - (1-hd)\left\langle -tr(\underline{\varepsilon}^e)\right\rangle\right]\underline{1} \quad (6)$$

$$\underline{X} = (1-d)\tfrac{2}{3}C\underline{\alpha} \quad (7)$$

$$R = (1-d^{\gamma})Qr \quad (8)$$