THE EFFECT OF INCLUSION SHAPE AND DISTRIBUTION IN BENDING OF DP STEEL SHEET

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1 Introduction

Forming of Dual-phase(DP) steels which are widely used in automotive industry is very critical and the material response is interconnected to its micro-structural features. DP steels consist of martensite (hard phase) dispersed in the ferrite (soft matrix) which leads to appropriate combination of ductility and strength. To simulate the forming process of DP steels, Micro/macro models are appropriate by capturing what happens in the microscopic level. In this work, FE simulation of sheet bending will be performed to obtain an insight how microstructural features affect the material response in sheet metal forming.

2 Numerical simulation

The model shown in figure 1 was used to simulate bending. Each element (e) has five degrees of freedom. Nodal displacements (u_1 and u_2 for element e) are used to find through-thickness strain (ε_z) . Each element has also curvature (κ), membrane strain (ε_m), and transverse strain (ε_t in Y direction) , degrees of freedom. The following formulation applies for this one-dimensional generalized plane-strain element:

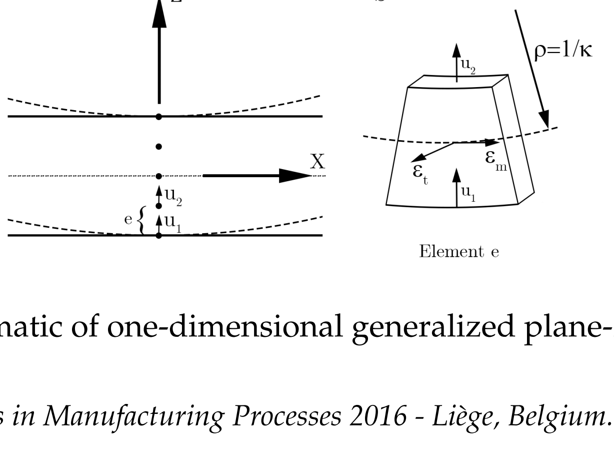

Figure 1: Schematic of one-dimensional generalized plane-strain element

$$\begin{Bmatrix} \boldsymbol{d}\varepsilon_{xx} \\ \boldsymbol{d}\varepsilon_{yy} \\ \boldsymbol{d}\varepsilon_{zz} \end{Bmatrix} = \boldsymbol{d}\varepsilon_m \begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} + \boldsymbol{d}\kappa \begin{Bmatrix} -z \\ 0 \\ 0 \end{Bmatrix} + \boldsymbol{d}\varepsilon_t \begin{Bmatrix} 0 \\ 1 \\ 0 \end{Bmatrix} + \begin{Bmatrix} \dfrac{-\boldsymbol{d}u_z}{r} \\ 0 \\ \dfrac{\partial \boldsymbol{d}u_z}{\partial z} \end{Bmatrix} \tag{1}$$

In order to include microstructural features of DP steel in the simulations, mean-field homogenization was used. In this work double inclusion (DI) interpolation method is employed in which the strain concentration tensor ($\mathbb{A}$) is calculated by interpolation between forward ($\overrightarrow{\mathbb{H}}$) and reverse ($\overleftarrow{\mathbb{H}}$) Mori-Tanaka (MT) approach [2]:

$$\begin{gathered} \mathbb{A} = \{(1-\phi(v_I)\overrightarrow{\mathbb{H}}^{-1} + \phi(v_I)\overleftarrow{\mathbb{H}}\}^{-1} \\ \overrightarrow{\mathbb{H}} = [\mathbb{I} - \mathbb{S} : (\mathbb{I} - \mathbb{C}_M^{-1} : \mathbb{C}_I)]^{-1} \quad \overleftarrow{\mathbb{H}} = [\mathbb{I} - \mathbb{S} : (\mathbb{I} - \mathbb{C}_I^{-1} : \mathbb{C}_M)]^{-1} \end{gathered} \tag{2}$$

$\mathbb{S}$ is the Eshelby's solution and depends on the geometry of inclusion and poisson ratio of the matrix. In this work two cases of sphere and oblate spheroid ($a < b = c,\ \alpha = a/b$) were simulated for which the eshelby tensor can be found in [3].

