Data Interpretation 3: Copper

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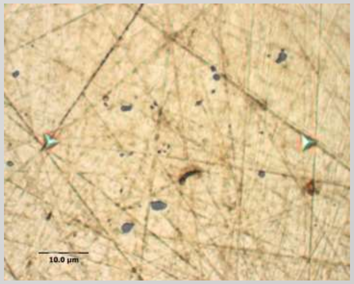
Copper

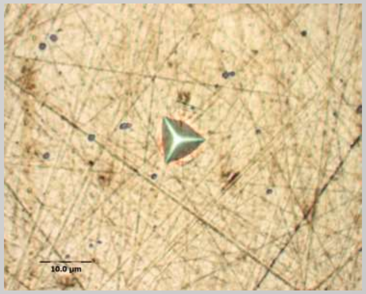
Copper is a soft and ductile metal which exhibits a relatively plastic response and therefore work hardens as a function of deformation. Exposure of its surface to ambient air will produce a native cuprous oxide layer (Cu_2O) which may have a thickness of 100 nm or more.

Copper

Both groups made similar sets of indentations:

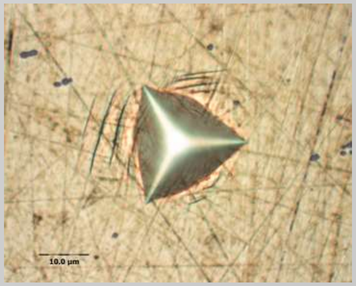
- 3 "Standard" nanoindentations with an applied load of 10 or 20 mN, pause at maximum load of 15 seconds and separation 50 µm





- 3 "Standard" nanoindentations at 50 or 100 mN (loading rate 100 mN/min., pause 15s, separation 100 µm)

- 3 "Standard" nanoindentations at 300 or 500 mN (loading rate 600 mN/min., pause 15s, separation 300 µm).



Copper 10 mN

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Method
Oliver & Pharr

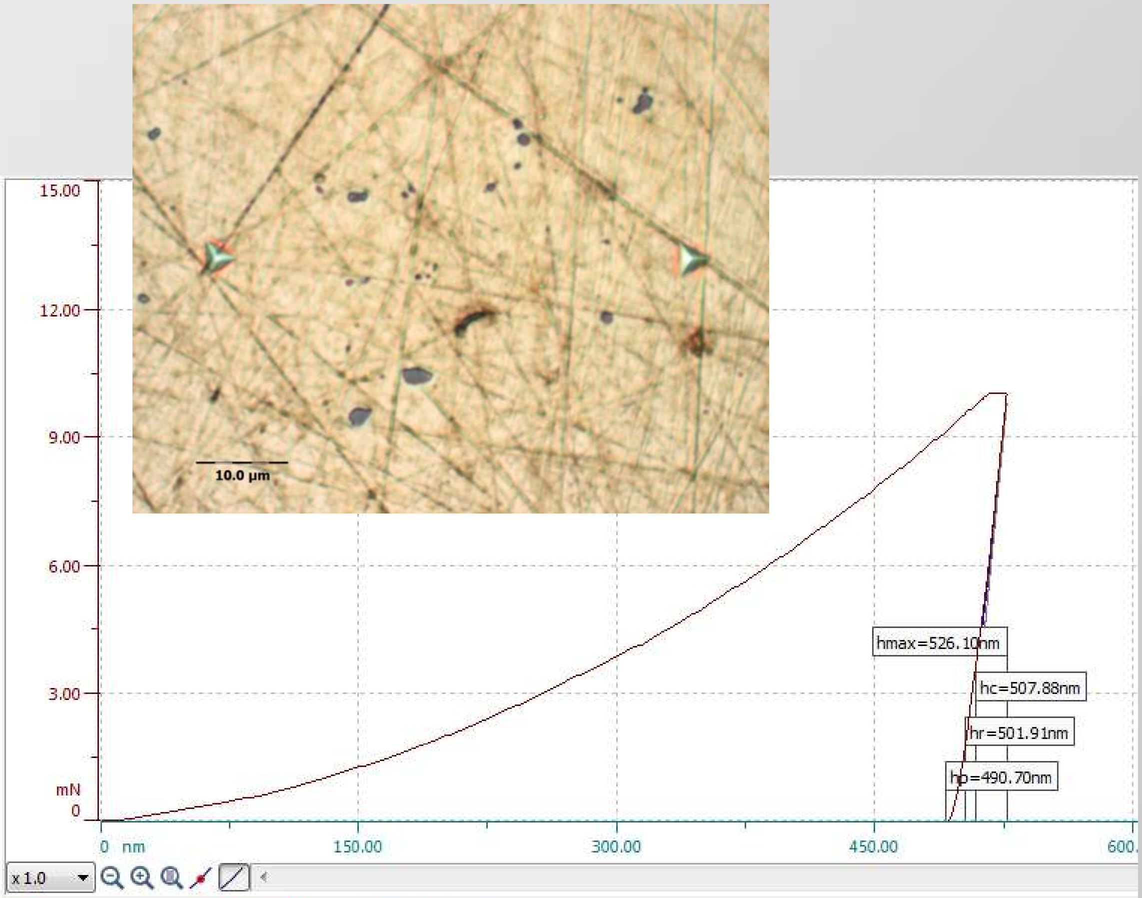
Main results
HIT= 1539.1 MPa
EIT= 144.04 GPa
E*= 158.28 GPa

