Micro-mechanism of Damage Evolution in Commercially Pure Titanium: An In-situ Study

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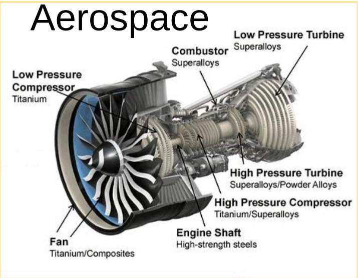
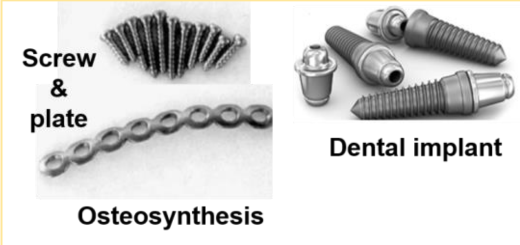
Introduction

- Ti and Ti alloys have high specific strength, room temperature ductility, fracture toughness
- Excellent corrosion resistance and biocompatibility
- Application → Aerospace, biomedical and transportation

Aerospace



Biomedical



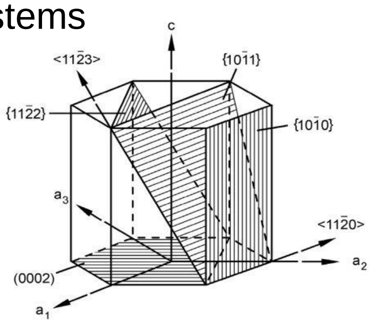
Transportation

Pressure Vessel

Deformation of titanium

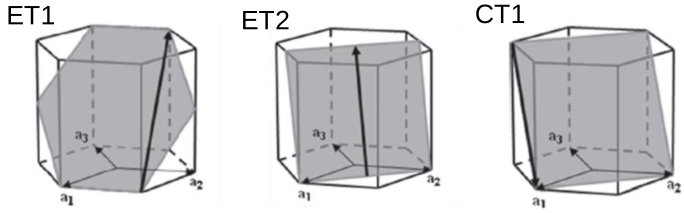
- Five independent slip/twinning → compatible deformation according to von-Mises criterion

Slip systems



- $\{0002\} < 11\bar{2}0 >$ basal
- $\{10\bar{1}0\} < 11\bar{2}0 >$ prismatic
- $\{10\bar{1}1\} < 11\bar{2}0 >$ pyramidal
- $\{10\bar{1}1\} < 11\bar{2}\bar{3} >$ pyramidal − I
- $\{11\bar{2}2\} < 11\bar{2}\bar{3} >$ pyramidal − II

Twinning systems



Mode	K_1 Plane	η_1 Direction	Misorientation (degree at axis)	Twin Shear
ET1	$\{10\bar{1}2\}$	$< \bar{1}011 >$	$85^0 < 11\bar{2}0 >$	0.171
ET2	$\{11\bar{2}1\}$	$< 11\bar{2}\bar{6} >$	$35^0 < \bar{1}100 >$	0.629
CT1	$\{11\bar{2}2\}$	$< 11\bar{2}\bar{3} >$	$65^0 < \bar{1}100 >$	0.221

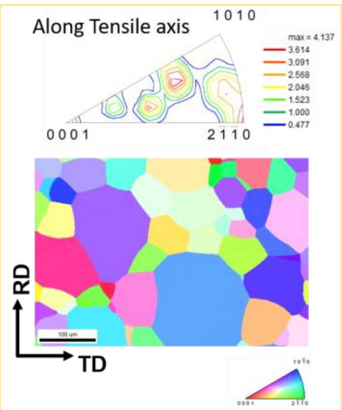
Ref: J W Christian and S Mahajan, Prog. Mater. Sci. (1995)

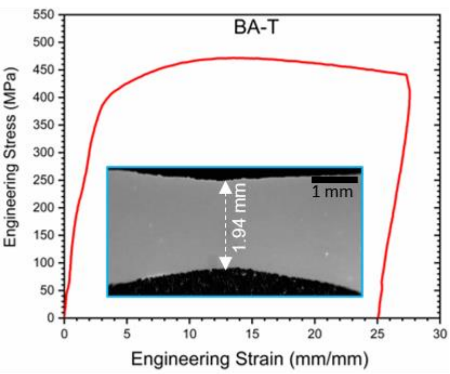
Motivation

- Void nucleation, growth and coalescence in ductile metal occurs by prosses of plastic deformation
- Micro-mechanism of ductile damage with crystallographic orientation

