Final Project Report for ENG2340

Implementation of Material Distribution for Steel Sheet with Heterogeneity

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1 Introduction

The formability of AHSS is a major concern for steel manufacture. It is influence by the interplay of multiple factors such as the phase volume fraction of the steel, the surface roughness, and the material heterogeneity of the steel. In this topic, we are interested in the effect of heterogeneity on steel sheet's formability.

In previous studies, material parameters in a given constitutive model for steels with different volume fractions were obtained based on RVE calculation. Based on these parameters, we can create some local areas which contains an irregularly high volume fraction of either ferrite or martensite to simulation the effect fo heterogeneity. To better recreate what is observed in experiments, an ellipsoidal shape of heterogeneity is desirable. Also, to achieve a better convergence in calculation and a more physical and realistic simulation, a transitioning zone with material properties smoothly graduating in it was created to surround the heterogeneity. This material distribution for different areas in steel sheet was implemented by SDVINI subroutine.

2 Principle of material distribution

In our study, 15 different material properties are studied as a prerequisite for material distribution, which are: F17M75, F20M72, F22M70, F25M67, F27M65, F32M60, F37M55, F47M45, F55M37, F60M32, F65M27, F67M25, F70M22, F72M20, F75M17. The plastic constitutive model we adopt for our simulation is shown in Eq.1

$$\dot{\varepsilon^p} = \dot{\phi_0} \left(\frac{\sigma_e}{g(\varepsilon_e^p)} \right)^{1/m} \frac{S_{ij}}{\sigma_e} \tag{1}$$

where $g(\varepsilon_e^p)$ is a function representing work hardening, the mathematical representation of $g(\varepsilon_e^p)$ is:

$$g(\varepsilon_e^p) = \sigma_0 + k_1(1 - exp(-k_2 \varepsilon_e^p)) + h_s(\varepsilon_e^p)^n \tag{2}$$

There are in total seven material paramters in the constitutive model, ϕ_0, m, σ_0, h_s, k_1, k_2, n. m is fixed to be 0.01, and all other six material parameters need to be calibrated. Based on RVE calculation, all the material parameters for each different material composition were obtained as Fig.1 shows. (More detail about constitutive model and the study of material parameters, see "Research Report in Fall 2015: The Influence of Heterogeneity on AHSS Deformation Behavior and Formability")

