SWTEST
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2024 CONFERENCE

Anisotropy in High-Strength Palladium Alloys for Foil Probe Applications

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Makers of High Tech Engineering Alloys

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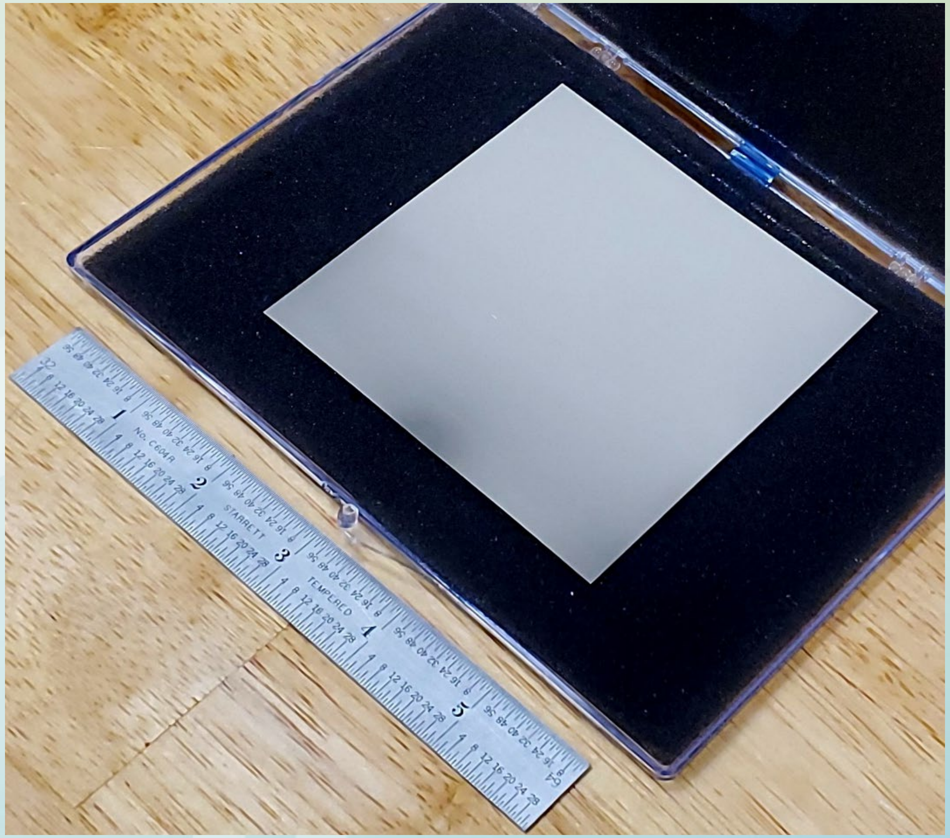
Introduction

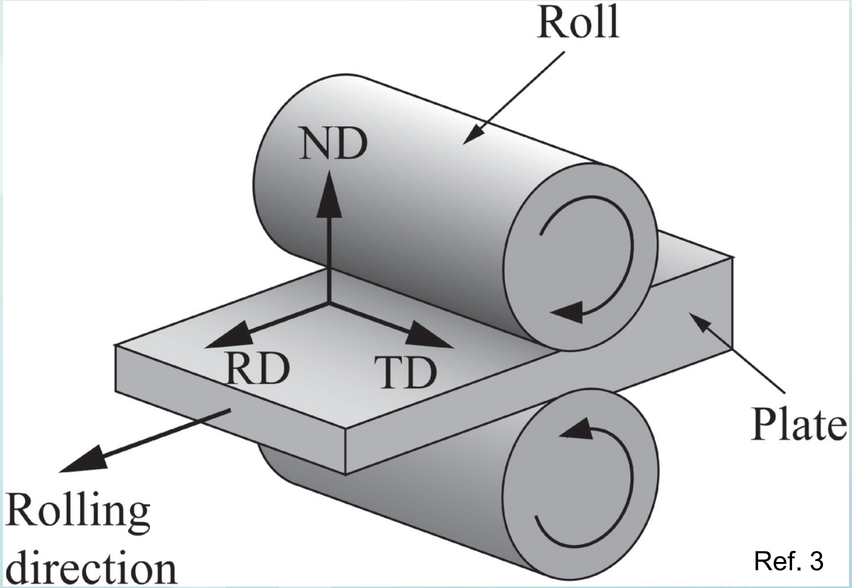
- Pd-Ag-Cu-based alloys used since 1970s[1] for buckling beam probes
- Over five decades, innovations led to new foil probes cut from metal sheets using lasers
- Allows different material choices versus electrodeposited MEMS
- Departure from wire introduces new material property-performance questions



Background

- During wrought processing, like rolling, grains tend to orient to a particular crystallographic direction, creating an inhomogeneous texture
- Material behavior often differs when loaded at angles to dominant texture[2]
- Anisotropy is directional variation in material properties

Full description	Engineering term	Customary term
Parallel to the flat rolling direction	RD	“Good way”
Transverse to the rolling direction	TD	“Bad way”
Normal to the rolling direction	ND	-



Study Objectives

- Aim: provide improved design guidance to foil test probe fabricators and users

- Hypothesis: Palladium alloys Paliney® 25 and 23 foil material properties will be strongly dependent on direction

