Real-time parametric analysis during the plasma treatment of carbon composite materials

V J Law[1], R. Amsarani[2] and D P Dowling[2]

[1]Dublin City University, National Center of Plasma Science and Technology, Collins Avenue, Glasnevin, Dublin 9, Dublin, Ireland

[2]School of Electrical, Electronic and Mechanical Engineering, University College Dublin, Belfield, Dublin 4, Ireland

Introduction

Carbon fibre reinforced composite materials are used widely in applications ranging from automobiles to aircraft and sports equipment. Plasma treatments can be used to activate the composite surface in order to enhance surface energy, prior to adhesive bonding [1]. In this study plasma metrology is used as a means of evaluating the performance of a reel-to-reel atmospheric pressure plasma system used to active a composite is investigated. A real-time electrical parametric analysis of the plasma treatment process was carried out as the carbon composite was passed through the plasma chamber. A reproducible correlation was obtained between the plasma parameters and the position of the composite in the plasma chamber.

Experimental

The atmospheric pressure plasma reel-to-reel system used in this study is the Dow Corning Labline™ [2, 3] and comprises two plasma chambers aligned around a central web roller. 0.25 mm thick aerospace grade carbon weave composite (CWC) used in these experiments (figure 1). The cured composite material were mounted onto a 30 cm diameter PET web using adhesive tape and passed through the plasma chambers at a rate of 1.5 m/min and a residence time of 25 seconds per pass. The plasma processing conditions are as follows: Drive frequency between 17 to 23 kHz, applied power ~ 1250 W, helium flow rate of 10 standard litres per min (slm), with the addition of oxygen at a flow rate of 10 ml/min. The focus of this study was to monitor the effect on plasma parameters of the passage of the CWC through the plasms. Specifically the plasma parameters were monitored under static position/clean (no CWC); web tension; carbon composite entering and leaving the plasma chambers; and the effect of plasma treatment duration (passes of CWC through the plasma). The current and voltage waveforms at the junction of the two chambers are monitored using North Star PVM-5

high voltage probe with a contention ratio of 1000:1 and a Bergoz Instrumentation France, toroidal current transformer (CT–E5.0) with an output of 5V to 1A. The electrical data is then processed and displayed within a LabVIEW software program. In this study, the current and voltage route mean square values and drive frequency are followed in process at refresh rate of 0.8 seconds and Principal Component Analysis (PCA) in both 2D-space [4] and 3D-space [5].

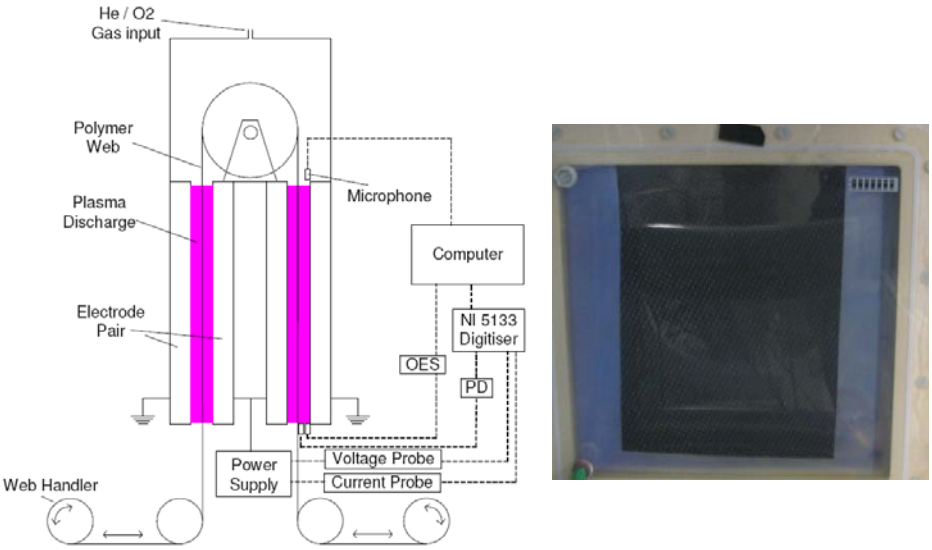


Figure 1: Schematic of reel-to-reel atmospheric pressure plasma system. Insert shows the CWC attached to web as it passes through the plasma.

