Carbon Nanotubes/Polymer Nanocomposites

-- From Fundamental to Application

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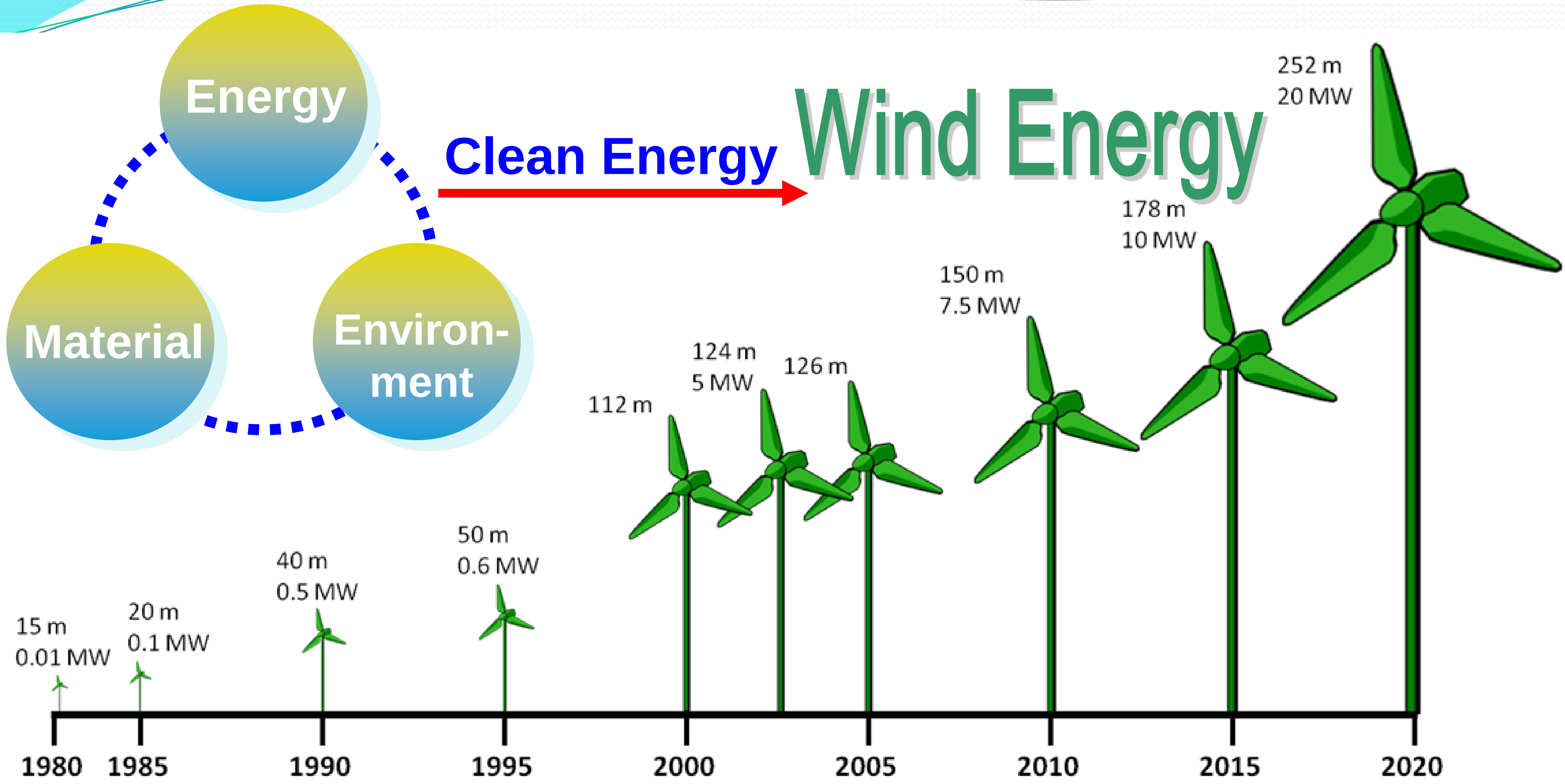
Outline

- **Engineering application of CNT/polymer nanocomposites**
  - -- Perspectives for wind blade materials
  - -- Sensory materials for defect monitoring in FRPs
- **Environmental application of (CNT)/polymer nanocomposites**
  - -- Materials for oil-water separation
  - -- Multi-functional textiles
- **Concluding Remarks**
- **Acknowledgement**

Engineering Applications of CNT/Polymer Nanocomposites

Perspectives for Wind Blade Materials

Introduction



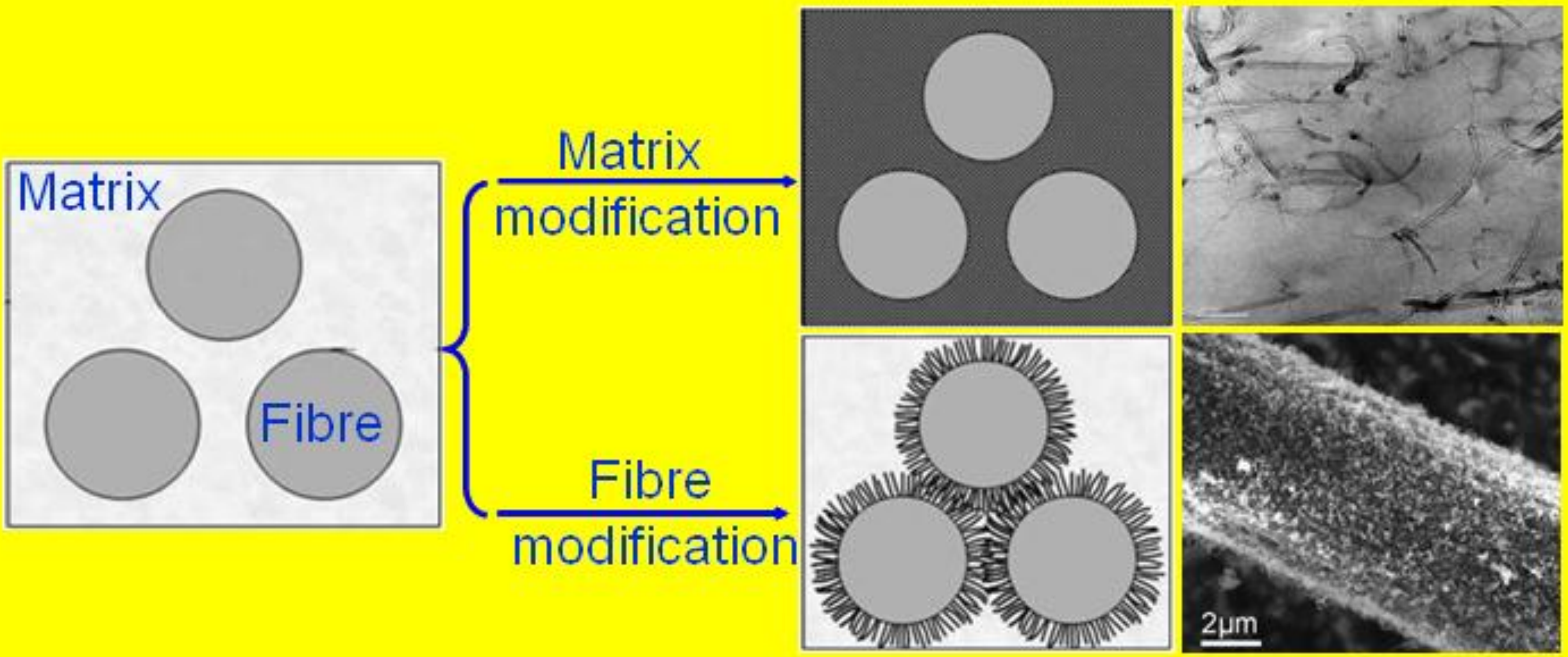
Requirements for Wind Blades

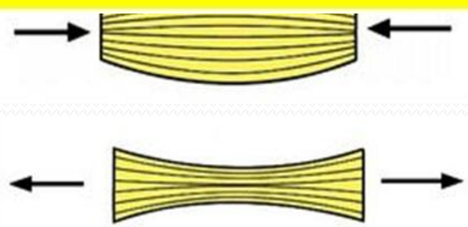
Larger Size **Higher Strength** **Better Stability**

Material Selection for Wind Blades

➢ FRP Structures for Wind Blades

How to improve FRP performance?





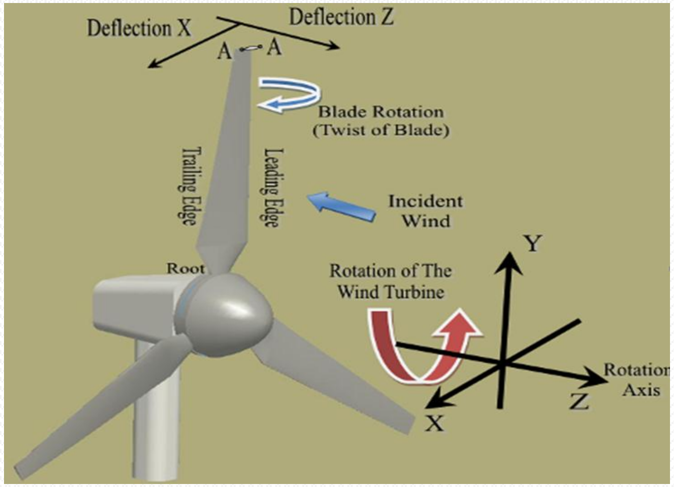
-- Environmental aspect: Lighting strike, humidity, thermal stability...

Ma, et al. Renew Sustain Energy Rev, 2014, 30, 651

Multi-functionality of CNTs in Polymer (I) – Mechanical Reinforcement

➢ Importance of Mechanical Properties for Blades

-- Blade length >40 m, structural integrity
-- Blade loading under different conditions
-- Properties: Modulus, strength, toughness, fatigue…



➢ Modulus and strength of CNT/Epoxy Nanocomposites

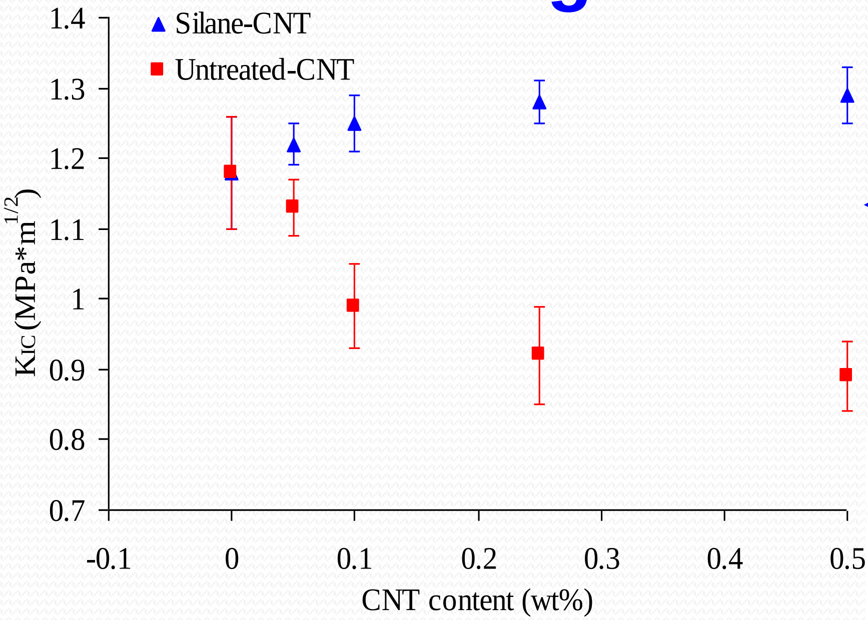
	Flexural modulus (GPa)	Flexural strength (MPa)
Epoxy	2.91±0.03	106.6±2.2
CNT/Epoxy	3.56±0.05	125.3±1.2

➢**CNT content: 0.25%;** 3-point bending test;
➢Epoxy: DGEBA (Epon-828) & m-phenylenediamine

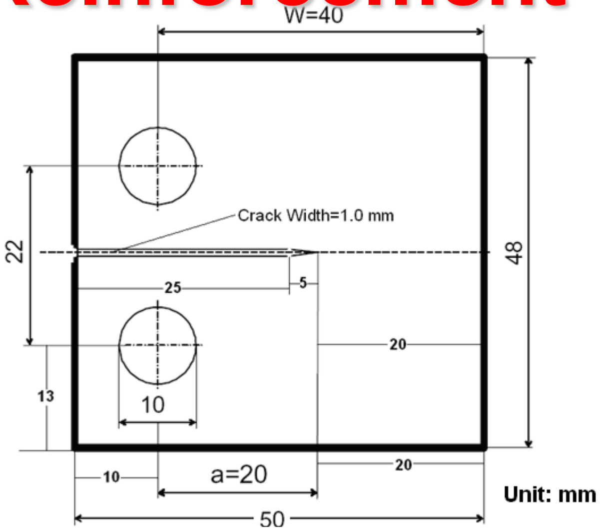
Ma, et al. Compos Sci Technol, 2007, 67, 2965

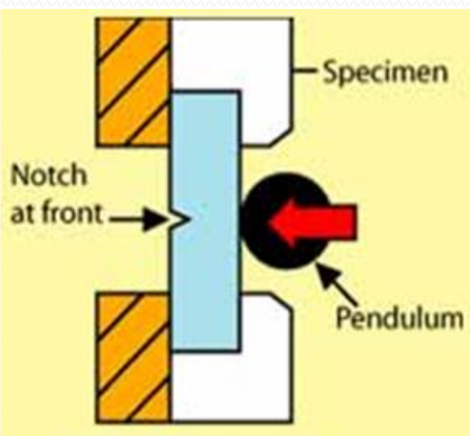
Multi-functionality of CNTs in Polymer (I) – Mechanical Reinforcement

➢ Fracture Toughness

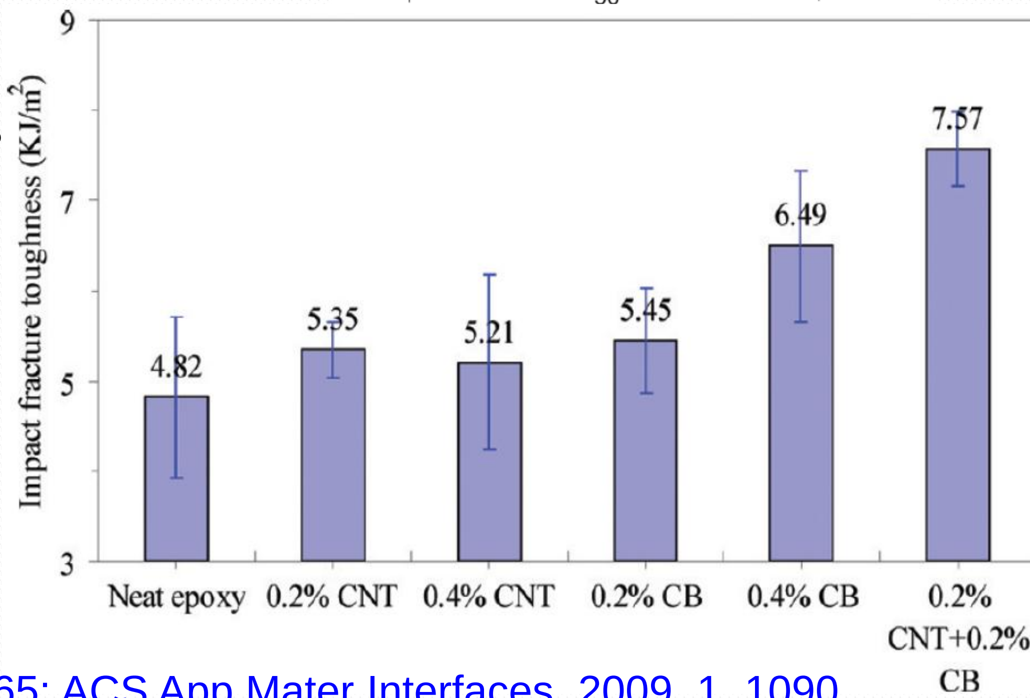


Compact Tension test





Charpy impact test



Ma, et al. Compos Sci Technol, 2007, 67, 2965; ACS App Mater Interfaces, 2009, 1, 1090

Multi-functionality of CNTs in Polymer (I) – Mechanical Reinforcement

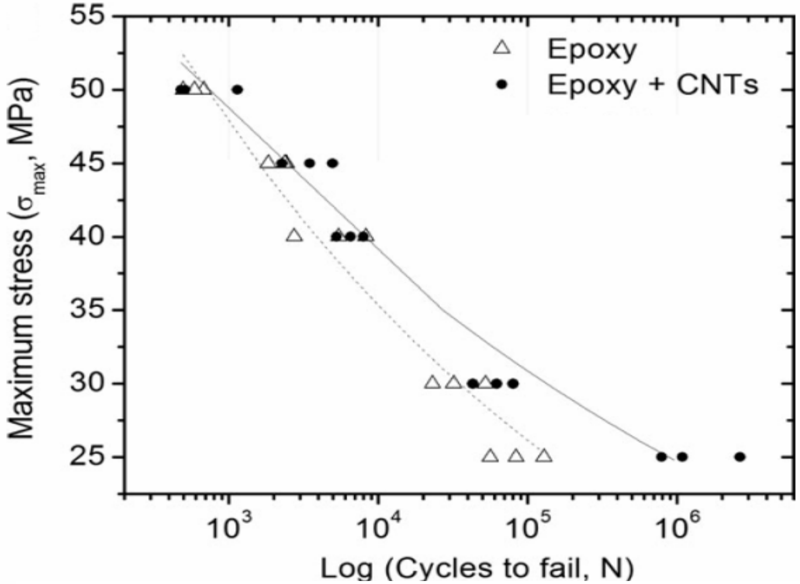
Matrix		CNT content	Enhancement on mechanical properties*		
			Modulus (%)	Strength (%)	Toughness (%)
Thermo-plastic	PA	1.0 wt.%	6.1 (42)	−5.3 (18)	–
	PB	1.5 wt.%	18 (91)	−27 (61)	−40 (67)
	PE	1.5 wt.%	22 (75)	−17 (33)	−69 (61)
	PI	7.0 wt.%	39 (61)	19 (31)	–
	PP	1.5 wt.%	55 (84)	−10 (13)	–
	PS	0.25 wt.%	−8.3 (25)	2.1 (50)	–
	PVA	2.5 wt.%	35 (40)	−4.8 (17)	–
	PMMA	0.10 wt.%	57 (104)	−2.7 (86)	–
Thermo-set	EP	0.10 wt.%	2.1 (6.7)	−2.2 (3.1)	17 (19)
		0.25 wt.%	8.6 (24)	6.8 (20)	35 (60)
		0.25 wt.%	8.7 (22)	3.6 (18)	−22 (8.5)
	PU	0.7 wt.%	48 (178)	27 (23)	–
		10 wt.%	340 (500)	51 (111)	–
	VR	25 phr	444 (594)	175 (244)	–
		1 phr	35 (28)	−7.8 (25)	–

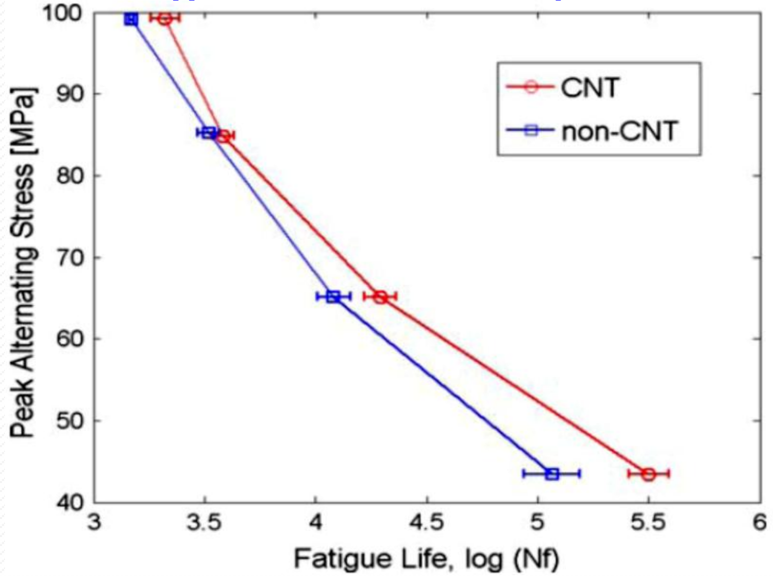
Data in bracket: Enhancement by employing functionalized CNTs

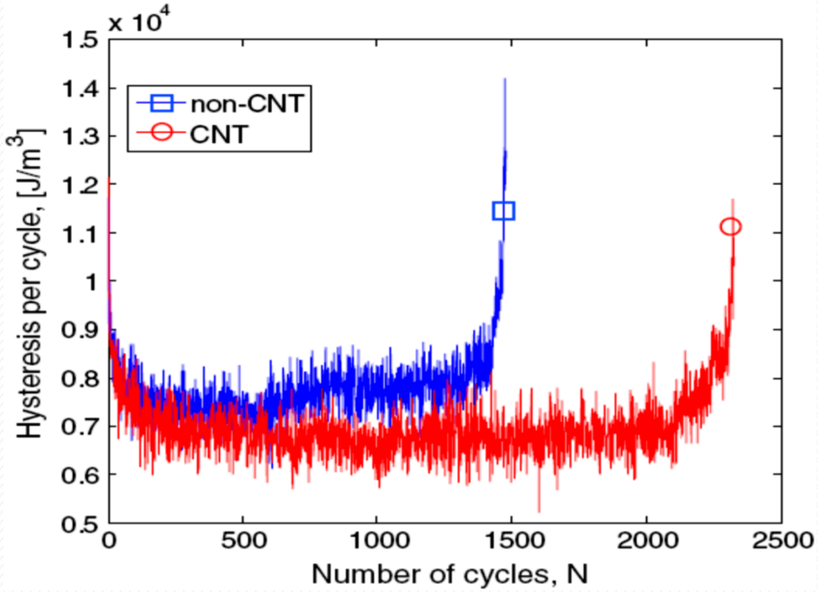
Ma, et al. Compos A, 2010, 41, 1345

Multi-functionality of CNTs in Polymer (I)
– Mechanical Reinforcement

➢ **Fatigue properties**: Cumulative damages due to the cyclic loading







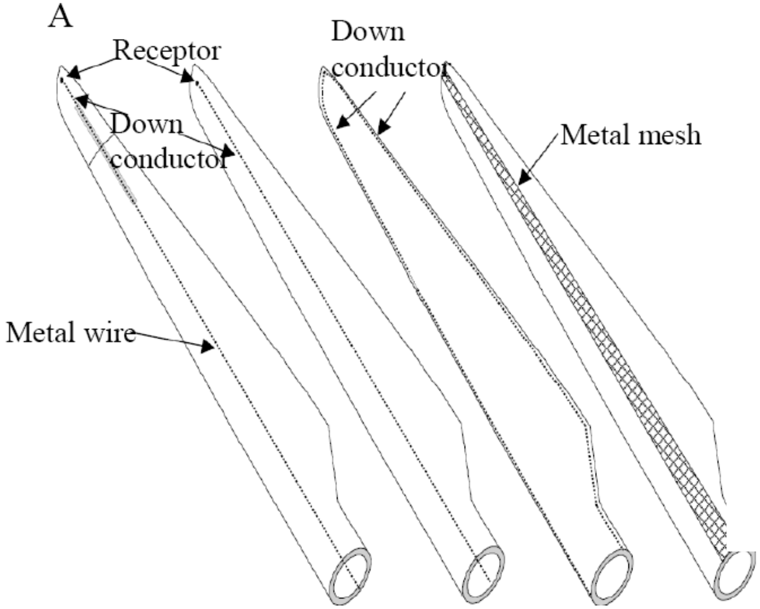
➢ **CNTs inhibit the formation of cracks:** A large density of nucleation sites by CNTs

➢ Contribution from the **fracture of CNTs** bridging across nanoscale cracks and **CNT pull-out** from polymer matrix

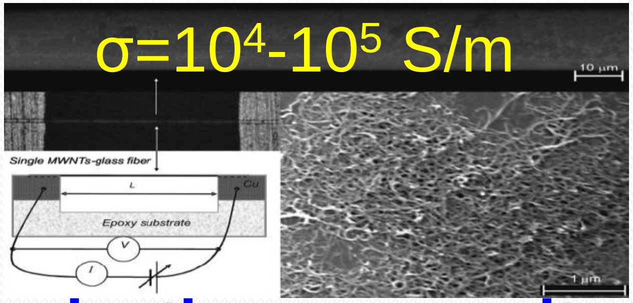
Grimmer, et al. J Mater Sci 2008, 43, 4487;
Loos, et al. Polym Eng Sci 2012, 52, 1882;
Ma, et al. Renew Sust Energ Rev, 2014, 30, 651

