Implantation by an implicit approach of an elastoplastic behaviour law in the finite element cast3m code

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Résumé

Ce papier est dédié à l'implantation d'une loi de comportement mécanique dans le logiciel éléments finis Cast3M à l'aide d'un générateur de code open source nommé Mfront. Pour ce faire, un modèle de comportement élasto-plastique a été choisi à partir des lois existantes dans la littérature. Suivant une discrétisation implicite, une bibliothèque matérielle correspondant au modèle de CHABOCHE à écrouissage isotrope et cinématique non linéaire est générée grâce à Mfront. L'interface informatique UMAT est utilisée pour construire la bibliothèque dans Cast3M. Une validation de l'approche a été menée en comparant les résultats numériques obtenus entre la bibliothèque matérielle générée et la bibliothèque équivalente préexistante dans Cast3M. Les simulations dans le cas d'une barre en traction et une plaque trouée montrent des résultats quasi identiques.

Mots Clés

Intégration du comportement mécanique; Modèle élastoplastique de CHABOCHE; Simulation numérique; Mfront; Cast3M

Abstract

This paper is dedicated to the implementation of a law of mechanical behavior in the finite element software Cast3M using an open source code generator named Mfront. To do so, an elastoplastic behaviour model has been chosen from existing laws in the literature. Following an implicit discretization, a hardware library corresponding to the isotropic and kinematic strain-hardening model is generated using Mfront. The UMAT computer interface is used to build the library in Cast3M. A validation of the approach has been carried out by comparing the numerical results obtained with the generated hardware library and the equivalent pre-existing library in Cast3M. Simulations in the case of a tensile bar and a perforated plate show almost identical results.

I INTRODUCTION

Simulation and numerical analysis have been developed over the last decades in industrial research (automotive, aeronautics...), improving industrial productivity, minimizing design costs and product quality [1-3]. Engineers are often confronted with the problems of safety and durability of structures. These problems necessarily require a better knowledge of the behavior of the materials used in the elaboration of these structures. Nowadays, many mechanical parts are made from new materials. These materials can have complex behavior: sensitive to strain rate, temperature, etc. Numerous models of mechanical behavior have been developed to describe the elastoplastic/viscoplastic behavior of a large number of materials [4]. In order to predict the behaviour of mechanical parts subjected to a set of complex stresses, the use of numerical methods, such as the finite element method (FEM), is essential. The quality of numerical prediction is strongly dependent on the law of mechanical behavior used. The numerous FEM software packages available on the market (ANSYS [5], Cast3M [6], ABAQUS [7], etc.), offer users a variety of behavioral laws for different problems. However, in certain situations, engineers are often led to develop or use a mechanical behaviour law that is not available in the software used. In these cases, it is necessary to know how to implement in the software of one's choice, a mechanical behaviour law of some kind. To date, significant progress has been made in the development of methodologies for implementing mechanical behavior laws in existing software. Bergheau et al. [8, 9] have proposed a methodology for the integration of a behavioral model coupling elastoviscoplasticity and damage for the study of a nuclear vessel requiring the consideration of creep and damage phenomena. Bernard et al. [10]have studied two behaviour models through two FEM computation codes: a simple phenomenological model, introduced in Cast3M, and a micromechanical model, introduced in ABAQUS/Explicit. Helfer et al. [11,12]have developed a tool to help the integration of new behavioural laws in the Cast3M calculation code and the CODE ASTER. The aim of this paper is to implement a law of elastoplastic behaviour of CHABOCHE in the finite element analysis software Cast3M, via the UMAT computer interface. We will use the Mfront tool developed by Helfer [13]. Finally, the implemented behaviour law will be validated on simple geometries to ensure its conformity.

II PRESENTATION OF THE MATERIAL BEHAVIOR MODEL.

The material behavior model that will be used in this paper is CHABOCHE's isotropic elastoplastic behavior model with nonlinear kinematics and nonlinear strain-hardening [4]:

- Stress-strain-elastic deformation relationship:

$$\underline{\sigma} = \underline{\underline{D}} : (\underline{\varepsilon}^{to} - \underline{\varepsilon}^{p}) \tag{1}$$

$\underline{\sigma}$: stress tensor, $\underline{\varepsilon}^{to}$: strain tensor, $\underline{\varepsilon}^{p}$: plastic strain tensor
- Plasticity criteria :

$$F(\underline{\sigma}, \underline{X}) = (\sigma - \underline{X})_{eq} - R(p) \leq 0 \tag{2}$$

