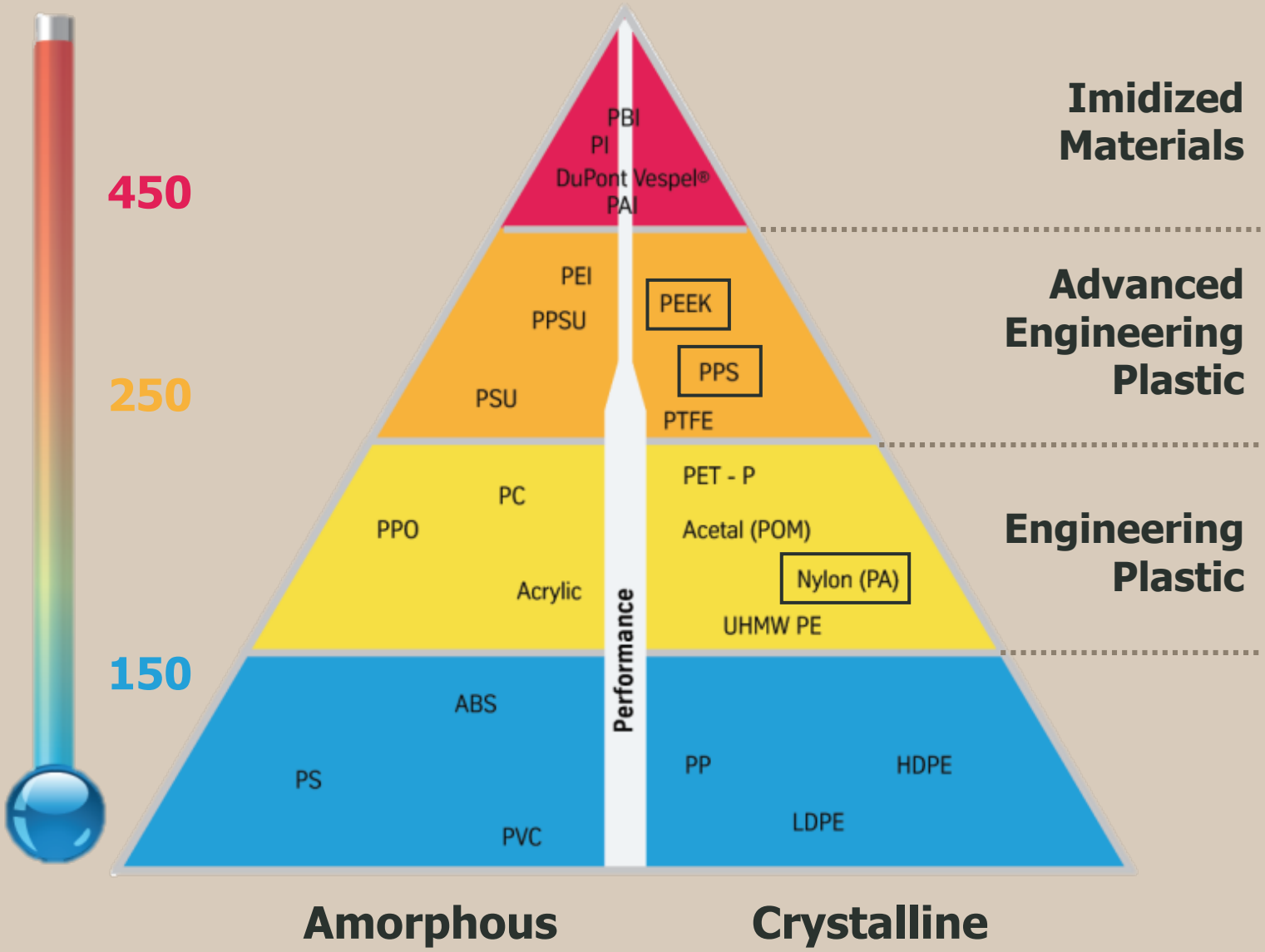
Research on the improvement of inter-laminar shear strength of CFRTP using MWCNT double introducing method

Korea institute of science and technology

Dr. Minkook Kim

Contents

Introduction – Engineering plastic (Thermoplastic)



Korea Institute of Science and Technology

Introduction – Carbon fiber reinforced **thermoplastic** polymer

CFRTP

= Carbon fiber + Thermoplastic = Interface property

Advantages

- Impact resistance
- Recycle (reforming)
- Unlimited shelf life
- Ability to be welded
- Short processing time
- High chemical resistance

Disadvantages

- High melting temperature
- High viscosity
- Cool down step
- Low surface free energy
- Impregnation with fibers
- Interfacial bonding strength

KIST
Korea Institute of Science and Technology

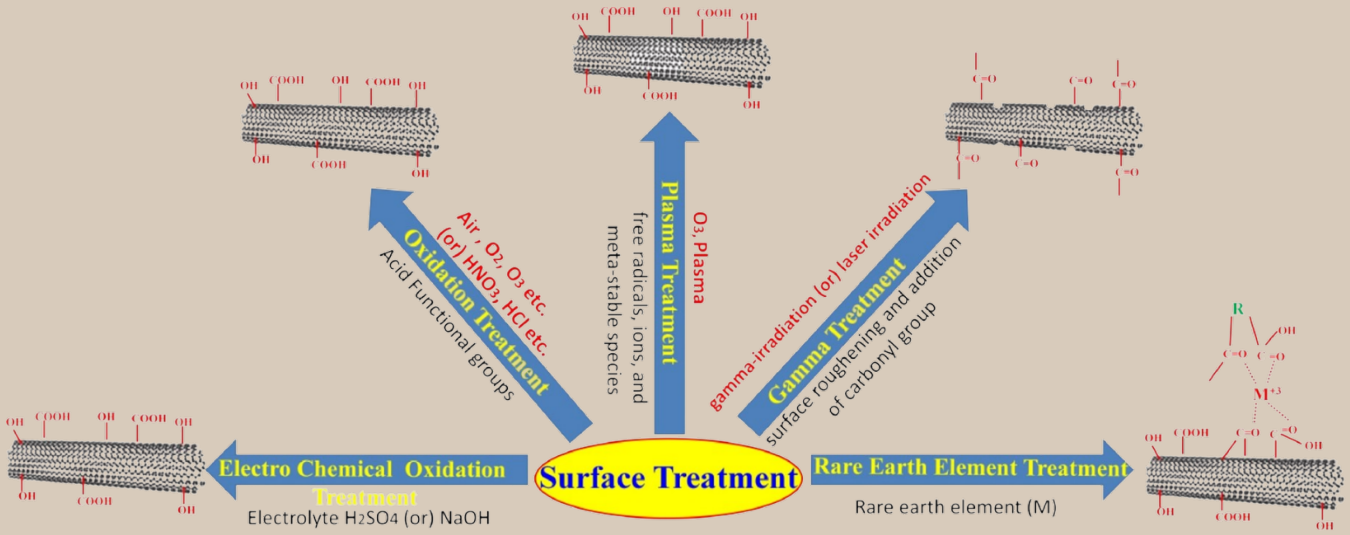
Introduction – CFRTP interface property

- **Carbon fiber + PA 6 matrix**

- Mechanical properties of the FRP is determined by the interface
- Impossible to construct the composite
- Chemical (surface treatment) or mechanical (nano filler) method

Introduction – Surface treatment and Nano filler

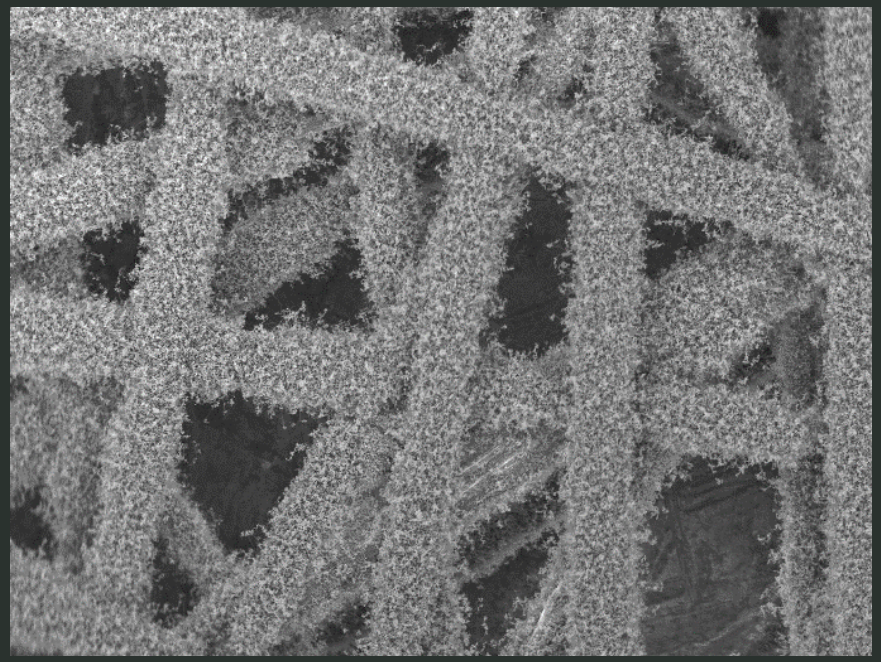
- **Surface treatment**



@출처: Nischith Raphael, Surface modification and grafting of carbon fibers: A route to better interface, Progress in crystal growth and characterization of materials, 2018.11

- **Induce the functional group on the surface**
  : -OH / -COOH / C-O
- Plasma, Gamma, Oxidation, chemical oxidation and element treatment

