
Encapsulated Functional Nanoparticles: Their Properties and Applications

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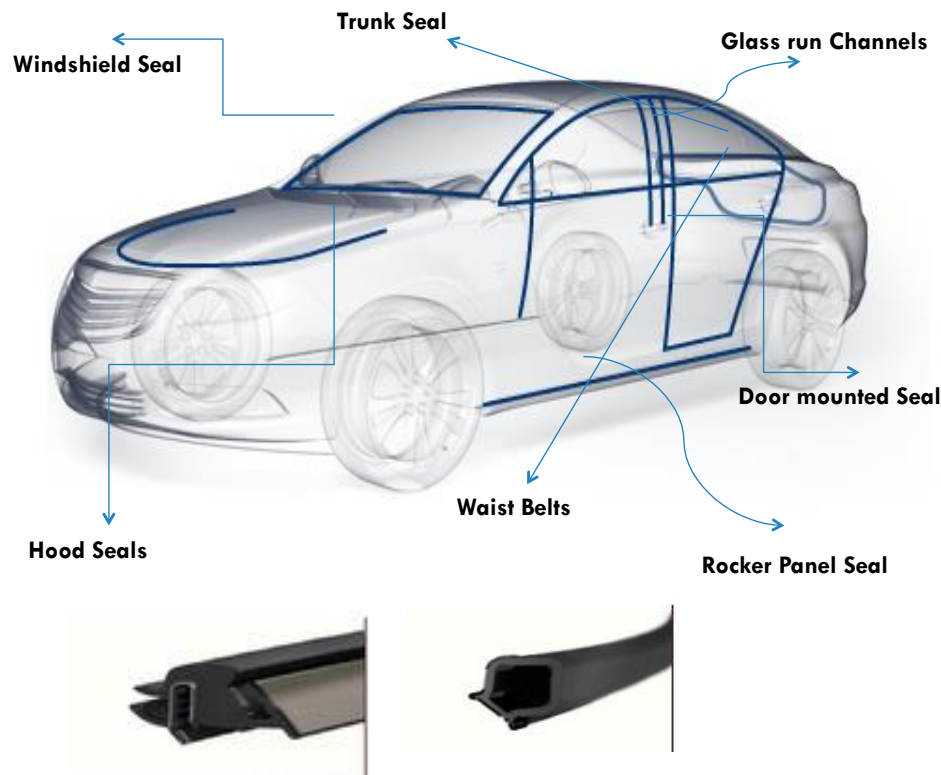
**Center for Particulate and Surfactant Systems (CPaSS)
Spring 2019 IAB Meeting
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Outline

- Application of particulate systems into polymeric media
 - Sealants for automotive and white-good appliances
 - Textile surfaces 2-D application
 - Extension on 3-D Printing
- Integration of nanoparticles into polymeric media for enhanced functionality in sealant applications
 - Mechanical properties
 - UV resistance
 - Antimicrobial functionality
- Integration of nano-capsules for controlled release and self-repair ability
- Methodology for utilization of functional nano-particle and nano-capsule systems for 3-D printing

Application of particulate systems into polymeric media

Sealants for automotive and white-good appliances

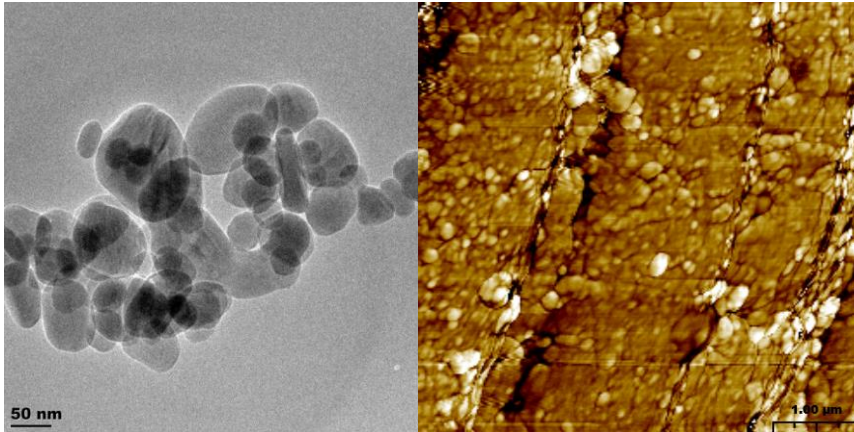


- Production of;
 - Abrasion resistant
 - Heat-tolerant
 - Durable to UV exposure
- Production of;
 - Antibacterial
 - Vibration resistant
 - Stable aesthetic properties (color, shine)
- Advanced functionality can be integrated to the sealants by addition of particulate systems.

Application of particulate systems into polymeric media

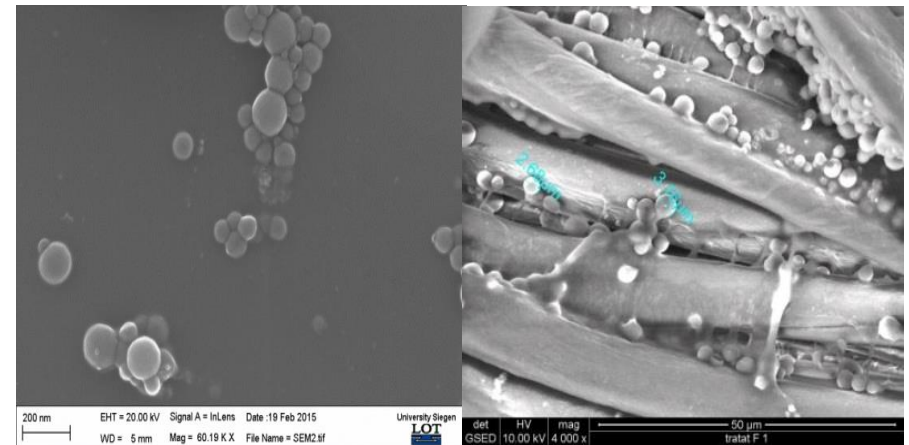
2-D Textile Surfaces

Nanoparticles/ Antimicrobial



- Textiles are prone to growth of microorganisms
- Microorganisms negatively affect public health and degrade the performance of the textile
- Most of the synthetic fibers, due to their high hydrophobicity, are more resistant to attacks by microorganisms as compared to the natural fibers.
- Antibacterial and tick-repellant textiles were developed with nanoboron particles and eucalyptus oil containing nano-capsules.

