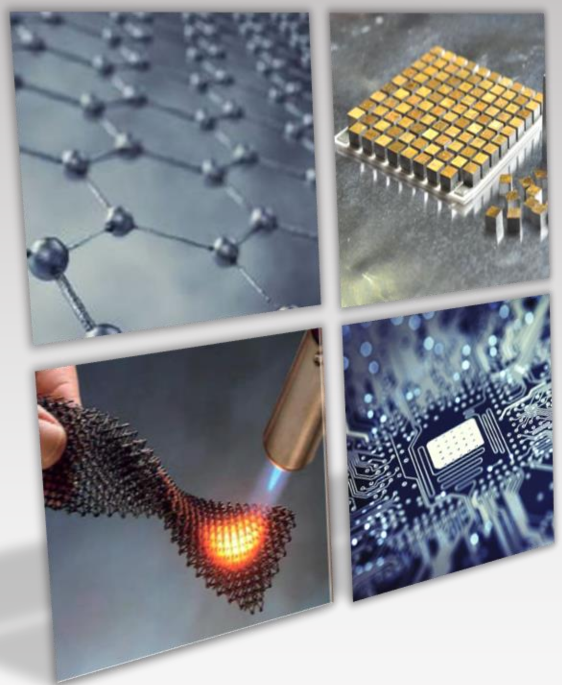
Technical University of Denmark, Denmark
Department of Wind Energy

Harbin Institute of Technology, China
Department of Materials

Air-to-air atmospheric pressure plasma treatment-perspective for composite manufacturing



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DACOMAT

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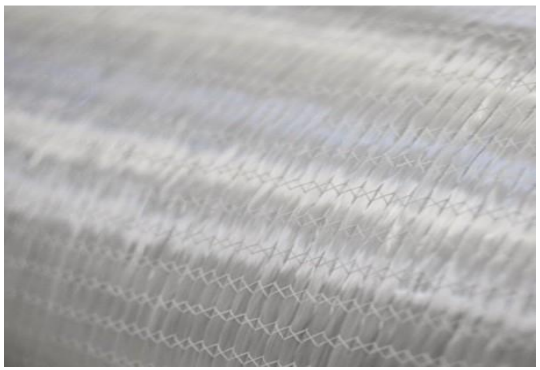
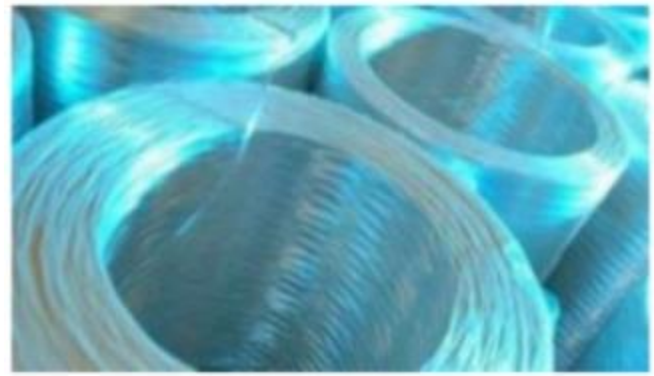
1. Background

Glass fibre reinforced polymer (GFRP) composites are widely used due to high strength-to-weight ratios, mechanical and corrosion resistance properties



GFRP Sheets



Glass fibre roving

Sporting equipment

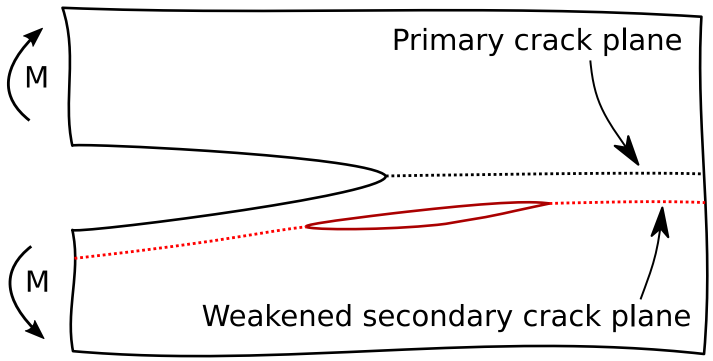
Vehicles

Architectures

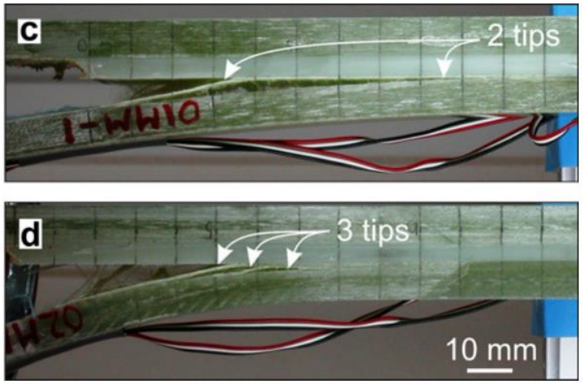
Wind turbine blades

1. Background

Introduction of a weak secondary plane in a composite layup may induce multiple delamination cracks [Goutianos & Sørensen 2016]. Multiple cracks have been shown experimentally (Double cantilever beam (DCB) with applied moments) to significantly enhance the fracture resistance of UD composites [Rask & Sørensen 2012].



Schematic of secondary delamination cracking in composite specimen under applied moments.



