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Simulation in 2D of a Martensitic Transformation in a Ferrous Alloy

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Abstract

It is noted in experiments that a test-tube undergoing a transformation of phase under a mechanical loading, even lower than the elastic limit, present a residual deformation much more important than the simple change of volume associated with the transformation. This plastic deformation, added with that generated by the changes with volume, plasticity of transformation is called. It is as well observed at the time of diffusive transformations like for the martensitic transformations. At the time of a martensitic transformation, martensite slats are created, each one in a random direction and create a microscopic deformation according to this direction. From a macroscopic point of view, the deformation is isotropic and corresponds to the change of volume at the time of the transformation. If the same transformation is operated under loading, even very weak, the martensite slats tend to be directed in the direction of the request. Then, in addition to the change of volume, this preferential orientation creates a macroscopic deformation in the direction of request.
In this work, one proposes a method of quantification of this deformation of the plasticity of transformation, which is induced by this structural change, by using the model of WEN. This model is a micromechanical model two-dimensional, with a grid with triangular basic elements. The grid of the cell breaks up into two zones: a central zone (of a size of 14x14) where the transformation occurs and a second zone, which represents the surrounding medium, in the objective to ensure the interactions with the close grains. The total size of the grid is of 22x22 bricks. This modelling takes into account the transformations anisothermes. The selection criterion of the plates is controlled not only by driving energies (i.e. the mechanical driving force and the chemical driving force), but also by a resistive

energy. It east represents by the energy of interaction associated with the transformation.

Keywords: Martensitic transformation, Model of Wen, Grain, Plasticity of Transformation, Plastic deformation, Microstructure, Change of Volume

1. Introduction

The operations of welding as well as the heat treatments generate thermal cycles which lead to phase shifts in a solid state. The thermal cycles are characterized by a heating followed by a cooling. The amplitude and the duration of this thermal way vary according to proceeds applied.

The thermal cycles lead to metallurgical modifications of material in the zone where the maximum temperature obtained with the heating is sufficiently important. These metallurgical modifications lead to a deformation of transformation because of the differences in compactness concerned by structure transformations. This deformation of transformation is added to the purely thermal deformation of origin. In the presence of constraints, even lower than the limit elastic of material at the temperature considered, one can observe a plastic deformation which occurs only during the advance of the transformation. This unrecoverable deformation is called plasticity of transformation (TRIP) [1].

In this work we analyze the evolution of TRIP and of the total mechanical deformation in steel 16MND5 with use of the digital model of Wen, by considering that the transformation is completely martensitic under a loading of uniaxial traction. The loadings applied are about 200, 100 et 50 Mpa.

2. Plasticity of transformation

The plasticity of transformation (Transformation Induced Plasticity ou TRIP) is the permanent deformation noted in steels undergoing a metallurgical transformation under a mechanical load lower than the elastic limit of the least hard phase. It is necessary to call upon models dedicated to predict it. Existing models, like that of Leblond [4] and its extension suggested by Taleb and Sidoroff [7] are particularly interesting, because they provide laws of evolution of the rate of TRIP according to the voluminal fraction of formed phase, laws which can be integrated in computation softwares of structure for the prediction of the consequences of interactions mechanics-thermics-metallurgy. Whereas many work showed the potential of these models to predict it TRIP for constant uniaxial loadings (Fig. 1) [9]

