Magnetic Barkhausen Noise Response to Temper Embrittlement of HY-80 Steel

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NDT in Canada NDTiC 2018 Canada's NDT Conference
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Halifax Convention Centre
Halifax, Nova Scotia

Applications

Challenges

- Saline water – 35,000 ppm
- Water temperatures – vary widely with latitude
- Temperature gradient – water temperature decreases with depth
- Other factors – exhaust ports, welding regions

Material requirements for submarine applications

- Corrosion resistance
- Stable physical properties
  - High strength-to-weight ratio
  - High modulus of elasticity
  - High toughness
  - Resistance to fatigue

Problem

- Temper Embrittlement – decrease of impact toughness
- Intergranular failure
- Occurs during post fabrication heat treatment
- Change of ductile-to-brittle transition temperature
  - Ductile-to-brittle transition temperature of HY-80 is -18 °C
- Measurement of temper embrittlement – destructive testing

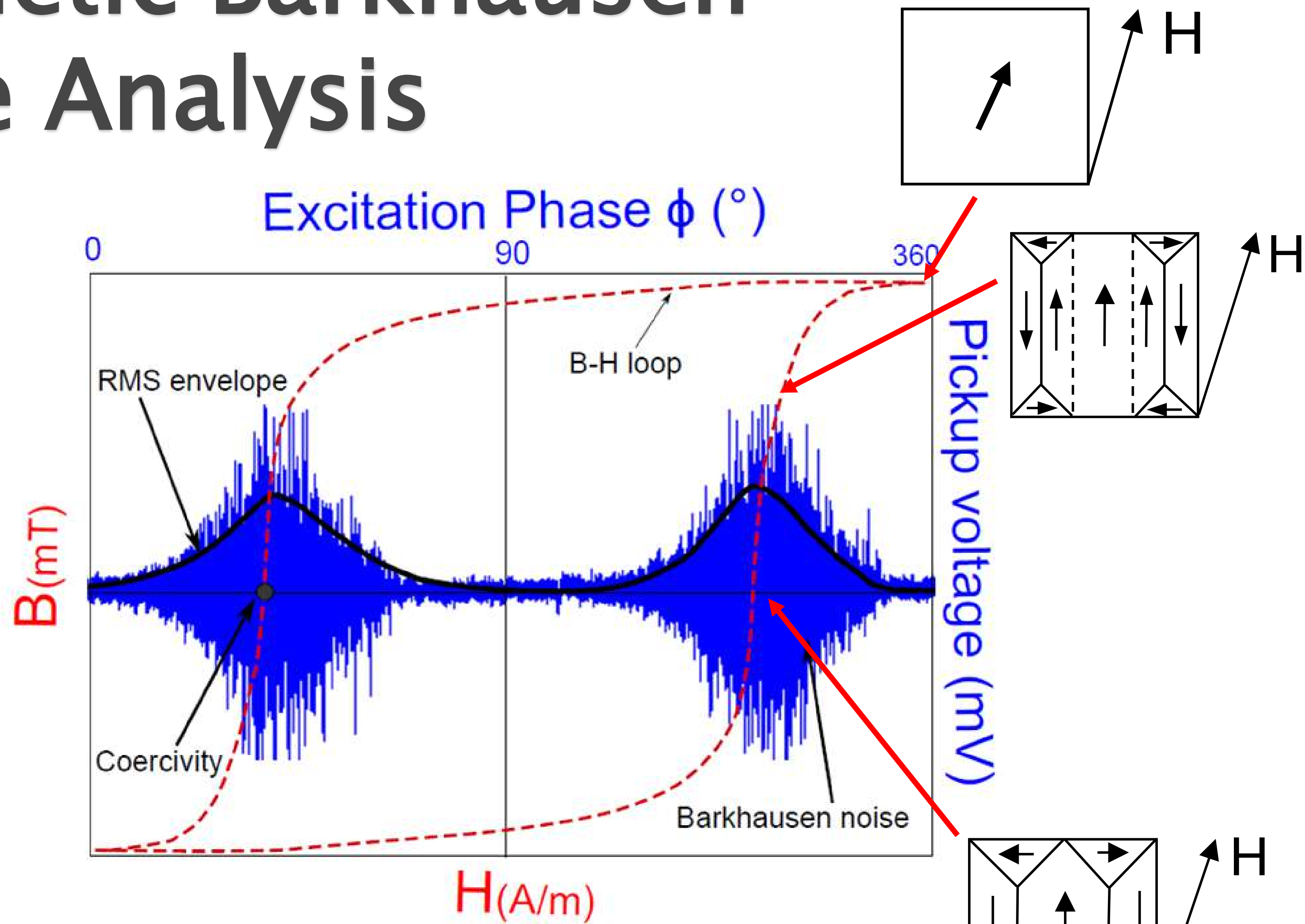
Failure due to brittle fracture

- Freezing temperature
- Impact loading
- Sulphur content
- Brittle fracture

Magnetic Barkhausen Noise Analysis

- Discontinuous magnetization changes – changing applied magnetic fields
  - Abrupt magnetic domain wall motion
- Sensitive to microstructural variations and stress state of material
  - Grain size, texture, inclusions
  - Strength and hardness
- Potential non-destructive testing (NDT) method