Multi-functionality of CNTs in Polymer (II)
– Electrical Conductor

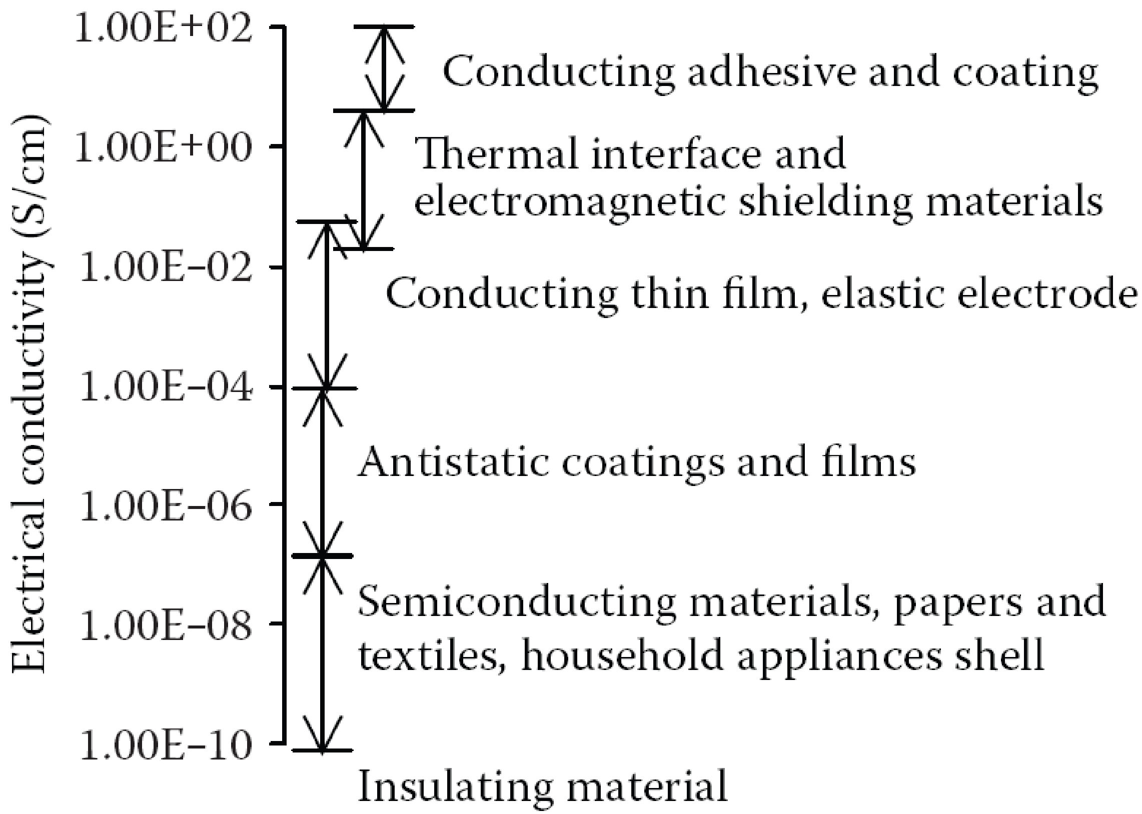
- Lightning strike to blades



- CNTs on glass fibre



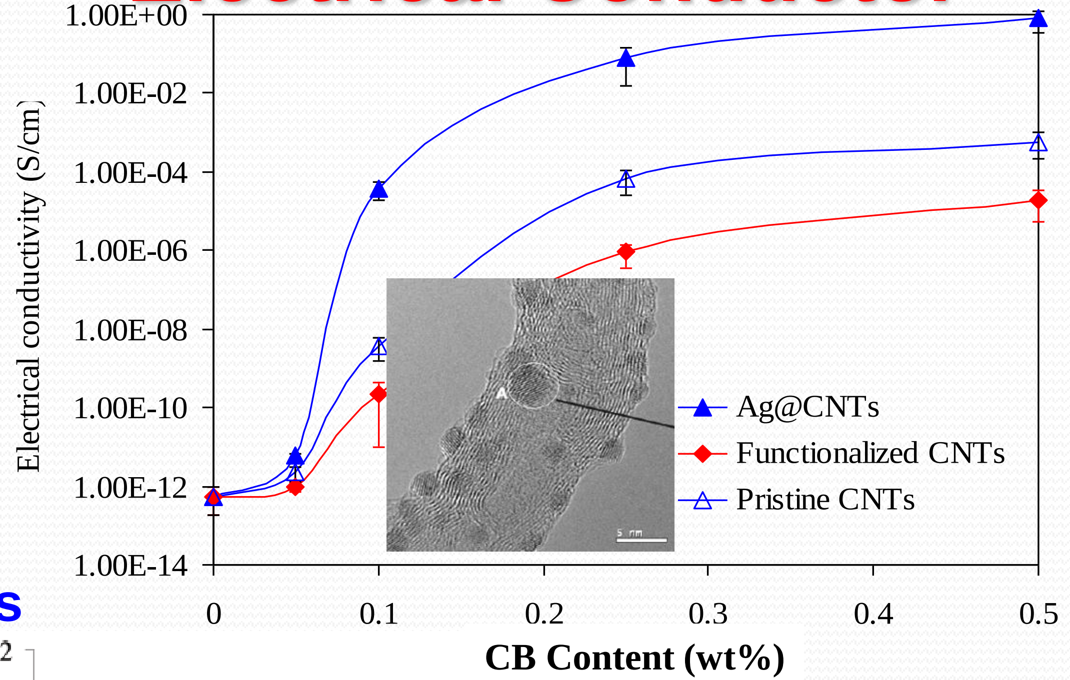
- Application of conducting composites



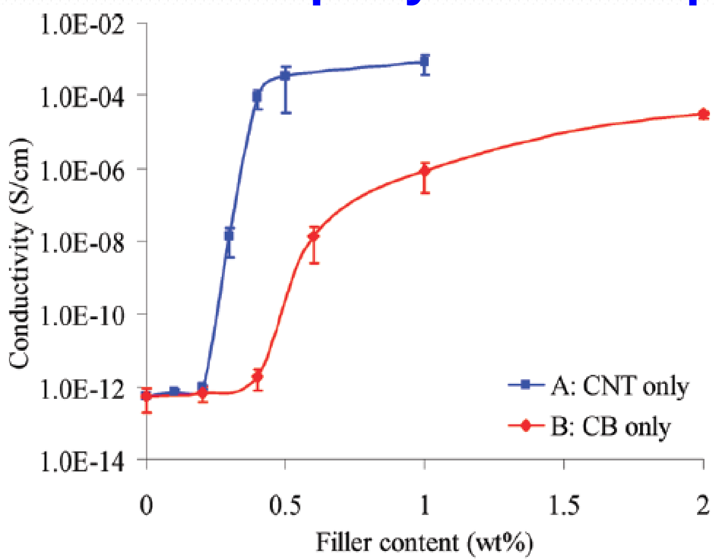
Ma, et al. CNTs for polymer reinforcement, CRC Press.

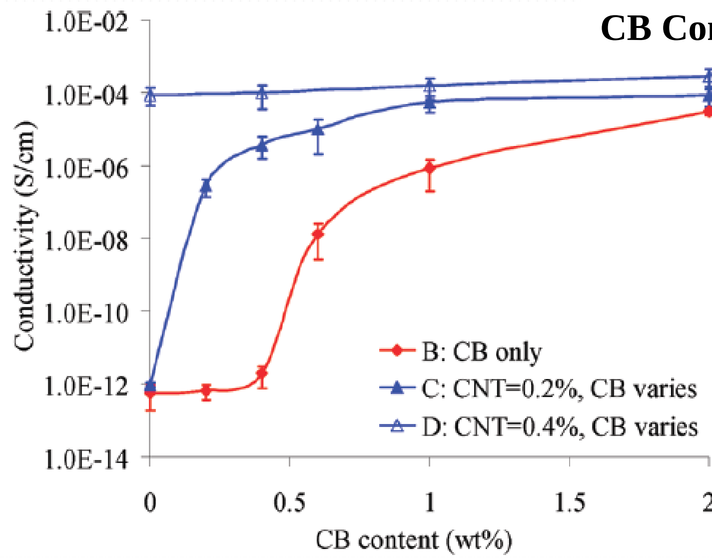
Multi-functionality of CNTs in Polymer (II) – Electrical Conductor

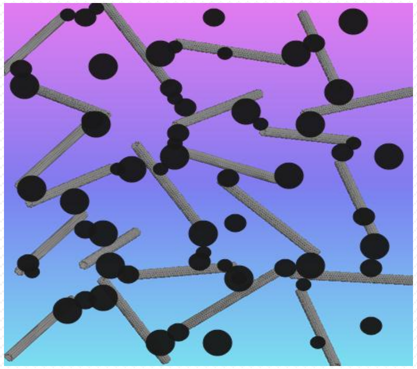
- **CNT/Epoxy Nanocomposites**
  -- Transition from the insulator to conductor;
  -- More pronounced increase in conductivity for Ag@CNT nanocomposites: From 2.2×10^{-13} to 0.81 S/cm (CNT=0.50 wt%).



- **Synergistic effect in CNT/CB/Epoxy nanocomposites**







Ma, et al. Carbon, 2008, 46, 1497; ACS App Mater Interfaces, 2009, 1, 1090

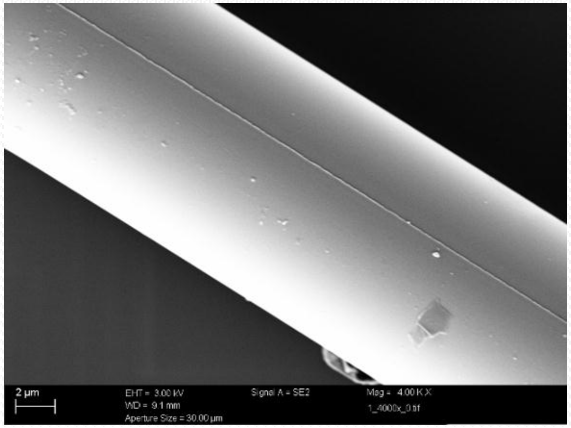
Multi-functionality of CNTs in Polymer (III) – Functional Coating for Fibres

➢ Problem of glass fibre used in FRPs

-- Lower strength than the theoretical prediction

-- Small defects in surface scratches, cracks and internal flaws

-- Environmental stability: -Si-O-Si- structure, chemical and humidity affected

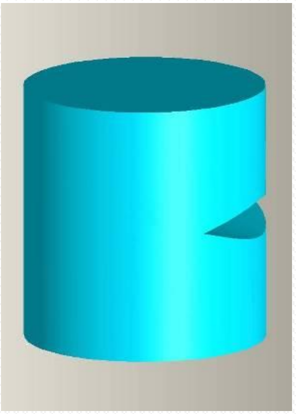


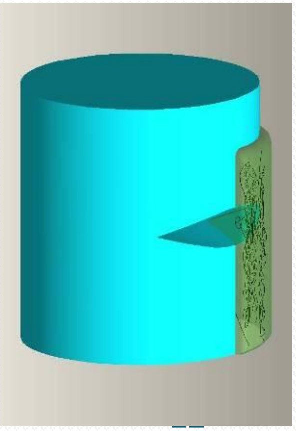
➢ CNT/Polymer Nanocomposite coating for fibres

-- **Healing** of fibre surface

-- **Multi-functional** glass fibres

-- **Role of nanocomposites** in properties of glass fibres





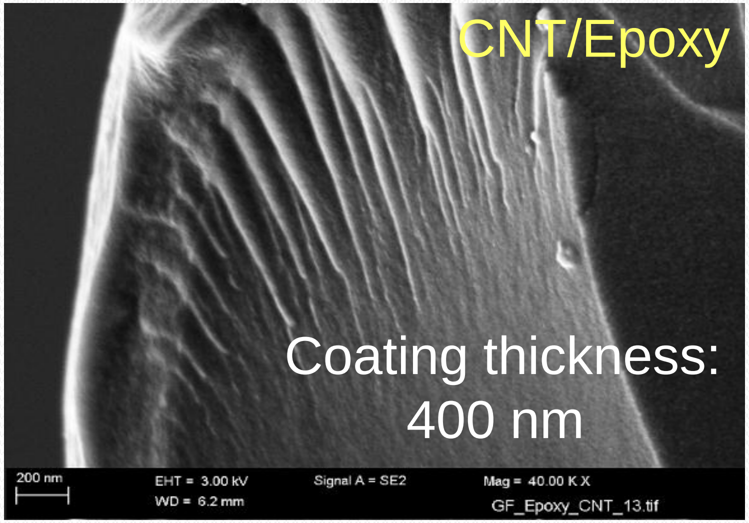
➢ How & Why?

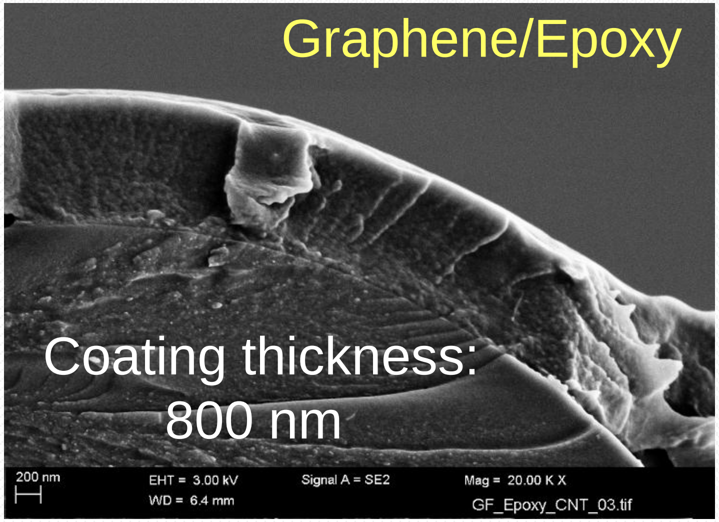
-- **Polymer**: Fill the micro-cracks on fibre surface

-- **CNTs**: Bridge and resist the opening of cracks

Multi-functionality of CNTs in Polymer (III)
– Functional Coating for Fibres

➢ Fibres with nanocomposites coating

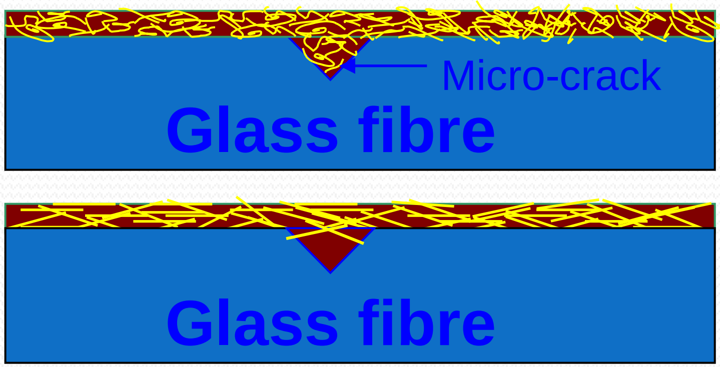




➢ Mechanical properties of Fibres

Coating	Strength (MPa)	Weibull modulus
No coating	2094±299	6.29
Epoxy	2231±238	6.45
CNT/epoxy	**2404±310**	**8.43**
Graphene/epoxy	2289±380	6.98

➢ Mechanism



Healing of glass fibre:

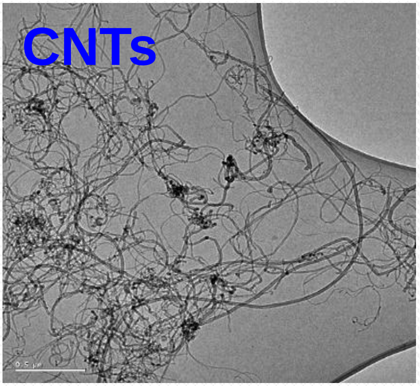
CNT > Graphene

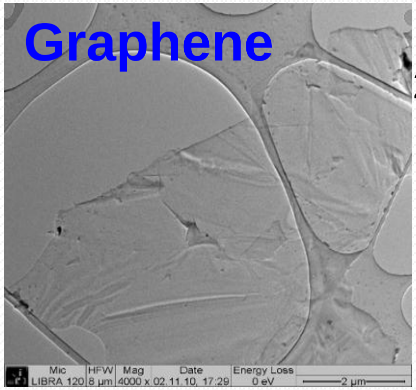
Ma, et al. Compos A, 2013, 44, 16

Multi-functionality of CNTs in Polymer (III) – Functional Coating for Fibres

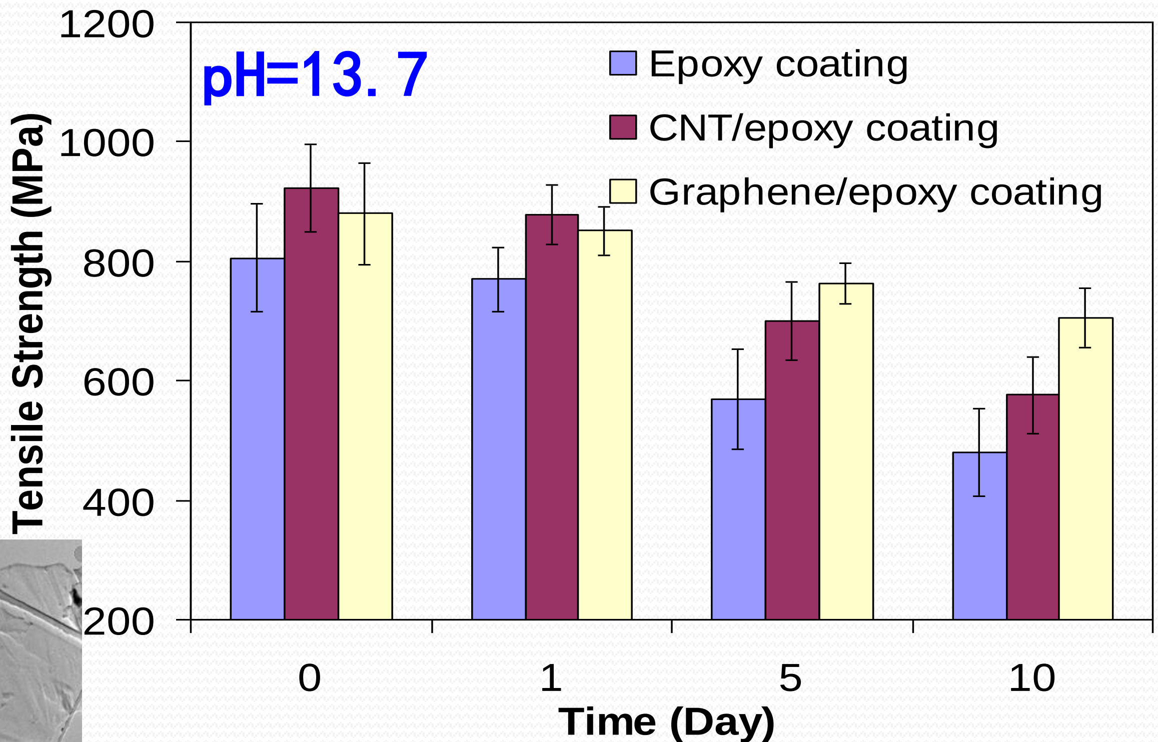
➢ **Offshore wind turbine**

Materials with improved resistance to humidity & salts





➢ **Barrier performance of fibres to humidity and alkali**



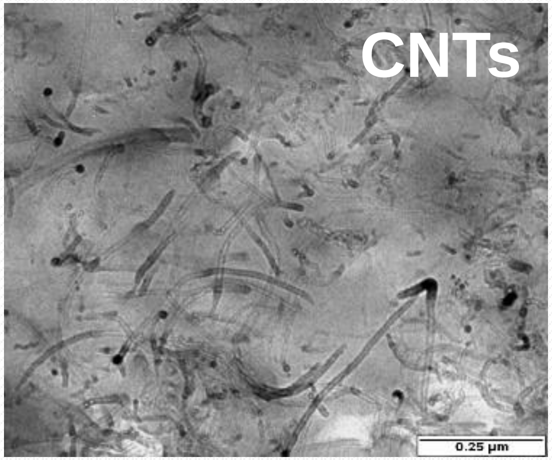
Ma, et al. Compos A, 2013, 44, 16

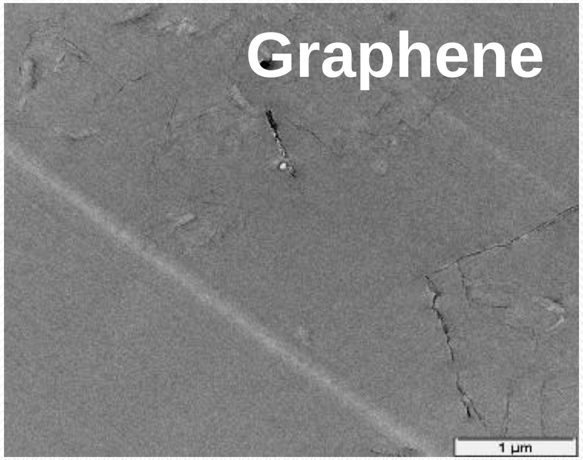
Multi-functionality of CNTs in Polymer (III)
– Functional Coating for Fibres

➢ Conducting glass fibres with coating

Coating	Measured length 5 mm	Measured length 5 mm	Measured length 5 mm
Epoxy	> 1000 MΩ	> 1000 MΩ	> 1000 MΩ
CNT/epoxy	10-100 MΩ	100-800 MΩ	100-800 MΩ
Graphene/epoxy	**10-100 KΩ**	**100-500 KΩ**	**500-1000 KΩ**

➢ Distribution of nanofillers in coating



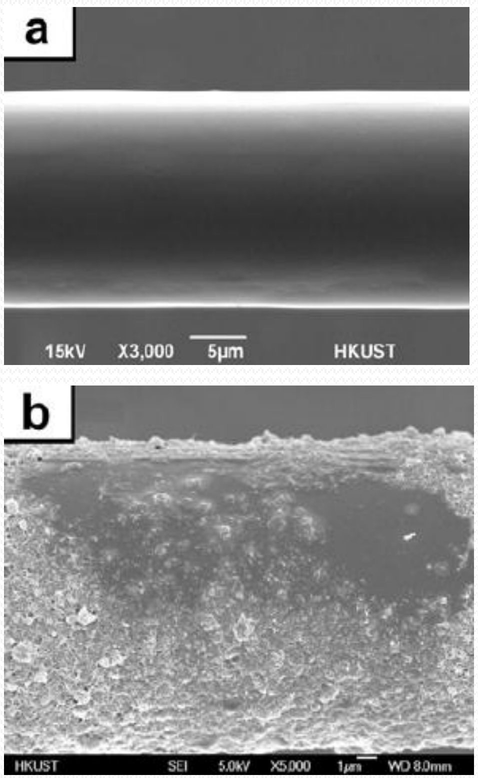


Mechanical induced
Graphene Alignment
in nanocomposites coating

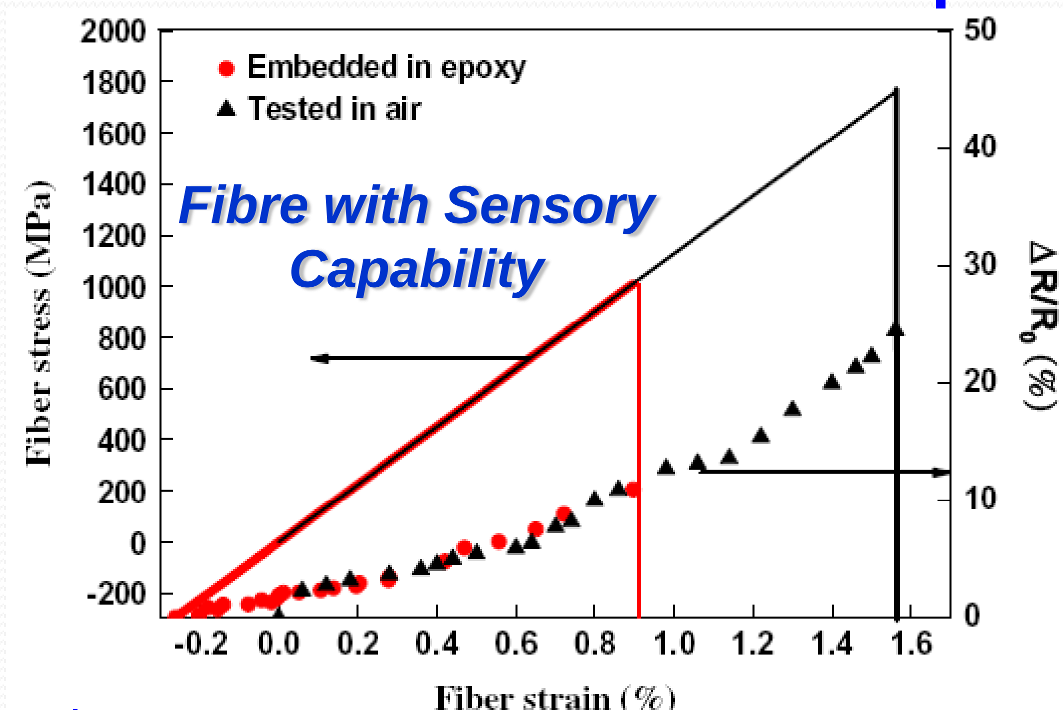
Ma, et al. Compos A, 2013, 44, 16

Multi-functionality of CNTs in Polymer (IV)
– Damage Sensor for FRPs

- **Specific discrete build-up** makes maintenance and damage analysis of FRPs a challenging task.
- **Advanced warning of defects** in composites using CNT-coated glass fibres
- **Fibres without/with CNT coating**



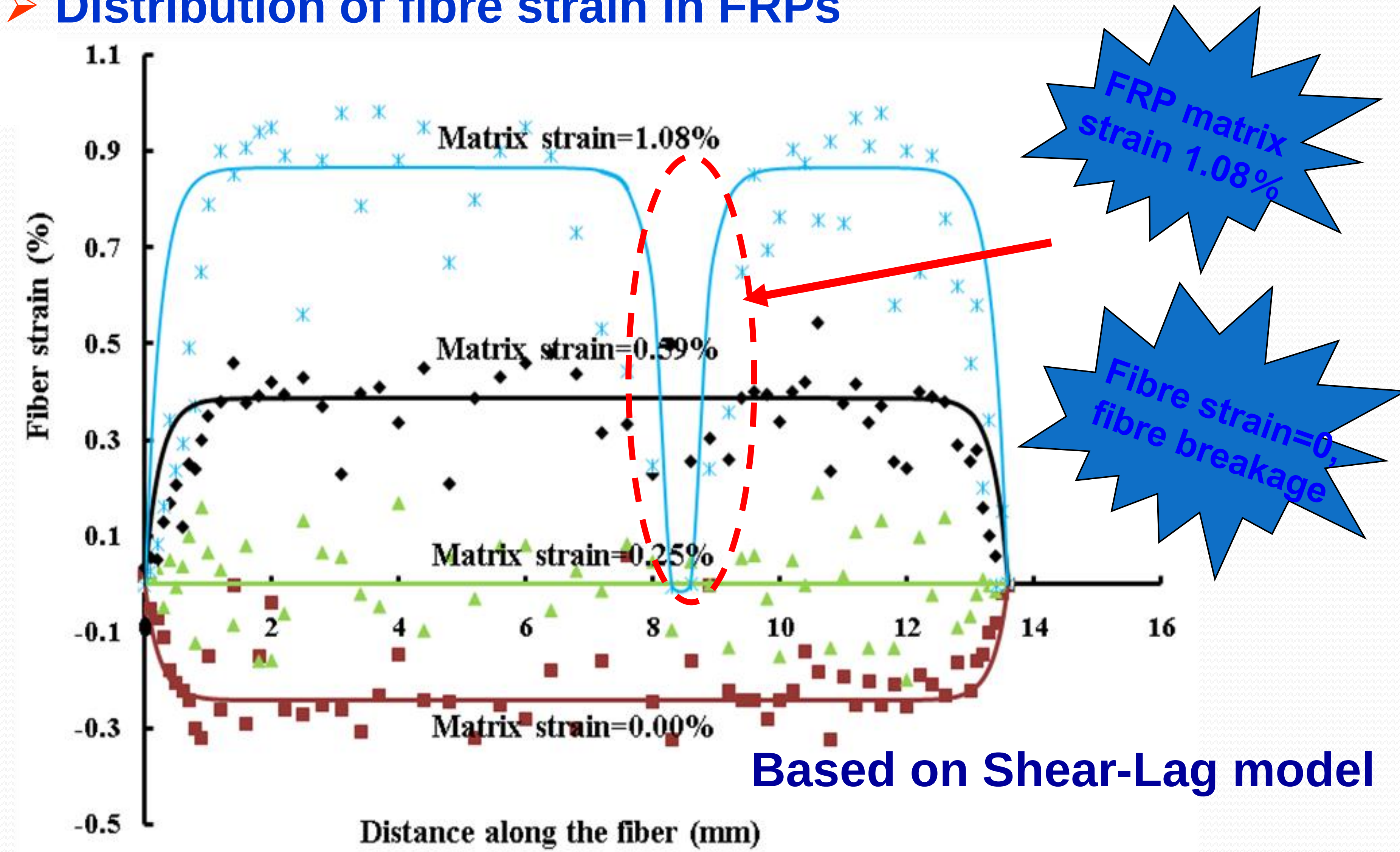
- **Fibre strain-stress-electrical response**