Nanocapsules/ Controlled release



- Application of nanocapsules to textiles help make them capable of controlled release of active agents;
 - Insect/tick repellent
 - Antimicrobial
 - Wound-care medications
- i. Type of nanocapsules and textile fibers affect the attachment mechanisms
 - i. Chemical/binder
 - ii. Physical

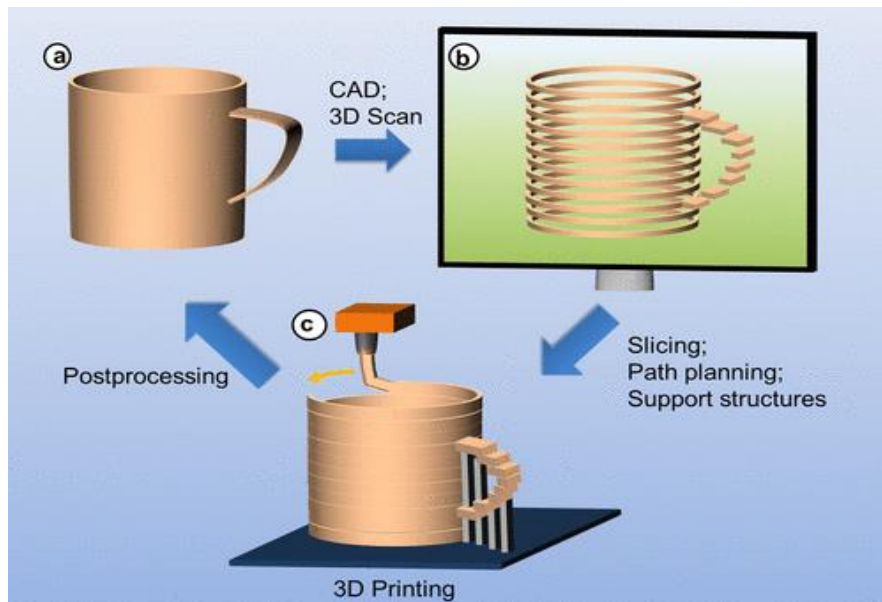
Application of particulate systems into polymeric media

Polymeric Media for 3-D printing

3-D printing is additive manufacturing (AM) and it translates computer-aided design (CAD) virtual 3D models into physical objects.

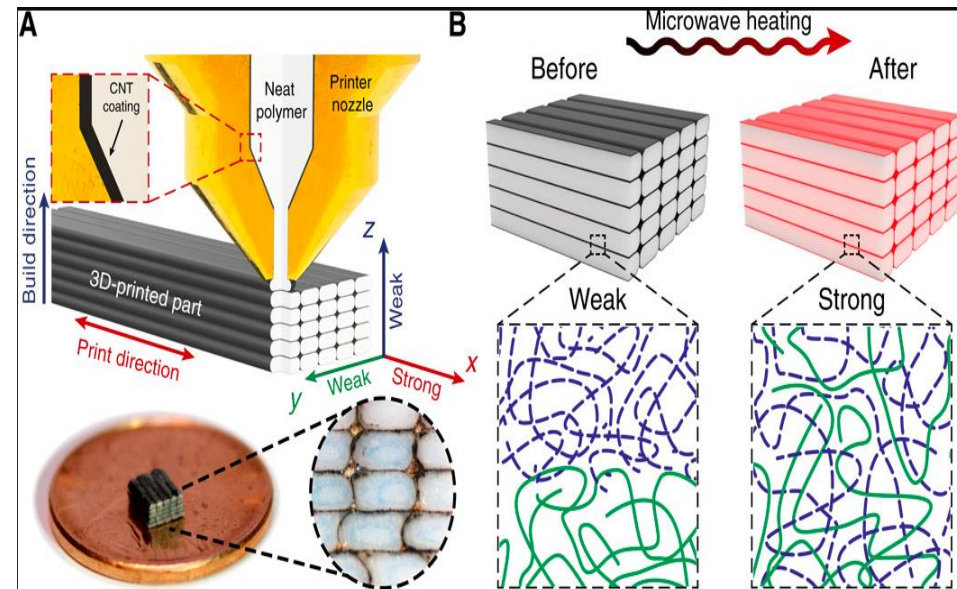
- No molding/ machining
- ABS, PLA, PET, PC are the commonly utilized polymers
- Nanoparticles can also be integrated into the matrix

3-D Printing Based Additive Manufacturing



<https://pubs.acs.org/doi/10.1021/acs.chemrev.7b00074>

3D-printed carbon nanotube–polymer composites



<https://advances.sciencemag.org/content/3/6/e1700262.full>

- Polymer based 3-D printing applications have to be tailored to be functional under high temperature and high shear of the nozzle application.

