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Damage mechanism and modeling of void nucleation process in a ferrite–martensite dual phase steel

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ABSTRACT

Damage initiation and growth behavior in high strength dual phase sheet steel, i.e. DP780, was investigated using smooth and notched tensile specimens. By SEM microstructural analyses of pulled and sectioned tensile specimens, void initiation and growth behavior were quantified. Finally, a simple model was proposed to predict the void nucleation kinetics for both kinds of specimens. The predicted values were in good agreement with the experimental data using the model.

1. Introduction

Void nucleation, growth and coalescence are three microscopic phenomena involved in ductile fracture process. In order to design and make failure resistant materials, it is necessary to well understand these microscopic phenomena. For the prediction of material failure, the mentioned damage micro-mechanisms should be cleared and quantified. Detailed electron microscopic analysis showed that void nucleation in microstructure occurred due to the breaking of constituent hard particles or decohesion of the interface between matrixes and second hard particles such as inclusions [1,2], second phase or reinforcing particles [3]. After void initiation, the growth of these voids will continue with a specific kinetics, depending on the material type, stress state and the applied strain. Rice and Tracey [4], by considering a single spherical void in a fully plastic matrix, showed that void growth kinetics followed an exponential trend. Rice–Tracey model has been widely used to predict damage kinetics [5–9]. Some researchers tried to improve this model for more real material conditions. For example, Huang et al. [10] revised this model in order to take into account the interaction between neighboring voids and strain hardening effect [6,11]. Chae and Koss [12] showed that the dependence of void growth on stress triaxiality was much stronger than that predicted by Rice–Tracey model and suggested a different constant coefficient. Also, it was shown that void nucleation was a continuous process [13] that happened until the final fracture of material; this should be considered in studying the overall kinetics of voids evolution and void volume fraction, but most existing descriptive damage models neglect progressive damage initiation process. So, in the present study, it is tried to find the void nucleation mechanism and its development during applying strain in a high strength dual phase steel, DP780, and analyze the effect of stress state on void nucleation behavior. Moreover, in the present study, uncoupled approach to fracture was covered to model the damage development.

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Nomenclature

a	notch root radius
C	constant value
h	half of the ligament length
L	number of analyzed data points
P	predicted value
t	local thickness
T	triaxiality
Y	experimental value
t_0	initial thickness
ε_p	equivalent plastic strain
σ_c	critical interface stress
f_v	void area fraction
σ_M	hydrostatic stress
σ_{ys}	yield strength
$\bar{\sigma}$	equivalent stress
$\sigma_{i,0}$	interface stress at initial yielding
$\varepsilon_{p,0}$	characteristic plastic strain value
N_0	initial density of potential nucleation sites
MSE	mean square error
$N_v(\varepsilon)$	void areal density

2. Materials and methods

The steel used in the present research was DP780, in the form of one millimeter thick sheet granted by POSCO Company. The sheet was machined into standard smooth specimens [14], and notched tensile specimens of 30 mm gage length and notch radii: $R = 1.5$, and 7.5 mm (Fig. 1). The inter-notch ligament of the specimens was selected to be 6 mm. The specimens were labeled as R for smooth, R1.5 and R7.5 for notched specimens with the notch root radius of 1.5 and 7.5 mm, respectively.

Zhang [15], showed that in uniaxial tensile testing and after applying low values of strains, stress triaxiality value will be almost constant until fracture occurs. This value has been estimated [16,17], in the center of the sheet specimens, as a function of the ratio of the notch root radius (a) to half of the ligament length (h) which is presented in Eqs. (1) and (2). It means that the fixed values of a/h imply the fixed values of triaxiality (T), which are about 0.83 and 0.46 for a/h values of 0.5, 2.5 respectively. For standard smooth tensile test specimen, T can be assumed as a fixed value of 0.33 [18].

$$T = \frac{\sigma_M}{\bar{\sigma}} = \left[\frac{1}{3} + \left(\frac{1}{F_T} - 1\right)\right] \tag{1}$$

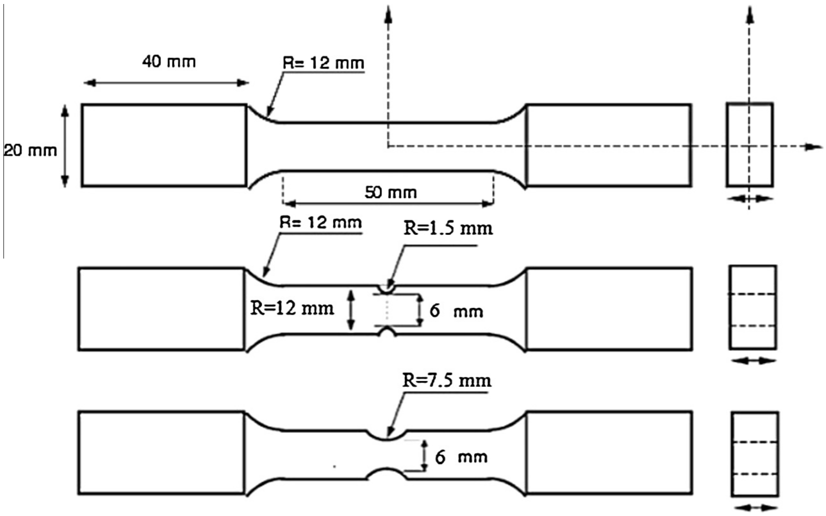

Fig. 1. Geometry of the tensile testing specimens.