Liu, Ma, et al. Compos Sci Technol, 2012, 72, 1548

Multi-functionality of CNTs in Polymer (IV) – Damage Sensor for FRPs

- **Distribution of fibre strain in FRPs**

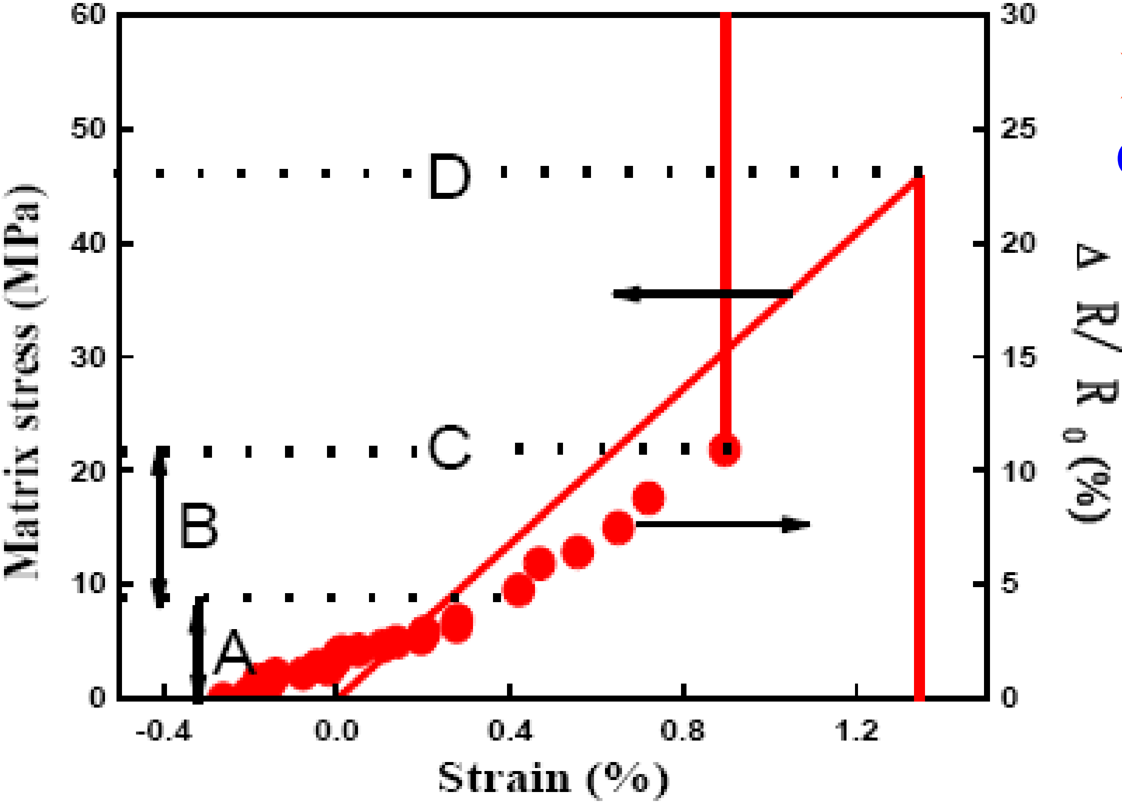


Based on Shear-Lag model

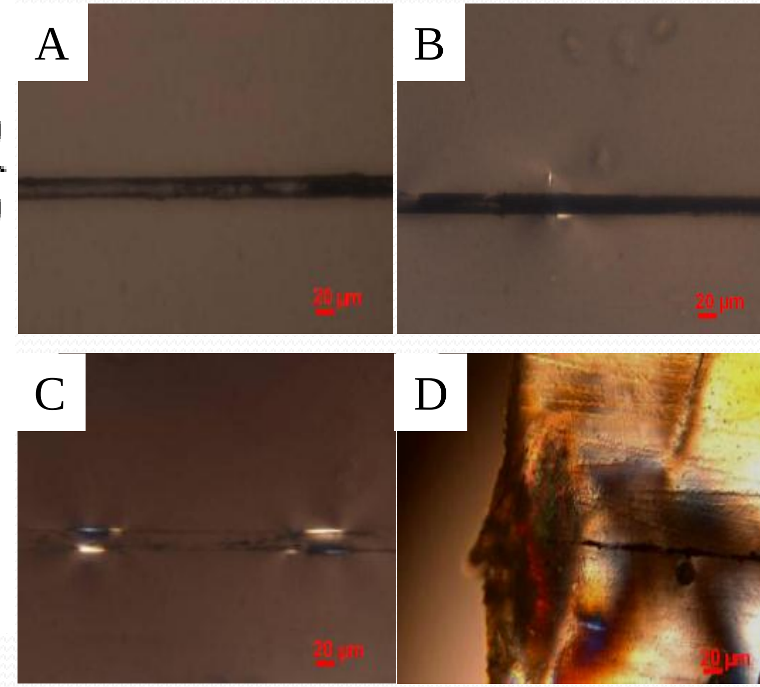
Liu, Ma, et al. Compos Sci Technol, 2012, 72, 1548

Multi-functionality of CNTs in Polymer (IV) – Damage Sensor for FRPs

➢ **Matrix stress-strain-fibre resistance**



➢ **Birefringence patterns of fibre in FRPs**



Earlier fibre breakage than matrix failure: Warning of damage process in FRPs

Liu, Ma, et al. Compos Sci Technol, 2012, 72, 1548

Summary

- **CNTs**

  -- Multi-functional modifier for FRP components:

  -- Polymer matrix: Improved mechanical, electrical, damping properties

  -- Fibre: Surface healing and sensory capability

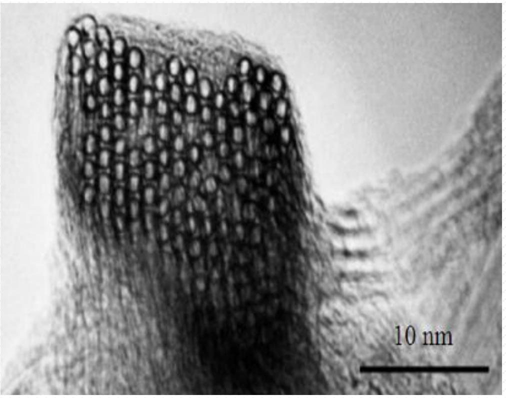
- **Challenges**

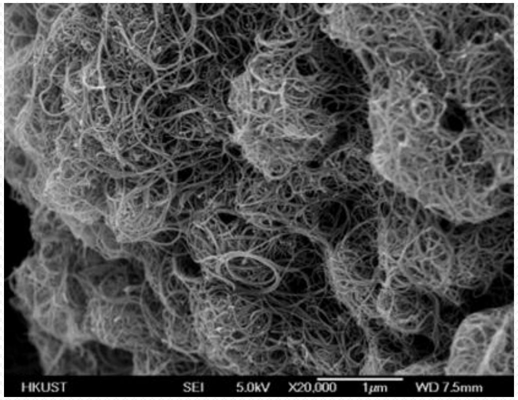
  -- Dispersion

  -- Functionalization

  -- Cost: ~ 2 US$/g

  -- FRP processing

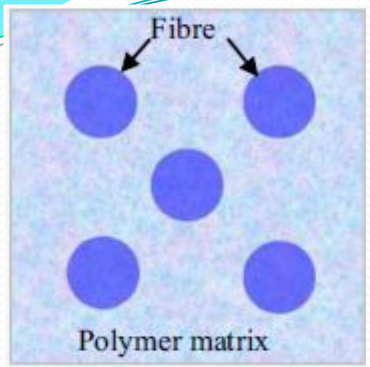


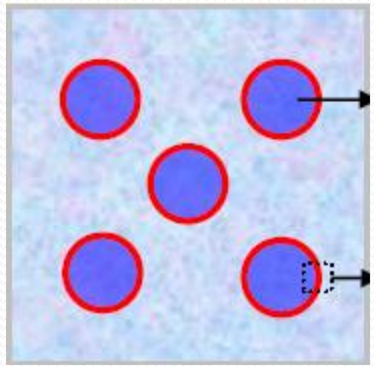


Engineering Applications of CNT/Polymer Nanocomposites

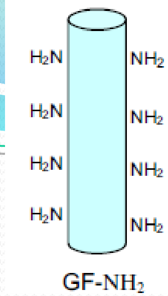
Sensory Materials for Defect Monitoring in FRPs

Introduction



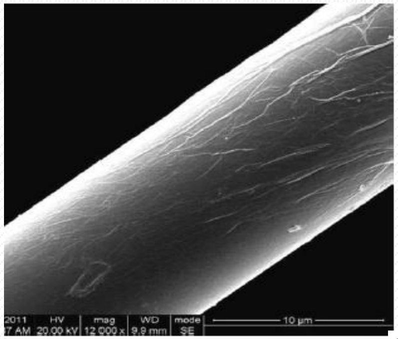


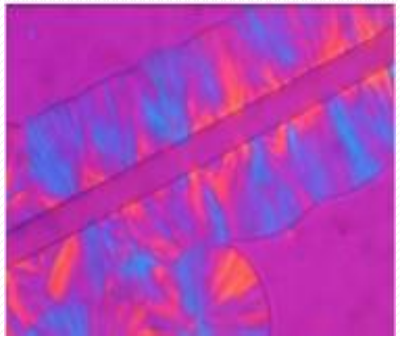
Modification

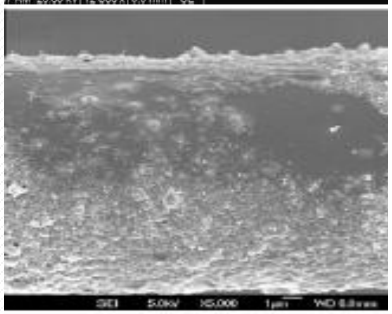


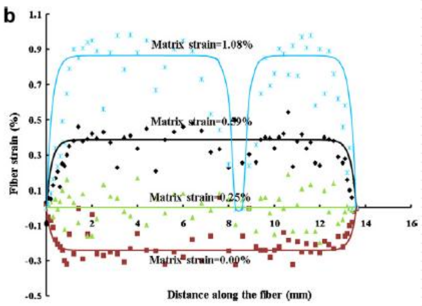
Bonding between fibre and matrix

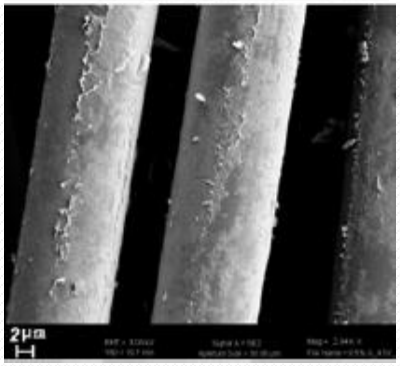
Key role of interphase

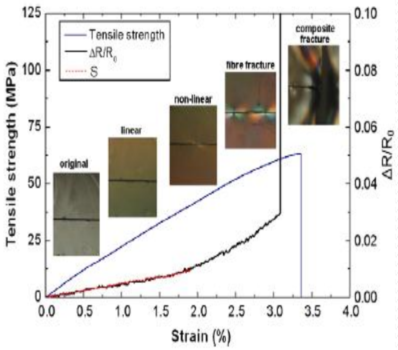












Much investigation in the interphase of GFRP: interfacial strength, other functions by CNT and Graphene.

CNT: 1 Dimension

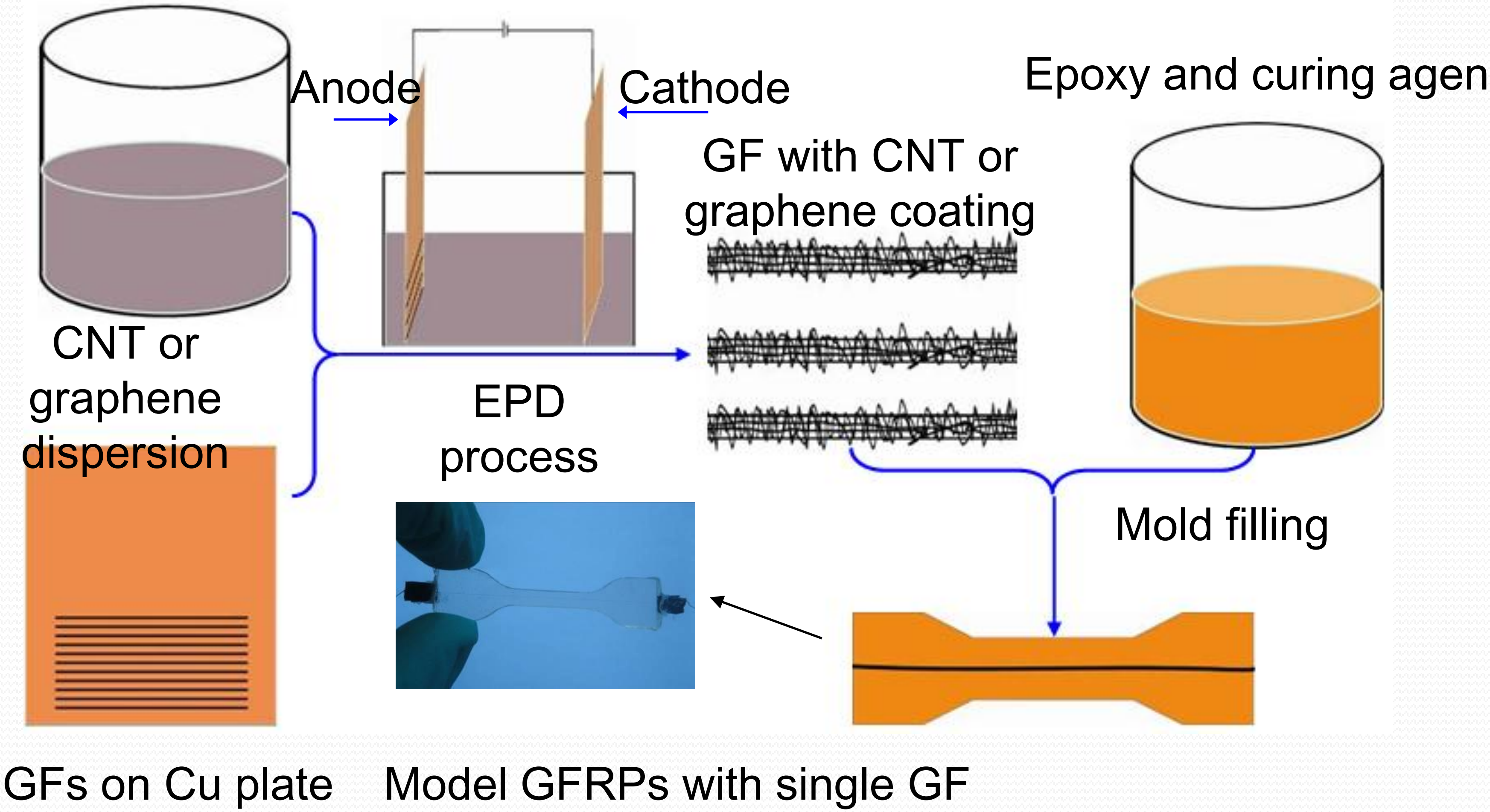
Graphene: 2 Dimension

The comparison between graphene coating and CNT coating

Zhang J, Carbon, 2010

Ma PC, Renewable&Sustainable Energy Reviews, 2014

Experimental Setups



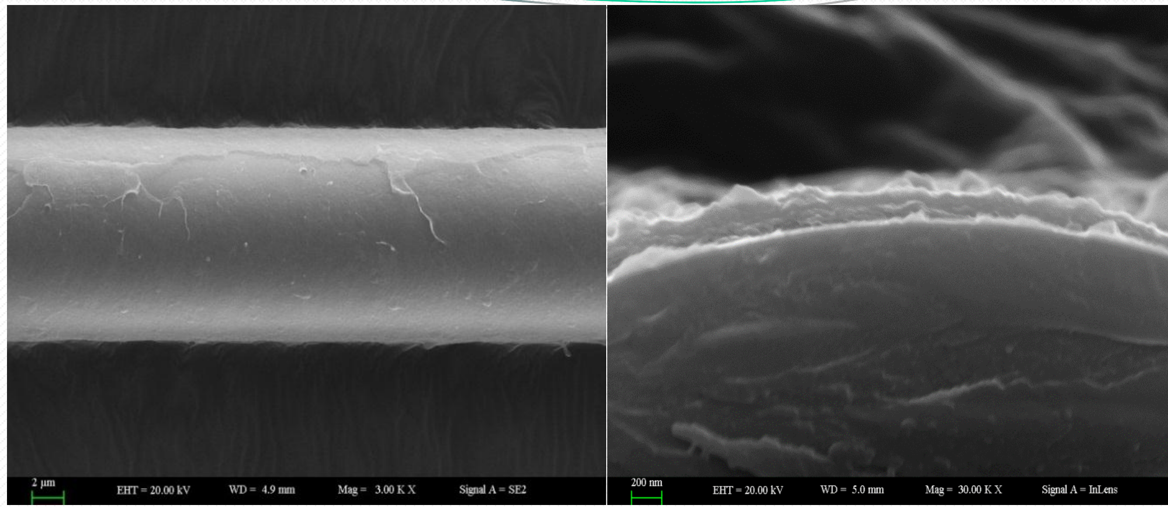
Process of Sample preparation

Results and Discussion

Graphene coating:

~ 10^2nm

10^{-2} ~ 10^{-1} Ω•cm

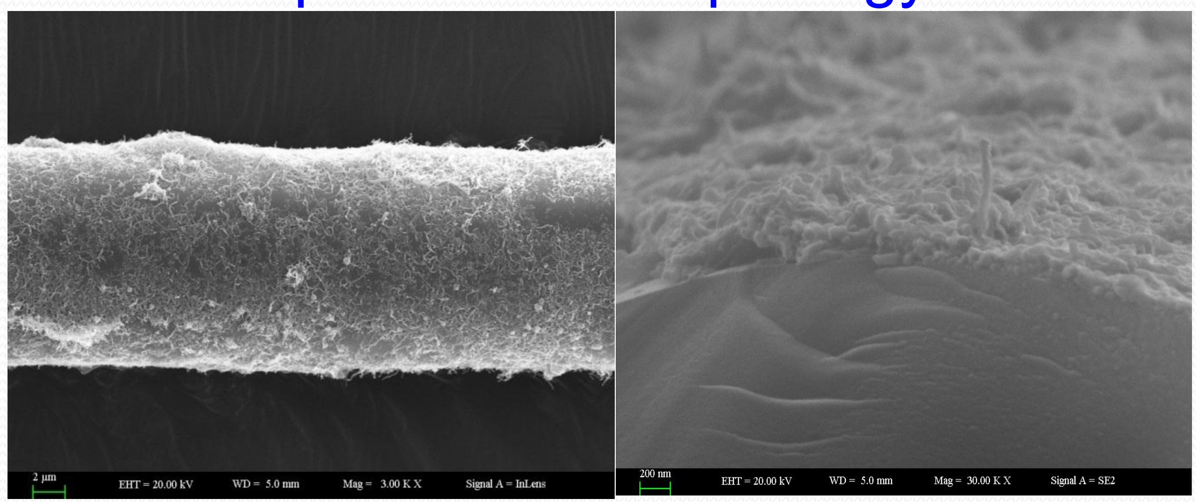


Graphene/GF morphology

CNT coating:

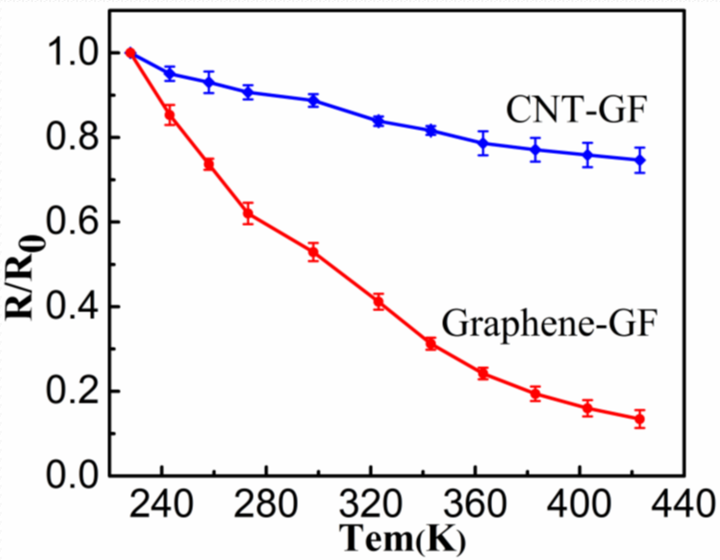
~ 10^2nm

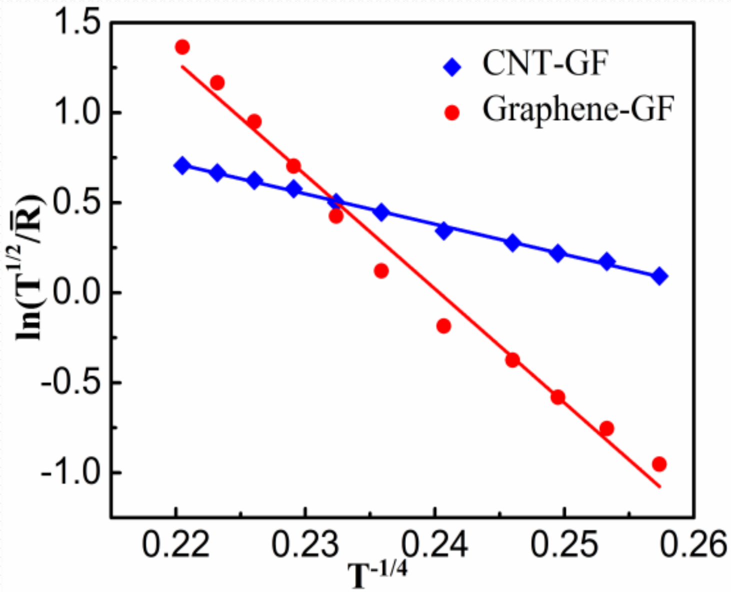
10^{-2}~10^{-1} Ω•cm



CNT/GF morphology

Results and Discussion





- ✓ Negative temperature coefficient (NTC)
- ✓ Change ratio

  Graphene/GF-80%, CNT/GF-20%

- ✓ Variable range hopping (VRH) model:

$$\ln(T^{1/2}/\overline{R}) \propto T^{-1/4}$$

- ✓ Hopping efficiency

  Graphene/GF: B=63.3; CNT/GF: B=16.8

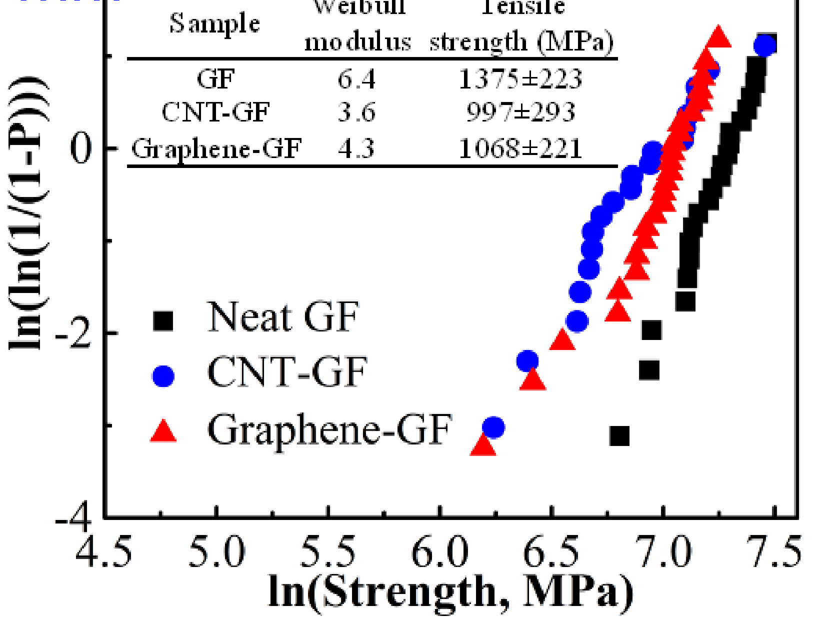
  Reason

- ✓ Structure difference

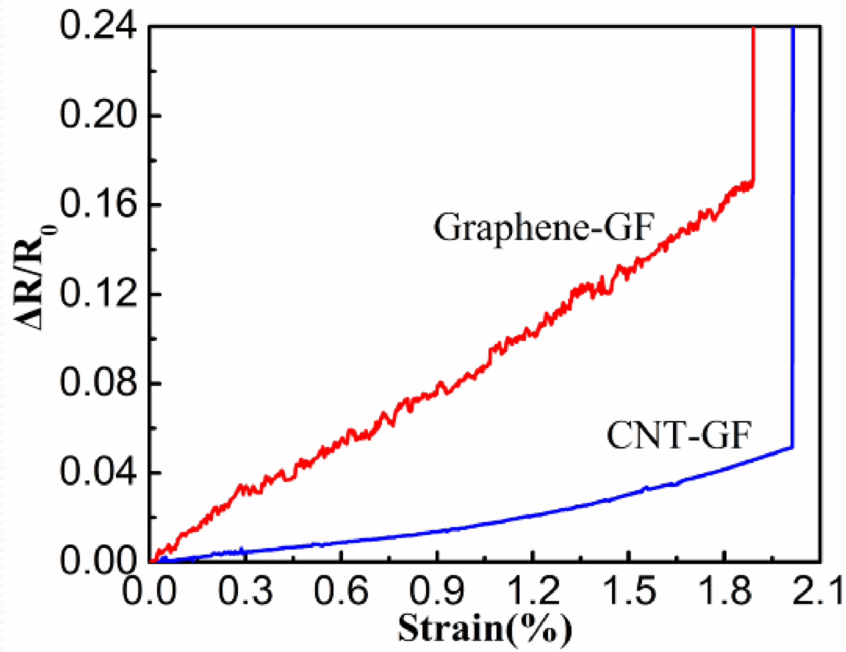
  Graphene/GF: More contacting area

Results and Discussion

-Tension rate – 0.5 mm/min, gauge length – 40 mm



Sample	Weibull modulus	Tensile strength (MPa)
GF	6.4	1375±223
CNT-GF	3.6	997±293
Graphene-GF	4.3	1068±221