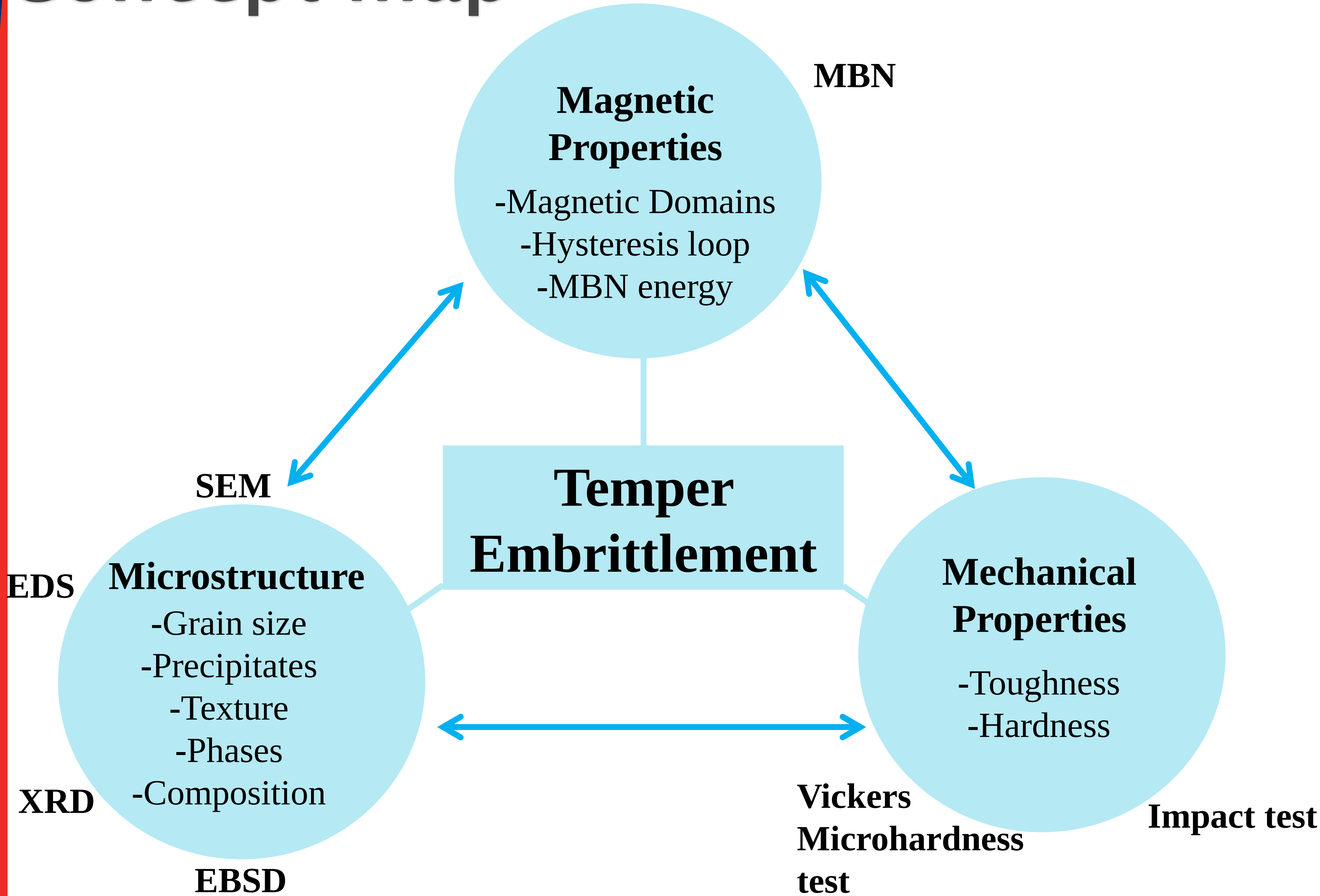
Magnetic Barkhausen Noise Analysis



$$\mathbf{MBN_{Energy}} = \sum_{\mathbf{events}} \int \mathbf{V^2\,dt}$$

Krause et al. , Micromagnetic Techniques, ASM Handbook, 2018

Concept map



Magnetic Properties
-Magnetic Domains
-Hysteresis loop
-MBN energy
MBN
Temper Embrittlement
SEM
EDS
Microstructure
-Grain size
-Precipitates
-Texture
-Phases
-Composition
XRD
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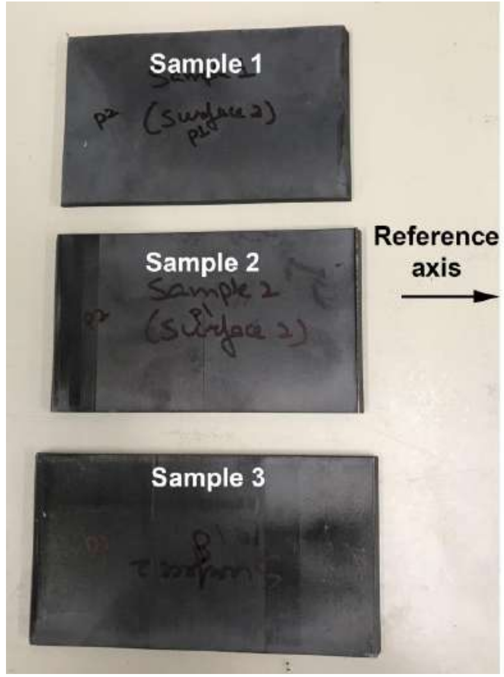
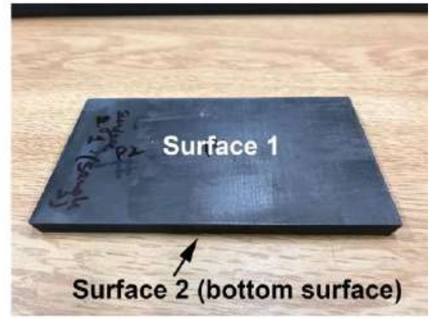
Mechanical Properties
-Toughness
-Hardness
Vickers Microhardness test
Impact test

Materials and Methodology

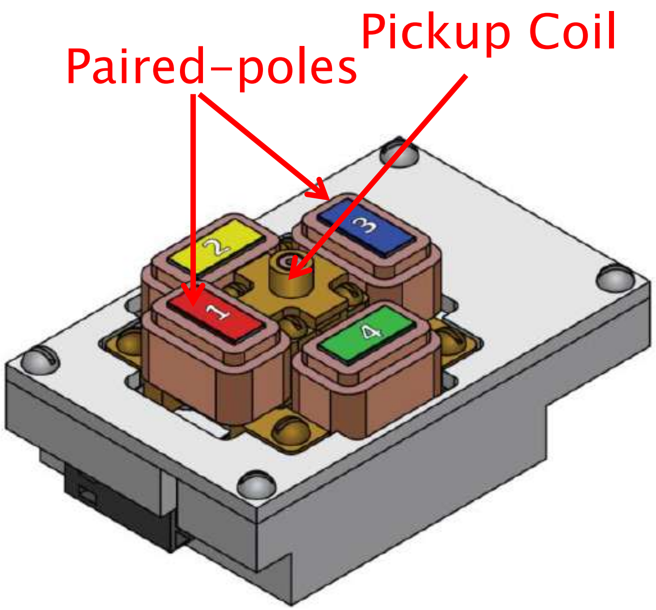




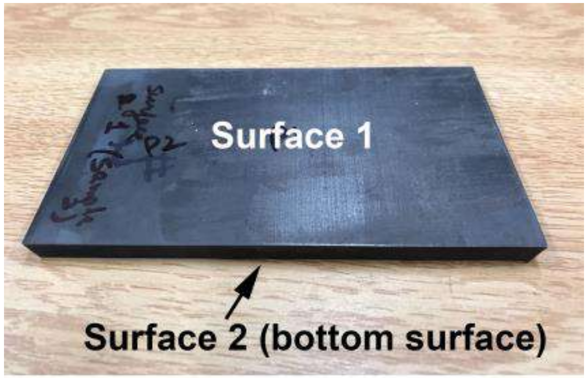
	Dimensions	Holding time at 525° C
Sample 1	114. 7 mm × 69.3 mm × 5.2 mm	48 hrs
Sample 2	120.4 mm × 69.2 mm × 5.2 mm	168 hrs
Sample 3	129.9 mm × 69.3 mm × 5.3 mm	336 hrs

Materials and Methodology

Magnetic Barkhausen Noise (MBN) Measurement



- Tetrapole probe
- Flux controlled (350 mT)
- 50 Hz



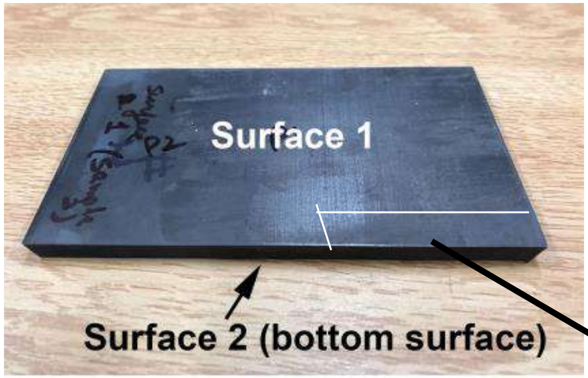
S. A. White, "A Barkhausen Noise Testing System for CANDU Feeder Pipes", Queen's University,, 2018

Materials and Methodology

Impact testing

Impact tester

Technical Bulletin No. 202-28-14(E) M-E-1 (11/74), Balanced Impact Machine for Metals, Monsanto



Energy absorbed until fracture (Toughness)

