# Optimization of Plasma Surface Modification for PET and PP Using Corona Treater in Microfluidic Applications

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**Abstract**: Plasma surface modification has proven to be an effective technique for enhancing the wettability and adhesion properties of polymeric materials, particularly in microfluidic applications. This study investigates the effects of corona plasma treatment on the surface properties of polyethylene terephthalate (PET) and polypropylene (PP) by analyzing surface roughness and contact angle measurements. Plasma treatment durations of 0, 30, 60, 120, and 180 seconds were applied to both materials. Scanning Electron Microscopy (SEM) revealed significant microstructural changes, with increased surface roughness and the formation of micro/nano-textures, enhancing fluid interaction. Contact angle measurements further confirmed the improved wettability, with PP decreasing from 96° (untreated) to 42° (180s plasma exposure), and PET from 93° to 18°, demonstrating PET's superior retention of hydrophilic properties. However, excessive plasma exposure led to over-etching effects, particularly in PP, affecting surface uniformity. The results highlight the effectiveness of corona plasma treatment in enhancing the functionality of PET and PP for microfluidic applications, with PET exhibiting greater long-term stability. These findings provide valuable insights into the role of plasma modification in improving polymer surface properties, paving the way for advancements in biomedical and analytical microfluidic device fabrication.

**Keywords**: Plasma technology, surface modification, microfluidics, PET, polypropylene, Contact Angle, SEM analysis

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## Introduction

Plasma technology has emerged as a transformative approach for the surface modification of polymeric materials, facilitating significant advancements across various industries. Unlike conventional chemical treatments, plasma-based techniques operate without altering the bulk properties of materials, providing a cost-effective and environmentally sustainable alternative. Central to its utility is the ability to enhance material surface properties, such as wettability, adhesion, and compatibility with other substances, while preserving the mechanical and chemical integrity of the underlying substrate. In microfluidics, where precision and reliability are paramount, plasma treatment offers a pathway to addressing challenges such as poor hydrophilicity and surface heterogeneity. This is particularly critical for biomedical and analytical applications, where fluid transport and interaction are fundamental to device performance (Chang, Lawless, & Yamamoto, 1991).

Polymeric materials like Polyethylene Terephthalate (PET) and Polypropylene (PP) are widely favored in microfluidic devices due to their mechanical robustness, chemical resistance, and ease of fabrication. However, these materials' hydrophobic nature limits their efficacy in fluidic systems, necessitating surface modification strategies. The inherent low surface energy of these polymers impedes fluid flow and can lead to issues such as bubble formation and poor interaction with aqueous solutions. Surface modification techniques, particularly those employing plasma treatment, offer promising solutions to these limitations by introducing functional groups that enhance hydrophilicity and surface energy (Ren et al., 2008; Sartori et al., 2008). Plasma technology operates by generating an ionized state of matter, often referred to as the fourth state of matter. This highly reactive medium facilitates chemical and physical modifications at the surface level. Reactive species in plasma, such as ions, electrons, and radicals, interact with the material surface, resulting in the incorporation of polar groups like hydroxyl and carbonyl. Additionally, plasma treatment creates micro- and nano-scale surface textures that further enhance surface energy and wettability (Deng et al., 2020). These properties are critical in microfluidics, where precise fluid manipulation and interaction with microchannel surfaces are fundamental to device functionality.

Atmospheric-pressure plasma, in particular, has garnered attention for its versatility and cost-efficiency. Unlike low-pressure plasma systems that require vacuum conditions and specialized equipment, atmospheric-pressure plasma can operate under ambient conditions, making it more accessible for large-scale and industrial applications. This approach enables the treatment of polymer surfaces using readily available gases like air, reducing operational costs while maintaining efficacy. However, achieving optimal results requires precise control of treatment parameters, including exposure duration, plasma intensity, and gas composition (Masruroh, Santjojo, & Taufiq, 2021). The effectiveness of plasma treatment is highly dependent on these parameters. For instance, oxygen-based plasmas are commonly employed for enhancing hydrophilicity due to their ability to introduce oxygen-containing functional groups onto polymer surfaces. Air plasma, although less efficient in certain aspects, offers a more economical alternative and has demonstrated comparable results in modifying surface properties (Zhou et al., 2016). Despite these advancements, challenges persist in ensuring the long-term stability of the modified surfaces. Aging effects, characterized by the gradual loss of hydrophilicity over time, remain a significant obstacle. This degradation is often attributed to molecular reorientation and contamination from the surrounding environment, which can negate the initial benefits of plasma treatment (Vasilakis et al., 2016). This study seeks to address these challenges by investigating the plasma treatment of PET and PP, focusing on optimizing treatment parameters to achieve durable and effective surface modifications. By employing Scanning Electron Microscopy (SEM) for surface analysis, this research provides a detailed examination of the microstructural changes induced by plasma treatment. Previous studies have highlighted the formation of micro/nano-textures on polymer surfaces as a key factor in enhancing wettability and fluid interaction. These structural changes, combined with the introduction of functional polar groups, significantly improve the performance of microfluidic devices (Chu, 2007). Furthermore, the study explores the comparative performance of PET and PP under varying plasma treatment conditions. PET, known for its optical transparency and high mechanical strength, has shown greater resistance to over-etching and structural degradation during prolonged plasma exposure. In contrast, PP, valued for its lightweight and flexibility, is more susceptible to over-etching, which can lead to surface irregularities and reduced functionality. Understanding these material-specific responses is crucial for tailoring plasma treatment protocols to meet the specific requirements of different microfluidic applications (Covington, 2015). The importance of surface modification extends beyond microfluidics to other domains such as biomedical devices and lab-on-a-chip technologies. For example, plasma-treated surfaces have been shown to enhance cell adhesion and protein immobilization, making them suitable for tissue engineering and diagnostic applications (Shishoo, 2007). Additionally, the hydrophilic properties induced by plasma treatment can improve the efficiency of oil-water separation systems and other industrial processes (Ren et al., 2016). These diverse applications underscore the potential of plasma technology as a versatile tool for advancing material performance across multiple fields.

