Failure behavior of nano structured Maraging steels

Kevin Jacob [a], Saurabh Dixit [b], Anton Hohenwarter [c], B. Nagamani Jaya [a]

[a] Indian Institute of Technology Bombay, Mumbai - 400076, India

[b] Mishra Dhatu Nigam Ltd. (MIDHANI), Hyderabad - 500058, India

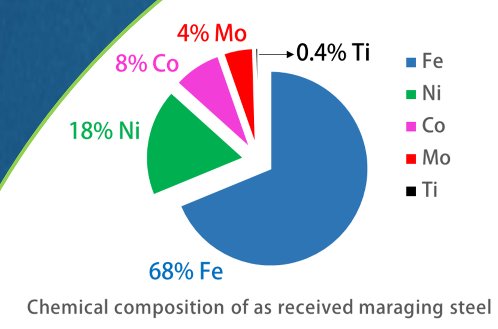
[c] Montanuniversität Leoben, Leoben - 8700, Austria

kevinjacobs1712@gmail.com

Micro-Mechanics of Materials Group

INTERNATIONAL CONFERENCE ON STRENGTH OF MATERIALS
ICSMA 19th
2022 June 26 - July 1, Metz - FRANCE

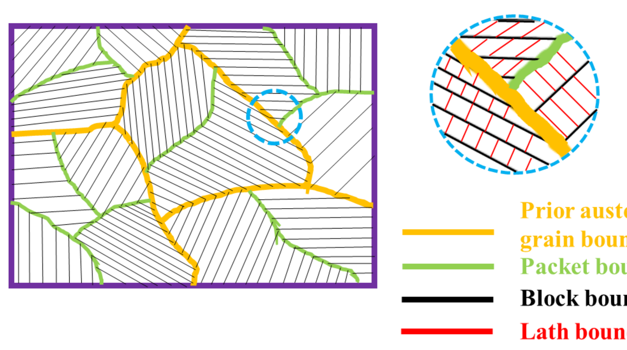
AR MDN 250 steel



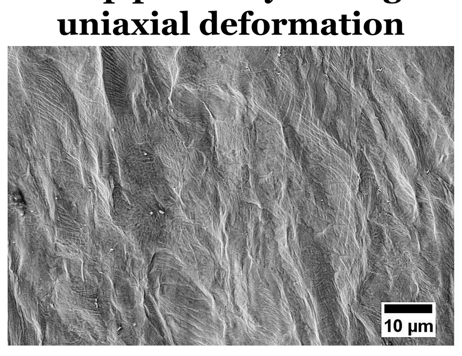
Chemical composition of as received maraging steel

18Ni MDN250

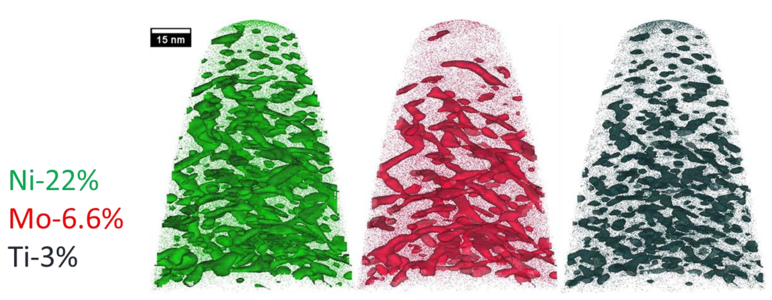
Hierarchical microstructure



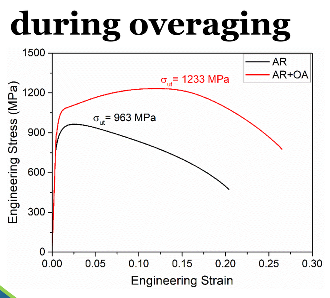
Slip planarity during uniaxial deformation