Results

As illustrated in Figure 2 under the conditions used 7 passes of the CWC are required to achieve the highest surface energy (> 55 mN/m) and water contact angle < 40°. Figure 2 also shows the drive frequency pulling effect as the CWC through the plasma. In the region 0-51 the CWC sample is outside the chamber and the web is being cleaned, between 51-115 the CWC is in the left hand chamber and between 115 and 151 the CWC is on the roller (top box). The subsequent measurements are a mirror image of the first set of data and reflect the passage of the CWC through and then of the right plasma chamber. Note the drive frequency response to tensioning and de-tensioning of web as the rollers start to rotate and stop.

Figure 3 provides a 3D-PCA of 2 CWC plasma process runs; n = 1 and n = 6. In run 1, the viewing 3D angle is chosen to the clearest view of cluster in the data set. Using projection the start of the process is clearly separated from the majoring of the data. In Run 6 the data points associated with the start and finish cluster with the remaining data points form time-stamped clusters that reflect individual stage within the process.

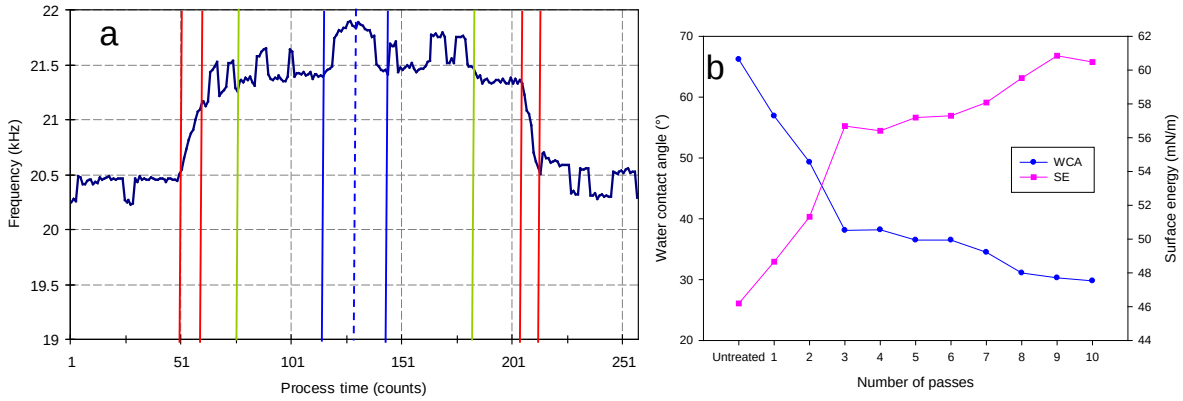


Figure 2ab: a: Drive frequency value as a function of process time for the CWC n = 7th pass, and b), CWC water surface contact angle and total surface energy as a function of passes.

