Cranfield Plasma Solutions

Special Report

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Title: 50W Plasma Tact - Surface Energy Modification: Polycarbonate

Executive Summary

The 50W Plasma Tact was deployed for surface energy modification on PolyCarbonate (PC) discs from CutMyPlastic, using optimised parameters: 50W forward power, 0W reflected power, 2.48GHz, 10L/min argon, and a 3mm stand-off distance. The surface free energy of the polymer discs was increased at speeds of up to 8m/min; this maximum speed was only limited by the acceleration curve range of the precision motion stage; the results clearly indicate that surface energy modification may be undertaken at even higher speeds, which has been demonstrated on other polymers. Water contact angles were reduced from (88.0±5.0)° down to (30.0±2.5)° and (35.0±2.5)° at processing speeds of 1m/min and 8m/min, respectively. This resulted in the average surface free energy increasing from circa 24mN/m up to as high as 70mN/m.

Method

The 50W Plasma Tact was installed into the RAP machine. The plasma torch parameters were set so that the optimal plasma was discharged for surface energy modification using pure argon gas: 50W forward power, 0W reflected power (0W was achieved rather than 1W due to the environmental conditions), 2.48GHz frequency, 10L/min gas flow rate, and a 3mm stand-off distance. The stand-off distance of 3mm was found to be optimal, in previous work packages, on a variety of materials including polymers such as Mylar [I].

A single plasma pass was conducted, using a complex path, over the surface of different PolyCarbonate (PC) discs, which all had 100mm diameters. The complex path was undertaken for two reasons: firstly, to demonstrate that such a pattern with small separation between routes, may be plasma processed at such high speeds, without any interaction between the different parts; and secondly, so that multiple points along the processed path could be measured. The latter point was important to analyse, because multiple points had to be measured to enable confidence in the error bars generated. Literature shows that typical water contact angles for unprocessed PolyCarbonate (PC) sheets varies from anywhere between 81° to 88° [II,III,IV]. The pre-processed water contact angles measured on the PC discs in this study were recorded to be (88.0±5.0)° and the pre-processed ethylene glycol contact angles were (66.0±5.0)°.

The videos titled ‘Polycarbonate 1m per minute’ and ‘Polycarbonate 8m per minute’ show the PC discs being processed at 1m/min and 8m/min, respectively. The highest processing speed possible was 8m/min, which is slower than previous experiments where speeds of 30m/min were demonstrated; however, the complex path and fast changes in stage direction limited the speed due to the maximum acceleration allowed by the precision motion stage.

Figure 1 shows the effect of how water preferentially sticks to the plasma processed path on the surface of the disc. Note well, that red dye was only added to the water in this photographed example to make the water clear to the reader; pure water and pure ethylene glycol were used in contact angle measurements. The letter ‘A’ was chosen, with the intention to spell out the word ‘ADTEC’, but time did not allow for the rest of the letters to be performed. Nonetheless, this letter clearly shows the distinct differences between areas that were plasma processed and those that were not; moreover, this test also shows the fine ability to leave a small area unprocessed in the middle of the letter. Future work is planned to plasma the entire word ‘ADTEC’ and an appropriate shade of blue dye will be used to illustrate the result.

Figure 1

Contact angles of deionised water and ethylene glycol were measured, at various stages on the path of the plasma, which enabled the surface energy along the path to be characterised. The Owens, Wendt, Rabel and Kaelble method for surface energy calculation was deployed, which is a well-established method for flat, smooth surfaces that naturally exhibit relatively low to high surface free energy [V].

50W Plasma Tact Results

Figure 2 shows the water contact angles and ethylene glycol contact angles on the PolyCarbonate (PC) disc surfaces, after the plasma process. Note well, that the pre-processed contact angles were (88.0±5.0)° for water and (66.0±5.0)° for ethylene glycol.