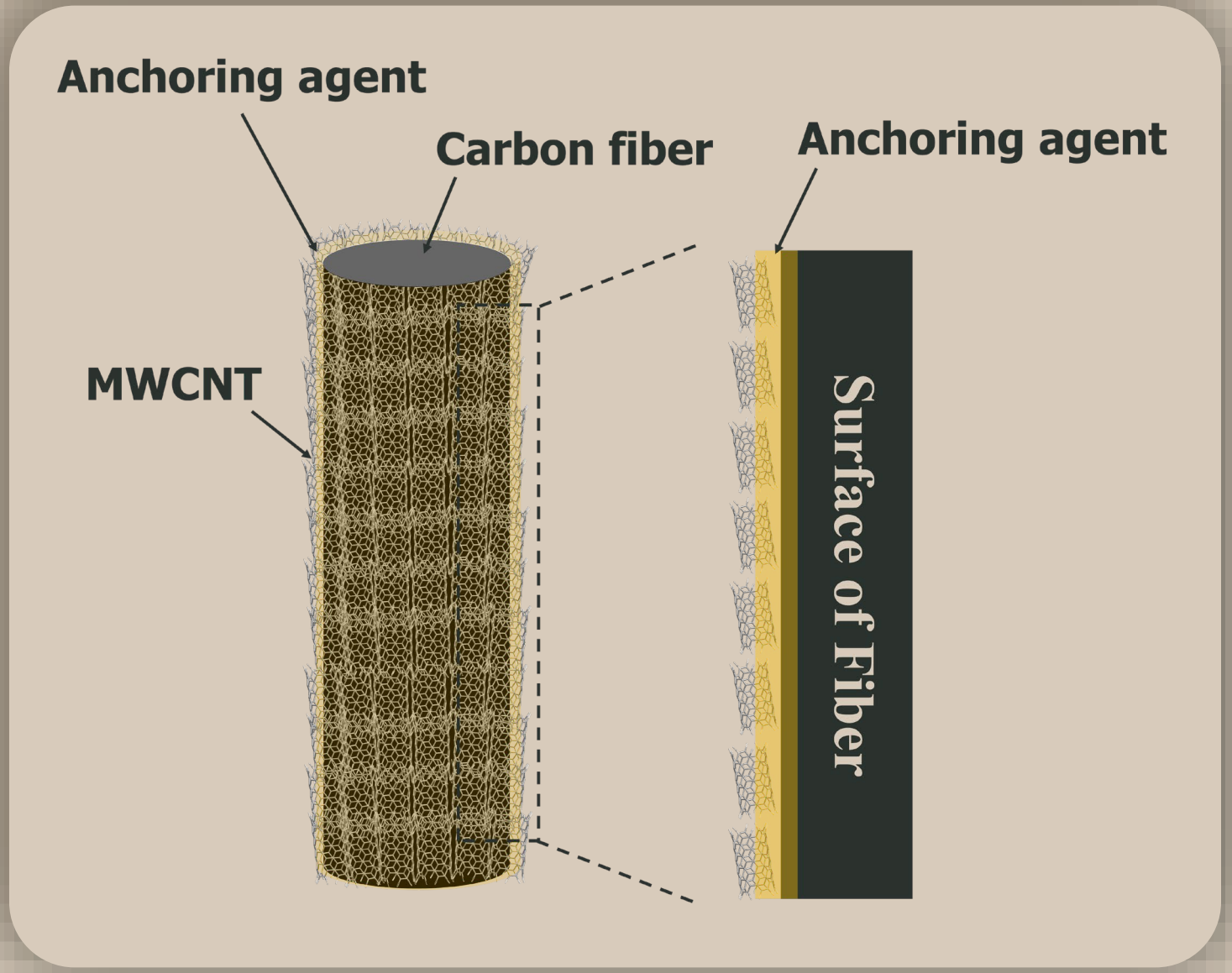
- **Nano filler reinforcement**



- CNT, graphene, silica, metal and etc.
- Simply mixing with matrix
  Directly growing
- **Synthesizing or CVD**

KIST
Korea Institute of Science and Technology

MWCNT-anchored carbon fiber

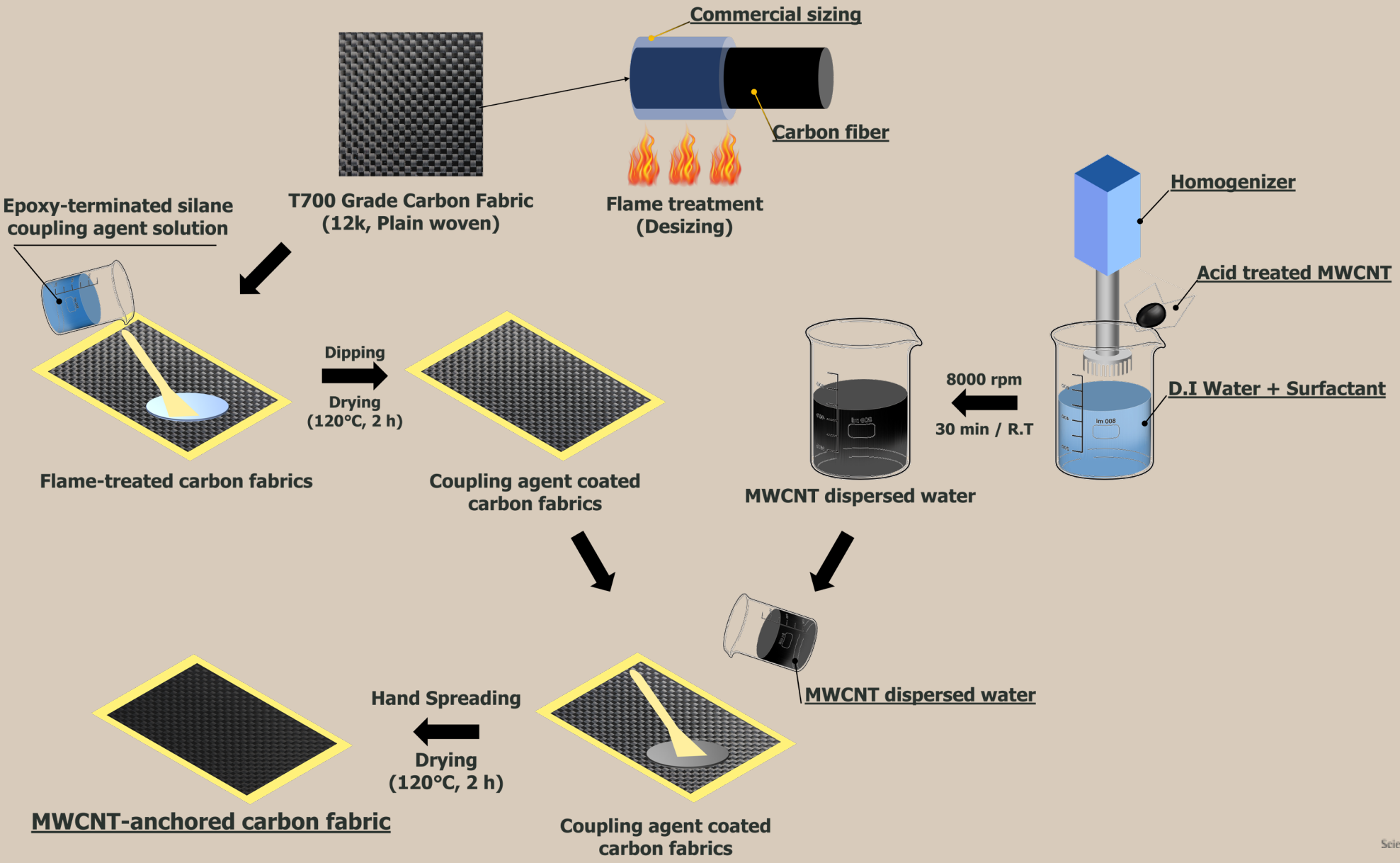


- CNT anchoring for load transfer
- Chemical + mechanical

- Mass production possible
  : Applicable for large area
- Low price treatment

KIST
Korea Institute of Science and Technology

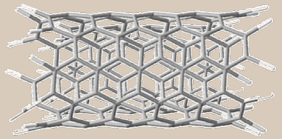
MWCNT-anchored carbon fiber fabrication process