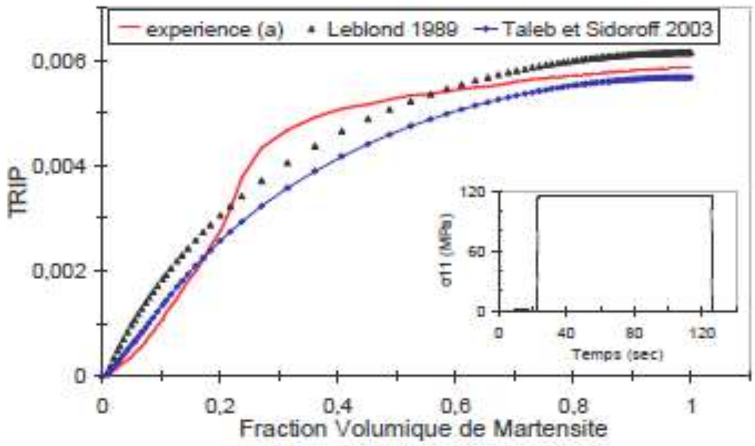

Fig. 1: Plasticity of transformation according to the voluminal fraction of martensite in steel 35NCD16 for a constraint equalizes with 118 MPa. Comparison enters the experiment and the models of Leblond [4] and of Taleb and Sidoroff [7].

2.1. Structure of the analytical models

The majority of the models of the plasticity of transformation, currently used in the structural analyzes are related to the transformations by diffusion. They are based on the mechanism of Greenwood and Johnson [5]. in the case of the transformations of phases, which develop under the effect of a weak loading and under the assumption that this constraint remains constant during the transformation, the principal existing models describing the plasticity of transformation can be written in the form of product of three functions: k, f2 and f3 [5],[8] :

$$\dot{\varepsilon}^{pt} = k(\frac{\Delta v}{v};\sigma_1^{\ y}) \times f_2(z)\dot{z} \times f_3(\underline{s};\sigma_y(z)) \quad (1)$$

ε^{pt} **:** The tensor of the plasticity of transformation.

$\frac{\Delta v}{v}$ **:** Voluminal variation relative graft phases produced and relationship.

σ_1^y **:** Elastic limit of the austenitic phase.

Z **:** Voluminal fraction of the produced phase

$\underset{-}{S}$ **:** The derivative tensor of constraints due to the loadings applied.

σ_y **:** Elastic limit of the mixture

3. Principal numerical models simulating the transformations of phases

Majority of work in this field, generally direct themselves towards the digital simulation of the martensitic transformations. Several models existing put various assumptions for better modelling the phenomenon of the plasticity of transformation, amongst other things the models of Wen, Iesman - Levitas and Ganghoffer - Simonsson. Principal work having a micromechanical approach, in the case of the martensitic transformations, is recapitulated in the table 1 [3].

Table 1: presentation of the digital models modelling the martensitic transformation [3].

Auteurs des modèles	Patoor et al. (1988,1993)	Leblond at al. (1986,1989)	Fischer (1990, 1992)	Daves et Fische (1991)	Diani et al. (1992)
Matériaux	Alliages à mémoire de forme	Acier	Acier	Acier	Acier
Echelle de la modélisation	Mésoscopique	Microscopique	Microscopique	Microscopique	Microscopique
Orientation des variants	Calculées	Nulles	Imposées	Imposées	Imposées
Écoulement plastique	non	Calculé	Calculé	Calculé	Calculé
Interaction des déformations plastiques aux interfaces	Calculée	Imposée	Imposée	Imposée	Calculée
Dimension du modèle	3	3	3	2	3
Cinétique de transformation	Calculée	Non considérée	Non considérée	Non considérée	Non considérée
Méthode du calcul	Auto-cohérent	Sach's/FEM	Taylor-Lin	FEM	Auto-cohérent
Application	Transformation dans les 2 sens	Transformation à sens unique	Transformation à sens unique	Transformation à sens unique	Transformation à sens unique

4. Numerical calculation of the deformation of the plasticity of transformation

In this simulation, the average total macroscopic deformation ε^{pt} is evaluated through the displacement of the nodes of the edge of the grid following the direction (x) load applied. This value of deformation represents the sum of four terms of deformation:

$$\varepsilon_x^{total} = \varepsilon_x^{el} + \varepsilon_x^{tr} + \varepsilon_x^{pc} + \varepsilon_x^{pt} \quad (2)$$

ε_x^{el} : Macroscopic deformation elastic according to direction X, due to the external loading.

ε_x^{pt} : Plastic deformation due to the transformation of phase.