Despite its promise, plasma technology is not without limitations. The susceptibility of plasma-treated surfaces to aging effects necessitates the development of strategies to stabilize the modified properties. Protective coatings and post-treatment chemical modifications have been proposed as potential solutions to enhance the durability of plasma-induced hydrophilicity. Moreover, the scalability of plasma treatment processes remains a challenge, particularly for industrial applications requiring high throughput and uniformity. Addressing these issues will be critical for realizing the full potential of plasma technology in both research and commercial settings (Yasuda, 2005). In summary, the introduction of plasma technology into the realm of surface modification has opened new avenues for enhancing the performance of polymeric materials in microfluidic applications. By systematically investigating the effects of plasma treatment on PET and PP, this study aims to provide valuable insights into the optimization of treatment parameters and the long-term stability of modified surfaces. The findings are expected to contribute to the broader adoption of plasma-based surface modification techniques, paving the way for innovations in biomedical, analytical, and industrial applications. Through a comprehensive understanding of the interplay between material properties and plasma treatment conditions, this research seeks to advance the capabilities of microfluidic devices and other polymer-based technologies.

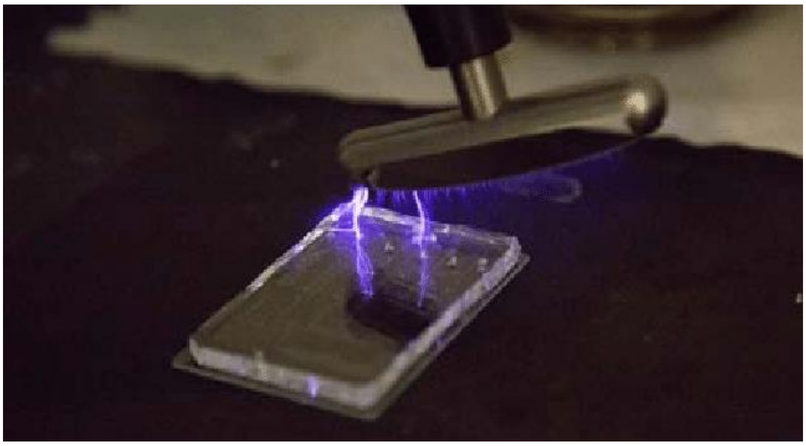
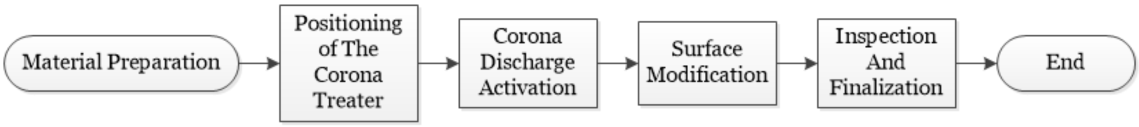
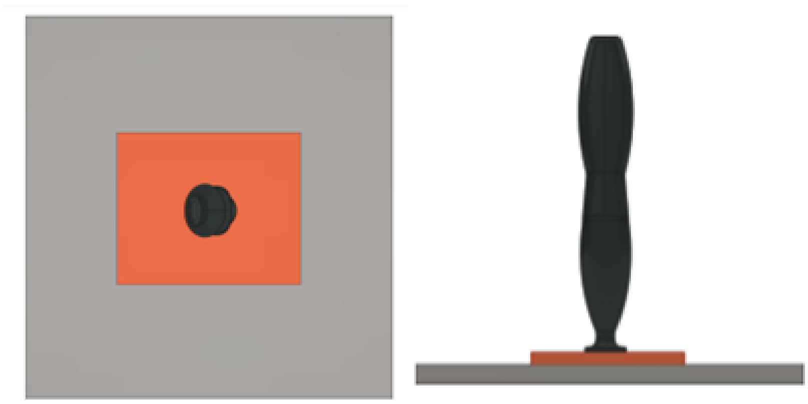


**Figure 1 Corona Release**

# Research Method

The This study focused on the plasma treatment of two polymeric materials, Polyethylene Terephthalate (PET) and Polypropylene (PP), which are commonly used in microfluidic applications. PET was selected for its high mechanical strength, optical transparency, and chemical resistance, while PP was chosen for its lightweight, flexibility, and chemical stability. Both materials are inherently hydrophobic, requiring surface modifications to enhance their performance in microfluidic devices. Prior to plasma treatment, the samples were cleaned with ethanol and deionized water to remove surface contaminants and then air-dried at room temperature. Plasma treatment was performed using a laboratory-scale corona treater under ambient conditions. The treatment parameters were systematically varied, including treatment durations of 0, 30, 60, 120, and 180 seconds. Ambient air was used as the plasma source, and a wire-to-plate electrode configuration was employed with an applied voltage of 115 V. These parameters were optimized to achieve significant surface modifications without causing material degradation. To analyze the effects of plasma treatment, surface morphology was characterized using Scanning Electron Microscopy (SEM). SEM images were captured at a magnification of 500× to observe microstructural changes, such as the formation of micro/nano-textures and increased surface roughness. The SEM images were further processed using MATLAB 2013 to quantify surface roughness, including the calculation of average roughness (Ra) and root mean square roughness (Rq), which represent the arithmetic mean and root mean square deviations of the surface profile, respectively. Statistical analysis was conducted using ANOVA to evaluate the significance of plasma treatment parameters on surface roughness. The relationship between treatment duration and roughness values was examined to identify optimal plasma treatment conditions that enhance surface properties while maintaining material integrity.