Korea Institute of Science and Technology

MWCNT-anchored carbon fiber chemical bonding

MWCNT

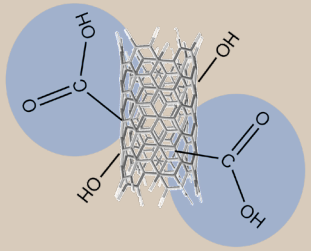


Acid Treatment

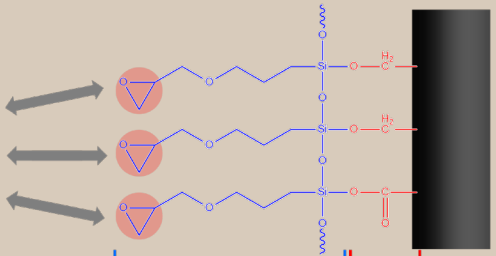
Carbon Fibers

Flame Treatment
&
Epoxy-terminated Silane Coupling Agent Coating

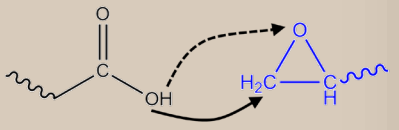
Acid-treated MWCNT

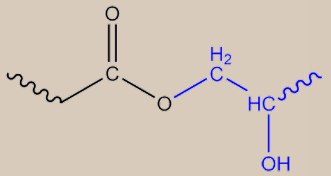


Coupling agent coated CF

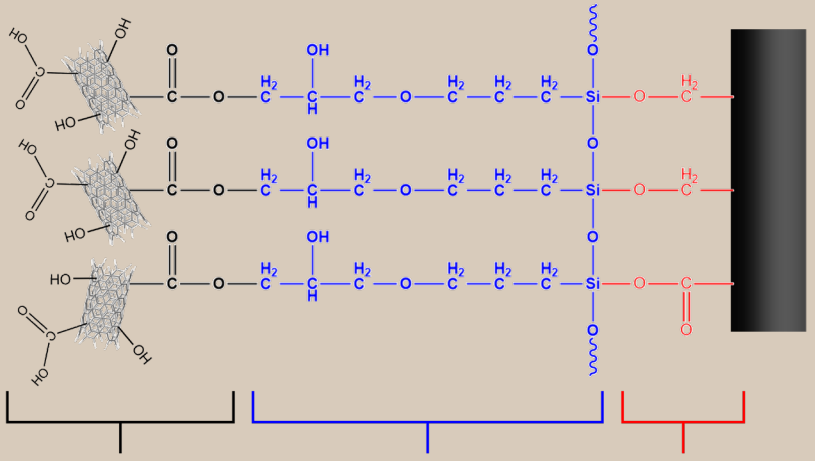


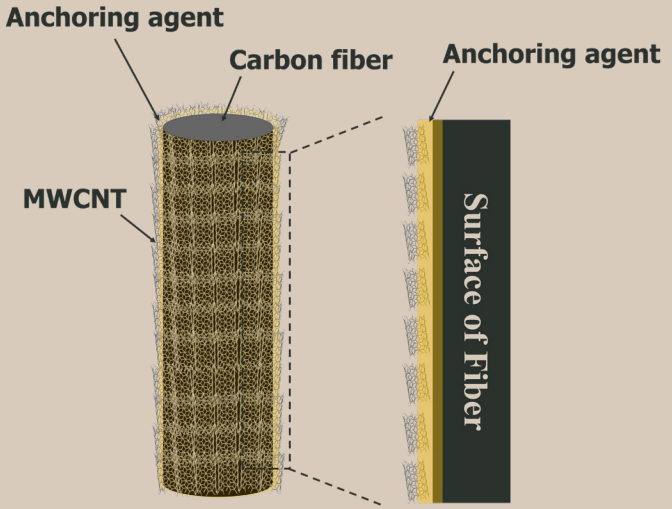
Esterification





MWCNT anchored carbon fiber

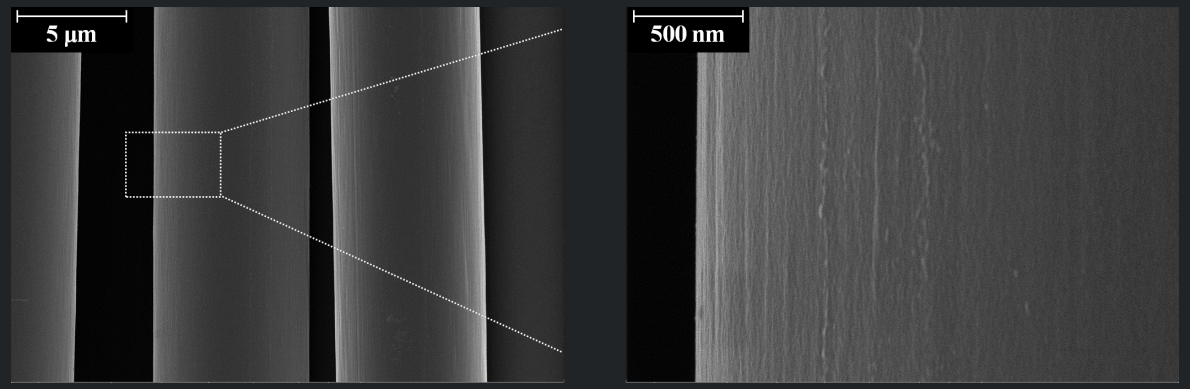




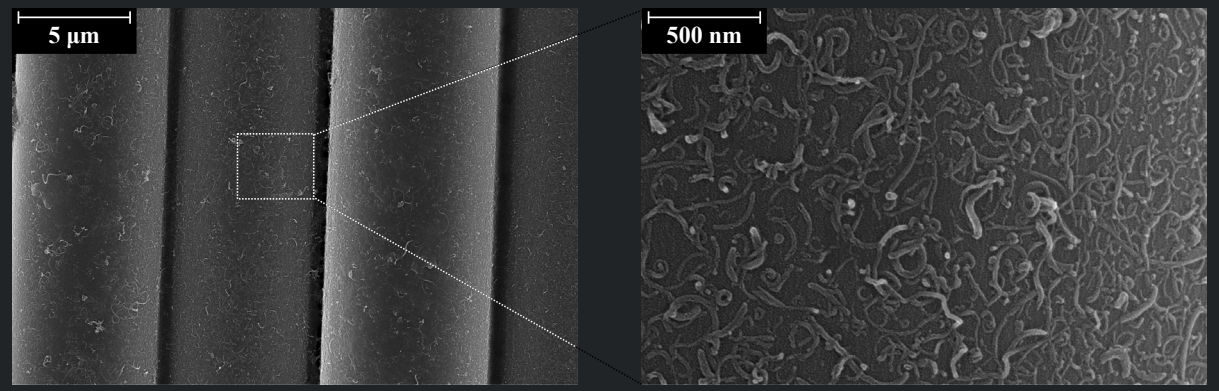
KIST
Korea Institute of Science and Technology

MWCNT-anchored carbon fiber chemical bonding

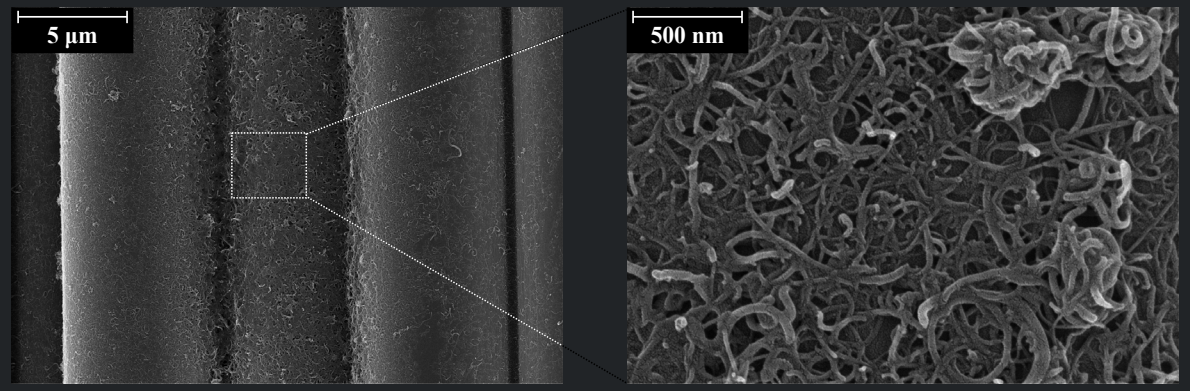
- **Pristine carbon fiber**



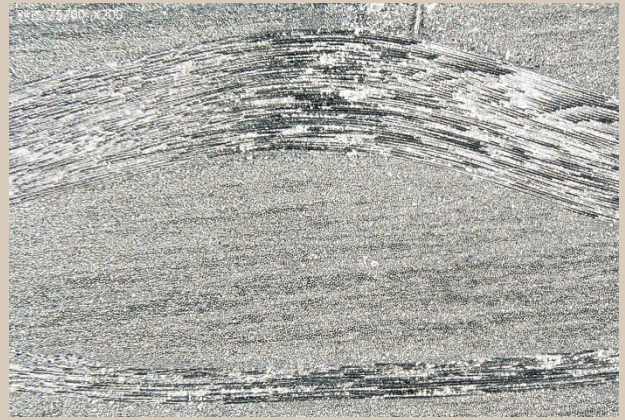
- **2 wt.% MWCNT-anchored carbon fiber**



- **4 wt.% MWCNT-anchored carbon fiber**



Cross section

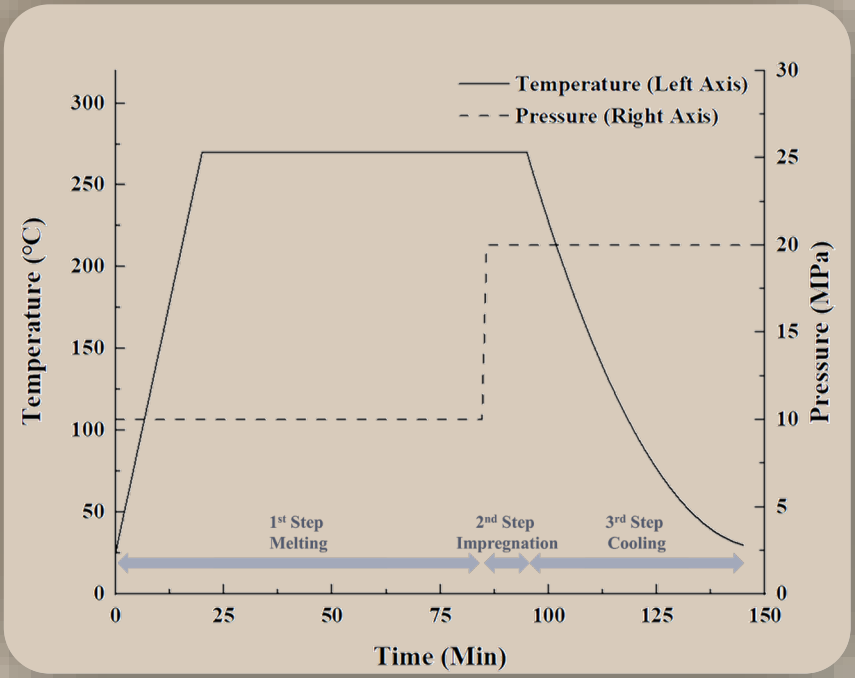


MWCNT-anchored CFRTP fabrication

- **Materials**

➢ T700 carbon fiber reinforcement
➢ PA 6 powder (< 150 μm)
➢ MWCNT 20~30 nm diameter and 10~30 μm length

- **Hot compression mold**



- **Specimens**

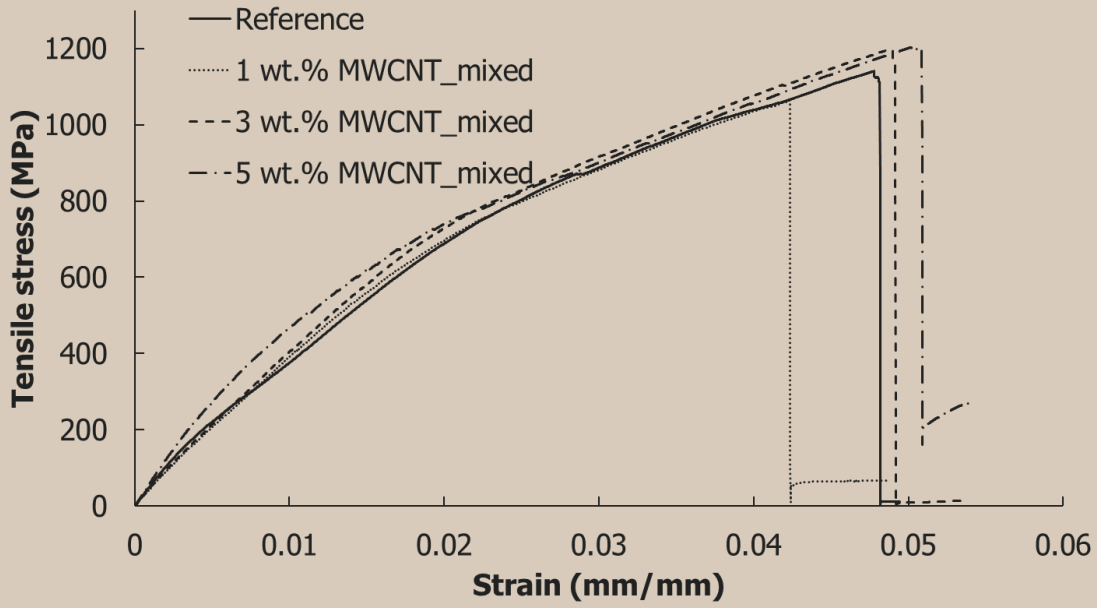
Reference specimen	
Reinforcement	**Pristine carbon fiber**
Matrix	Pure PA6 powder

MWCNT-mixed CFRTP	
Reinforcement	Pristine carbon fiber
Matrix	MWCNT mixed PA6 powder
MWCNT concentrations (wt.%) in the PA6 Matrix	1, 3, 5 wt.%