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Integration of nanoparticles into polymeric media for enhanced functionality in sealant applications

Motivation:

- Abrasion caused by friction
- High level of waste 10% - 13%
- Problems with UV durability
- Complex profiles
- Metal to plastic adhesion
- Customer expectations differ
- Quality control
- Cost reduction
- Aesthetic properties (color, shine)
- Bacteria growth prevention

Approach:

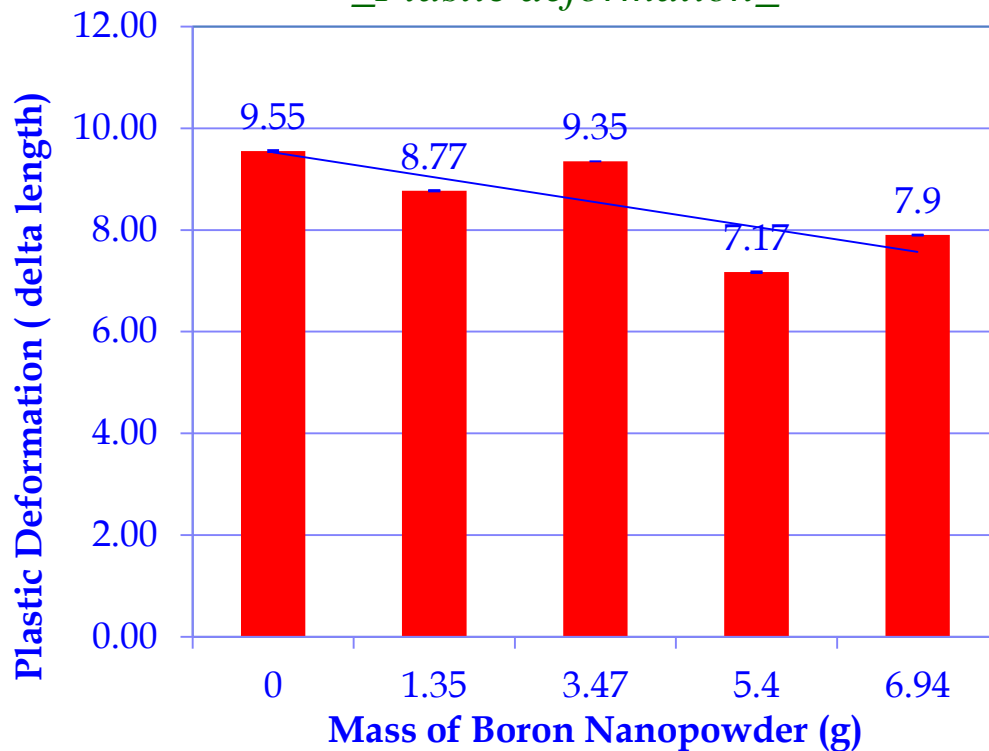
- Integrate nano-particles into the polymer (EPDM) matrix
 - *Mechanical properties*
 - *UV resistance*
 - *Antimicrobial functionality*
- Synthesis of nano-capsules
- Integration of nanoparticles and nanocapsules into the polymer matrix.
- Evaluation of the controlled release and self-repair ability.

Mechanical Properties

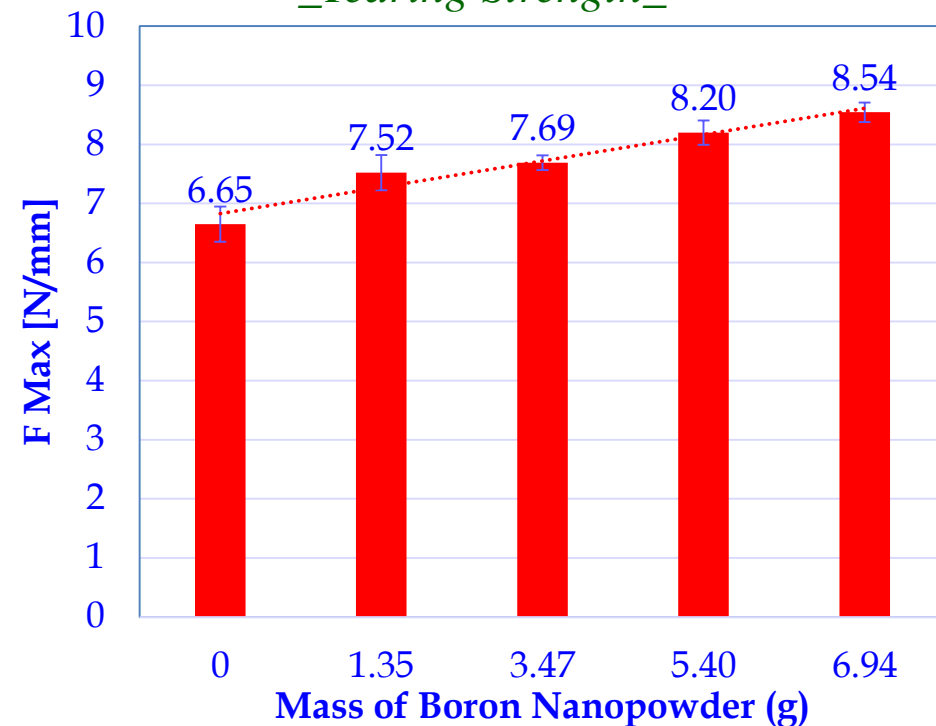
Design of Experiments for Nanoparticle Addition

Mass of Boron Nanoparticle	Central Composite Design	Percentage in the Mixture
0 g	-1.68	0%
1.35 g	-1.00	0.1%
3.47 g	0	0.26%
5.40 g	1	0.4%
6.94 g	1.68	0.51%