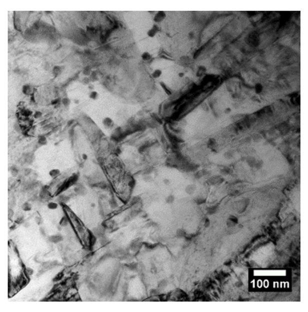


Precipitation hardened alloy



Strain softening in unaged condition and hardening during overaging





ρ~ 10^{14} m^{-2}

G.S ~ 355±55 nm

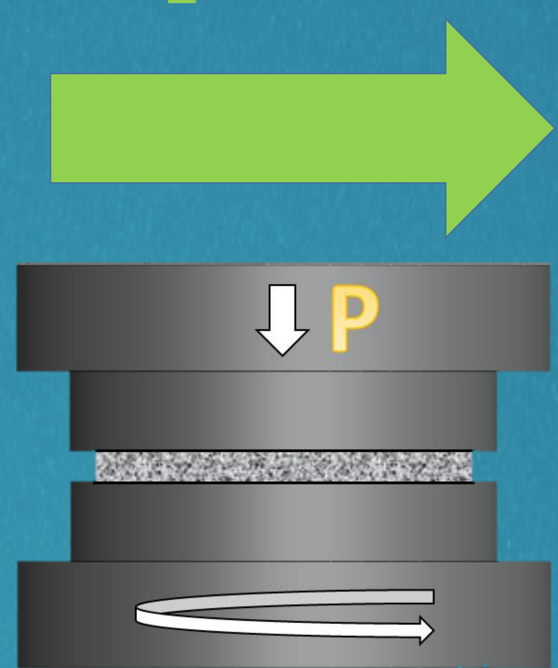
38 % reverted austenite

Reverted austenite and spherical Fe_2Mo precipitates improve strain hardening

Peak strength after aging ⇒ 1.7 GPa

Increased ductility at the cost of strength

HPT processing



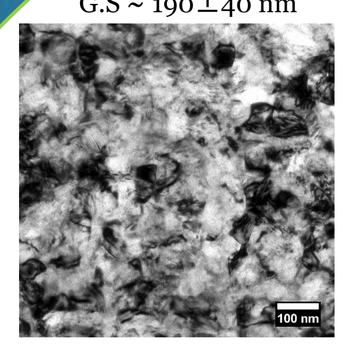
Peak strength after deformation and aging ⇒ 2.9 GPa

Increased strength at the cost of ductility

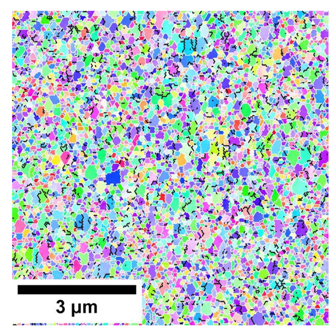
HPT processed MDN steel

ρ ~ 10^{16} m^{-2}

G.S ~ 190±40 nm

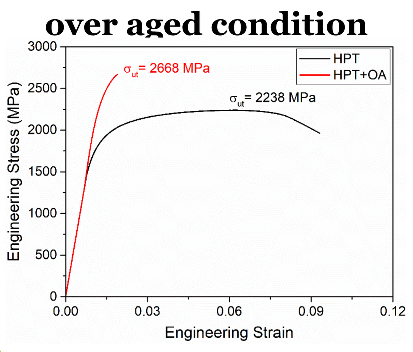


Breakdown of grain structure

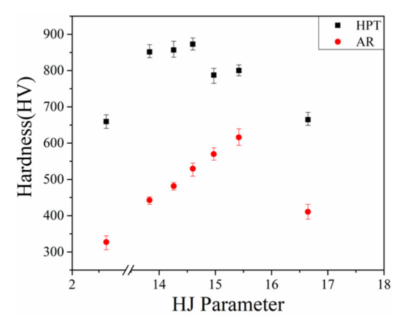


Presence of ultrafine grains without texture prevented planar slip

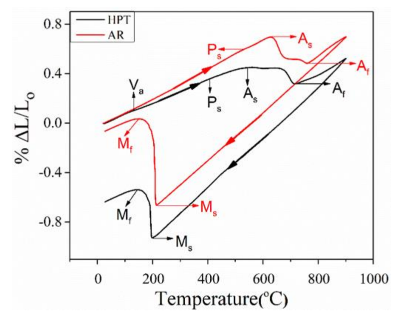
Hardening in unaged and brittle failure in over aged condition