$(\sigma - \underline{X})_{eq}$: equivalent stress of Von Mises, $\underline{X}$: kinematic strain hardening,
p : cumulative plastic strain, $R(p)$: isotropic strain-hardening

- Evolution of plastic strain: Law of normality:

$$\underline{\dot{\varepsilon}}^p = \dot{p}\underline{n} \tag{3}$$

$$\text{With } \underline{n} = \frac{3}{2}\frac{\sigma - X}{(\sigma - \underline{X})_{eq}}$$

- $\underline{X}$ Represents non-linear kinematic strain-hardening. Combination of 2 kinematic strain-hardening $\underline{X} = X_1 + X_2$;
- Kinematic strain-hardening X_i:

$$\underline{X_i} = \frac{2}{3}c_i\underline{\alpha_i} \tag{4}$$

$$\underline{\dot{\alpha_i}} = \underline{\dot{\varepsilon}}^p - \gamma_i\underline{\alpha_i}\dot{p} \tag{5}$$

- The isotropic strain-hardening function R(p) is defined by:

$$R(p) = R^\infty + (R^0 - R^\infty)exp(-bp) \tag{6}$$

$R^\infty, R^0, b, c_1, c_2, \gamma_1, \gamma_2$: constants of CHABOCHE's law

The identified values of the constants of CHABOCHE's law are presented in Table 1.

Table 1: Constants of CHABOCHE's law

Constants	R^∞	R^0	b	c_1	c_2	γ_1	γ_2
Values	150	150	0	309	3343	149	103

III   DISCRETIZATION BY THE IMPLICIT METHOD.

The discretization of the equations of the law of behavior is carried out according to an implicit algorithm. Thus, the implicit scheme consists in determining the quantities $Y|_{t+\Delta t}$ at time $t+\Delta t$ from the same quantity at time t, $Y|_t$ [14]. The discretized function to be solved is presented in equation 7:

$$F = (\sigma, X) = 0 \leftrightarrow \begin{cases} (\sigma|_{t=\Delta t} - \underline{X}|_{t+\Delta t})_{eq} - R(p(t+\Delta t)) & = 0 \\ \Delta\underline{\alpha_i} - \Delta\varepsilon^p = \gamma_i(\alpha_i + \Theta\Delta\underline{\alpha_i})\Delta p & = 0 \\ \Delta\underline{\varepsilon}^{el} - \Delta\underline{\varepsilon}^{to} + \Delta\underline{\varepsilon}^p & = 0 \end{cases} \tag{7}$$

According to this algorithm, the hardware library of CHABOCHE's law is built using an open source code generator "Mfront", compatible with the Cast3M software, thanks to the UMAT computer interface [11].

IV RESULTS AND DISCUSSIONS

In this section, we present the results of numerical simulations obtained from our constructed hardware library. Our results will be compared with the equivalent model existing in the Cast3M code. In a first step, the hardware library is used on hardware point simulations. In a second step, the simulations are performed on a bar and a plate with hole in tension

4.1 Simulation on material point.

The simulations presented in this paragraph are carried out using an open source tool to simulate the mechanics of a material point called "Mtest" [15]. The simulations are performed for repeated and completely reversed traction/compression loading cycles. In this part, we will be using our library built materials ;

4.1.1 Loading cycle completely reversed.

The simulation of the material behavior is carried out for a loading cycle with completely reversed imposed strain in the range $[-0.007; 0.007]$. Figure 1 shows the imposed strain loading and the material response, respectively.
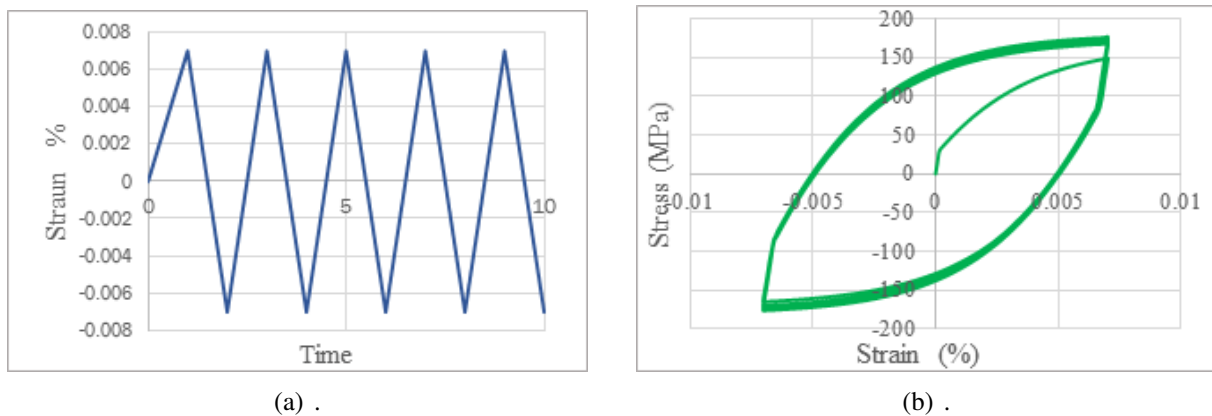

(a) . (b) .