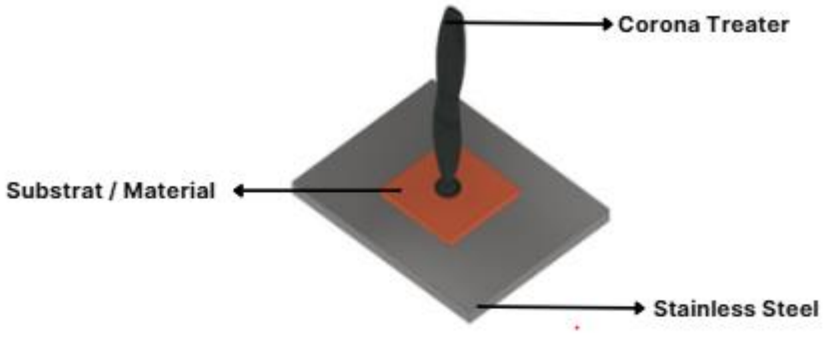
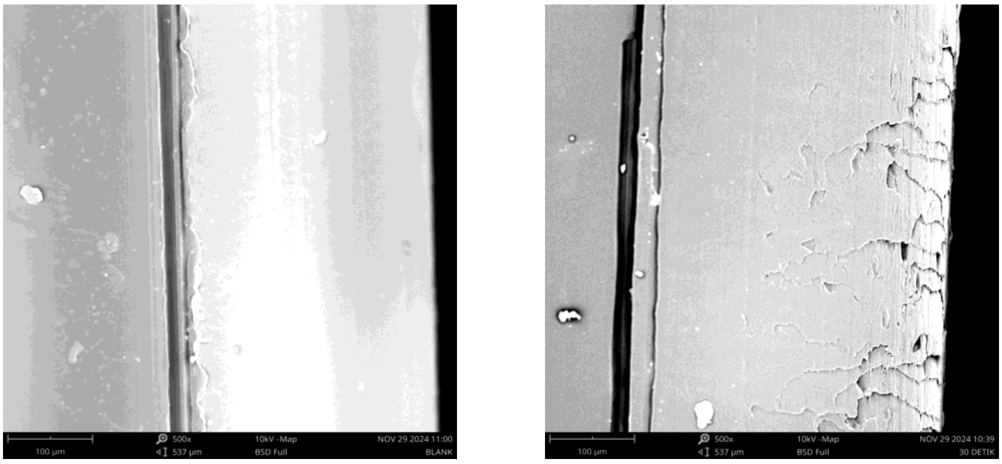



**Figure 2 Design Experimental**

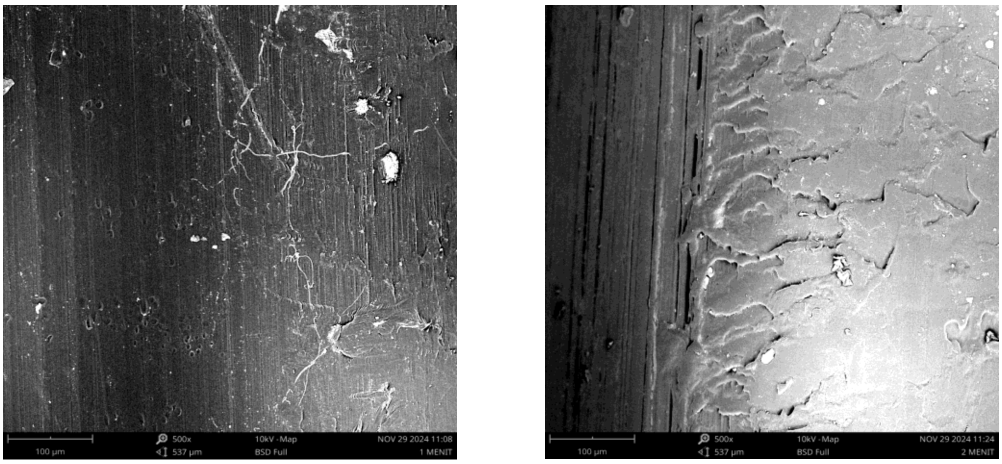
## Result and Discussion

One of the major challenges in plasma surface modification is the aging effect, which leads to the gradual deterioration of hydrophilic properties over time. This phenomenon is primarily caused by molecular reorientation, where polar functional groups (-OH, -COOH) introduced during plasma treatment migrate into the bulk material, reducing surface energy. Additionally, environmental contamination, such as the adsorption of airborne molecules and moisture, can further diminish the surface modifications. In this study, the effects of plasma treatment on the surface morphology of Polypropylene (PP) and Polyethylene Terephthalate (PET) were analyzed using Scanning Electron Microscopy (SEM). For untreated PP, the surface was smooth and homogeneous, lacking significant microstructural features. After 30 seconds of plasma treatment, initial microstructural changes appeared, with small protrusions and limited distribution of micro-textures. At 60 seconds, the micro-textures became more prominent, characterized by larger and more uniformly distributed structures, indicating increased surface roughness. The surface treated for 120 seconds exhibited the most complex microstructure, with well-defined protrusions and evenly distributed micro-textures, achieving peak roughness values. However, at 180 seconds, over-etching effects were observed, leading to partial erosion of the microstructures and a less uniform surface. The contact angle measurements for polypropylene (PP) surfaces subjected to plasma treatment at different time intervals are presented. The untreated PP surface exhibited a high contact angle of 96°, indicating its inherently hydrophobic nature. Upon plasma treatment, a significant reduction in the contact angle was observed, demonstrating improved hydrophilicity. After 30 seconds of plasma exposure, the contact angle decreased to 68°, suggesting the initial formation of polar functional groups and slight surface roughness modifications. However, further exposure to 60 seconds resulted in a marginal change (67°), implying that the rate of surface modification begins to stabilize. The most pronounced effect was recorded at 120 seconds, where the contact angle reached 53°, indicating the optimal plasma treatment duration for enhancing wettability. Beyond this threshold, at 180 seconds, the contact angle further dropped to 42°, signifying the highest level of hydrophilicity achieved within the tested parameters. These results suggest that plasma treatment effectively enhances the wettability of PP by introducing polar functional groups (-OH, -COOH) and modifying the surface morphology. However, the decreasing trend in the contact angle beyond 120 seconds also indicates possible over-etching, which could lead to surface degradation or increased roughness, potentially affecting long-term stability. The findings align with previous studies demonstrating that plasma treatment enhances polymer surface properties by reducing hydrophobicity and increasing adhesion capabilities, which are crucial for applications in microfluidics, biomedical devices, and flexible electronics. Future studies should investigate the long-term stability of plasma-induced hydrophilicity, considering aging effects and potential mitigation strategies such as protective coatings or post-treatment chemical modifications.