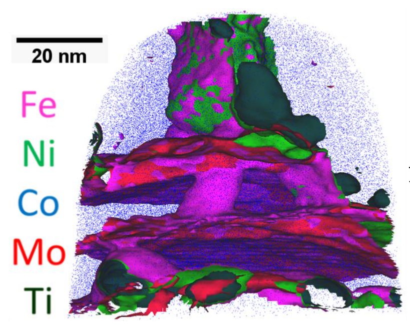
Aging kinetics accelerated



Transformation temperatures quickened



Nanograined austenite and plate like Fe-Mo precipitates acted as stress concentrators



Isosurface concentrations

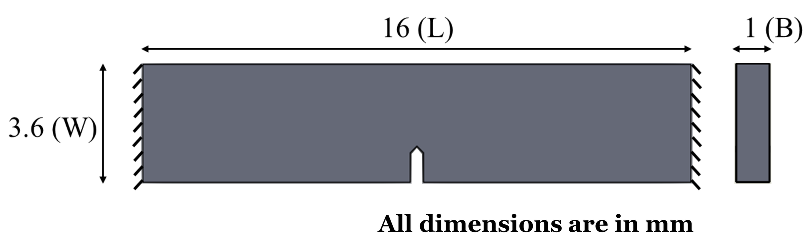
Fe-66%, Ni-20%, Mo-8 % Ti- 4%

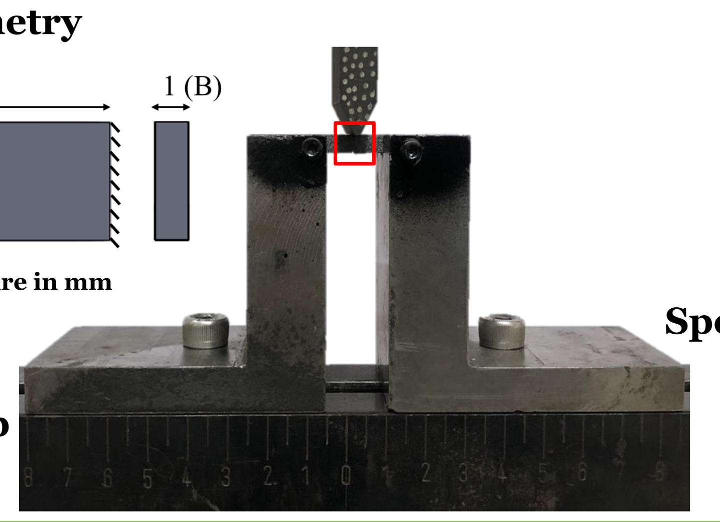
35 % reverted austenite

Deformation induced precipitate shape change

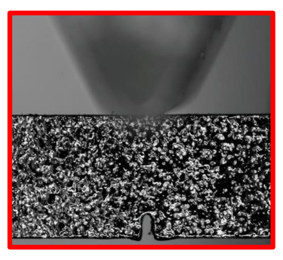
Fracture tests were carried out in a Jinan ™ UTM coupled with an *in-situ* optical DIC strain measurement (Sobriety™ Mercury DIC software)