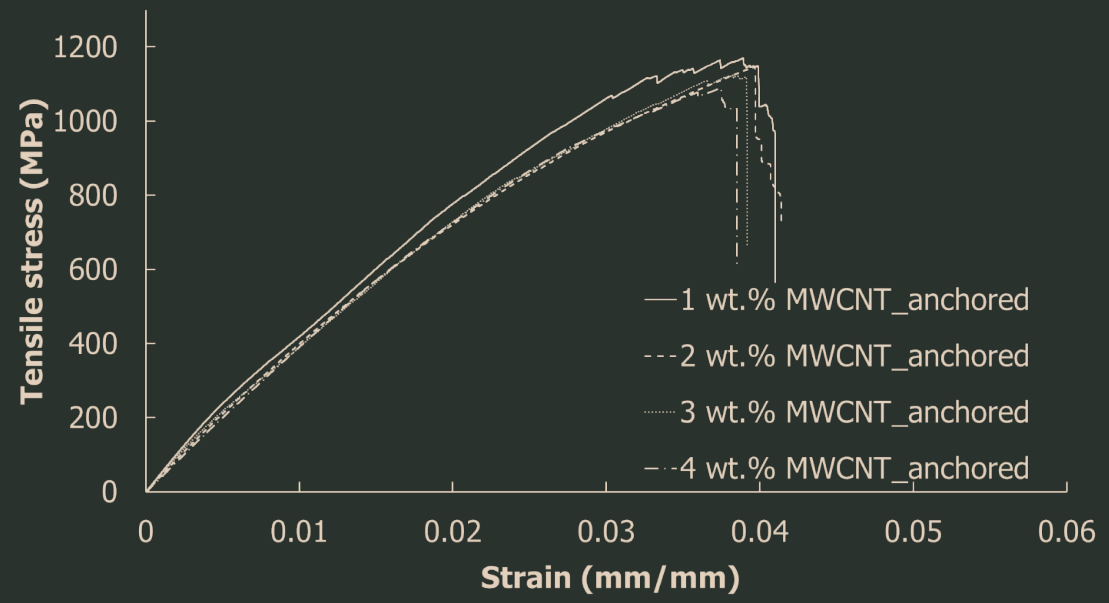
MWCNT-anchored CFRTP	
Reinforcement	**MWCNT-anchored carbon fiber**
Matrix	Pure PA6 powder
MWCNT concentrations (wt.%) in the MWCNT dispersed water	1, 2, 3, 4 wt.%