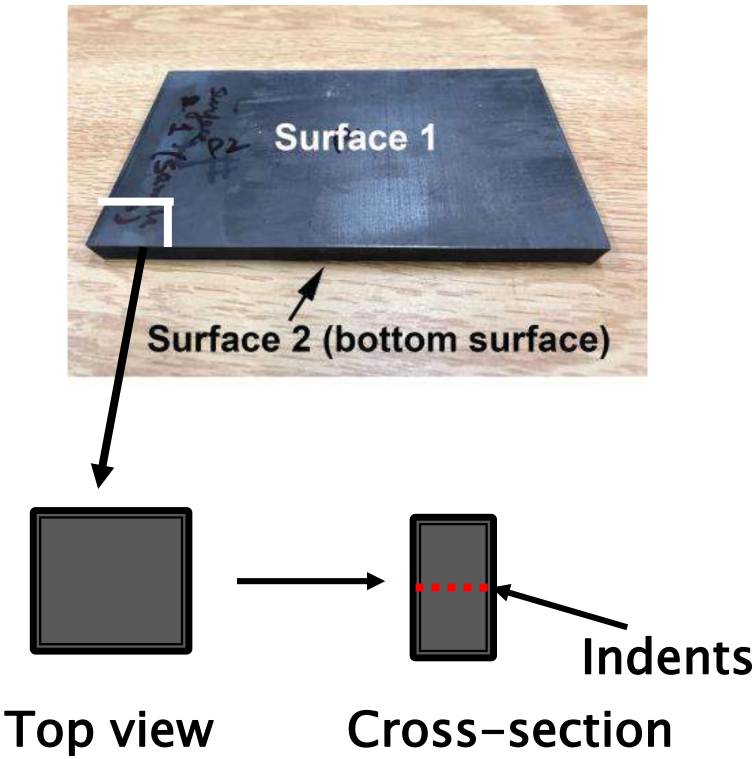
Sample before testing

Sample after fracture

Materials and Methodology

Hardness testing

Vickers microhardness tester



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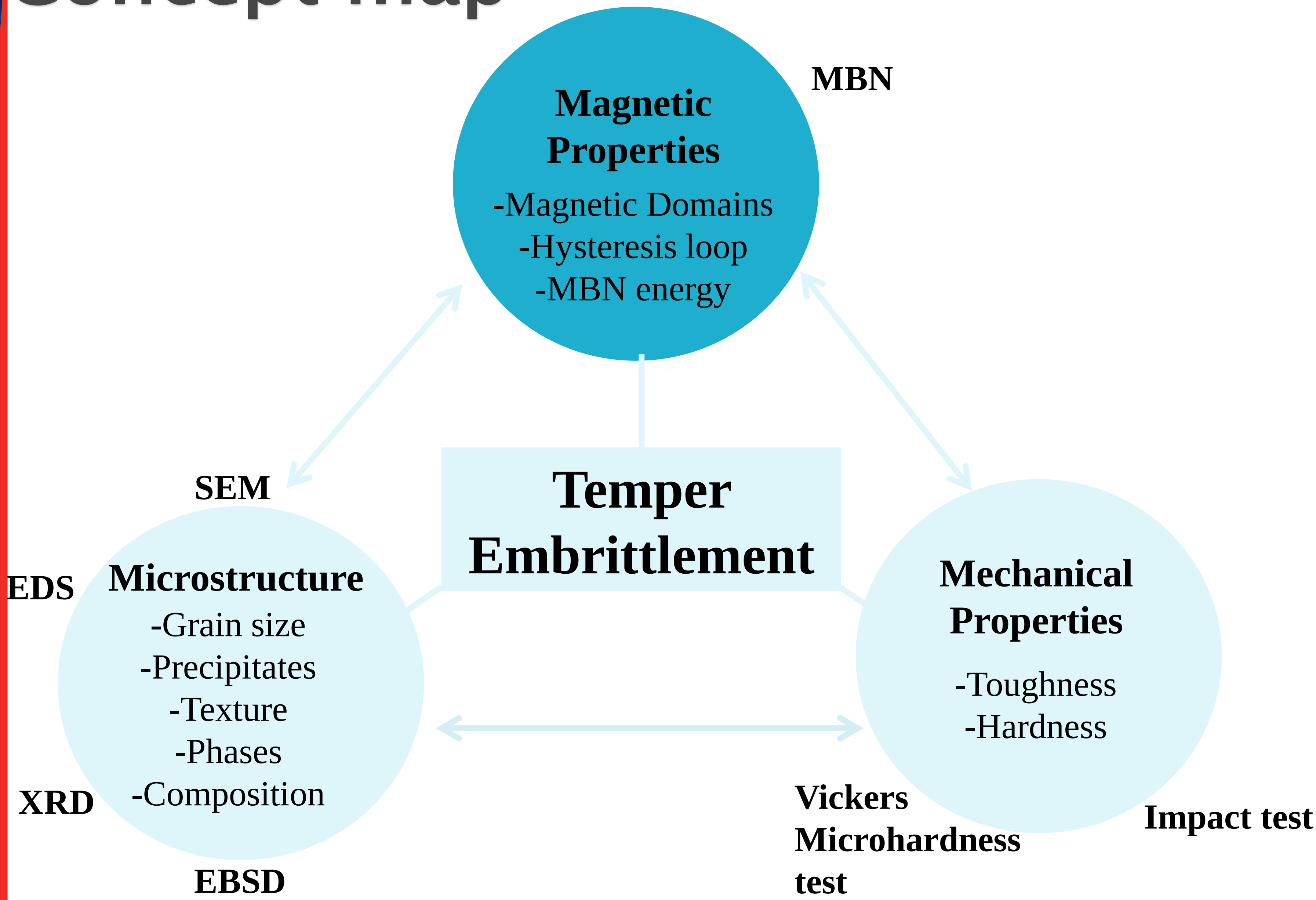
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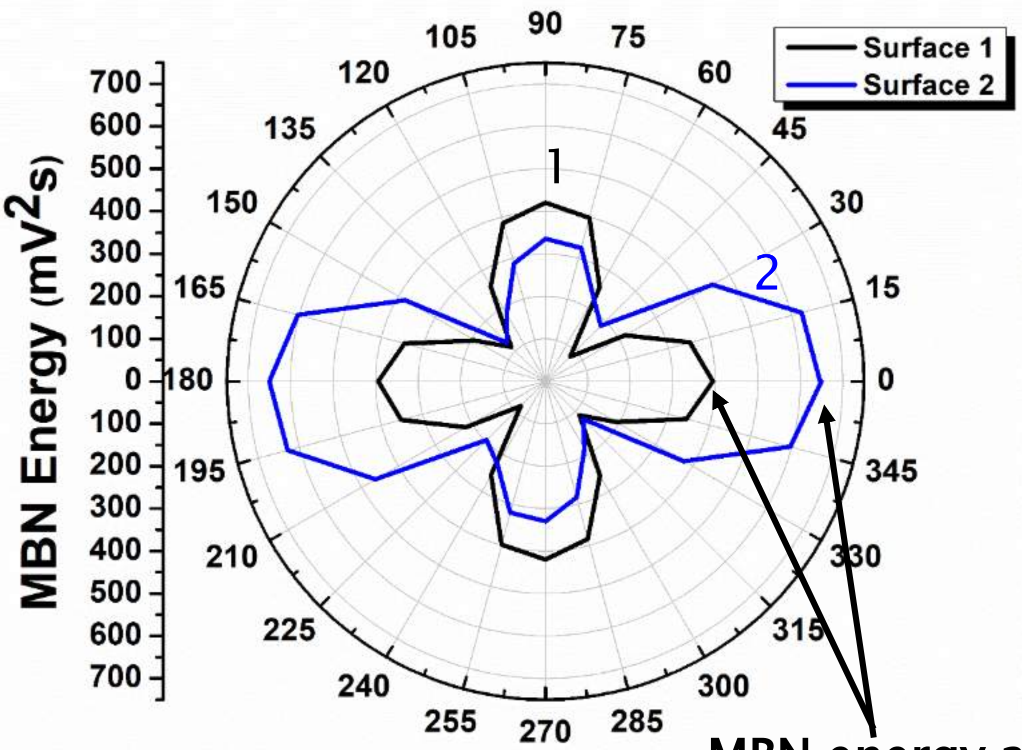
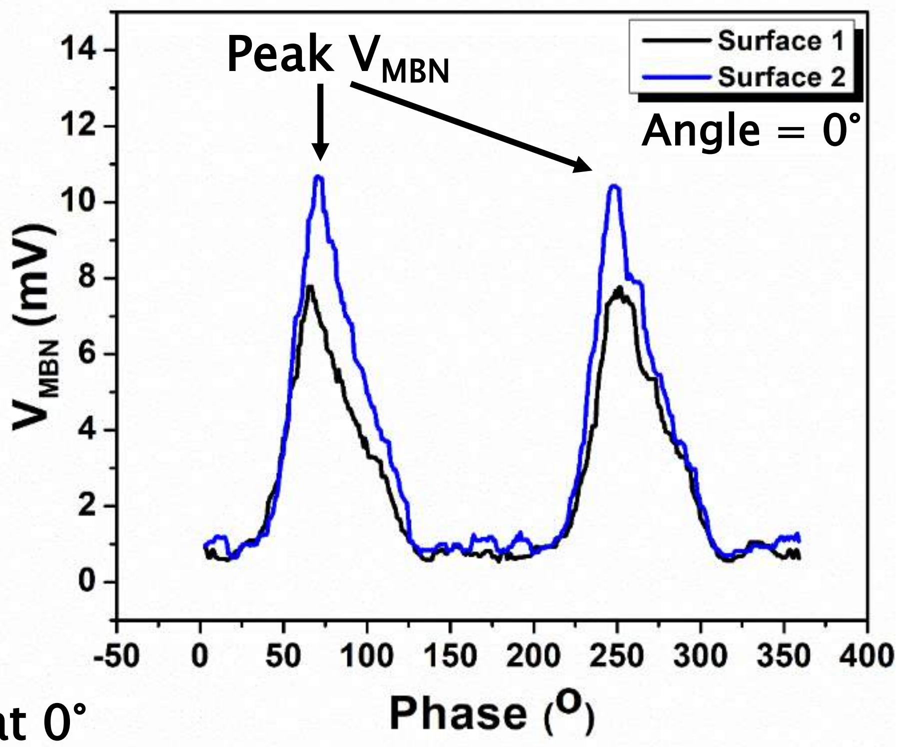
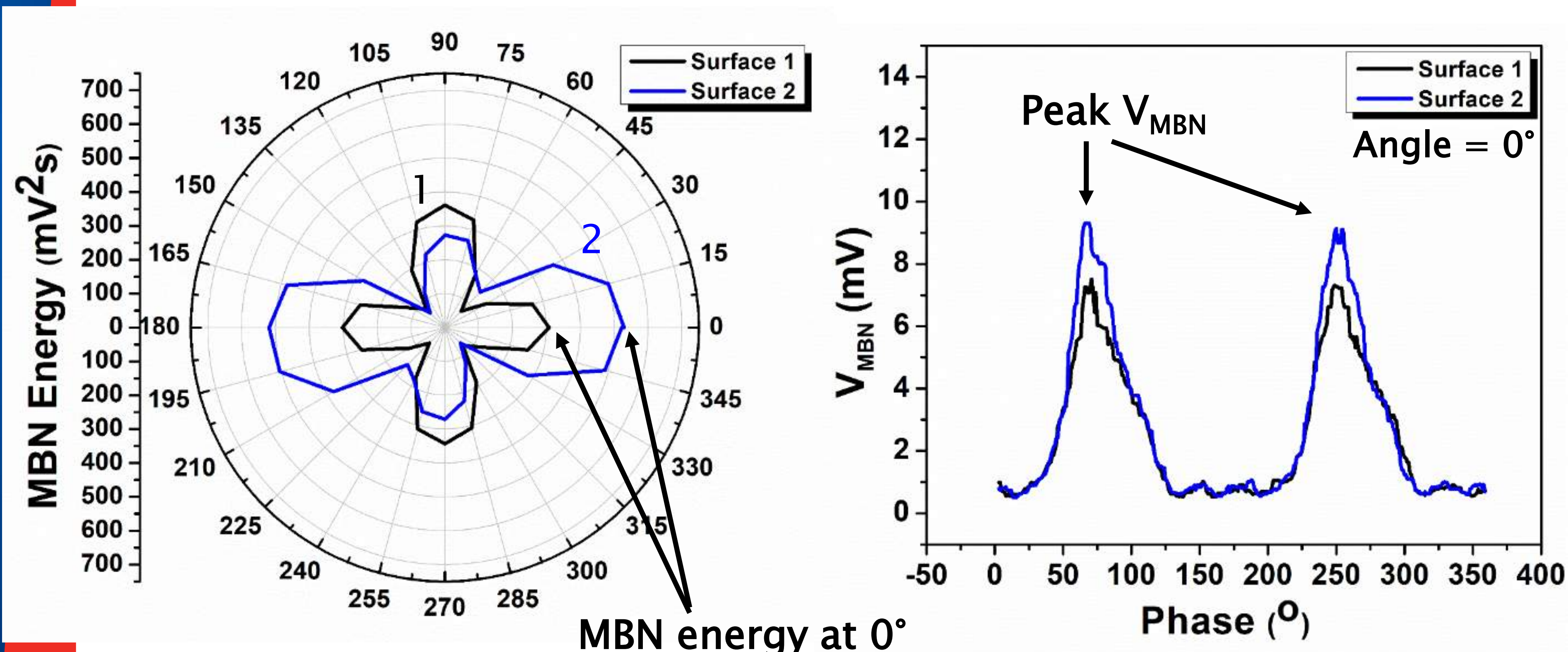
MBN Results – Sample 1



