15th International Conference on Fracture (ICF15)
June 11-16, 2023 Atlanta, GA USA

INSIGHTS INTO VOID NUCLEATION AND GROWTH IN A DUAL PHASE STEEL BY SMALL SCALE MECHANICAL TESTING

Chunhua Tian[1], Angelica Medina[2], Konrad Prikoszovich[2], Reinhard Pippan[3], Patric A. Gruber[2], Subin Lee[2], Christoph Kirchlechner[5]

[1]*Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany*, now at *EMPA, Thun, Switzerland*
[2]*Institute for Applied Materials, Karlsruhe Institute of Technology, Karlsruhe, Germany*
[3]*Erich Schmid Institute, Austrian Academy of Sciences, Leoben, Austria*
**Presenting Author email*: *christoph.kirchlechner@kit.edu*

Abstract
Dual phase (DP) steels are comprised of a soft ferrite matrix and hard martensite islands. They are often used in automotive applications due to their advantageous combination of high strength and good ductility. During forming, DP steels can suffer from ductile damage, i.e. the formation and growth of voids, which typically occur by interface decohesion and martensite fracture [1]. As of now, the void content of a deformed part cannot precisely be predicted and, therefore, safety factors are used to assure the required mechanical properties and component lifetime. These safety factors are opposing sustainability and light-weight design. Consequently, the DFG-funded collaborative research center TRR188 aims at a quantitative characterization, prediction and control of ductile damage during forming.

In the talk, micromechanical experiments on the plasticity and fracture of single ferrite grains and martensite islands of two nominal identical steel grades will be presented. While one steel grade exhibits a low ferrite and a high martensite strength, the other shows a significantly stronger ferrite and lower strength martensite compared to the first steel grade [2]. This results in huge differences in the void nucleation and growth characteristics of the two steel grades.

1. Methodology

We used focused ion beam (FIB) based micromechanics to investigate the mechanical properties at the microstructure length scale. For understanding the plastic properties of individual constituents, we used 3 µm sized micro pillars in ferrite (single crystalline) and 1 µm sized in martensite. Besides the behavior of constituents of the as-prepared samples we also investigated the properties of pre-deformed specimens (macro strain up to 20%) to shed light on the strain hardening behavior of individual phases.

To understand the void nucleation process in martensite islands we used elasto plastic fracture mechanics [3]. The micro cantilevers were notched by FIB. To avoid any unwanted plasticity in ferrite we milled an additional gauge section.

2. Results

The most important findings are:

1) Both DP800 steel grades exhibit the same ultimate tensile strength (UTS).
2) One DP grade shows a low ferrite strength and a high martensite strength (large mechanical heterogeneity). The second one, in contrast, a very high ferrite strength and low martensite strength (low heterogeneity).
3) While damage nucleation is abundand in the DP grade with large heterogeniety, the number of nucleated voids in the sample with low heterogeneity is substantially smaller.
4) Samples with large mechanical heterogeneity do not show extensive void growth. In contrast, the samples with low mechanical heterogeneity exhibits extensive void growth which results in early failure (less macroscopic uniform elongation and less strain to failure).
5) The strain hardening behavior of ferrite is identified as key-parameter preventing damage growth.

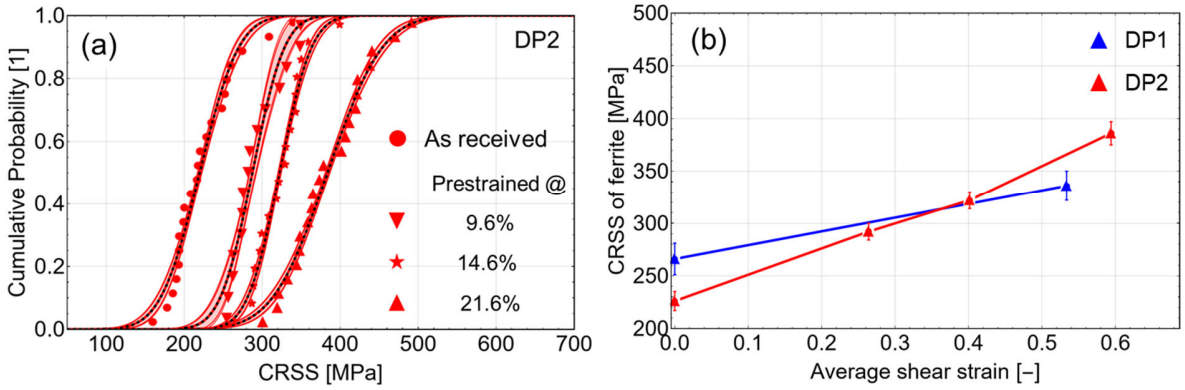

Fig.1 – The yield strength of ferrite plotted against the global prestrain.

Acknowledgements
The authors acknowledge funding by the German research foundation (Deutsche Forschungsgemeinschaft, DFG) within the Collaborative Research Center (TRR 188, "Damage Controlled Forming Processes", 278868966) in project B03 "Understanding damage initiation and growth at microstructural scale".

References

[1] C. Kusche, T. Reclik, M. Freund, T. Al-Samman, U. Kerzel, S. Korte-Kerzel, "Large-area, high-resolution characterisation and classification of damage mechanisms in dual-phase steel using deep learning", PLOS ONE 14 (2019).

[2] C. Tian, D. Ponge, L. Christiansen, C. Kirchlechner, "On the mechanical heterogeneity in dual phase steel grades: Activation of slip systems and deformation of martensite in DP800", Acta Materialia 183 (2020) 274-284.

[3] C. Tian, C. Kirchlechner, "The fracture toughness of martensite islands in duall-phase DP800 steel", Journal of Materials Research 36 (2021) 2495-2504.