Tensile test results

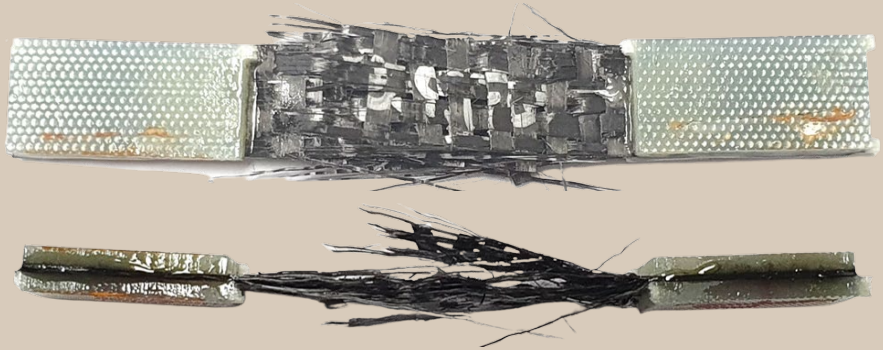
- **MWCNT simply mixed with matrix**



- **MWCNT-anchored CFRTP**



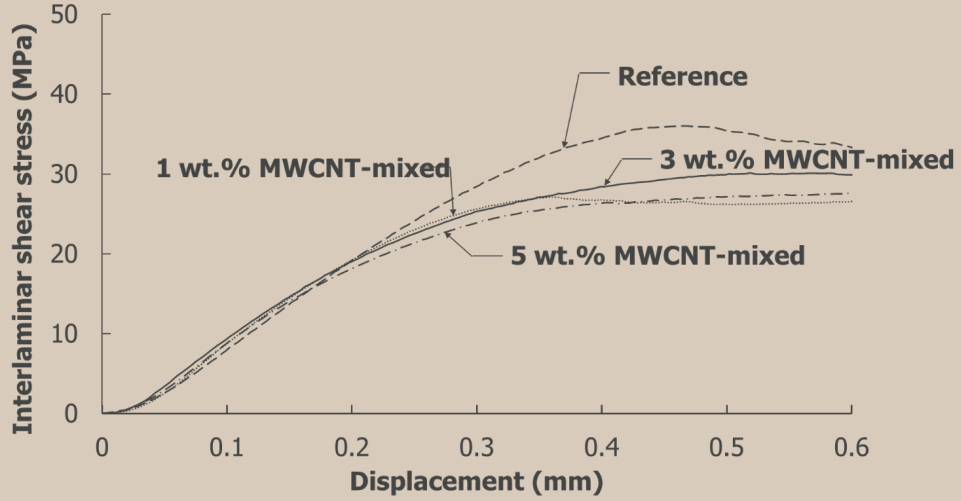
➢ **Inter-laminar failure**

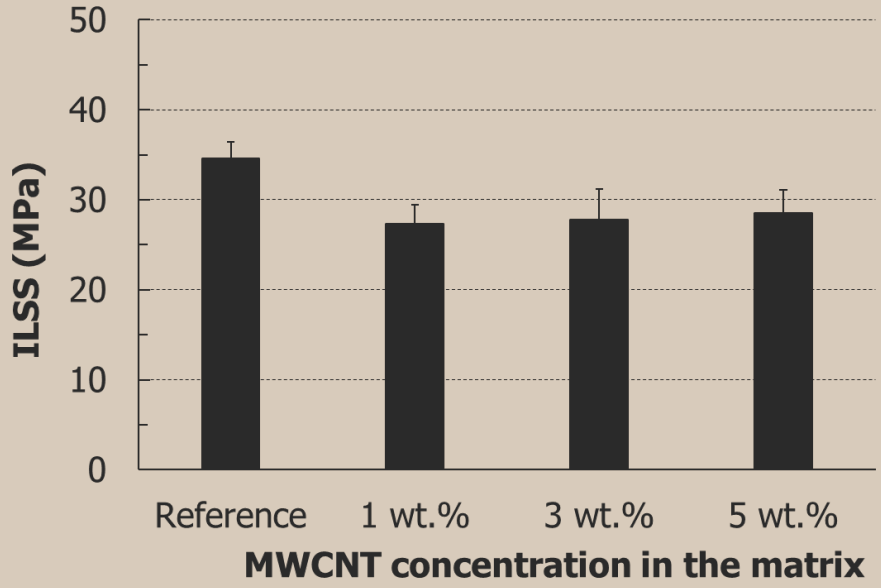


➢ Tensile failure or fiber pull-out

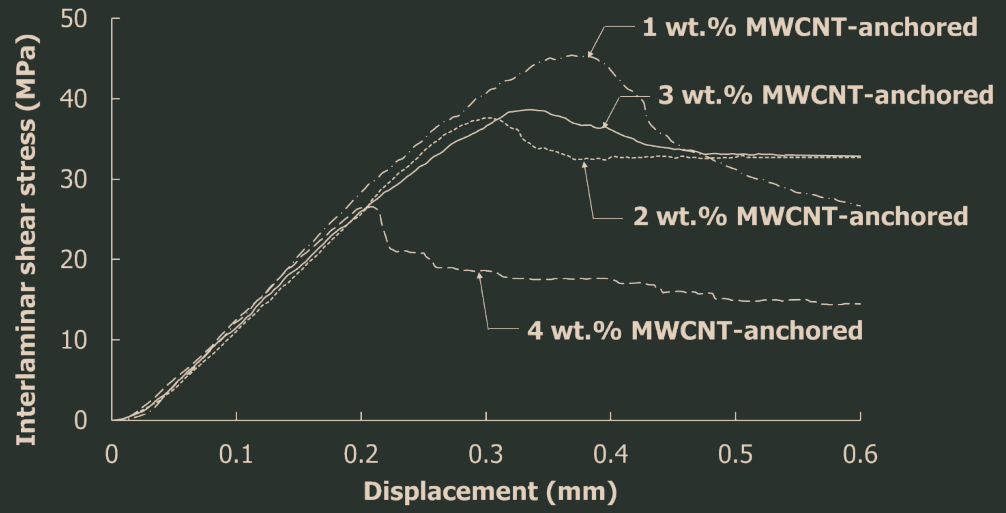
Inter-laminar shear strength

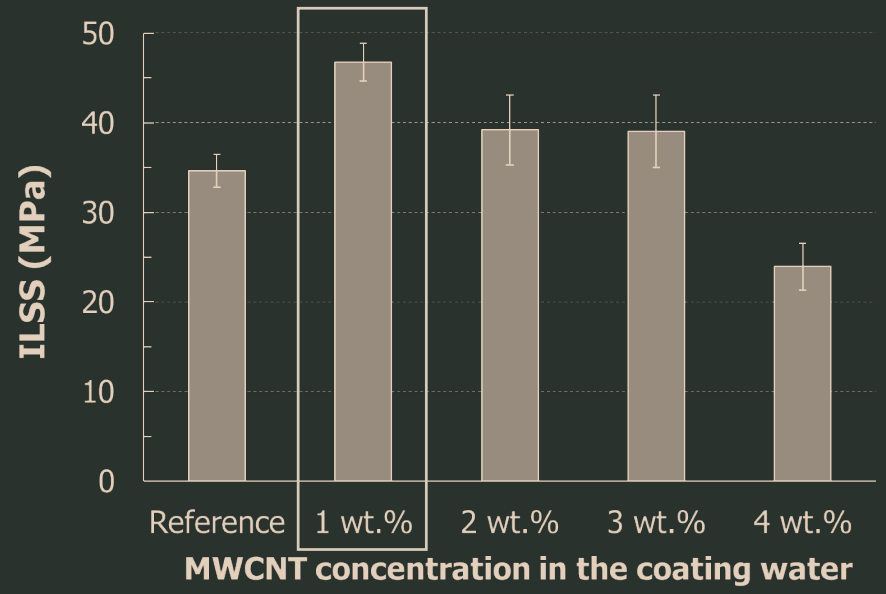
- **MWCNT simply mixed with matrix**





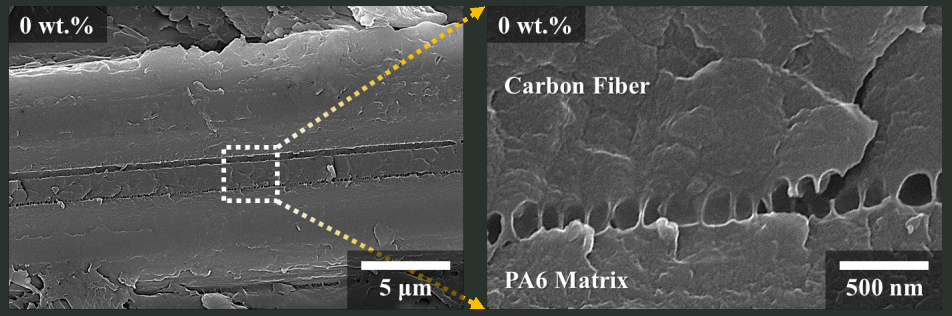
- **MWCNT-anchored CFRTP**

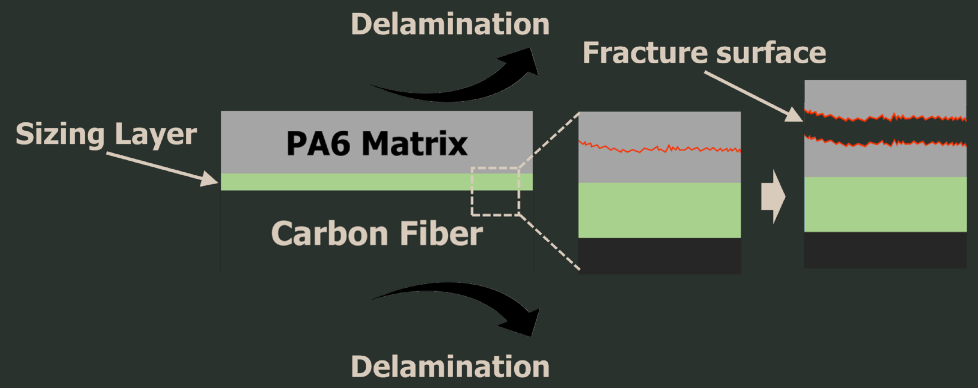




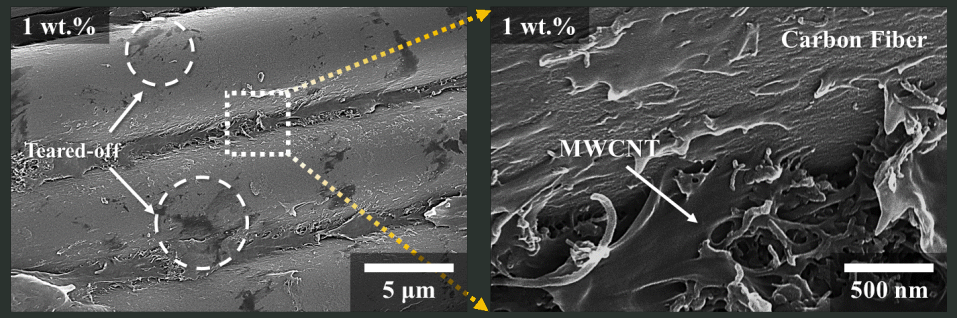
Inter-laminar shear failure surface

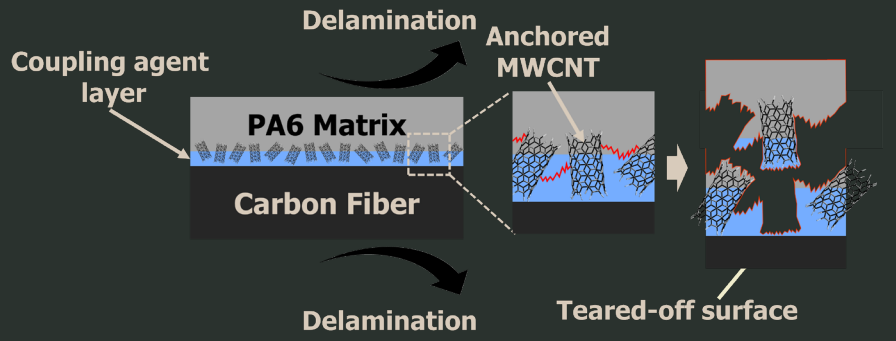
- **Pristine carbon fiber**



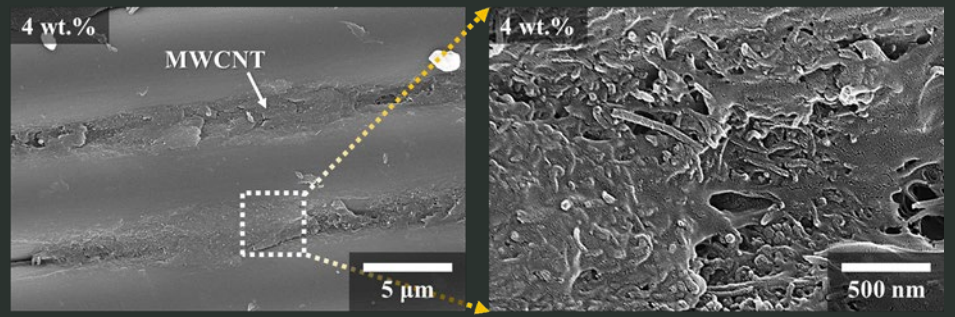


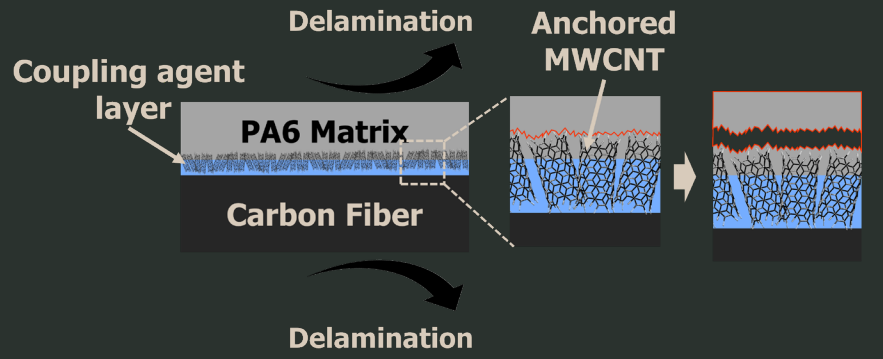
- **1 wt.% MWCNT-anchored carbon fiber**