Plastic deformation

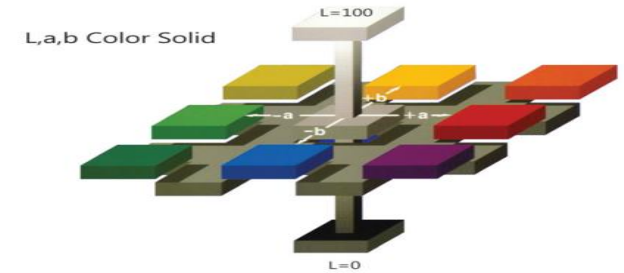


Tearing Strength

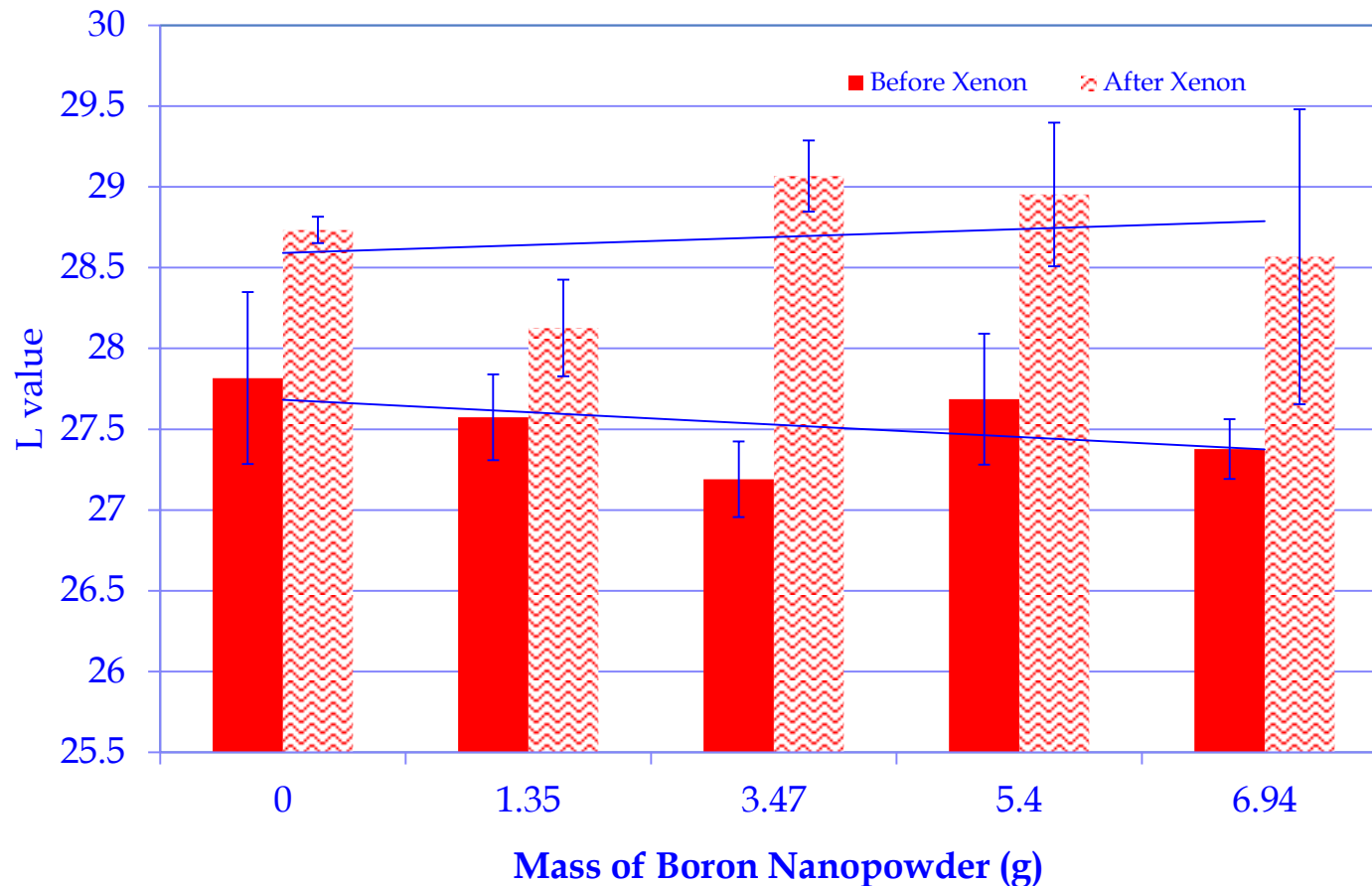


- Only 0.5% addition of nanoboron particles into the EPDM based sealant resulted in improved mechanical properties.

UV Properties



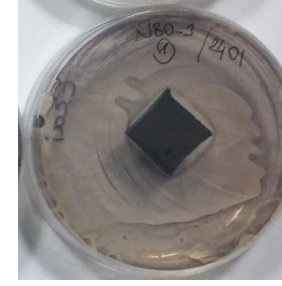
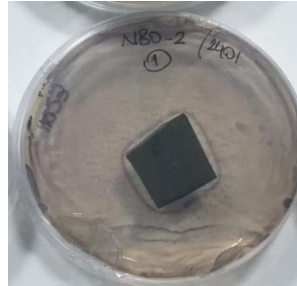
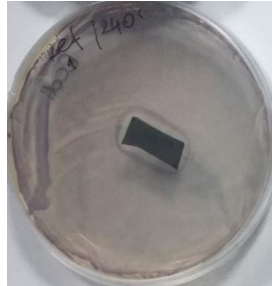
L – Test_ Level of Black Color



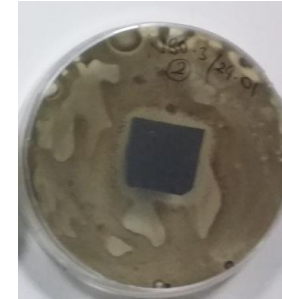
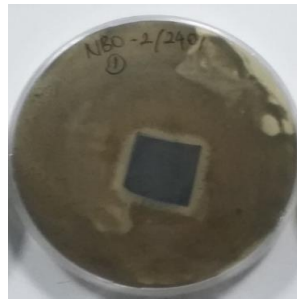
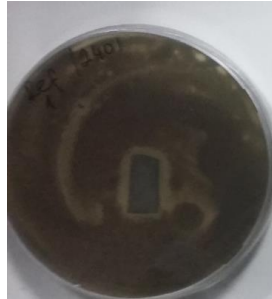
- L = 0 Black, tendency to get more black with nano boron addition after xenon exposure (21 days). This is critical for the long term esthetic performance on the automobiles.

