Hydrophobicity performance of thermoplastic polyurethane coated with TiO_2 under thermal aging effect

S. Jasmee[1,2,*], G. Omar[1,2], M.N.A. Nordin[1,2] , N.A.B. Masripan[1,2] , A. A. Kamarolzaman[1,2]

[1)] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: solehahjasmee@gmail.com

Keywords: TPU; contact angle; RMS roughness

ABSTRACT –Water repellent characteristics using ceramic-based coating may protect the surface from degradation, moisture absorption and corrosion due to the hydrophobicity behavior of the surface after coating. This paper seeks to provide insight into characterization and understanding on the effect of thermal aging on the hydrophobic performance of polymer substrate (TPU) with and without coated of Titanium Dioxide (TiO_2). The results reveal that hydrophobicity of TPU increases on coated and thermally aged. Although the contact angle does not differ much after coated with TiO_2, the substrate still behaves as hydrophobic. Surface roughness was found to be one of the factors affecting the hydrophobicity of the surface.

1. INTRODUCTION

Printed Flexible Circuits (PFC) is currently gained a lot of interest in electronic application due to its flexibility and elasticity. PFC based normally comes from polymer-based materials [1-2]. However, polymer materials could suffer from high moisture absorption that can degrade the performance of the PFC [3].

Coating is one of the solutions that could be used to provide a protective layer from moisture absorption [4]. Ceramic is found as one of the promising water repellency coatings such as Titanium dioxide (TiO_2) [5].

The ability of a surface to repel water can be expressed in three different categories which are hydrophilic, hydrophobic and superhydrophobic. The contact angle for hydrophilic is $\theta \leq 90^{\circ}$, hydrophobic is $\theta \geq 90$ and superhydrophobic is $\theta \geq 150^{\circ}$.

It has been reported that surface energy and surface roughness play an important role in wettability. Wenzel and Cassie-Baxter theory has shown the effect of roughness on contact angle. According to Wenzel, a hydrophilic surface will become more hydrophilic while hydrophobic surface will become more hydrophobic when roughness increases. Cassie- Baxter further explained that liquid droplet cannot diffuse between rough structures due to air trap [6].

Thermoplastic Polyurethane (TPU) is a well-known polymer for its flexible and stretchable properties. The water repellency performance and the acceptance of coating on TPU are expected to be one of the most promising flexible substrates for electronics packaging.

This paper investigates the hydrophobicity performance of TPU and the impact of temperature on the polymer hydrophobicity. Besides, TiO_2 will be used as a coating material on TPU in order to understand the effect of water repellency at elevated temperature. This study will also find the correlation of the surface roughness created by thermal aging on surface hydrophobicity.

2. RESEARCH METHODOLOGY

2.1 Sample Preparation

Thermoplastic Polyurethane (TPU) was used as a polymer substrate meanwhile TiO_2 as a coating material.

The substrate was cut into small pieces (50mm x 15mm x 0.1mm: length x width x thickness) and cleaned with liquid detergent before ultrasonicated with distilled water. Later, the sample was keep dried at ambient temperature.

2.2 Experimental

This study was done at three different conditions. Firstly, the contact angle of the as-received sample was measured. After that, the sample undergoes heat treatment at room temperature (RT), 40˚C, 60˚C, and 80˚C. Lastly, the sample was coated with TiO2 by using spin coating method at 300 r.p.m and followed by heated at RT, 40˚C, 60˚C, and 80˚C. The contact angle and surface roughness for all samples at different conditions were measured.

The contact angle measurement was done by using self-fabricated contact angle measurement tools for three-time at six different determinations to ensure its accuracy and precision while the surface roughness was done by using Profilometer Surfatest SJ-410.

3. RESULTS AND DISCUSSION

3.1 Contact Angle

Figure 3.1 shows the contact angle of uncoated and coated TPU after heated. From the graph, the contact angle of as received TPU at RT shows hydrophobic behavior with contact angle larger than 90° (CA: 98°±1.74). According to Hejda et. al, the surface energy is one of the factors influencing the CA [7]. TPU is a polymer that comes from urethane based which basically attributed to the lower surface energy of the polymer due to the polar/dispersion interaction. The lower surface energy of the surface cause higher in surface tension of the liquid and higher CA. Gooch (2011) shows that TPU has a surface energy that does not exceed the level of 40 mJ/m2 which is the reason of TPU behaves as hydrophobic [8].

Further heating for both coated and uncoated cause the contact angle to increase. However, TPU/ TiO_2 shows higher hydrophobicity compared to TPU/UC.

