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IMPLEMENTATION BY AN IMPLICIT APPROACH OF AN ELASTOPLASTIC BEHAVIOR LAW IN THE FINITE ELEMENT CAST3M CODE

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Abstract. The implementation of a law of mechanical behavior into the finite element software Cast3M using an open source code generator named Mfront is realized. An elastoplastic behavior model is chosen from the 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 is carried out by comparing the numerical results obtained with the generated hardware library and the equivalent pre-existing library in Cast3M. The simulations for the case of a tensile bar and a perforated plate show almost identical results.

Key words: implementation of behavior law, elastoplastic medium, finite elements, Cast3M, Mfront.

Introduction.

The 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]. The 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 the 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 behavior 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 behavior 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 behavior 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 behavior 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 behavioral laws in the Cast3M calculation code and the CODE ASTER.

The aim of this paper is to implement a law of elastoplastic behavior 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 behavior law will be validated on simple geometries to ensure its conformity.

1. 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:

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

Plasticity criteria:

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

Evolution of plastic strain: Law of normality:

$$\underline{\dot{\varepsilon}^{p}} = \dot{p}\underline{n} \ \text{ with } \ \underline{n} = \frac{3}{2}\frac{\tilde{\sigma} - X}{(\sigma - \underline{X})_{eq}}. \tag{3}$$

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

Kinematic strain-hardening $\underline{X_i}$:

$$\underline{X_i} = \frac{2}{3} c_i \underline{\alpha}_i. \tag{4}$$

$$\underline{\dot{\alpha}_i} = \underline{\dot{\varepsilon}^{p}} - \gamma_i \underline{\alpha}_i \dot{p}. \tag{5}$$

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

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

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

Table

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

2. 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 the equation:

$$F \leftrightarrow \begin{cases} (\underline{\sigma}|_{t+\Delta t} - X|_{t+\Delta t})_{eq} - R\big([(p(\ \ )]_{t+\Delta t})\big) = 0; \\ \Delta\underline{\alpha}_i - \Delta\underline{\varepsilon^{p}} + \gamma_i(\underline{\alpha}_i + \theta\Delta\underline{\alpha}_i)\Delta p = \underline{0}; \\ \Delta\underline{\varepsilon^{ol}} - \Delta\underline{\varepsilon^{to}} + \Delta\underline{\varepsilon^{p}} = \underline{0}. \end{cases} \tag{7}$$

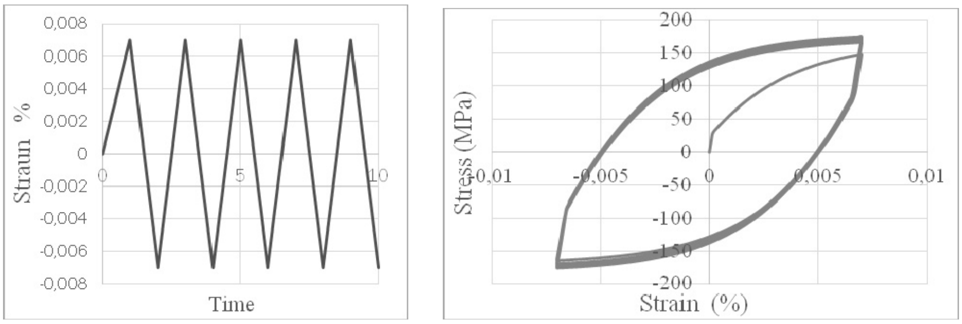
According to this algorithm, the hardware library of CHABOCHE's law is built using an open source code generator "Mfront", compatible with the Cast3M software, thanks to the UMAT computer interface [11].

3. 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.

3.1. 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.

3.1.a. 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]. Fig. 1 shows the imposed strain loading and the material response, respectively.