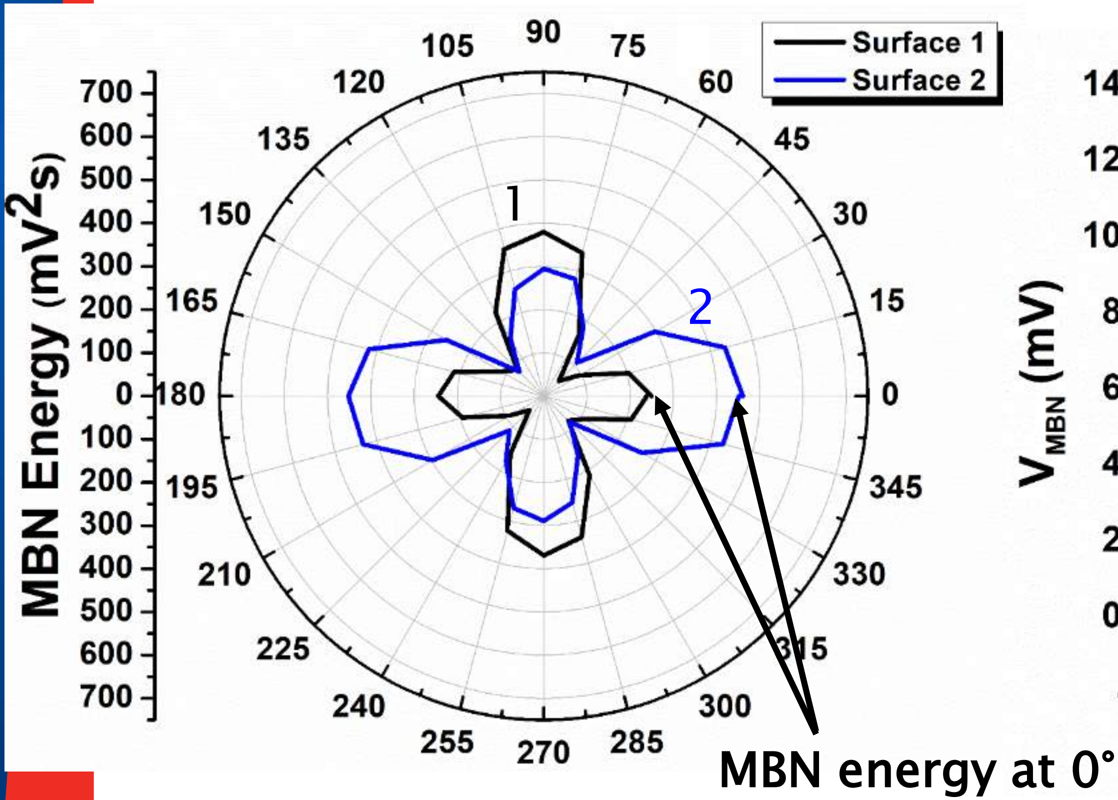


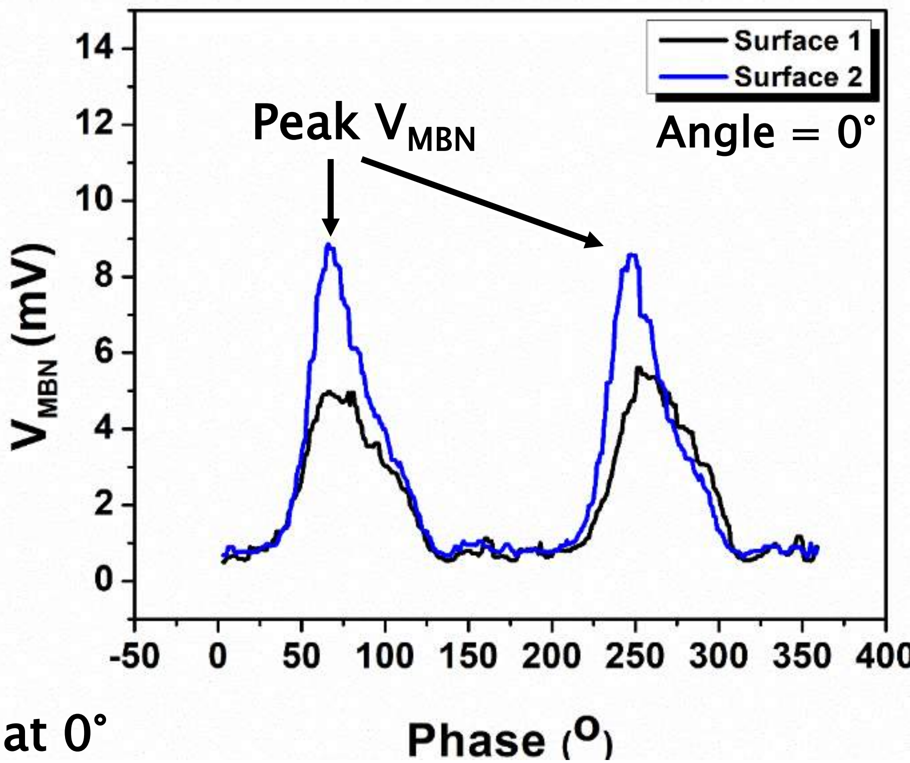
MBN energy at 0°

MBN Results – Sample 2

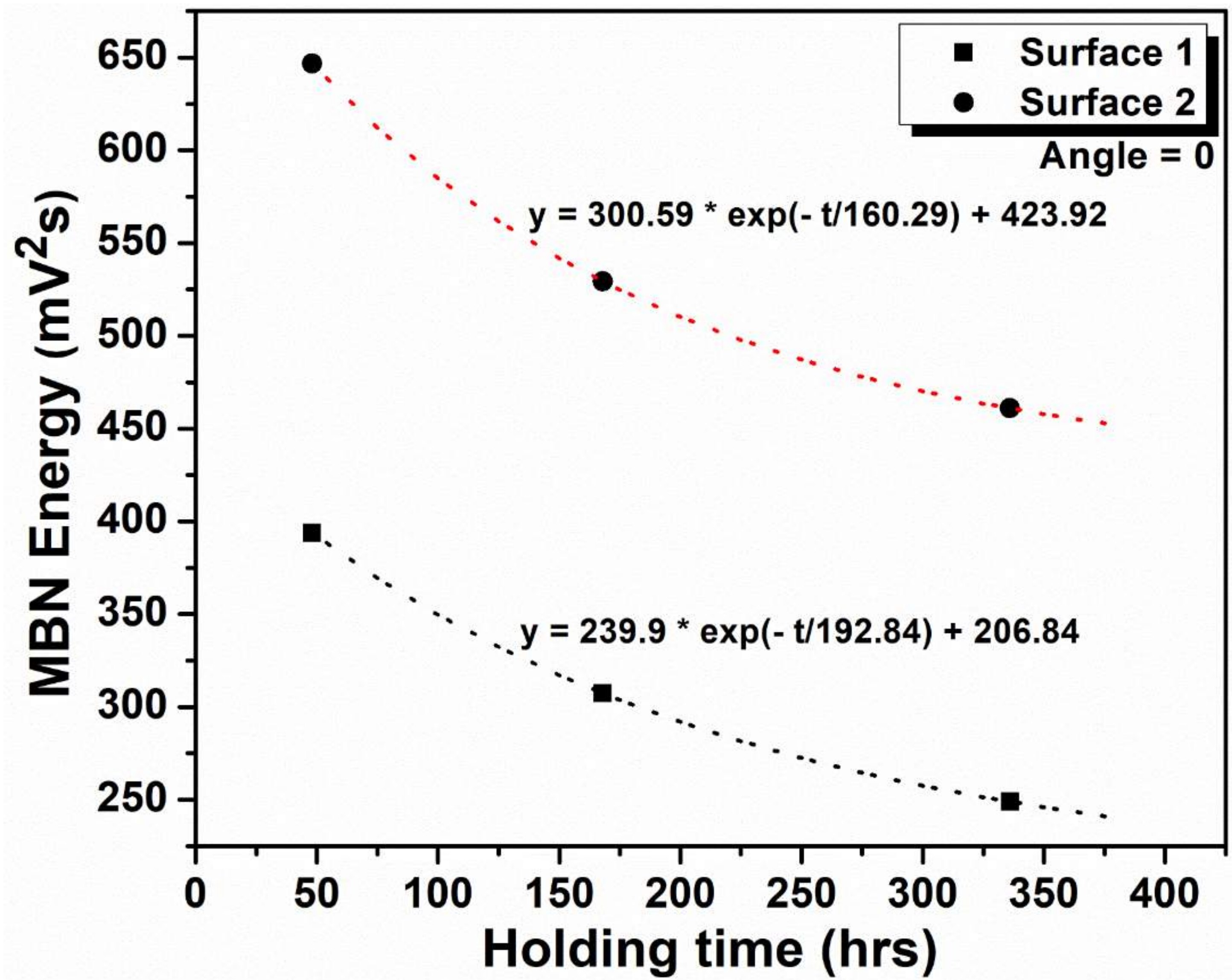


MBN Results – Sample 3





Effect of holding time



