ARC JETS BLOWN BY OUTGASSING POLYMERS IN AIR

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ABSTRACT

This paper describes experimental results about the behaviour of arc jets transversely blown in the presence of outgassing polymers (POM $-CH_2O-$ or PMMA $-C_5H_8O_2-$). The arc jets are ignited in air between copper electrodes under a 2 kA, 50 Hz AC current. High speed photography and optical emission spectroscopy are used to study the mechanism leading to the increase of the arc voltage when polymers are used instead of non-ablating materials (e.g. quartz). It is found that the transversal blowing flow caused by the injection of ablation vapours have a weak effect on the arc voltage build-up. Instead, the chemical changes in the plasma environment appear to better explain the observed increase in the arc voltage when polymers are used.

1. INTRODUCTION

Polymeric materials are known to improve the performance of electrical switchgear (e.g. breakers, contactors, etc) [1]. These materials vaporize (through a process known as ablation) when exposed to high-energetic, high-intensity thermal plasma arcs generated between two contacts during interruption of high fault currents [2]. The generated vapours assist to efficiently control and extinguish the tremendous energy dissipated in the plasma arc such that currents can be successfully interrupted.

In the literature, two different mechanisms (or a combination of them) have been proposed to explain this process. First, the control of the arc is assumed to be caused by the flow generated by ablated released material [3]. Second, it is considered that the thermodynamic properties of the plasma environment are changed by the ablated organic vapours, modifying the arc behaviour [4]. Unfortunately, it is still not clear which is the contribution of each mechanism to the overall control and quenching of the arc.

This paper intends to experimentally investigate the behaviour of arc jets initiated in an electrode arrangement designed to amplify the blowing effect caused by the vapours released by outgassing polymers. In this manner, it is possible to assess the influence of this blowing effect on the measured arc voltage. In addition, some preliminary insight into the chemistry of the organic vapours released by ablation is performed and reported.

2. EXPERIMENTAL SYSTEM

The experimental setup is composed by a pair of hemispherically capped copper electrodes forming an air gap along the same vertical axis. In order to reach the transversal blowing of the arc, a test wall with a protruding piece is placed beside the electrodes as shown in Fig. 1.a. The arc is ignited between the electrodes by an external voltage pulse, which is followed by a 50 Hz current delivered by a synthetic circuit. The experimental results presented in this paper correspond to a 300 V system with a prospective peak current of 2 kA.

In order to visualize the arc jets in the experiment, photographs are recorded with a high speed camera (FASTCAM A3), with 5000 fps and a resolution of 614x416 pixels. In addition, a combination of a band pass filter (BPF) with central wavelength of 510 nm and neutral density filters (NDF) is used to detect only the copper emission in the recorded images.

A three channel charged-coupled device (CCD) optical spectrometer is used to detect the optical emission spectra of the arc between 250 and 720 nm. The recorded spectra correspond to the radiation at an observation point (shown in Fig.

1.a) located at the mid-section of the interface between the protruding piece of the wall and the air gap. A set of fused silica lenses is used to collimate the emission from the observation point (with a maximum diameter of about 1 mm) to an optical fiber connected to the spectrometer. Inline attenuators are used to avoid saturation of the spectrometer, which records the spectra every millisecond. The location of the measurement instruments is shown in Fig. 1.b.

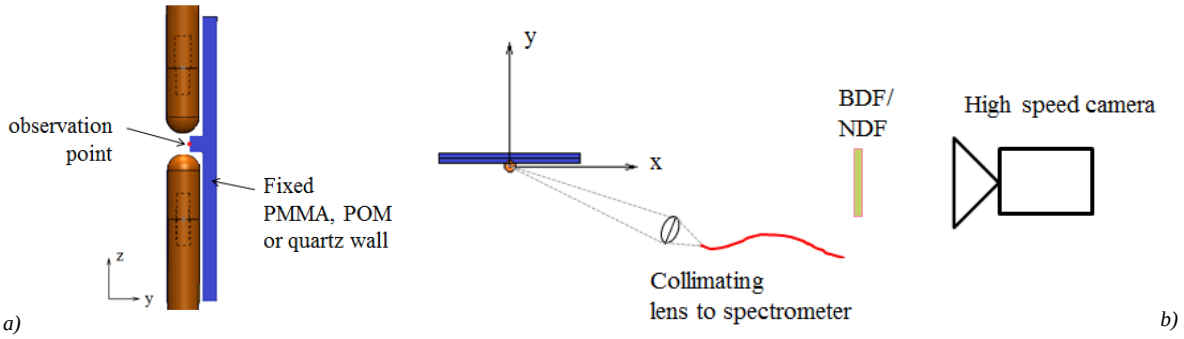

Fig. 1. Details of the experimental setup, a) side view of the electrodes and the wall, b) top view of the electrode configuration and the measurement instruments.

