FRACTURE BEHAVIOUR OF HPT PROCESSED MARAGING STEELS

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Abstract

Maraging steels are a class of precipitation hardened steels wherein different micro-mechanisms of deformation such as planar slip, interaction with coherent/incoherent precipitates, and reverted austenite affecct the overall mechanical behavior of the material. High-pressure-torsion (HPT) processing introduces a large density of dislocations that form sub-grain boundaries within the refined nano-scale structure, leading to changes in precipitate morphology compared to hot-rolled maraging steels. The impact of such nanostructuring on the deformation and fracture micro-mechanisms is being reported for the first time using *in-situ* characterization techniques along with transmission electron microscopy and atom probe tomography analysis, in this study. Digital image correlation has been used to quantify the full field strain maps in regions of severe strain localization as well as to determine the fracture toughness through critical crack tip opening displacements.

1. Introduction

MDN250 maraging steels have a hierarchical microstructure as the base, wherein the parent austenite colony gets converted to micron-scale martensitic packets, blocks and nano-scale laths, in their peak aged conditions possess high strength (1700-1800 MPa) in conjunction with good fracture toughness (70-80 MPa√m). The present technological thrust is to increase the strength through processing alterations without compromising on fracture toughness. HPT processing has been shown to lead to an increase in strength in materials by creating nanocrystalline structures with high dislocation densities and very little preferred orientation. Our recent work on HPT processing followed by the aging of these maraging steels showed a 30% increase in strength but an accompanying 83% decline in ductility for the unaged condition under a uniaxial stress state [1]. Optimising the degree of deformation processing and aging treatment for such materials requires a detailed understanding of the mechanism of deformation accommodation under uniaxial and triaxial stress states, which is not addressed in the literature.

2. Results

It is seen that the phenomenon of planar slip leads to strain softening under uniaxial deformation and to crack branching under a triaxial stress state in hot rolled maraging steels. On the other hand, nano-structuring after HPT processing creates a large number of high angle grain boundaries as dislocation barriers, leading to strain hardening under uniaxial tension and nearly straight crack path with catastrophic fracture under triaxial stress state. In the overaged fracture test samples of both the hot-rolled and HPT conditions, crack tips show a signature of strain induced transformation of the reverted austenite to martensite, due to the accompanying severe strain gradients. This leads to a higher fracture toughness even while achieving high strengths in the overaged conditions of the nanocrystalline HPT overaged samples. Planar slip occurring in hot-rolled as-received (AR) samples leads to strain-softening in tension and is detrimental to tensile ductility [2], and yet enhances the fracture toughness through crack branching in a bending based fracture test.

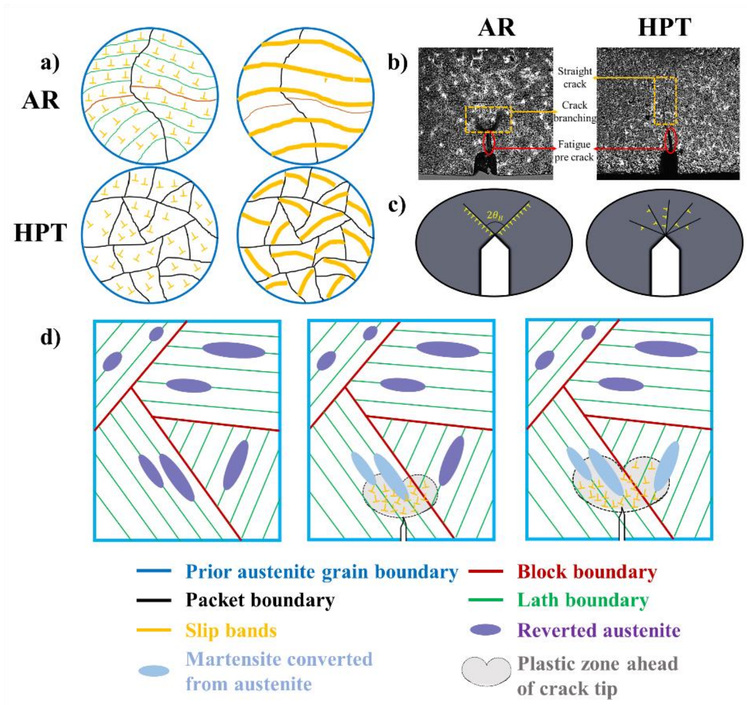

Fig.1 – a) Schematic representing the failure micro-mechanisms in AR and HPT processed samples during uniaxial tensile loading b) Crack propagation paths as observed in case of the AR and HPT processed conditions c) Schematic representing crack growth in the presence and absence of planar flow of dislocations d) Conversion of reverted austenite to martensite due to stress ahead of a crack tip in case of the corresponding overaged samples

3. Conclusions

The impact of nano-structuring of maraging steels via HPT processing on the micro-mechanisms of deformation and fracture behavior was quantified in this study through a combination of in-situ micromechanical testing and electron microscopy and APT. It is found that micro-mechanisms of failure in maraging steels are dependent on the external factors such as stress-state, specimen dimensions and test geometry, all of which must be accounted for, in addition to microstructural parameters. These results will have technological implications both during forming and in service and allow a better understanding for further microstructural engineering of maraging steels.

Acknowledgements

The authors would like to thank the funding support that was received through the Max Planck Society and IRCC seed grant for this work. Department of Science and Technology (DST)-Fund for Improvement of Science and Technology (FIST) for providing *in-situ* tensile SEM facilities, the National Facility for Atom Probe Tomography (NFAPT), IIT Madras for the APT facilities and Central facility of IIT Bombay for MFM facilities are also gratefully acknowledged.

Reference

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