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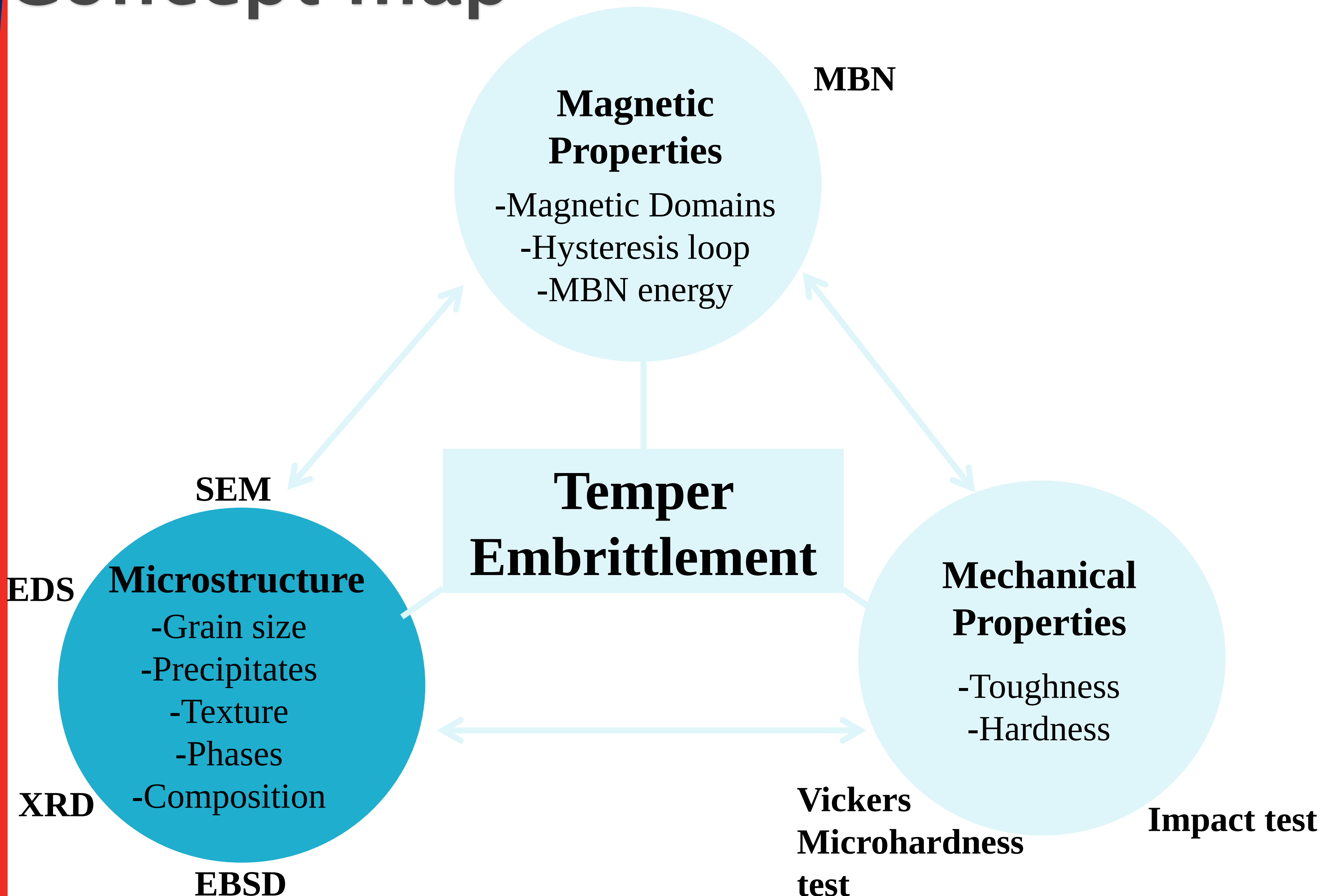
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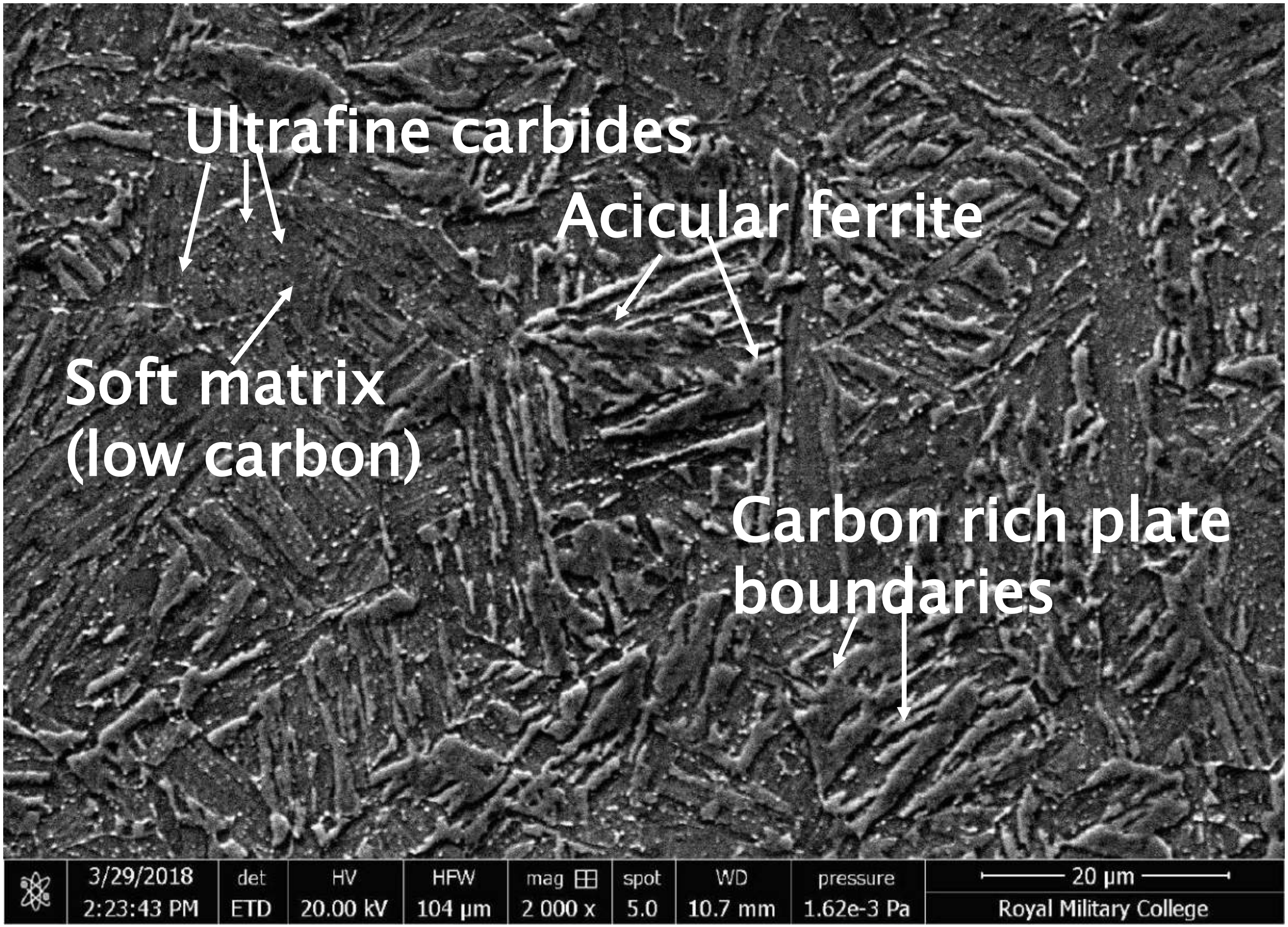
SEM Microstructure