(a) (b)

**Figure 3 Polypropylene SEM Test Results: (a) Plasma-free treatment & (b) 30-second plasma treatment**




(a) (b)

**Figure 4 Polypropylene SEM Test Results: (a) Plasma 60 second & (b) 120 second plasma treatment**

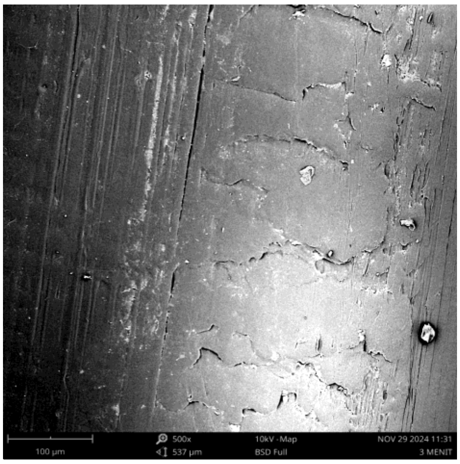
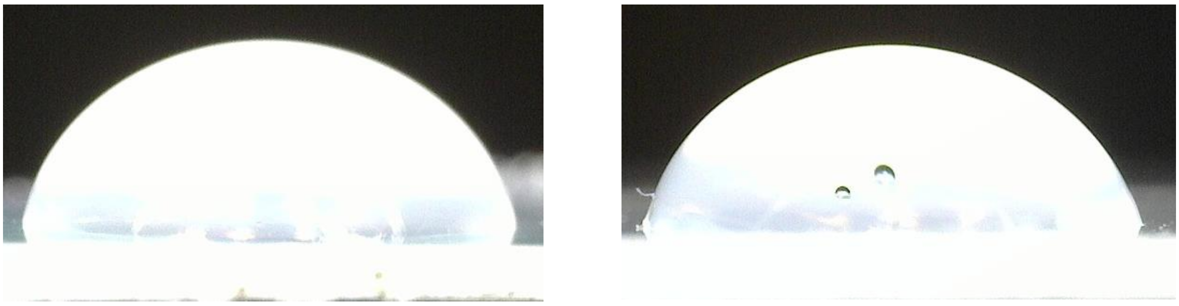
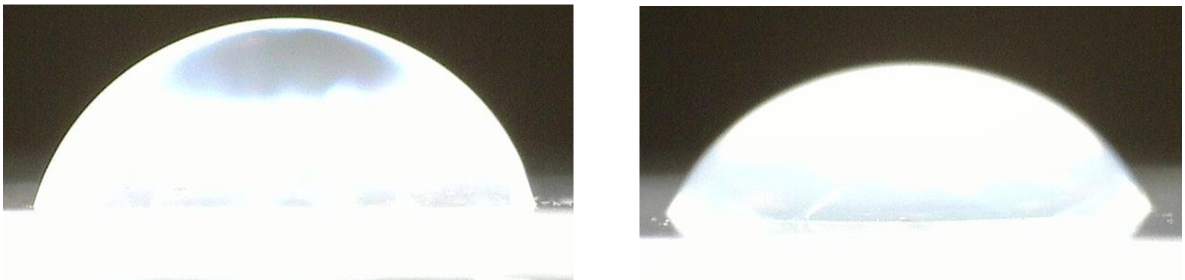



**Figure 5 Polypropylene SEM Test Results: 180 seconds Plasma Treatment**



(a) (b)

**Figure 6 Polypropylene Contact Angle (a) Plasma-free treatment & (b) 30 second plasma treatment**



(a) (b)

**Figure 7 Polypropylene Contact Angle (a) Plasma 60 second & (b) 120 second plasma treatment**

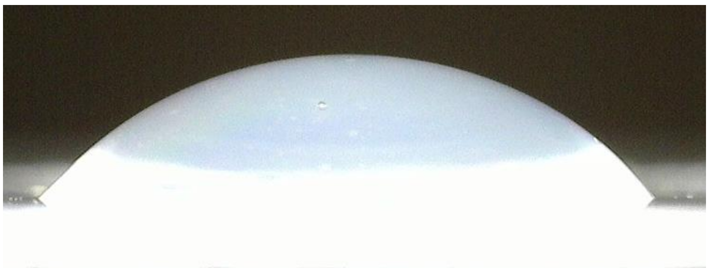
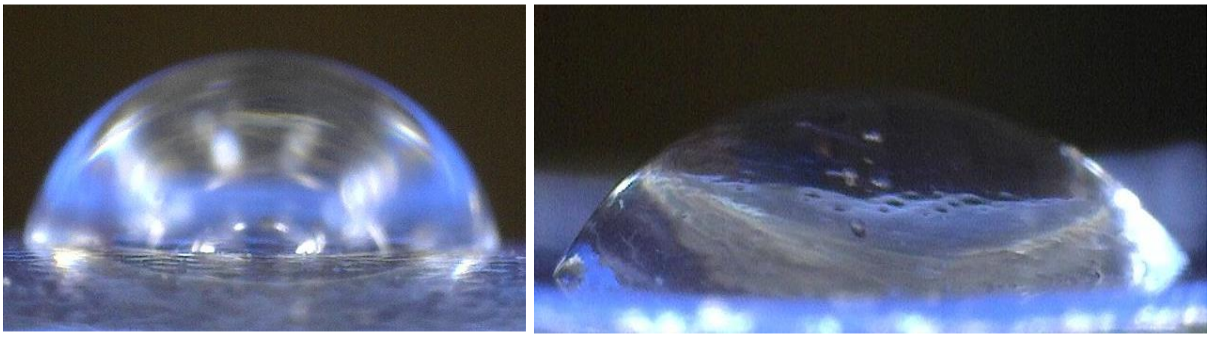