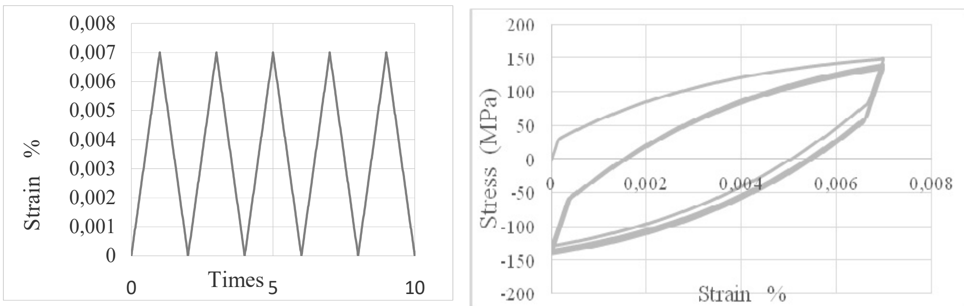


a *b*

Fig. 1 (a) reversed top-up loading cycle, (b) simulation result obtained on material point

Fig. 1, *b* presents the answer obtained from our material library of CHABOCHE's elastoplastic law for a uniaxial, cyclic loading, completely reversed (fig. 1, *a*). 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 behavior for this type of loading [4].

3.1.b. Repeated loading cycle. In this paragraph, the simulation is carried out for a loading cycle with repeated imposed strain between 0 and 0,007%. Fig 2 shows the loading cycle and its material response respectively.



a *b*

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

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

3.2. 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.

3.2.1. Structures studied. The 2D bar is meshed by QUAD4 type elements (fig. 3, *a*). The plate with hole is meshed with TRI3 type elements (fig. 3, *b*). Fig. 3 shows the dimensional characteristics and meshing of the bar and the perforated plate in tensile.

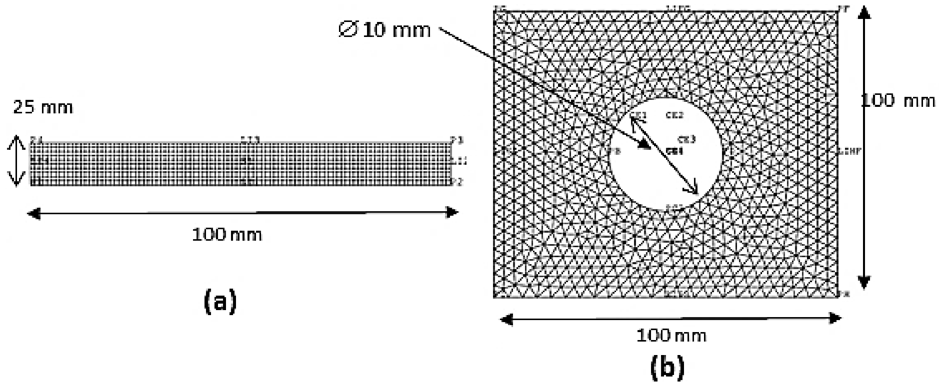
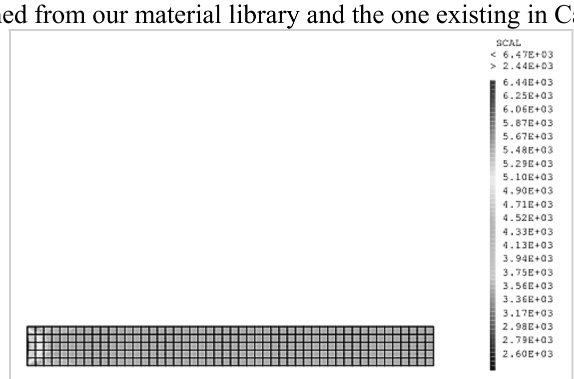
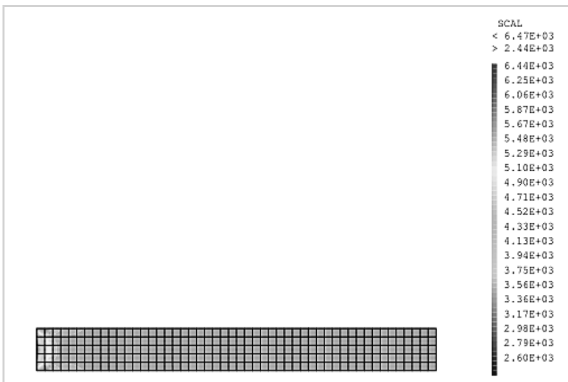


Fig. 3 Dimensional characteristics and meshing of structures

3.2.2. 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. Fig. 4 presents the stress maps of the structure obtained from our material library and the one existing in Cast3M.