Hypothesis
Poisson's ratio(nu)= 0.30

Additional results
HVIT= 142.54 Vickers
CIT 0.01/30/15= 1.98 %
nIT= 7.08 %
Fmax= 10.01 mN
hmax= 526.10 nm
S= 0.4139 mN/nm
hc= 507.88 nm
hr= 501.91 nm
hp= 490.70 nm
m= 1.4634
Epsilon= 0.75
R2= 0.999
Ap= 6504089.74 nm²
Welast= 140.24 pJ
Wplast= 1841.63 pJ
Wtotal= 1981.87 pJ

Relevant

+ Standard
Acquisition Rate : 10.0 [Hz]
Linear Loading
Max load : 10.00 mN



Time=19.00 s Fn=176.69 mN Pd=2268.52 nm

Copper 50 mN

Method
Oliver & Pharr

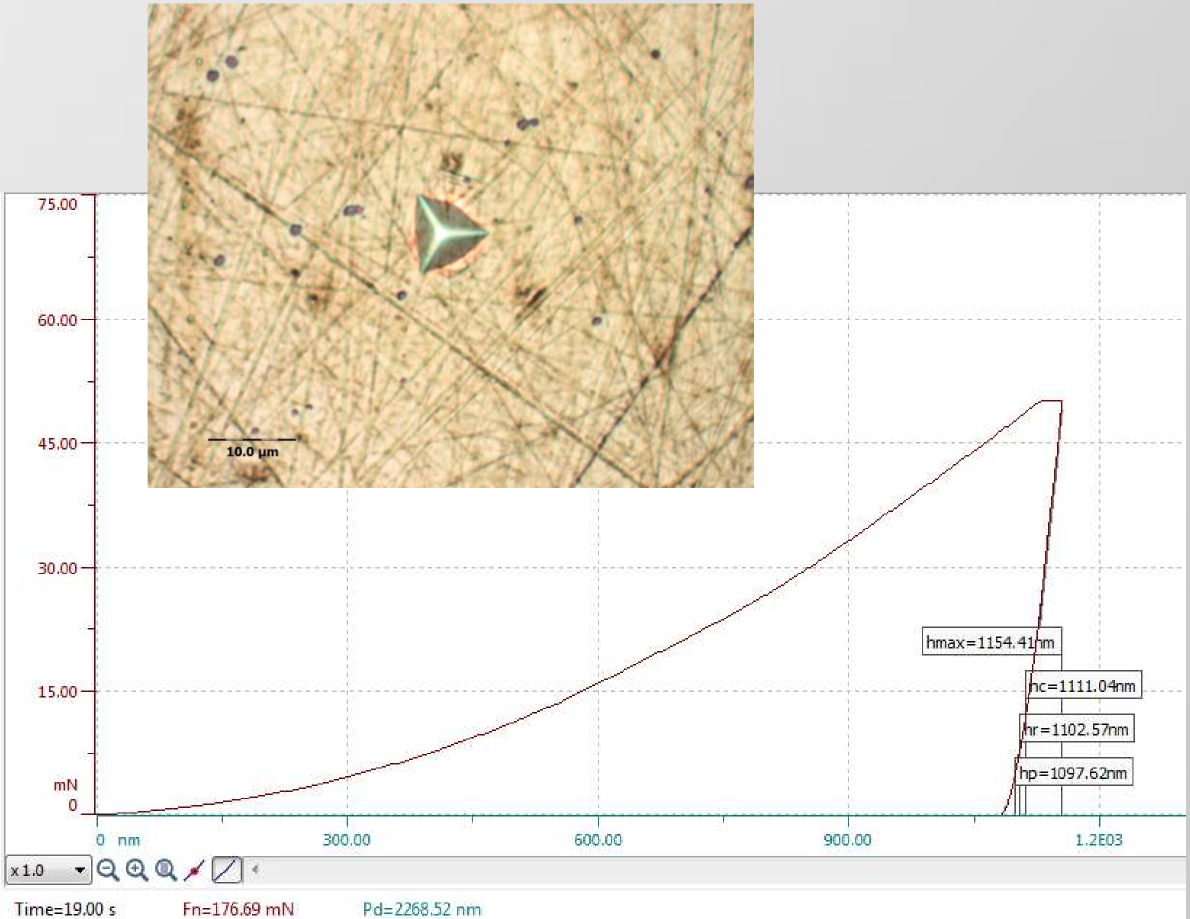
Main results
HIT= 1636.1 MPa
EIT= 156.44 GPa
E*= 171.91 GPa