Results:

- Lower tensile strength

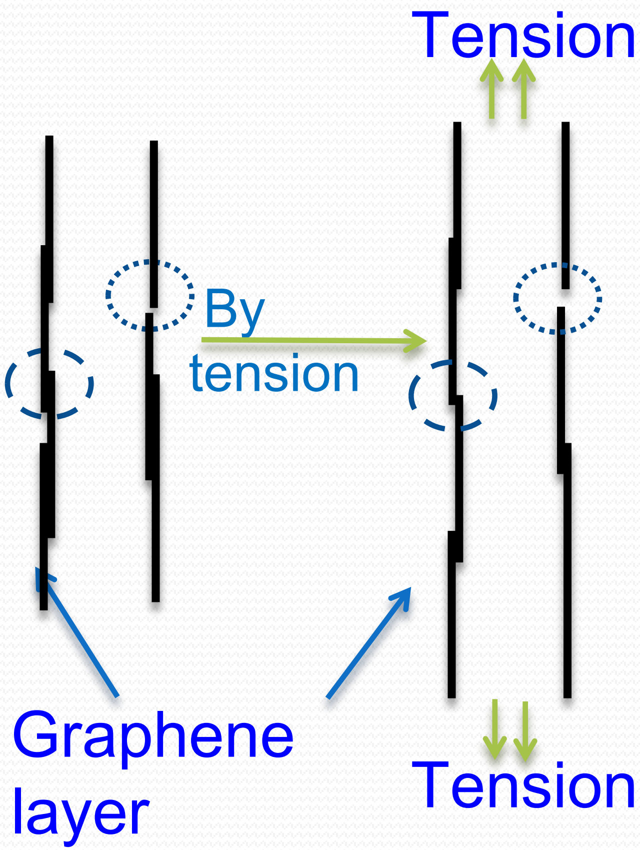
-Resistance increases with strain

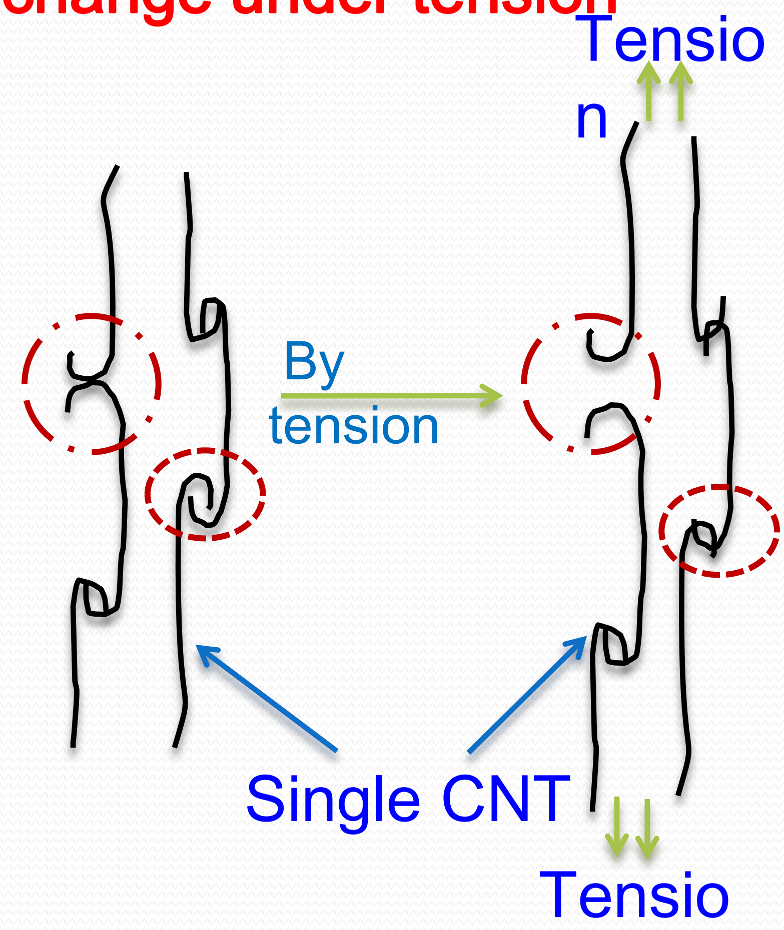
-Sensitity: Gauge factor $K = \frac{R(\varepsilon) - R_0}{R_0} / \varepsilon$

CNT/GF: 2.3±0.1, Graphene/GF: 9.5±0.4

Results and Discussion

Mechanism – Different structure change under tension



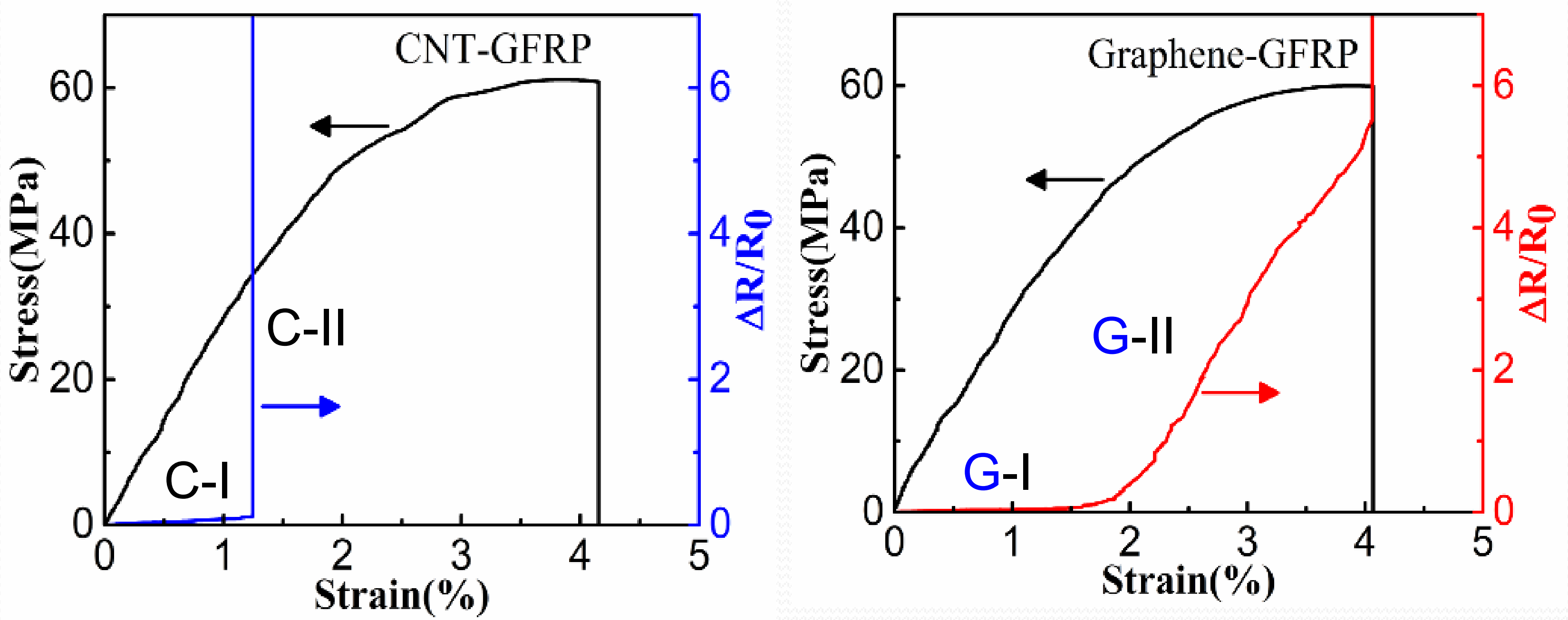


Graphene coating: contacted area was reduced under tension

CNTs coating: rebuilt of the conductive paths

Results and Discussion

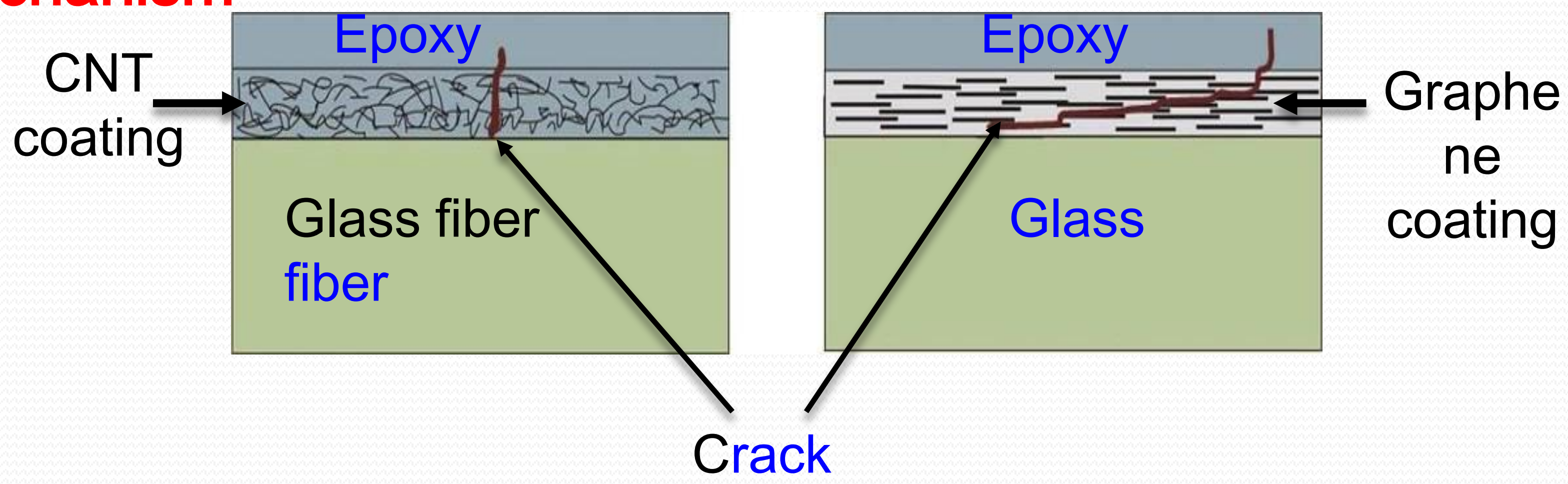
Model GFRP tension test



- ✓No change in tensile strength after combining with single fiber.
- ✓CNT-GFRP: non-conductive (Strain=1.3%) before breakage of matrix (4.2%)
- ✓Graphene-GFRP: resistance change in two different slope, remained conductive until break of matrix

Results and Discussion

Mechanism



Structure of coating in GFRP

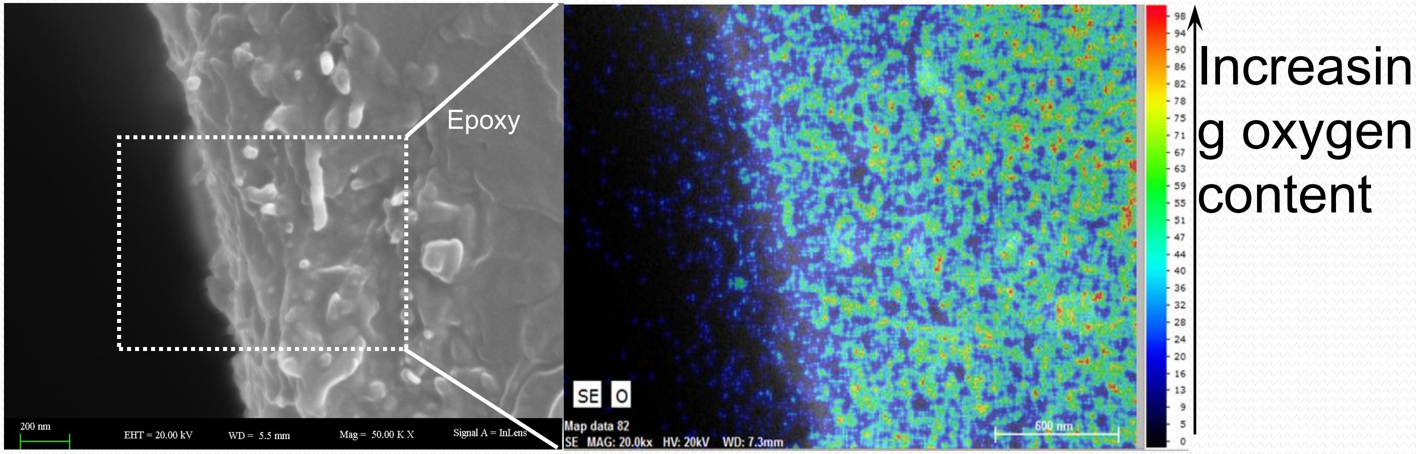
CNT-GFRP: nanocomposites made of epoxy and CNT

Graphene-GFRP: mainly made of Graphene layers

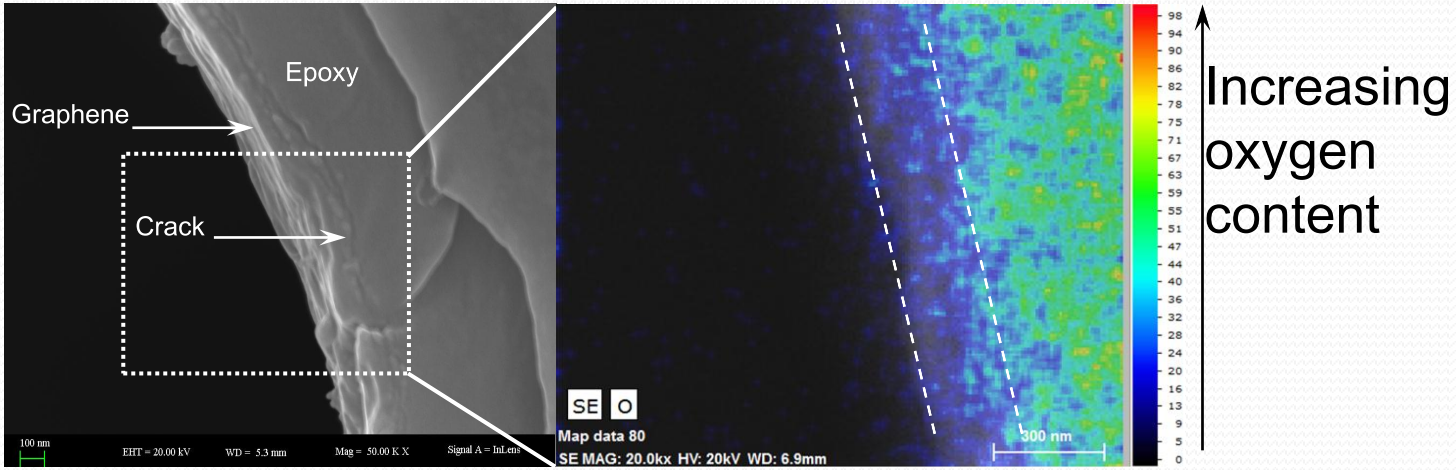
Different paths of crack

Different performance in resistance change

Results and Discussion



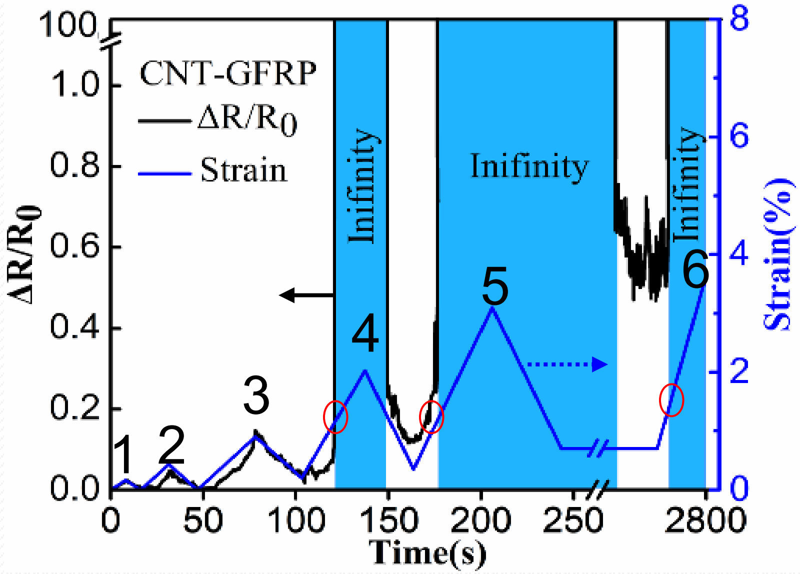
CNT-GFRP: nanocomposites made of epoxy and CNT

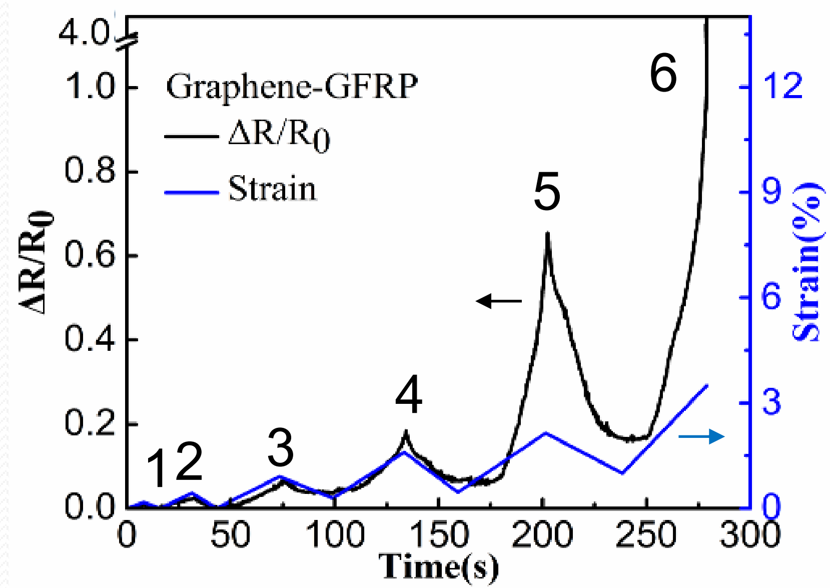


Graphene-GFRP: nanocomposites and Graphene layers

Results and Discussion

Piezoresistive responses of GFRPs under cyclic mechanical loadings





Stage 1, 2 (below 0.5%): reversible

Stage 3 (strain peak was 0.9%): irreversible

Stage 4 (strain peak was 2%):

Switch effect, starting strain =1.14%

Stage 5 (strain peak was 3.1%):

Delayed switch effect

Stage 6: Break of GFRP

Stage 1, 2 (below 0.5%):

reversible

Stage 3,4,5:

irreversible

Stage 6: Break of GFRP

Summary

- ✓ **Successful deposition of CNT or graphene on glass fibre**
- ✓ **Single fibre test:**

  Graphene-GF: more sensitive to T and tension
- ✓ **Different interphase structure in GFRP**

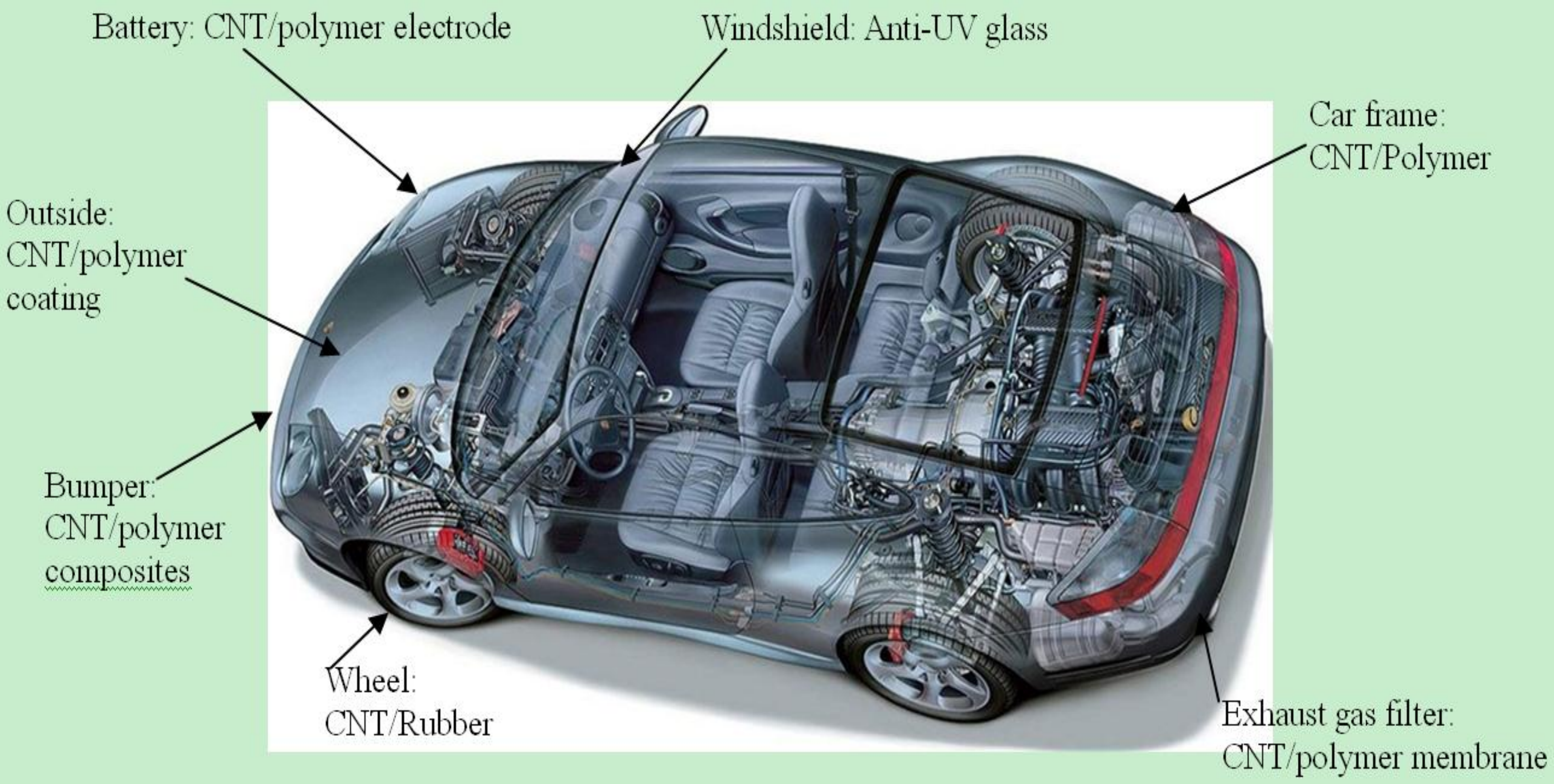
  Graphene-GFRP: mainly made of graphene layers

  CNT-GFRP: nanocomposites by CNT and matrix
- ✓ **Different piezoresistive responses**

  Graphene-GFRP: conductivity could be remained until break of matrix CNT-GFRP: nonconductivity before break of matrix

Other Engineering Applications of CNT/Polymer Nanocomposites (I)

- **Automobile Industry**



Ma, et al. CNTs for polymer reinforcement, CRC Press.

Other Engineering Applications of CNT/Polymer Nanocomposites (II)

Environmental Applications of (CNT)/Polymer Nanocomposites

Materials for Oil-water Separation

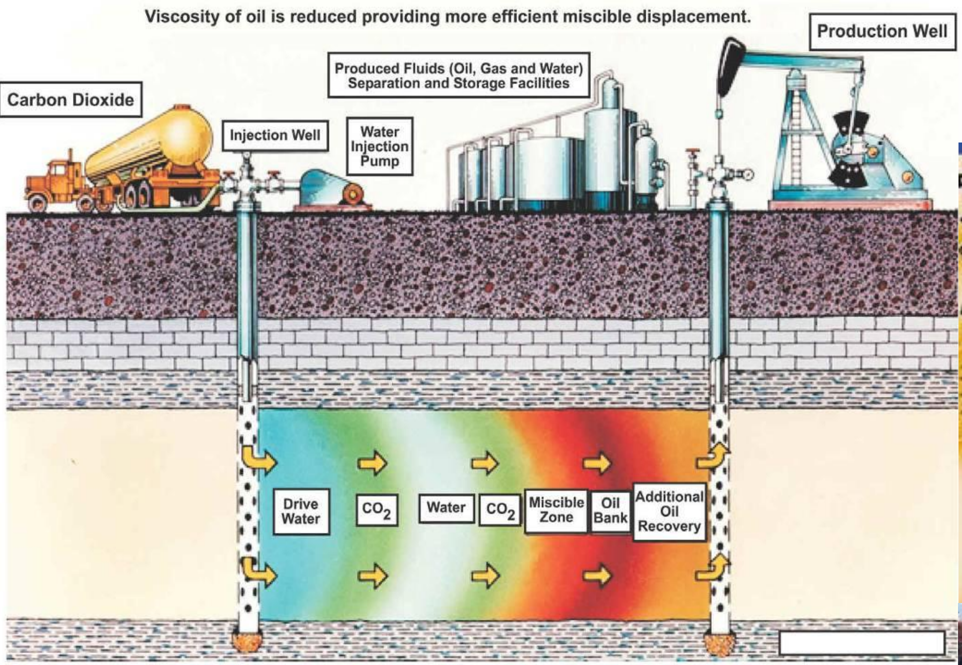
Where is Xinjiang?