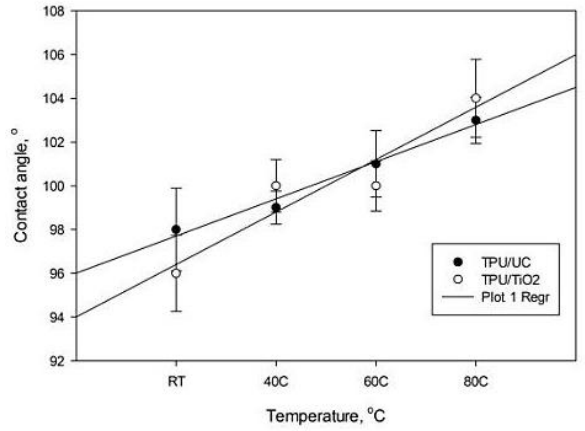

Figure 3.1 contact angle of TPU and TPU/TiO_2 at RT, 40˚C, 60˚C, and 80˚C

3.2 Surface Roughness

It has been reported that the wetting behavior of liquid on a solid surface depends on the surface morphology (i.e. surface roughness) [9]. Figure 3.2 shows the surface roughness of TPU and TPU/TiO_2 against temperature.

Overall, both sample shows increment in surface roughness as temperature increase. With regard to the contact angle shown in Figure 3.1, the effect of the surface roughness of the samples on the contact angle is quite noticeable. Increasing the surface roughness will cause the contact angle to be larger, according to Wanzel. This is because the water droplet does not diffuse easily on the rough surface which leads to the larger contact angle [10]. Rough surface also increases the air trap between roughness which causes the geometry of solid-liquid area to decrease, thus enhance the contact angle as stated in Cassie-Baxter.

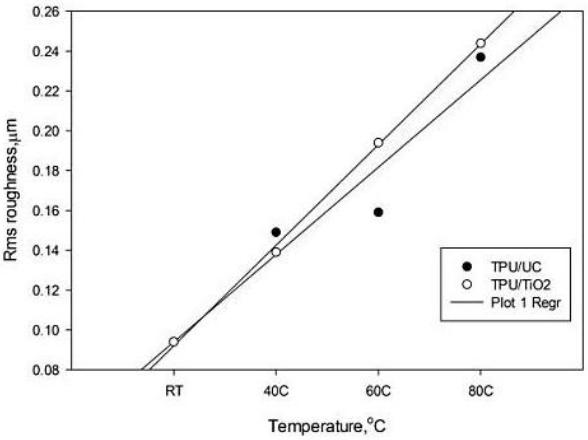

Figure 3.2 surface roughness of TPU and TPU/TiO2 at RT, 40˚C, 60˚C, and 80˚C

4. SUMMARY

This paper has successfully demonstrate the hydrophobicity behavior of the TPU coated and uncoated. The hydrophobicity of both surface have increase after heat treatment due to increase in surface roughness. The results obtained consistence with the Wenzel and Cassie- Baxter theory when surface energy, roughness and air-trap between the liquid-air interface does effect the hydrophobicity.

REFERENCES

[1] H.K. Seung et al. (2007). "All-inkjet-printed flexible electronics fabrication on a polymer substrate by low-temperature high-resolution selective laser sintering of metal nanoparticles," Nanotechnology, vol. 18, no. 34.

[2] P. McLeod (2003). A Review of Flexible Circuit Technology and its Applications.: PRIME Faraday Partnership.

[3] W. Hans, D. Eirini, W. Bernhard, and M. Bernd (2010). "Influence of moisture on humidity sensitive material parameters of polymers used in microelectronic applications," in 2010 3rd Electronic System-Integration Technology Conference (ESTC), Berlin, Germany.

[4] L. Ziyin, L. Yan, L. Zhou, and W. Ching-ping (2011). "Novel preparation of functionalized graphene oxide for large scale, low cost, and self-cleaning coatings of electronic devices," in 2011 IEEE 61st Electronic Components and Technology Conference (ECTC), Lake Buena Vista, FL, USA .

[5] O. Simona, L.C. Anna, and D. Michele (2015). "TiO2 Nanosols Applied Directly on Textiles Using Different Purification Treatments," Materials (Basel), vol. 8, no. 11, pp. 7988-7996.

[6] Y. Wan, J. Luo, J. Xu, X Zhang, and H. Yu (2013). "Experimental study of surface roughness effects on wettability," in Proceedings of the International Conference on Manipulation, Manufacturing and Measurement on the Nanoscale, IEEE, Piscataway, pp. 97-100.

[7] F. Hejda, P. Solar, and J. Kousal (2010). "Surface Free Energy Determination by Contact Angle," in WDS'10 Proceedings of Contributed Papers, Prague, Czech Republic, pp. 25-30.

[8] J. W. Gooch (2011). Encyclopedic Dictionary of Polymers, 2nd ed. New York: Springer.

[9] J. T. Simpson, S. R. Hunter, and T. Aytug (2015). "Superhydrophobic materials and coatings: A review," Reports on Progress in Physics, vol. 78, no. 8, p. 086501, July.

[10] L. F. Wang and Z. D. Dai (2016). "Effects of the natural microstructures on the wettability of leaf surfaces," Biosurface and Biotribology, vol. 2, pp. 70-74.