

Radial Evolution of Modification Effect of He APPJ on LDPE Film

Guo-qiang Li¹, Zheng-shi Chang^{1,2*}, Guan-jun Zhang¹

¹ State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, Shaanxi, China

² Key Laboratory of Materials Modification by Laser, Ion and Electron Beams, Dalian University of Technology, Dalian, Liaoning, China

E-mail: changzhsh1984@163.com

Abstract: In this paper, the modification effect of He APPJ treating LDPE film at a fixed point was studied. The water contact angle (WCA), surface roughness, oxygen content was measured. In radial direction, it was found that the WCA increases firstly and then decreases and finally increases to saturation. The surface roughness increases significantly when the radius < 10 mm. The oxygen content has a maximum value at $r=5$ mm. The results indicate that the modification effect of APPJ on the surface of the film is nonlinear along the radial direction.

Keywords: Surface modification, Radial distribution.

1. Introduction

In recent years, the atmospheric pressure plasma jet (APPJ) has been widely used in surface modification. It has many advantages such as the separation between discharge zone with treatment zone, the ability to treat complex object surfaces and simple configuration without vacuum equipment.^[1] However, most of the current researches mainly focus on the overall effect after plasma processing film. The research on the reaction characteristics while the plasma treating film is far from enough. With the outstanding physical-chemical properties such as flexibility, chemical resistance, optical transparency, low density polyethylene (LDPE) is potentially used in biomedical applications which includes stents, artificial heart valves, bio receptive scaffold, etc.

In this paper, the modification effect of He APPJ treating LDPE film at a fixed position was studied. The water contact angle (WCA), surface roughness and oxygen content were tested, respectively. It was found that the modification effect of APPJ on film is nonlinear along the radial direction. The hydrophilicity of LDPE film surface is related to the oxygen content and the surface roughness.

2. Experimental Setup

The experimental setup is shown in Figure 1, helium atmospheric pressure plasma jet (He APPJ) reactor is consists of a quartz tube (D_{inner}/D_{outer} , 4.0/6.2mm) and two copper strip electrodes wrapped around the tube with thickness of 0.15 mm and width of 10.0mm. The high voltage electrode is 10.0mm from the nozzle and 20.0mm from the ground electrode. The LDPE film is 10 mm from the nozzle. To generate APPJ, a sinusoidal alternating voltage is applied across the electrodes with a peak-to-peak voltage of 8.9 kV and a frequency of 20 kHz. A roughmeter (Mar Surface 300C) is used to measure the surface profile and roughness. Optical contact angle measuring instrument (DSA100S, KRUSS) is used to measure the water contact angle. The range of WCA

measured is from 0 to 180 ° with an accuracy of 0.1 °. X-ray photoelectron spectrometer (ESCALAB Xi+, Thermo Fisher) is used to measure the oxygen element content on the film surface.

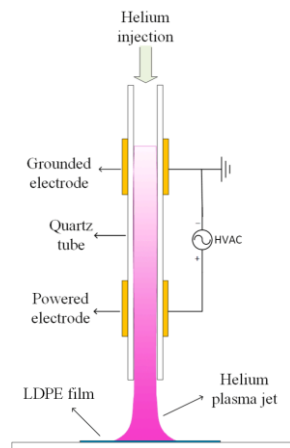
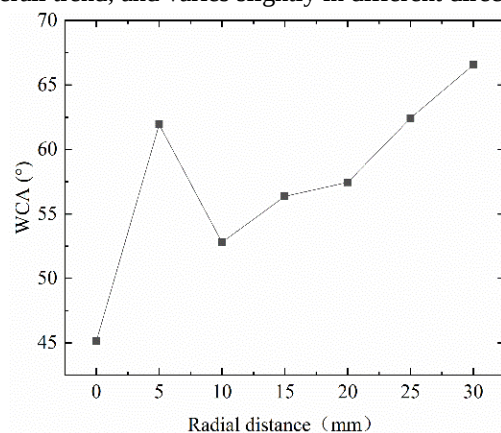


Fig. 1. The configuration of electrode structure

3. Results and discussion

The water contact angle after plasma treatment is shown in Figure 2. The water contact angle in the radial direction increases first and then decreases and finally increases. It has a minimum point at $r=10$ mm. It increases in overall trend, and varies slightly in different direction.