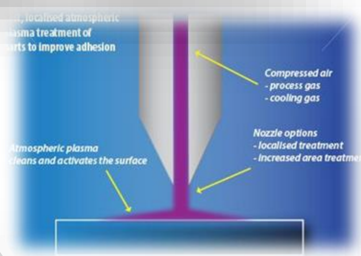
Mixed mode DCB specimen showing multiple cracks.
Source: Rask & Sørensen 2012

1. Background

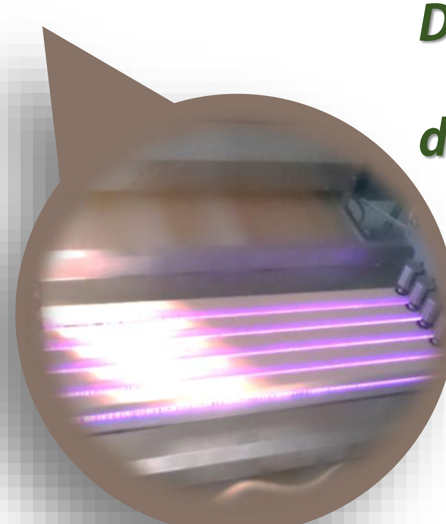
Atmospheric pressure plasma treatment

Gliding arc

Cold plasma torch

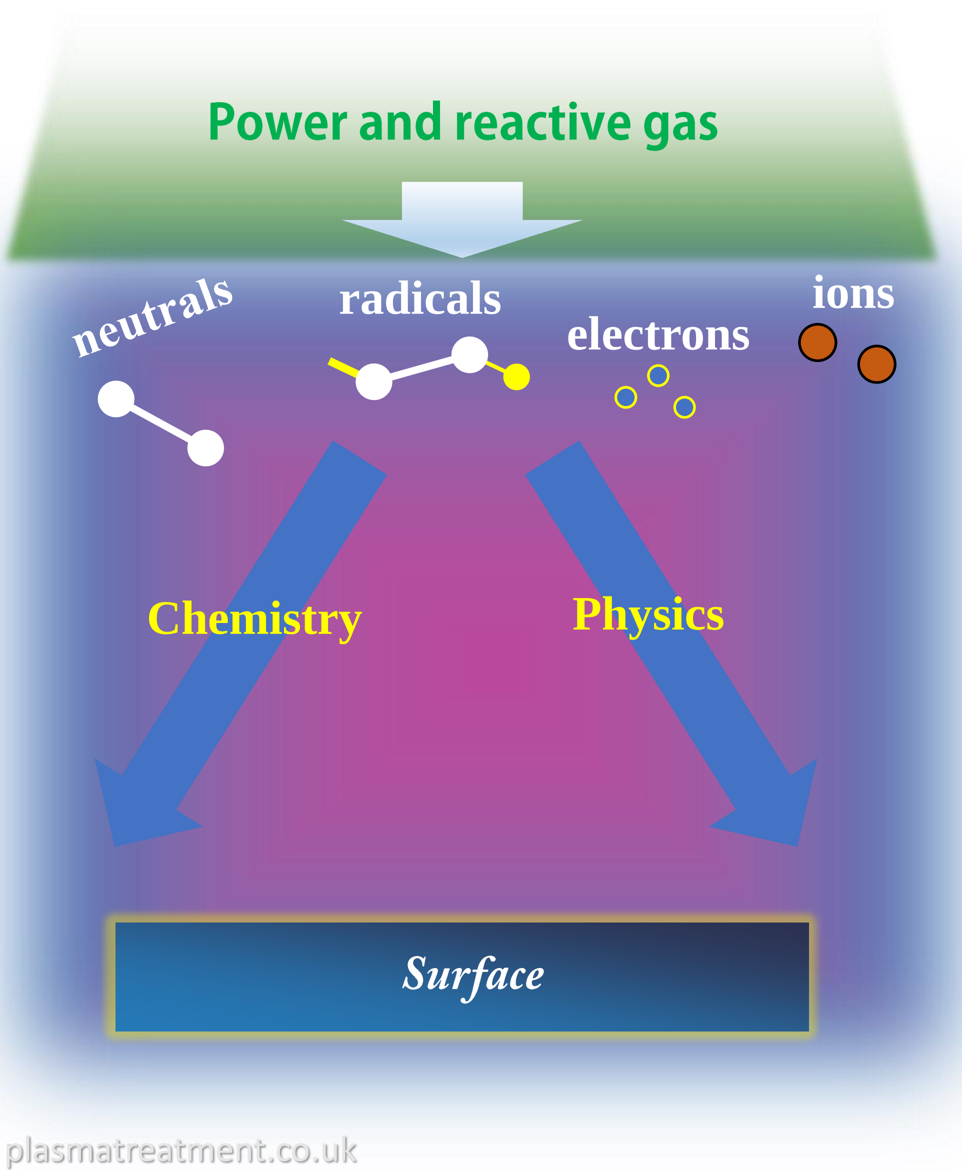


Dielectric barrier discharge (DBD)



