APPARENT ELASTIC MODULUS OF POLYETHYLENE AND ITS NANOCOMPOSITES MEASURED AT DIFFERENT SCALES

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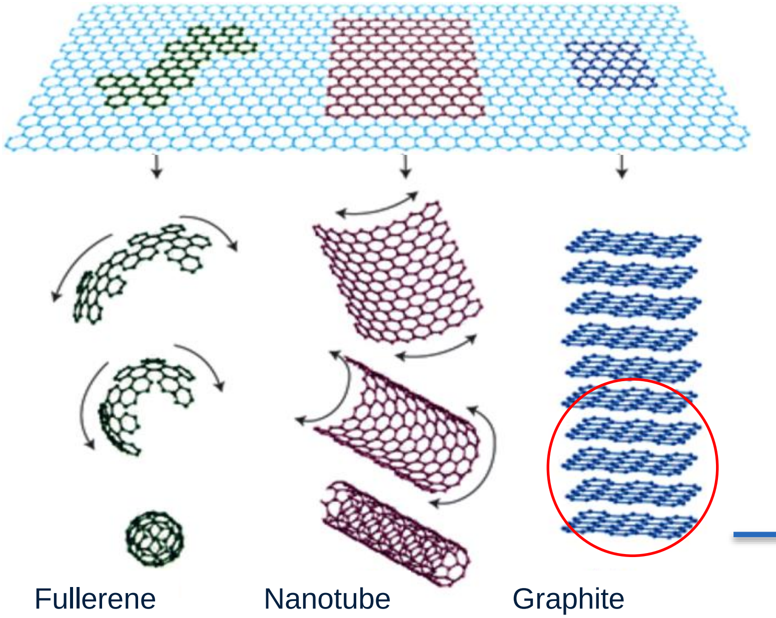
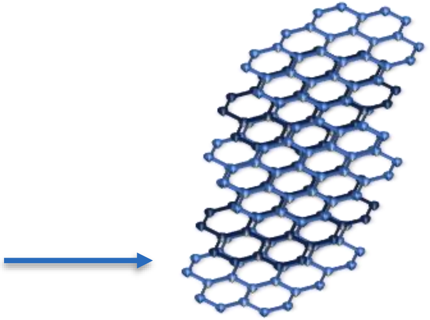
INTRODUCTION

Graphene/Graphite Nanoplatelets (GNPs)



	Graphene	Ref.
Strength (MPa)	130000	350 (steel)
Stiffness (GPa)	1000	200 (steel)
Thermal conductivity (W/K.m)	4000	400 (silver)
Electrical conductivity (S/cm)	6000	70% > silver



Nanoplatelets

Kumar, A., Sharma, K. & Dixit, A.R. A review on the mechanical properties of polymer composites reinforced by carbon nanotubes and graphene. Carbon Lett. 31, 149–165 (2021).