Antimicrobial Functionality

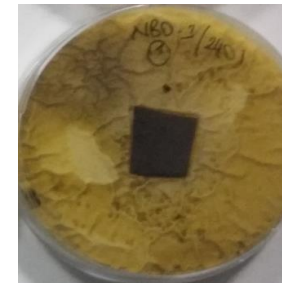
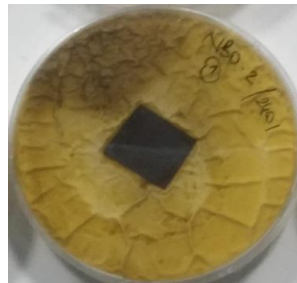
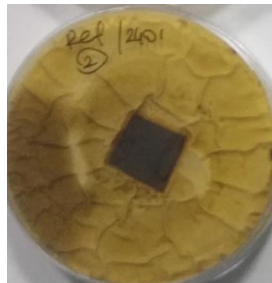
Antomicrobial Activity for kaolin replacement with Nanoboron-oxide
(phr_parts per hundred rubber)



E.coli



S.aureus



A.niger

Baseline
40 phr
Kaolin

1.6% NBO
6 phr NBO
34 phr Kaolin

3.4% NBO
13 phr NBO
27 phr Kaolin

- Zone formation was observed for E.coli and S. Aureus, not effective against A. niger)

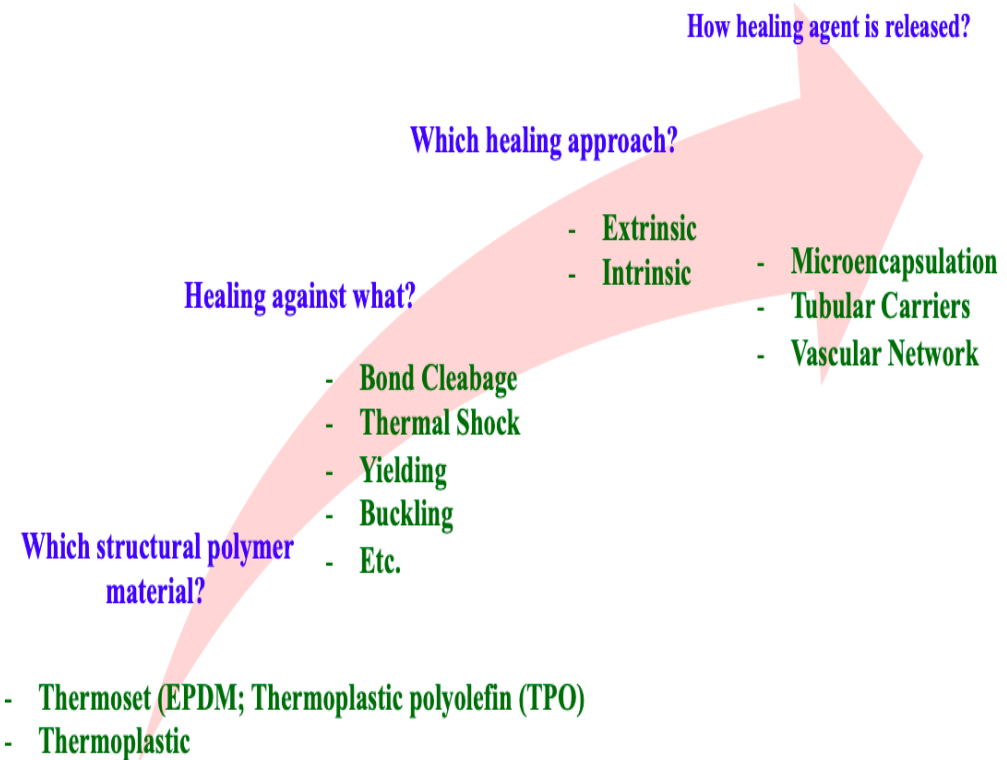
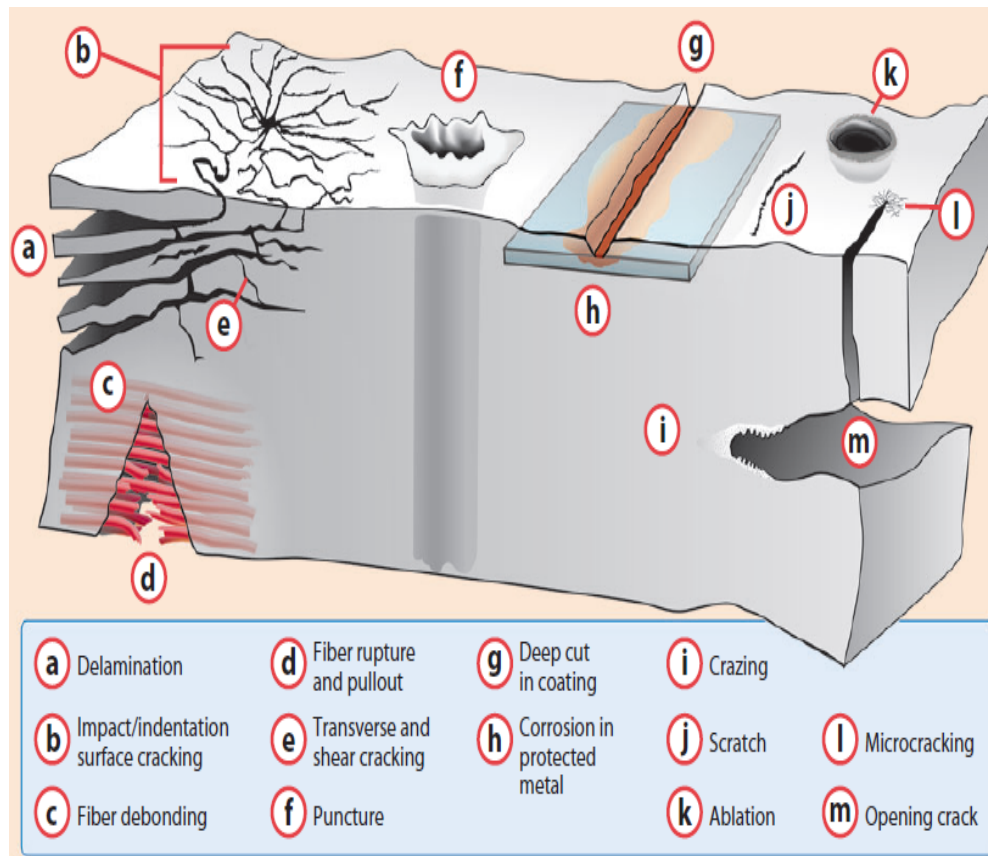
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Integration of nano-capsules for controlled release and self-repair ability