Clamped beam geometry





Experimental setup

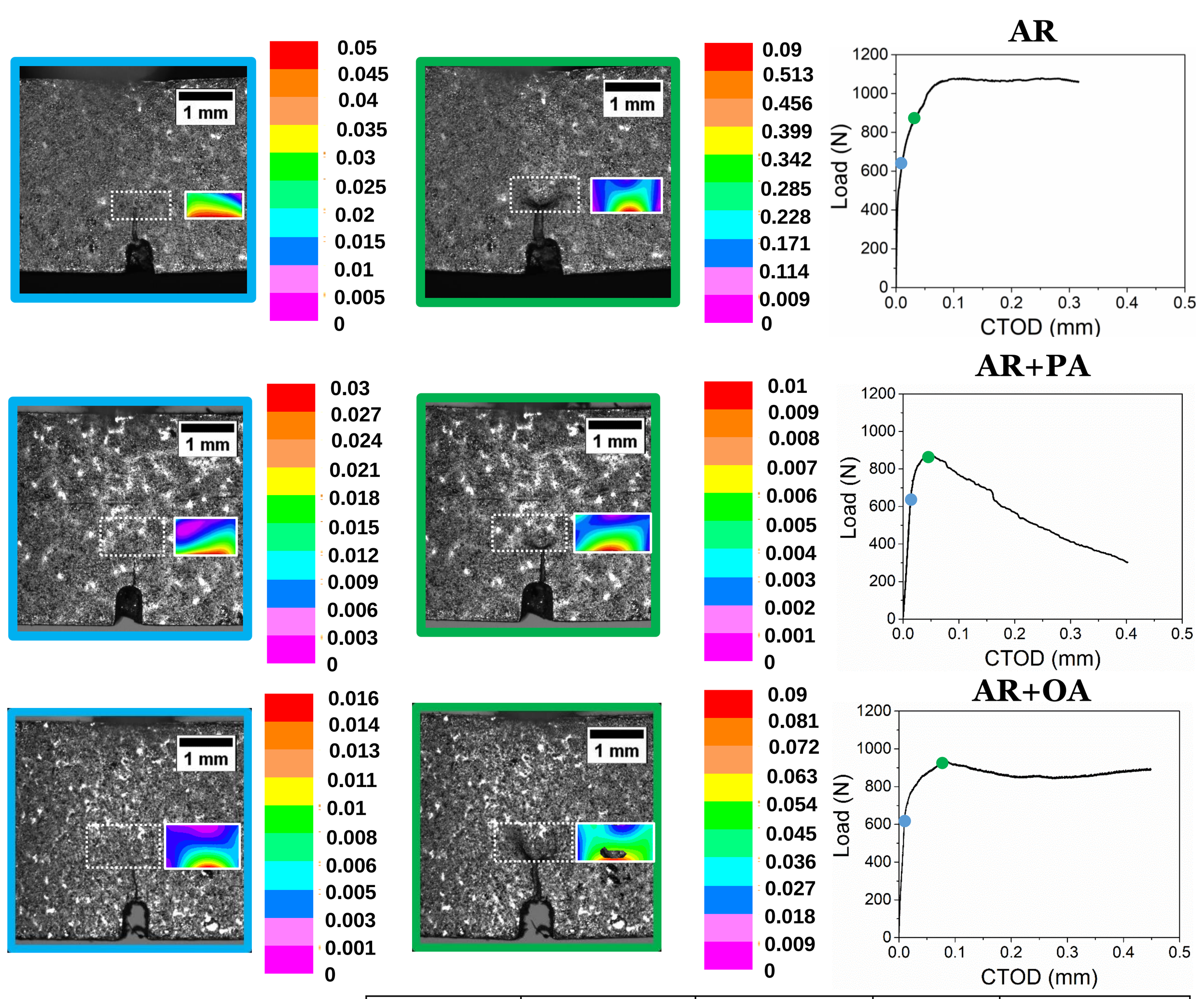


Speckle pattern for DIC strain mapping

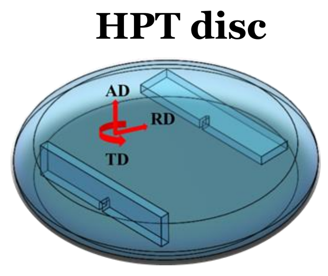
- **Fatigue pre cracked upto a/w of 0.3**
- **Critical CTOD measured using optical DIC at the crack initiation was used to quantify J_C^{CTOD}**

