IN-SITU INVESTIGATIONS OF SMALL STRAIN PLASTICITY IN DUAL-PHASE STEEL

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Summary Characteristic small strain deformation behavior of dual phase (DP) steel is investigated through in-situ deformation experiments using different SEM-based imaging techniques. Results show that the transformation-induced dislocations around martensite-ferrite interfaces are rarely mobile, and therefore, do not significantly contribute to the observed continuous yielding. New experiments are underway to investigate the role of transformation-induced residual elastic stresses on DP steel small strain plasticity.

Background and Goal

Over the last decades, the use of martensitic-ferritic steels in the automotive industry has increased significantly. Although commonly referred to as dual phase (DP) steels, these steels have more complex microstructures, typically including retained austenite and bainite phases. In fact, the industrial interest is mainly based on this complexity which allows a wide range of properties to be achieved through relatively simple modifications in the processing cycle (e.g. intercritical annealing). However, achieving a full understanding of the interesting microstructure-property relationships of DP steel is also more challenging due to this complexity. Characteristic small strain behavior (i.e. continuous yielding and high initial strain hardening) of DP steel is, for example, not fully understood, and in this work we aim to enhance this understanding.

Experimental Strategy

Continuous yielding necessitates some mechanism of plasticity that can be triggered at low levels of externally applied stress. Indeed, high resolution digital image correlation analysis in Fig. 1 shows that certain ferritic grains of favorable size, orientation and morphology are more readily plastically deformed upon the application of an external load, compared to others. Careful inspection of Fig. 1 also reveals different levels of plasticity even within single ferritic grains, suggesting that the mechanism responsible of early plasticity is due to some sort of heterogeneity within ferritic grains.

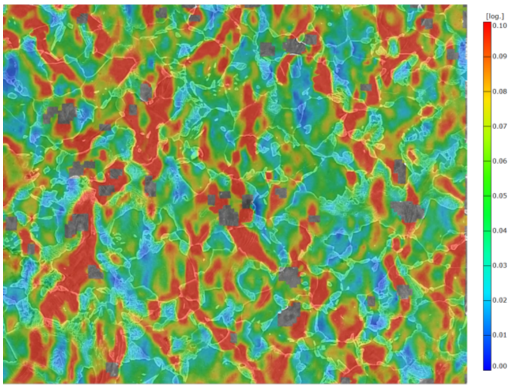

Figure 1. In-situ microscopic inspection of DP steel deformation behavior with local strain overlay (from digital image correlation).

Austenite to martensite phase transformation induced dislocation distribution heterogeneities are well-known through post-mortem TEM analyses of DP microstructures [1]. However, it is trivially not possible using post-mortem analyses to clarify whether it is (i) the high mobility of these accommodation dislocations, or (ii) the assistance of the transformation-induced elastic residual stress fields to the externally applied stress fields that facilitate the early (and heterogeneous) plasticity in DP steel microstructures. On the other hand, in-situ deformation experiments are perfectly suitable for capturing these micro-mechanisms, especially in SEM environment, where numerous regions of interest can be tracked simultaneously using different SEM-based techniques; i.e. ECCI (for dislocation imaging), EBSD (for stress-induced phase transformations), micrographic DIC (for strain partitioning), and FIB (for isolated testing of microstructural regions of interest). Therefore, different DP steel microstructures are produced by intercritical annealing[1], and tested using a Kammrath-Weiss deformation stage. SEM imaging is carried out using a FEI Quanta 600F (for micrographic DIC) and a Zeiss-Crossbeam XB 1540 FIB-SEM with a Gemini-type field emission gun (for EBSD, ECCI, FIB).

Results

Experiments carried out on different DP microstructures confirm dislocation heterogeneity in the undeformed state and the immediate start of dislocation activity (i.e. rearrangement of surface dislocations, appearance of new surface dislocations,

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[1] Note that some researchers have also proposed that the stress induced retained austenite to martensite transformation plays a significant role in the observed high initial strain hardening rate [2]. To simplify the problem at hand, the DP steel microstructures in this study are produced by heat treatments designed to minimize the amount of retained austenite.

appearance of slip steps) with the application of the external load (see the ECCI images in Fig. 2).