Types of Deformation in Polymer Composites

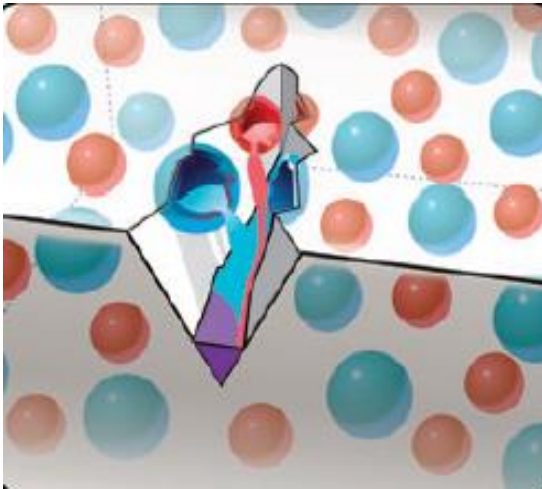
Classification of Healing Mechanisms



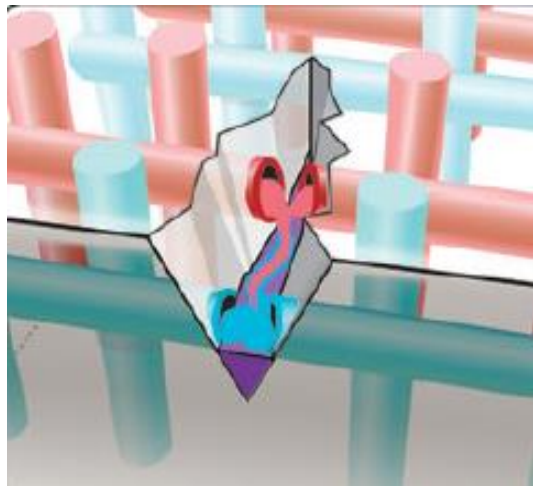
➤ Healing of the polymeric media can be achieved through different mechanisms.

Methods of Self Healing

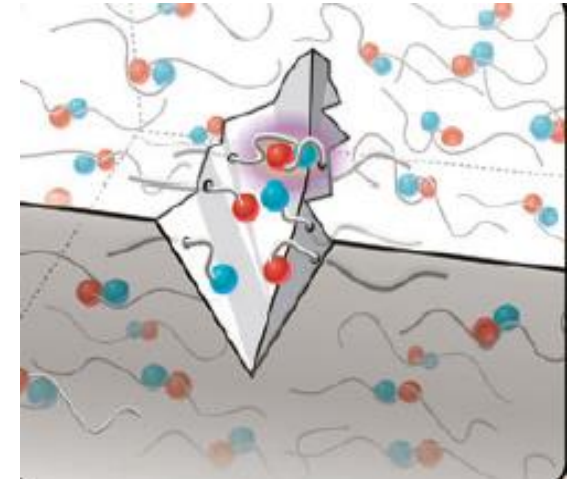
Capsule Based



Vascular



Intrinsic



Capsule based: self-healing materials, the healing agent is stored in capsules until they are ruptured by damage or dissolved.

For vascular materials: the healing agent is stored in hollow channels or fibers until damage ruptures the vasculature and releases the healing agent.