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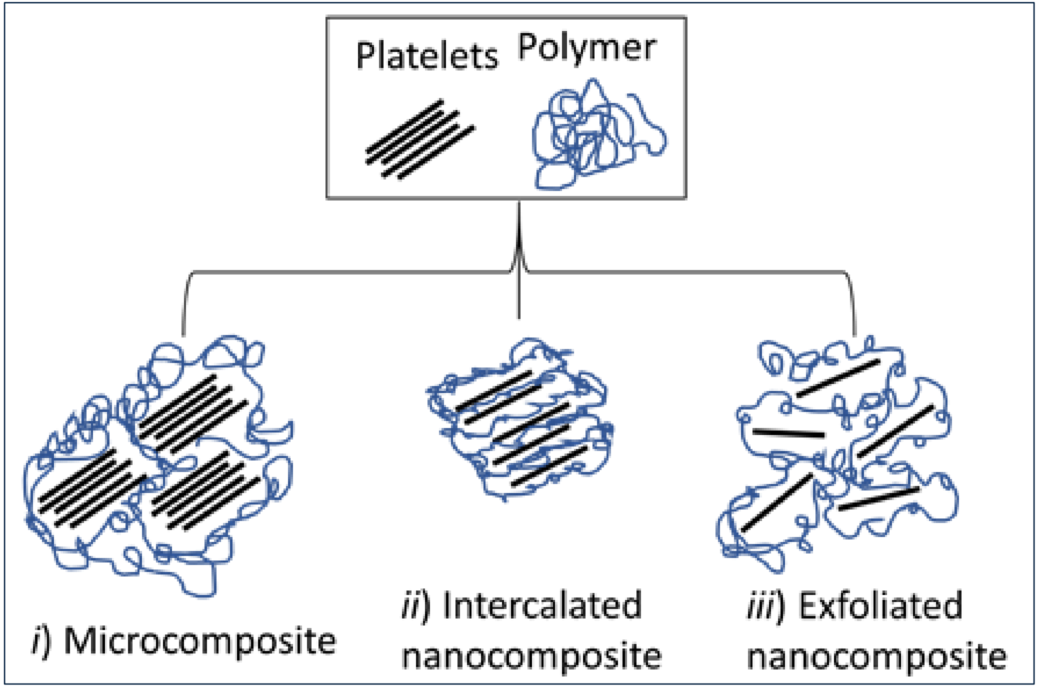
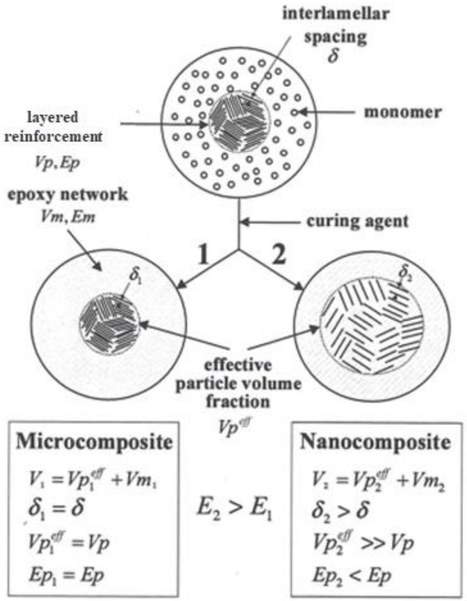
Agglomeration Challenges





Kornmann, X. (2001). Synthesis and characterisation of thermoset-layered silicate nanocomposites (Doctoral dissertation, Luleå tekniska universitet).

Real composite is a mixture of all of the above!

Challenging to predict the properties at this scale

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OBJECTIVES

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- How can we best characterize nanocomposites?
- How valid is the different techniques at different scales? How do they compare? Which is the most representative?
- What are advantages and disadvantages of each of those techniques?

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METHODOLOGY

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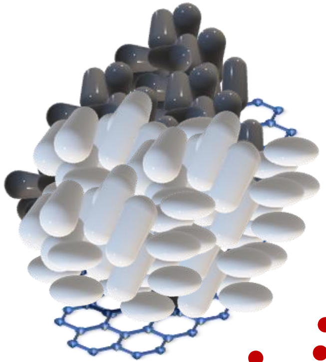
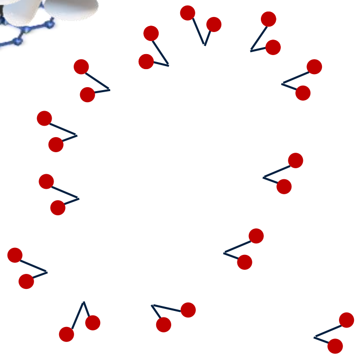
GNP Masterbatch

Masterbatch



35 wt% GNP
40 layers
50 µm lateral size
20 nm thickness



Functional groups
OH, C=O

High density Polyethylene
(HDPE)

