156 In-situ micro-mechanical investigation of cut-edge failure: microstructure-driven crack toughening in laser-cut affected zones

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Abstract

Cut-edge failure after blanking and laser cutting was studied in detail by tracking the microstructure evolution before and after cutting and during subsequent deformation to failure, by *in-situ* biaxial Marciniak testing under optical and electron microscopy with digital-imaged-correlation-based strain mapping and nano-indentation, all for the same steel. This wealth of data sheds new light on the apparent contradiction in the 'cut-edge failure' literature, e.g. why micro-damage initiated much earlier in laser-cut specimens but their strain-to-failure is almost twice that of blanked specimens. Guide-lines for improved cutting process are provided.

Introduction

Among the many cutting techniques, blanking and laser cutting are the most commonly used cutting techniques due to their high efficiency, sufficient accuracy and reasonable cost. A key concern for the industry, however, is failure at the cutting surface during the subsequent forming, so-called 'cut-edge failure', especially for advanced high strength steels with complex phases used by the automotive industry. Yet, the number of well-defined micro-structural investigations of cut-edge failure in combination with the resulting micro-mechanical effects on formability is limited. Moreover, no direct comparison of the fundamental differences between two different cutting techniques, applied to the same sheet material, is available in the literature. Therefore, the goal of to investigate cut-edge failure in more depth by (i) by characterizing the microstructure evolution before and after cutting and during subsequent deformation up to failure, (ii) comparing these results for blanking and laser cutting, and (iii) by focusing on a well-known steel grade, i.e. dual phase steel.

Methods

Therefore, in this work, the as-cut microstructure and resulting micro-mechanical deformation of blanking with 2.5% and 10% clearance and laser cutting was characterized in detail using in-situ biaxial Marciniak testing [6] under optical and electron microscopy [2,7,8] combined with digital-imaged-correlation-based strain mapping [1,3] and nano-indentation.[4,5] Dual phase (DP) steel is selected as a model material for this study because of (i) its relatively simple microstructure consisting only of ferrite [11] and martensite [12], (ii) extensively researched microstructure and damage evolution, also in our lab (see, e.g., [1-13]), and (iii) high relevance for the automotive industry.

Results

The strain-to-failure of laser cutting is almost twice that of blanking, even though micro-damage initiates already at 8% strain in the ~60µm-thick, brittle, fully-martensitic surface layer in the laser-cut affected zone. Detailed microstructural investigation, see, e.g., Fig. 1, revealed that the ~145µm-thick tempered-martensite sub-surface layer provides the toughness to first delay micro-damage propagation and subsequently arrest the crack growth, see, e.g., Fig. 2, which explains the high strain-to-failure of laser cutting.

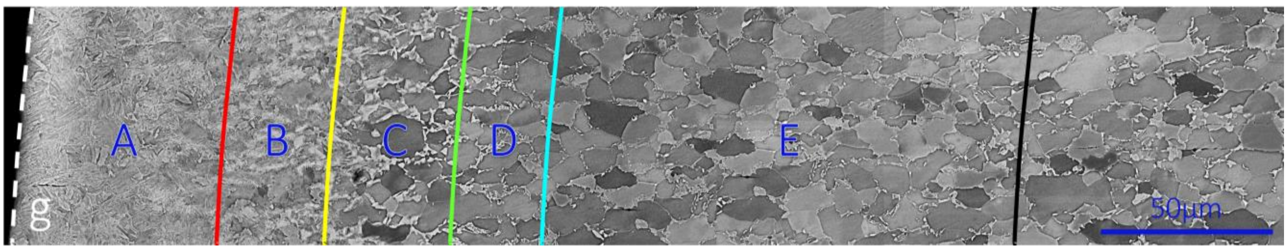

Figure 1: Secondary electron (SE) image of the different microstructures in the heat-affected zone of a laser-cut specimen (the white dashed marks the cutting edge)

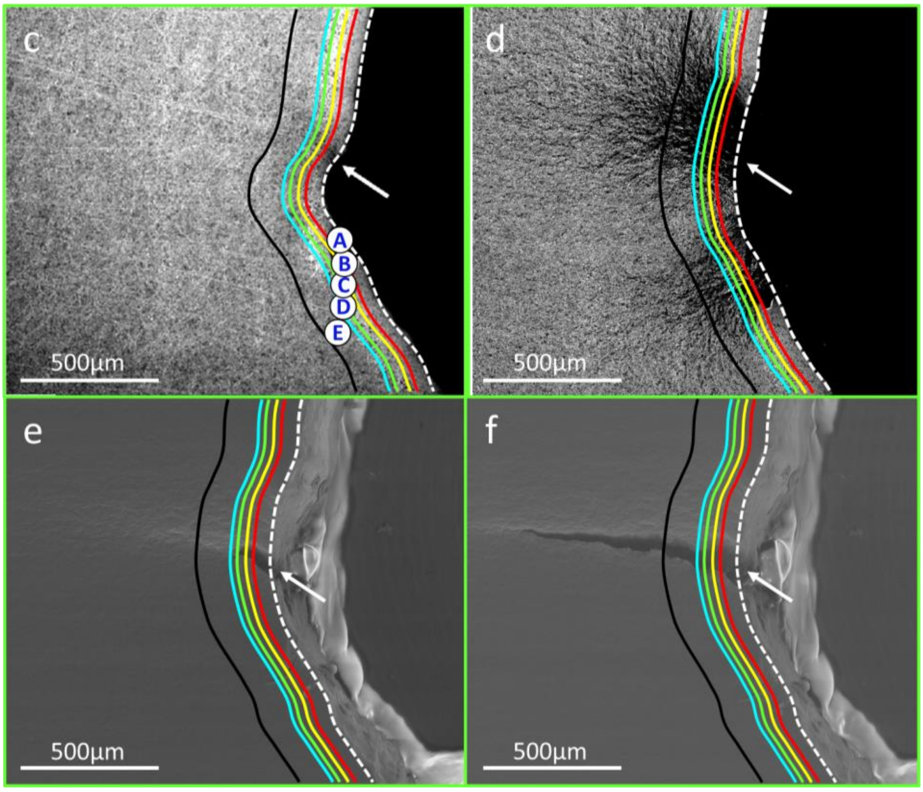

Figure 2: (c–f) *In-situ* SEM images, captured in (c,d) BSE-mode for micro-damage visualization and (e,f) SE-mode for crack propagation visualization, at (c) first observation of micro-damage (indicated by the white arrow), (d) the last image before macro-crack observation, (e) arrested crack growth, and (f) final failure. The colored curves in (c–f) mark the location of heat-affected sub-zones, A – E, with the same color coding and distance to the (deformed) cut edge taken as the as-cut state in Fig. 1. The rolling direction is in the vertical direction.

Conclusions

Blanking and laser cutting was studied in detail for dual phase steel, providing interesting new insight and understanding in cut-edge failure in general as well as specific guide-lines for an improved cutting process that can be readily adopted by the industry.

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