



Theoretical study on mechanical properties of AZ31B Magnesium alloy Sheets under multiaxial loading

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ABSTRACT. Numerical simulation by plastic deformation of the shaping processes currently has a large industrial interest. It allows you to shorten the time of design and construction related products and tools to analyze and to optimize processes. An essential part of simulation tools is the constitutive law used to describe the material used. The activity of characterization and modeling of material behavior of the plastic deformation shaping remains a very important research field of activity; the objective of proposing laws of behavior used in computer codes, essentially based on finite element is sufficiently to represent the real behavior of materials.

Considering the nature of the materials used and the stresses they experience the behavior laws account for several requirements which make them increasingly complicated. Among these requirements, we cite in particular plastic anisotropy, the great transformations, the complexity and diversity of loads, etc.

The complexity of these laws makes them more difficult to implement and in particular to identify: the classic tests are no longer sufficient for identification. The objective of this work is based on two essential points: Suggest a construction strategy, particularly of identifying laws elastoplastic behavior anisotropic operational for the numerical simulation of plastic deformation shaping processes with particular attention to sheet metal magnesium.

Magnesium sheet metal manufacturing process involves rolling operation. In a cost-cutting goal, this operation now takes place cold, implying a very marked anisotropy of the material at the output of the mill.

KEYWORDS. Mechanical behavior; Tensile test; Loading direction; Lankford coefficient; Identification.



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INTRODUCTION

A large majority of the metal parts are obtained by forming during which the material is plastically deformed. These forming processes are optimized to reduce cost; this requires manufacturers to increasingly use numerical simulation and therefore need to describe the material behavior.

These simulations are often flawed by a simplified description of the plastic behavior of the material; particularly the anisotropy of rolled sheets [1-3]. Therefore, it is important to accurately model the plastic behavior of metals in large deformation in order to better predict the behavior of the part during the forming. The formulation of the anisotropic elasto-plastic behavior in large deformations is well understood now: using the formalism of rotating frame ensures the objectivity of the behavior law regardless of the constitutive model functions, [2-5].

To describe the plastic behavior of the material, it is necessary to clarify two concepts: (i) a load surface related to a plasticity criterion [6] that indicates the conditions of plastic flow, (ii) an anisotropy evolution.

The experimental determination of these areas through various mechanical testing and mathematical modeling has been the subject of many research efforts such as using the Von Mises criterion: due to its implementation in most commercial finite element analysis codes. This criterion is called energy criterion in which the elastic deformation energy of the material must not exceed a limit value in order to remain within the elastic range.

In the case sheet metal, the material is treated as having orthotropic plasticity where retained three preferred directions used in the expression of the Hill criterion.

Also, in order to describe the asymmetric behavior in tension and compression such as the anisotropy of a structure of a sheet metal Cazacu, Barlat and al proposed in a new orthotropic criterion [7-11].

The objective of this work is to provide a model for the numerical simulation of forming processes by plastic deformation of thin metal sheets. Hence, the importance of developing a general framework for elasto-plastic orthotropic models (initial orthotropic and isotropic hardening) based on the choice of an equivalent stress, a hardening law and a plastic potential [12-14] and a model identification strategy using an experimental database [15].

This database consists of various hardening curves from various tests interpreted as homogeneous [2] and their Lankford coefficients. These plates are obtained from a hot-rolling process. At this point, the identification of constitutive parameters of the material behavior laws is an important step. A new identification strategy with its validation using Barlat's criterion will be presented.

ANISOTROPIC ELASTO-PLASTIC CONSTITUTIVE LAWS

In this work, we are interested in a plastic hardening behavior. The materials are treated as incompressible with negligible elastic deformations. The plastic hardening constitutive laws that we have to study fall within the following framework:

$$\bar{f}(\bar{\sigma}, \bar{\alpha}) \leq 0, \bar{\alpha} = \mathbf{Q}[\alpha] \tag{1}$$

with \mathbf{Q} the transformation tensor between the initial time t_0 and the current time t .

α Represents the internal hardening variable.

$$\bar{\mathbf{D}} = \lambda \bar{h}(\bar{\sigma}, \bar{\alpha}) \tag{2}$$

$$\dot{\bar{\alpha}} = \lambda \bar{l}(\bar{\sigma}, \bar{\alpha}) \tag{3}$$

With λ plastic multiplier that can be determined from the consistency condition $\dot{\bar{f}} = 0$ and $\bar{\mathbf{D}}$ is the plastic strain rate tensor.

This work is limited to plastic orthotropic behavior. Models are formulated for standard generalized materials with an isotropic hardening described by an internal hardening variable, a law of evolution and an equivalent deformation. The material is initially orthotropic and remains orthotropic; isotropic hardening is assumed to be captured by a single scalar internal hardening variable denoted by α . In particular, we will assume that the elastic range evolves homothetically, the yield criterion is then written as follows:



$$f(\bar{\sigma}^D, \alpha) = \sigma_c(\bar{\sigma}^D) - \sigma_s(\alpha) \tag{4}$$

$\bar{\sigma}^D$ is the deviator of the Cauchy stress tensor (incompressible plasticity).