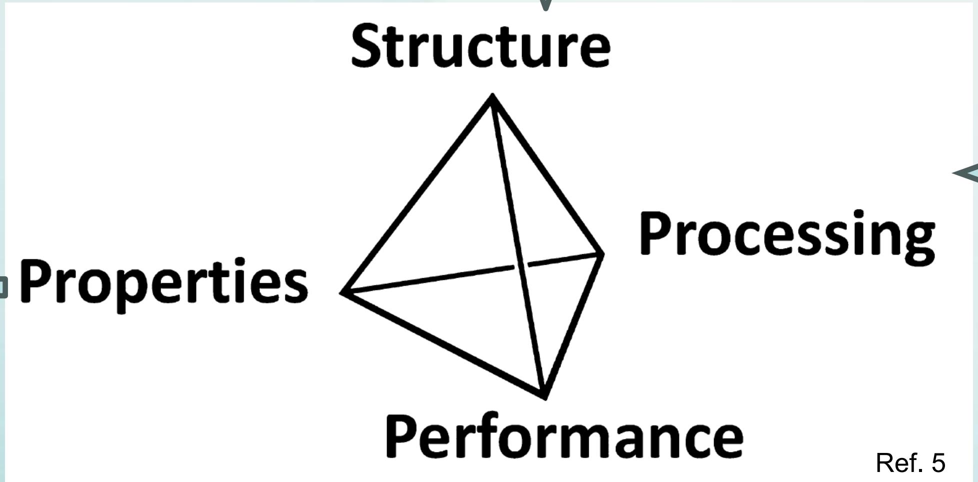
- Study designed to confirm or refute this hypothesis for both mechanical and electrical properties

Materials

Materials Science tetrahedron for studied materials

- Compositions based on Pd-Ag-Cu-Re[4]
- Three-phase structure
  FCC disordered solid solution
  CsCl-type long range order
  HCP Re-based

- Paliney 25 typ.
  180 ksi UTS
  6% elongation
  27% IACS
  HV 380
- Paliney 23 typ.
  210 ksi UTS
  4% elongation
  24% IACS
  HV 460

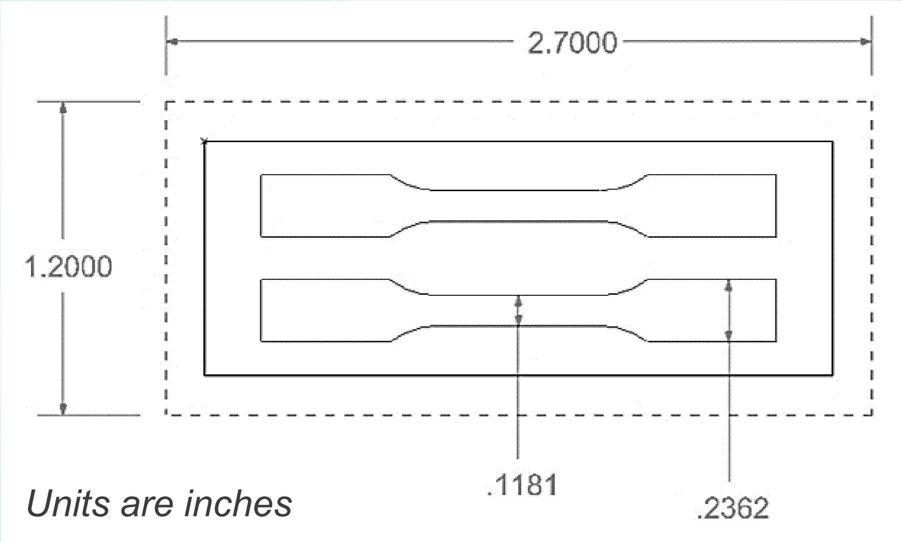


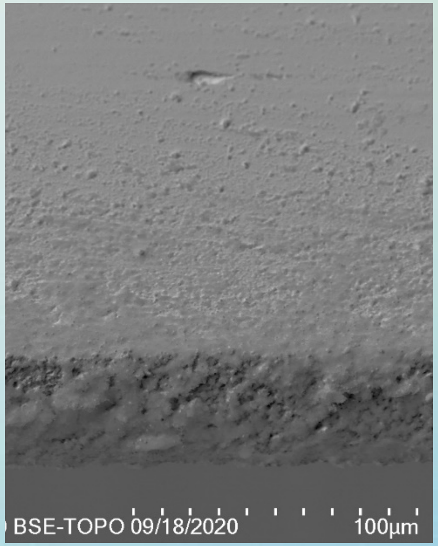
- Multiple cold roll & anneal steps to 50µm
- Solution anneal
- Age hardening heat treatment ("HTA" temper)

Methods

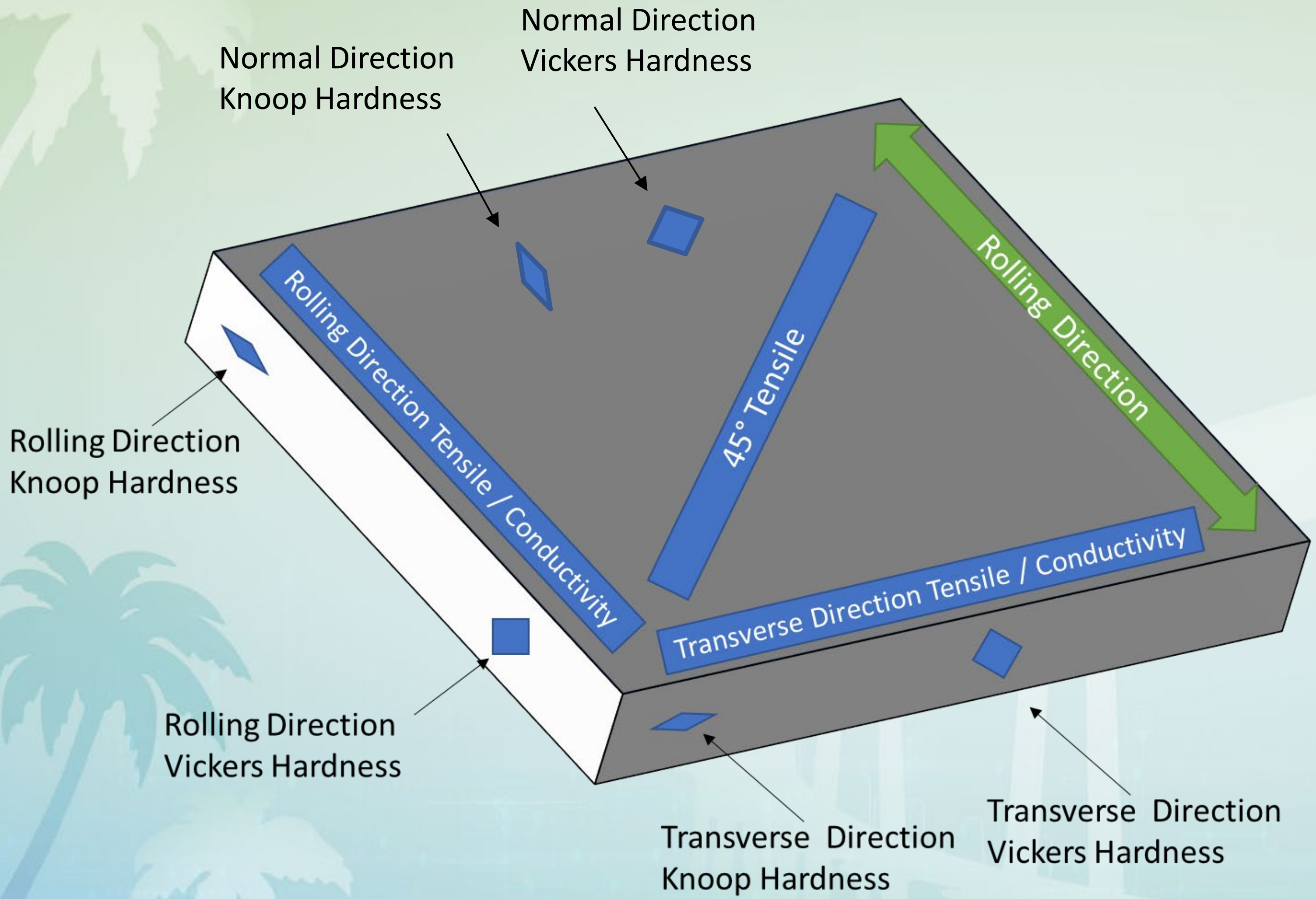
Property responses tested:

- Knoop and Vickers microhardness per ASTM E384
- Electrical conductivity using Kelvin clips and a four-wire resistance measurement on a precision multimeter
- Tensile testing using quasi-ASTM E8 miniature “dog-bone” tensile samples fabricated by wire electro-discharge machining (EDM)
- Hypothesis testing using a two-tailed, unpaired T-test at 99% confidence





Methods

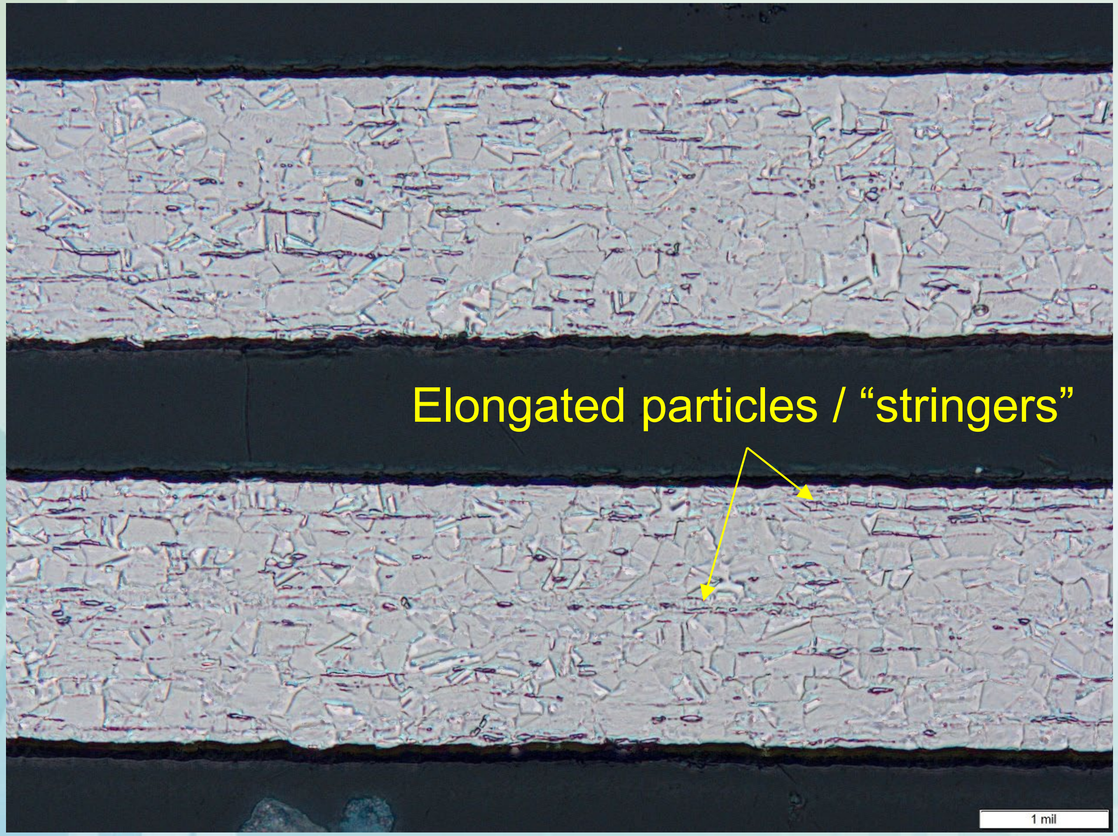


- **Tested four total orientation, including the rolling direction**
- **Replicate sizes:**

