Enhancing the mechanical performance of injection moulded parts through the use of atmospheric plasma pre-treatments

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Abstract:. This study reports on the development and evaluation of a pilot-scale barrel atmospheric plasma reactor for the pre-treatment of acrylonitrile butadiene styrene (ABS) polymer particles. The effect of plasma treatment time on the level of activation of the treated polymers was investigated. It was established that, the optimised treatment for ABS involved a 15-minute plasma activation of a 500 g batch of polymer particles. The polymer particles were injection moulded after the plasma pre-treatment. Tensile testing of the resulting dog-bone polymer parts, demonstrated that up to a 10.5 % increase in strength was obtained, compared with those fabricated using un-activated polymer particles.

1. Introduction

Plasma treatments have been extensively applied to enhance the surface properties of polymer particles through the introduction of polar groups and cross-linking on the surface without affecting the bulk composition [1]. In contrast to flat polymeric substrates, there have been very few publications on the atmospheric plasma treatment of polymer particles to-date. Amongst the plasma reactor designs for the treatment of polymer particles are fluidised bed reactors, downer reactors and batch reactors. These reactors are difficult to apply at an industrial scale due to these sized limitations, as well as the high consumptions of power and gas [2]. Most of the previous studies on the activation of polymer particles have focused on experiments using laboratory scale particle batch sizes of few grams. This study evaluates the performance of a pilot scale barrel plasma reactor which was designed to treat 500 g of polymer particles. Plasma activation studies with this source were carried out using acrylonitrile butadiene styrene (ABS) polymer particles.

2. Experimental work

A photograph of the fabricated pilot-scale atmospheric barrel plasma reactor is given in Figure 1. This reactor has a 35 cm long quartz chamber and the helium discharge is driven using a 1500 W, high voltage power source (Plasma Technics Inc., USA). In this system, by varying the percent ON time vs OFF time (pulse density modulation (PDM) %) from 1 to 100%, output power can be controlled. The high voltage power source is directly connected to two aluminium rods, which act as the biased and earthed electrodes and these are also used to rotate the plasma chamber in order to agitate the particles during treatment. Prior to the plasma activation treatment, the barrel chamber was purged for 5 minutes with helium, while rotating the polymer particles. The cylindrical ABS particles had a diameter of 2 mm and height of 3 mm.

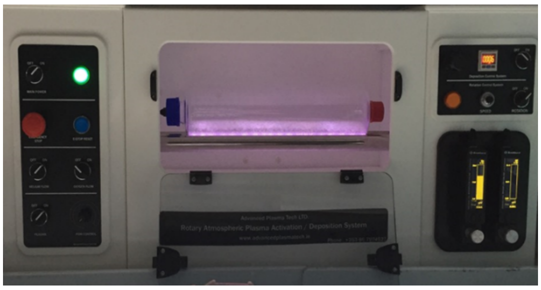

Figure 1: Photographs of the pilot-scale barrel plasma reactor

The level of polymer particle activation after plasma treatment, was evaluated based on water contact angle (WCA) measurements. XPS analysis was also used to monitor the surface chemistry of the particles with level of plasma activation. Optical emission spectroscopy (OES) was used as a diagnostic tool to monitor changes in atomic and molecular species intensity in the plasma with experimental conditions.

A Battenfeld 250 plus injection moulding machine was used to produce tensile test (dog-bone) specimens, with the standard dimensions according to the ASTM D1708-13 from both un-activated and plasma activated ABS polymer particles.

3. Results and discussion

Figure 2 shows the effect of plasma treatment time on the water contact angle of 500 g batches of ABS particles. It was found that, the water contact angle (WCA) decreased from 95° to 46° after 5 minutes treatment time and that further increasing the treatment time to 10 minutes did not yield any further significant decrease in contact angle.

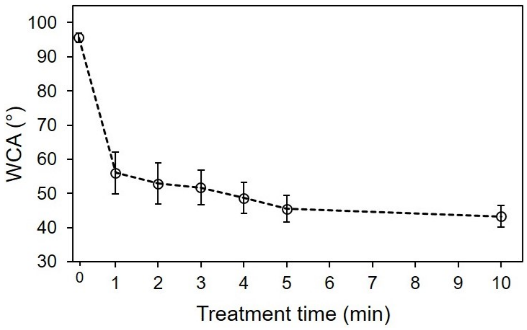

Figure 2: Effect of plasma treatment time on water contact angle of 500 g batches of ABS polymer particles.

The XPS analysis results demonstrated increased oxygen containing functional groups after the plasma treatment, these contribute to increase in the surface hydrophilicity of the polymer particles [3].

In order to investigate if the atmospheric plasma treatments of the polymer particles influenced the mechanical performance of the resultant injection moulded ABS polymer parts, tensile testing were carried out. The plasma pre-treatment of 400 g of polymer particles was carried out using the pilot-scale reactor and the activated particles were injection moulded immediately after treatment. The measurements were obtained from batches of five injection moulded dog-bones samples and the results averaged to find the maximum tensile strength in each batch. As shown in Figure 3, the maximum increasing in the tensile strength of the inject moulded parts was 10.5 %, when a treatment time of 15 minutes was used. Note the decrease in the tensile strength observed for the longer treatment times. A possible explanation for this is due to polymer surfaces modification due to excessive plasma exposure. These can leave active sites at the surfaces which are subject to post-reactions; this is also called aging [4].

The probable explanation for the increased mechanical strength of injection moulded parts after plasma treatment of the polymer particles, is the enhanced bonding achieved between the activated particles. In addition to enhancing the surface energy of the polymer, the plasma may also remove moisture or organic contaminations present on the surface [5]. Similar enhancements in polymer mechanical performance have previously been demonstrated by us for activated polymer particles, which were used to produce 3D printing filaments [6].

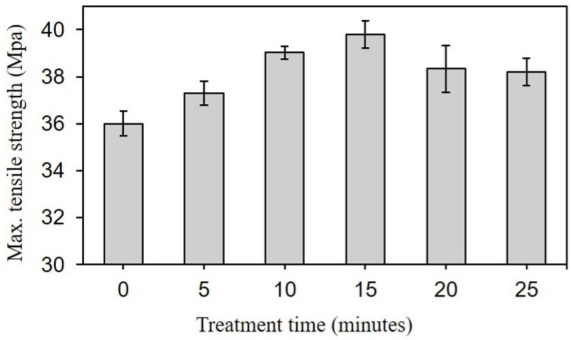

Figure 3: Effect of plasma treatment time on the tensile strength of the inject moulded parts

4. Conclusions

A pilot scale barrel plasma system for the treatment of up to 500 g of polymer was successfully developed and evaluated. An increase of up to 10.5 % in mechanical strength was obtained using the plasma pre-treated ABS polymer particles, compared with those fabricated without this treatment. This enhancement is likely to be due to a combination of the enhanced surface energy of the activated polymer particles, as well as the removal of moisture and/or organic contaminants on the polymer surface. This is the first time that the use of plasma activation pre-treatments of polymer particles, has been found to yield enhanced mechanical strength in injection moulded parts.

Acknowledgements

The authors would like to acknowledge the support of the Enterprise Ireland Innovation Partnership programme and the SFI funded I-Form Research Centre 16/RC/3872.

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