**Figure 8 Polypropylene Contact Angle 180 second plasma treatment**



(a) (b)

**Figure 9 Polyethylene Terephthalate Contact Angle: (a) Plasma free treatment & (b) 30 second plasma treatment**

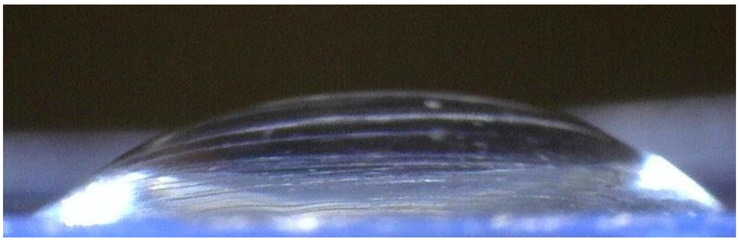


**Figure 10 Polyethylene Terephthalate Contact Angle 60 second plasma treatment**

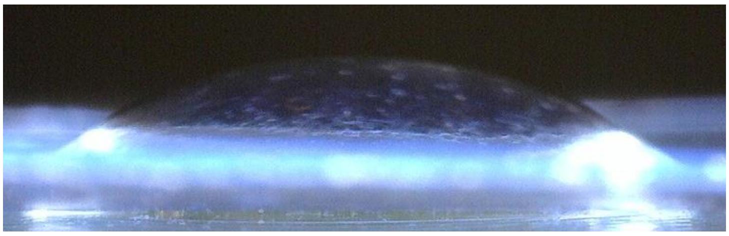


**Figure 11 Polyethylene Terephthalate Contact Angle 120 second plasma treatment**

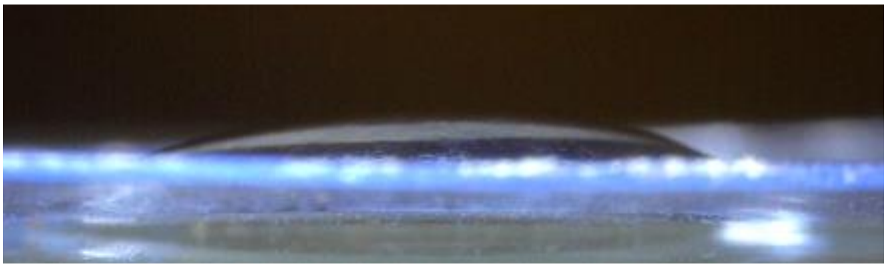
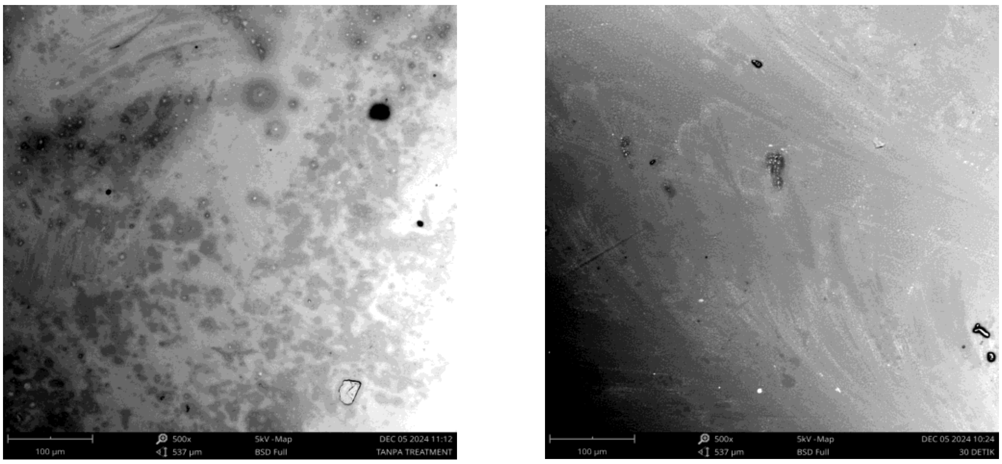