Hypothesis
hc out of calibrated range [19 nm, 644 nm]
Poisson's ratio(nu)= 0.30

Additional results
HVIT= 151.52 Vickers
CIT 0.05/30/15= 2.29 %
nIT= 6.62 %
Fmax= 49.98 mN
hmax= 1154.41 nm
S= 0.9641 mN/nm
hc= 1111.04 nm
hr= 1102.57 nm
hp= 1097.62 nm
m= 1.0955
Epsilon= 0.84
R2= 1.000
Ap= 30548339.89 nm^2
Welast= 1414.13 pJ
Wplast= 19962.45 pJ

Relevant

+ Standard
Acquisition Rate : 10.0 [Hz]
Linear Loading
Max load : 50.00 mN



Copper 300 mN

Method
Oliver & Pharr

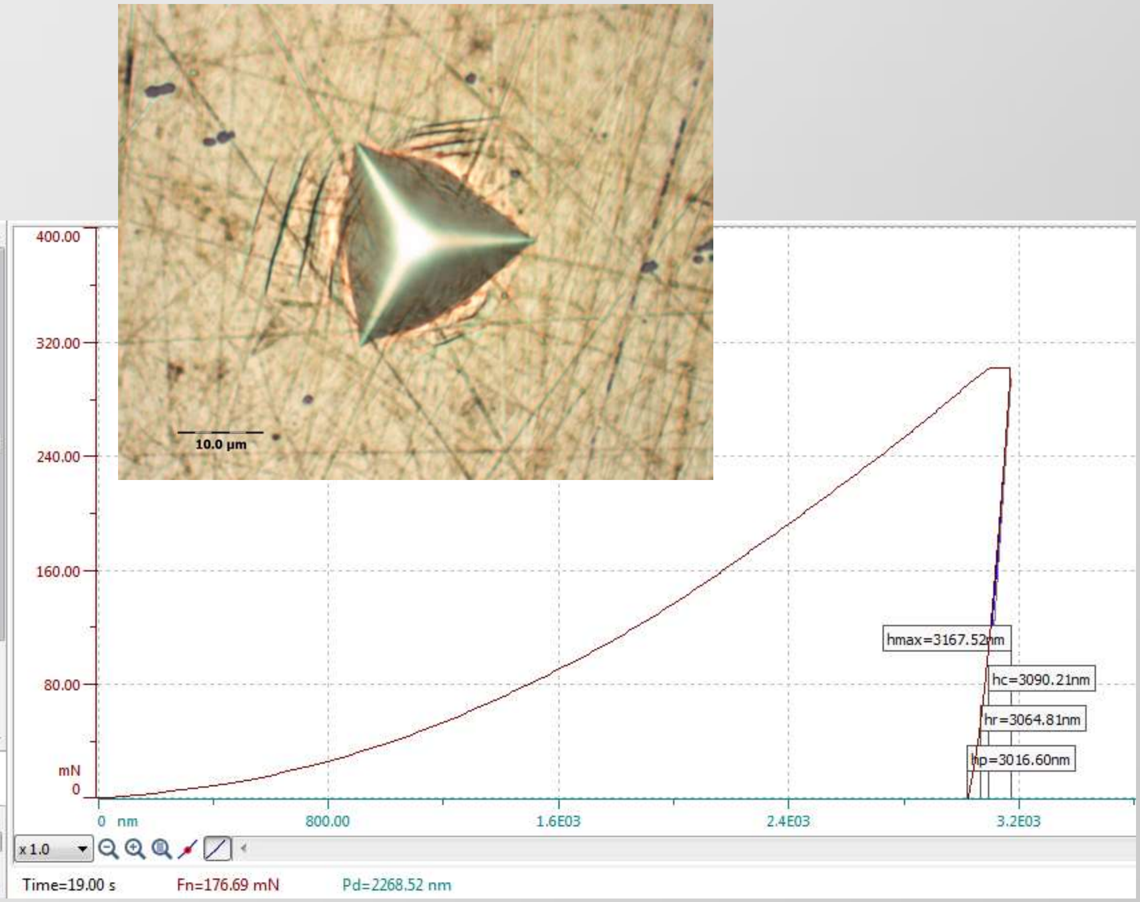
Main results
HIT= 1280.6 MPa
EIT= 173.99 GPa
E*= 191.2 GPa