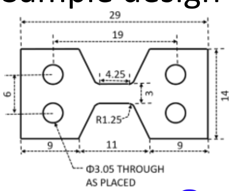
Methodology

- Cold rolled annealed commercially pure titanium Grade II
- Deformed at cross head velocity of 0.2mm/min

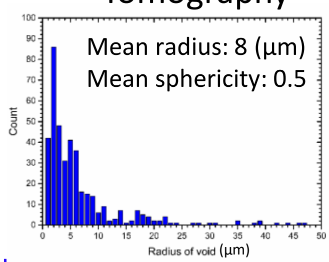




Sample design



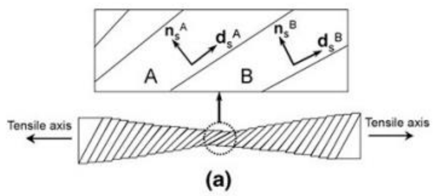
Tomography



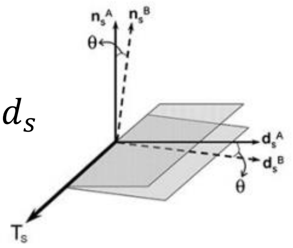
Scanning steps

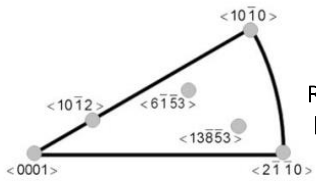
Step 0	Step 1	Step 2
0	0.15 mm	0.44 mm

Intra-granular misorientation analysis (IGMA)



$T_s = n_s \times d_s$



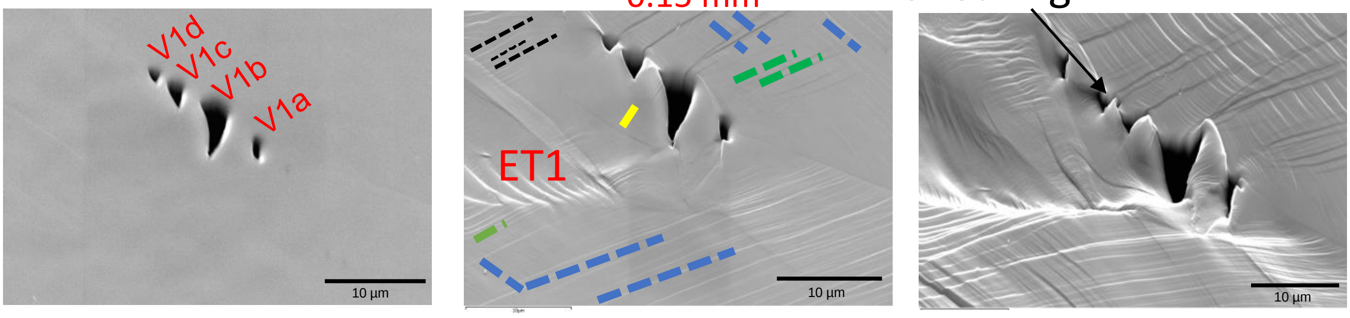


Slip system	Number of slip variants	Taylor axis	Number of variant of the Taylor axis
$\{10\bar{1}0\} < 1\bar{2}10 >$	3	$< 0001 >$	1
$\{0002\} < 1\bar{2}10 >$	3	$< 1\bar{1}00 >$	3
$\{10\bar{1}1\} < 1\bar{2}10 >$	6	$< 10\bar{1}\bar{2} >$	6
$\{01\bar{1}1\} < \bar{1}\bar{1}23 >$	12	$< 13\,\bar{8}\,\bar{5}\,3 >$	12
$\{11\bar{2}2\} < \bar{1}\bar{1}23 >$	6	$< 1\bar{1}00 >$	3

Ref: Y.B. Chun et al., Metall. Mater. Trans. A Phys. Metall. Mater. Sci. 41 (2010) 3473–3487. https://doi.org/10.1007/s11661-010-0410-4.