- **High efficiency**
- **Environmental**
- **Easy operation**

1. Background



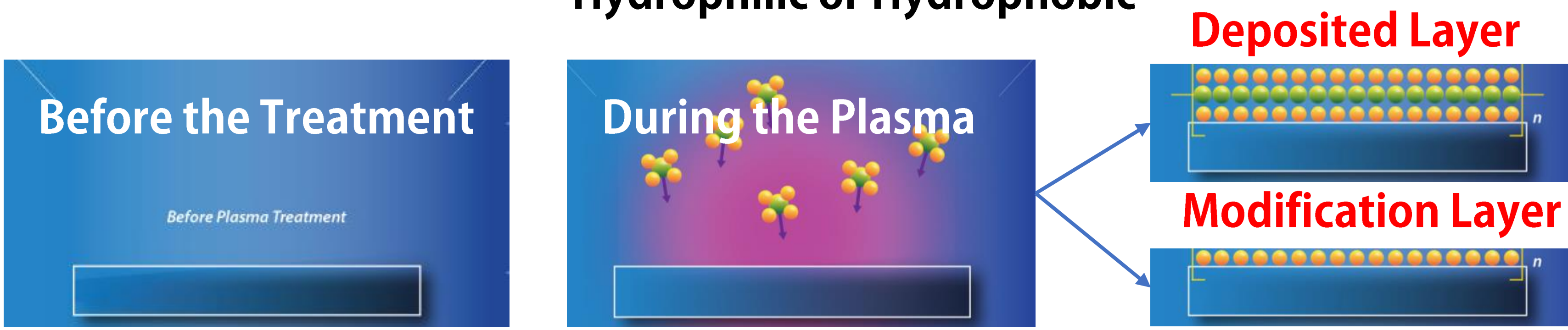
DBD treatments are often used to alter the surface properties of a wide range of materials to make them easier to bond, glue and paint.

Usually this method is to improve their adhesion , but what we do is the opposite

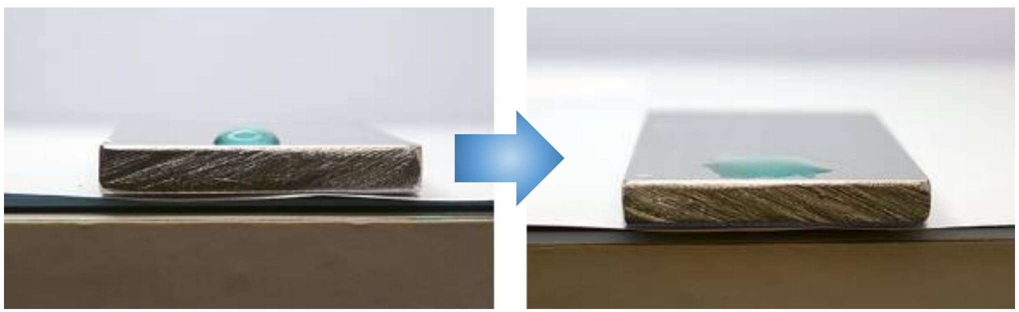
A plasma contains positive ions, electrons, neutral gas atoms or molecules, which can carry a large amount of internal energy. All of these components can interact with the surface during plasma treatment. By choose the gas mixture, power, pressure etc. we can control the effects of the plasma treatment simply.

1. Background

Hydrophilic or Hydrophobic

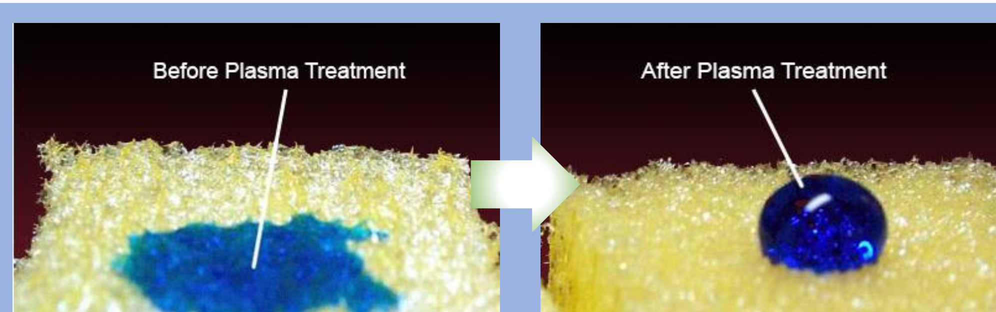


Different modification directions



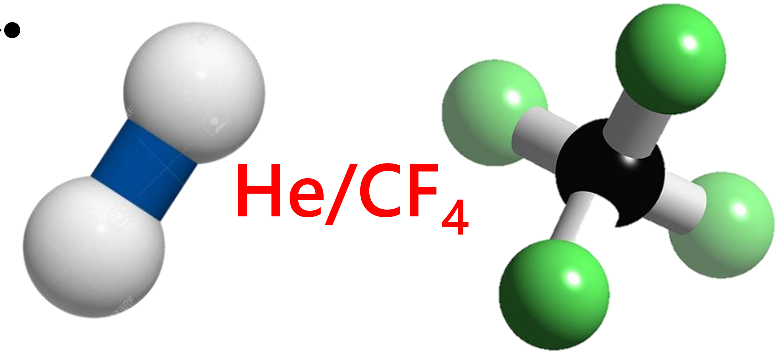
Hydrophilic

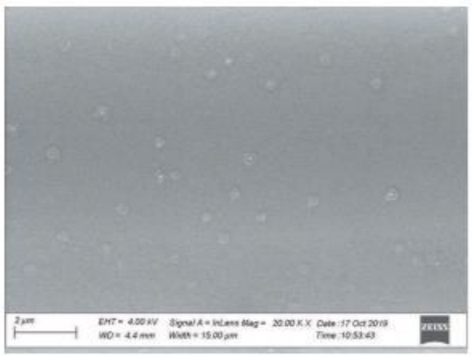
Hydrophobic
(Our research)



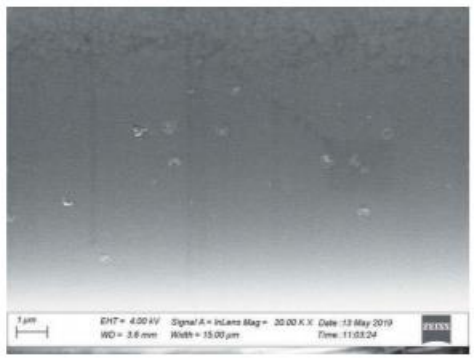
1. Background

Designed lower interactions between glass fibre fabrics with a polymer matrix by creating a TEFLON like surface using a DBD in a helium/tetrafluoromethane (He/CF_4) gas mixture.