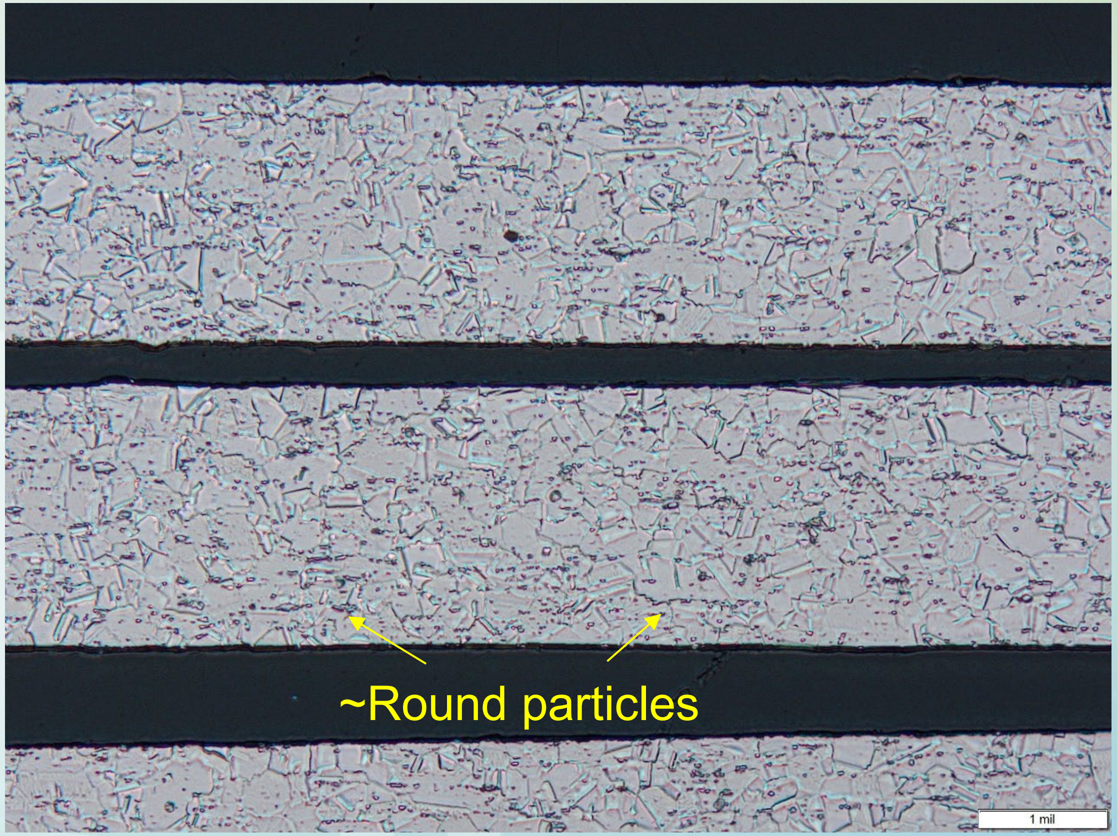
Direction	RD	TD	ND	45°
Tensile	5	5	-	5
Hardness	10	10	10	-
Conductivity	3	3	-	-

Results - Microstructure

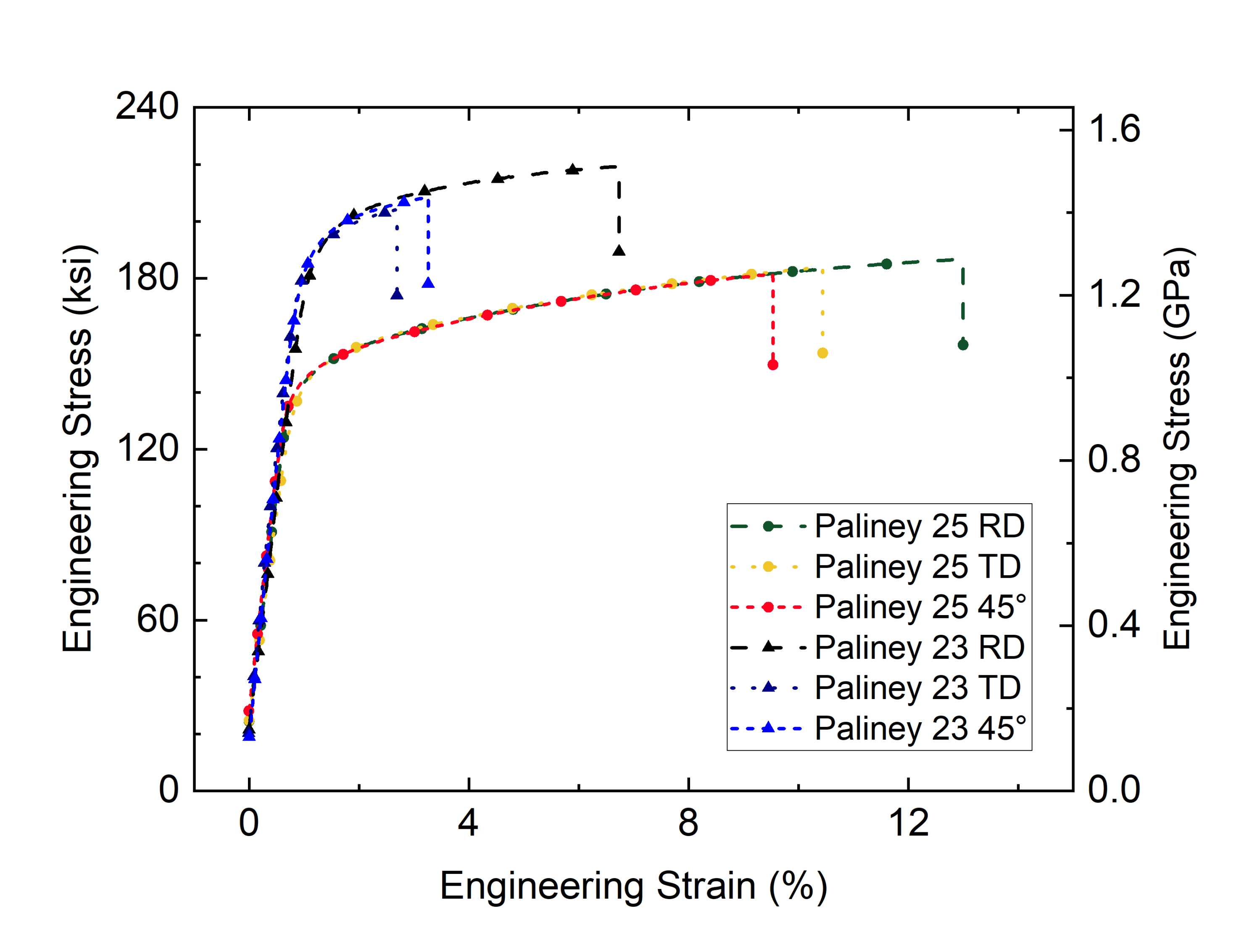
Paliney 25 rolling direction (RD)