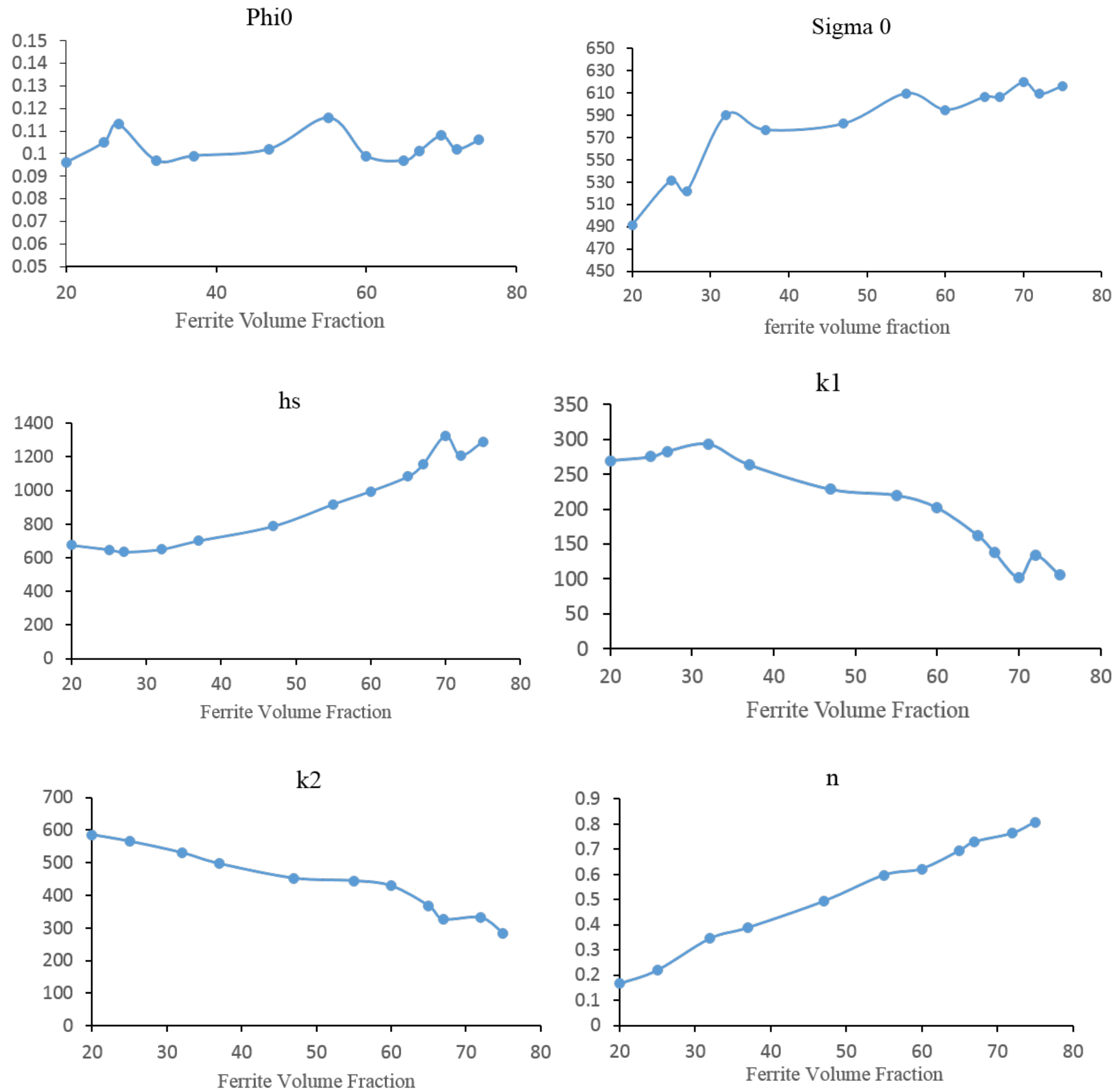

Figure 1: Material Parameter changing with ferrite volume fraction

Based on the experimentally observed results, the ellipsoidal heterogeneity is a created as an planar ellipse extruding along thickness direction. The transitioning zone is 5mm in length to the surface of the heterogeneity with the same thickness as the heterogeneity. For the matrix part of the steel sheet, the material applied is F47M45. To simulate the martensite and ferrite rich ellipsoidal heterogeneity, the material properties we used are from F20M72 and F72M20, respectively.

The most challenging part of this project is the material definition for the smoothly transitioning zone around the heterogeneity. From Fig.1, it can be observed that ϕ_0 is relatively stable around 0.1 with fluctuation, all other parameters present roughly linear relation with ferrite volume fraction. In this project, as an rough approximation, we just adopted linear fitting scheme for parameters σ_0, h_s, k_1, k_2, n, and fix the ϕ_0 to be 0.1 in the transitioning zone.

The fitting function for σ_0 is $y = -1.8105x + 490.23$.
The fitting function for h_s is $y = 12.712x + 290.75$.
The fitting function for k_1 is $y = -3.3475x + 373.91$.
The fitting function for k_2 is $y = -5.5273 + 711.81$.
The fitting function for n is $y = 0.00118x - 0.0601$.

The fitting lines with the material changing curves are shown in Fig.2.

