THE INFLUENCE OF TRANSFORMATION INDUCED PLASTICITY ON DAMAGE DEVELOPMENT IN THIRD-GENERATION ADVANCED HIGH STRENGTH STEELS

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Abstract

Considerable research has been invested in developing thin sheet Advanced High Strength Steels (AHSSs) and to metastabilize phases at ambient temperatures; however, little has been done to determine the extent to which the transformation from austenite to martensite (TRIP), can suppress/delay damage. The damage processes that lead to fracture in AHSSs are complex and understanding them requires a careful assessment of the strain partitioning amongst the phases, the evolution of microstructure with strain and how damage accumulates in the form of voids and microcracks. This can only be accomplished by applying a range of methodologies tracked as deformation proceeds, including micro-Digital Image Correlation (µDIC), Electron Backscattered diffraction (EBSD), X-ray microtomography (µXCT) and synchrotron-sourced High Energy X-ray diffraction (HEXRD). Such experiments have also been applied to notched specimen to further understand the response of AHSSs at different states of stress. Data will be presented on a range of ultrahigh strength AHSSs with and without TRIP-assistance (dual phase (DP), quench & partition (Q&P), and Medium-Mn steels). The data suggests that grain refinement, TRIP and decreased mechanical heterogeneity amongst phases can be used to suppress damage. It remains a challenge to quantify these effects separately, opening new avenues for experimental and modeling investigations.

1. Introduction

The ability to tailor the stability of retained austenite during deformation has been crucial in manipulating the strength to ductility ratio of third generation AHSSs. With that being said, however, non-TRIP-assisting DP steels remain the most widely used due to their robust thermomechanical processing and attractive mechanical properties. Recently, it has been seen that small additions of vanadium (V) can increase the usage of ultrahigh strength DP steels which is traditionally compromised by their poor damage tolerance. A novel µDIC-based processing technique has been applied to characterize the 'strain gradient' across dissimilar phase interfaces, indicative of the accumulation of geometrically necessary dislocations . A comparison of this DP steel to a Q&P steel, with similar ultrahigh strength levels and grain sizes, shows that the strain gradient, and therefore, the micromechanical heterogeneity is reduced in the Q&P steel. The ultimate difference between both steels is TRIP. By diversifying the range of ultrafine-structured AHSSs tested, we can gain a better understanding of the benefits and/or pitfalls TRIP contributes to steel damage tolerance. Furthermore, while designating ductility by means of tensile elongation is applicable to understanding a material's response under stretching operations, this not applicable to most complex forming operations. In analyzing a series of AHSSs, an alternative means of defining a steel's performance by classifying it's ability to deform under a concentrated load (local forming potential) versus that of a uniform load (global forming potential) is being used. With µXCT, we have been able to demonstrate that grain refinement, TRIP and decreased micromechanical heterogeneity amongst phases can all be used to suppress damage, and therefore,increase the local true strain to fracture. Moreover, current damage models are validated using uniaxial tensile testing, and hence, limited to predicting material response at low triaxialities (i.e; a material's performance when subjected to a concentrated load). There is a unique relationship between the true strain at fracture and triaxiality which has already been highlighted in the literature. The primary objective of this work is to determine the mechanisms that control the damage and fracture response of ultrafine structure DP, Q&P steels and Medium-Mn steels and to thereby suggest approaches that will optimize damage suppression, with or without TRIP-assistance. In some instances, we are attempting to use the volume expansion associated at an optimized TRIP exhaustion rate to suppress damage. A secondary objective of this work is to determine the sensitivity of damage to stress-state/triaxiality. Hence, in addition to unnotched specimen, notched specimen are used to fully understand the impact complex forming operations will have on TRIP kinetics and damage evolution.