ε_x^{pc} : Plastic deformation due to the external loading (if a pre-work hardening of l'austénite).

ε_x^{tr} : Deformation of transformation in the direction of the loading at the temperature considered

In our calculations, the plasticity of transformation is given by the following formula [6]:

$$\varepsilon_x^{pt} = \varepsilon_x^{total} - \left(\varepsilon_x^{el} + \varepsilon_x^{tr} + \varepsilon_x^{pc}\right) \quad (3)$$

5. Results and analyses numerical simulation

In the digital simulations one uses a micromechanical approach for the forecast of the plasticity of processing of the steel 16MND5, under an axial plain loading of traction not exceeding the yield stress of the phase more the mole (the austenitic phase. Figures 2, 3 and shows the evolution of the total strain during the loading of traction. Figures 4, 5 and 6 respectively represent the variation of the plasticity of transformation under loadings equal to 200,100 and 50MPa. Calculation was carried out with a grid of 968 triangular elements.

It is noted that the value of the mechanical total deflection, believes linearly according to the advance of the transformation. One observes according to figures 4, 5 and 6 that the values of the TRIP increase quickly at the beginning of the transformation to reach a maximum when the transformation Z is equal to 0,1. Thus, one can conclude that the shape of the curves approaches those given by analytical and numerical modelling [4] [7].

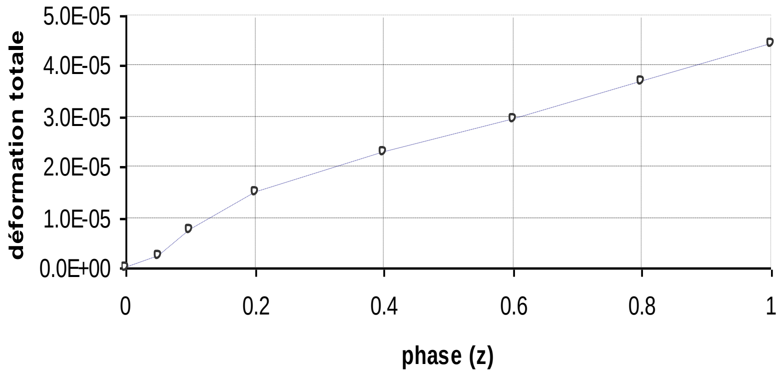

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Figure (2):evolution of the strain total according to the martensitic phase formed sig =200 MPa (traction)

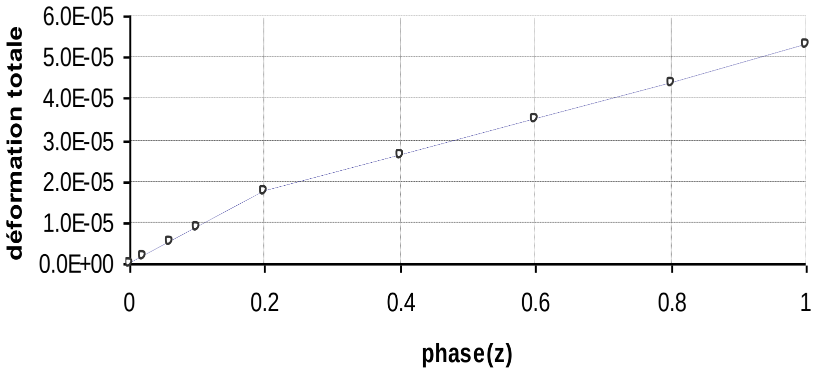

Figure (3): evolution of the strain total according to the martensitic phase Formed sig =50 MPa (traction)