Hypothesis
hc out of calibrated range [19 nm, 644 nm]
Poisson's ratio(nu)= 0.30

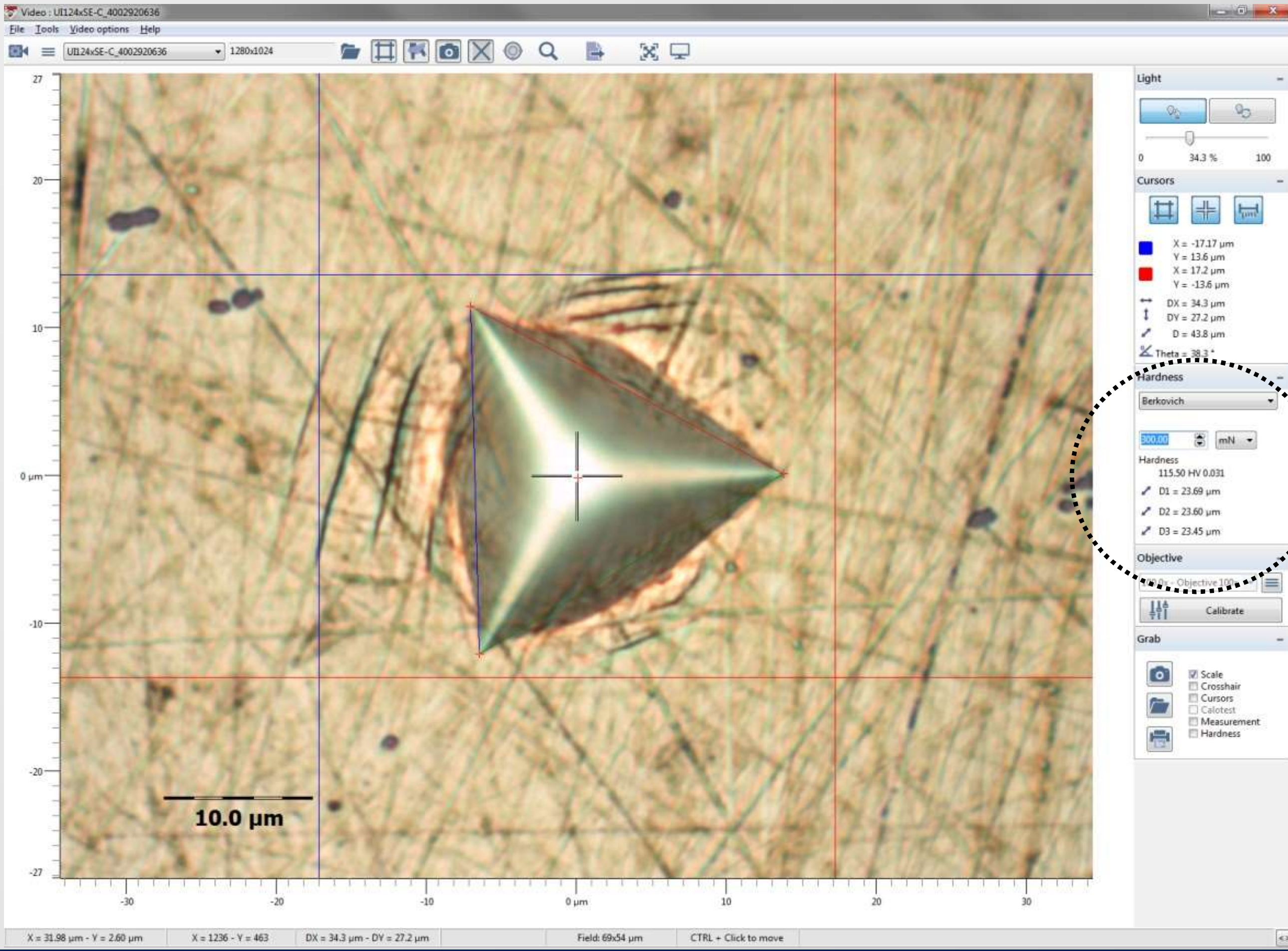
Additional results
HVIT= 118.59 Vickers
CIT 0.3/30/15= 2.52 %
nIT= 5.09 %
Fmax= 301.17 mN
hmax= 3167.52 nm
S= 2.9322 mN/nm
hc= 3090.21 nm
hr= 3064.81 nm
hp= 3016.60 nm
m= 1.4694
Epsilon= 0.75
R2= 1.000
Ap= 235187604.93 nm²
Welast= 18079.42 pJ
Wplast= 336976.57 pJ