Where is Xinjiang?

Oil-Field in Xinjiang

Oil-Water Separation

Enhanced Oil-Recovery Technique

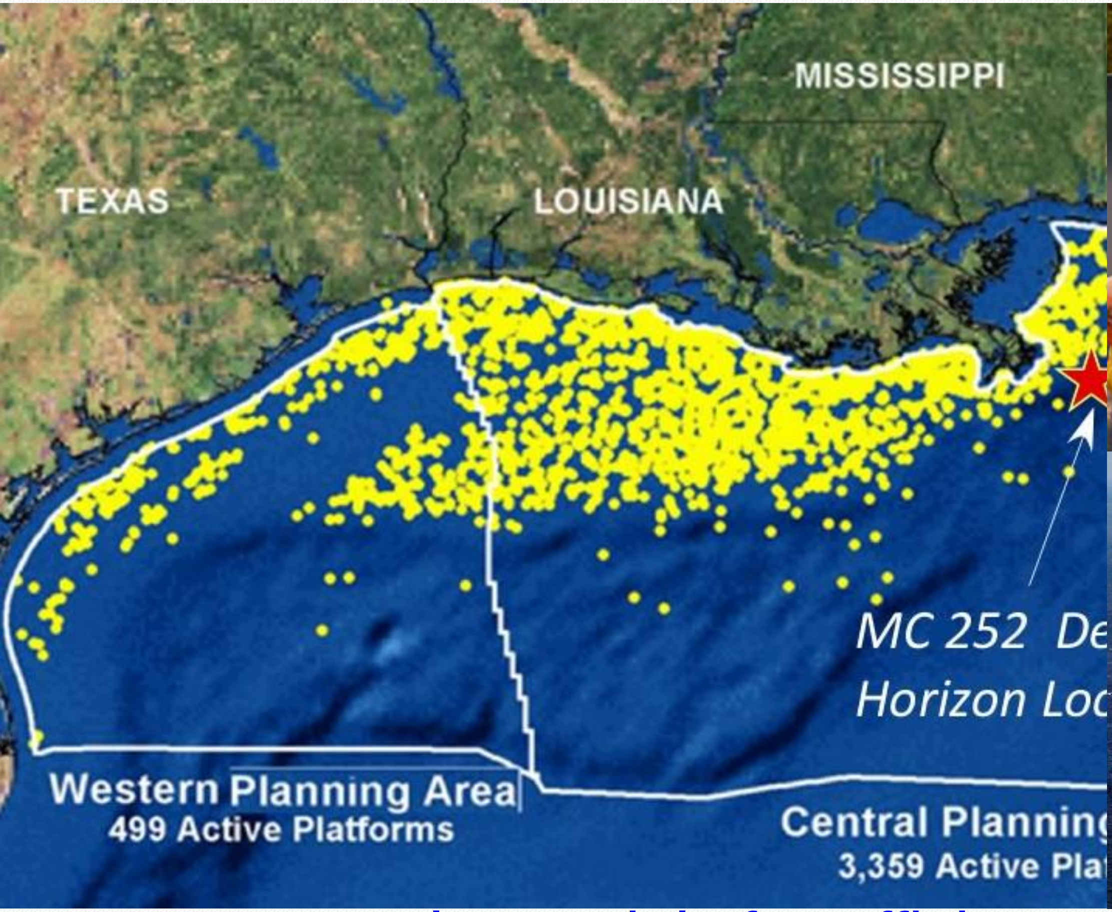


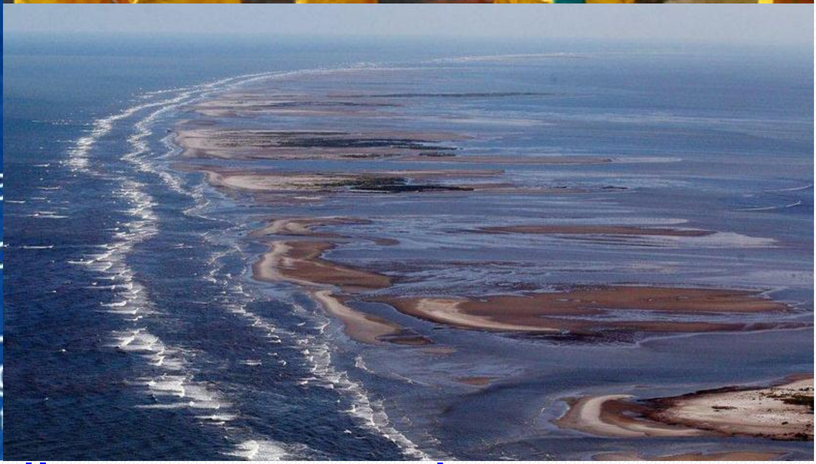
H_2O in oil fluid: >90%

Accidents by Oil Spillage & Chemical Leakage

Oil-Water Separation

Accidents by Oil Spillage & Chemical Leakage





Novel Materials for Efficient Oil-H_2O Separation:

Enhancement for Energy Production and

Protection for Environmental and Ecological Systems

Outline

- **Introduction**

  -- Materials for oil-water separation

  -- C-based nanomaterials

  -- Research objectives

- **Experiment and Results**

  -- Preparation (Materials, method…)

  -- Characterization (Morphology, surface chemistry…)

- **Application of Polymer Nanocomposites**

  -- Oil-water separation (Adsorption capacity, recyclibility…)

  -- Oil collector (Design, performance…)

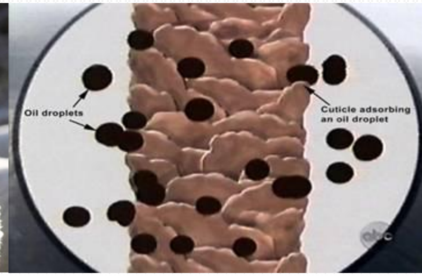
  -- Perspectives

- **Concluding Remarks**

Materials for Oil-H_2O Separation (I)

Traditional materials for Oil-Water Separation

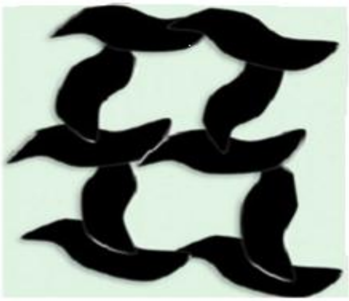
Parameter	***Natural materials (Wool, cotton…)***	***Inorganic materials (Clay, graphite…)***	***Polymers (Fibre, foam…)***
Adsorbate	Oil and water	Oily compounds	Oils & chemicals
Capacity (g/g)	< 10	5-10	> 10
Material cost	High	Low	Medium
Operation convenience	Hard (Fabrics)	Hard (Powders and particles)	Easy (Flexible)
Reusability	No	Yes	Yes
Dimension stability	Instable	Instable	stable
Regeneration of adsorbate	No	Yes	Yes

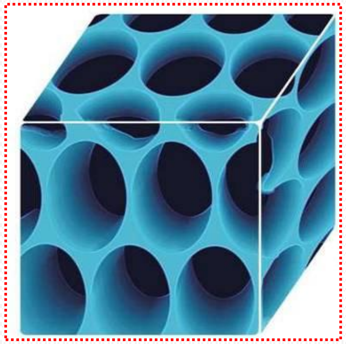


Materials for Oil-H_2O Separation (II)

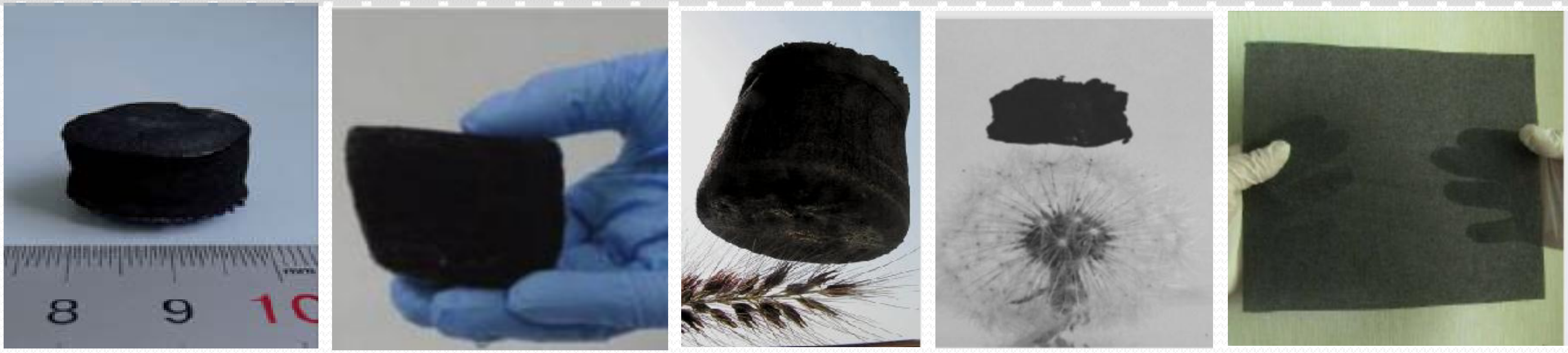
C-based nanomaterials (CNTs, CNFs, Graphene)



- Low density
- High porosity
- High surface area
- Processability



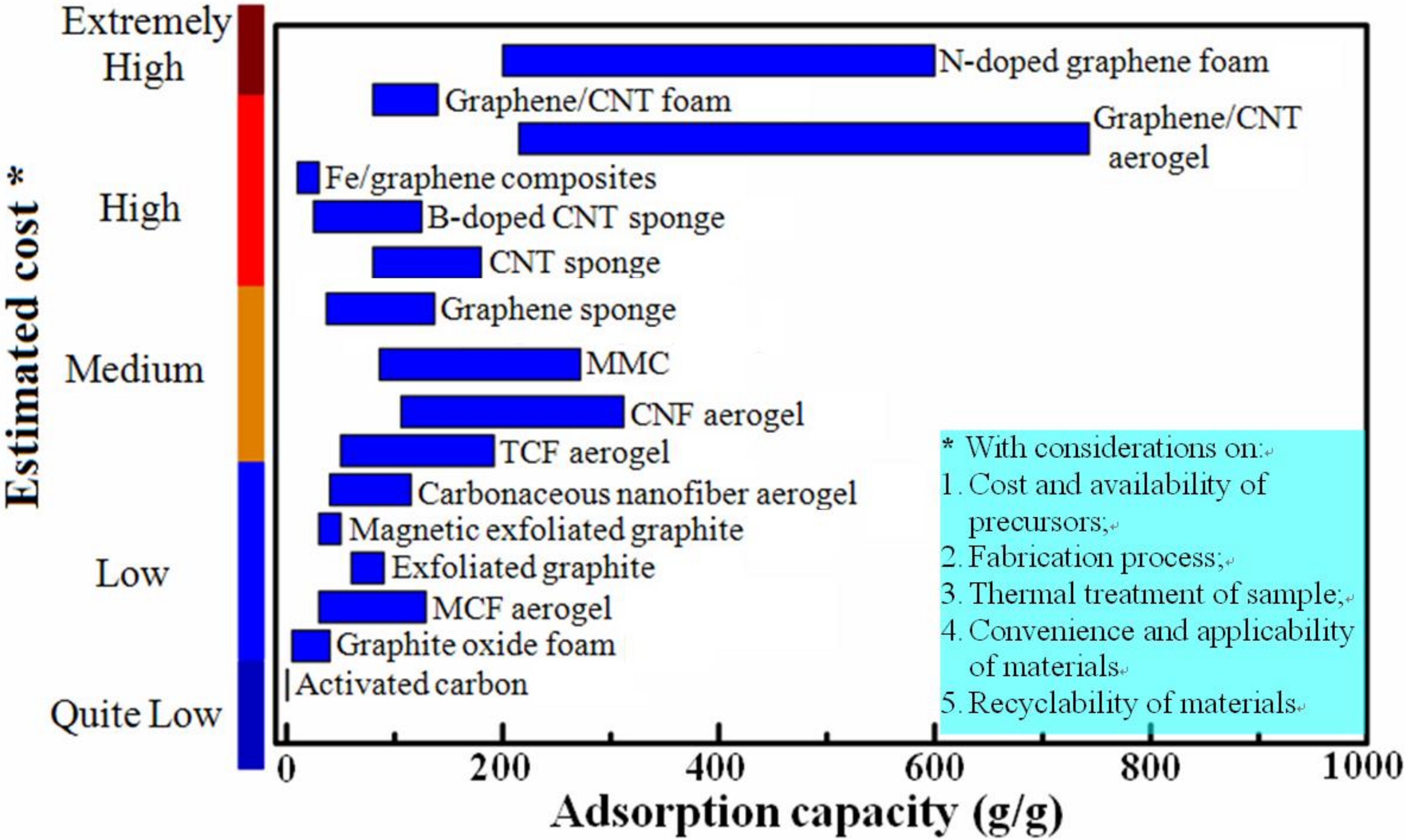
Inherent hydrophobic nature of carbon makes C-based nanomaterials ideal material for oil-water separation



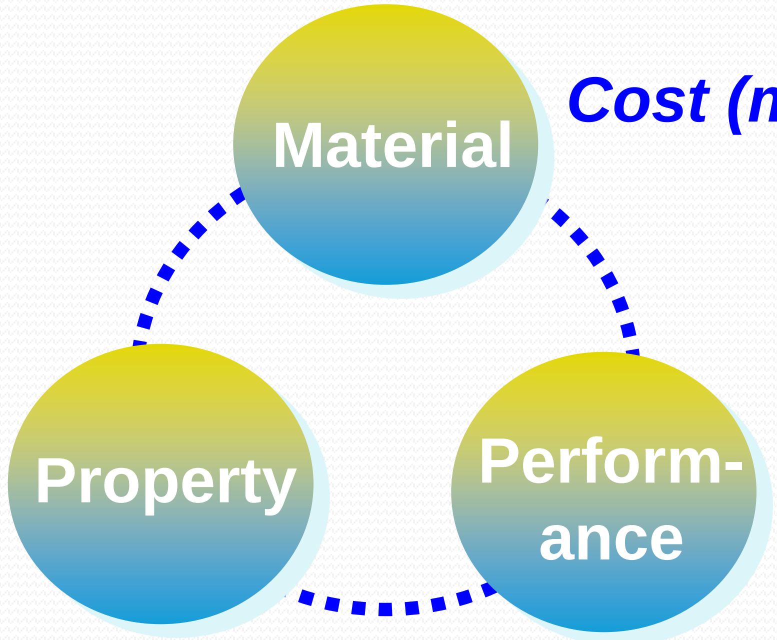
Foam, Sponge, Aerogel, Membrane…

Materials for Oil-H_2O Separation (III)

Adsorption Capacity of C-based Nanocomposites



Research Objectives



Cost (materials, preparation) & Scalability

Adsorption capacity & applicability

Stability & Recyclability

How?

-- Chemical modification for commercial available polymer foams

-- Changing on surface and structural properties of foams

-- Macro-, meso- and micro-pores for oil-H_2O separation

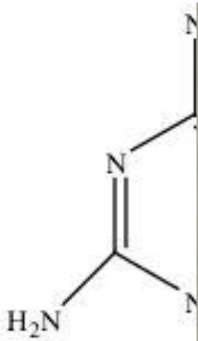
What?

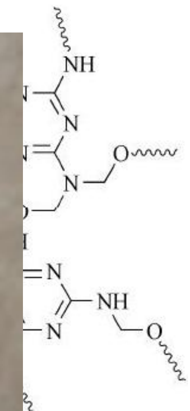
-- Polymer foams with nanocomposites coating

-- Oil collector using polymer nanocomposites as key components

Experimental Setups (I)

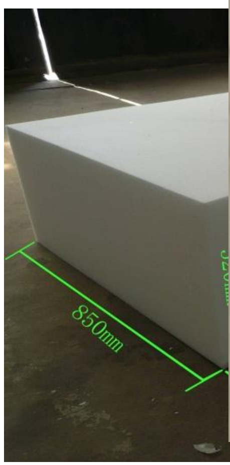
Material-- Melamine foam (MF)

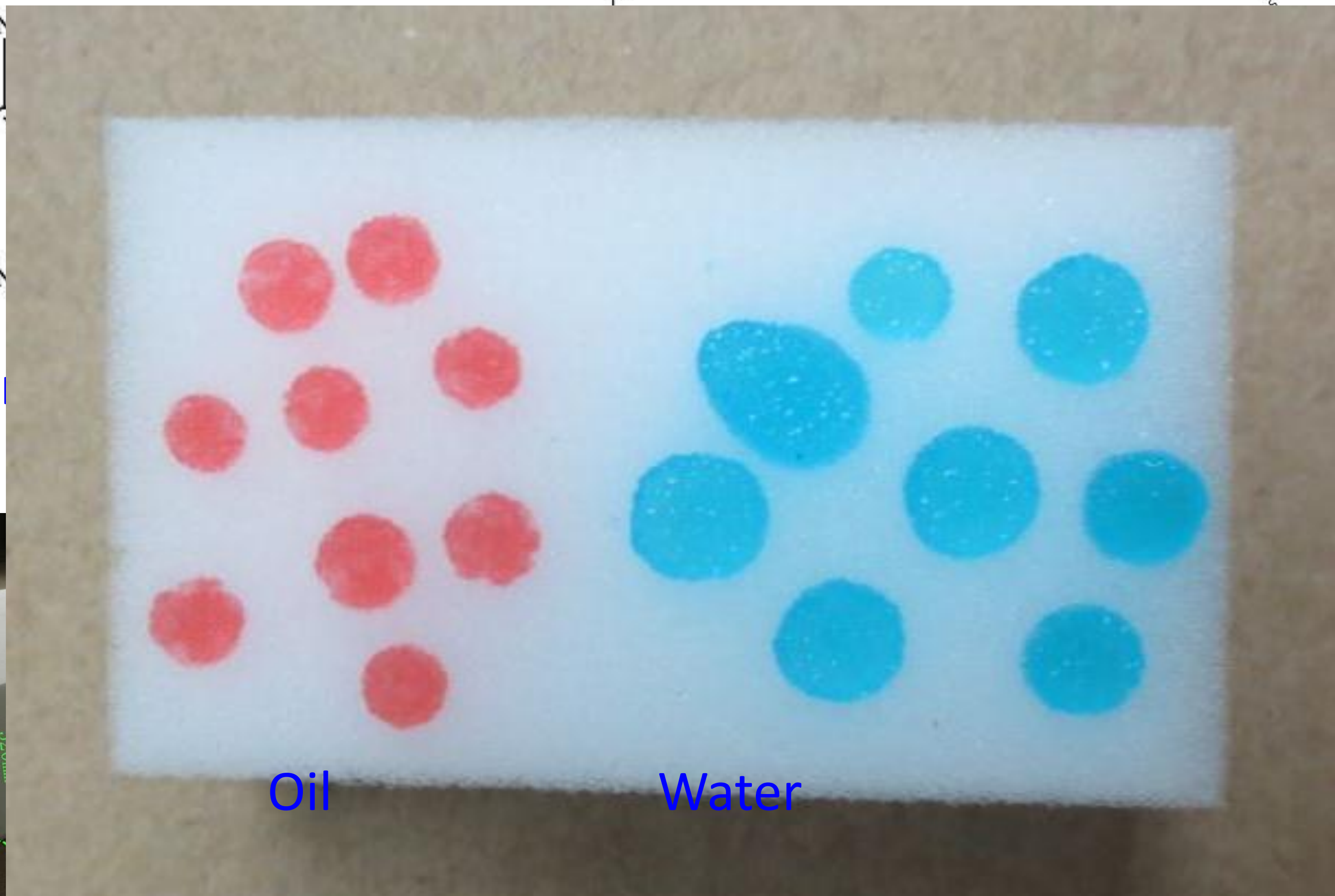




Mela

oam





Porosity > 99%, Density < 10mg/cm^3, Super-Light materials

Figures are from Internet

Experimental Setups (II)

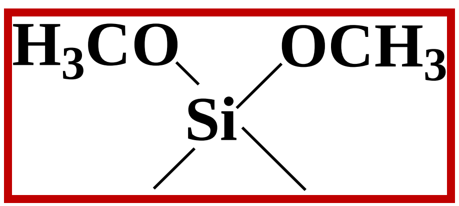
Modification of MF using silane

Ethanol & water mixture

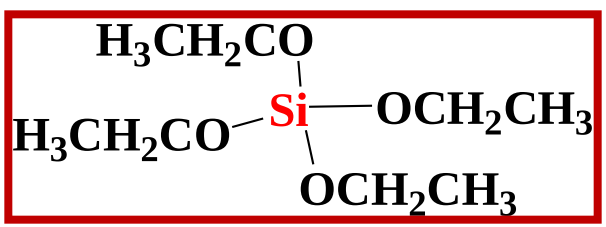
+

MTMS & TEOS mixture

Silanization process



MTMS

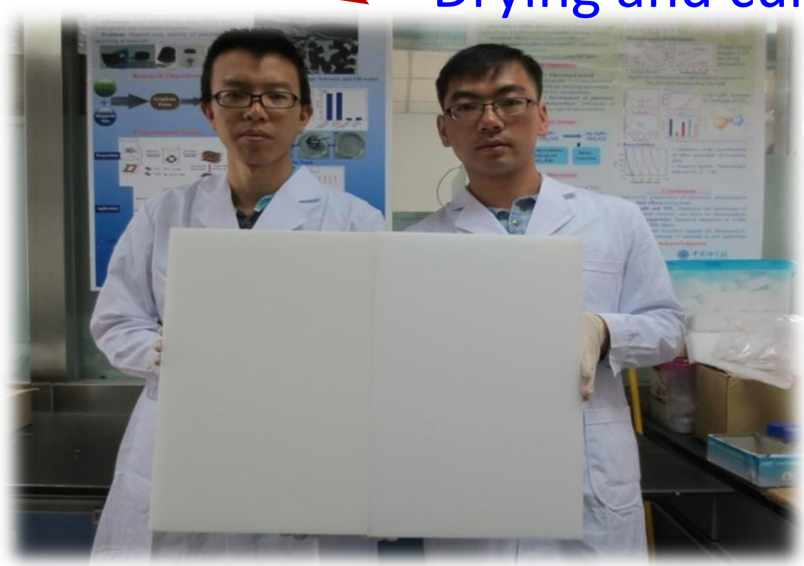


TEOS

HAc

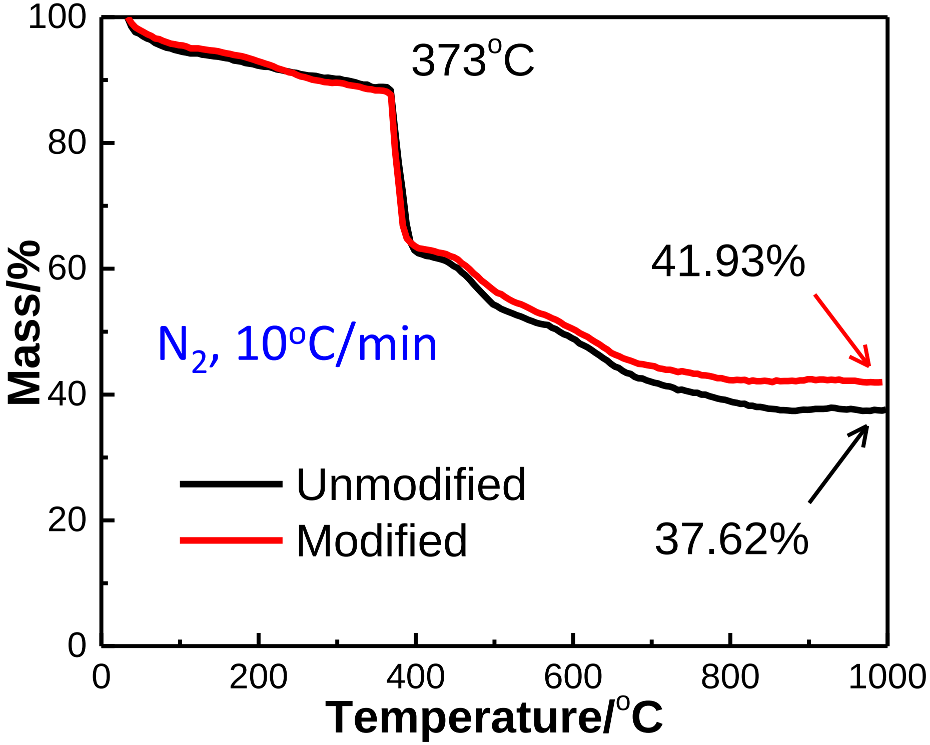
Immersion

Drying and curing



What Happens for MF with Silane?