Using the special setup of the space deviators, the general form of the equivalent orthotropic plan stress, is thus:

$$\sigma_c(\bar{\sigma}^D) = \sigma_c(\bar{X}_1, \bar{X}_2, \bar{X}_3) = |\bar{\sigma}^D| / f(\theta, 2\psi) \tag{5}$$

With $\bar{X}_1 = |\bar{\sigma}^D| \cos\theta$; $\bar{X}_2 = |\bar{\sigma}^D| \sin\theta \cos 2\psi$; $\bar{X}_3 = |\bar{\sigma}^D| \sin\theta \sin 2\psi$

Any type of criterion (4) can be written in the form:

$$f(\theta, 2\psi) = |\bar{\sigma}^D| / \sigma_s(\alpha) \tag{6}$$

Where θ is the angle that defines the test and ψ the off-axis angle [12-14].

Test	Expansions Equibiaxes (E.E)	Simple Traction (S.T)	Large Traction (L.T)
θ	$\pi/3$	$\pi/6$	$\pi/2$

Table 1: Values of θ relative to the various tests

IDENTIFICATION PROCEDURES

In this section we focus on the phenomenology of plastic behavior; especially modeling plasticity and hardening based on experimental data represented as families of hardening curves, and Lankford coefficient data. In order to simplify our identification process, the following assumptions are adopted:

Identification through “small perturbations” process, the tests used are treated as homogeneous tests, we neglect the elastic deformation; the behavior is considered rigid plastic incompressible, the plasticity surface evolves homothetically (isotropic hardening) and all tests are performed in the plane of the sheet resulting in a plane stress condition.

The identified model is defined by an equivalent stress $\sigma_c(\mathbf{A}; \sigma^D)$ when σ_c is an isotropic function; it is assumed that the shape is defined by coefficient of the form m , \mathbf{A} is the 4th order orthotropic tensor defined by anisotropy coefficients f, g, h, n' and the hardening curve $\sigma_s(\alpha)$.

Knowing that hardening's curve $\sigma(\epsilon)$ is determined from experimental tests as $r(\psi)$. We can also begin our identification procedures using the Lankford coefficient; as determined from the tensile test by:

$$r = \dot{\epsilon}_2 / \dot{\epsilon}_3 = -1 / (1 + \dot{\epsilon}_1 / \dot{\epsilon}_2) \tag{7}$$

We can notice that the Lankford coefficient is independent of ϵ . This coefficient is equal to one in the case of isotropy, and remains constant in the case of transverse isotropy. However, in the case of orthotropy, it varies depending on the off-axis angle ψ . This coefficient completely characterizes the anisotropy of the sheet when loaded in its plane.

RESULTS AND DISCUSSIONS

This identification strategy requires:

- Experimental database.
- Criterion for anisotropic plasticity.



– Validation strategy

In the particular case of Magnesium sheets where anisotropy is present, the identification of this constitutive law requires the identification of the hardening function, the anisotropy coefficients, the form factor m and $r(\psi)$ the Lankford coefficient. Using as a hardening function a Hollomon law:

$$\sigma_s = k\varepsilon^n \tag{8}$$

And as a plasticity criterion using the Barlat model [6]:

$$\sigma_c^m = |q_1 - q_2|^m + |q_2 - q_3|^m + |q_1 - q_3|^m \tag{9}$$

Where q_1, q_2 and q_3 are the eigenvalues of the tensor \mathbf{q}

$$\sigma_c(\mathbf{q}) - \sigma_s(\alpha) \leq 0. \text{ Where } \mathbf{q} = \mathbf{A}(a_i): \boldsymbol{\sigma} \text{ thus } \mathbf{q} = \boldsymbol{\sigma} \mathbf{A}(a_i): a \tag{10}$$

Using the simplex algorithm and using the plastic Barlat model and respecting the assumptions, the identification of the thin Magnesium sheet is equivalent to choosing the model coefficients while minimizing the squared difference between the theoretical and experimental results.

ψ	k	n
00°	408.5	0.102
22.5°	410.6	0.096
45°	425.6	0.101
67.5°	432.5	0.0901
90°	437.1	0.0873

Table 2: Identification of the constants of hardening law for different tractions tests.

Knowing that the coefficient n is the same for all tests as demonstrated at the beginning of this work, by convention we choose n for traction in direction $\psi = 00^\circ$ as reference. For $n=0.102$, we present different values of k (see Tab. 3).

ψ	k
00°	418.1
22.5°	418.1
45°	427.1
67.5°	447.3
90°	455

Table 3: Identification of the constant hardening law for fixed n .