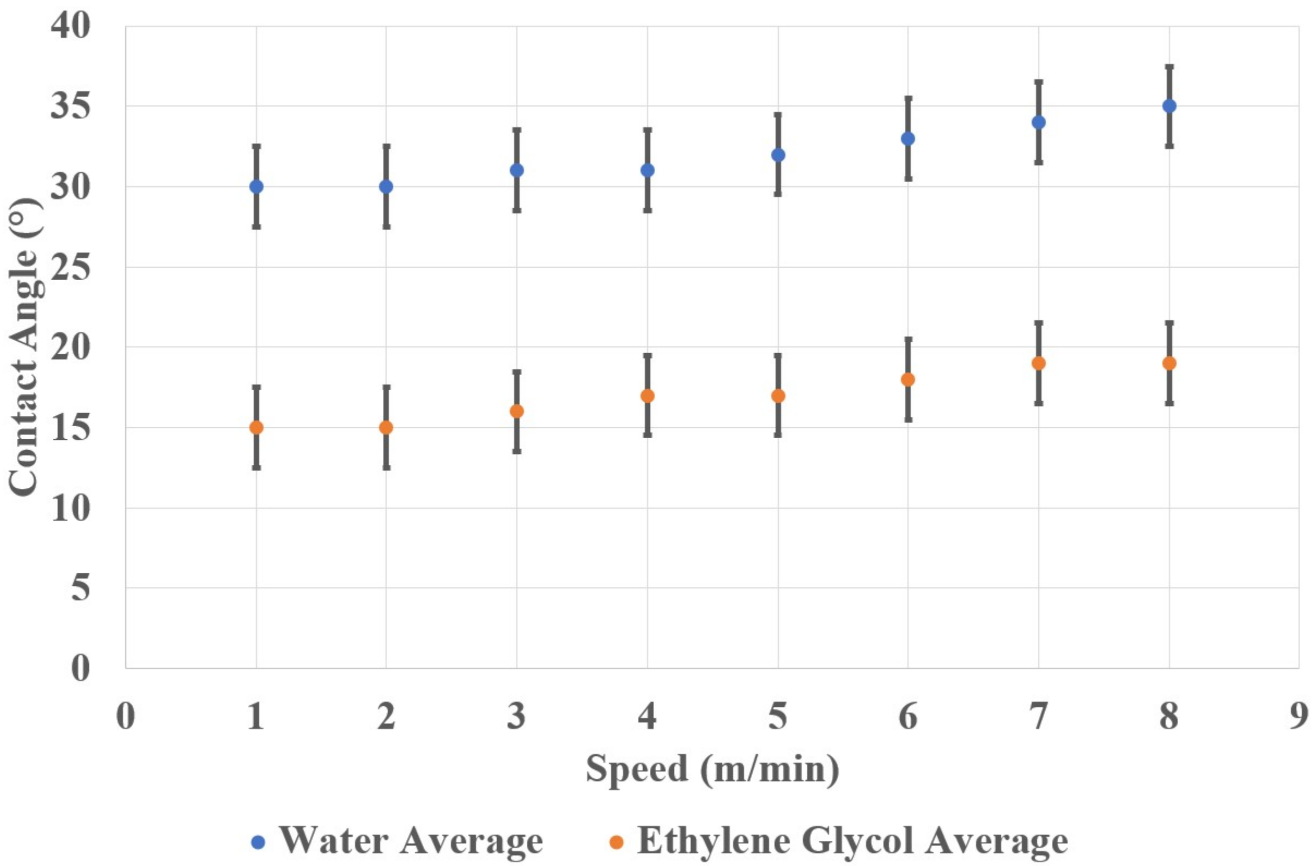

Figure 2
50W Plasma Tact – Polycarbonate – Contact Angles After Plasma Process
Starting Contact Angles: Water = (88.0±5.0)°; Ethylene Glycol = (66.0±5.0)°

The 50W Plasma Tact result – a single process that took seconds – is significant, when taken in context of other plasma technology. Huang et al. conducted work using an atmospheric pressure plasma torch operating with the following parameters: 175W forward power, 13.56MHz frequency, 10L/min argon gas flow rate, and a plasma processing speed of only 0.15m/min. Now this process also required a pre-plasma cleaning stage, which entailed ultrasonic cleaning for 30min in a soap bath and thorough rinsing with deionized water for 60min [IV].

The 50W Plasma Tact post processing contact angles on PolyCarbonate (PC) all fall within a relatively narrow range, irrespective of the processing speed, which indicates that significantly higher speeds could be deployed. Contact angles for water ranged between (30.0±2.5)° and (35.0±2.5)° for processing speeds of 1m/min and 8m/min, respectively. Contact angles for ethylene glycol ranged between (15.0±2.5)° and (19.0±2.5)° for processing speeds of 1m/min and 8m/min, respectively.