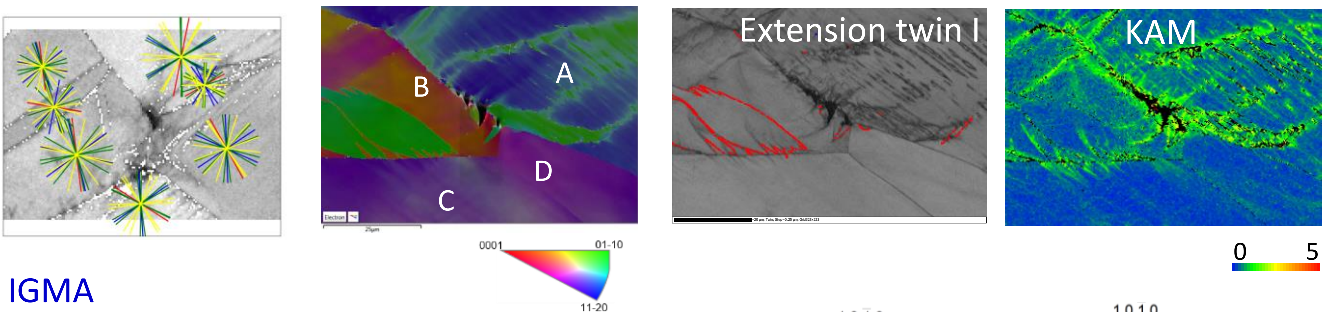
Case 1

0.0 mm | 0.15 mm | Shearing 0.44 mm

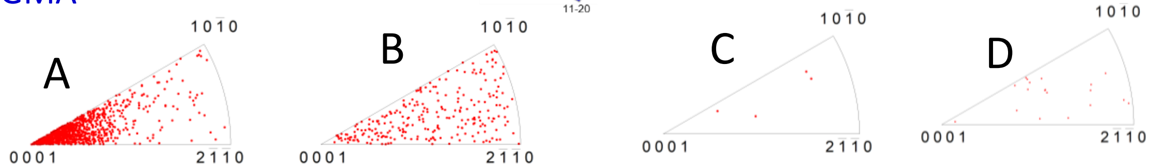


Plane trace

0001 | 10$\bar{1}$0 | 10$\bar{1}$1 | 11$\bar{2}$2

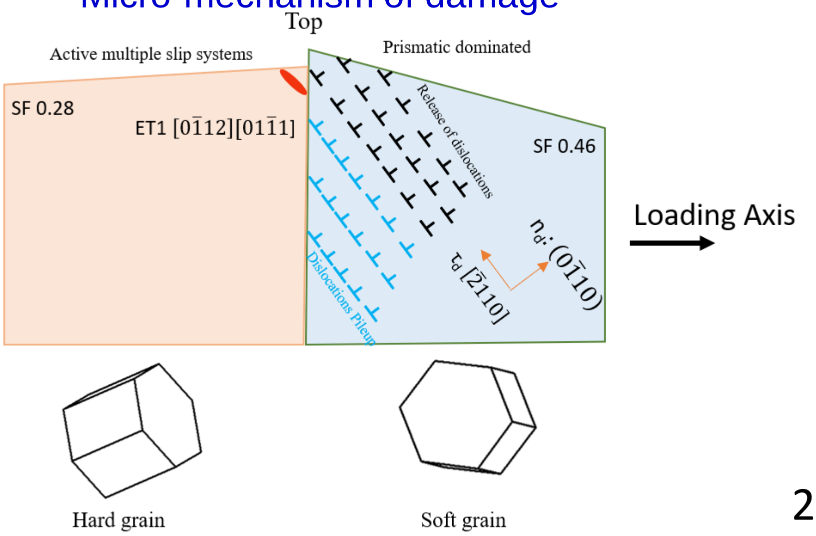


IGMA

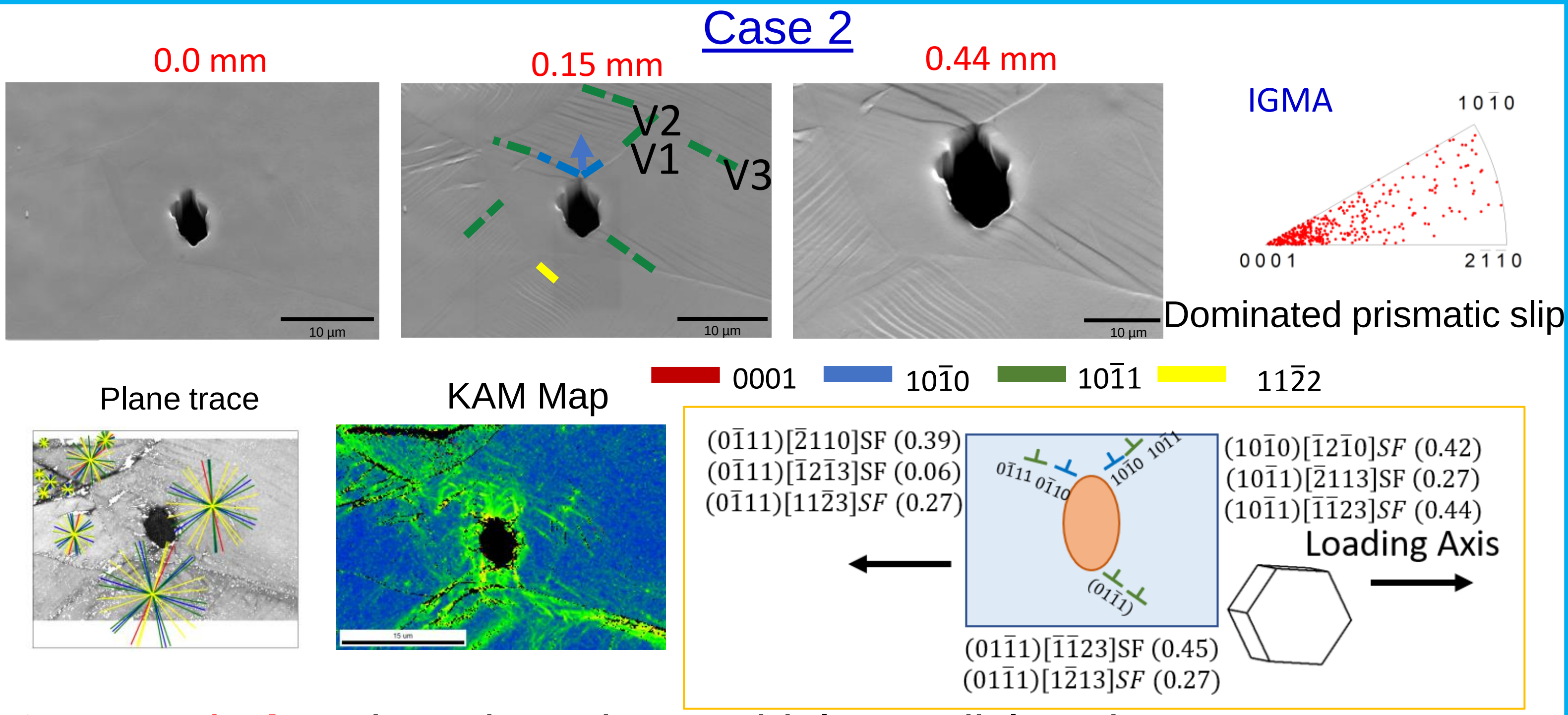


Dominated prismatic slip | Multi-activated slip

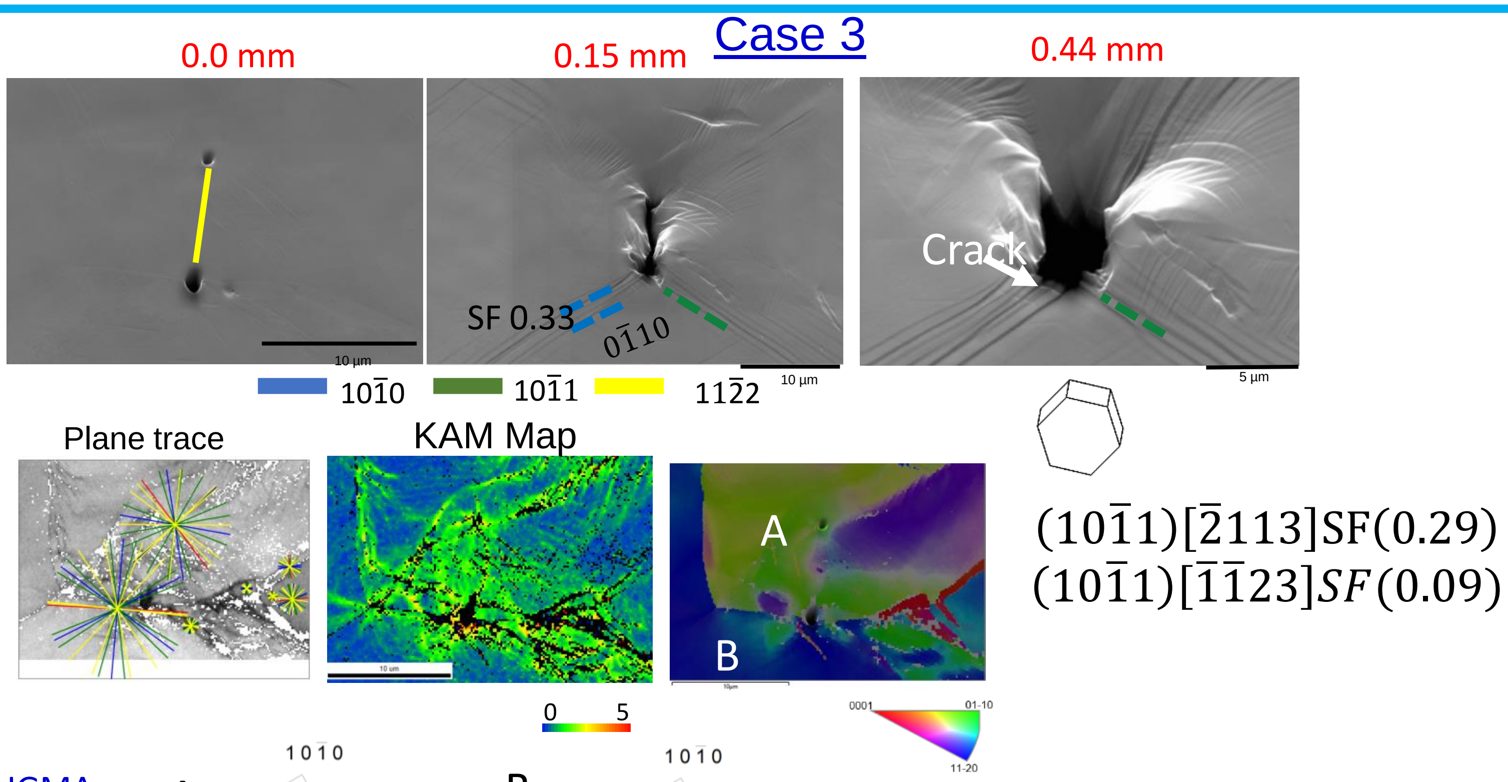
Micro-mechanism of damage

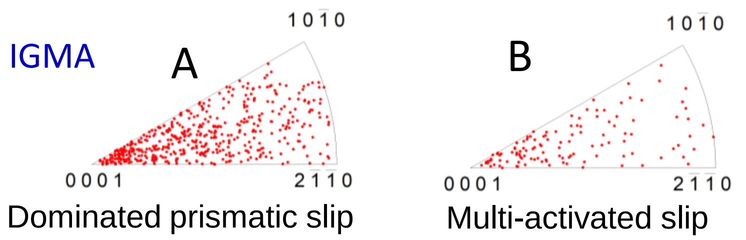


- **Nucleation** → Grain boundary + ET1
- **Growth** → Grain boundary, ET1 boundary, localized slip
- **Coalescence**→ Shearing



➤ Growth → Prismatic and pyramidal type dislocation





➤ Growth → Prismatic plane dominated over pyramidal plane

Conclusion

- Nucleation → Due to incompatibility at hard (Multi-activated slip) and soft (dominant prismatic slip) grain, pileup of prismatic dislocations at boundary
- Growth → High energy grain boundary, extension type I twin, prismatic and pyramidal type dislocations
- Coalescence→ Shearing, near pyramidal type II

Acknowledgement

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