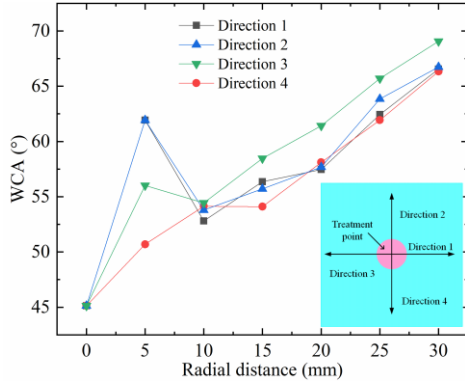


Fig 2. The water contact angle in radial direction after treatment. (a) in one direction. (b) in four different directions.

The surface roughness before and after treatment is shown in Figure 3. After treatment, the arithmetic mean roughness R_a increases sharply and the closer to the center, the larger the R_a value. When the distance exceeds 15 mm, the R_a value does not change significantly. This result indicates that APPJ has an etching effect on the LDPE film and its range is within 10 mm radially.

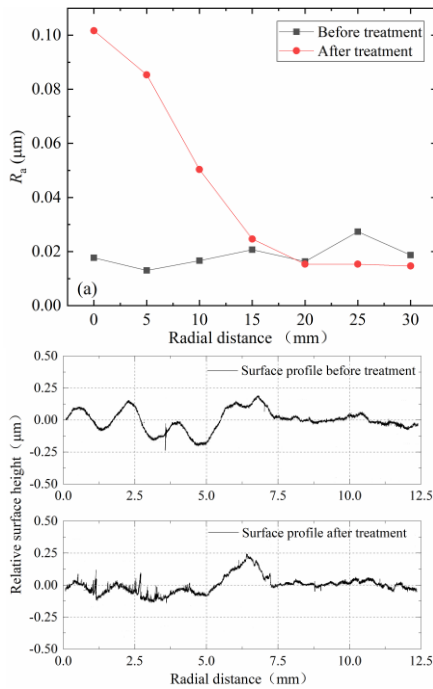


Fig 3. The surface roughness before and after treatment. (a) R_a value. (b) surface profile.

The oxygen element content on the surface after plasma treatment is shown in Figure 4. It also increases firstly and then decreases along radial direction. It increases significantly within the range of $r < 15$ mm. The maximum value of oxygen element content is at $r = 5$ mm rather than the center point. It can be seen that when plasma treating LDPE film oxygen-containing group is induced into the surface and its distribution is nonlinear

along radial direction.

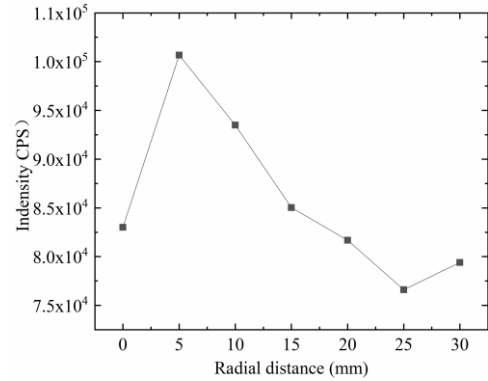


Fig 4. The oxygen element content in radial direction after treatment

Overall, the nonlinear modification effect in the radial direction is obtained when the LDPE film was treated by employing the glow-like He APPJ. The hydrophilicity of the film surface is positively related to the content of oxygen elements on the film surface. This is in agreement with the research of Rich S A, et al.^[2] It is found that the surface water contact angle of LDPE film is also related to surface roughness. Related reason and mechanism needs to be further investigated combining the hollow structure of the plasma bullet.^[3]

4. Conclusion

When the plasma jet is fixed at a point to treat LDPE film, the modification effect of the plasma jet on the film is nonlinear along the radial direction. The water contact angle increases firstly and then decreases and finally increases to saturation. The surface roughness increases significantly when the radius less than 15 mm. The oxygen content also increase firstly and then decreases with a maximum value at $r = 5$ mm. The hydrophilicity of the film surface is positively related to the content of oxygen elements on the film surface and related to the surface roughness.

5. Acknowledgement

This work was partially supported by National Natural Science Foundation (Grant No. 51777165, 11775175), State Key Laboratory of Electrical Insulation and Power Equipment (EIPE19305), Key Laboratory of Materials Modification by Laser, Ion and Electron Beams (Dalian University of Technology), Ministry of Education (KF1704) and State Key Laboratory of Intense Pulsed Radiation Simulation and Effect (SKLIPR1706).

6. References

- [1] Pandiyaraj K N, Kumar A A, RamKumar M C, et al. Current Applied Physics, 2016, 16(7): 784-792.
- [2] Rich S A, Dufour T, Leroy P, et al. Plasma Processes and Polymers, 2015, 12.8: 771-785.
- [3] Chang Z, Zhao N, Li G, et al. Scientific Reports, 2018, 8(1):7599.