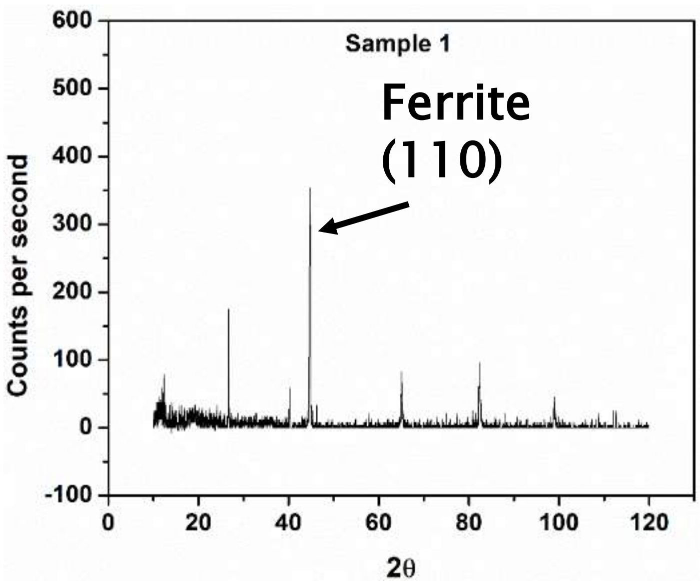


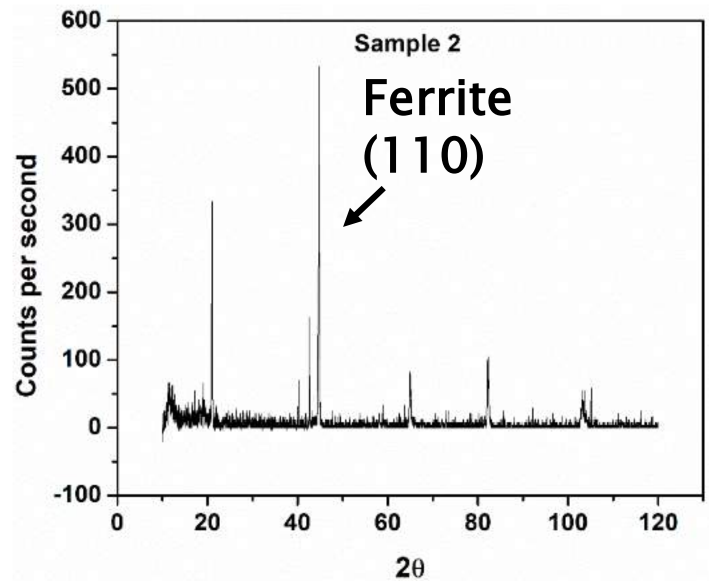
SEM Microstructure

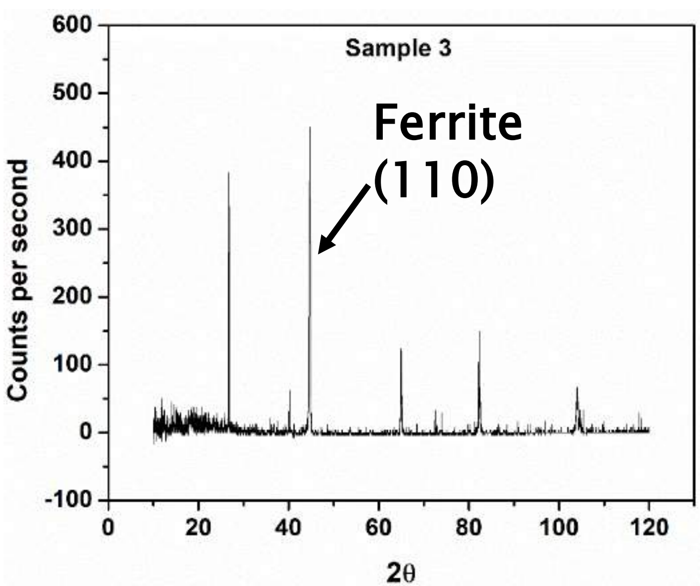
	Soft Ferrite Matrix (μm)	Acicular ferrite (μm)
Sample 1	9 ± 2	1.9 ± 0.46
Sample 2	17 ± 3	2.68 ± 0.64
Sample 3	15 ± 1.8	2.3 ± 0.569

- Crystallite size increases with holding time – MBN energy decreases
- Carbides distributed throughout the matrix (EDS)
- With increase in holding time, carbides segregate near the boundaries and increase in size – soft matrix