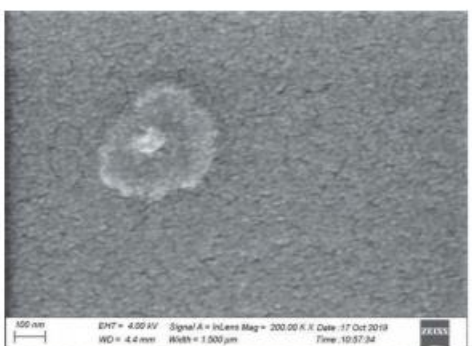




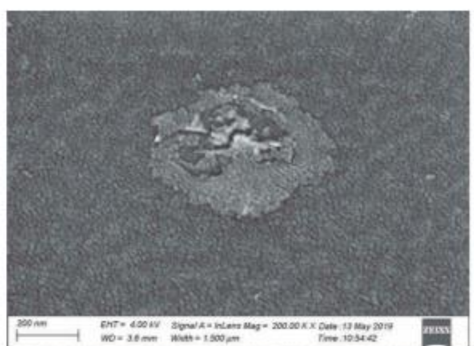
(a) Untreated fibre.



(b) Treatment: DBD 100W.



(c) Untreated fibre.



(d) Treatment: DBD 100W.

By introducing fluorine, wetting rates with glycerol are significantly reduced for fibres treated with plasma in He/CF_4.

Cederløf, D. J. H., Kusano, Y., & Fæster, S. Fluorination of sized glass fibres for decreased wetting by atmospheric pressure plasma treatment in He/CF_4. The Journal of Adhesion,2020

1. Background

It is reported that use of plasma polymerizable fluorocarbons such as hexafluoropropylene (HFP. C_3F_6) and octafluorocyclobutane (OFB. C_4F_8) in a DBD exhibits better hydrophobic effects than use of CF_4

Kusano Y, Yoshikawa M, Naito K, Okazaki S, Kogoma M 1994 SPSM 7 77-81

2. Main Content

Research strategy

Toughness of composites should be improved

Requirement: **We want multiple cracks**

By introducing weak layer

Approach: **By introducing weak layer**

At present

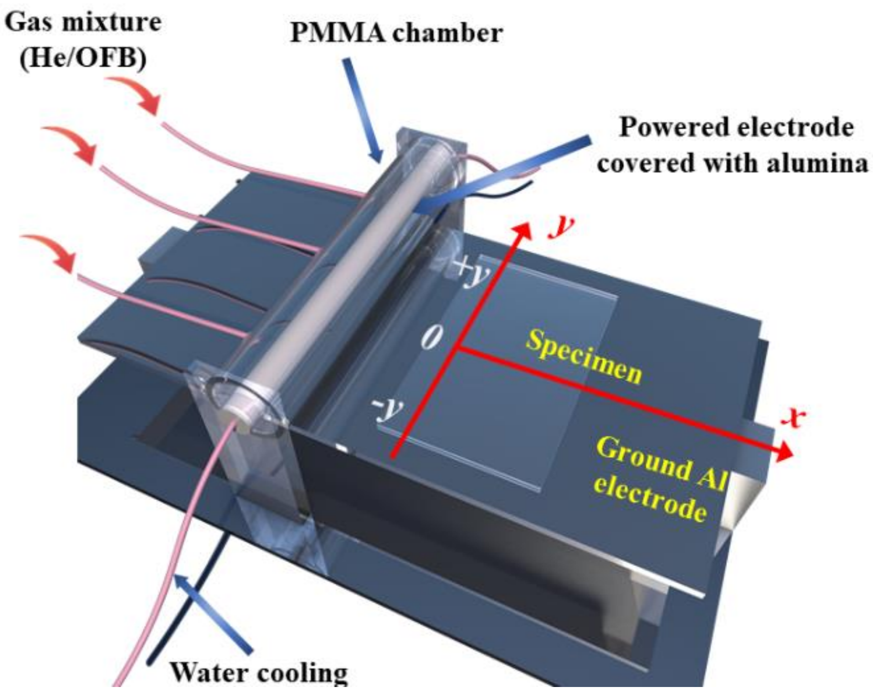
DBD in OFB is how we introduce TEFLON like weak layer

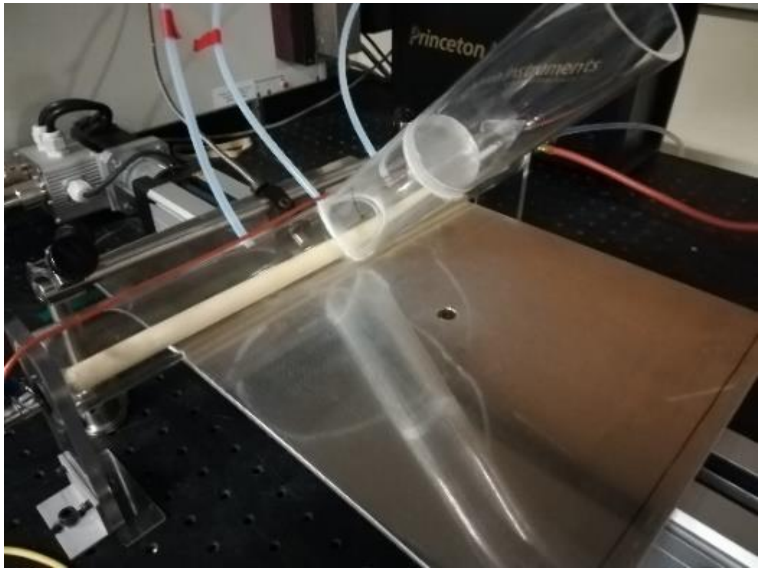
Our work

Air-to-air atmospheric pressure plasma treatment – perspective for composite manufacturing