**Figure 12 Polyethylene Terephthalate Contact Angle 180 second plasma treatment**

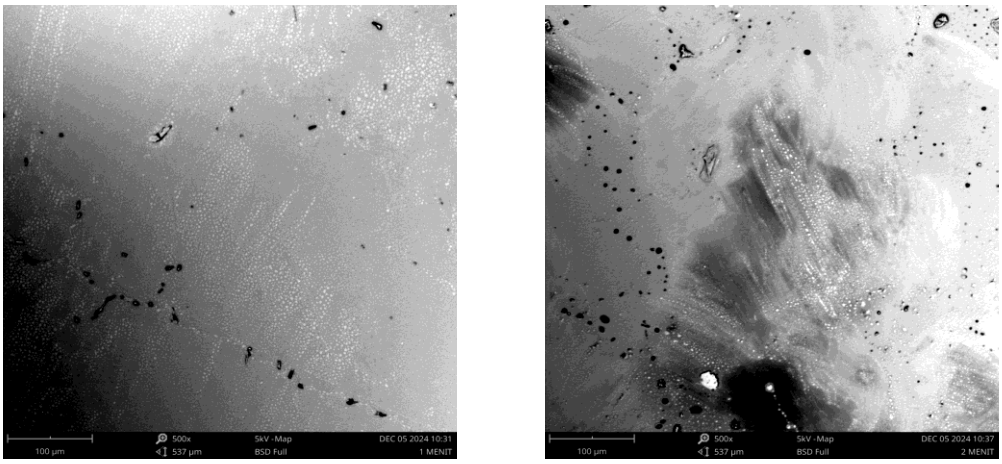
The contact angle measurements for polyethylene terephthalate (PET) after plasma treatment indicate a significant enhancement in surface wettability. The untreated PET surface exhibited a high contact angle of 93°, confirming its hydrophobic nature. However, after plasma treatment, there was a continuous and substantial reduction in the contact angle, indicating a progressive increase in hydrophilicity. After 30 seconds of plasma exposure, the contact angle sharply dropped to 52°, suggesting a significant modification in surface energy due to the introduction of polar functional groups (-OH, -COOH). This trend continued with a further decline to 35° at 60 seconds, followed by 32° at 120 seconds, indicating near saturation of the surface modification effect. At 180 seconds, the lowest contact angle of 18° was recorded, signifying the highest level of hydrophilicity achieved during the treatment process. These results demonstrate that PET exhibits a greater and more stable response to plasma treatment compared to polypropylene (PP). The gradual decrease in contact angle with increasing plasma exposure suggests a strong retention of plasma-induced surface modifications. Unlike PP, PET did not show signs of over-etching or instability at extended treatment durations, reinforcing its suitability for applications requiring prolonged hydrophilic properties, such as microfluidic devices, biomedical coatings, and lab-on-a-chip technologies.

Additionally, the consistent decrease in contact angle suggests that PET maintains a high degree of structural stability during plasma exposure, making it a promising candidate for long-term modifications. Future studies should investigate the aging effects of plasma-treated PET surfaces and explore strategies such as chemical grafting or protective coatings to further enhance stability over extended periods. Similarly, the untreated PET surface was smooth, with no significant microstructural features. After 30 seconds of plasma treatment, fine micro-textures began to develop. By 60 seconds, the surface exhibited a notable increase in complexity, with evenly distributed microstructures and enhanced roughness. At 120 seconds, the surface reached its peak roughness, characterized by well-defined micro-textures across the entire surface. Unlike PP, the PET surface remained relatively stable even after 180 seconds of plasma treatment, with minimal signs of over-etching. We can see in table 3 for comparison PP and PET for contact angle.



(a) (b)

**Figure 13 Polyethylene Terephthalate SEM Test Results: (a) Plasma-free treatment & (b) 30-second plasma treatment**



(a) (b)

**Figure 14 Polyethylene Terephthalate SEM Test Results: (a) 60 seconds plasma treatment & (b) 120 seconds plasma treatment**

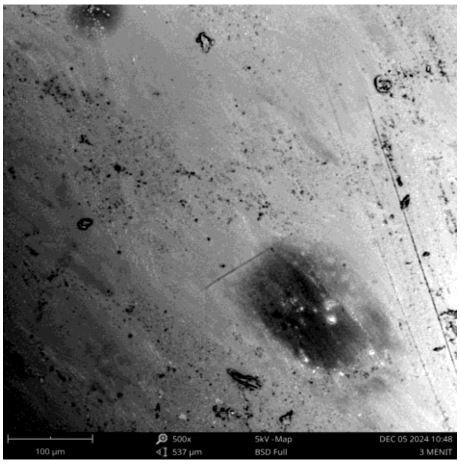


**Figure 15 Polyethylene Terephthalate Test Results: 180 seconds Plasma Treatment**

Surface roughness was quantified using MATLAB 2013, focusing on Roughness Average (Ra) and Root Mean Square Roughness (Rq). For PP, Ra and Rq increased progressively with treatment duration, from Ra = 47.54 µm and Rq = 58.65 µm (untreated) to Ra = 226.57 µm and Rq = 297.10 µm (180 seconds). A similar trend was observed for PET, where Ra and Rq values increased from Ra = 143.46 µm and Rq = 185.09 µm (untreated) to Ra = 235.21 µm and Rq = 277.53 µm (180 seconds). PET exhibited higher initial roughness and greater resistance to over-etching compared to PP, making it more stable under extended plasma treatment. Statistical analysis using ANOVA confirmed that plasma treatment duration significantly affected surface roughness for both materials ($p < 0.05$). The optimal treatment duration for both PP and PET was identified as 120 seconds, where the materials exhibited the highest surface roughness and uniformity. Over-treatment at 180 seconds resulted in reduced surface uniformity, particularly for PP, due to over-etching effects. These findings highlight PET's superior stability and suitability for applications requiring extended or intense surface

**Table 1 Comparison of Surface Roughness of Polypropylene Materials (Ra and Rq) to Plasma Duration**

| No | Condition Treatment | *Roughness Average* (µm) | *Root Mean Square Roughness* (µm) |
|---|---|---|---|
| 1 | No Treatment Plasma | 47.54 | 58.65 |
| 2 | Treatment Plasma 30 Second | 100.92 | 141.84 |
| 3 | Treatment Plasma 1 Minute | 163.25 | 217.34 |
| 4 | Treatment Plasma 2 Minute | 188.56 | 256.48 |
| 5 | Treatment Plasma 3 Minute | 226.57 | 297.10 |

**Table 2 Comparison of Surface Roughness of PET (Ra and Rq) to Plasma Duration**

| No. | Condition Treatment | *Roughness Average* (µm) | *Root Mean Square Roughness* (µm) |
|---|---|---|---|
| 1 | No Treatment Plasma | 143.46 | 185.09 |
| 2 | Treatment Plasma 30 Second | 165.39 | 212.90 |
| 3 | Treatment Plasma 1 Minute | 171.69 | 228.79 |
| 4 | Treatment Plasma 2 Minute | 220.72 | 260.49 |
| 5 | Treatment Plasma 3 Minute | 235.21 | 277.53 |