Relevant

+ Standard
Acquisition Rate : 10.0 [Hz]
Linear Loading
Max load : 300.00 mN



Copper 300 mN



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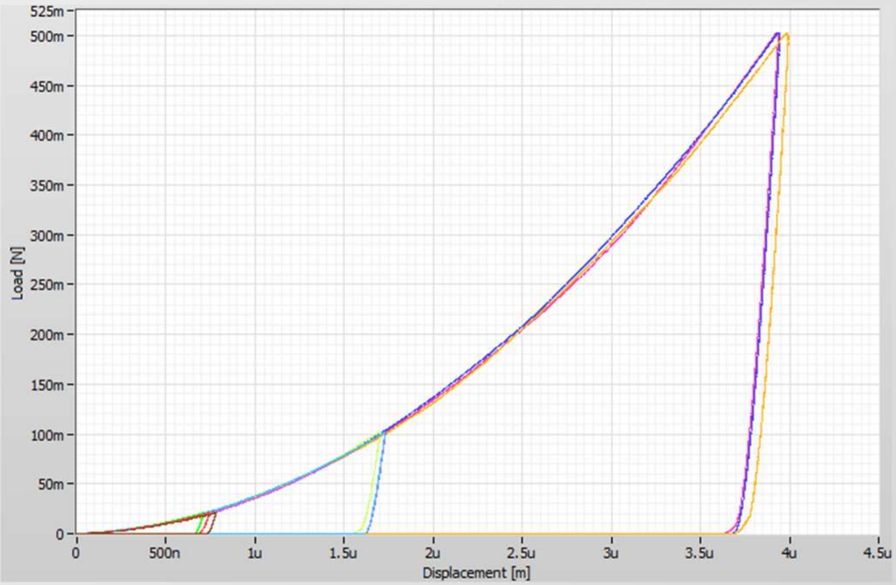
Copper Results

$$H_{IT} = \frac{F[N]}{A_p} = \frac{9.81 \times F[Kgf]}{A_d \sin\alpha} = \frac{9.81}{\sin\alpha} HV$$

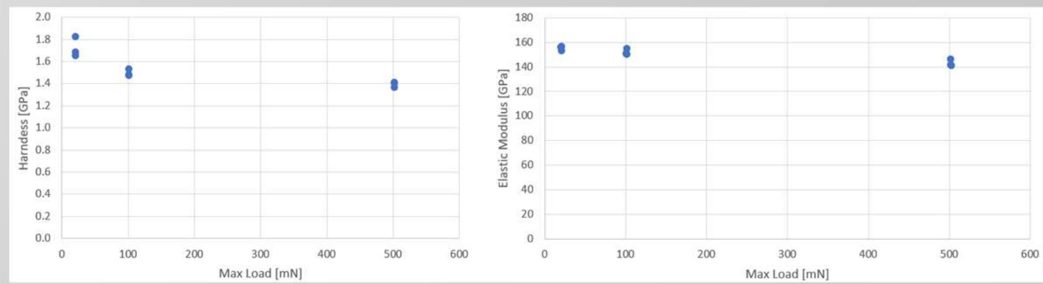
$$HV \approx H_{IT} / 10.80$$

Max indentation load (mN)	Hardness, HIT (MPa)	Elastic Modulus, EIT (GPa)	Recalculated Vickers Hardness, HVIT (Vickers)	Calculated Conventional Hardness, HV (Vickers)	%age difference between HV and HVIT
10	1693	156	157	128	18.5
50	1657	151	154	110	28.6
300	1313	179	122	117	4.1