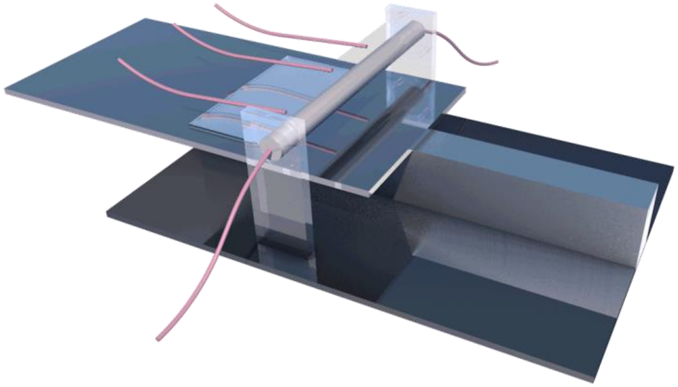
2. Main Content

Photo image and a diagram of the device

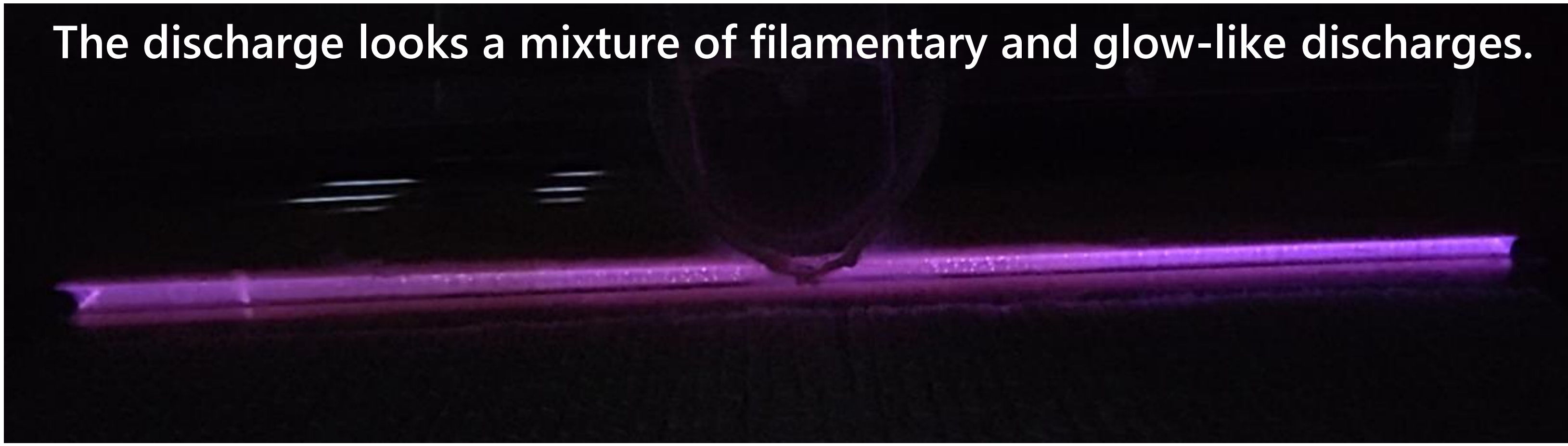




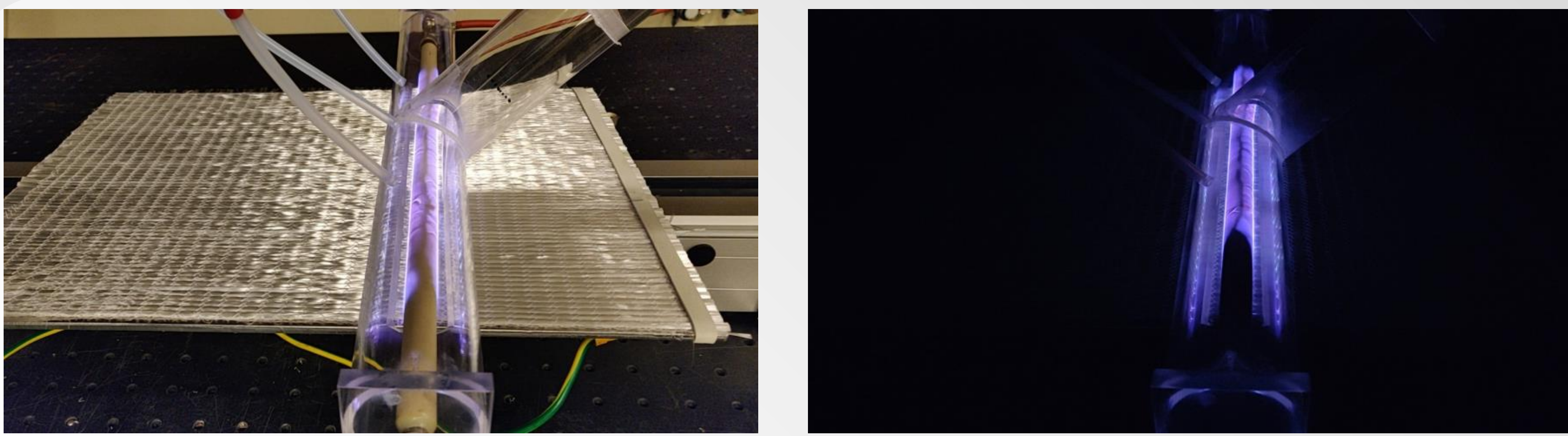
- The powered electrode is water-cooled cylindrical metallic tube covered with an alumina tube;
- Inner and outer diameters of the alumina tube are 12 and 16 mm;
- The lower ground electrode is an aluminium plate (280 mm x 400 mm);
- The gap between the alumina tube and the aluminium plate was adjusted to 0.6 mm or 2.0 mm.