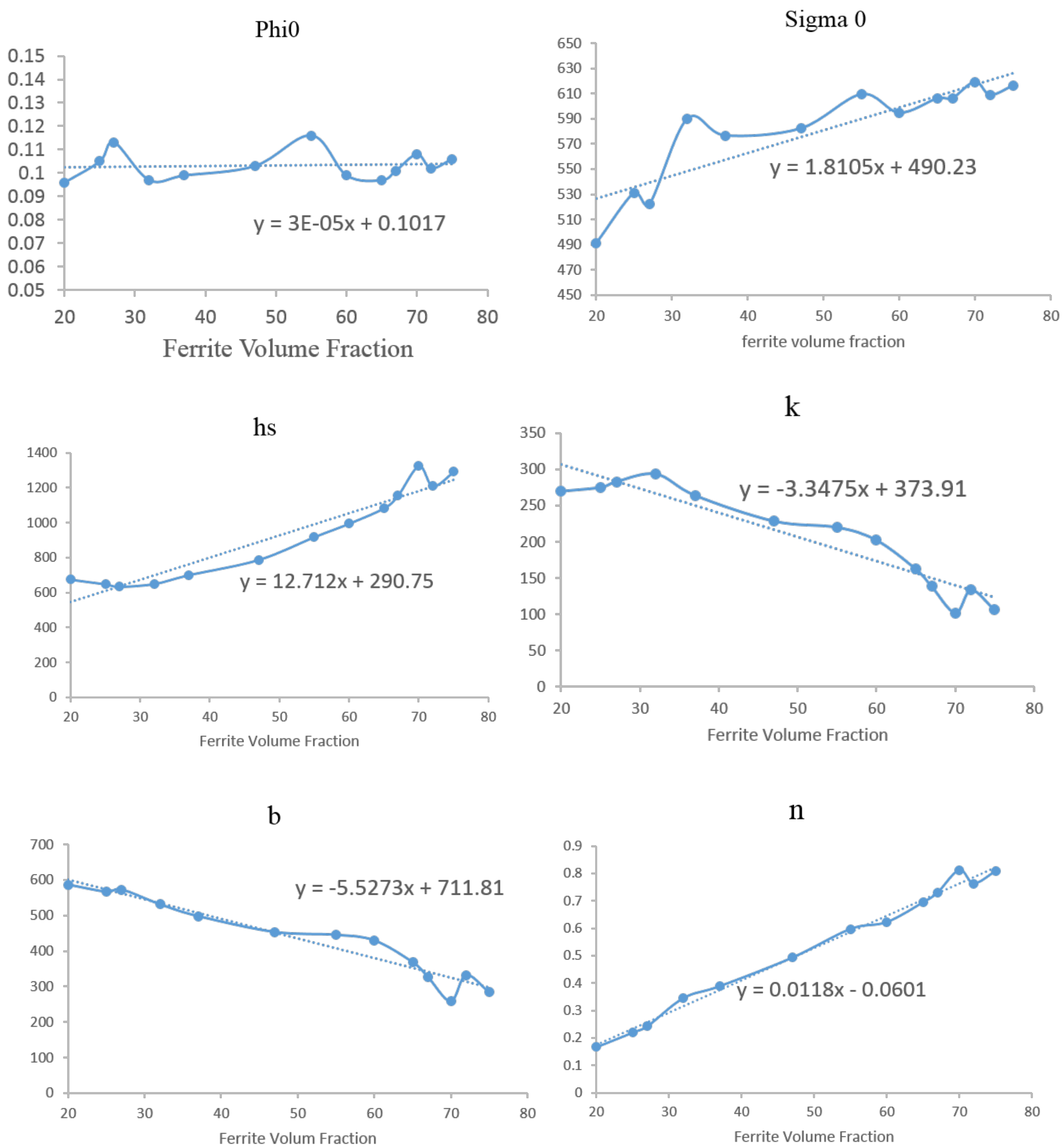

Figure 2: Material Parameter changing with ferrite volume fraction

In the above fitting function, the variant x is the ferrite volume fraction. So that in the transitioning zone, we also need to define the ferrite volume fraction at specific point in the area. The scheme we adopt is to take an exponential function to interpolate the ferrite volume fraction at the specific point with respect to the distance from the center of heterogeneity to the point.

For ferrite rich heterogeneity, the interpolation function is $y = A * exp(-C * x)$.
For martensite rich heterogeneity, the interpolation function is $y = A * (1 - exp(-x)) + C$.

where A and C are constant, and can be determined by the ferrite volume fraction on boundary of heterogeneity and matrix of the steel sheet. x is the distance from a specific point to the center of heterogeneity, y is the ferrite volume fraction on this point. Thus, combining these ferrite volume fraction interpolation function with the material parameter fitting function, the material parameters for each point in the transitioning area can be determined.

Based on all the discussions above, the implementation procedure of material distribution can be summarized as below:

i)Extracting coordinates for each nodes from input file, defining the ellipsoidal heterogeneity function and transitioning zone function.
ii)Defining the area of heterogeneity, transitioning zone and matrix part of the steel sheet, assign material properties for heterogeneity and matrix part.
iii)Calculate ferrite volume fraction for nodes in transitioning area based on the interpolation function and the distance from the point to the surface of of heterogeneity. Then, find its material parameters based on the material fitting functions, and assign the parameters for all the nodes in transitioning area.

The material distribution results are shown in 3.