Figure 1: (a) reversed top-up loading cycle (b) simulation result obtained on material point

Figure 1a presents the answer obtained from our material library of CHABOCHE's elastoplastic law for a uniaxial, cyclic loading, completely reversed (figure 1a). We observe in figure 1b a material behavior describing a stabilized hysteresis curve, called accommodation. This result is consistent with the observations made in the literature by other authors on the law of elastoplastic behaviour for this type of loading [4].

4.1.2 Repeated loading cycle.

In this paragraph, the simulation is carried out for a loading cycle with repeated imposed strain between 0 and 0.007%. Figure 2 shows the loading cycle and its material response respectively.

Figure 2b shows the material response obtained for the deformation cycle in Figure 2a. As in the case of the reverse cycle, we also see an accommodation response for this loading case.
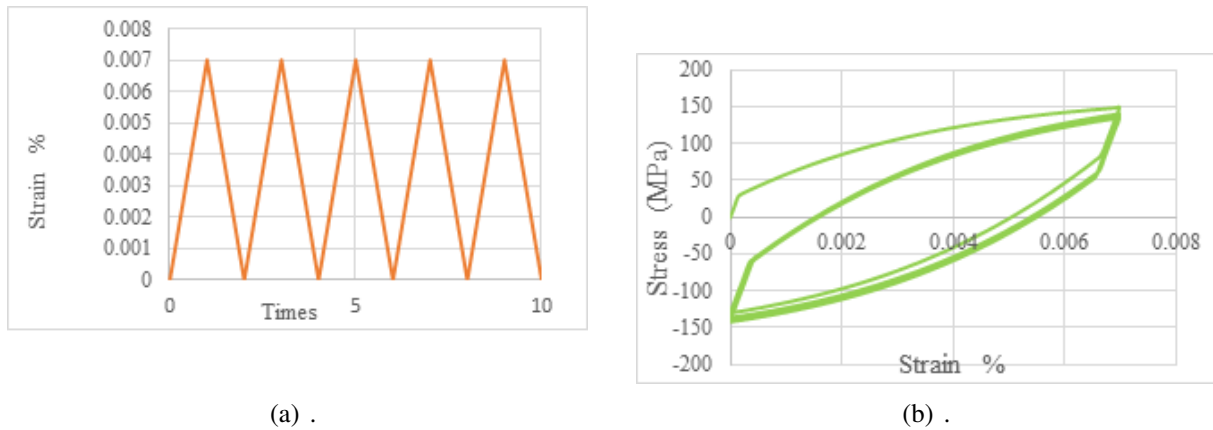
(a) .   (b) .

Figure 2: (a) repeated top-up loading cycle, (b) simulation result obtained on material point

4.2 Structural simulation

The simulations presented in this section are all performed in Cast3M. The objective is to compare the results generated by our material library and the library available in Cast3M. The simulations are performed for a plain axial tensile load on a rectangular bar and a plate with hole.

4.2.1 Structures studied

The 2D bar is meshed by QUAD4 type elements (figure 3a). The plate with hole is meshed with TRI3 type elements (see figure 3b). Figure 3 shows the dimensional characteristics and meshing of the bar and the perforated plate in tensile.
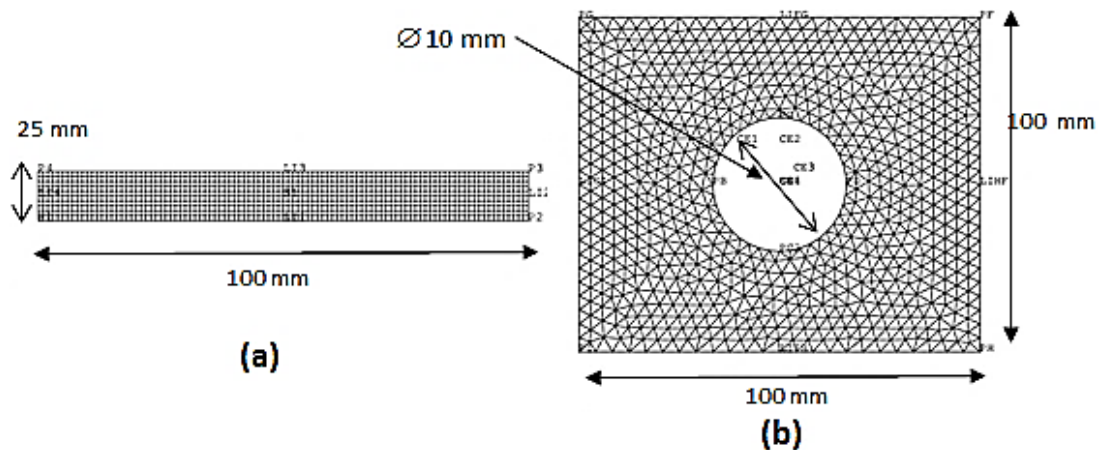