In Fig.1, the experimental hardening curve (exp) and the curve identified from a model (iden) using an average value of n are represented. For tensile tests, the models (iden) give a clear fit between the theoretical and experimental results. Our second identification step amounts to determining the coefficients of anisotropy (f, g, b, n) and the shape coefficient m (Tab. 4), considering the non-quadratic Barlat's criterion (9).

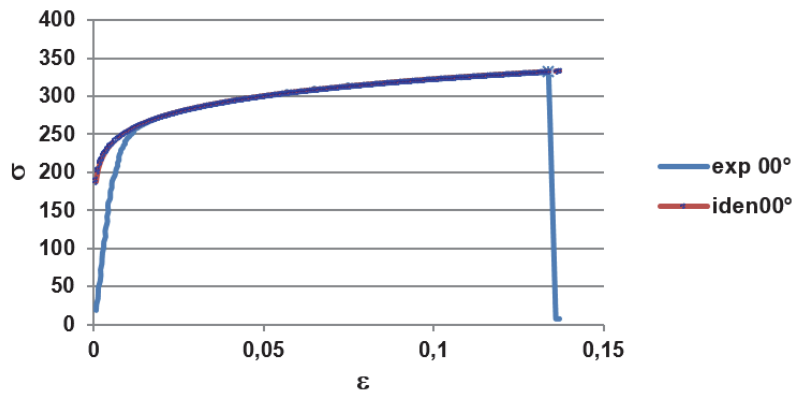


Figure 1: Identification of the hardening curve: $\psi = 00^\circ$.

f	g	b	n'	m
0.137	0.0992	1.4889	3.104	1.1999

Table 4: Identification of anisotropic coefficients and a shape coefficient m

In Fig. 2 the model (ident) allows us to study the load surface on each test. We note that this material is resistant to simple shear like simple traction.

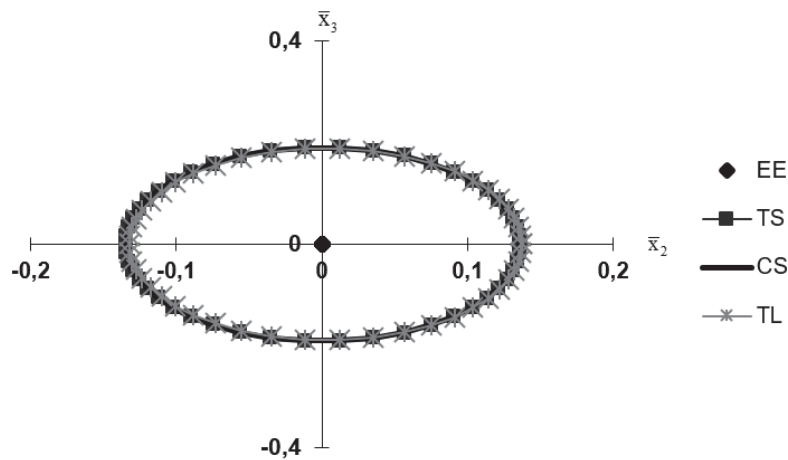


Figure 2: Evolution of the load surface in the deviatoric plan (\bar{x}_2, \bar{x}_3) .

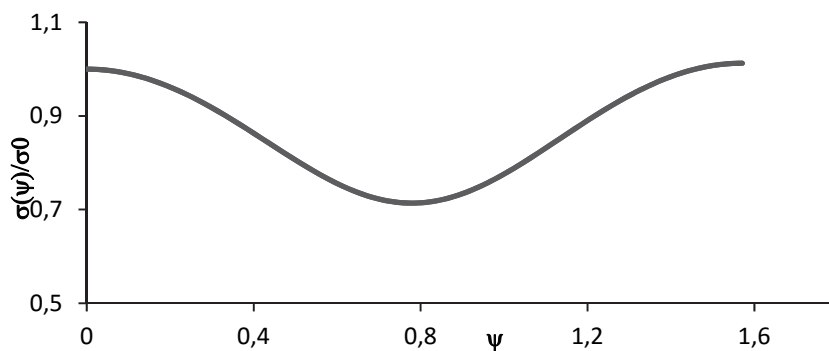


Figure 3: Evolution of the anisotropy.



Using the identified anisotropic coefficients, we represent in Fig. 3 the evolution of the anisotropy based on off-axis angles; using the Barlat's criterion this material is very anisotropic at $\psi = 45^\circ$.

CONCLUSION

In this work we show that identification strategy results can be extracted. This identification has focused both on plastic material parameters of the constitutive law and Lankford coefficient. Thus, the plastic behavior model: Hollomon Law and Barlat criterion with 5 parameters are identified. A validation by comparing model / to experiment data was performed. The model using the Barlat's criterion is in good agreement with experimental results relating to Lankford coefficients. Following this strategy, we observed very pronounced anisotropy of AZ31BMagnesium and the load surface for different tests at the end of this identification. With this strategy, we can study in a more precise way the anisotropy of the Magnesium model by integrating Barlat in integrating the model Hill.

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