**Table 3 Comparison of Contact Angle of PP and PET to Plasma Duration**

| No | Condition Treatment (Second) | Material | |
|---|---|---|---|
| | | Polypropylene | Polyethylene Terephthalate |
| 1 | 0 | 96 | 93 |
| 2 | 30 | 68 | 52 |
| 3 | 60 | 67 | 35 |
| 4 | 120 | 53 | 32 |
| 5 | 180 | 42 | 18 |

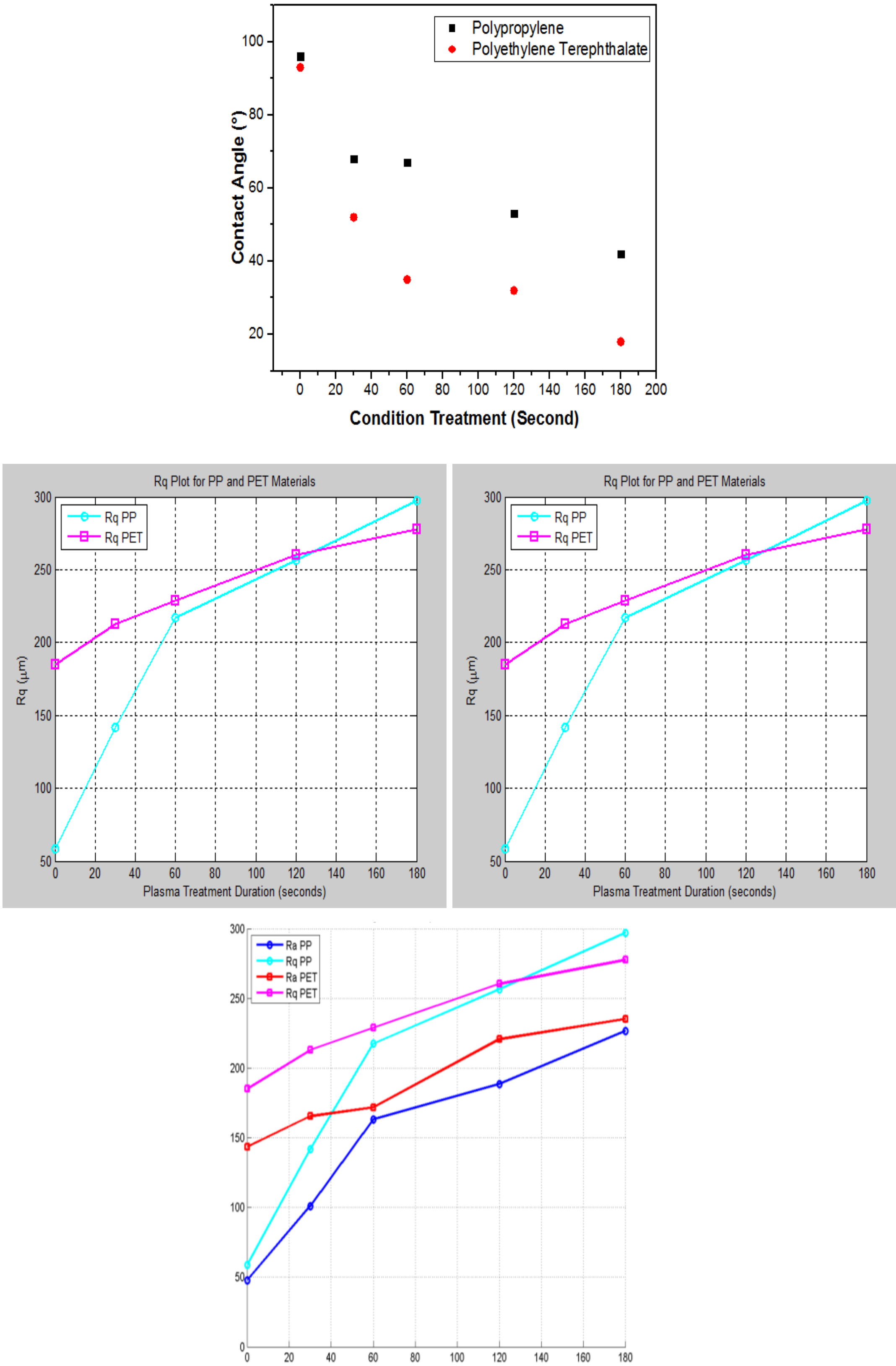



**Figure 16 Comparison Chart Ra and Rq**

The plasma treatment effectively enhanced the surface properties of both Polypropylene (PP) and Polyethylene Terephthalate (PET), with noticeable differences in their responses to varying treatment durations. The SEM analysis revealed significant microstructural changes for both materials, particularly the formation of micro-textures that became more prominent with increasing treatment duration. For PP, optimal surface complexity was achieved at 120 seconds of treatment, beyond which over-etching effects were observed, leading to partial erosion and reduced surface uniformity. Conversely, PET exhibited greater resistance to over-etching, maintaining stable microstructural features even after 180 seconds of plasma treatment. This robustness under prolonged exposure highlights PET's suitability for applications requiring extended or intense surface modifications. Quantitative analysis of surface roughness parameters further confirmed the effectiveness of plasma treatment in enhancing surface characteristics. Both PP and PET showed progressive increases in roughness (Ra and Rq) with treatment duration, reaching their peak values at 120 seconds. This increase is attributed to plasma-induced etching and the development of micro/nano-textures, which are crucial for improving fluid interaction in microfluidic applications. However, the plateauing or slight reduction in roughness observed for PP at 180 seconds indicates that over-etching can compromise surface quality, emphasizing the need for precise control of treatment duration to avoid material degradation. In comparison, PET demonstrated higher baseline roughness and better structural stability, suggesting it is more suitable for applications requiring long-term durability.