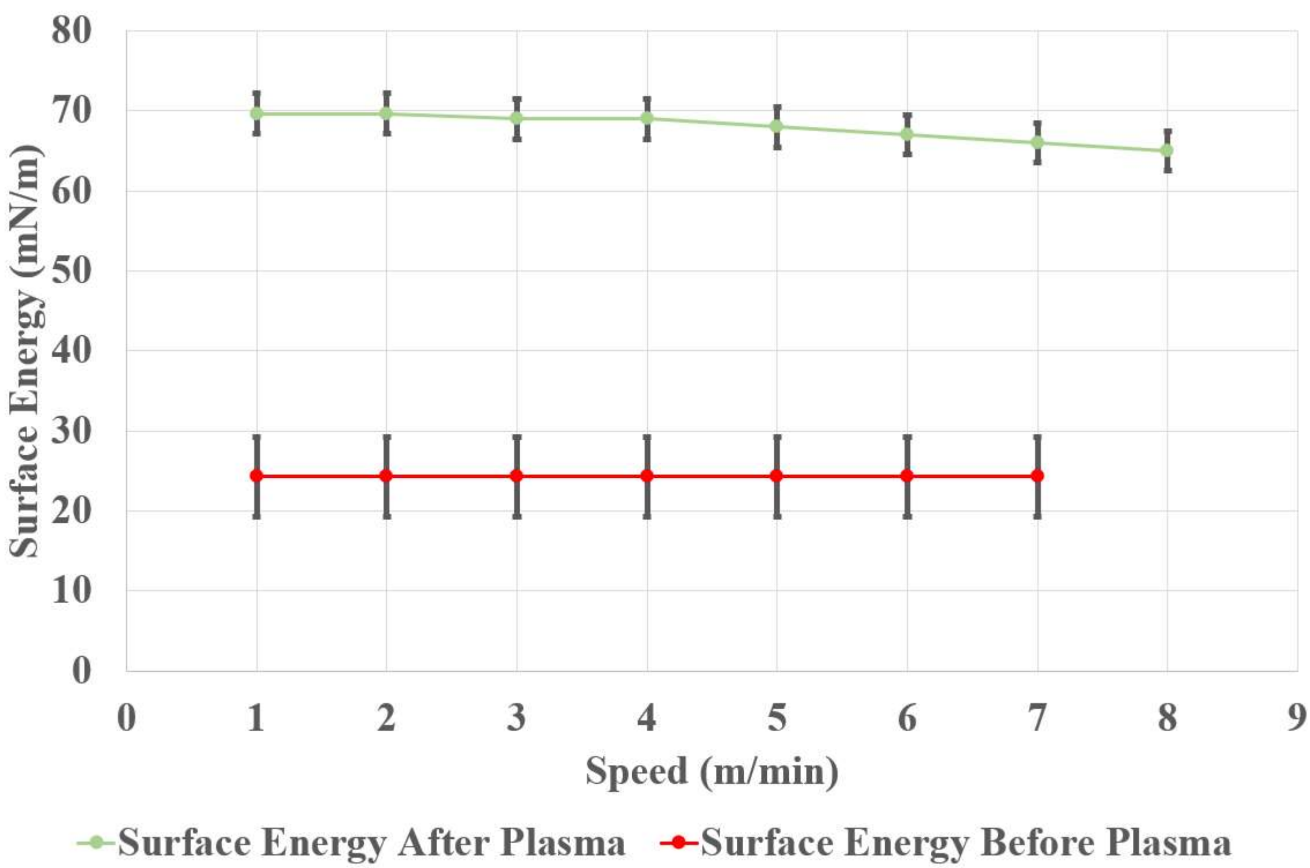

Figure 3

50W Plasma Tact – Polycarbonate – Surface Free Energy

Figure 3 shows the surface energy on the PolyCarbonate (PC) disc, both before and after plasma processing the surface. The surface energy before plasma processing was (24.25±5.00)mN/m, which then increased after plasma processing to between (65±5)mN/m and (70±5)mN/m for processing speeds of 1m/min and 8m/min, respectively.

The increase in surface energy corresponds to the increased wettability of the PC disc surface, which is shown in Figure 1. This result shows that plasma adds value to manufacturing chains, by increasing the wettability and hence the bonding of the surface to other materials and coatings. Further cleaning of the surface could be performed, but would require processing at slower speeds and would add very little additional benefit as surface energy levels of (70±5)mN/m is already higher than other values reported in literature [II].

Conclusion

The 50W Plasma Tact has been deployed to increase the hydrophilicity of PolyCarbonate (PC). The wettability was achieved with optimised plasma parameters at a processing speed range of between 1m/min and 8m/min, which is significantly faster than other work reported in literature. Contact angles for water were reduced from (88.0±5.0)° down to between (30.0±2.5)° and (35.0±2.5)° for processing speeds of 1m/min and 8m/min, respectively. Contact angles for ethylene glycol were reduced from (66.0±5.0)° down to between (15.0±2.5)° and (19.0±2.5)° for processing speeds of 1m/min and 8m/min, respectively. Consequently, the average surface free energy of the surface was increased from (24.25±5.00)mN/m, up to between (65±5)mN/m and (70±5)mN/m for processing speeds of between 1m/min and 8m/min, respectively.

References

I. 50W Plasma Tact - Surface Energy Modification: Mylar, Cranfield Plasma Solutions, Special Report, 06/06/2022
II. J. Kelar, et al.; 2018; Activation of polycarbonate (PC) surfaces by atmospheric pressure plasma in ambient air; Polymer Testing; 67: 428 – 434
III. M. Sira, et al.; 2008; Surface modification of polycarbonate in homogeneous atmospheric pressure discharge; Journal Of Physics D: Applied Physics; 41: 015205
IV. C. Huang, et al.; 2011; Static Water Contact Angle Analysis of Cyclonic Atmospheric Pressure Plasma-Activated Polycarbonate; Japanese Journal of Applied Physics; 50: 01AH05
V. HellermannTyton: Chapter 5; Industrial Identification Effect Of Surface Energy