2. Main Content



Front view: A photo of the DBD in He/OFB gas mixture (gap: 2.0 mm, MR value: 0.45 %).



Side views: treatment of glass fabric

2. Main Content

Gas mixing ratio

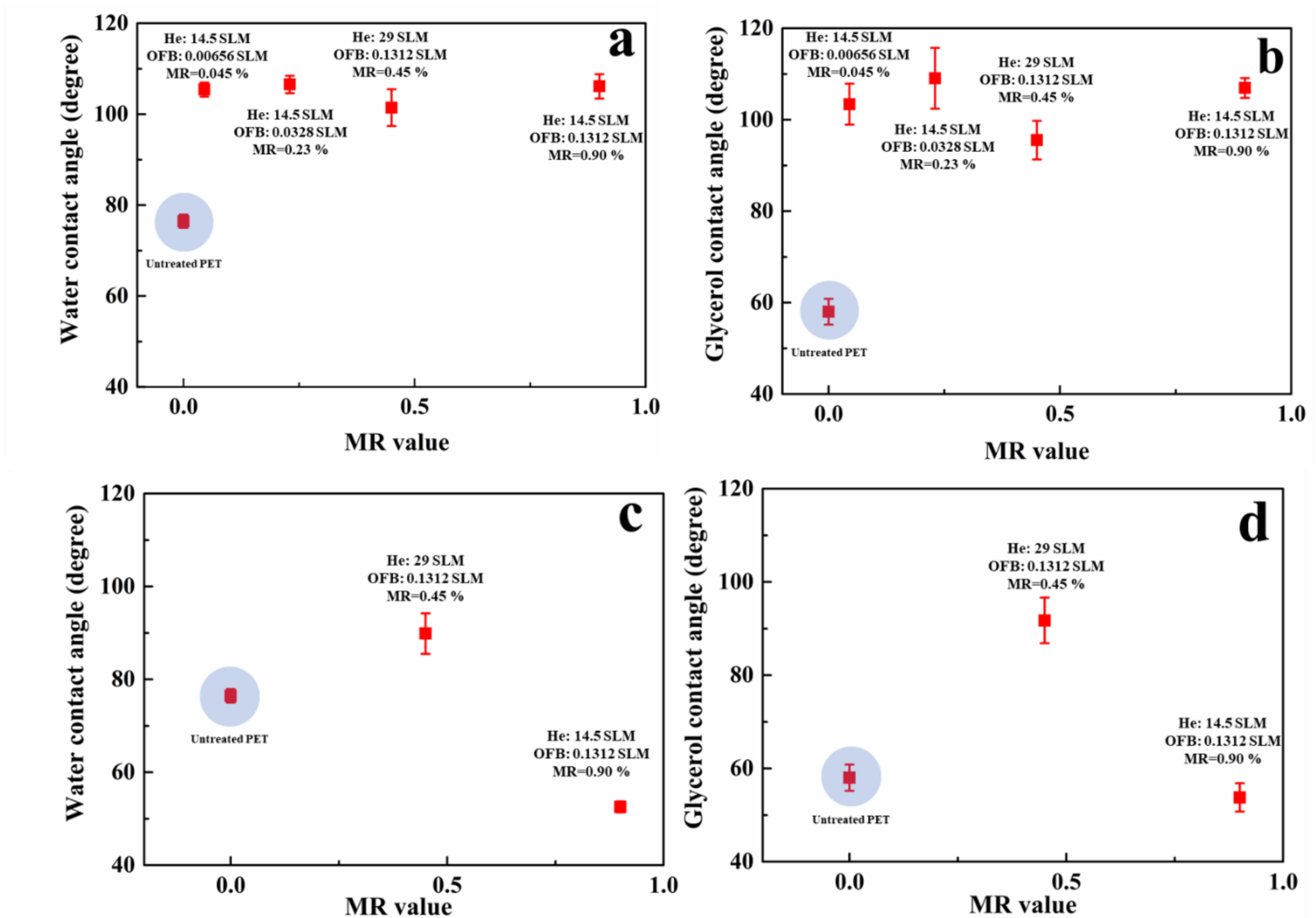
Gas mixing ratio (MR) is defined as :