GNPs

Commercial product

Recyclable

Stable production

Suitable form for industry

Less hazardous

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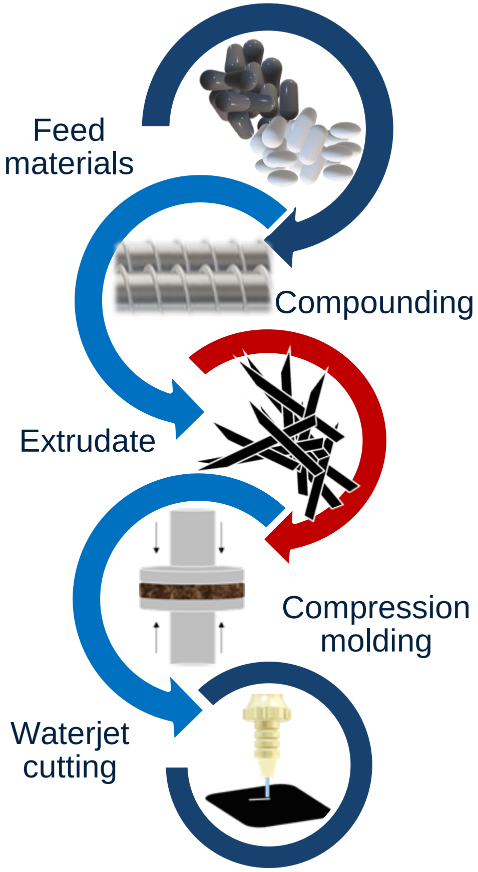
Melt Compounding



Advantages

Upscaling possibility

Use of masterbatch

No process modification

Environmentally friendly

Solvent free

Limitations

High viscosity of the melt

High percolation threshold

Limited to short fibers

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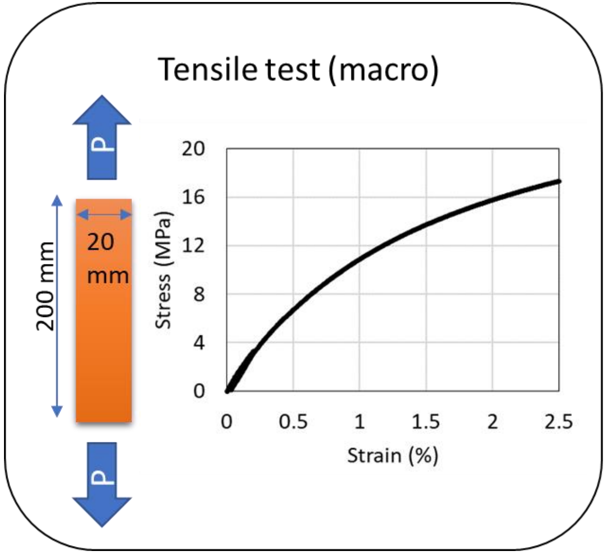
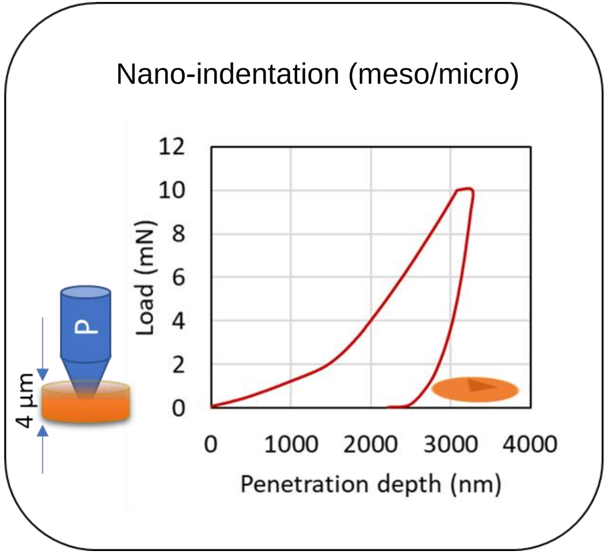
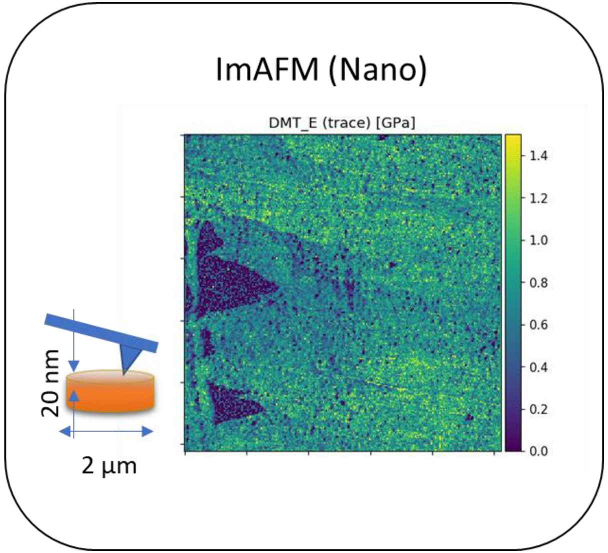
Tests at Different Scales