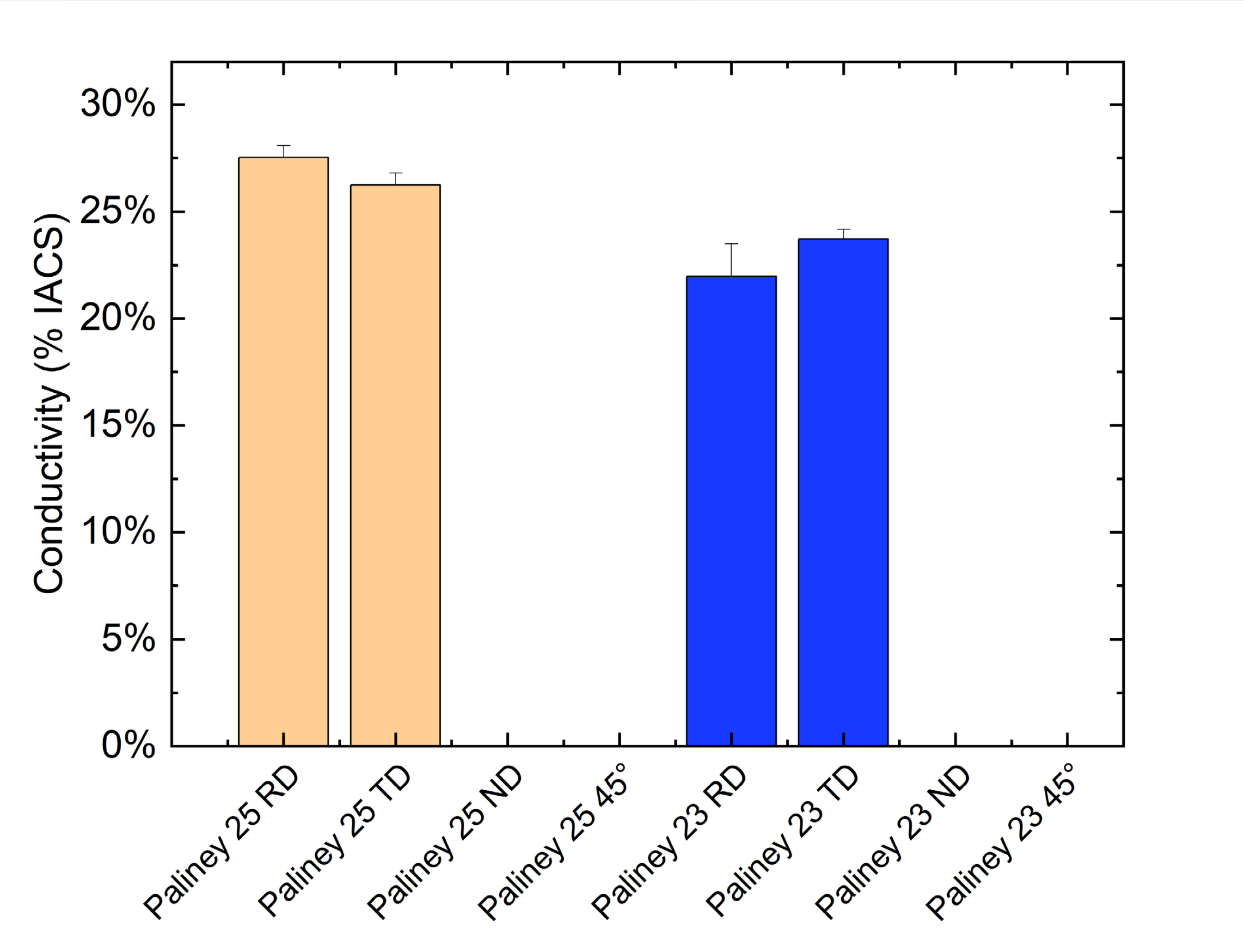
Paliney transverse direction (TD)



Results – Typical stress-strain behavior



Results - Conductivity Anisotropy



T-test results (p-values)