$$MR = F_{OFB} / (F_{He} + F_{OFB}) \times 100 \text{ (vol. \%)},$$

F_{OFB} and F_{He} are the flowrates of OFB and He

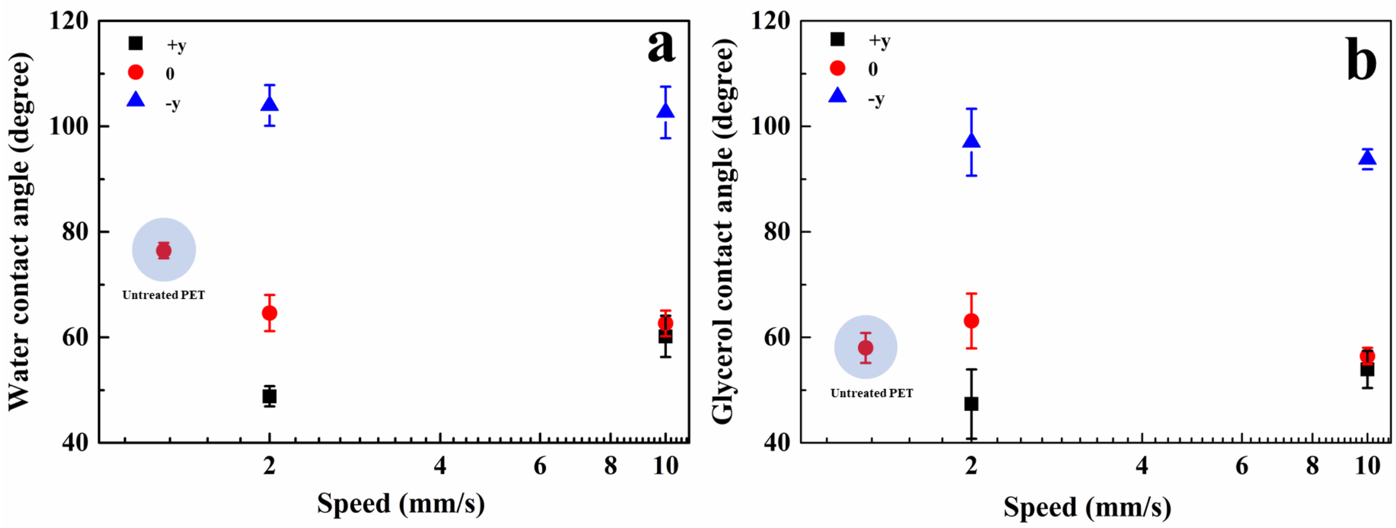
- ☐ He and OFB were used as a dilute gas and a reactive gas;
- ☐ The flowrate of He was adjusted between 14.5 and 29 standard litre per minute (SLM);
- ☐ OFB flowrate was adjusted between 0.066 and 0.262 SLM.

2. Main Content

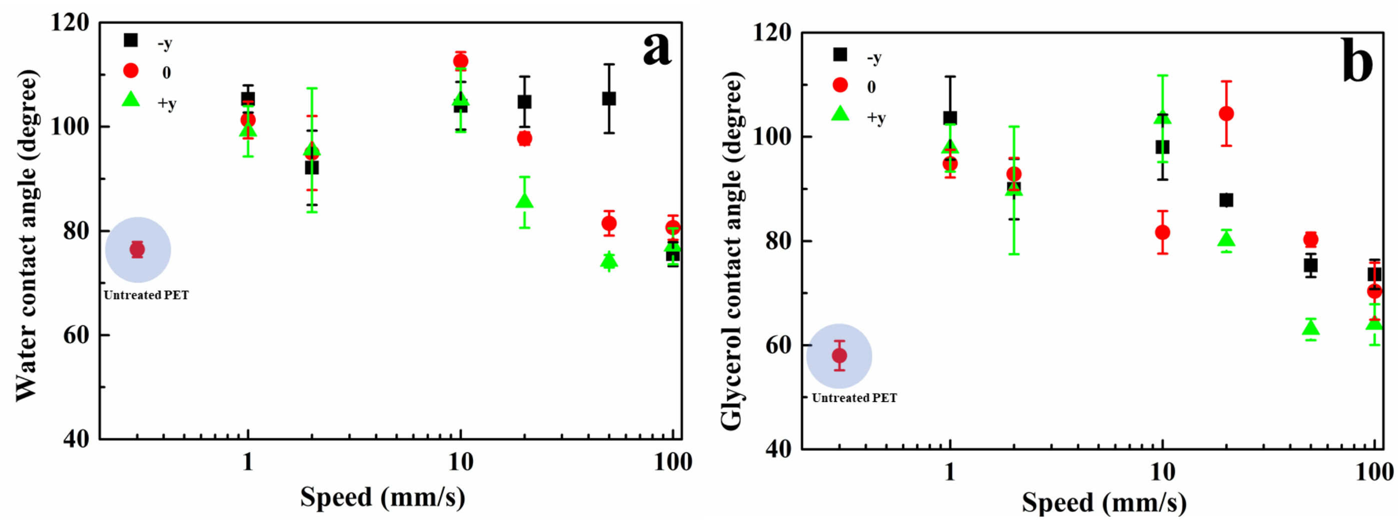


Contact angles of deionized water and glycerol with the gaps of 0.6 mm (a, b) and 2.0 mm (c,d). (exposure: 4 times, MR value: 0.045 %, 0.23 %, 0.45 %, and 0.90 %)