Instron 3366
Displacement control test
2mm/min



NanoTest Vantage
10 mN max load
15 sec loading time
Berkovitch indenter



A Bruker Dimension Icon AFM
ImAFM mode
Frequencies near resonance
TAP300 DLC Probe

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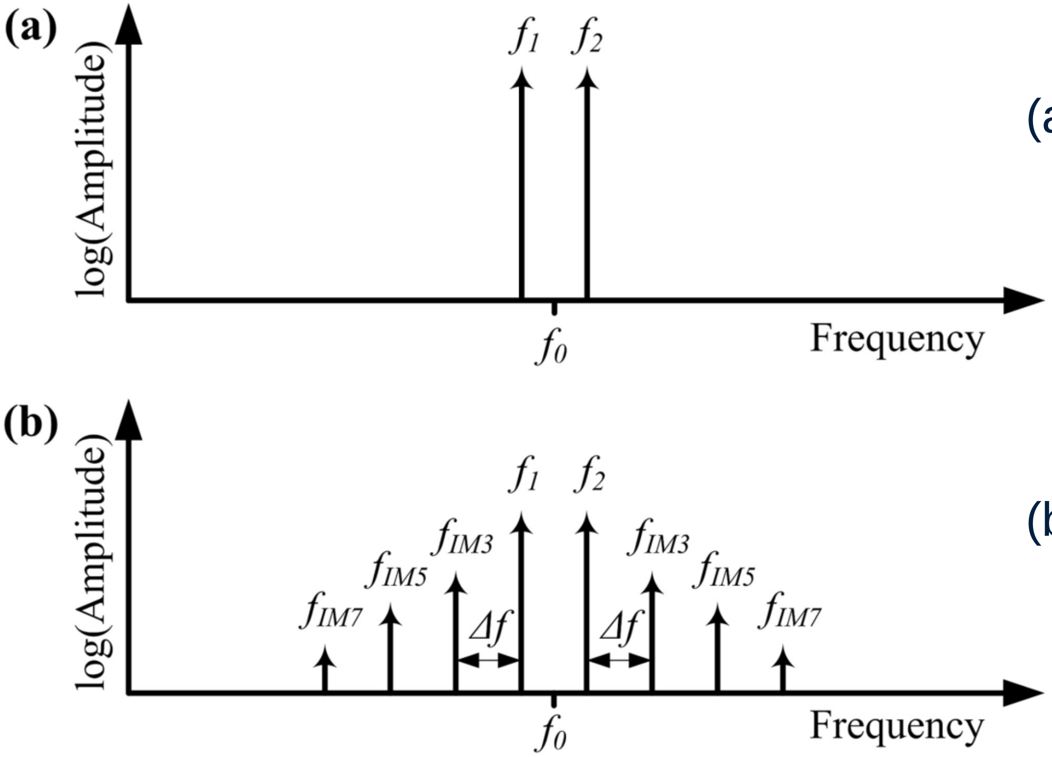
ImAFM



(a) The linear response of the resonator away from the surface. When driven with two frequencies, $f1$ and $f2$, the linear system responds with oscillation at $f1$ and $f2$.

(b) When close to the surface, nonlinear tip-surface interactions generate IMPs of many orders.

PLATZ, Daniel, et al. Intermodulation atomic force microscopy. *Applied Physics Letters*, 2008, 92.15: 153106.