$$K_Q = \sqrt{J_C^{CTOD} \times E}$$

AR conditions

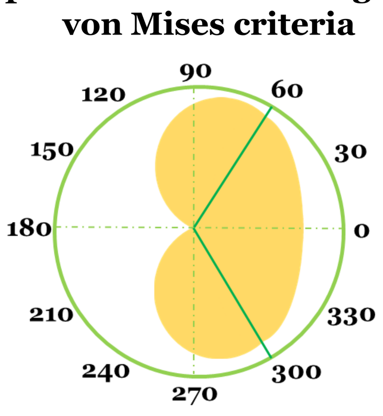


Tested orientations of HPT disc

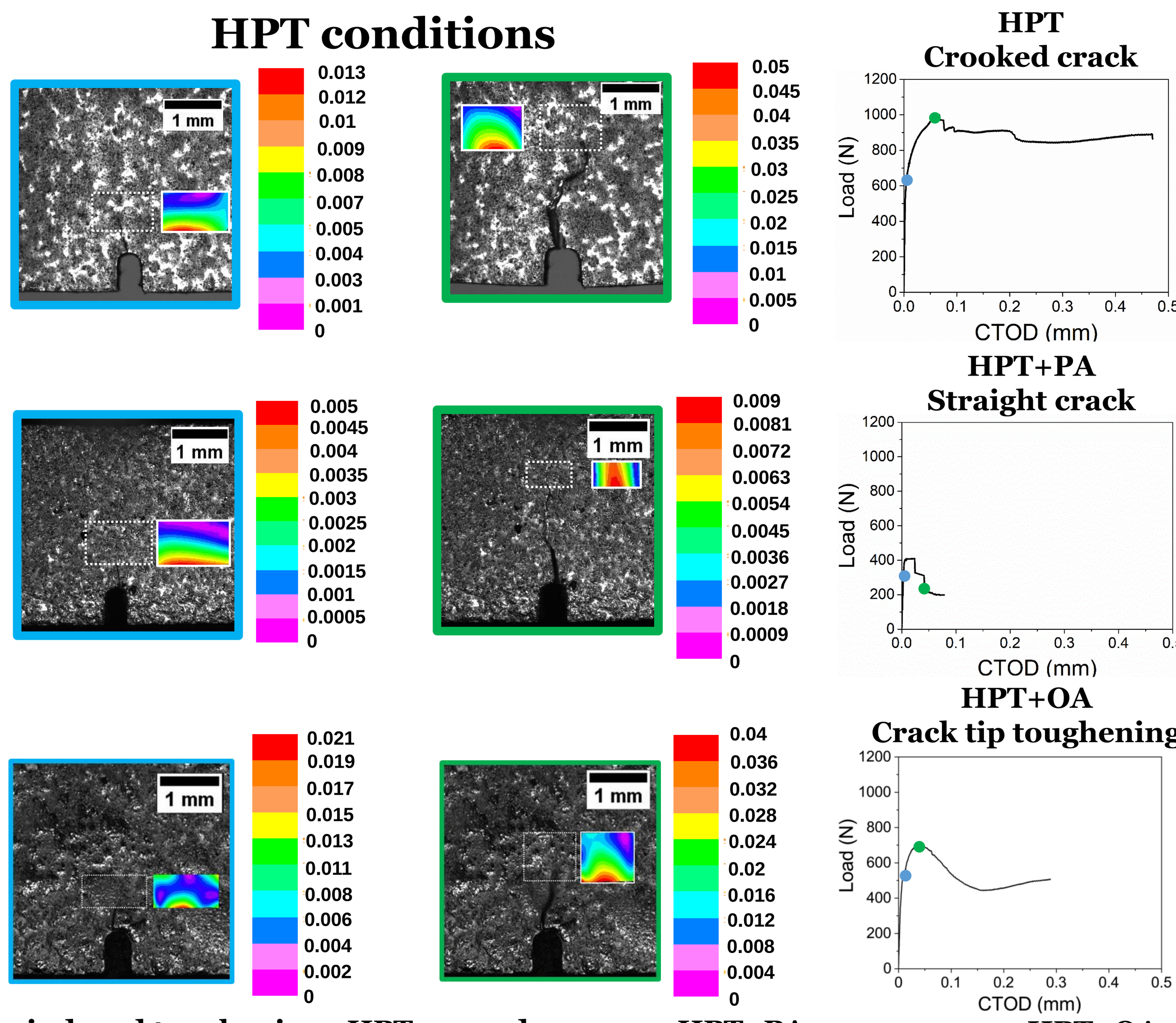


All 3 conditions showed branching of crack beyond fatigue pre crack

Plastic zone form under plane stress according to von Mises criteria



HPT conditions



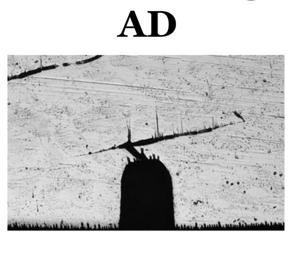
Delamination induced toughening improved the fracture toughness in HPT unaged condition