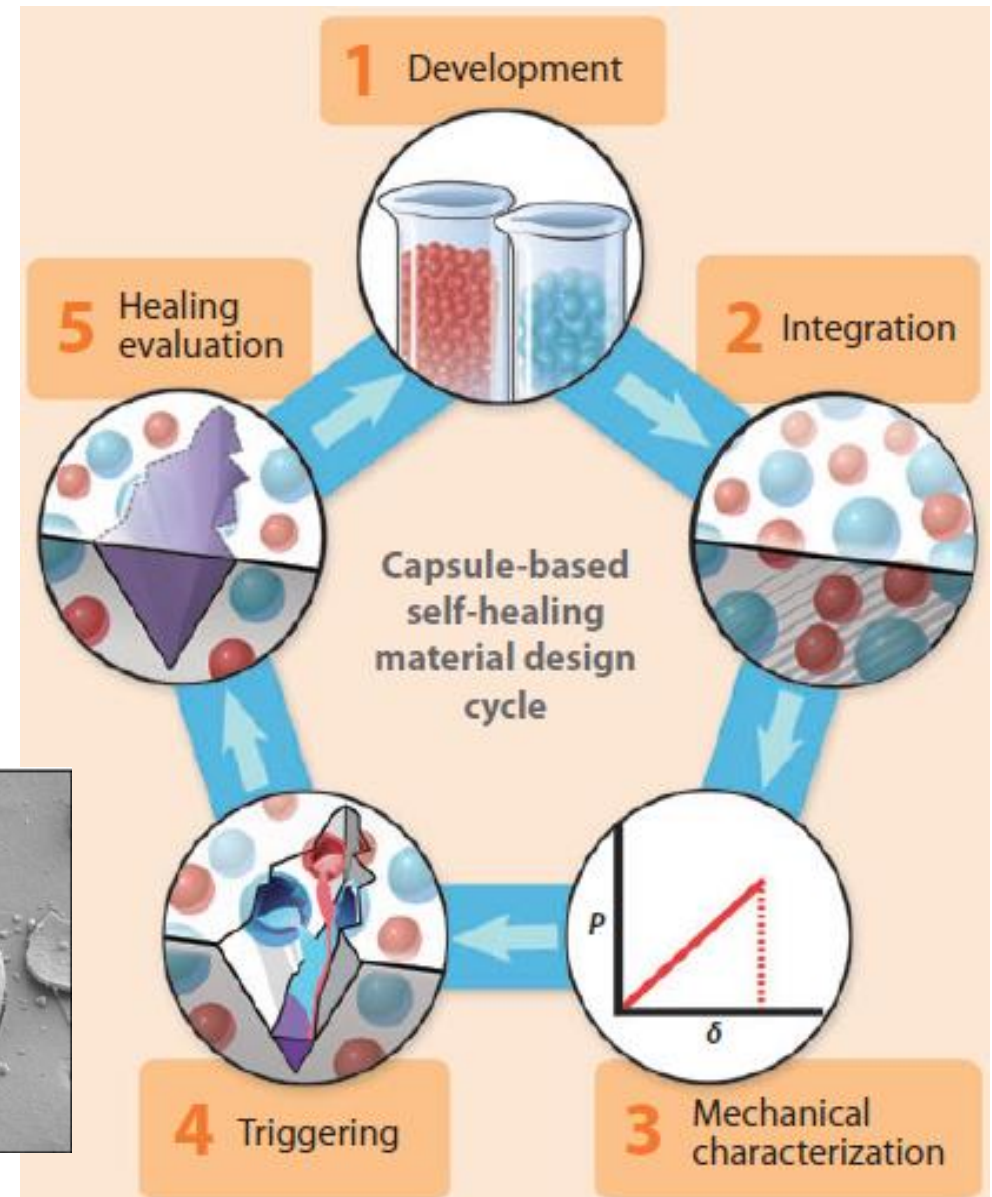
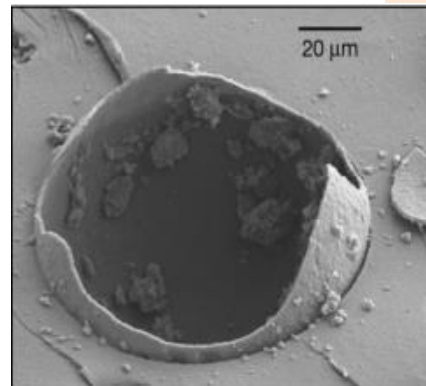
Intrinsic materials: contain a latent functionality that triggers self-healing of damage via thermally reversible reactions, hydrogen bonding, ionic arrangements, or molecular diffusion and entanglement.

- Mechanically releasing capsules can be utilized for the 3-D printing polymers by encapsulating the monomers and the initiators.

Methods of Self Healing

Design Cycle for Capsule-Based Self-Healing Materials

- Crack propagates within the polymer matrix Polymer matrix
- Crack ruptures the microcapsules and releases liquid healing agent into crack plane
- Subsequent polymerization in contact with catalyst seals the crack faces



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Methodology for utilization of functional nano-particle and nano-capsule systems for 3-D printing

- Background
 - Determination of polymer matrix and suitable healing agents
 - Selection of suitable nanoparticles
 - Selection of encapsulation method
- Preparation of Microcapsules
 - Polymer based
 - Polymer/nanoparticle based
- Validation of controlled release and self-healing potential
 - 2-D analyses on free capsules
 - Characterization of Microcapsules
 - (FTIR, AFM, SEM, DLS,...)
- Preparation of Microcapsule-Containing Polymers
 - Blending
 - 3-D printing conditions
 - Testing of encapsulated polymer
- Mechanical/ thermal and bio-degradability analyses
- QC analyses

