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Miniature Marciniak Setup for in-situ SEM Observation of Damage Micro-mechanisms

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1 Scientific relevance

The industrial and scientific interest for ductile damage and fracture has significantly increased in the last decades due to the popularity of new advanced materials, such as high strength steels and nanostructured metals [1]. To allow for detailed investigation of micro-events such as the damage micro-mechanisms, the deformation needs to be studied in real time with in-situ scanning electron microscopy, allowing for digital image correlation (DIC) of the high resolution images for local strain mapping [2], see e.g. Figure 1. These studies, however, were limited to deformation under uni-axial tension due to the constraints of in-situ SEM testing.

At the same time, parallel research efforts have focused on elucidating the effect of the followed strain path on the ductile deformation micro-mechanisms, and its consequence for the resulting macroscopic forming and fracture limits in sheet metal [3]. Unfortunately, in these studies the damage micro-mechanisms were studied from post-mortem fracture analysis [4], due to the absence of a miniaturized testing setup capable of deforming sheet metal up to failure in alternative strain paths (e.g. plane strain or biaxial tension).

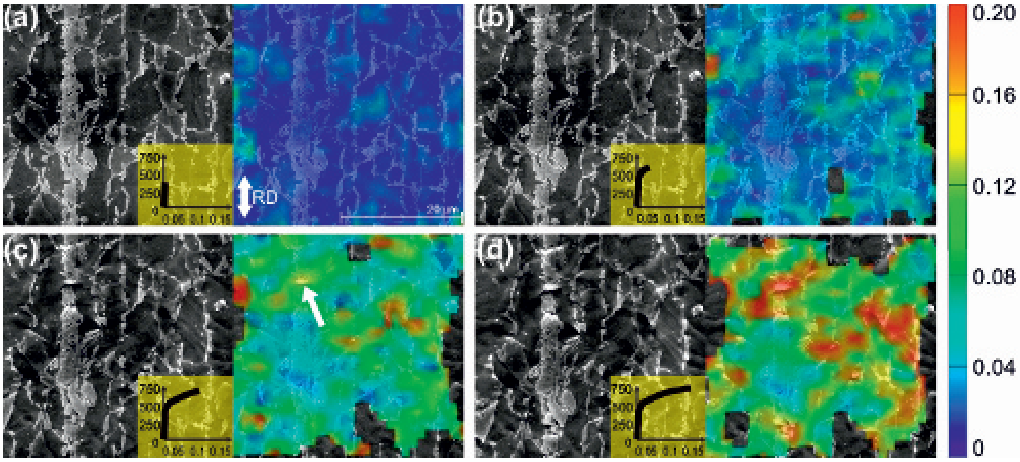

Fig. 1. SEM image and effective strain overlay at 4 different deformation stages for dual phase steel [7].

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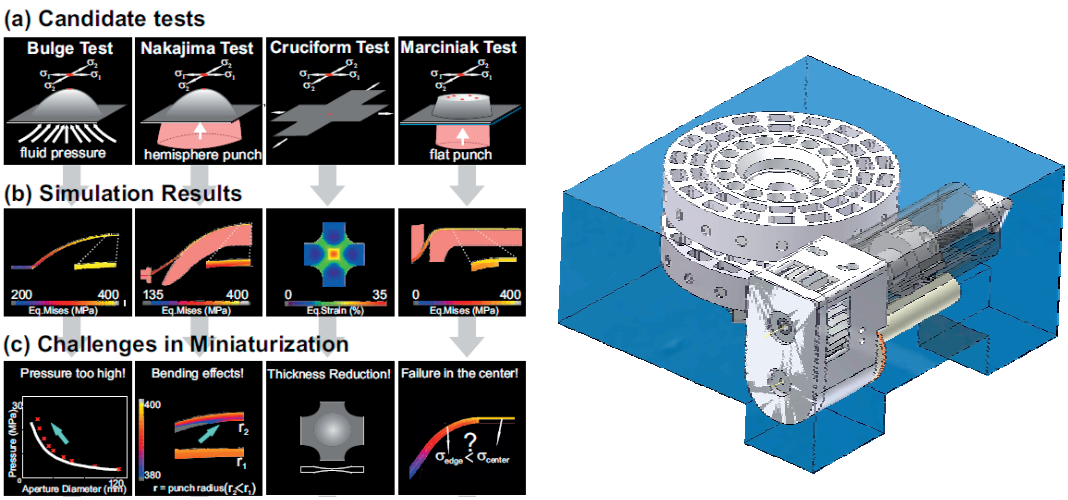
2 Research goal and results

In this work, we set out to develop a test setup that allows for deformation of sheet metal at various strain paths up to the point of fracture under in-situ SEM observation. Figure 2(a) shows an experimental-numerical analysis of candidate testing setups (bulge test, Nakazima test, cruciform test, and Marciniak test), which identified the Marciniak test setup as the most suited for miniaturization [5]. Still, significant design challenges were identified, including (i) high load levels (>100 kN) to be reached within the (small) SEM-chamber, (ii) forcing fracture to occur inside the "contactless" gauge section, and (iii) assuring the safety of the electron microscope.



(a) (b)

Fig. 2. (a) experimental/numerical evaluation of candidate multi-axial test setup for miniaturization, and (b) the final design of the miniaturized Marciniak Setup with the SEM vacuum chamber depicted in blue.

These challenges were successfully addressed and an in-situ miniaturized 150kN Marciniak setup (Figure 2(b)) was designed and built, which allows for world-first experimentation of multi-axial testing of sheet metal up to fracture under in-situ SEM observation. A case study is presented, in which strain-dependent damage initiation from microstructural bands in steels is investigated from SEM-DIC strain maps.

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