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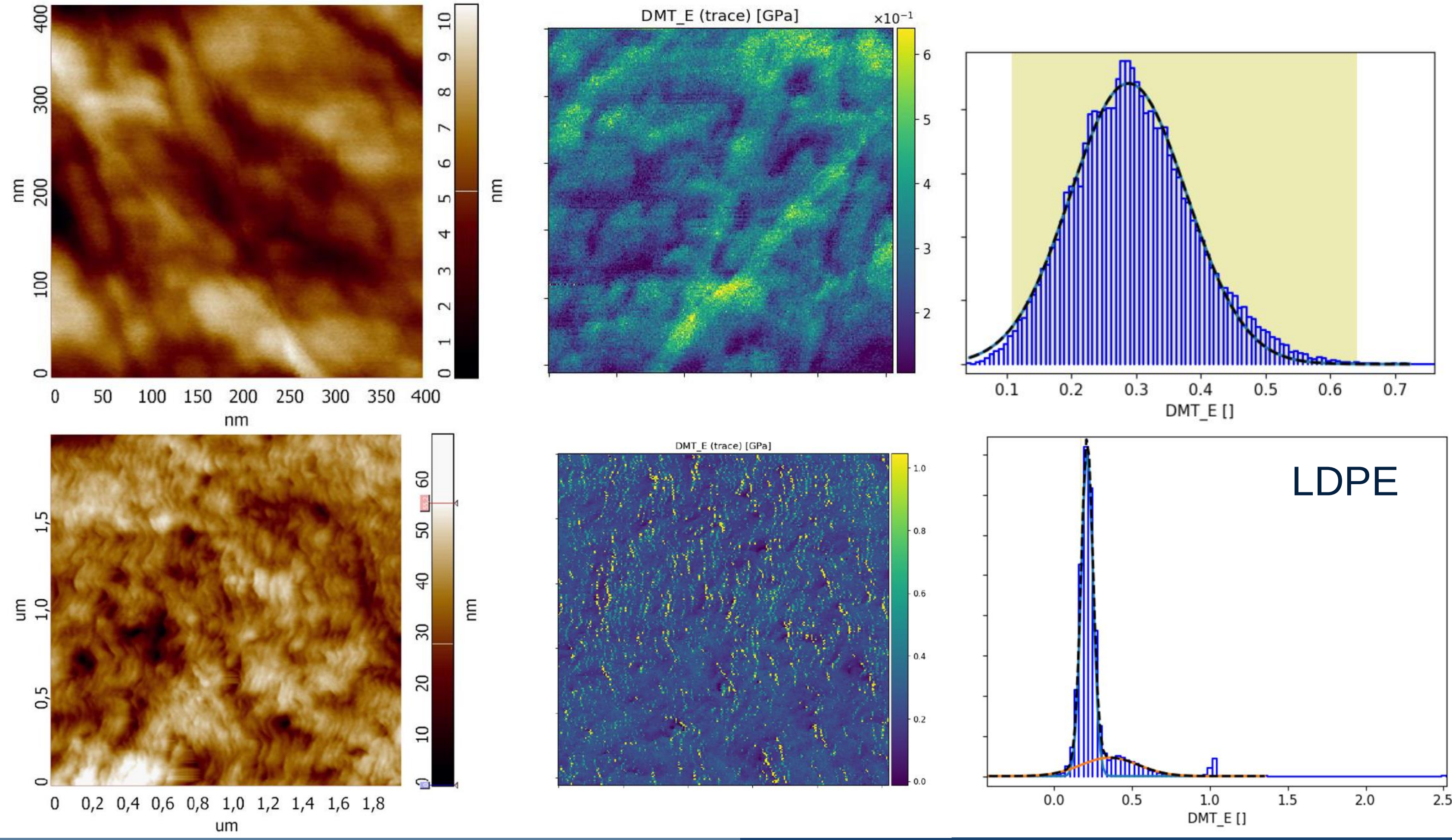