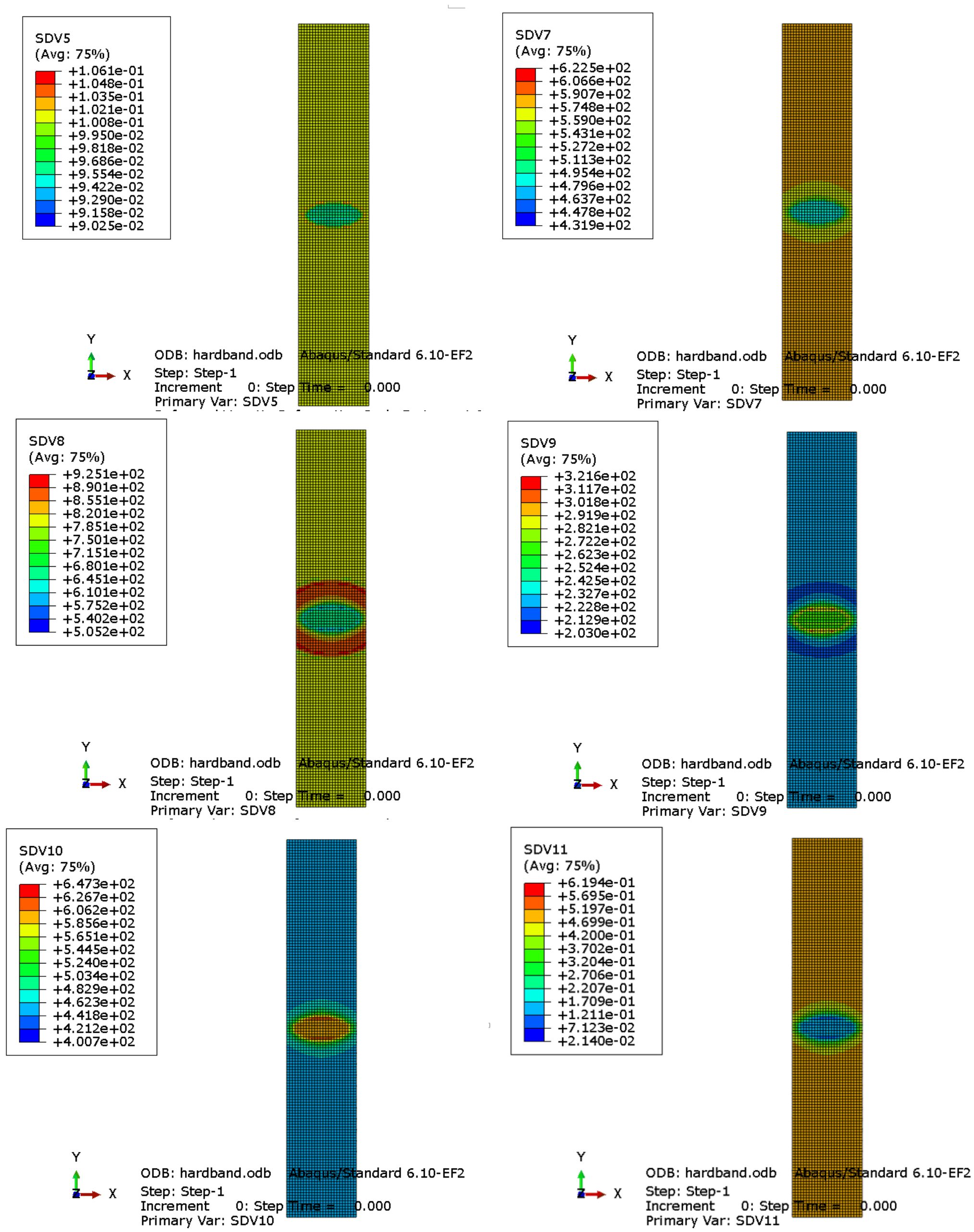

Figure 3: Implementation results of material parameter distribution

3 Tension simulation results and discussions

Based on the material distribution practice discussed above, we can study preliminarily about the effect of heterogeneity on formability by uniaxial tension test simulation in ABAQUS/Standard. A displacement of 30mm is applied on the top surface of the sheet, and the bottom surface is fixed. Fig.4 shows the effective plastic strain contour when necking occurs for steels with martensite rich (left) and ferrite rich heterogeneity (right).