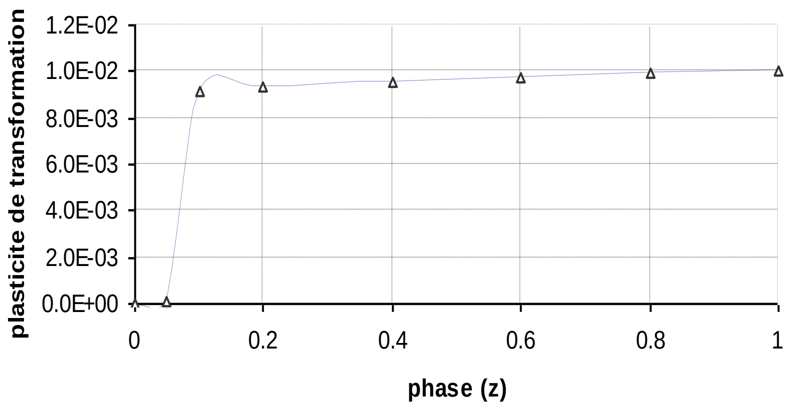

Figure (4):evolution of plasticity of transformation according to the phase martensitic formed sig =100 MPa (traction)

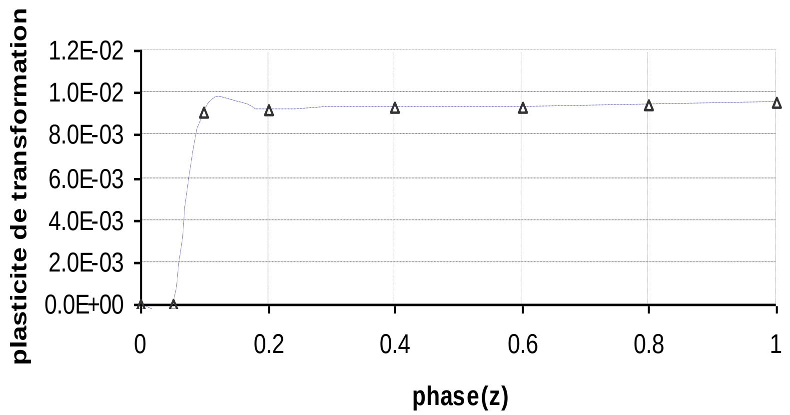

Figure (5):evolution of plasticity of transformation according to the phase martensitic formed sig =200 MPa (traction)

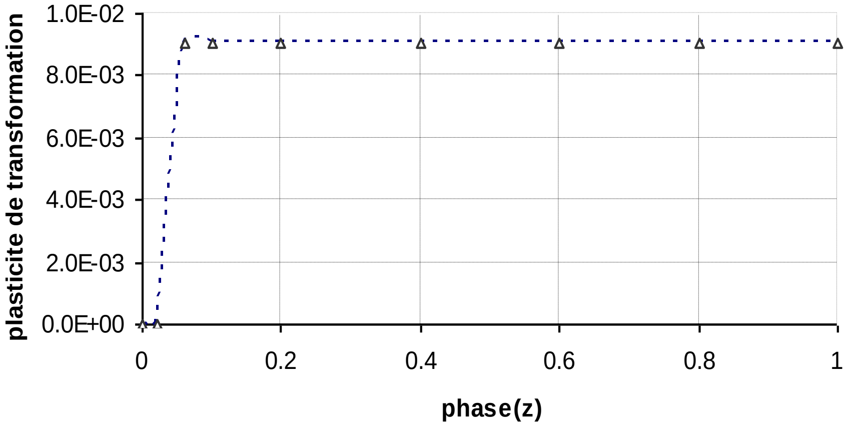

Figure (6):evolution of plasticity of transformation according to the phase martensitic formed sig =50 MPa (traction)

6. Conclusion

In this work, some research on the plasticity induced by transformation was carried out considering a martensitic transformation in steel 16MND5. Several aspects were considered in order to contribute to a better comprehension of the phenomenon and to improve its modelling.

The model of WEN, is a two-dimensional micromechanical model on the scale mono grain, it was developed with an aim of simulating numerically, by the finite element method the martensitic transformation in steel 16MND5, with an application of various values of the mechanical constraint of traction (200, 100 et 50 MPa) According to the results obtained, one notices that the variation of TRIP according to the fraction of the martensite phase formed in conformity with that is obtained in experiments and by other models, but the forecasts are not in agreement with the bibliographical results [9].

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