3 Results and discussion

Figure 2-a shows the comparison of non-dimensional moment versus non-dimensional curvature obtained from simualtions and analytical solution [1] which shows a good agreement. Slight deviation may be originated from discretization and numerical errors. In figure 2-b the influence of volume fraction of martensite on the moment-curvature response of the sheet is depicted. As shown, when the volume fraction of martensite is high, unloading after bending does not follow a straight line, which may be originated from re-yielding of softer ferrite phase. There is experimental evidence on re-yielding of soft phase during bending of multi-phase steels which makes this observation plausible [5]. The higher the martensite fraction, the more pronounced the re-yielding phenomenon.

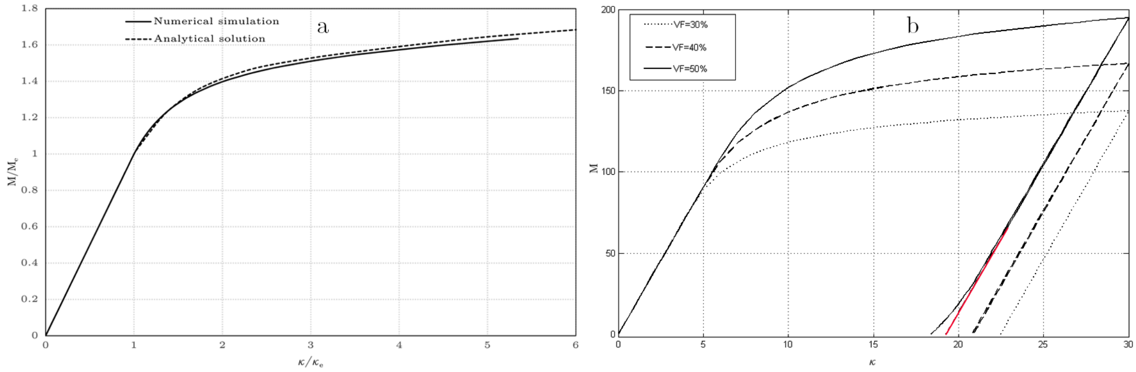

Figure 2: (a) Validation of the model (b) effect of volume fraction

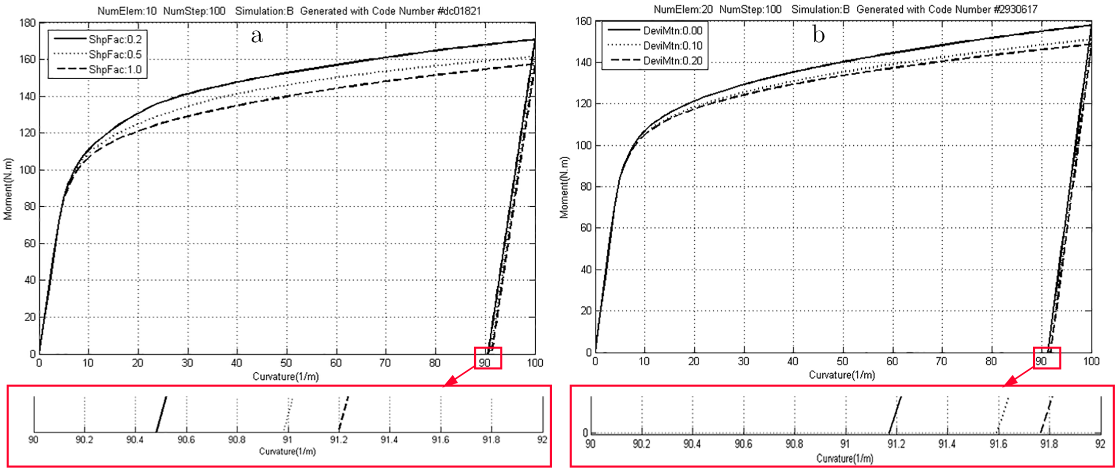

Figure 3: The effect of (a) Martensite shape and (b) distribution in pure bending

Figure 3 illustrates the influence of martensite shape factor (Oblate spheroid) and martensite distribition on the sheet behaviour during bending. As the aspect ratio of martensite islands increases the maximum moment and the amount of springback after unloading increases. In addition to that, there is experimental evidence that DP steels comprise martensite bands specifically concentrated in the mid-line of the thickness [4]. Figure 3-b shows the moment-curvature diagrams for three cases in which the average volume fraction on thickness of the sheet remains constant (0.4), while the mid-line elements (10 percent of the thickness) have relatively higher martensite volume fraction with respect to the outer elements. In this case the higher the martensite concentration in the mid-line the lower the springback.

References

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