Comparison of Quantitative Damage Characterization Methodologies

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ABSTRACT

The introduction of advanced high strength steels, e.g., into the automotive industry, initiated a huge interest in understanding ductile fracture of sheet metals, and prediction of damage evolution by advanced forming simulations. This instigated the development of experimental methodologies that provide microvoid evolution parameters. Previously, the authors demonstrated that the popular indentation-based damage characterization, which relates degradation of elastic modulus and/or hardness to damage evolution, is fundamentally flawed, for both hardness- and modulus-based damage quantification [1]. For increasing degree of deformation, both the hardness and the elastic modulus not only decrease due to damage, but also either increase or decrease due to many other ‘hidden’ microstructural factors, such as strain hardening, grain shape change, texture development, indentation pile-up, etc., which eliminate the indentation-based damage methodology as a reliable method for accurate damage quantification.

Therefore, this present work critically compares a number of other common and/or promising damage characterization techniques with respect to their statistical/systematic measurement accuracy and sensitivity:

• void area fraction quantification using scanning electron microscopy,
• void volume fraction quantification using high-resolution X-ray microtomography,
• highly-sensitive local density measurements using surface profilometry and mass balance,
• and local elastic compression tests on 1 mm³ electro-discharge-machined cubes.

For all techniques, a measure for the damage (increase in void area/volume fraction, or decrease in density or elastic modulus) was measured as a function of the local strain, as measured using digital image correlation, on a single set of aluminum 6016 uni-axial tensile samples used for each technique. The preliminary results are shown in Fig. 1.

Our sensitivity analysis, of which the details will be presented at the conference, revealed the following conclusions:

• The area fraction method is a common, seemingly practical method in quantifying damage. Our results, however, show that the method is very sensitive to many experimental parameters and hence should only be used for cases where high accuracy or absolute damage parameters are not necessary.
• The sensitivity of the volume fraction method is basically determined by the resolution of the equipment used. However, even when excellent resolution and high signal/noise ratio is possible, the ‘thresholding’ process to distinguish voids from material introduces significant systematic errors.
• The preliminary results shown here for the density methodology are promising. However, decreasing the experimental noise in the local measurements requires intensive care.

• The elastic compression tests may perhaps show a decrease of modulus with increasing strain, as predicted by accompanying FEM simulations of the experiment (not shown). However, a better specimen processing method is a requisite. Moreover, an improved local compression methodology based on meso-sized compression pillars will be suggested. This line of research is being continued in order to scrutinize these techniques. Therefore, more detailed results are to be expected.

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**Figure 1.** The measure for damage plotted as a function of the local strain for (a) the void area fraction methodology, (b) the volume area fraction methodology, (c) the highly-sensitive local density measurements, and (d) the local elastic compression tests (data points indicated by a black arrow are probably erroneous due to an observed ‘burr’ from electro-discharge machining). The lines are ‘guides for the eye’.

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**References**