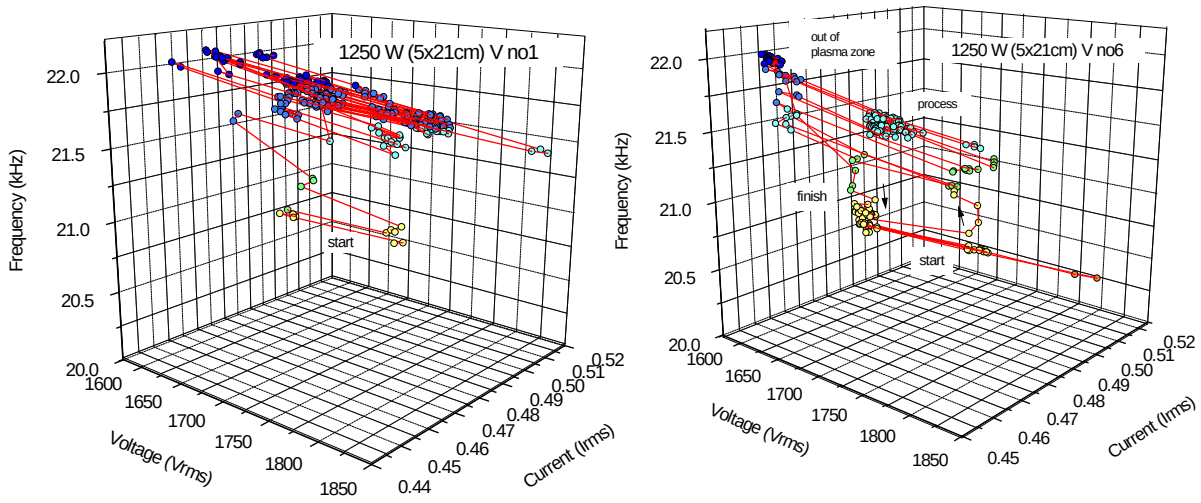
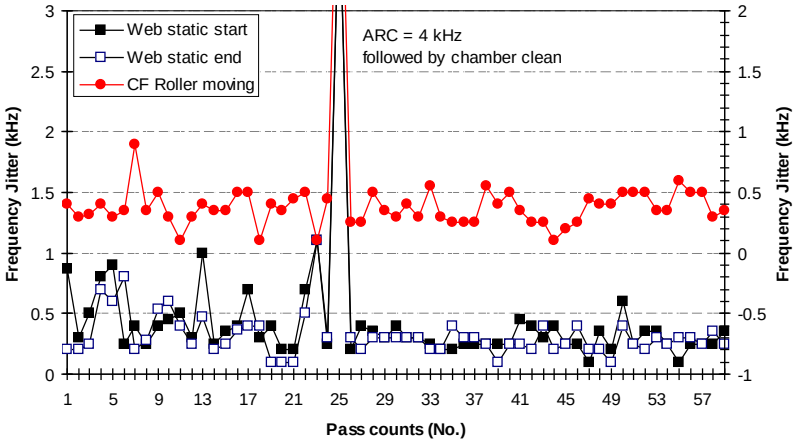


Figure 3: 3D-PCA of CWC as a function of for n = 1 and n = 6 passes. The data clusters and trajectory reveal the plasma clean stage; web tensioning, pass through; web un-tensioning and post clean.

The use of system drive frequency as a means of investigating the 'cleanliness' of the chamber during the plasma activation of the CWC was investigated. The Labline chamber is used for both coating deposition (particularly siloxanes) and for surface activation. The presence of organic contaminants on the chamber walls was reflected in the level of frequency jitter observed for the first 24 passes as illustrated in Figure 4. In this figure the level of frequency jitter with passes of the composite through the plasma is shown. On the 25th pass an arc was formed in the chamber as illustrated by the data spike. At that point the activation process was stopped and the chamber walls were mechanically / solvent cleaned. As illustrated in Figure 4 for the next set of passes 26 – 60 the level of jitter was reduced by approximately 50%.



Region before clean	Mean Frequency Jitter (kHz)
Web static start	0.63
CF roller region	0.52
Web static end	0.53
Region after clean	
Web start	0.29
CF roller region	0.37
Web static end	0.27

Figure 4: Run-to-run jitter analysis of frequency data for 3 process stages as function of CWC passes.

Conclusions

This paper has demonstrated the capability of plasma diagnostics to obtain real-time plasma parametric metrology of carbon composite material passing through a reel-to-reel atmospheric plasma. The 2D and 3D representations of the electrical data demonstrate that the individual sequential steps within the process flow can be detected and related to the position of the CWC within the plasma. The monitoring of the level of frequency jitter and arcing events can be used as a fault classification that triggers chamber cleaning.

Acknowledgements

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References

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