Typical Copper Results with Alemnis ASA



Max Load mN	H GPa		E GPa	
	mean	SD	mean	SD
20	1.72	0.07	155	1.6
100	1.49	0.03	152	2.1
500	1.39	0.02	143	2.3



Effects of surface roughness

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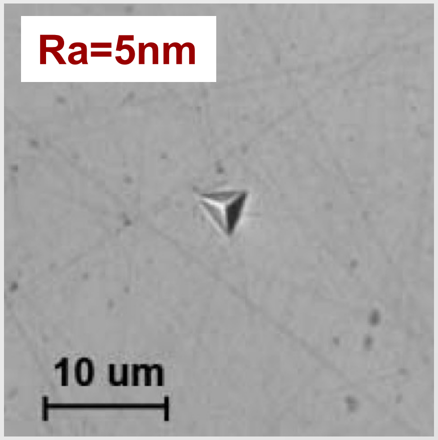

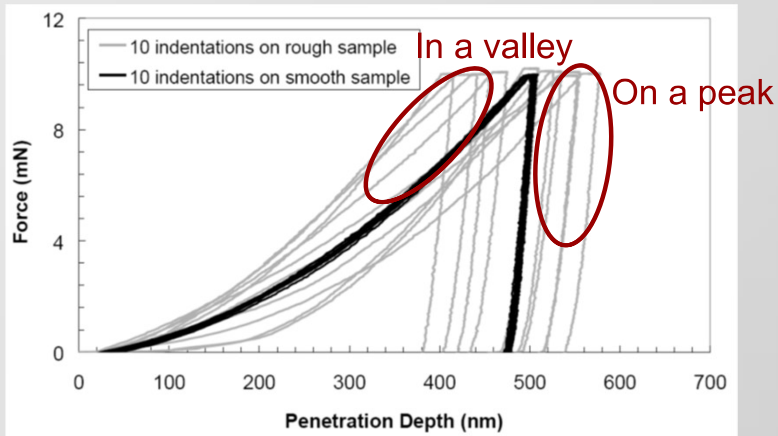

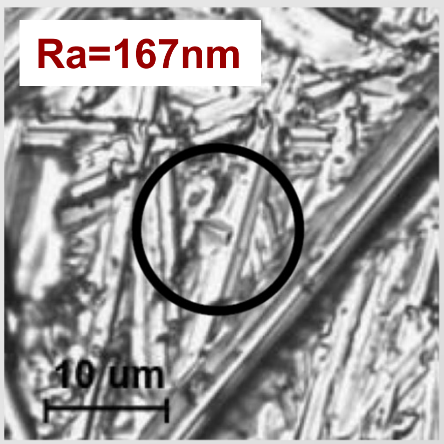

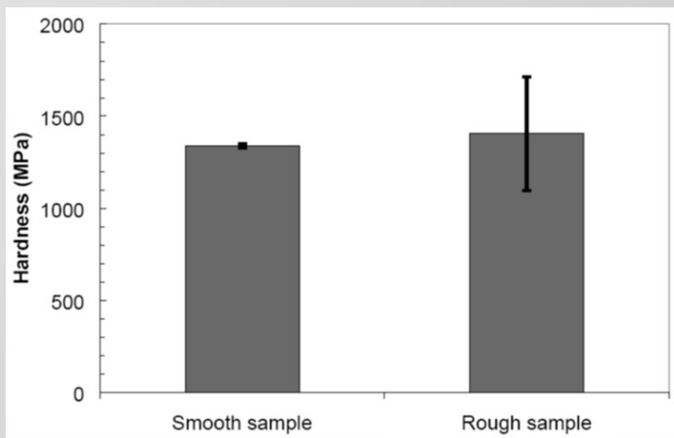

Remember also that polished copper will have a work hardened layer at the surface which may influence data at low loads and depths!