MFM done near the crack tip showed a reduction in the austenite fraction indicating the transformation to martensite due to plasticity

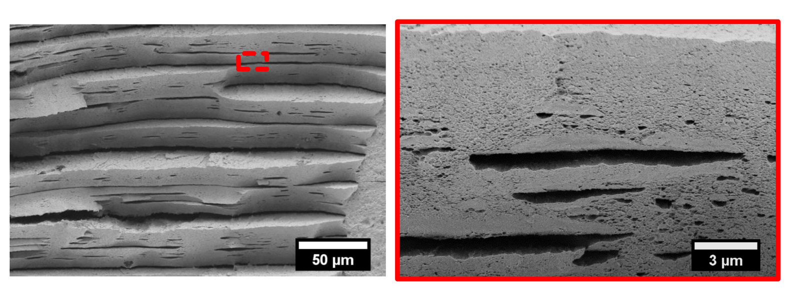
Fracture toughness values for different processing conditions

Processing condition	Critical CTOD at crack initiation (δ) (mm)	Initiation fracture toughness (K_Q) $(MPa\sqrt{m})$	Plastic zone size (r_p) (mm)	Minimum thickness for plane strain (B_Q) (mm)
AR	0.039±0.002	89.6±1.8	1.4	22
AR+PA	0.021±0.003	81.7±2.6	0.4	6
AR+OA	0.011±0.002	64.9±2.1	0.4	7
HPT	0.012±0.004	61.3±3.5	0.1	2
HPT+PA	0.004±0.001	44.7±4.2	0.04	1
HPT+OA	0.006±0.001	54.7±3.8	0.07	1