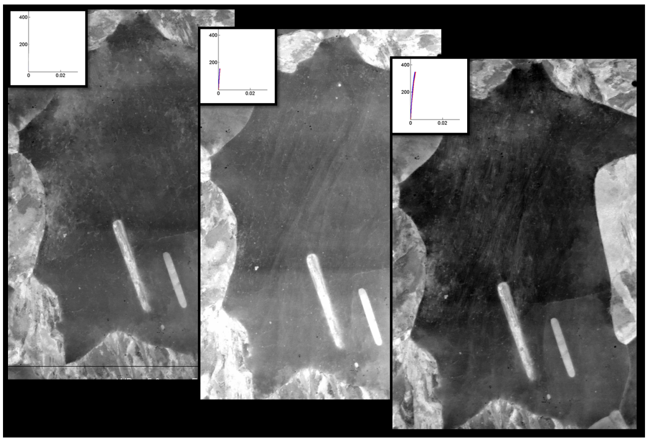

Figure 2. ECCI images of a deforming ferritic grain. Slip lines are observed (in the center of the ferritic grain, away from the martensite interface) simultaneously with the externally applied load.

However, interestingly, the dislocation activity is first triggered near the martensite interface only in few of the investigated grains. Although this observation is already a strong counterargument for the high mobility accommodation dislocations explanation of the continuous yielding, the complicated nature of the polycrystal slip conditions and the influence of the (unknown) 3rd dimension of the microstructure make it difficult to draw conclusions from such observations. Therefore, next to these experiments, a novel approach incorporating micro-scale testing of isolated regions in DP microstructures is employed (Fig. 3a,b). ECCI images obtained from isolated testing of ferrite-martensite bicrystals consistently revealed the same general results that the dislocation activity is generally more pronounced away from the interface (Fig. 3c).

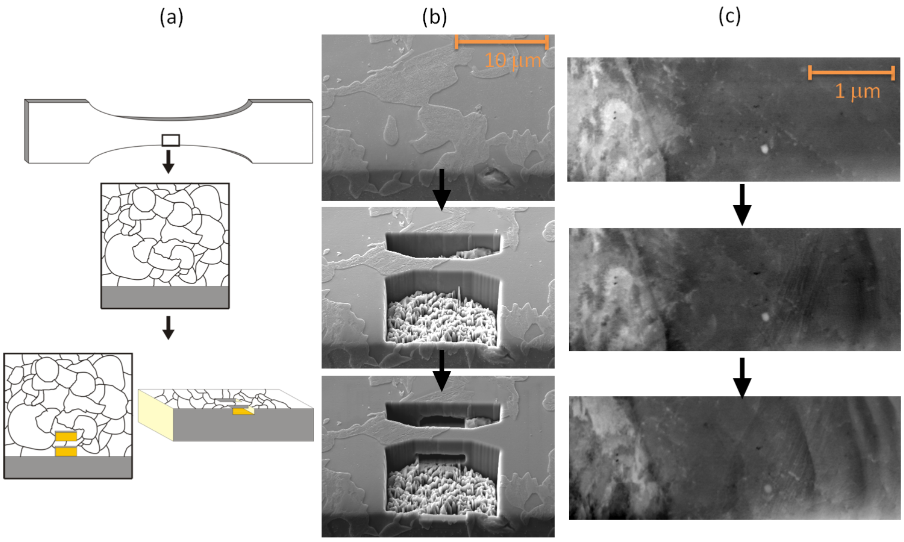

Figure 3. New micro-scale testing methodology: (a) cartoon showing the strategy; (b) FIB steps to produce the isolated micro-sample; (c) ECCI images of a martensite-ferrite bicrystal showing slip to be initiated away from the interface.

Ongoing Work

Currently new in-situ experiments are underway (employing cross-correlation analysis of EBSD patterns) to investigate the influence of elastic residual stresses to the applied external stress.

References

[1] Korzekwa D.A., Matlock D.K., Krauss G.: Dislocation Substructure as a Function of Strain in a Dual-Phase Steel. *Metall Trans A* **15A**:1221–1228, 1984

[2] Rashid M.S.: Dual Phase Steels. *Ann Rev Mater Sci* **11**:245–266, 1981