Despite the promising results, challenges remain, particularly the susceptibility of PP to over-etching during prolonged plasma treatment. This issue highlights the importance of optimizing plasma parameters, such as applied voltage and treatment duration, to balance surface modification effectiveness and material integrity. Another critical challenge is the long-term stability of the hydrophilic properties induced by plasma treatment, which can degrade over time due to molecular reorientation or atmospheric contamination. Future research should focus on enhancing the stability of modified surfaces, potentially through protective coatings or chemical stabilization post-treatment. Overall, this study provides valuable insights into the plasma treatment of polymeric materials for microfluidic applications. The findings underscore the importance of optimizing plasma parameters to achieve improved surface properties while minimizing material degradation. The comparative analysis of PP and PET highlights their respective strengths and limitations, offering guidance for material selection based on application-specific requirements.

# Conclusions

This study demonstrates the effectiveness of plasma treatment in enhancing the surface properties of Polypropylene (PP) and Polyethylene Terephthalate (PET) for potential applications in microfluidic devices. Plasma treatment significantly improved surface roughness and microstructural complexity, with optimal results observed at a treatment duration of 120 seconds for both materials. SEM analysis revealed that plasma-induced micro/nano-textures on the material surfaces contributed to enhanced functionality, such as better fluid interaction. However, over-etching effects were evident in PP at prolonged treatment durations, emphasizing the importance of precise parameter optimization. The comparative analysis highlighted the superior stability of PET under extended plasma treatment, making it more suitable for applications requiring prolonged durability and consistent performance. On the other hand, while PP achieved notable improvements in surface roughness, its susceptibility to over-etching limits its application in scenarios requiring extended treatment. Despite these advancements, challenges remain, particularly in addressing over-etching effects and ensuring the long-term stability of the hydrophilic properties induced by plasma treatment. Future studies should explore methods to mitigate aging effects, such as post-treatment stabilization or protective coatings, and further optimize plasma parameters to improve treatment efficiency and material reliability. The contact angle measurements of polypropylene (PP) and polyethylene terephthalate (PET) surfaces after plasma treatment demonstrate a significant improvement in wettability, confirming the effectiveness of plasma modification in enhancing surface hydrophilicity. For PP, the contact angle decreased from 96° (untreated) to 42° (180 seconds of plasma treatment). The most substantial reduction occurred within the first 120 seconds, after which the decline became less pronounced. However, the slight stabilization of contact angle at extended durations suggests the possibility of surface over-etching, which may impact long-term stability. For PET, the contact angle exhibited a more significant and consistent decline, from 93° (untreated) to 18° (180 seconds of plasma treatment). The gradual decrease across all time intervals indicates superior structural stability and a stronger retention of plasma-induced modifications compared to PP. The minimal signs of over-etching or surface degradation suggest that PET is more suitable for applications requiring prolonged hydrophilic properties.

Overall, the findings confirm that plasma treatment effectively enhances the wettability of both PP and PET, but PET exhibits better long-term stability and hydrophilic retention. These results highlight PET's potential for biomedical, microfluidic, and surface coating applications, where extended hydrophilicity is critical. Future research should focus on mitigating aging effects and optimizing treatment conditions to further enhance surface durability and functional longevity.

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## References

Chang, J. S., Lawless, P. A., & Yamamoto, T. (1991). Corona discharge processes. IEEE Transactions on Plasma Science, 19(6), 1152–1166.

Chu, P. K. (2007). Recent applications of plasma-based ion implantation and deposition to microelectronics. Surface and Coatings Technology, 201(9–11), 4828–4832.

Covington, J. A. (2015). Polymeric materials in microfluidics. Annual Review of Analytical Chemistry, 8, 231–252.

Deng, Y., et al. (2020). Recent development of super-wettable materials and their applications in oil-water separation. Journal of Cleaner Production, 266, 121624.

Grill, A. (1996). Cold plasma in materials fabrication. IEEE Transactions on Plasma Science, 24(6), 1233–1248.

Hegemann, D., Brunner, H., & Oehr, C. (2003). Plasma treatment of polymers for surface and adhesion improvement. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 208, 281–286.

Masruroh, M., Santjojo, D. J. D. H., & Taufiq, A. (2021). Analysis of optical emission spectra during nitrogen-plasma treatment to control the wettability of polystyrene surface. Chiang Mai University Journal of Natural Sciences, 20(3).

Meichsner, J. (2009). Plasma physics of atmospheric pressure plasmas. Contributions to Plasma Physics, 49(8), 495–512.

Morent, S., De Geyter, N., Desmet, T., Dubruel, P., & Leys, C. (2011). Non-thermal plasma treatment of polymers for biomedical applications. Plasma Processes and Polymers, 8(3), 171–190.

Owens, D. K., & Wendt, R. C. (1969). Estimation of the surface free energy of polymers. Journal of Applied Polymer Science, 13(8), 1741–1747.

Ren, C.-S., Wang, K., Nie, Q.-Y., Wang, D.-Z., & Guo, S.-H. (2008). Surface modification of PE film by DBD plasma in air. Applied Surface Science, 255(5), 3421–3425.

Ren, Y., et al. (2016). Surface aging effects of polymeric materials treated with atmospheric pressure plasma. Applied Surface Science, 371, 303–310.

Sartori, S., et al. (2008). Surface modification of a synthetic polyurethane by plasma glow discharge: Preparation and characterization of bioactive monolayers. Reactive and Functional Polymers, 68(3), 809–821.

Shishoo, R. (2007). Plasma technologies for textiles. Woodhead Publishing.

Vasilakis, N., Moschou, D., Carta, D., Morgan, H., & Prodromakis, T. (2016). Long-lasting FR-4 surface hydrophilisation towards commercial PCB passive microfluidics. Applied Surface Science, 368, 69–75.

Yasuda, H. (2005). Plasma polymerization for biomaterials: Past, present, and future. Plasma Processes and Polymers, 2(4), 293–304.

Zhou, R., et al. (2016). Effects of atmospheric-pressure N2, He, air, and O2 microplasmas on mung bean seed germination and seedling growth. Scientific Reports, 6(1).