a

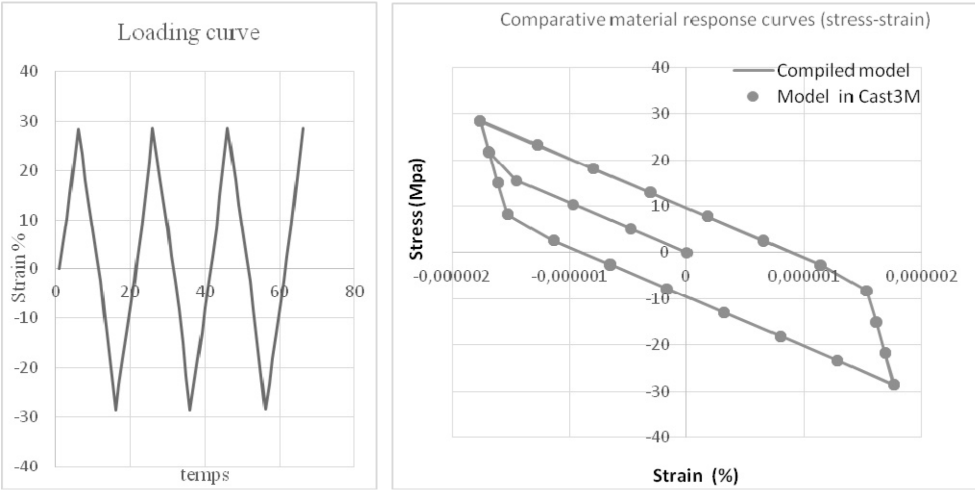


b

Fig. 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

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

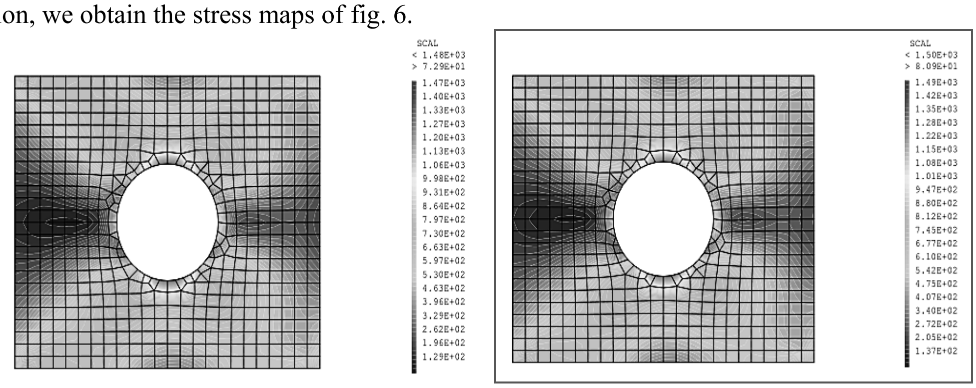
In fig. 5, *a*, a second result confrontation is performed by comparing the response curves (stress-strain) for cyclic stress with imposed strain. We can observe on this fig. 5 that our library generates the same curve as the one generated by the equivalent reference model available in Cast3M.



a *b*

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

3.2.3. 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 fig. 6.



a *b*

Fig. 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

Fig. 6, *a* 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. Fig. 6, *b* on the other hand presents the stress mapping for the library of the equivalent model available in Cast3m. It can be seen that the stress evolves from a Minimum value of 137 MPa to a Maximum value of 1490 MPa.

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 behavior 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.

РЕЗЮМЕ. Використано закон механічної поведінки середовища в програмі скінченних елементів Cast3M за допомогою генератора відкритого коду Mfront. Модель пружнопластичної поведінки вибирається з існуючих в літературі законів. Після неявної дискретизації за допомогою Mfront генерується бібліотека, що відповідає ізотропній та кінематичній моделі деформаційного зміцнення. Комп'ютерний інтерфейс UMAT використовується для створення бібліотеки в Cast3M. Перевірка підходу здійснюється шляхом порівняння чисельних результатів, отриманих із згенерованою бібліотекою та еквівалентною попередньо існуючою бібліотекою в Cast3M. Моделювання для випадку стержня, що розтягується, і перфорованої пластини показує майже ідентичні результати.

КЛЮЧОВІ СЛОВА: використання закону поведінки середовища, пружнопластичне середовище, скінченні елементи, бібліотека з Cast3M, програма Mfront.

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From the Editorial Board: The article corresponds completely to submitted manuscript.

Надійшла 24.09.2020 Затверджена до друку 13.12.2022