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RESULTS

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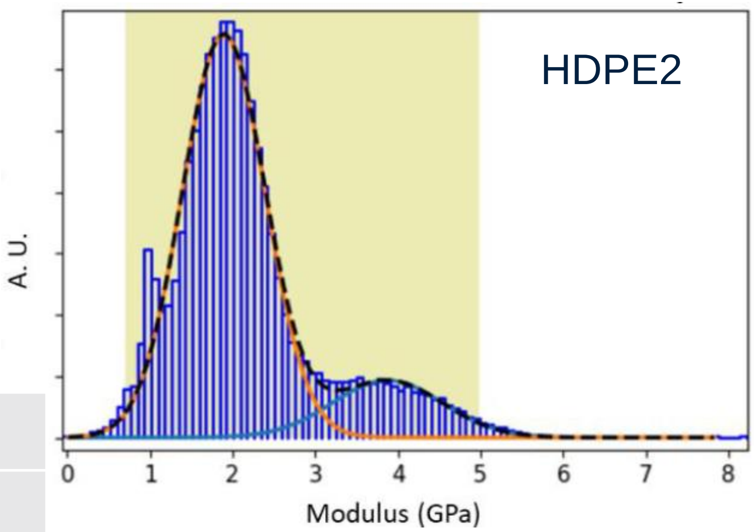
Comparison of results at the different scales



Apparent Modulus (GPa)			
	Tension	NI	ImAFM
LDPE	0.42	0.71	0.42-1.1
LDPE4	0.79	0.71	0.9
HDPE	1.89	1.84	2.7
HDPE2	2.11	3.46	3.3
GNPs	4.79*	22.6*	~4

* Calculated using micromechanics

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Tensile test

- Can obtain more than one property (modulus, strength, Poisson’s ratio, etc.)
- More averaged/homogenized value useful for material selection for application (on the final stage of materials development)
- Limitation – require large amount of material to produce statistically representative results

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Nano-indentation

- Relatively small samples – good for materials under development
- Could do large number of indents in relatively short time for statistics
- Limitations – more complicated sample preparation routines, expensive equipment, viscoelastic effect (VE-effect)
- Needing to know Poisson's ratio to evaluate the modulus (in Oliver Pharr model) $\frac{1}{E_r} = \frac{1-\upsilon_m^2}{E_m} + \frac{1-\upsilon_i^2}{E_i}$

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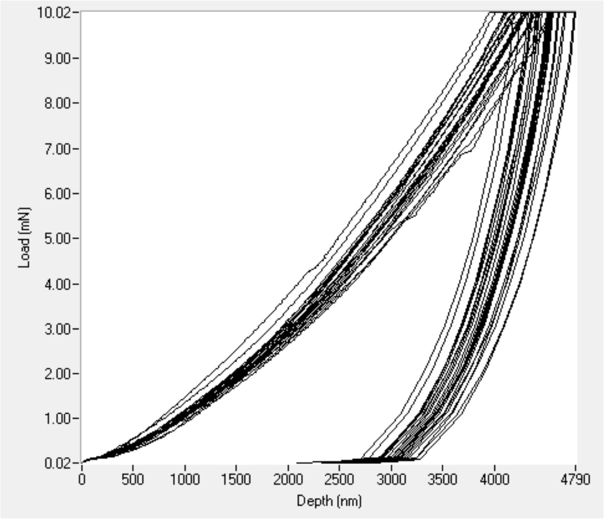
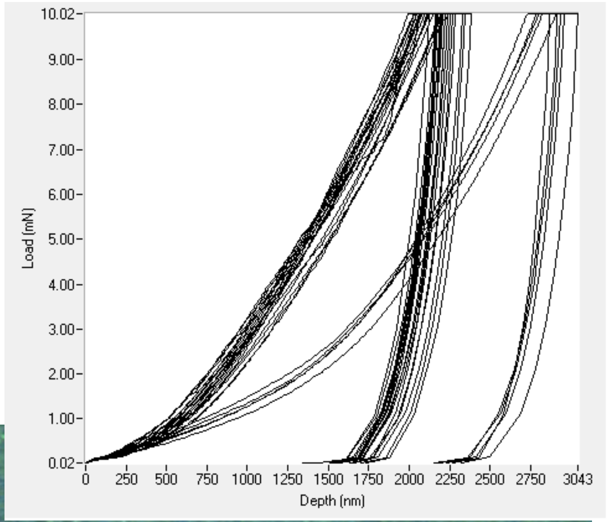
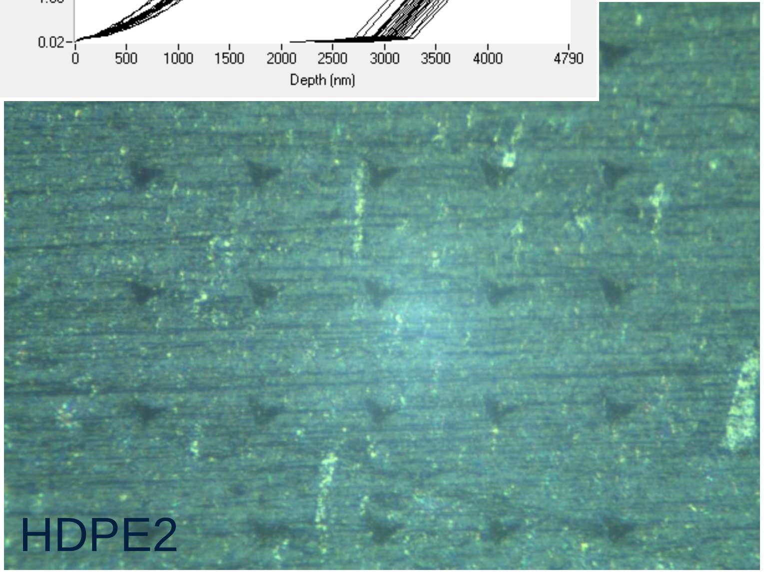