Figure 3: Dimensional characteristics and meshing of structures

4.2.2 Results on rectangular bar

The simulations carried out in this paragraph are performed for a tensile load of 20 kN. A zero imposed displacement is applied on one of the faces of the bar. The load is applied on the opposite side. Figure 4 presents the stress maps of the structure obtained from our material library and the one existing in Cast3M.

Figure 4 a illustrates the constraint mapping obtained from our material library. Figure 4b presents the stress mapping for the equivalent model library available in Cast3M. Regardless of

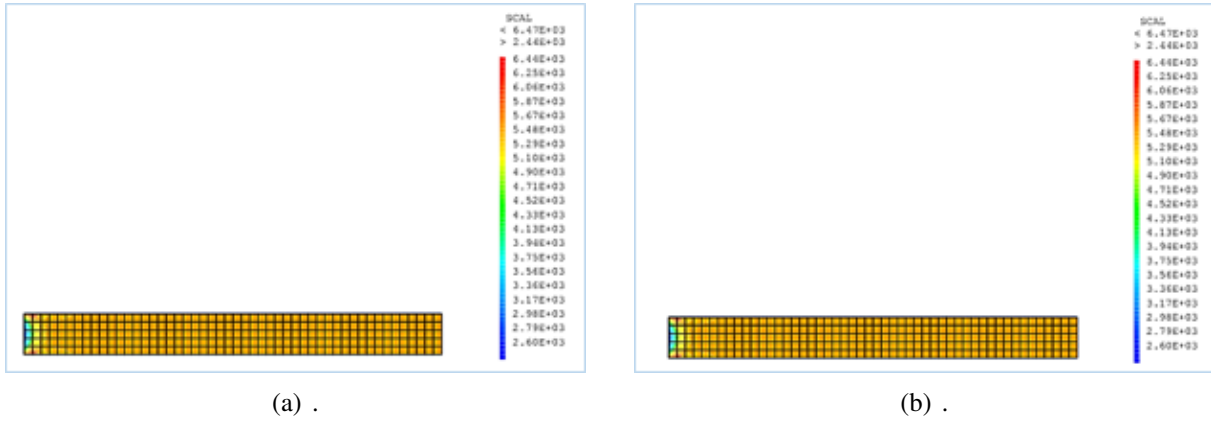(a) .   (b) .

Figure 4: Stress mapping obtained for the case of a bar in tension: (a) using the compiled model (our built library) and (b) equivalent behavior model available in Cast3M

the constraint mapping considered, we find that the stress values are identical. The observed stresses have a minimum value of 260 MPa and a maximum value of 644 MPa.

In figure 5a, a second result confrontation is performed by comparing the response curves (stress-strain) for cyclic stress with imposed strain. We can observe on this figure 5 that our library generates the same curve as the one generated by the equivalent reference model available in Cast3M.
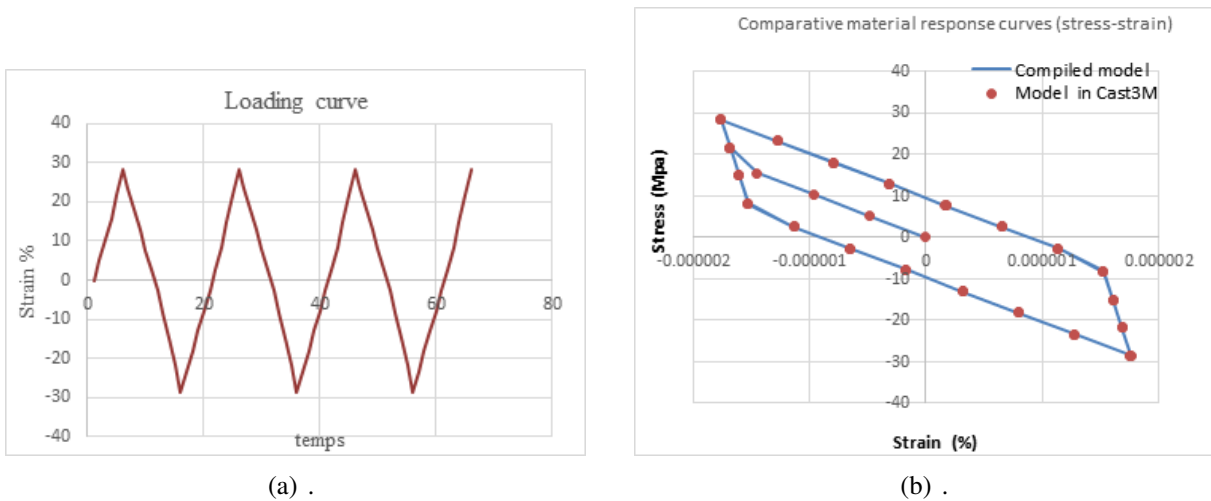