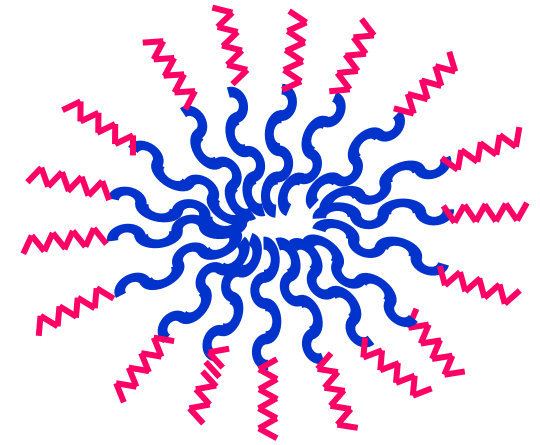
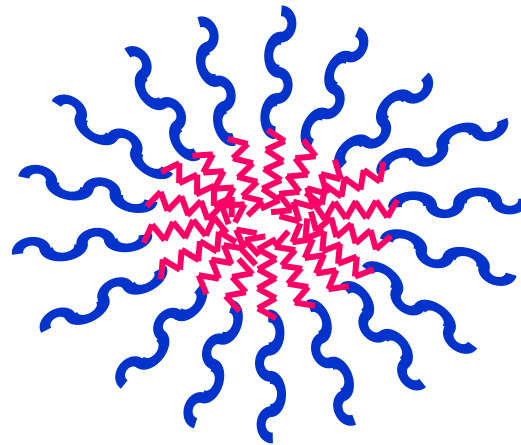
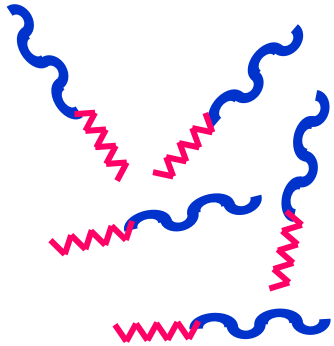
Preparation of Microcapsules

Co-polymeric Capsules

 Hydrophilic  Hydrophobic

Hydrophilic Media

Hydrophobic Media

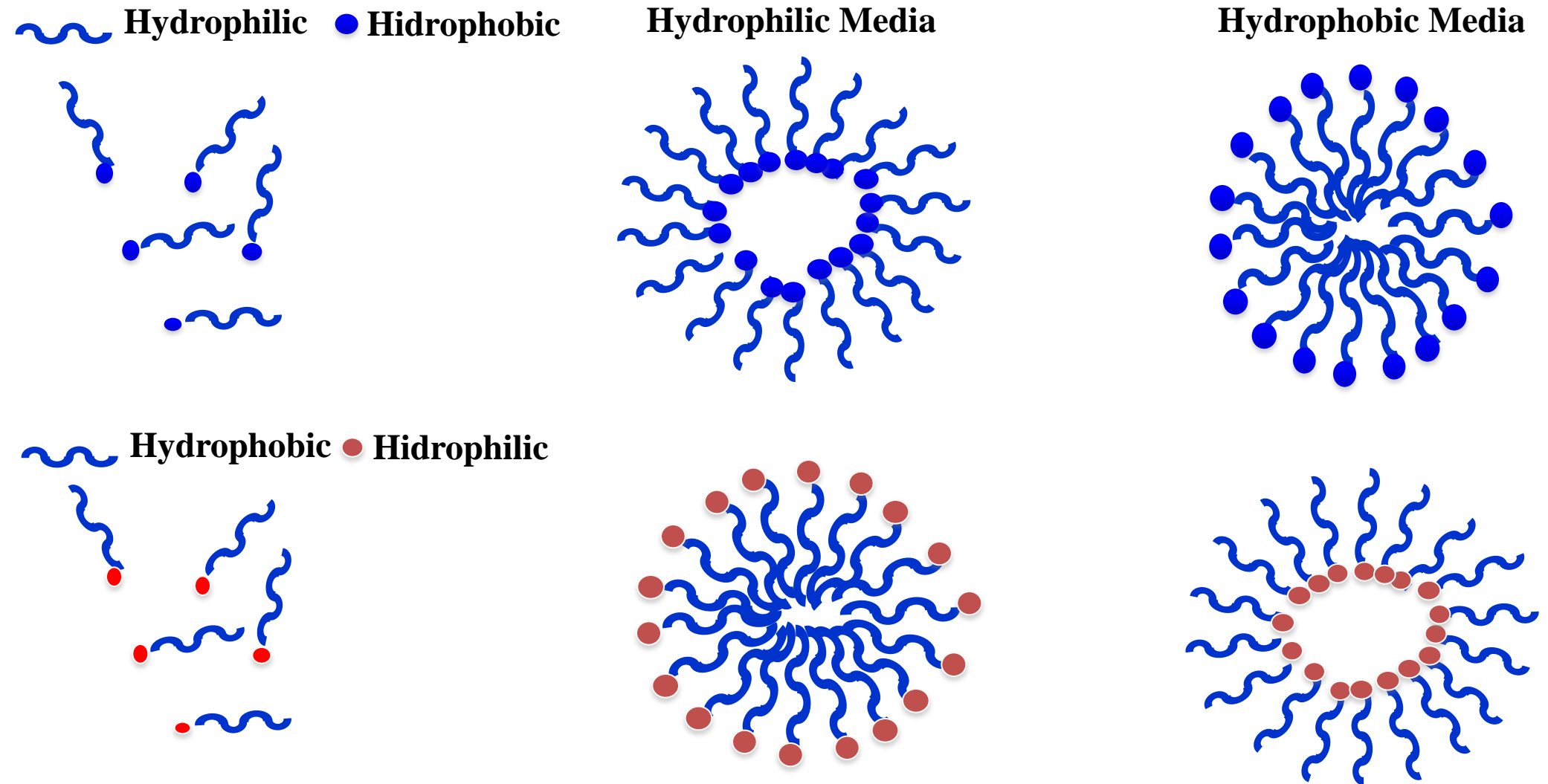


Aqueous Concentration < CMC

Aqueous Concentration > CMC

Preparation of Microcapsules

Polymer/Nano-particle Tailored Capsules



Aqueous Concentration < CMC

Aqueous Concentration > CMC

Summary

- 3-D printing is an additive manufacturing technique that can benefit from the improved polymeric media.
- Nanoparticles and nanocapsules can be integrated into the polymer matrix to enhance their performance.
- Nano additives will be formulated to be integrated into the polymers designed for 3-D printing of medical devices
- The self healing ability will be introduced by controlled release techniques through nano-capsules with nanoparticle support.

QUESTIONS/COMMENTS?

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