Effects of surface roughness

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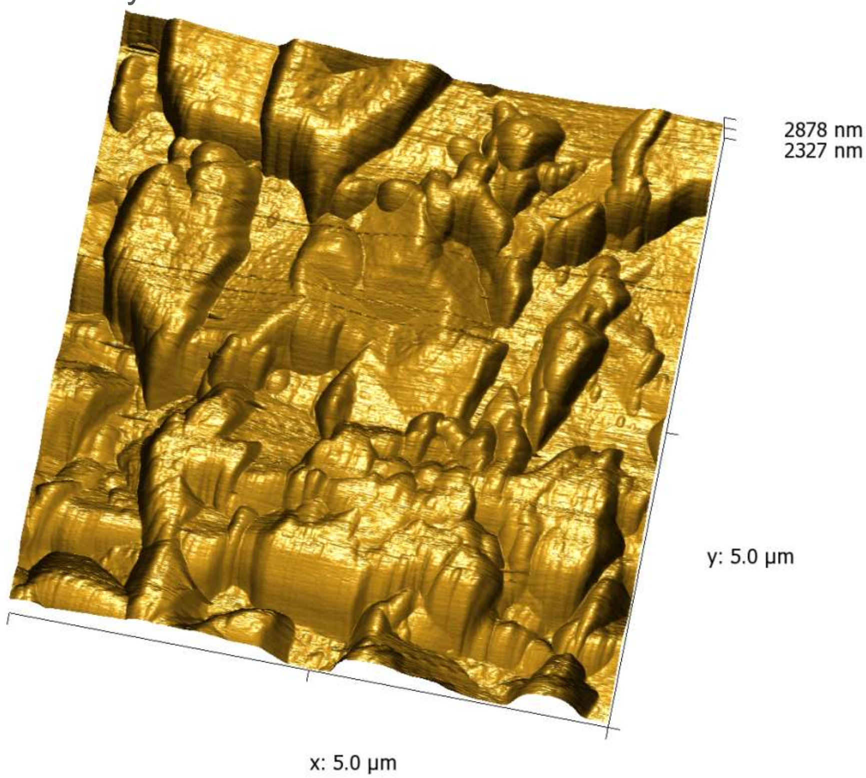
- It is imperative to know the condition of a surface before proceeding with an instrumented indentation test.
- The International Standard ISO 14577-4 stipulates that the Ra value should be less than 5% of the maximum penetration depth.

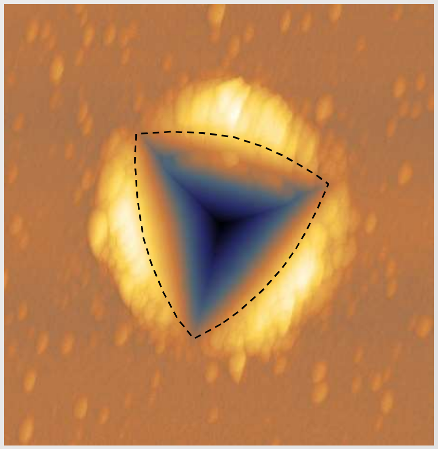
Effects of surface roughness

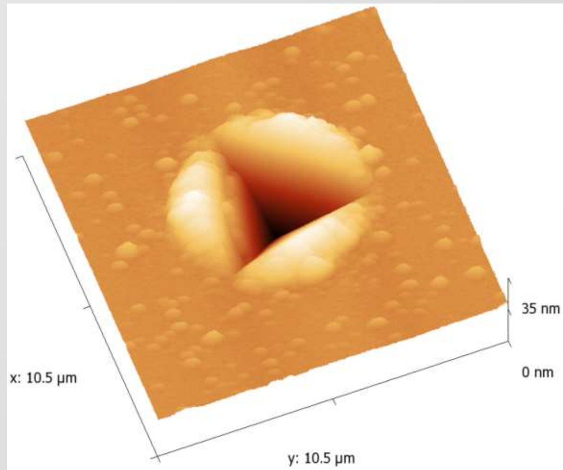
2 mN on nanocrystalline steel



Does this indent make sense..?