2. Main Content



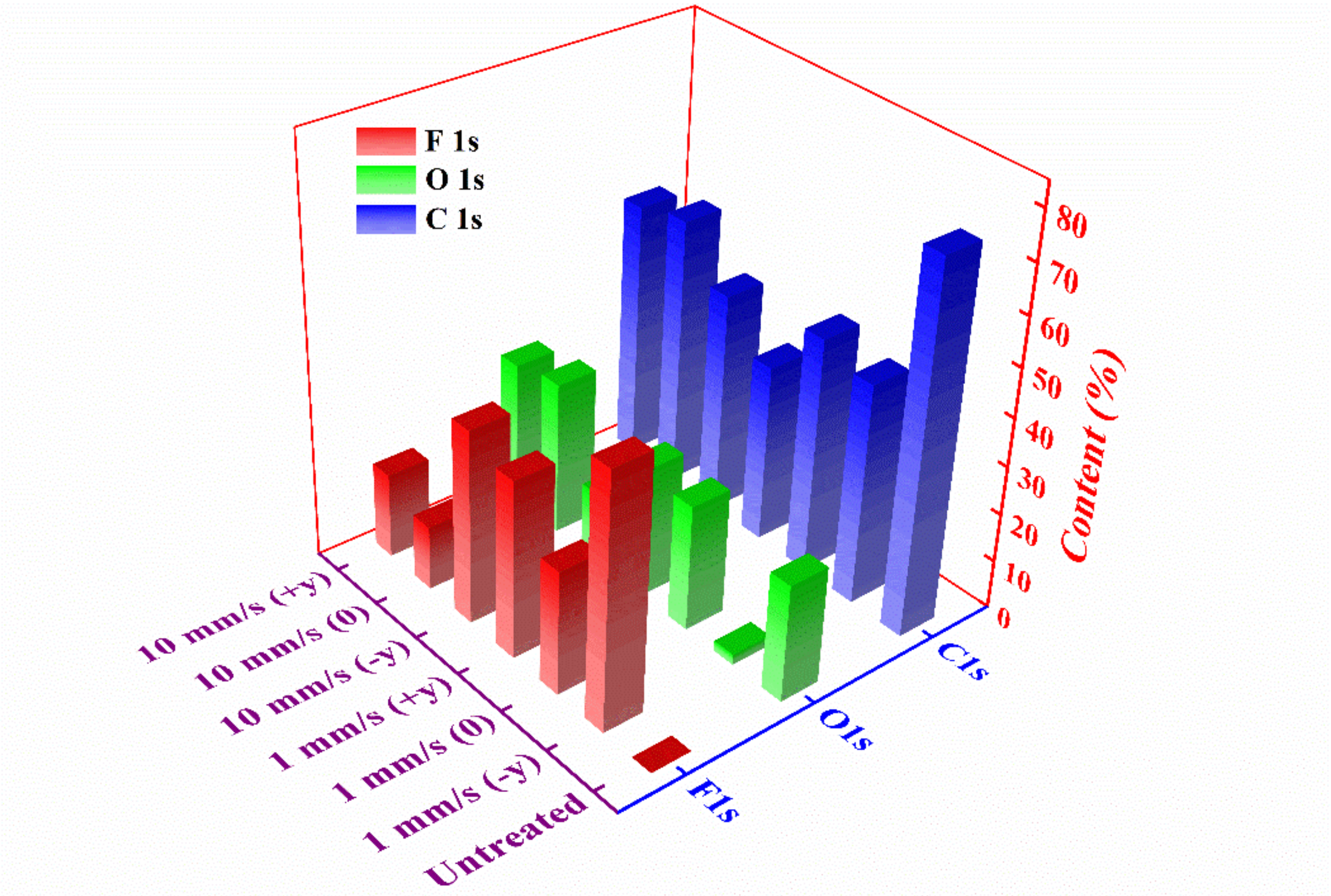
Contact angles at position of –y, 0, and +y. (a) deionized water, (b) glycerol (exposure: once, gap: 2.0 mm, MR value: 0.45 %, He flowrate: 29 SLM).



Distributions of contact angles at positions –y, 0, and +y. (a) deionized water, (b) glycerol (gap: 2.0 mm, exposure: once, MR value: 0.90 %, He flowrate: 29 SLM).

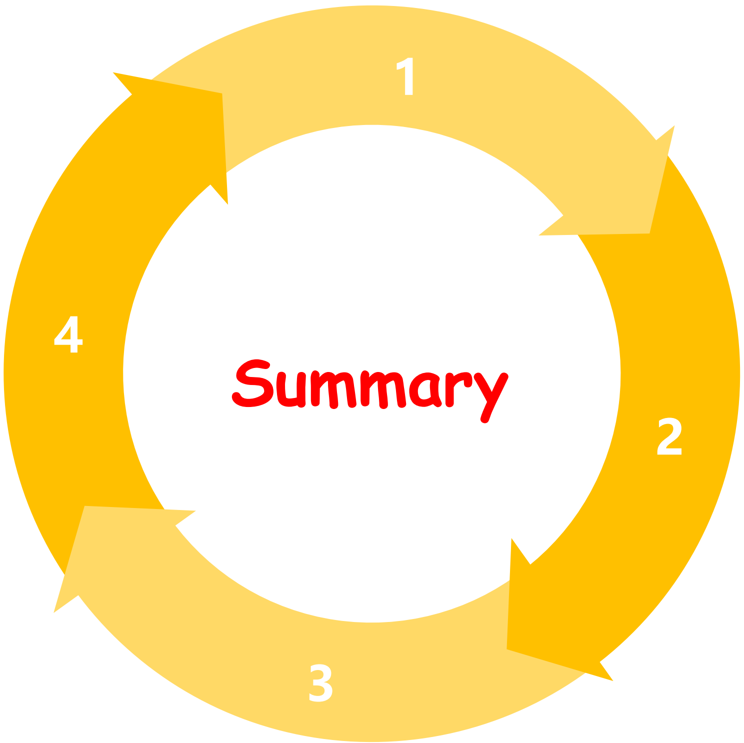
2. Main Content

Both fluorination and oxidation simultaneously occurred at these positions.



XPS elemental analysis of the PET films (gap: 2.0 mm, exposure: once, MR value: 0.90 %).

3. Conclusions



1. An air-to-air DBD plasma in a He/OFB gas mixture can introduce fluorine and promote hydrophobicity of the PET films;
2. The flowrates of the gases and the gap of the electrode played important roles for the treatment effects, attributed to the gas content in the plasma;
3. The measured wetting characteristics of hydrophobicity was rather insensitive to the difference in elemental composition of the PET surfaces;
4. The technique presented can be used for continuous surface treatment of sheet-like specimens.

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Thank you for your attentions

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