- **4 wt.% MWCNT-anchored carbon fiber**

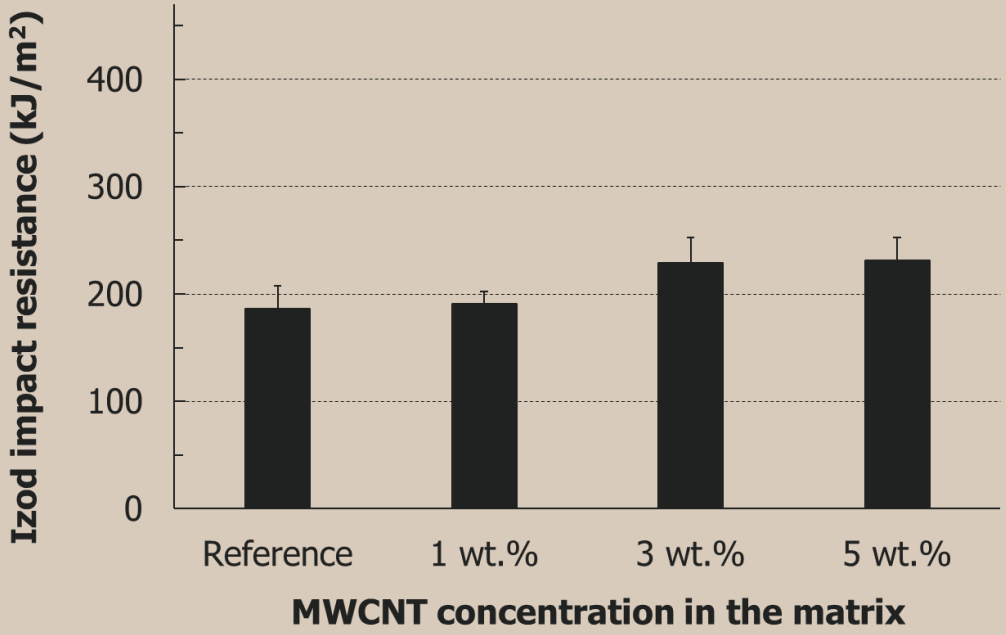


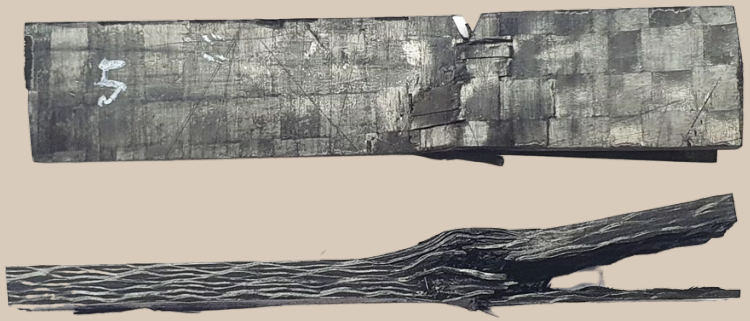


Korea Institute of Science and Technology

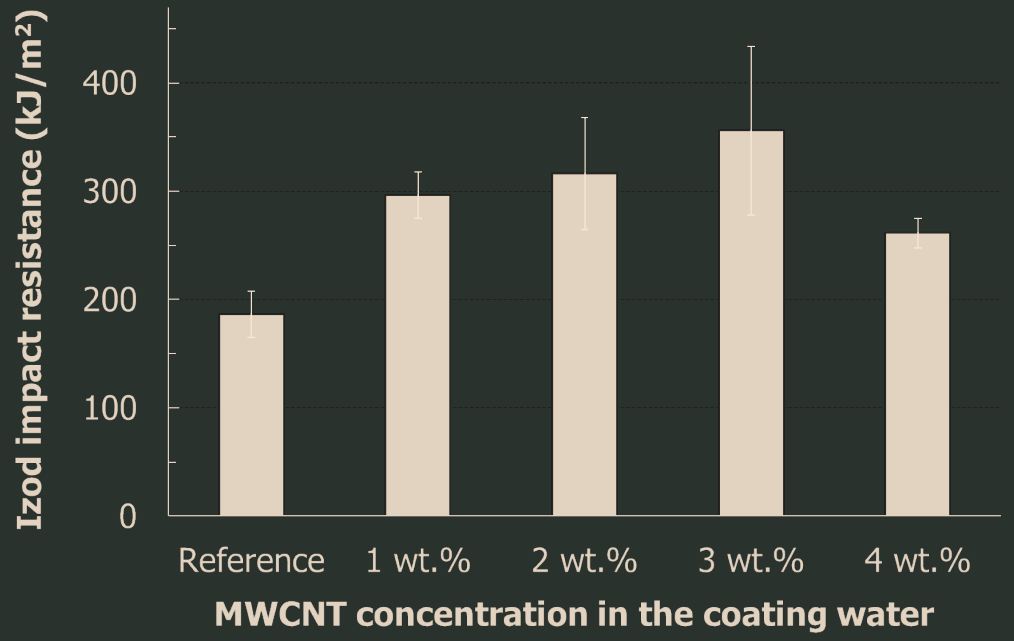
Izod impact strength

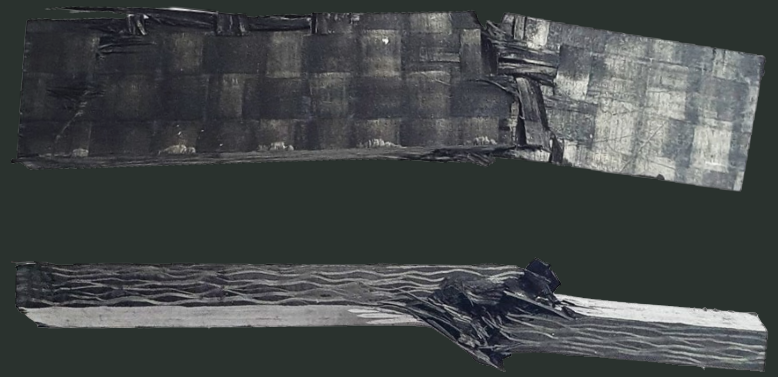
- **MWCNT simply mixed with matrix**





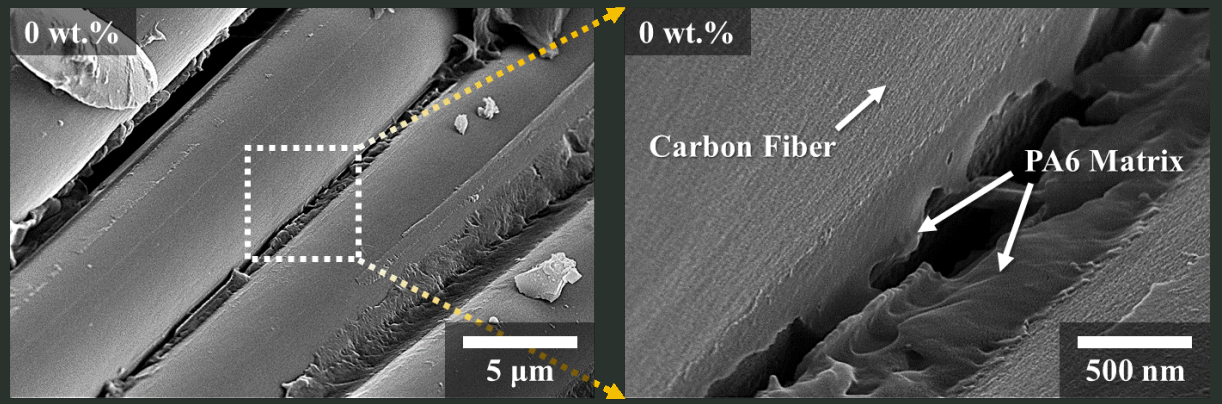
- **MWCNT-anchored CFRTP**



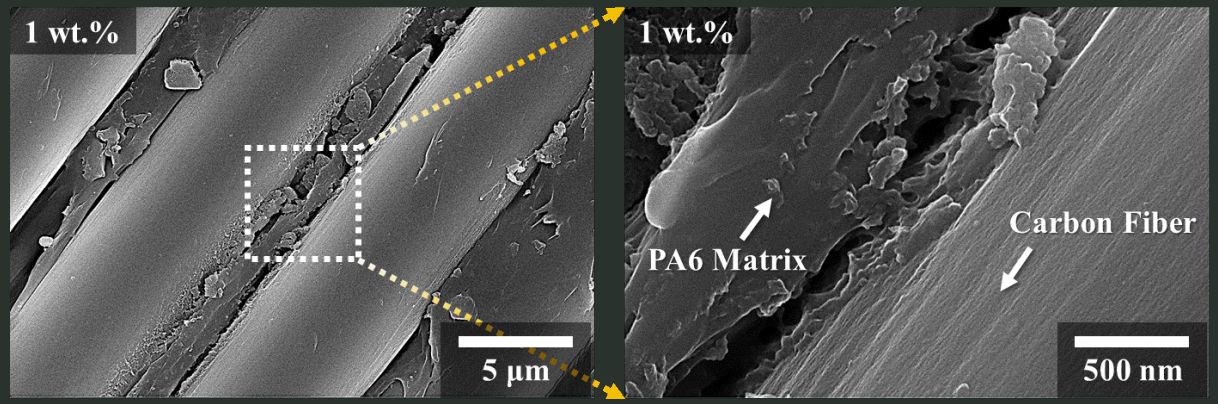


Izod impact strength

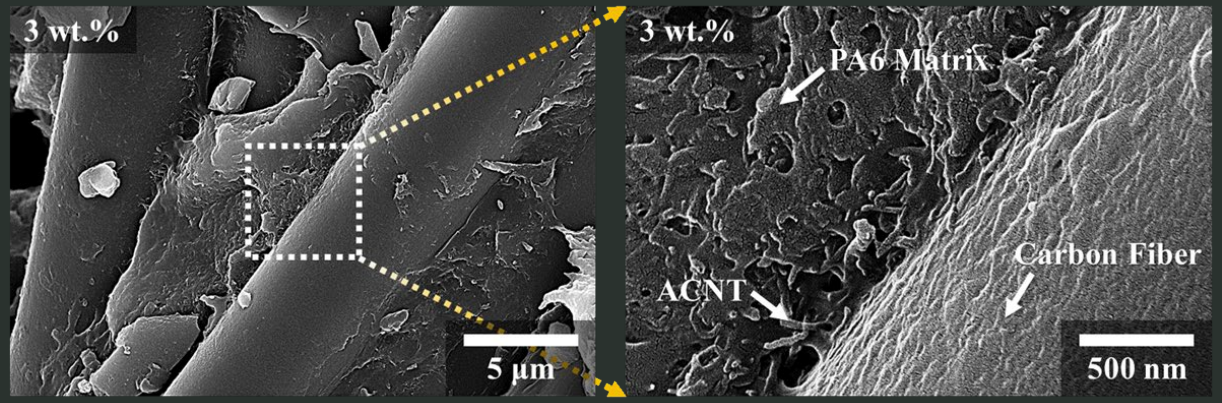
- Pristine carbon fiber



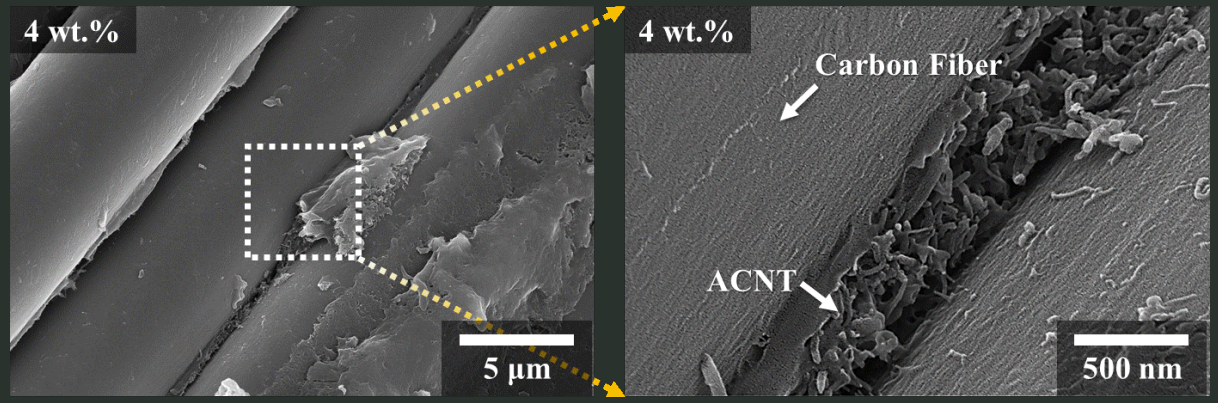
- 1 wt.% MWCNT-anchored carbon fiber



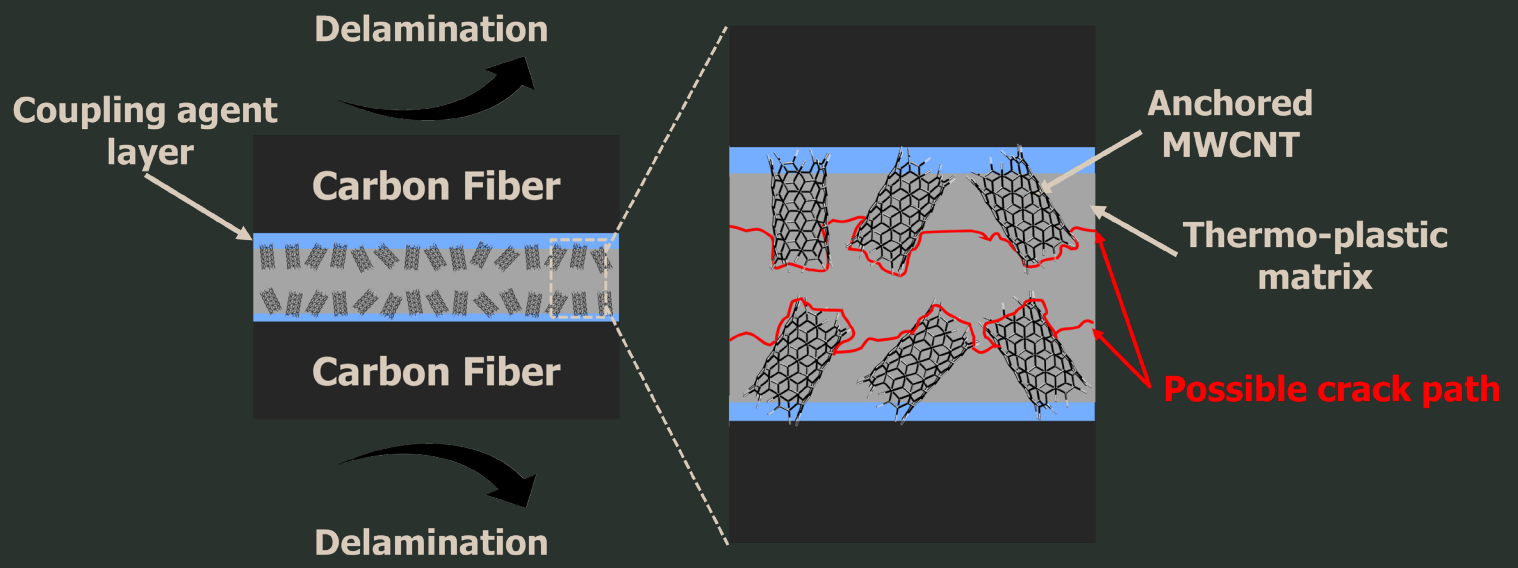
- 3 wt.% MWCNT-anchored carbon fiber



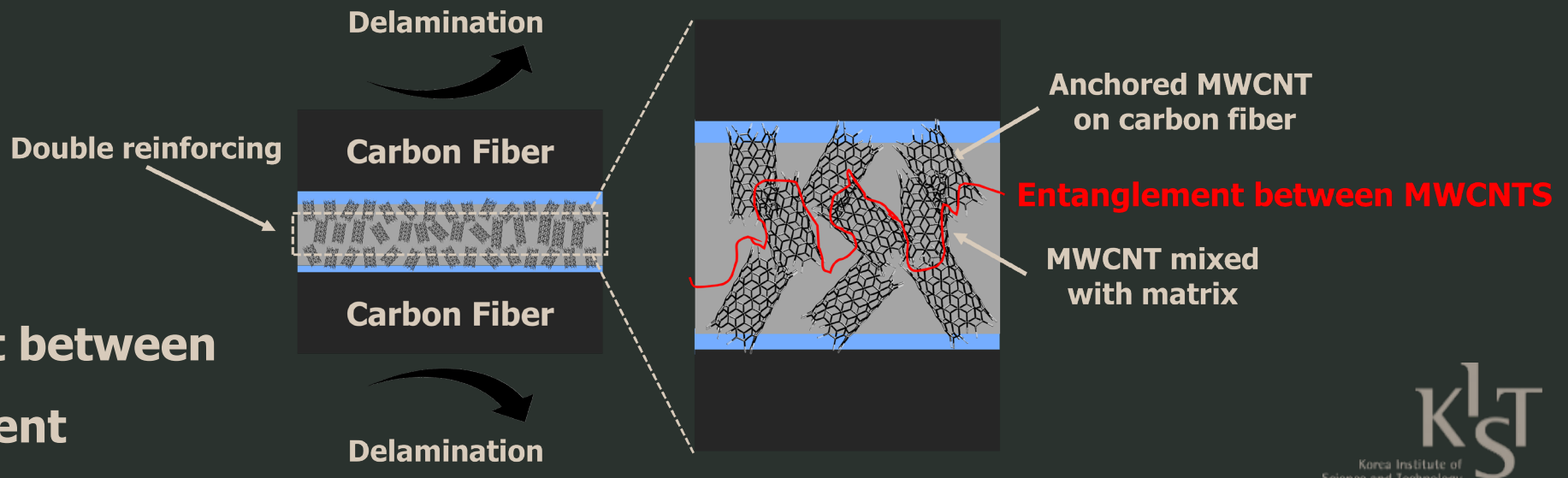
- 4 wt.% MWCNT-anchored carbon fiber



Double introduced MWCNT & entanglements



Double MWCNT reinforcing
on carbon fiber and with matrix resin



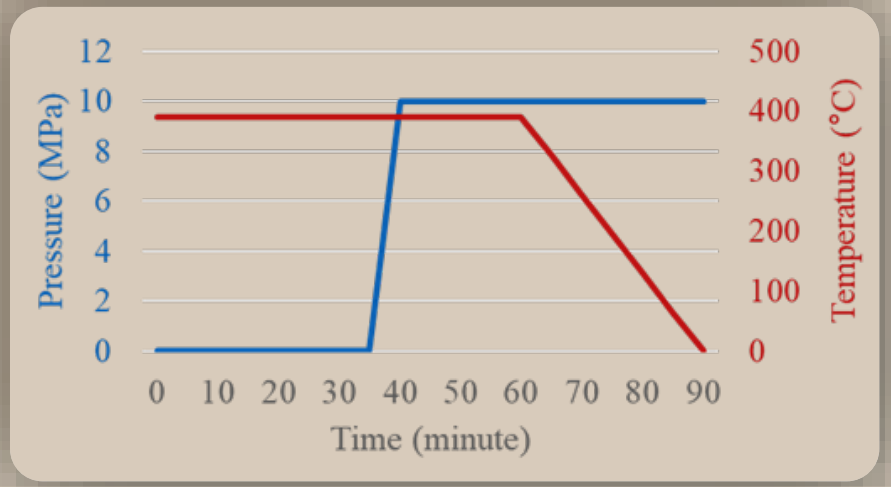