(a) .   (b) .

Figure 5: (a) imposed loading (b) comparison of the response curves of the Compiled model and the model available in Cast3M

4.2.3   Results on plate with hole.

The simulations carried out on the plate containing a hole as we present in this paragraph, are performed for a tensile load of 1kN. This load is applied on the opposite side to the one where a zero displacement is imposed. After simulation, we obtain the stress maps of figure 6.

Figure 6a illustrates the stress mapping obtained from our material library. We find a stress that evolves from a Minimum value of 129 MPa to a Maximum value of 1470 MPa. Figure 6b on the other hand presents the stress mapping for the library of the equivalent model available in

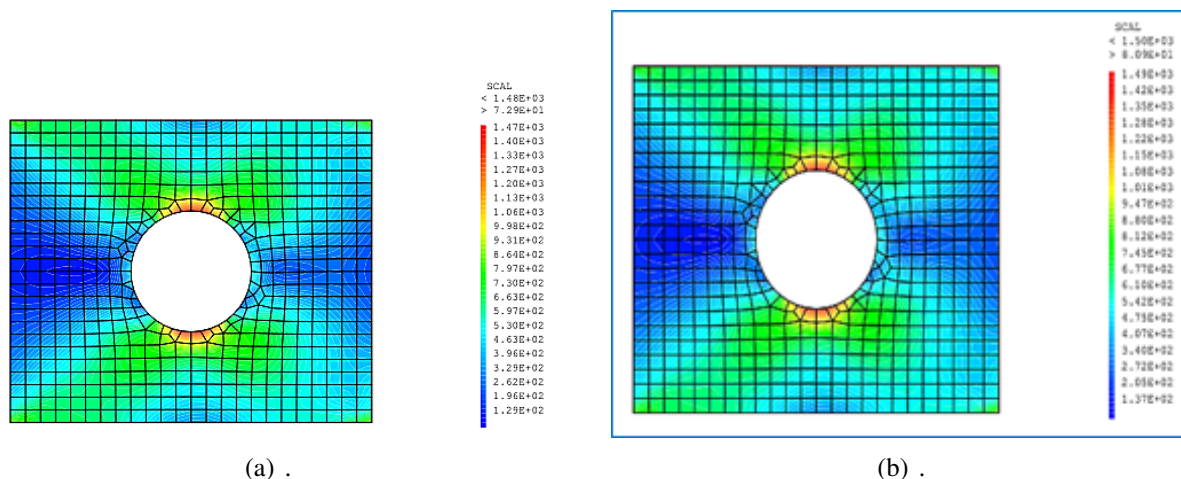(a) .   (b) .

Figure 6: Stress mapping obtained for the case of a plate with hole in tension: (a) using the compiled model (our built library) and (b) equivalent behavior model available in Cast3M

Cast3m. It can be seen that the stress evolves from a Minimum value of 137 MPa to a Maximum value of 1490 MPa.

V   CONCLUSION

This paper presented a successful implementation of a law of mechanical behavior in a finite element software Cast3M. A material library of CHABOCHE's behaviour law has been defined thanks to the Cast3M compatible Mfront code generator using the UMAT computer interface. In a first step, simulations performed on material points from the Mtest tool [15] for different cyclic loading cases gave satisfactory results. In a second step, the implemented behavior law was validated by comparing the simulations on simple geometries in Cast3M. The confrontation consisted in comparing the results obtained from our new library with the existing equivalent library in Cast3M. The stress maps obtained in the case of a bar and a plate with holes in tension are practically similar for the two material libraries.

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