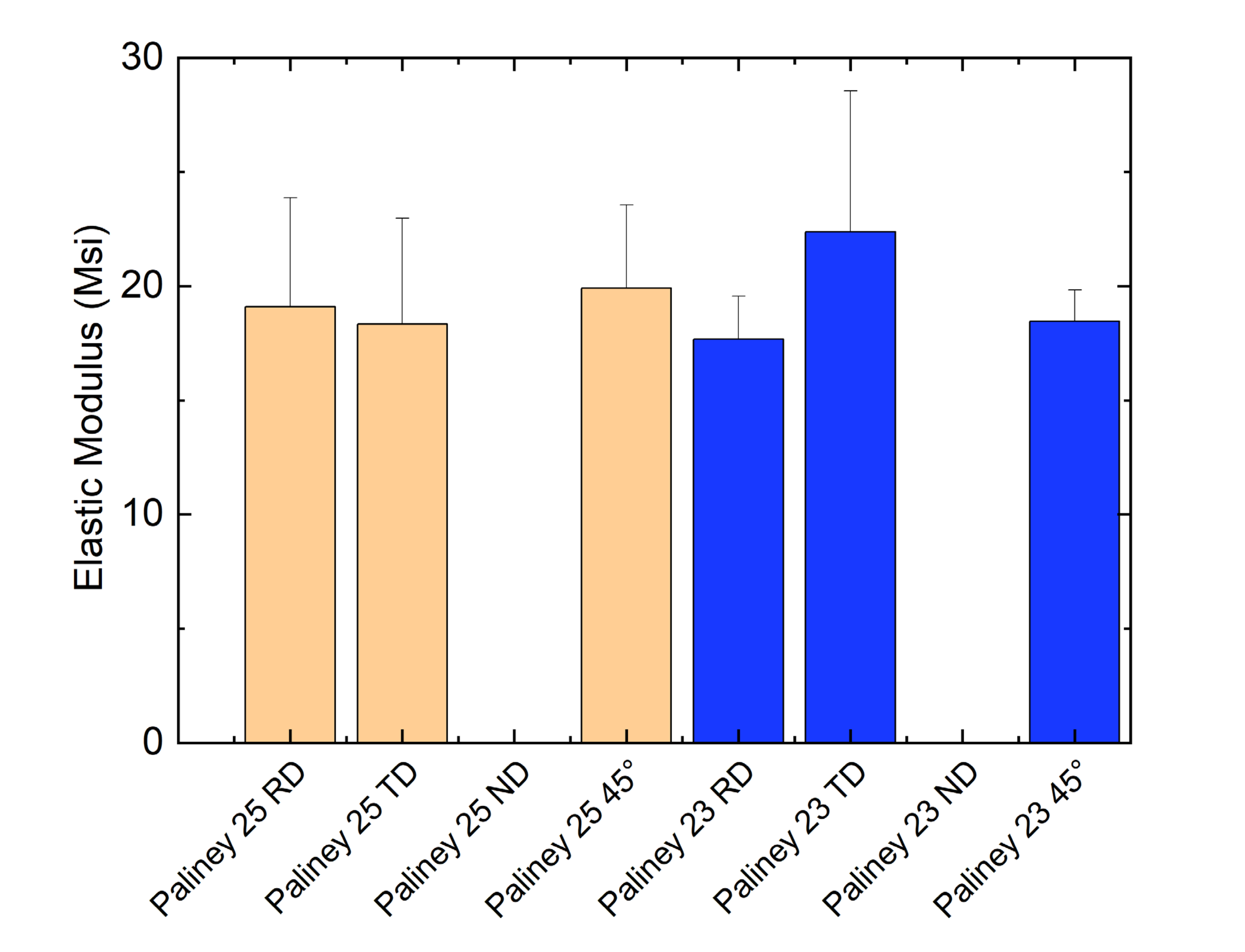
Paliney 25

	RD	TD
RD	1	0.0467
TD		1

Paliney 23

	RD	TD
RD	1	0.1335
TD		1

Results - Modulus Anisotropy



T-test results (p-values)

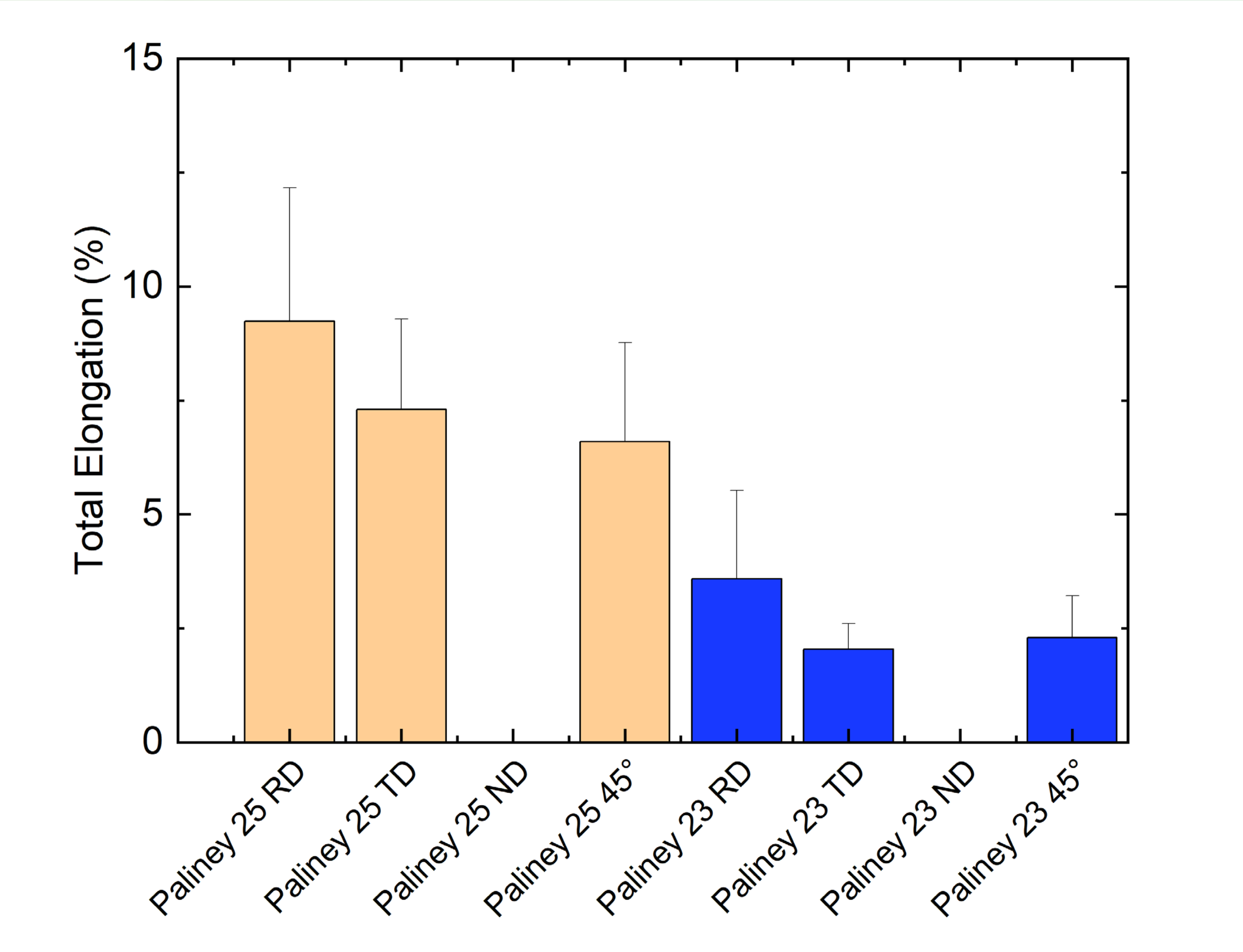
Paliney 25

	RD	TD	45°
RD	1	0.8068	0.7696
TD		1	0.5689
45°			1

Paliney 23

	RD	TD	45°
RD	1	0.1432	0.4791
TD		1	0.2039
45°			1

Results - Elongation Anisotropy



T-test results (p-values)