- Micro bridging effect between MWCNTs entanglement

Korea Institute of Science and Technology

Double introduced MWCNT & entanglements

- **Materials**
  - Polyether ether ketone (PEEK) powder (PEEK150UF10)
  - Particle size ~ 10 μm
  - **Melting point ~ 343°C**
  - **Processing Temp. ~ 400°C**

- **Hot compression mold**



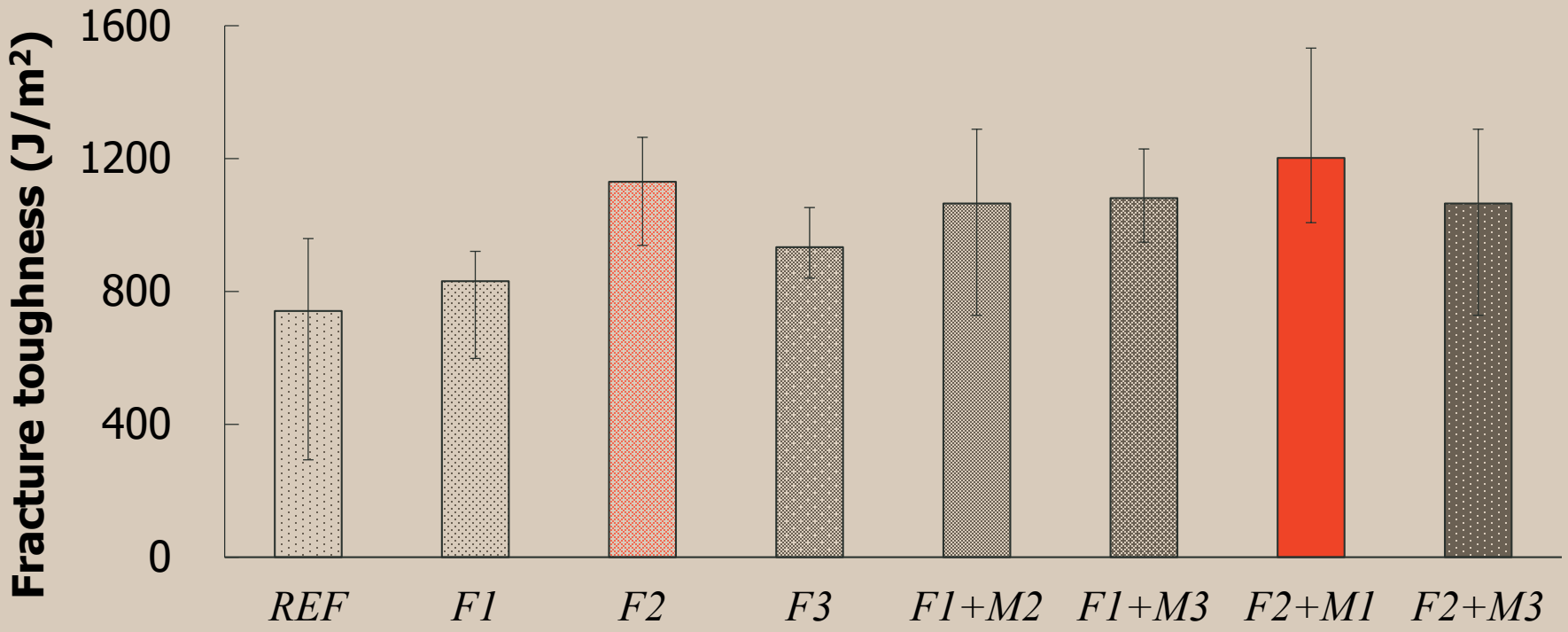
- **Specimens**

MWCNT anchored on CF	MWCNT mixed with matrix			
	0	1 wt.%	2 wt.%	3 wt.%
0	*REF*			
1 wt.%	*F1*		*F1+M2*	*F1+M3*
2 wt.%	*F2*	*F2+M1*		*F2+M3*
3 wt.%	*F3*			

KIST
Korea Institute of Science and Technology

Double introduced MWCNT & entanglements

- **MODE 1 Fracture toughness**



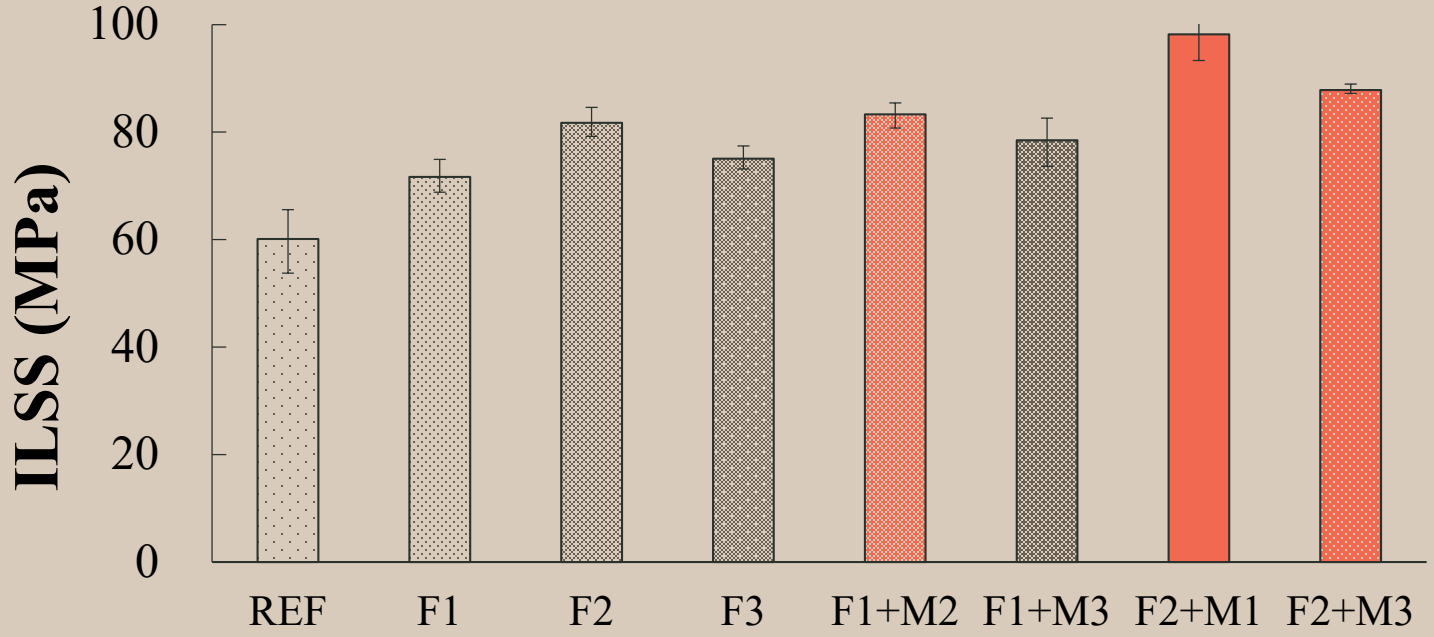
· ***REF*** had a fracture toughness of 741.4 J/m^2. The fracture toughness of ***F2*** specimens (with 2 wt.% MWCNTs anchored on the CF) increased by 50% to 1130.4 J/m^2.