TGA



FT-IR

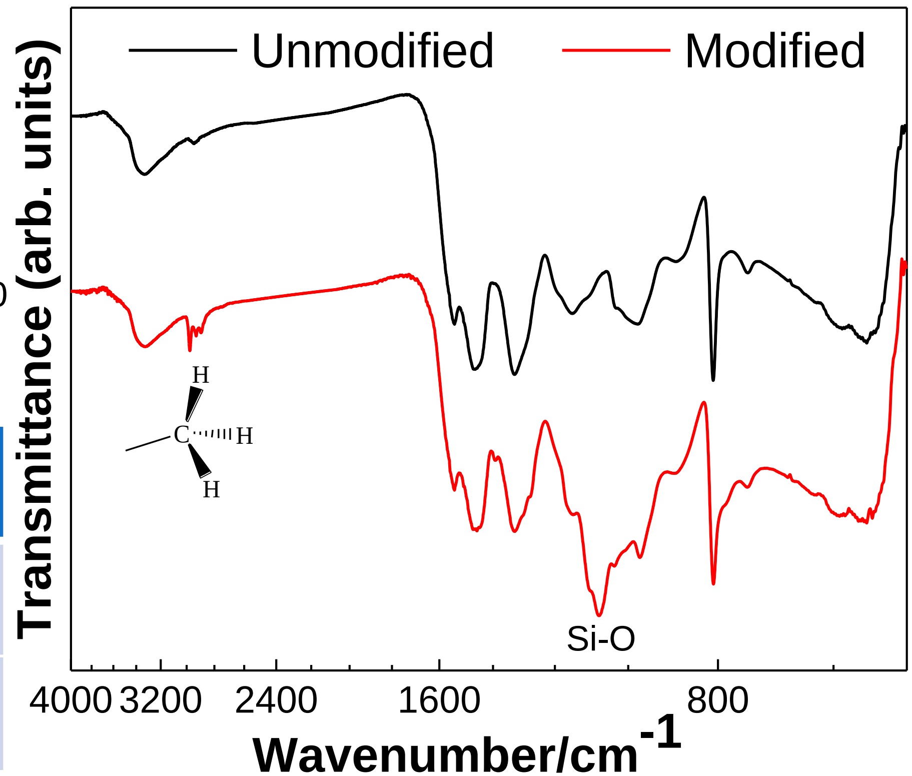
C-H (-CH_3)

Asymmetric stretching: 2975 cm^{-1}

Symmetric stretching: 2895 cm^{-1}

Si-O (Si-O-Si)

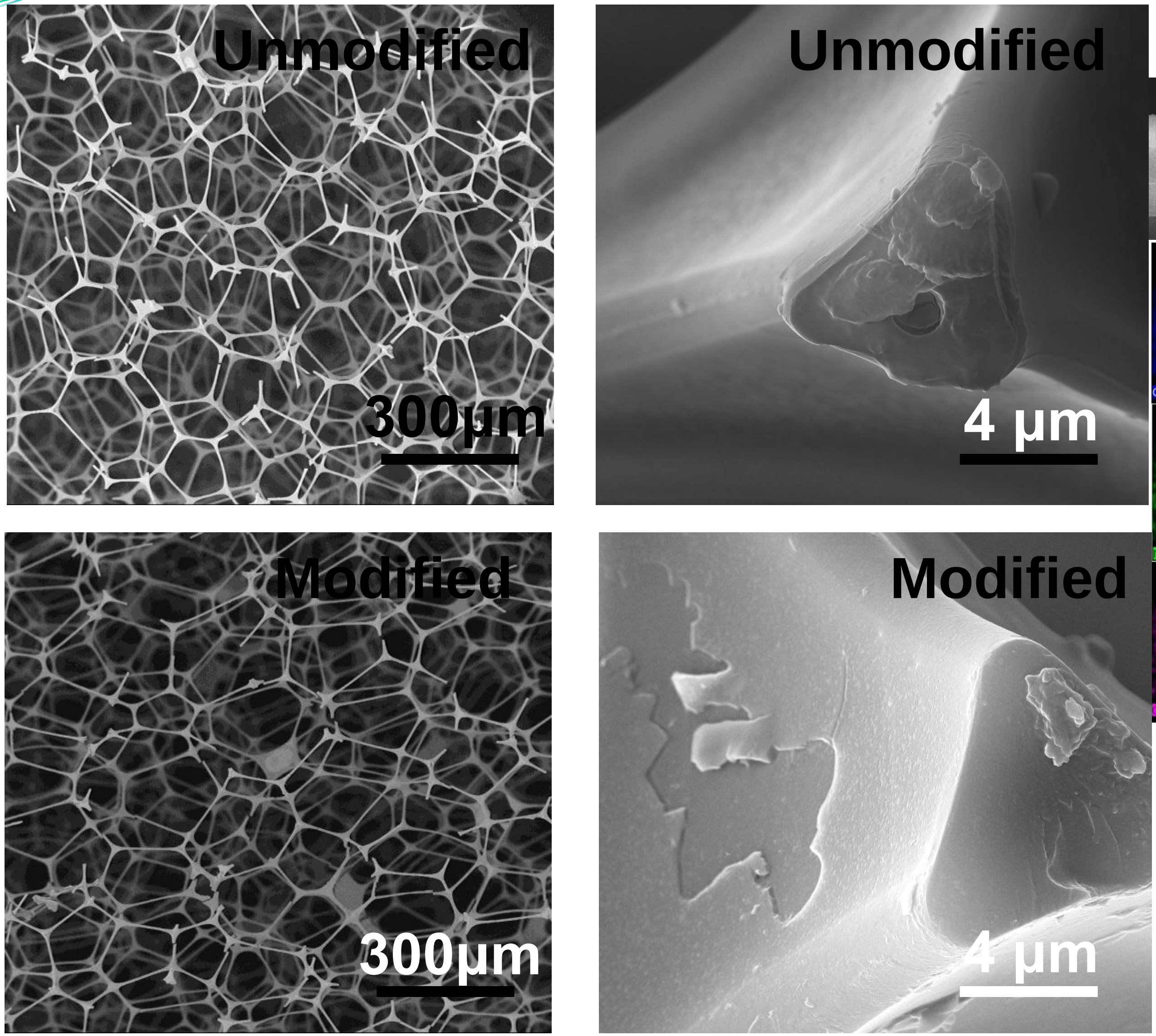
Asymmetric stretching: 1076 cm^{-1}

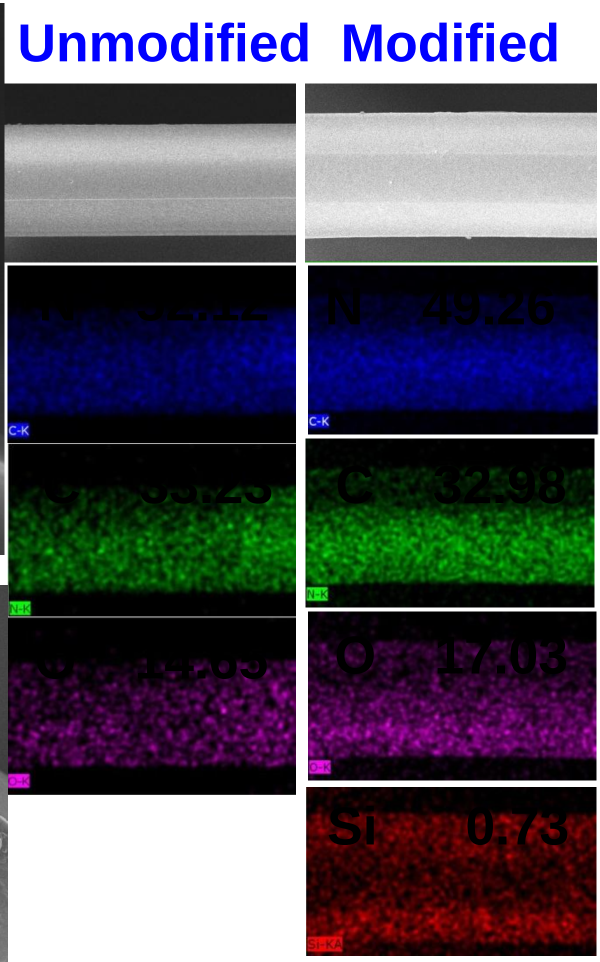


Density

Sample	ρ (mg/cm³)
MF	7.38±0.28
Modified MF	8.25±0.13

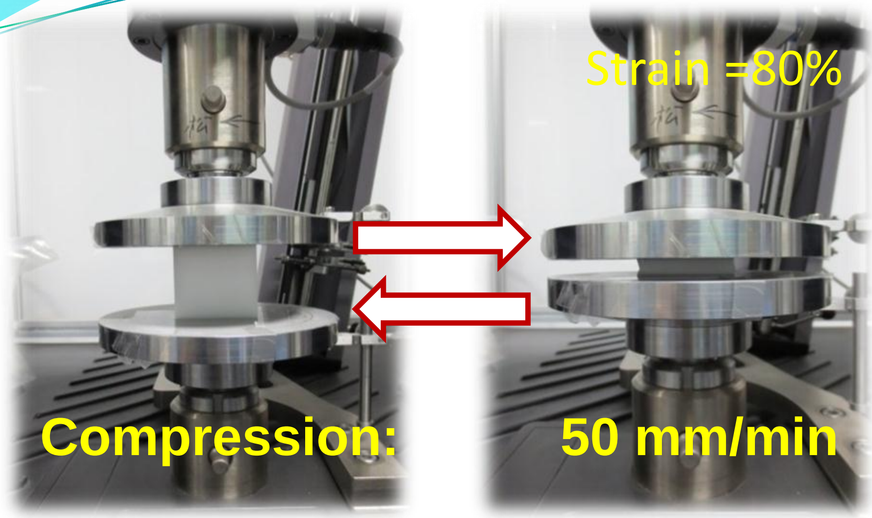
Morphology & Composition of MF

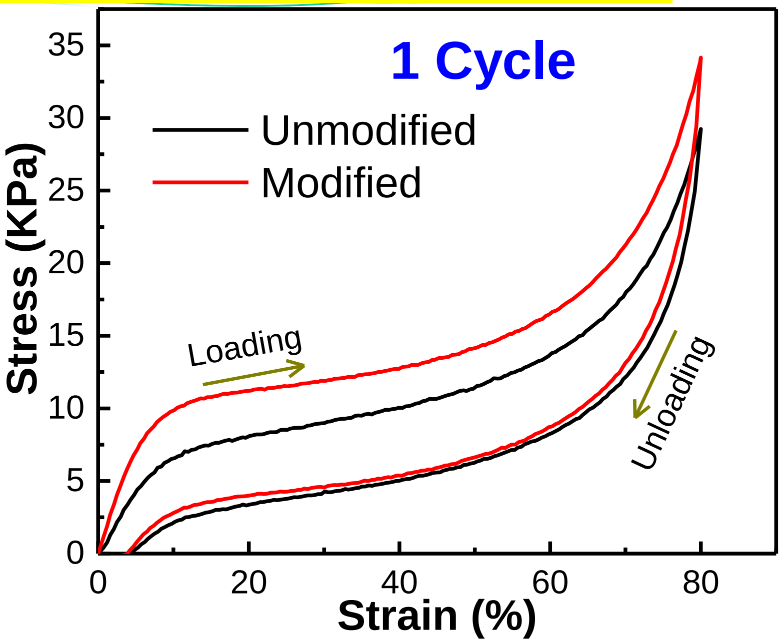


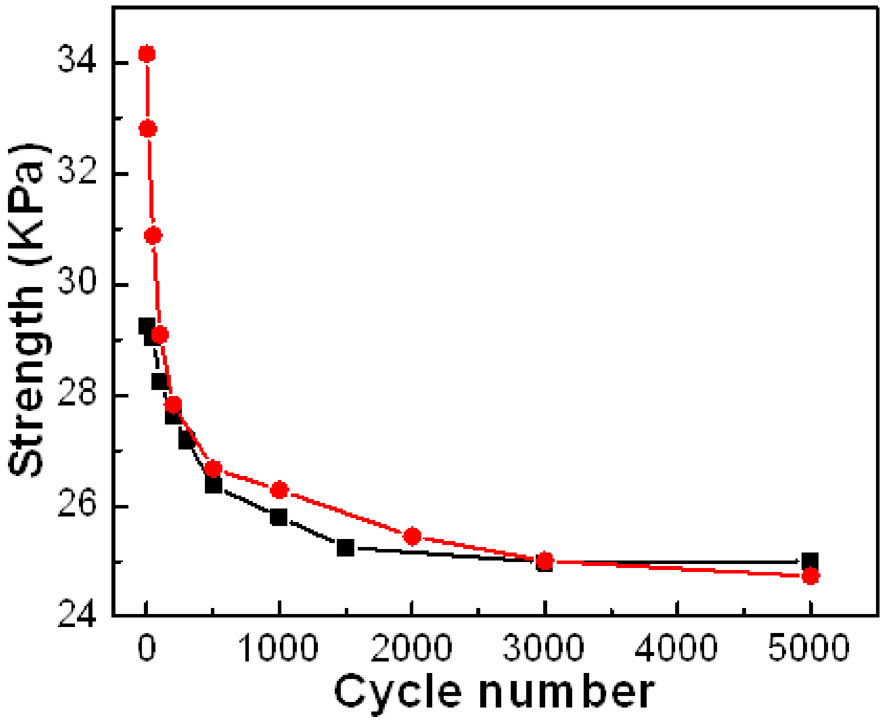


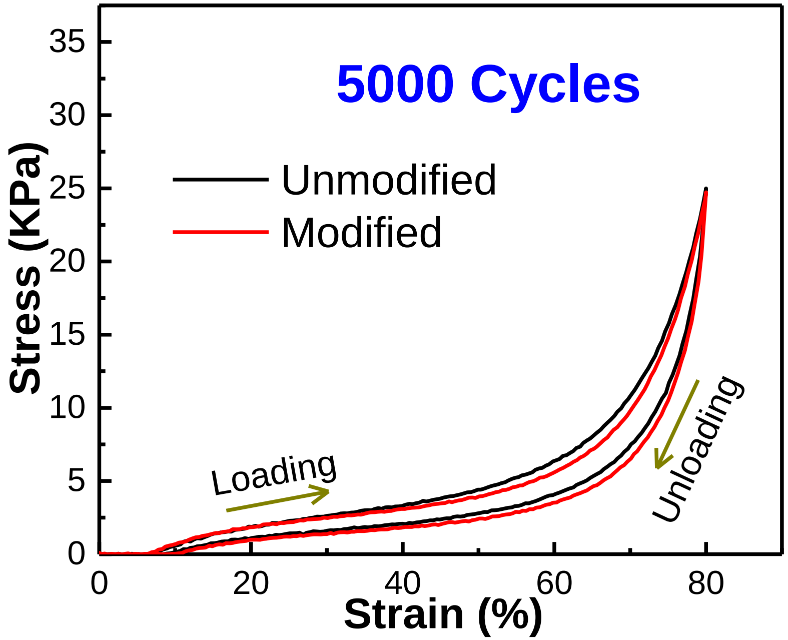
EDS Mapping Results

Mechanical Properties of MF

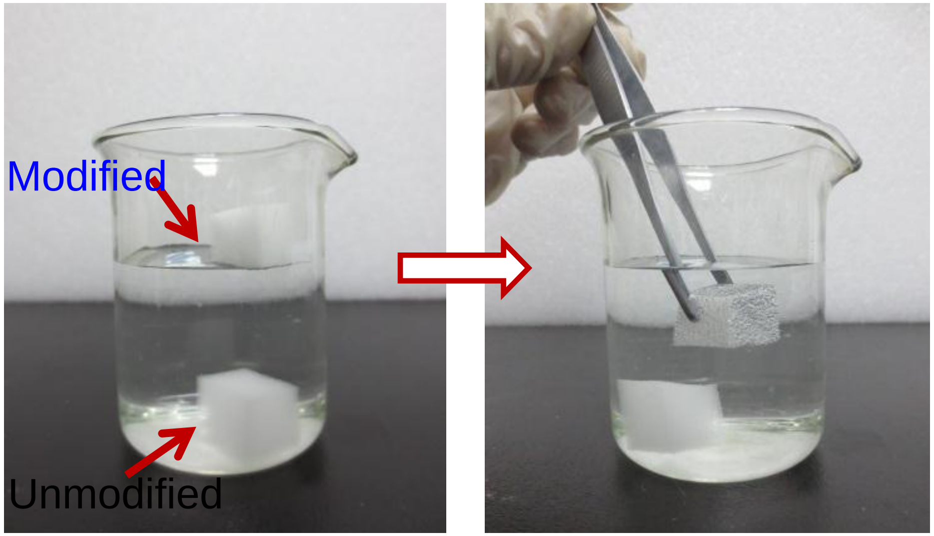


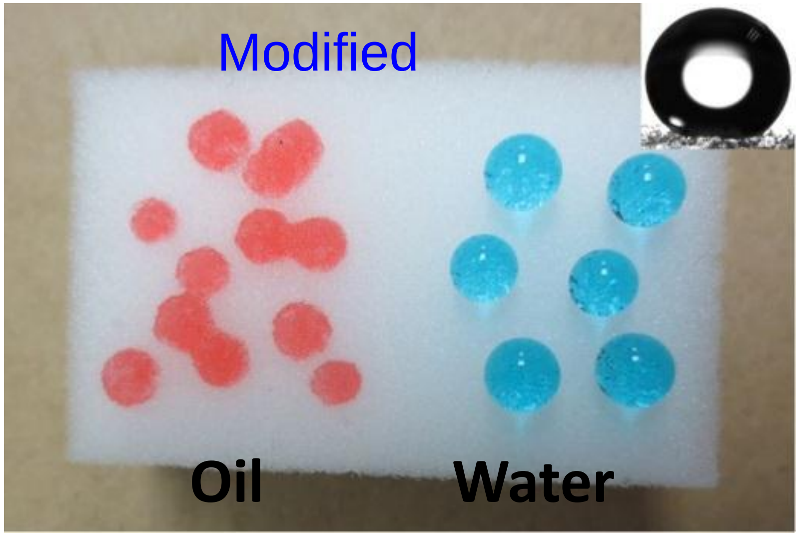






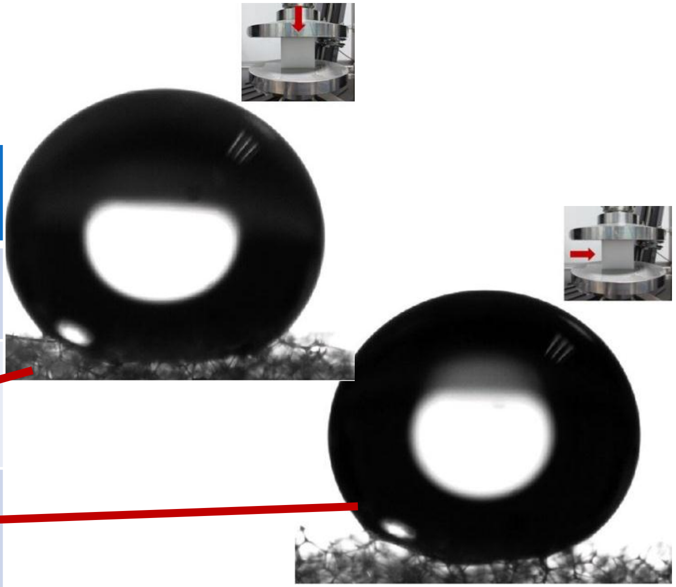
Wettability of MF



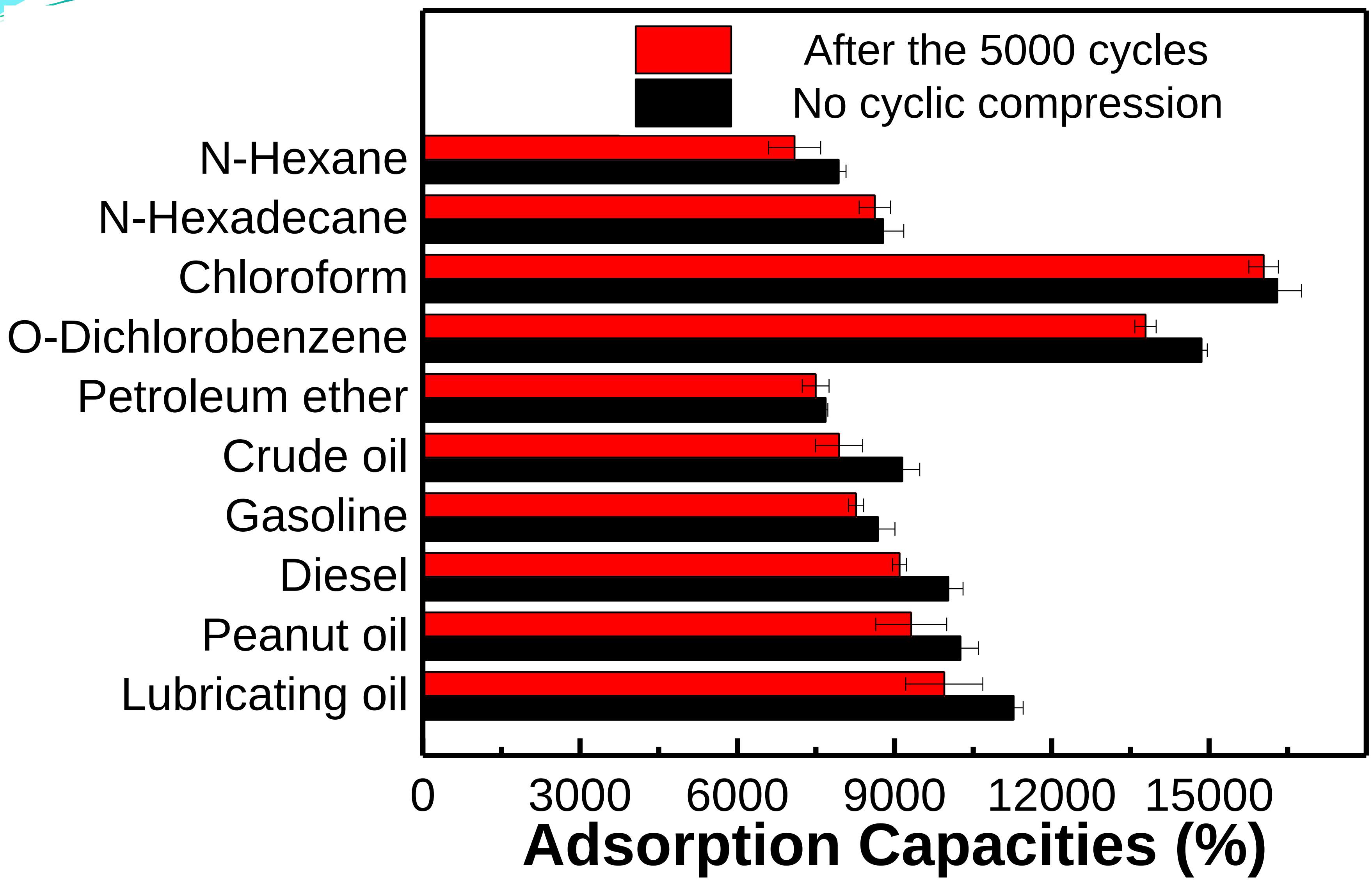


Contact angle of MF with H_2O

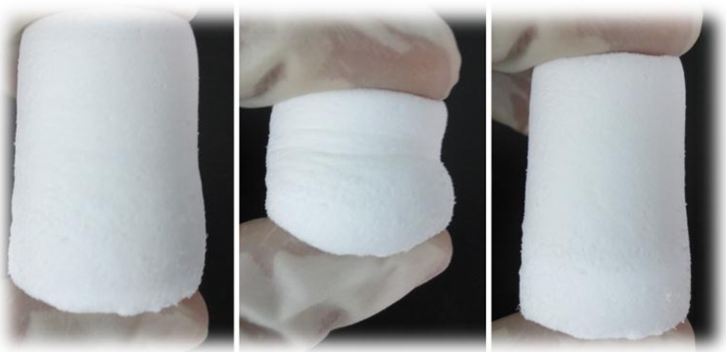
Modified MF	Contact Angle/°
Before compression	156.4±1.9
After 5000 cycles Parallel to compression	153.0±3.2
After 5000 cycles Vertical to compression	150.2±2.1

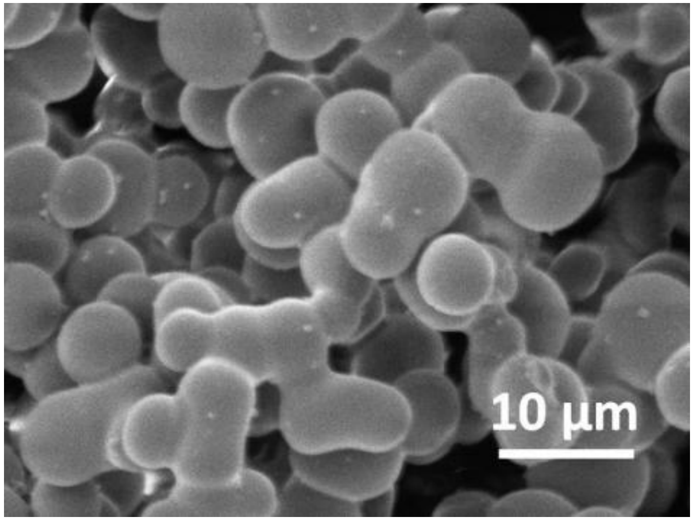


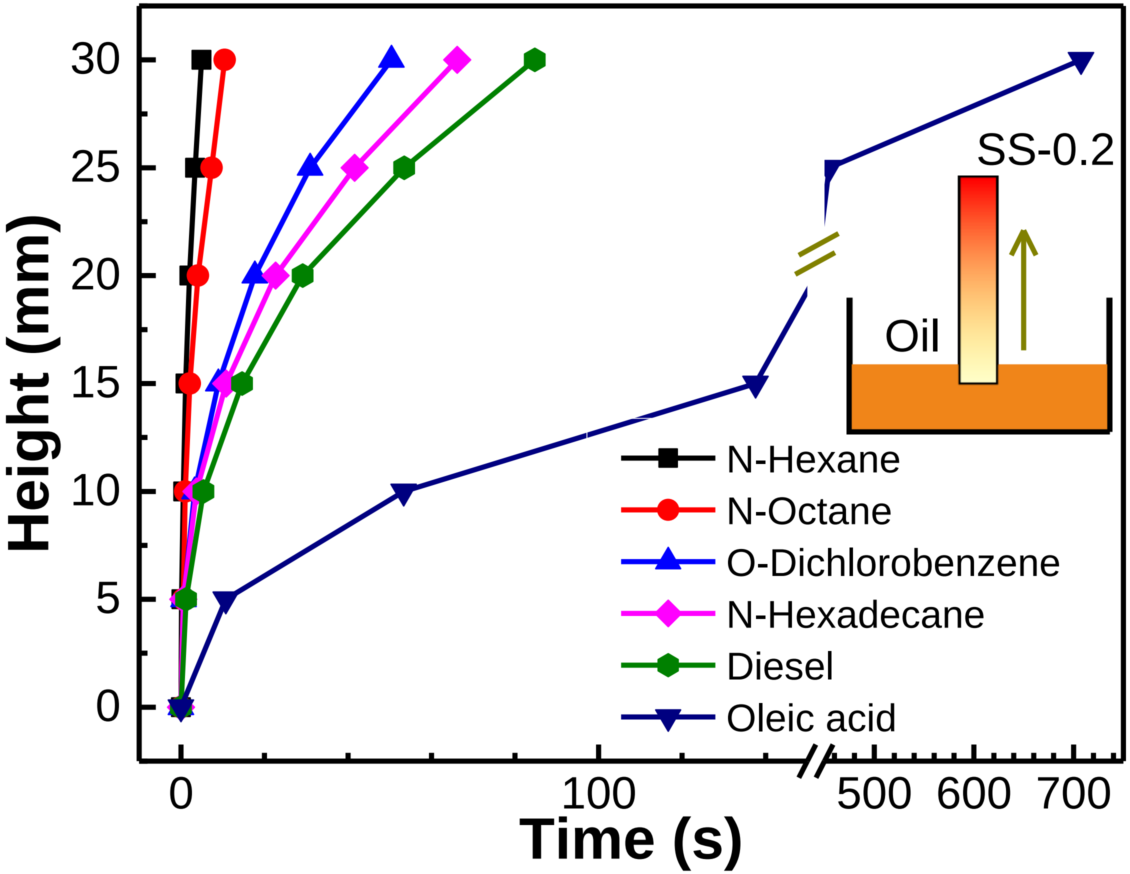
Adsorption Capacity of MF



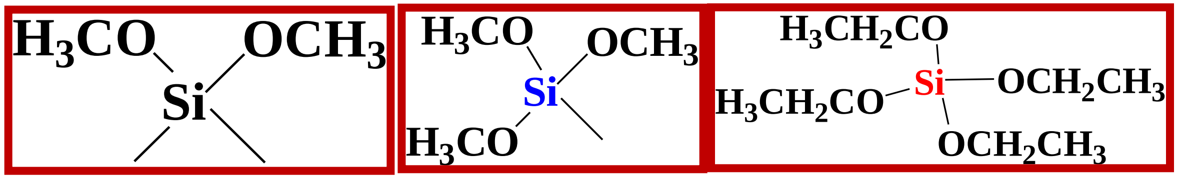
Novel Application of Polymer Foam







Possible to separate miscible organic liquids



Mu L, Ma PC, et al. Polym. Chem. 2015, 6, 5869.