2. Results

Variation in starting microstructure and Intercritical Annealing (IA) parameters, even through a narrow IA temperature window, from 665°C to 710°C, of continuous-galvanizing-line compatible Medium-Mn alloys has shown the potential to dramatically impact TRIP kinetics. A Medium-Mn steel with a martensitic-ferritic starting microstructure intercritically annealed at 685°C for 120 seconds showed optimized conditions by achieving 3G mechanical targets as well as the highest total elongation, highest true strain at fracture, prolonged TRIP and monotonic work hardening. In-situ tensile testing coupled with µDIC has shown that there is moderate strain partitioning between phases in this Medium-Mn steel, with the severely notched specimen showing the least strain partitioning between dissimilar phases, as shown in Figure1a-c. To date, µXCT of a fractured specimen enables damage evolution,quantified as a function of local true strain, shows that the 685°C IA condition accumulates the least amount of closed voids up to fracture and greatest variation in void diameters. The sensitivity damage to triaxiality at this optimized IA shows void growth to the same overall variability, with a severely notched sample showing the lowest true strain to fracture, as shown in Figure 1d.

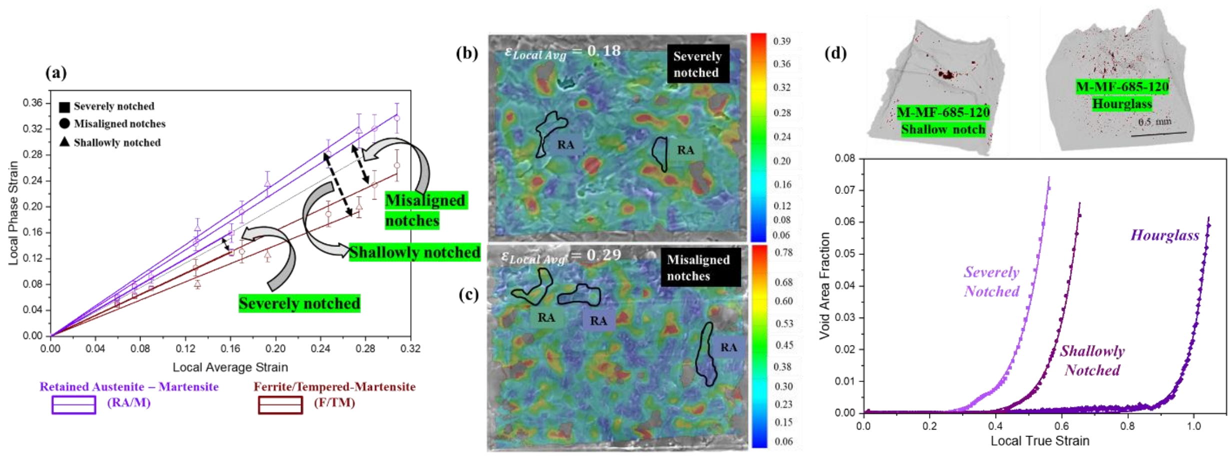

Fig. 1: (a) Strain partitioning between RA/M and TM/F in a Medium-Mn steel (b,c) DIC images highlighting regions of RA in the severely notched, and misaligned notches specimen, respectively (d) local true strain as a function of void area fracture of notched specimen at the optimized 685°C condition

HEXRD was performed on unnotched specimen at varied IA temperatures and on shallow, misaligned and severely notched specimen at the optimized IA temperature coupled with high resolution two-dimensional DIC. Preliminary results have revealed that the relationship between triaxiality and TRIP is non-monotonic.

3. Conclusions

The optimal TRIP exhaustion rate for a Medium-Mn steel was determined, through uniaxial tension, XRD, in-situ SEM tensile testing coupled with µDIC analysis and µXCT, for a MF starting microsturcture intercrically annealed at 685°C for 120 seconds. Intercrical annealing was used to vary the TRIP exhaustion rate in efforts to use the volume expansion associated with TRIP to suppress damage. In-situ tensile testing coupled with µDIC has shown that there is moderate strain partitioning between phases in this Medium-Mn steel, even under different states of stress/triaxialities. Through µXCT, the 685°C condition showed that the least closed voids nucleated up to its true strain at fracture with the greatest variability in void diameter size. Samples tested in the optimized 685°C condition, show void growth to the same variability in diameter with increasing triaxiality, with the severely notched sample showing the lowest true strain to fracture. Overall, HEXRD revealed that the relationship between triaxiality and TRIP is non-monotonic.

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