X-Ray Diffraction

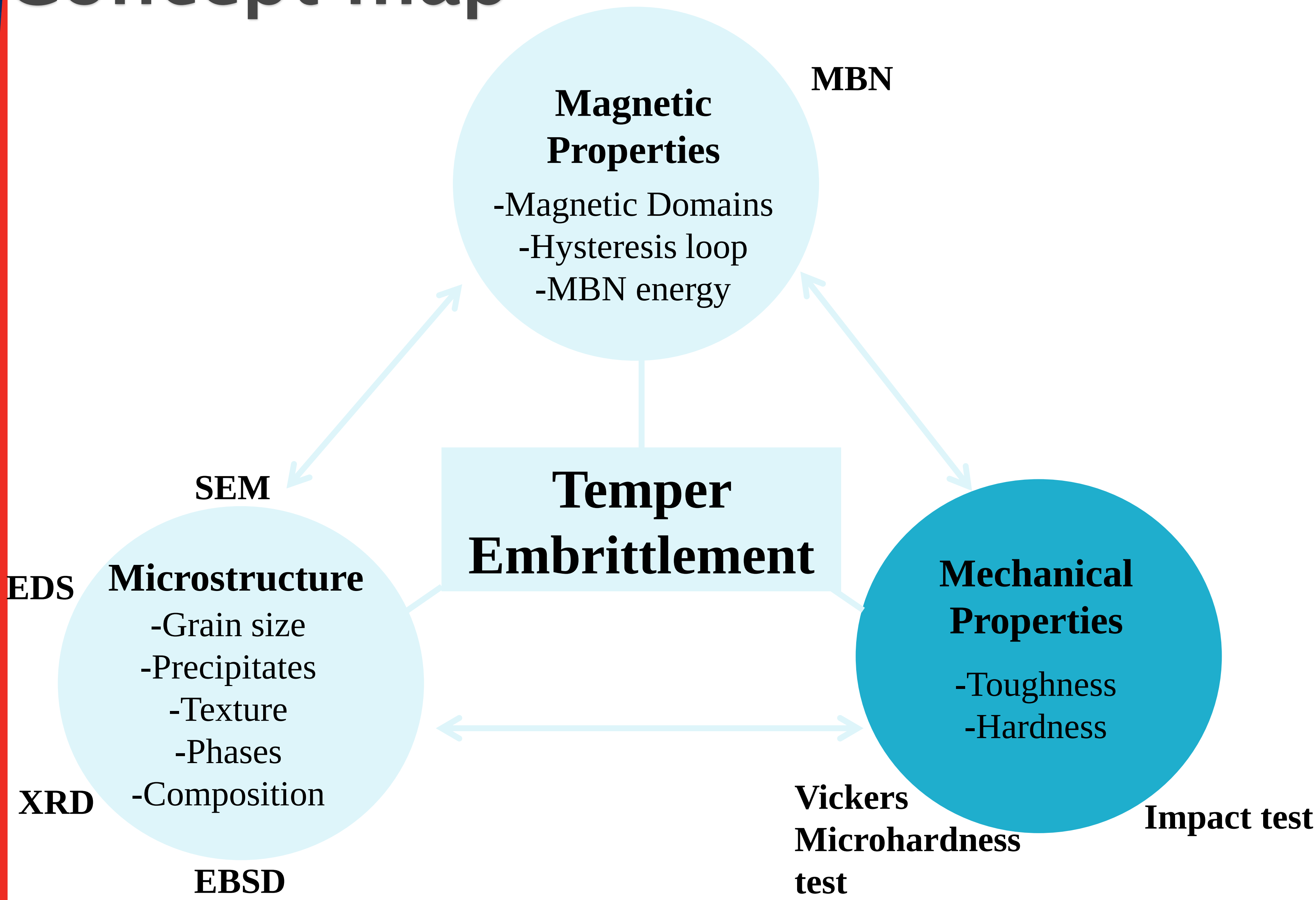






Ferrite peak (110) 2θ = 44.5	Sample 1	Sample 2	Sample 3
FWHM	0.20	0.15	0.16

Concept map



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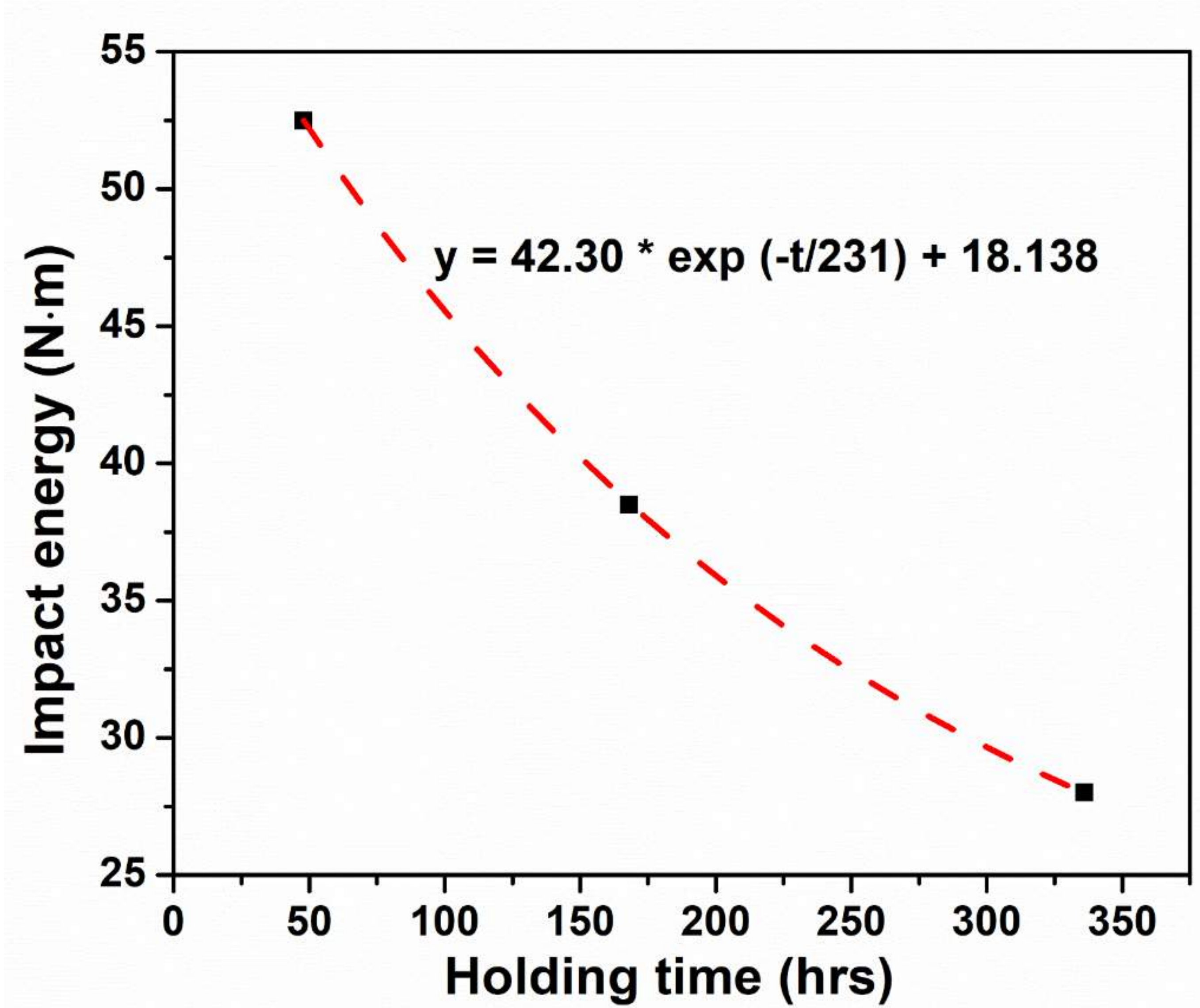
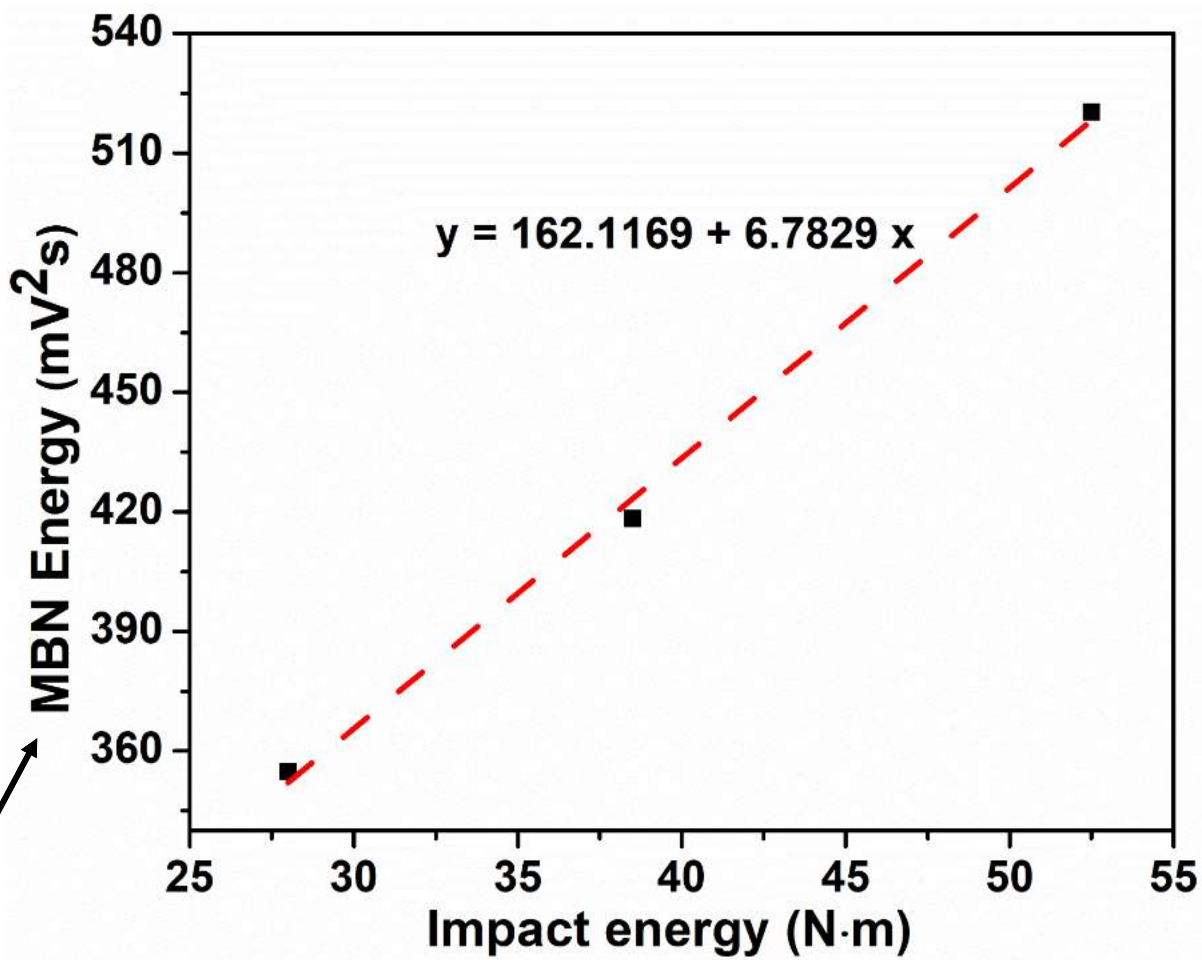
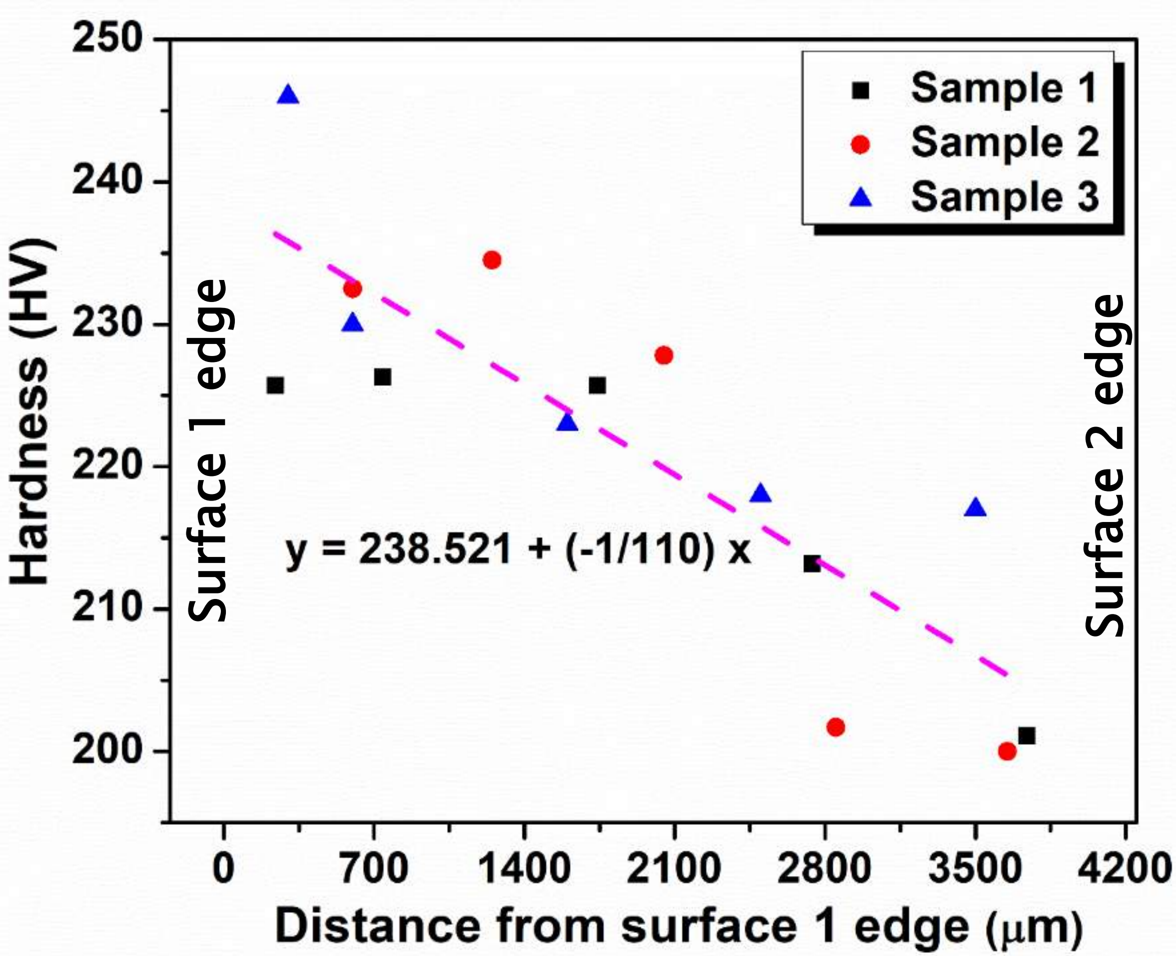