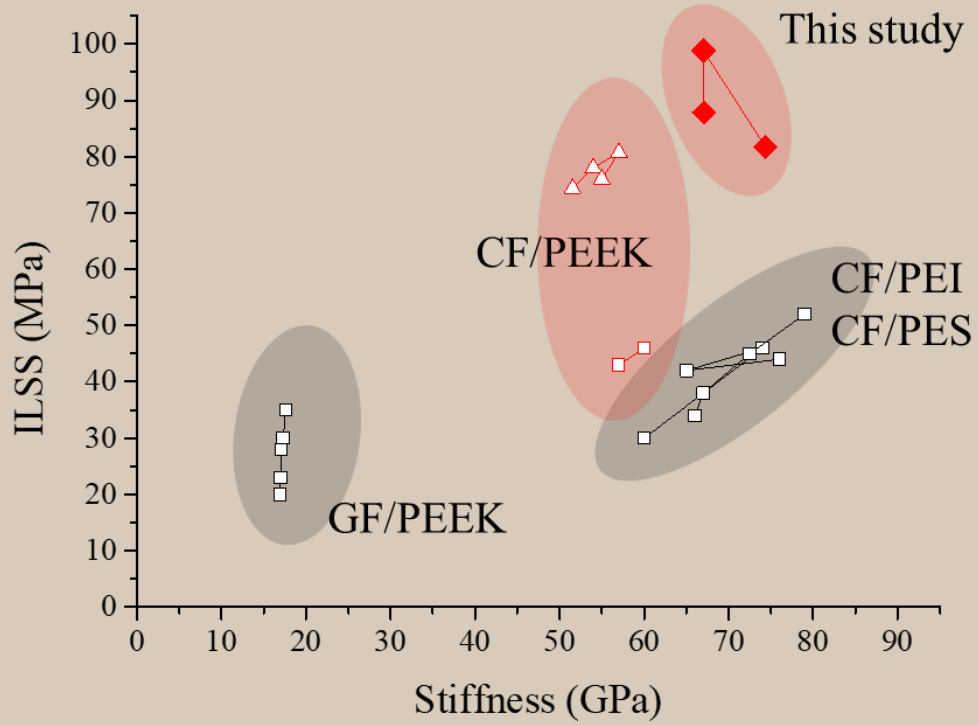
· Optimal concentration of the double MWCNTs reinforcing was ***F2+M1***, and the fracture toughness further increased by 61.7% to 1202.2 J/m^2.

KIST
Korea Institute of Science and Technology

Double introduced MWCNT & entanglements

- **Inter-laminar shear strength**





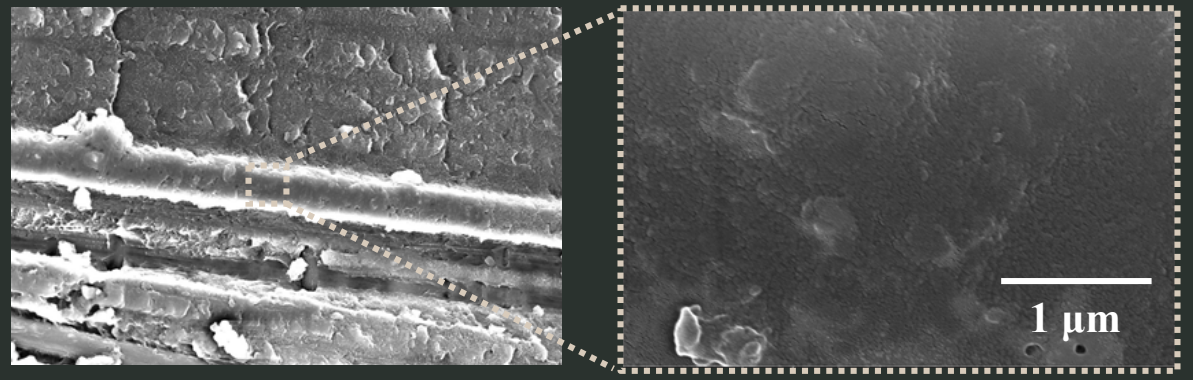
· Optimal concentration for the ILSS of the double MWCNTs reinforcing was also ***F2+M1***, and the ILSS increased by 63.4% to 98.2 MPa.

· It was confirmed that the interfacial bonding strength was significantly improved compared to the specimen in which MWCNTs were only attached to the carbon fiber.

Korea Institute of Science and Technology

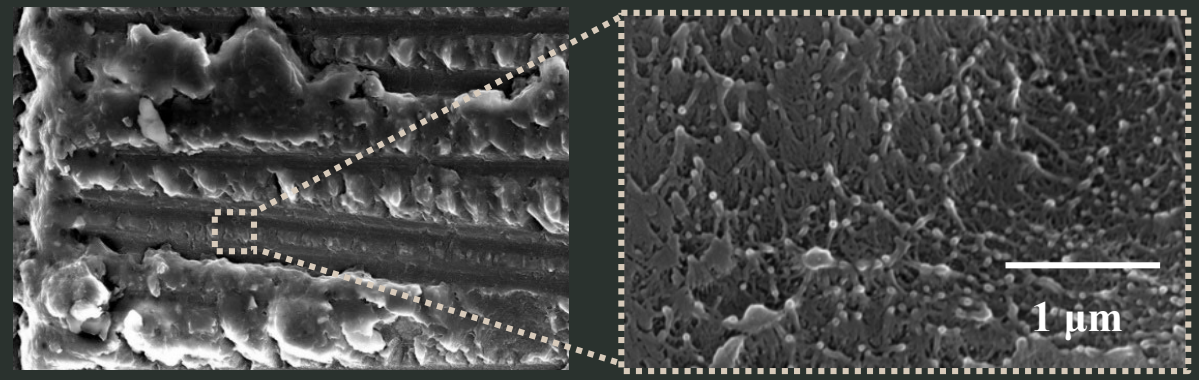
Fracture surface after the mode 1 test

- *REF*



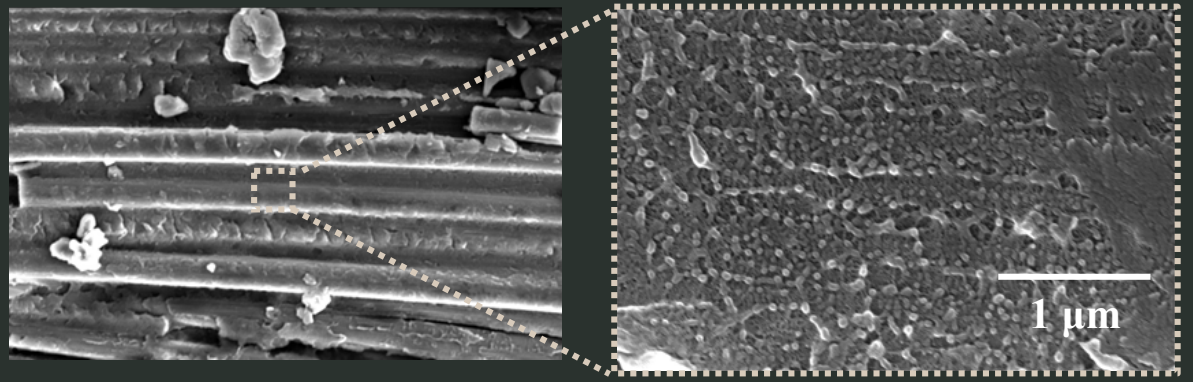
➢ Clean surface

- *F2+M1*



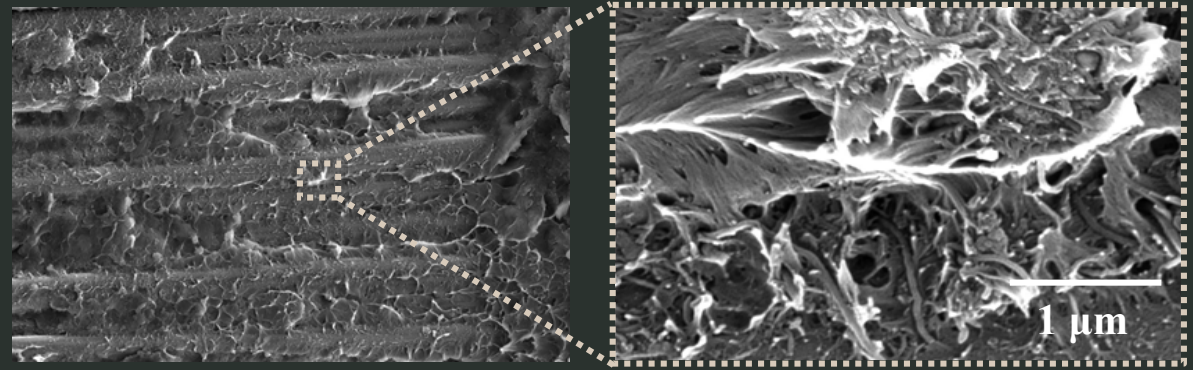
➢ Uni-direction fracture due to bridge effect

- *F2*



➢ Visibility of MWCNTs within the fractured area

- *F2+M3*



➢ *F2+M3* - MWCNT aggregation

Conclusions

- MWCNT-anchored carbon fibers were developed to improve the impact resistance and ILSS of CFRTPs. The MWCNTs were chemically anchored on the CF through an esterification reaction.
- Simply mixing MWCNTs with the thermoplastic matrix increased the Izod impact resistance of the resulting CFRTP; however, it decreased the corresponding ILSS due to the increased resin viscosity.
- The ILSS and the impact resistance of the MWCNT-anchored CFRTP were increased by 34% and 91%, respectively, with optimum MWCNT-anchoring concentrations.
- By double MWCNTs reinforcing on CF (2 wt.%) and with thermoplastic matrix (1 wt.%), the ILSS of the PEEK based CFRTP increased by 63.4% to 98.2 MPa.
  It is the results of the strong entanglement between the doubly introduced MWCNTs prevented crack propagation and maximized the fracture length.

Thank you

Q & A

Korea Institute of Science and Technology
KIST
한국과학기술연구원

ICCM 23
INTERNATIONAL CONFERENCE ON
COMPOSITE MATERIALS
BELFAST 2023
30 JULY – 4 AUGUST