Effects of pile-up in Copper



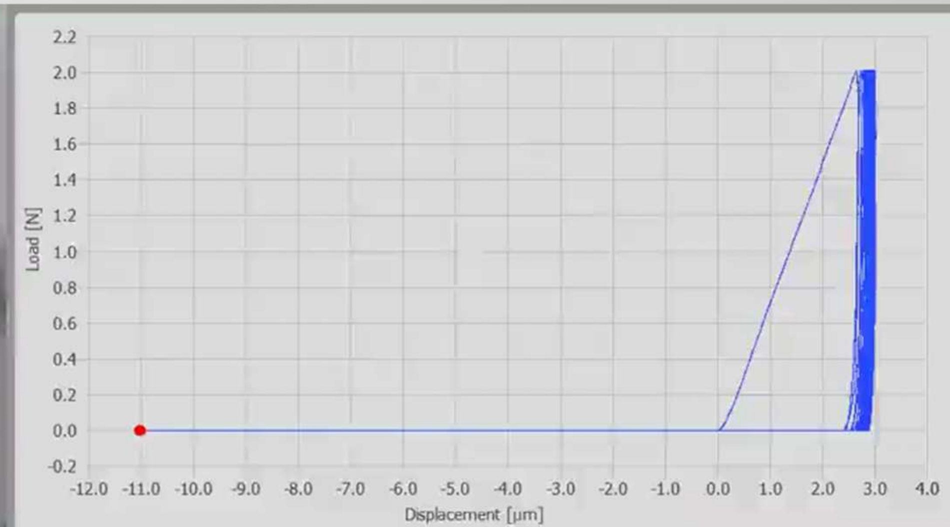


Indentation on Copper at 10 mN.

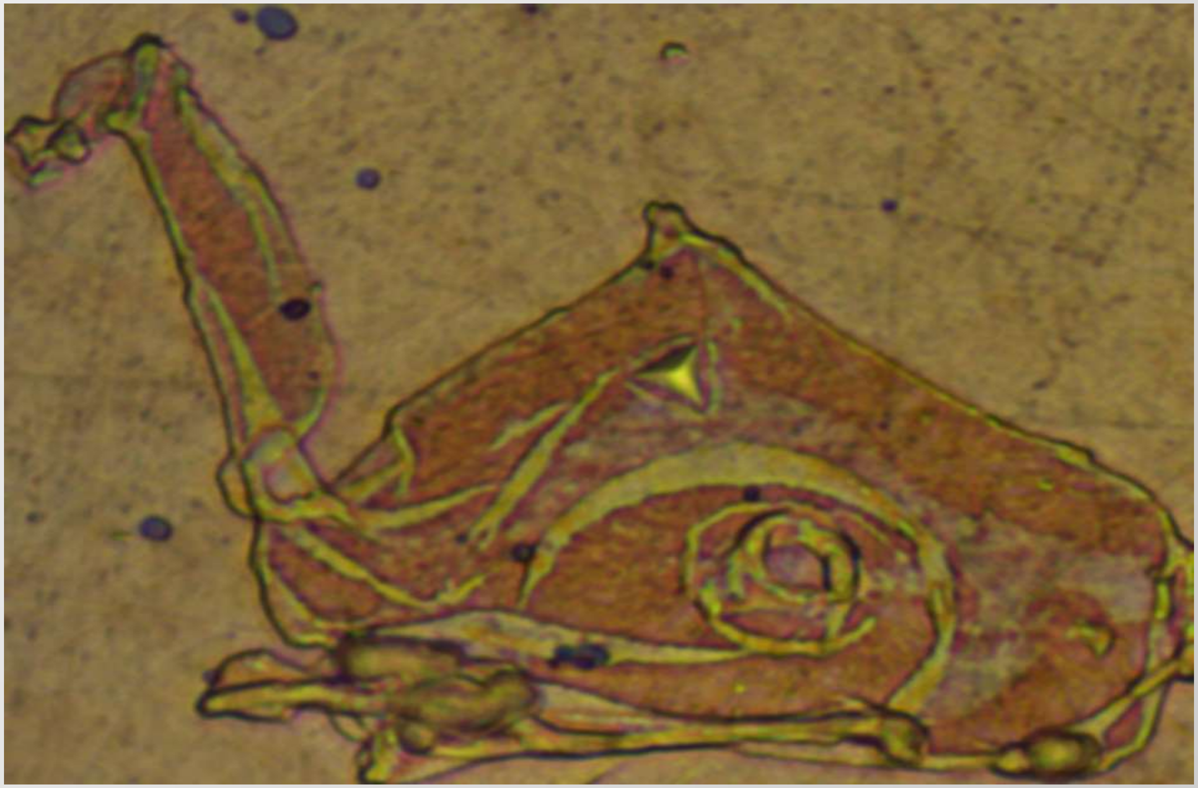
- Using Oliver and Pharr model, the contact area was measured at 6.65e+6 nm^2 giving a hardness of 89 Hv.
- With the help of the AFM, the true contact area was measured at 7.46e+6 nm^2 giving a hardness of 78,6 Hv.
- In that example, a difference of almost 12% is noticed for contact area and hardness values between with these two methods of calculation.

Cyclic indentation in Copper

High speed impact testing of Cu:



Beware of contaminants!



The Camel
Contamination on Cu calibration sample during a TTX-NHT install in Algeria….