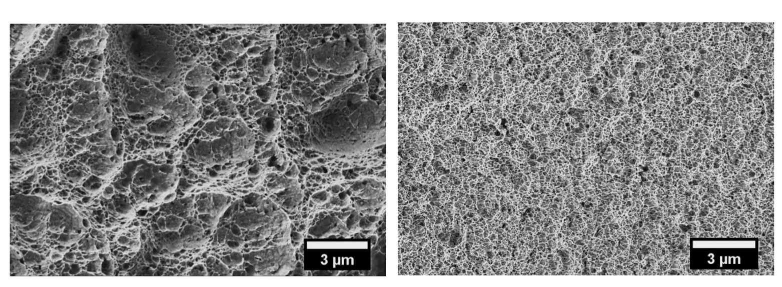
Notch along AD

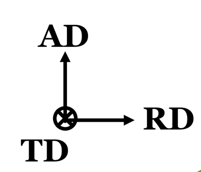


Delamination induced toughening - HPT unaged

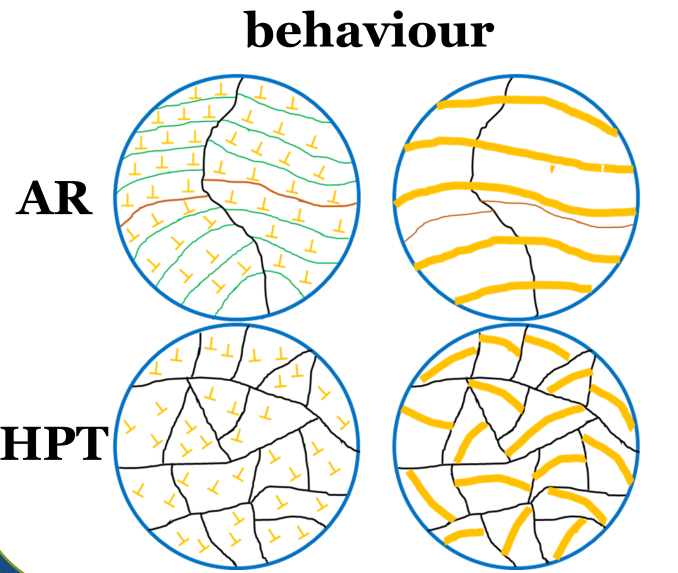


HPT+PA **HPT+OA**

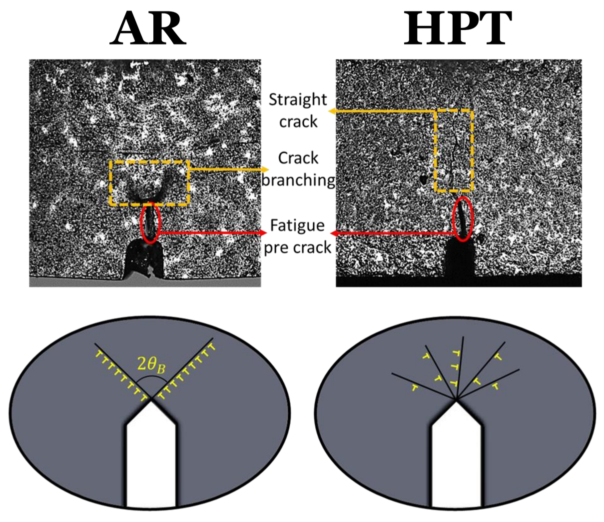




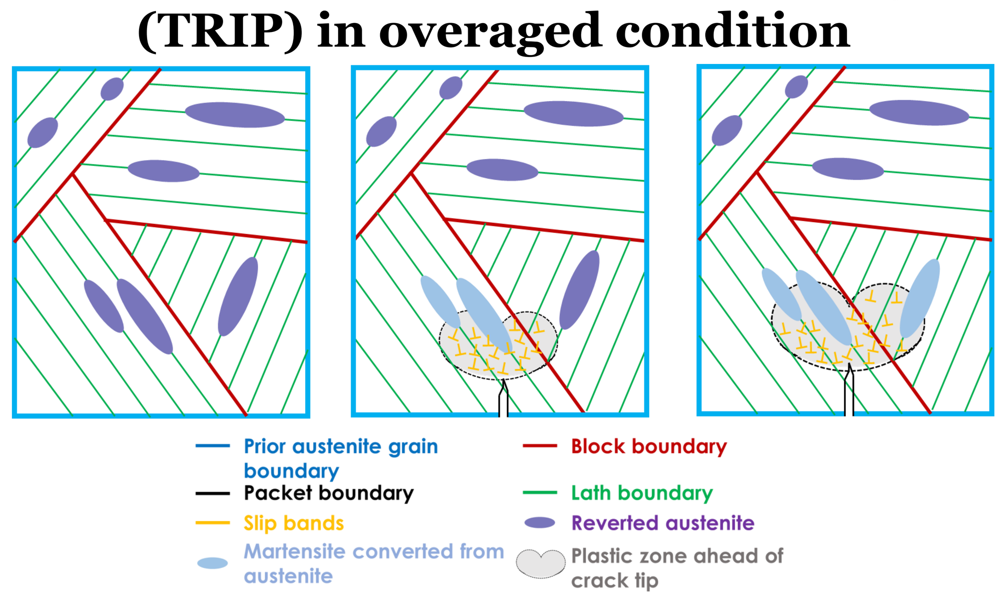
Planar slip deformation behaviour



Crack branching phenomenon



Transformation Induced Plasticity (TRIP) in overaged condition



Conclusion

- Planar slip in AR was detrimental for tensile stress-strain behaviour and yet enhanced fracture toughness through crack branching
- Absence of planar slip and occurrence of TRIP effects due to reverted austenite enhanced the overall ductility and fracture toughness of AR+OA at the cost of strength
- Nano scaled reverted austenite formed through HPT processing showed significant TRIP effect leading to enhanced crack tip toughening and improved fracture toughness

Acknowledgements

- Max Planck Society and IRCC seed grant for funding provided to carry out this work
- Central facilities at IIT Bombay