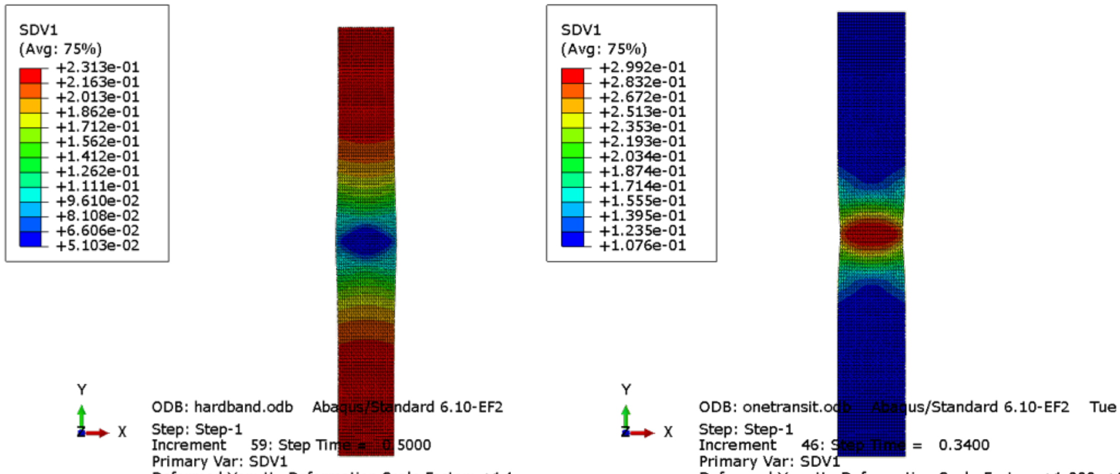

Figure 4: martensit rich and ferrite rich ellipsoidal heterogeneity inside steel sheet

It can be seen from Fig.4 that for sheet with martensite rich heterogeneity, the highest plastic strain is 0.2313, necking occurs near the top and bottom surface. For sheet with ferrite rich heterogeneity, the maximum effective plastic strain is 0.2992, and obvious localization can be observed in heterogeneity area. The flow behavior for both two steels can also be obtained as Fig.5 shows.

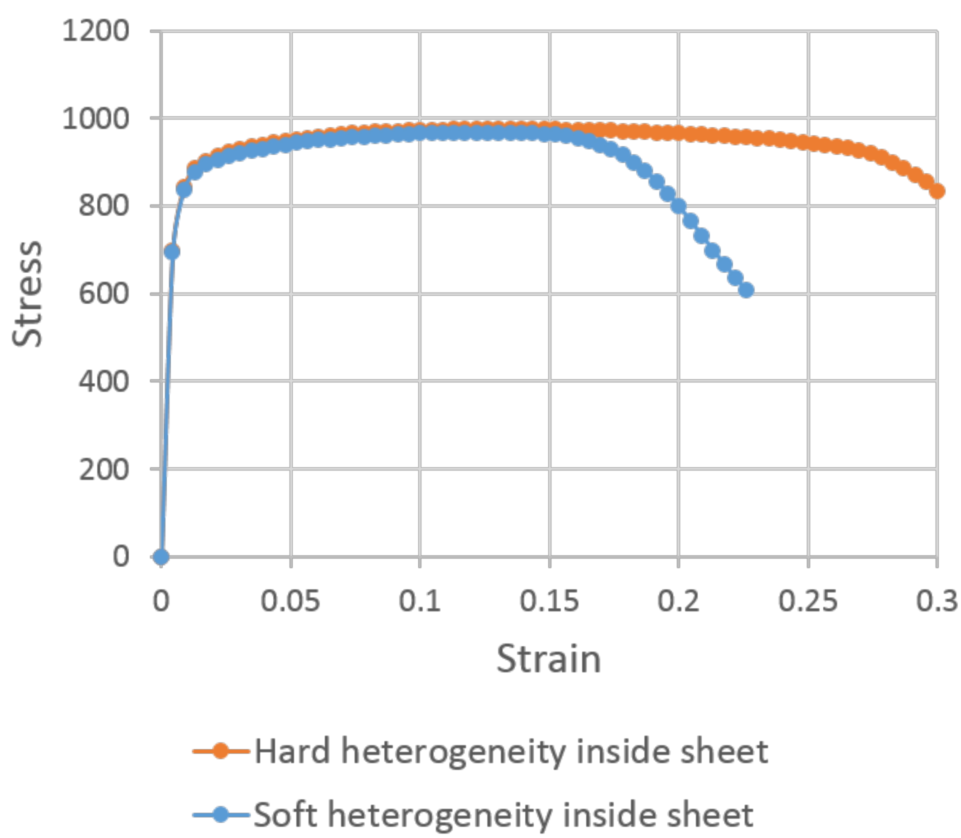

Figure 5: Comparison of flow behavior for ellipsoidal heterogeneity inside sheet

From Fig.5, it can be seen that sheet with martensite rich heterogeneity localizes when strain is 0.27, however, sheet with ferrite rich heterogeneity localizes when strain 0.16. This result indicates that ferrite rich heterogeneity can seriously weaken the formability of steel.

It also should be noted that there are some limitations in our current study. From 3, we can see that for some material parameters, especially SDV8 and SDV9, which correspond to h_s and k_1, are not consistent on the boundary between transitioning zone and matrix, or transitioning zone and heterogeneity. This is because the material parameters are fitted for all the different composition, rather than interpolating piecewisely between each composition. This problem can be solved by using linear interpolation for materials between each composition. In our future works, the interpolation scheme will be adopted, and the heterogeneity will be shaped more closely to the experimental results.