Development of the numerical procedure for identification of the random cellular automata finite element fracture model parameters based on the in-situ tensile test

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Abstract

The overall goal of the work is focused on the identification of critical parameters of the random cellular automata finite element (RCAFE) fracture model. The investigated parameters are related to the crack initiation criteria at the microscale level in Dual Phase steels. Parameters for brittle and ductile failure initiation will be identified based on the experimental and numerical in-situ tensile tests. Concept of the proposed methodology and examples of initial results are presented within the paper.

Keywords: in-situ test, RCAFE, dual phase steel

1. Introduction

Development of the numerical RCAFE model based on the digital material representation (DMR) idea [2, 3] capable to take into account different brittle and ductile failure mechanisms in dual phase steels is carried out for last several years [4].

The RCAFE model developed by the Authors is a unique fully coupled solution combining two computational approaches random cellular automata (RCA) and finite element (FE) methods [3]. The proposed model is designed to have the capability to take into account all four fracture mechanisms observed in DP steels: brittle martensite fracture, delamination between ferrite and martensite phases, ferrite grain boundary fracture and ferrite transcrystalline fracture.

The ground-breaking nature of the developed RCAFE method is associated with the assumption that the CA cells exactly correspond to particular nodes of the FE mesh as presented in Figure 1 [4]. Thus, the RCAFE model takes advantages provided by the cellular automata modelling and overcomes one of the major disadvantages associated with reliable description of the CA space deformation under plastic deformation.

It is worth mentioning, that due to the irregular nature of the cellular automata space in the random CA method, classical definitions of neighbourhoods have to be substituted by a specified radius neighbourhood. With this approach it is possible to identify CA cells contributing to the cell state changes via transition rules. The RCA model holds information on microstructure morphology and by a combination with the finite element model also information on microstructure deformation during forming. As an outcome an influence of morphological features on fracture initiation in those complex steels grades can be obtained.

However, to successfully use the RCAFE model for modelling of particular steel grade, proper identification procedure of model parameters have to be performed. A set of model coefficients will identified within the realized work on the basis of performed in-situ tensile test on the selected DP steel. The input data in the form of load-displacement values and images of microstructure after deformation stages from various sample zones are used during the investigation.

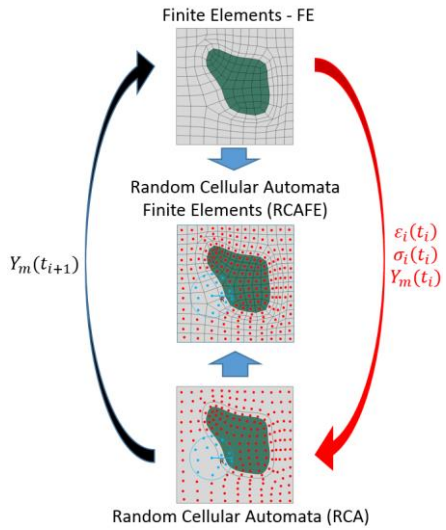

Figure 1 Concept of the RCAFE method.

2. Procedure for identification of critical fracture parameters of the martensite and ferrite phases.

First a set of in-situ tensile test experiments was realized to obtain mentioned input data as presented in Figure 2 and Figure 3.

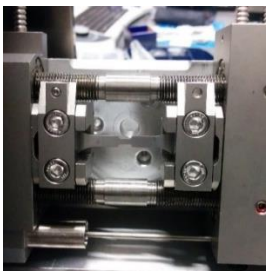

Figure 2 Experimental setup of the in-situ tensile test.

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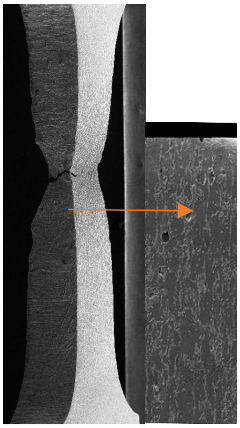

Figure 3 Example of microstructure after deformation composed from subsequent high resolution images.

Based on the laboratory experimental procedure of in–situ tensile test Authors developed corresponding numerical model that exactly matches the experiment, both in case of microstructure geometry, macroscopic sample dimension and tensile test conditions. The numerical model of the macro scale sample and applied boundary conditions are presented in Figure 4a. Specimen is deformed along OY axis in one direction while the second end of the sample is fixed. This deformation is selected to match the experimental conditions. The specimen for tensile test is discretized with 76440 using 8 node biquadratic (CPE8) finite elements.

Along the centre line of the macroscopic sample a set of micro scale models taking into account digital material representation are assigned. The developed micro scale models of the investigated DP steel matches to the typical microstructure morphology observed experimentally.

In the present approach, results of displacement field obtained at the macro scale model are then used as boundary condition that are applied to the micro scale DMR models. The local strain/stress values calculated with such DMR models (Figure 5) in various zones of the sample will be compared during further work with the obtained high resolution image of the microstructure. That way critical parameters for initiation of various fracture modes will be identified.

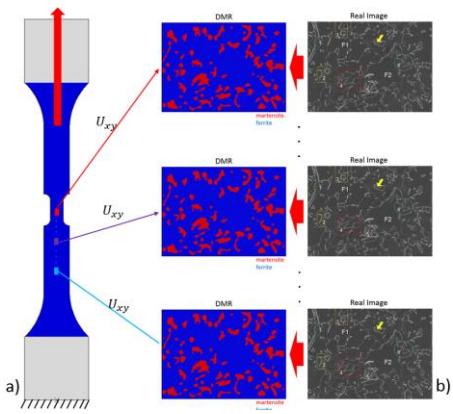

Figure 4 a) Macromodel and b) schematic locations of micro scale DMR models [1].

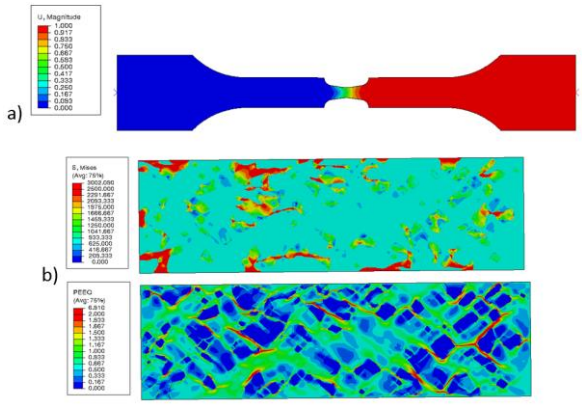

Figure 5 a) Displacement distribution in macro model and b) example of stress and strain distributions in the selected DMR model.

3. Conclusions

The concept of identification procedure for critical RCAFE model parameters describing fracture initiation criteria was presented within the paper. At this stage of the research a set of in-situ tensile tests, detailed imaging of microstructure and corresponding numerical models based on digital material representation concept were realized. Initial results prove that local heterogeneities in strain field at the micro scale level can be attributed to fractures observed experimentally. Thus, this approach will be used during further work for detailed identification of fracture initiation criteria for various failure modes observed in DP steels.

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