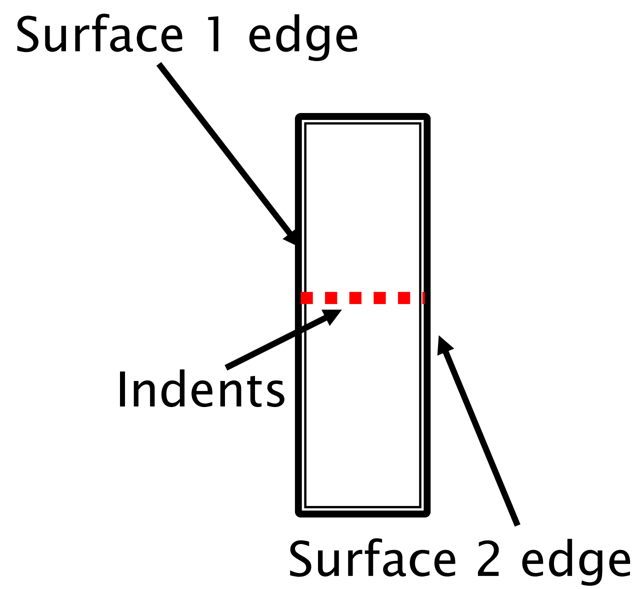
Impact energy vs MBN energy



Average MBN energy for
Surface 1 and Surface 2

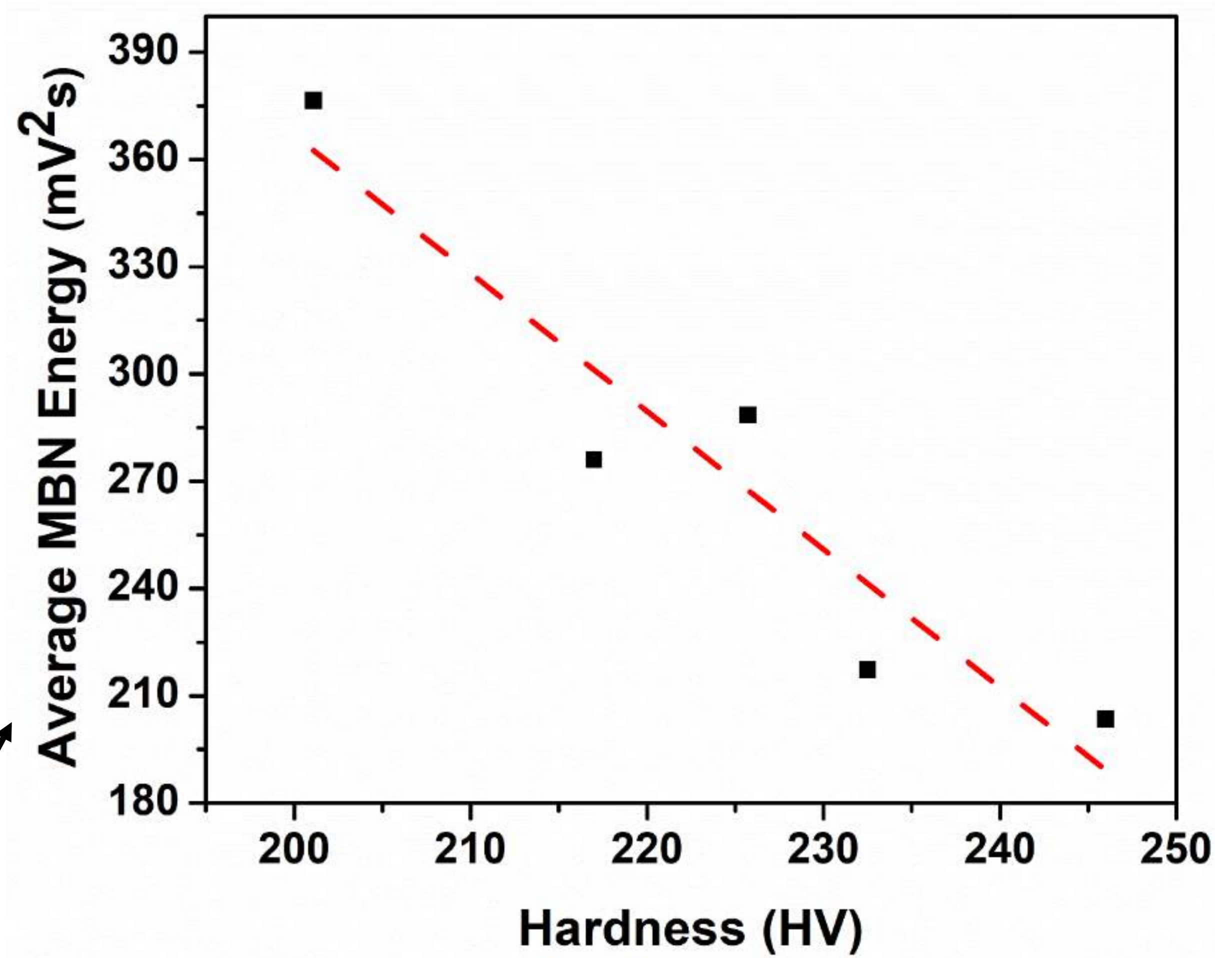
Hardness – cross section





Sample cross-section

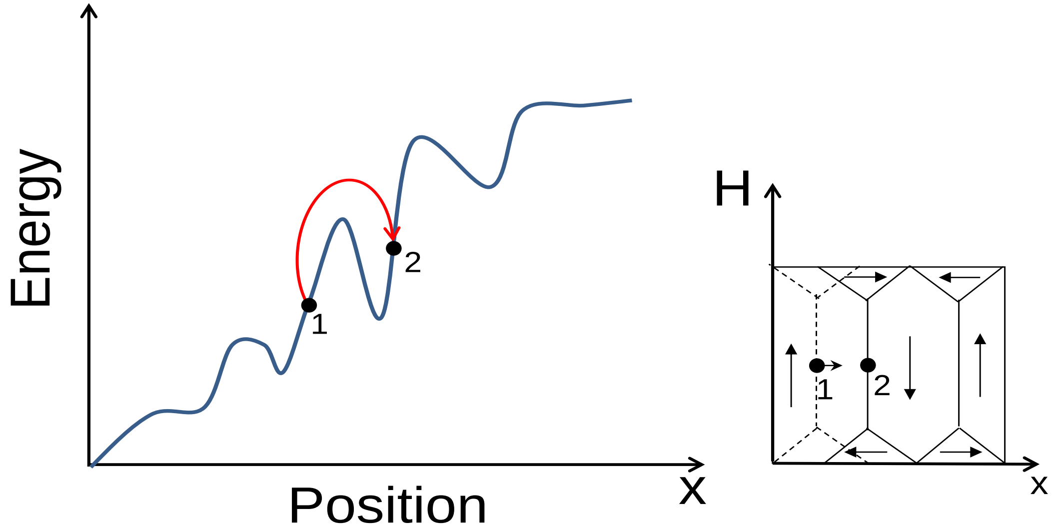
Hardness vs MBN energy



Average MBN energy from
Angle = 0° to 360°

Hardness – cross section

- Carbide segregation near Surface 1 results in higher hardness near Surface 1 than Surface 2
- Carbides uniformly distributed – pinning – MBN energy isotropic for Surface 1
- Texture effect on MBN more dominant than carbide effect – Surface 2



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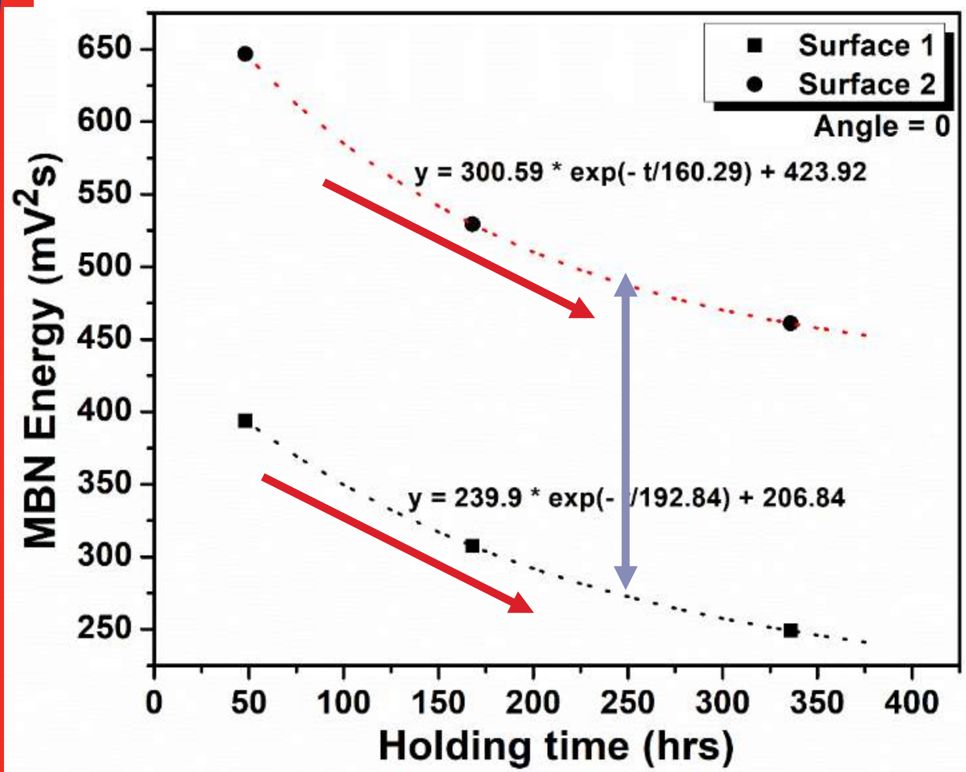
Summary

MBN signal decreases exponentially



- Increase in Crystallite size
- Carbides – near the boundaries – soft matrix
- Migration of trace elements towards grain boundaries (P, Sn, As)

MBN energy ↔ Toughness

- Carbide segregation near surface 1 – pinning effect
- Hardness higher for Surface 1
- Texture effects – Surface 2

Acknowledgements

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Thank you