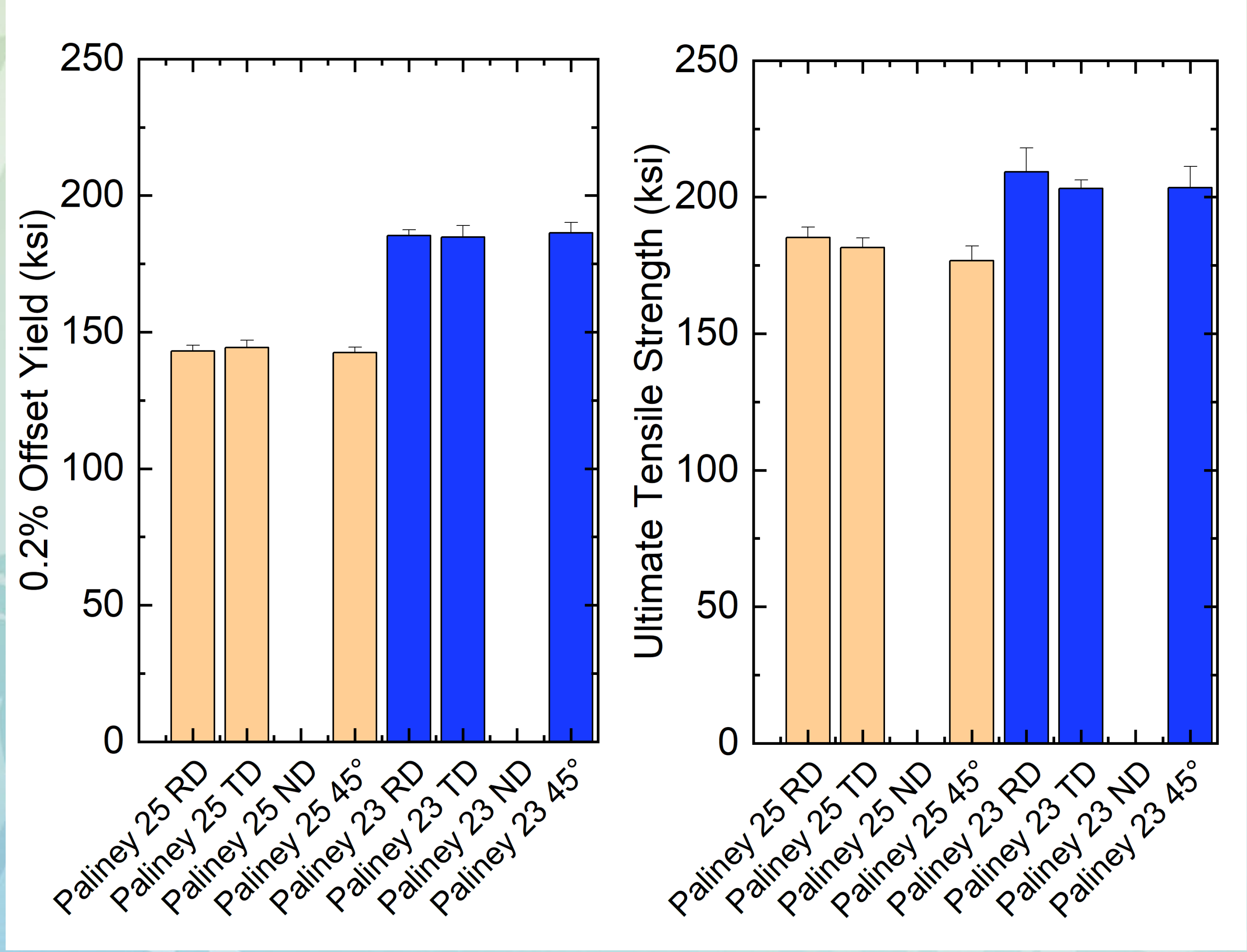
Paliney 25

	RD	TD	45°
RD	1	0.2623	0.1489
TD		1	0.6129
45°			1

Paliney 23

	RD	TD	45°
RD	1	0.1103	0.2041
TD		1	0.5524
45°			1

Results - Strength Anisotropy



T-test results (p-values)