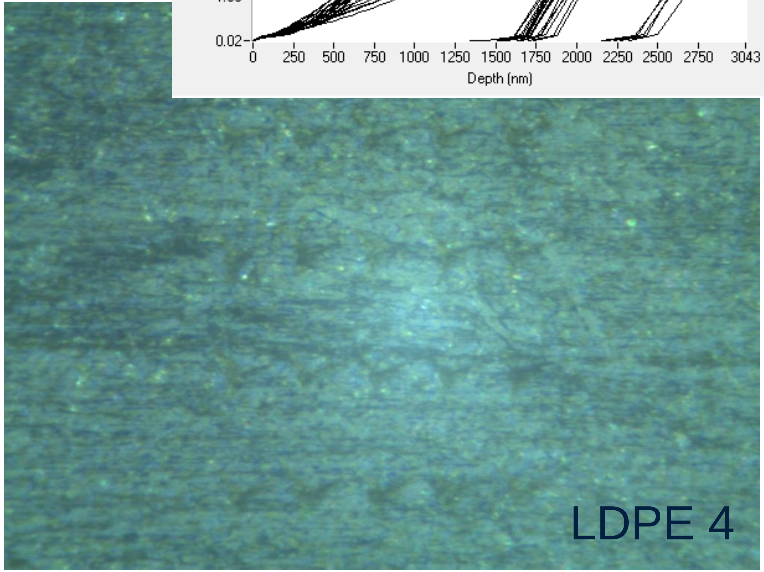
VE-effect in NI

Indents disappear with time for materials exhibiting higher VE

Evaluating stiffness based on other missing properties of particle







ImAFM

- Can resolve microstructure of polymer as well
- Affected by surface freshness (presence of oligomers)
- Working in the scale of reinforcement
- Quantitative output together with image of mapped property
- Relatively less demanding surface preparation (compared to NI)

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Conclusions

- Characterization has been performed at the different scales and ImAFM seems to be good complementary technique in the development stage of material.
- ImAFM gives reasonable values of the effective modulus of particles that could be used for modelling
- Nano-indentation gives values depending on the indented area and requires wider pre-knowledge of the material
- All techniques fail to predict or solve the problem at higher concentrations due to interaction between the particles

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THANK YOU FOR LISTENING

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