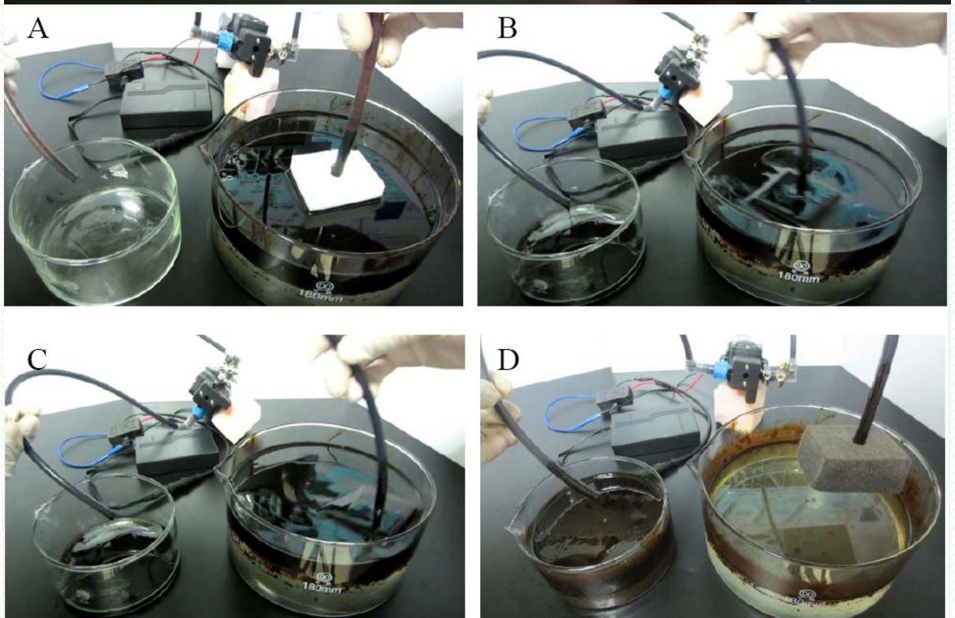
Comparison: Cost Vs. Performance

Surface modification of various sponges

Parameter	*PU sponge*	*MF sponge*	*MF*
Modification *methods*	Oxidation & immersion	Solution immersion	Solution immersion
Modifier	PDMS, CNTs, fluorinated silane	PDMS, CNTs, graphene, fluorinated silane	**Common silane (MTMS & TEOS)**
Adsorbate	Oils & Organic solvent	Oils & Organic solvent	Oils & Organic solvent
Capacity (g/g)	10-25	40-180	40-180
Material cost	Cheap/High	Cheap/High	**Cheap/Cheap**
Cyclic used times	300	~ 10	**>1000**

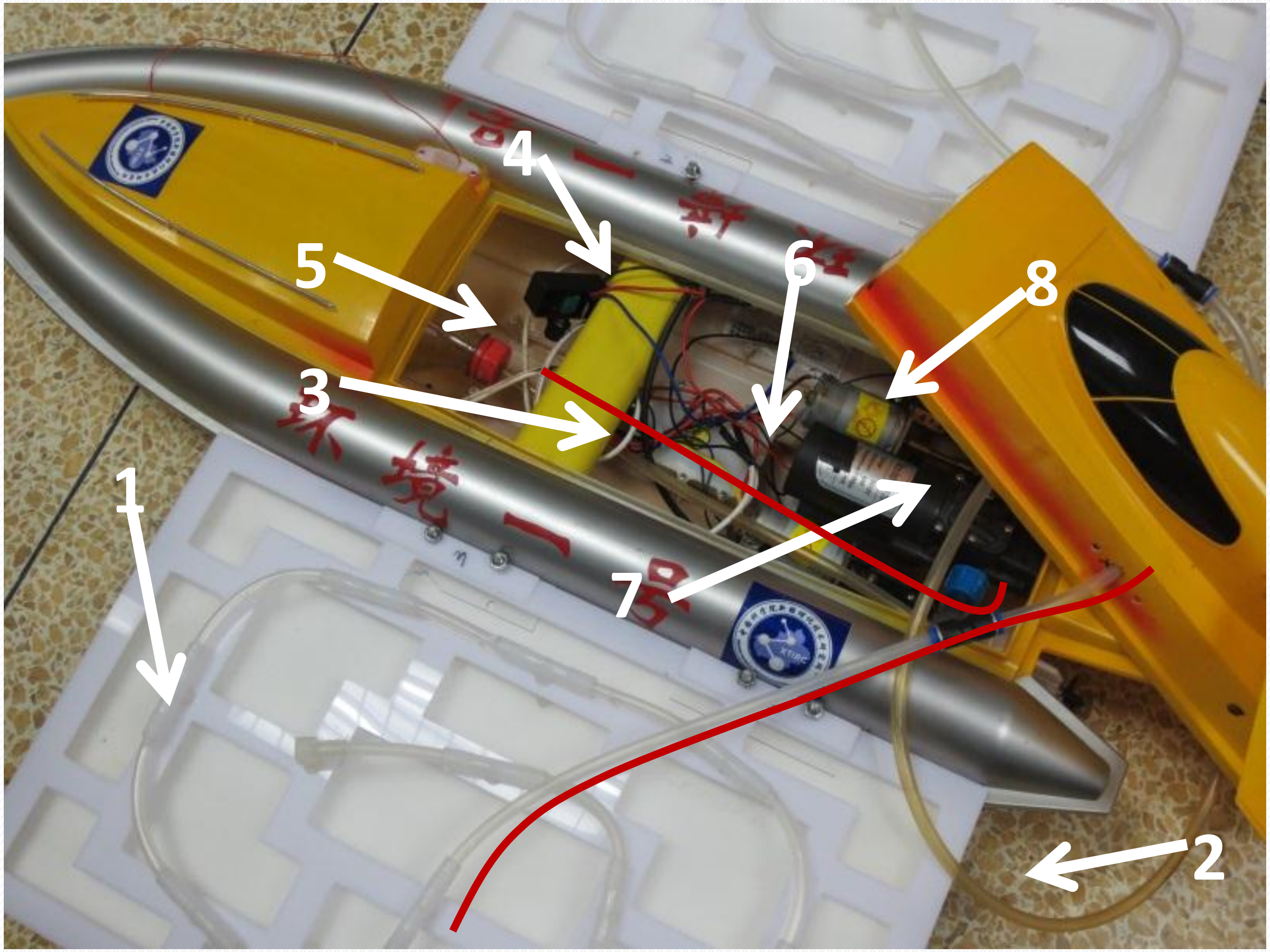
Practical Application of Modified MF (I)

Oil-collector (EN-0) Using MF as *Key Material*



Practical Application of Modified MF (I)

Oil-collector (EN-1) Using Nanocomposites as *Key Material*



1: Polymeric Sponge

2: Oil Pipe Network

3: Power (Battery)

4: Power Divider

5: Oil Storage

6: Remote Controller

7: Pump

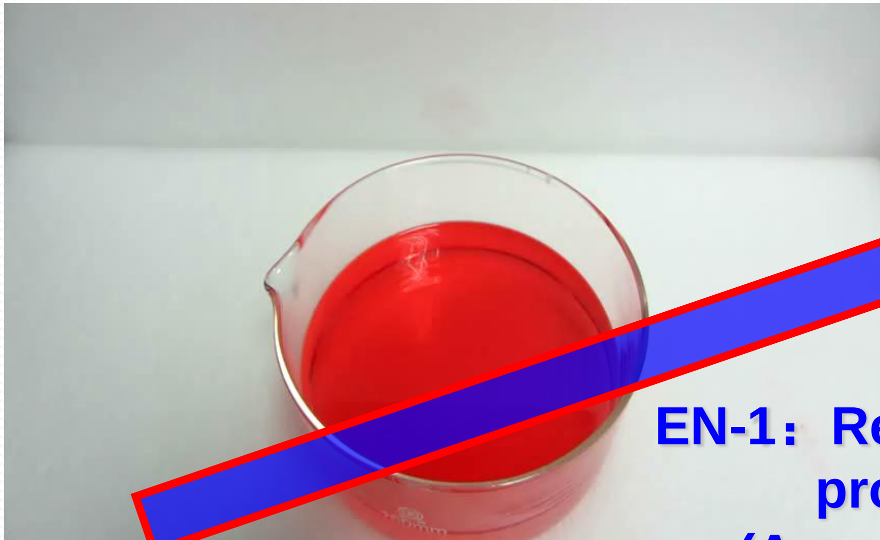
8: Motor

Practical Application of Modified MF (I)

Oil-collector (EN-1) **Using Nanocomposites as** ***Key Material***

Perspectives (I)

Oil Collector: *Environmental No. X Series*



EN-2：Remote controllable oil collector (Ongoing)

http://www.lamor.com/products/

EN-1：Remote control prototype (Accomplished)

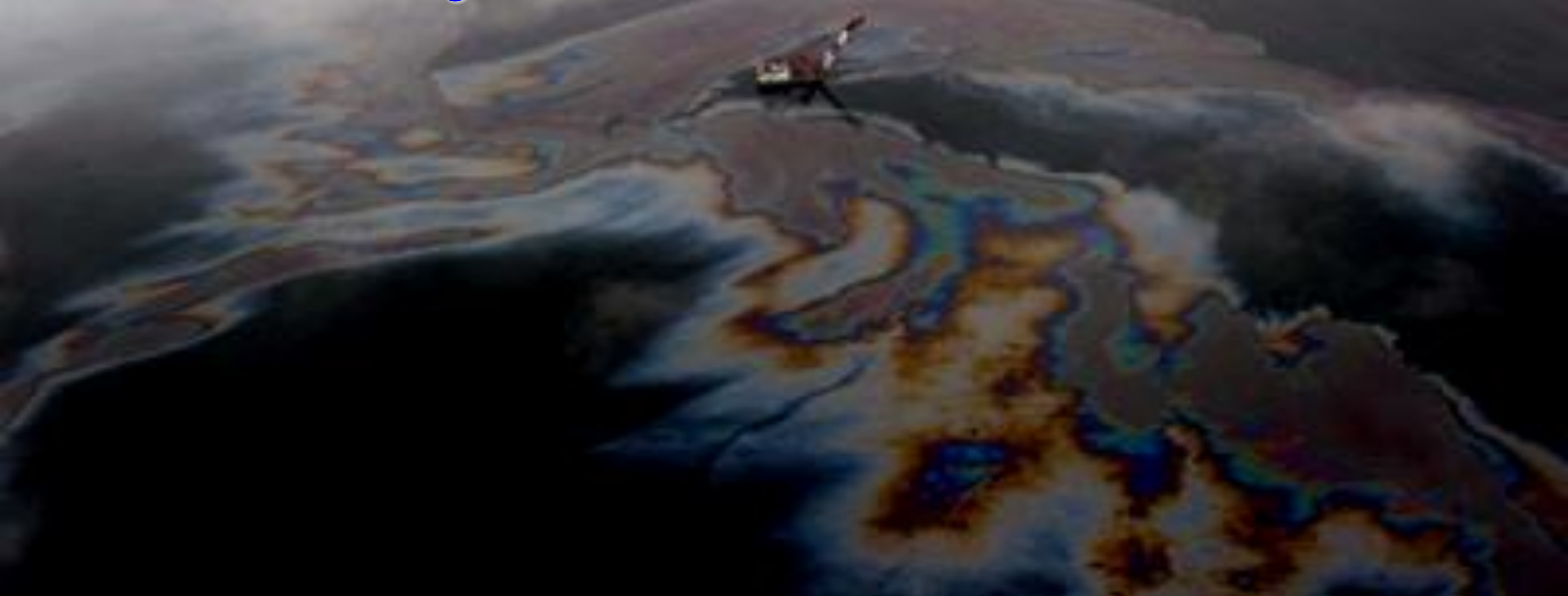
EN-0: Portable (Accomplished)

Perspectives (II)

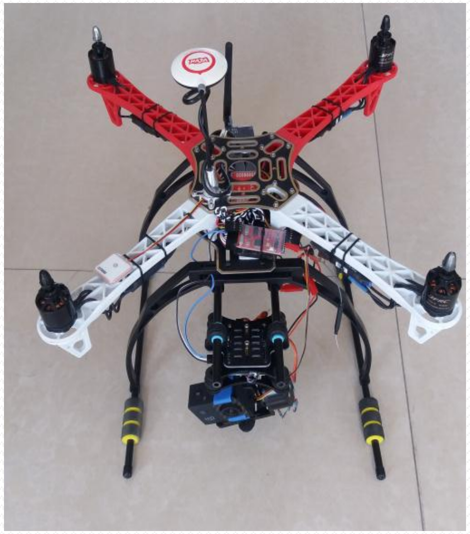
EN-3：Recovery for Oil Spill & Chemical Leakage

Integrated System and Solution

- **Offshore**: Remote control, monitoring and support
- **Inshore**: Leakage site, mothership and collectors (EN-2)
- **Overhead**：Monitoring using UAV, GPS navigation and wireless controlling for EN-2



Perspectives (III)



Conclusions

- ***A simple and efficient method*** for the modification of MF using silane-derivated nanocomposites
- MF with nanocomposite modification:
  - -- ***Superhydrophobic and superlipophilic*** behaviors
  - -- ***High adsorption capacities*** with stable cyclic operations
  - -- Excellent ***thermal stability*** and ***mechanical properties***
- ***Design and verification of oil collector*** for oil-H_2O separation using ***polymer nanocomposites as key component***

White Polymer

Black Crude Oil

Environmental Applications of (CNT)/Polymer Nanocomposites

Multi-functional Cotton Fabrics with Nanocomposite Coating

Introduction

Functional cotton materials

Hygiene Textiles

OP-textile

Wound dressing

Filtration/Membranes

Oil sorbent cotton

Singh el at. Eng. Chem. Res. 53(30), 11954-11961 (2014)

Oil spills clean up

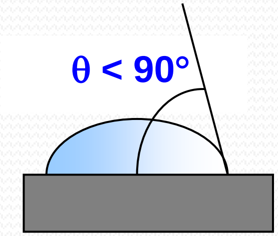
Oil /water separation

Li et al. Adv. Mater. Interfaces 2015;2:1500220

Research Background

Characteristic of pristine cotton

- Hydrophilic and strong absorption capability
- High specific surface and porous structure
- Bio-degradable
- Available in different form and relatively less cost



Hydrophilic

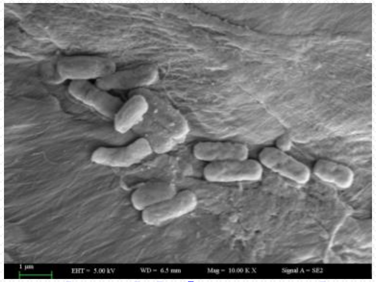

Cotton Fiber


Cotton Yarn

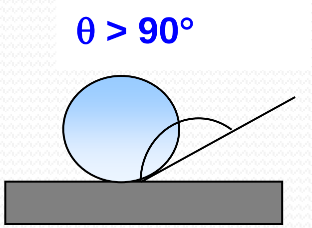

Cotton Fabric

Limitations for advanced application

- High superhydrophilicity
- Impotent antimicrobial property
- Poor UV protection property
- Low strength for some applications


Microbial growth on cotton

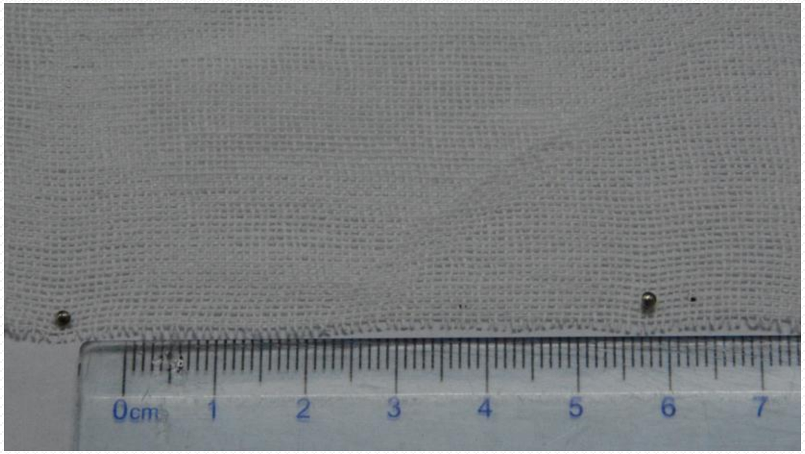
UV-shielding



Hydrophobic

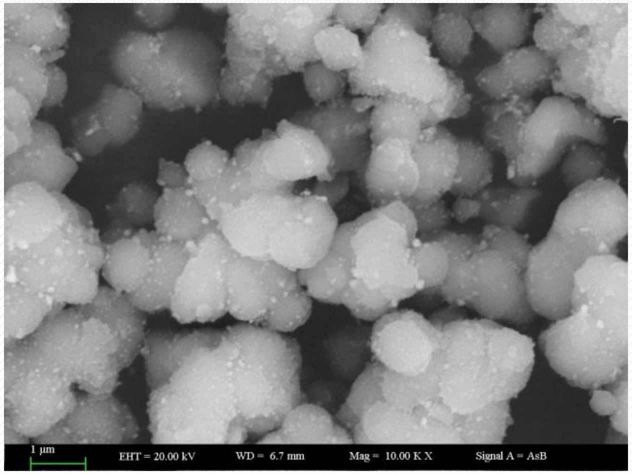
Materials and Method

Cotton gauze



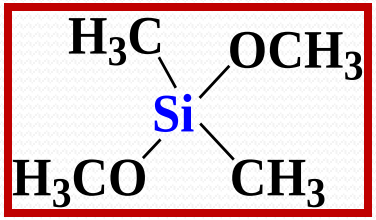
Fabric weight: 60 g/m^2

AgBr-TiO2 composite:

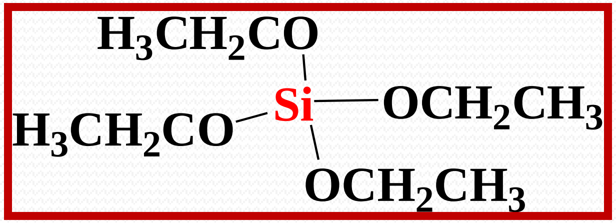


Particle size: 400-600 nm

Silane (anchoring agent):

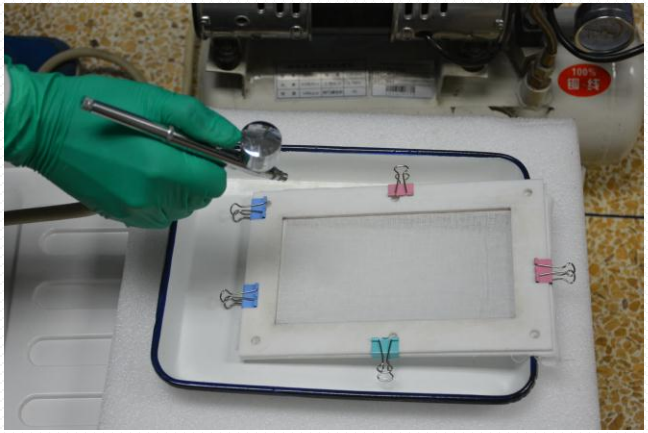


DMDMS(as polymers)



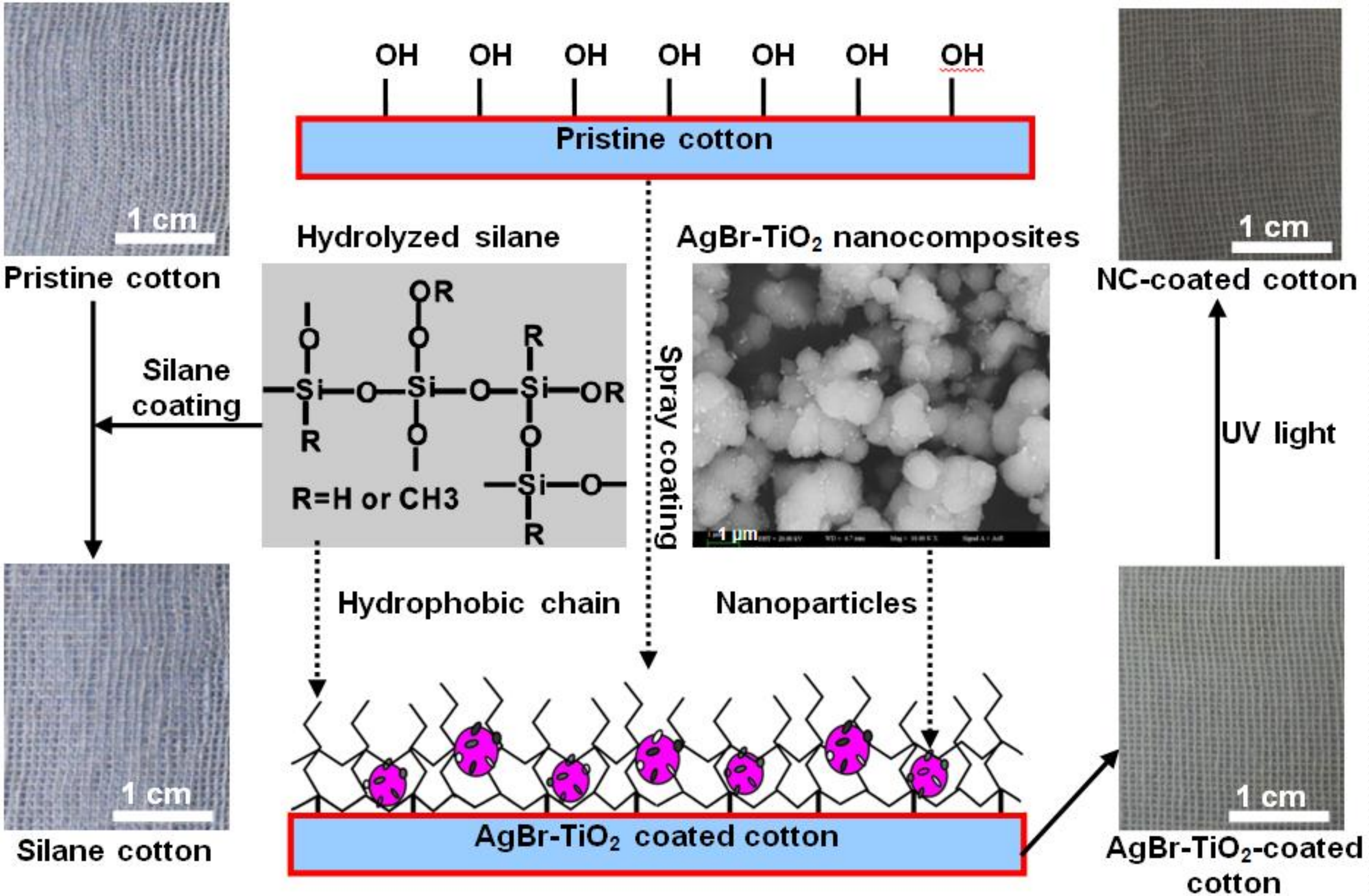
TEOS(as x-linker)

Spray coating:



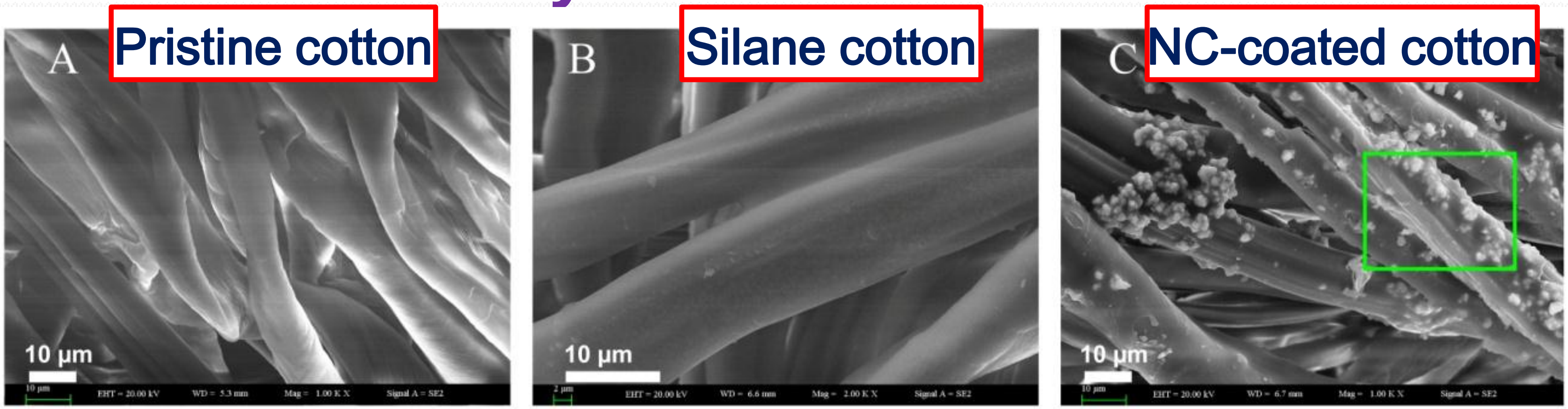
Materials and Method

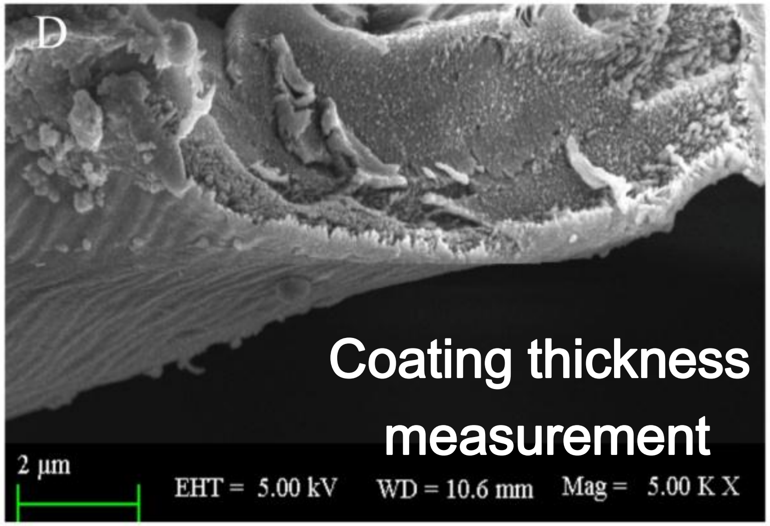
Schematic diagram of the experiments:

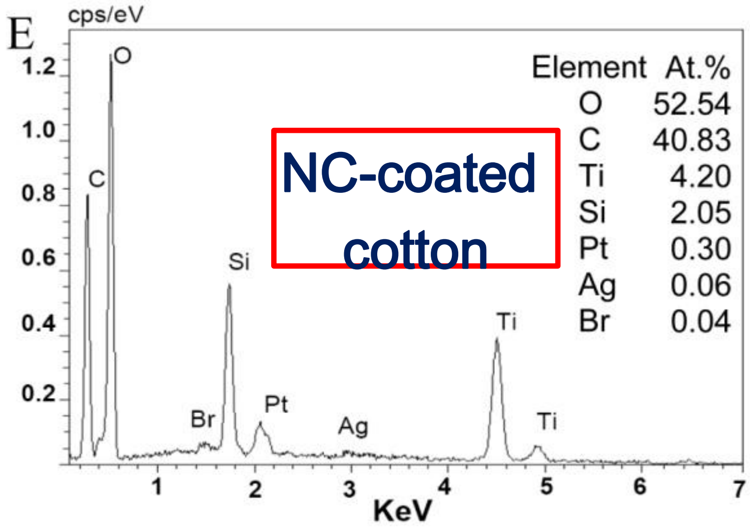


Result and Discussion

SEM and EDX analysis

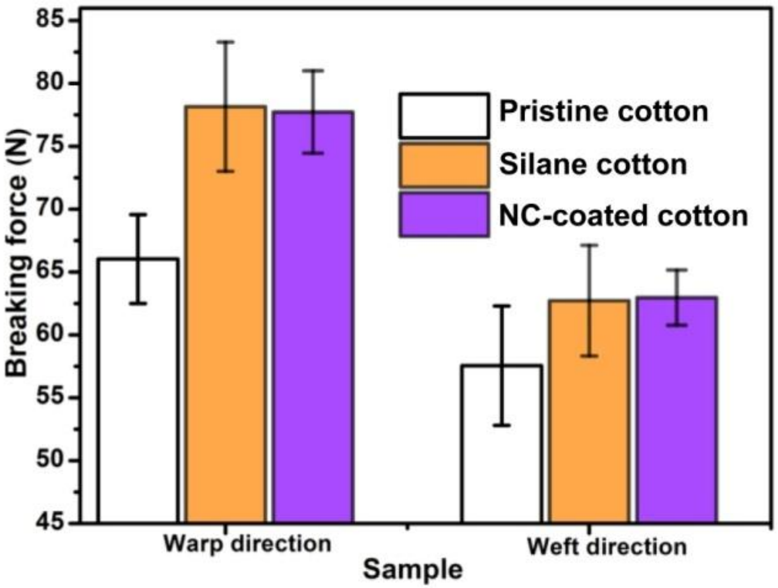






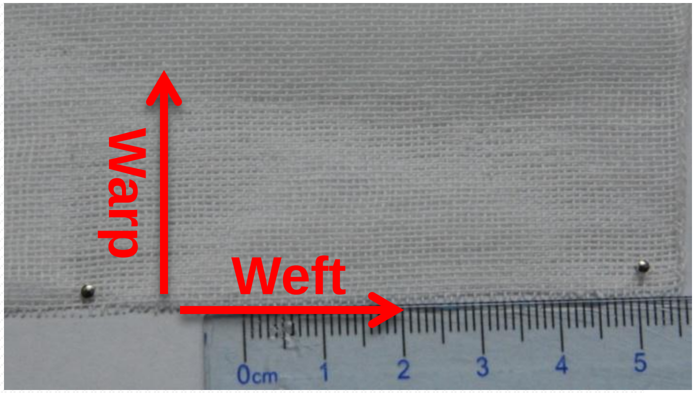
Result and Discussion

Mechanical and surface wetting properties



Breaking force enhancement

- 18% in warp direction (66.0 N to 77.7 N)
- 9% in weft direction (57.5 N to 63.0 N)



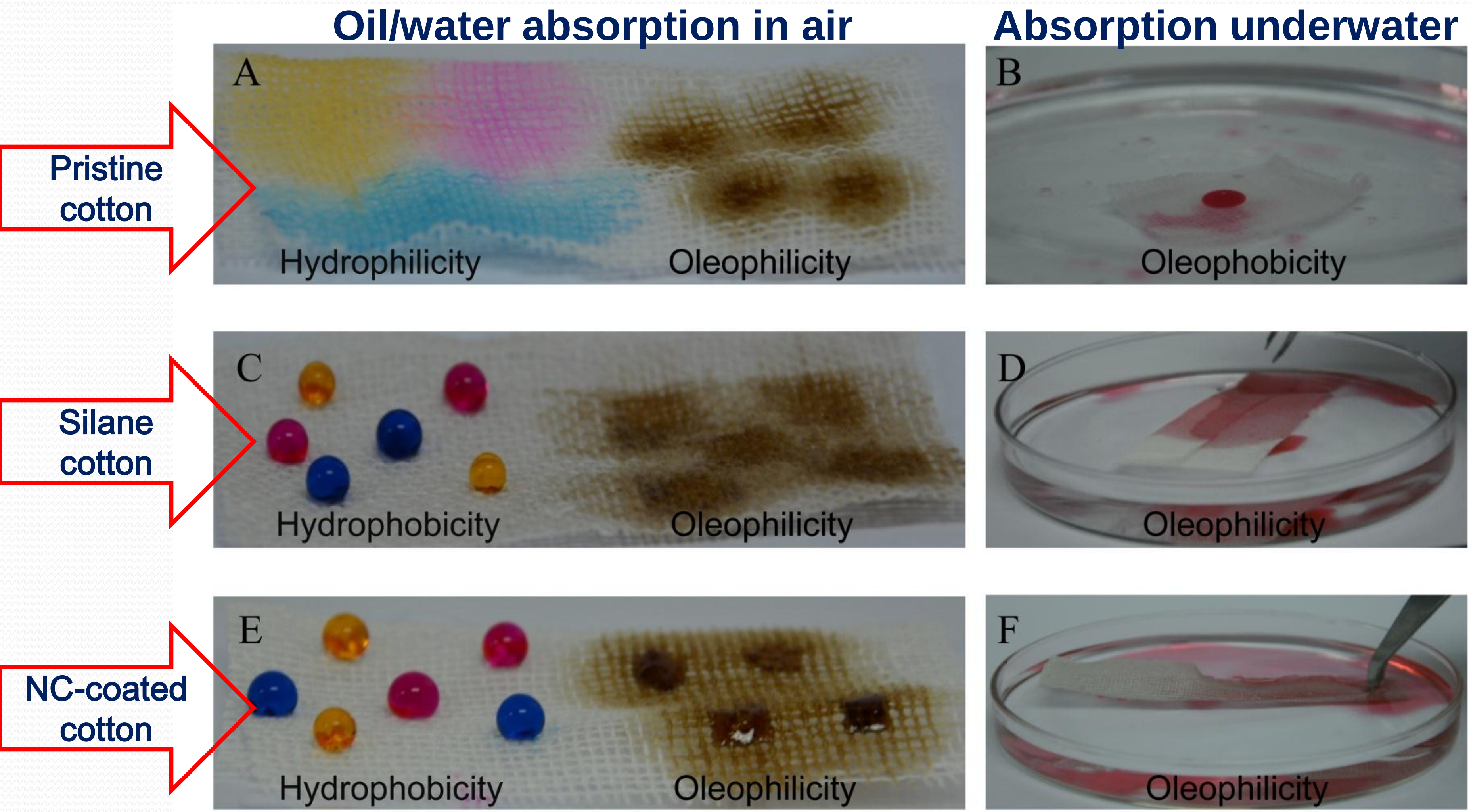
ıble 1: Contact angle measurement of uncoated and coated cotton.

Sample	Contact angle	
	Degree(θ)	Image (10s)
Pristine cotton	0*	
Silane cotton	149.1±2.8	
NC-coated cotton	145.8±2.0	

**Apparently zero*

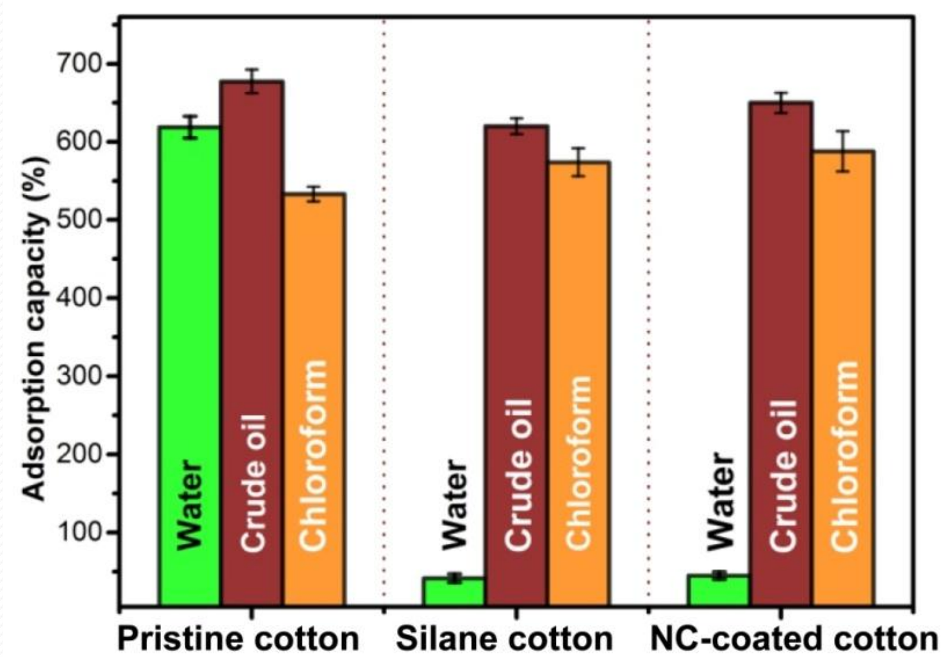
Result and Discussion

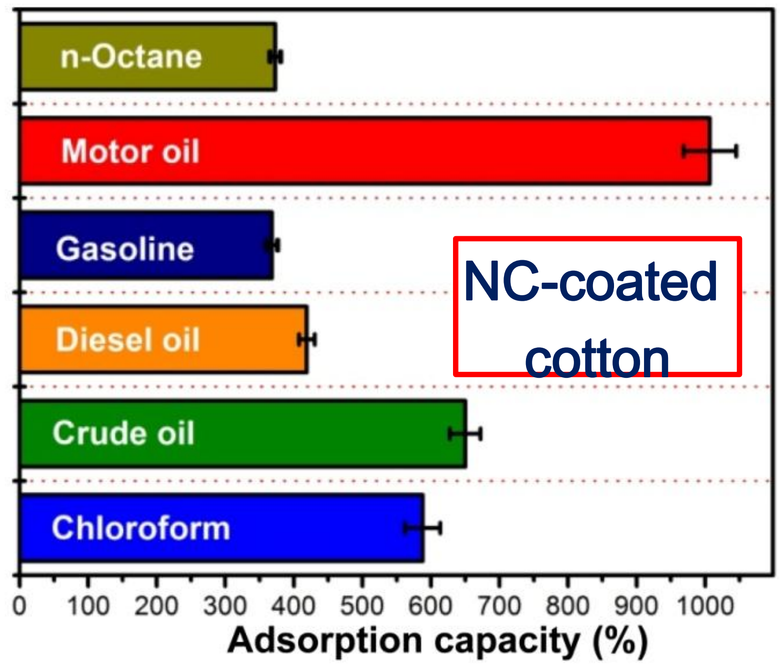
Water and oil absorption behavior



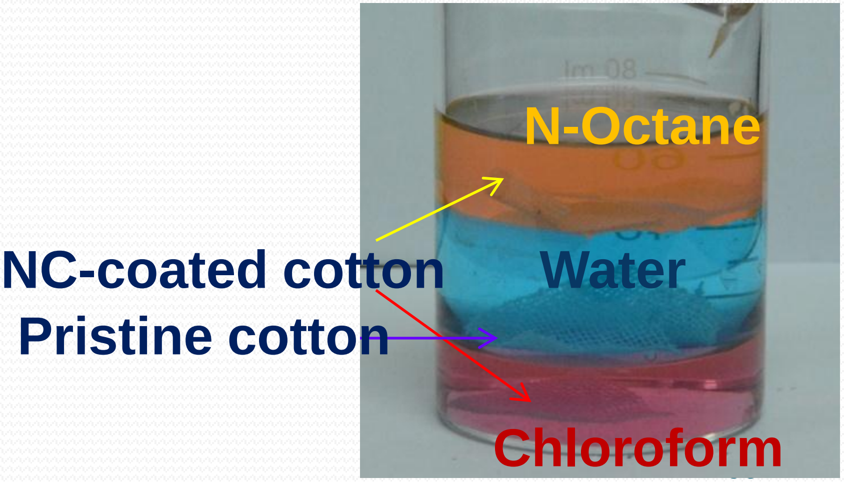
Result and Discussion

Oil/water adsorption capacity





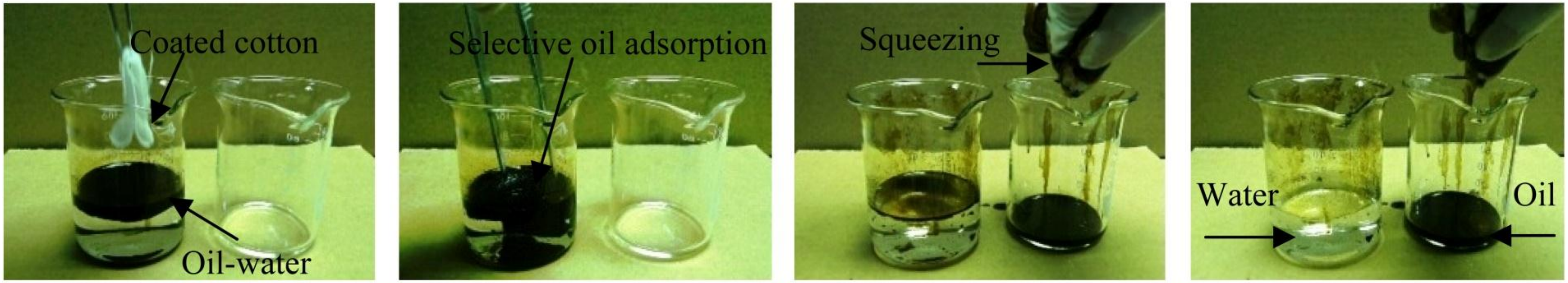
- Water adsorption changed from **6.2** times to **0.4** times
- Oil adsorption remain almost unchanged



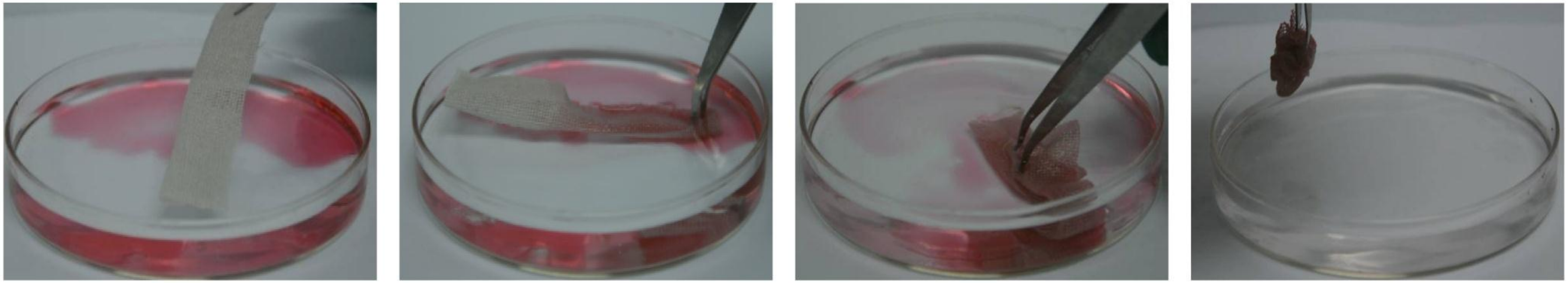
Result and Discussion

Selective oil adsorption properties

Separation of floating oil/water mixtures

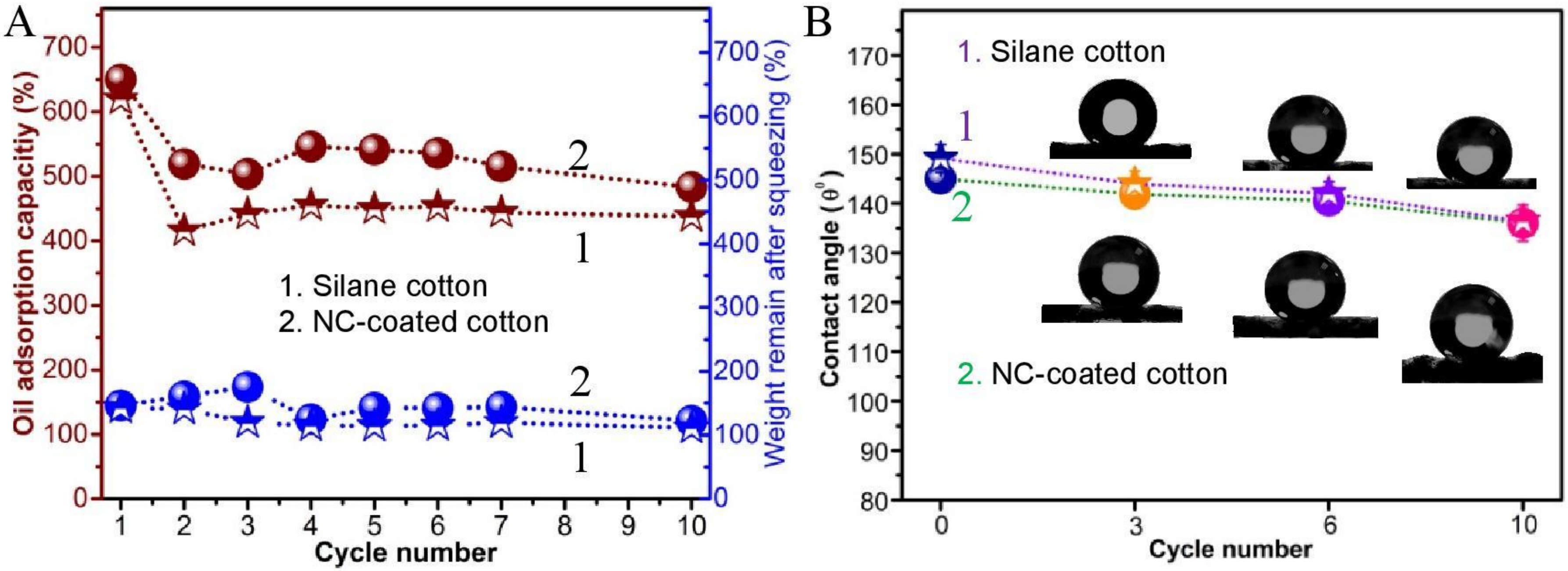


Separation of oily liquids from underwater



Result and Discussion

Cyclic performance of material



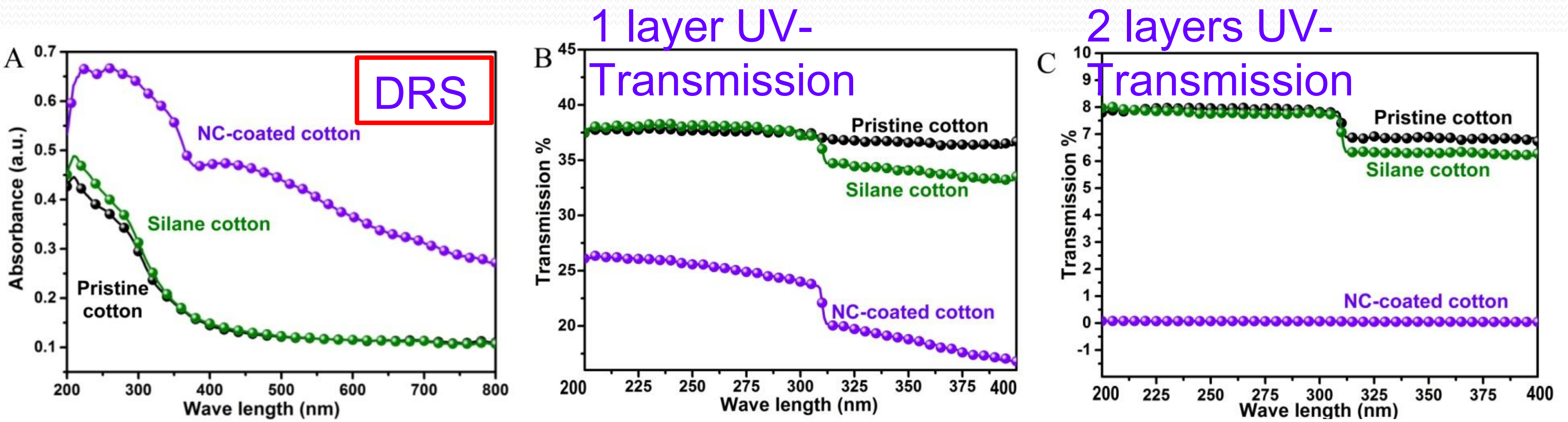
Crude oil recovery by hand squeezing

CA= 145° → after 10 cycle → CA= 136°

- Crude oil uptake changed **6.5** times to **5.2** times of its original wt. after 1st cycle
- Oil remained always about **1.5** times of wt. of original cotton in the structure.

Result and Discussion

UV-Vis. light absorption and transmission



$$UVA = \frac{1}{86}\sum_{\lambda=315}^{\lambda=400} T_i(\lambda)$$

$$UVB = \frac{1}{26}\sum_{\lambda=290}^{\lambda=315} T_i(\lambda)$$

$$UPF = \frac{\sum_{\lambda=290}^{\lambda=400} E(\lambda)*\varepsilon(\lambda)*\Delta(\lambda)}{\sum_{\lambda=290}^{\lambda=400} E(\lambda)*T(\lambda)*\varepsilon(\lambda)*\Delta(\lambda)}$$

Table 2: UVA, UVB and UPF values of different cotton fabrics.

Sample	UVA	UVB	UPF (1 layer)	UPF (2 layers)
Pristine cotton	36.1	37.3	2.7	13.5
Silane cotton	33.5	36.7	2.8	14.1
NC-coated cotton	18.2	23.0	4.6	41.9

Result and Discussion

Antibacterial property

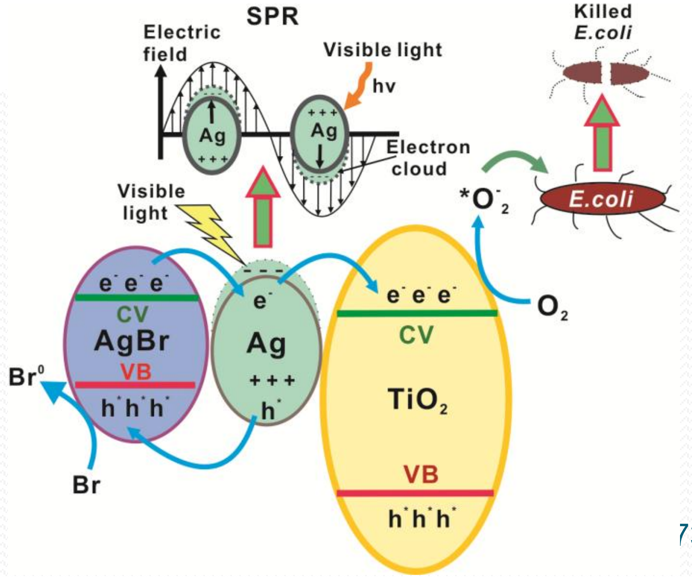
Table 3: Antimicrobial activity of uncoated and coated cotton fabrics.

Sample	Concentration of bacterial in the initial suspension, M_0 (CFU/ml)	Concentration of bacterial after incubation, M_{In} (CFU/ml)	Reduction ratio, R (%)
Pristine cotton	6.20×10^4	1.79×10^7	0
Silane cotton	6.20×10^4	1.59×10^7	0
NC-coated cotton [1]	6.20×10^4	80	99.87
NC-coated cotton [2]	4.30×10^4	7.8×10^3	81.43

[1] *Under the fluorescent light;* [2] *Under the dark condition without light.*

Antibacterial Reduction Ratio (%)

$$R = \frac{(M_0 - M_{In})}{M_0} \times 100\%$$



Summary

◆ **A facile method to enhance the technical value of cotton fabrics with nanocomposite coating**

◆ **Multi-functional properties of cotton fabrics with nanocomposites coating**

-- Enhanced mechanical property,

-- Controllable wettability to water and oil mixture

-- Highly antibacterial activity against microorganism

-- Excellent properties for UV blocking and shielding

◆ **Cotton fabrics with nanocomposite coating: A promising candidate for medical, personal hygiene and environmental applications**

Acknowledgements

千人计划

RECRUITMENT

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Thank You
Questions & Comments