Paliney 25 UTS

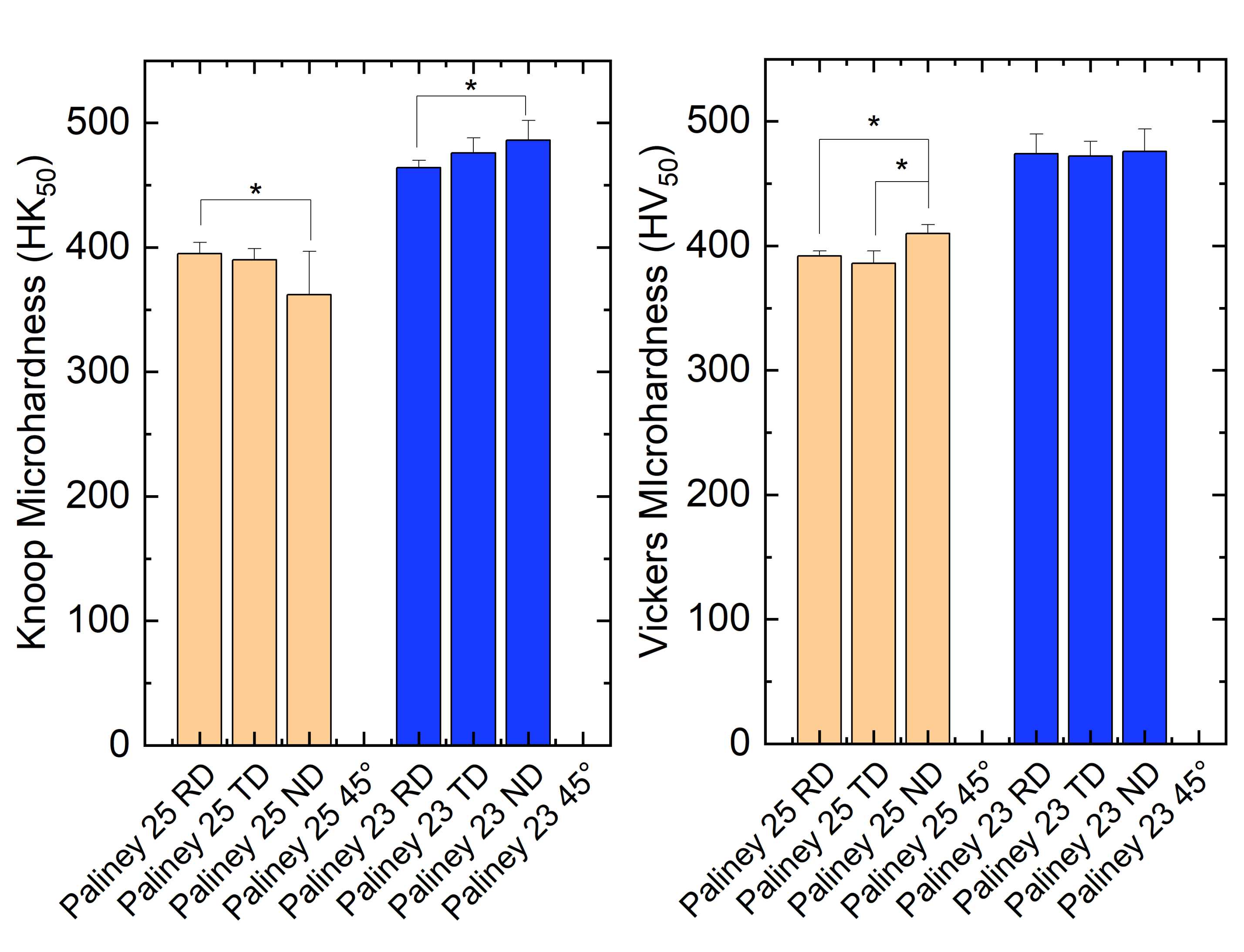
	RD	TD	45°
RD	1	0.1634	0.0224
TD		1	0.1407
45°			1

Paliney 23 UTS

	RD	TD	45°
RD	1	0.1805	0.2917
TD		1	0.9686
45°			1

Note: no significant results ($p<0.01$) for 0.2% offset yield strength

Results - Hardness Anisotropy



T-test results (p-values)

Paliney 25 HK_{50}

	RD	TD	ND
RD	1	0.2301	0.0098
TD		1	0.0247
ND			1

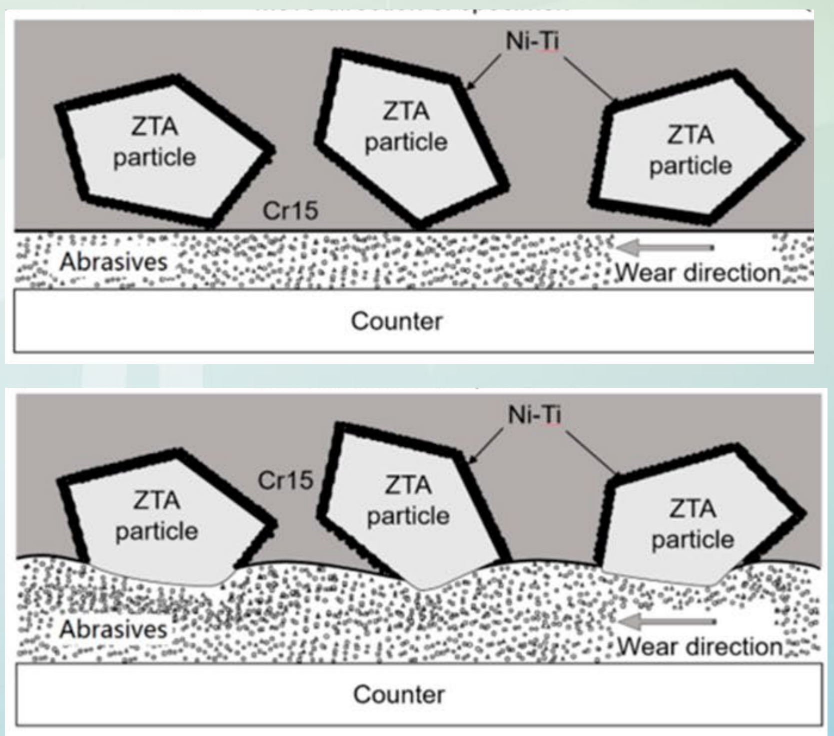
Paliney 23 HK_{50}

	RD	TD	ND
RD	1	0.0111	0.0007
TD		1	0.1313
ND			1

Note: T-tests also significant for HV_{50} Paliney 25 RD-ND $p<0.0001$, and HV_{50} Paliney 25 TD-ND $p<0.0001$

Discussion

- RD-ND and TD-ND microhardness anisotropy observed in both palladium alloys
- Microhardness generally correlates with abrasive wear resistance
- Key considerations:
  1. Mismatch between ceramic abrasive cleaning agent hardness (ca. > HV 1,000) *vs.* ± HV 20-30 foil anisotropy
  2. Wear contribution of sub-micron third, HCP, Re-based phase
- Microhardness directionality unlikely to affect wear performance



Schematic example of composite wear, ref. 6

Conclusions

- Hypothesis of strong anisotropy in palladium alloy foils is rejected: studied materials were functionally isotropic
- Probes can be fabricated in arbitrary orientations without performance debit

Future Study

- Study of wear and elastic constants or third-phase hardness by instrumented nanoindentation, if required
- Directional property characterization of new alloys (sibling alloys to Paliney 25 & 23, and next-generation materials)

Bibliography

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