3. RESULTS

The electric current and voltage for the different wall materials in the experiment are shown in Figure 2. In general, a strong effect of the POM wall is observed on the arc voltage (and therefore on the current), compared with the case with PMMA or with the reference (non-ablating) quartz wall. Furthermore, note that the arc is quenched after the zero crossing when the polymeric walls are used.

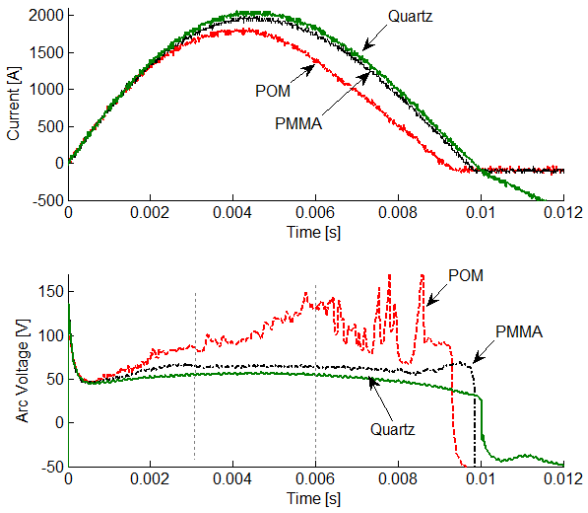

Fig. 2. Measured current and arc voltage for the different wall materials.

In order to illustrate the shape and orientation of the arc jets under the influence of the different materials, the recorded pictures at two different time instants are shown in Fig. 3. At the first instant (t = 3 ms), the current in all cases is about 1.7 kA although the arc voltage is different (88, 65 and 55 V for POM, PMMA and quartz walls respectively). At the second instant (t=6 ms), the current is significantly lower in the case of POM (about 1.4 kA) compared with the current when the PMMA or the quartz walls are used (about 1.8 kA). In addition, there is also a significant difference in the arc voltages recorded at this time (130, 65 and 55 V for POM, PMMA and quartz walls respectively).

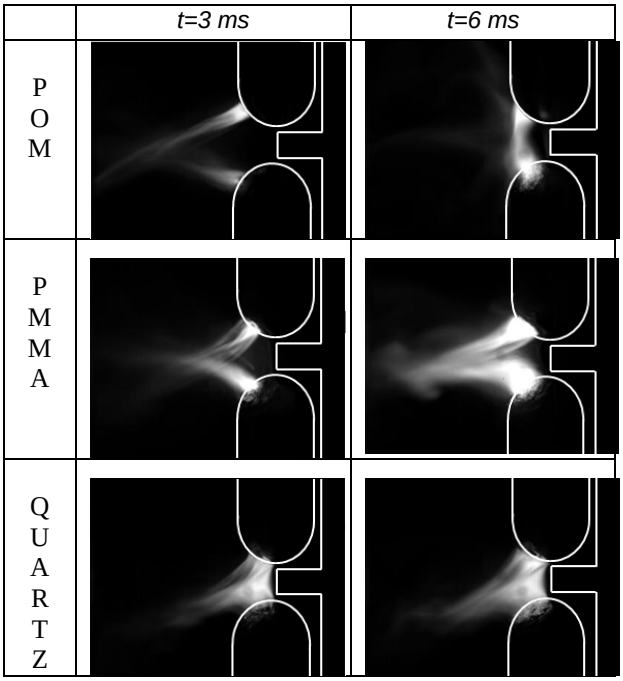

Fig. 3. Pictures of the arc jets for the different wall materials at 3 and 6 ms.

Observe that the increase in arc voltage reached with the POM walls cannot be attributed to the transversal blowing caused by the local pressure increase due to the generated vapours. In this case, the lateral displacement of the arc jets is

maximum at t = 3 ms even though the arc voltage at this time is significantly smaller (about 65% lower) than at t = 6 ms (when the blowing effect is weaker). In the same manner, the larger blowing effect observed with PMMA walls compared with quartz walls is not translated in terms of a significant increase of the arc voltage (the differences are only 10 V).

It is worth to mention that the pictures in Fig. 3 also show clear differences in the optical width of the arc jets for the considered materials. Thus, the arc width under the influence of a POM wall is significantly smaller than in the case of PMMA and quartz walls. This observation agrees well with the measured arc voltages in the considered cases. Even though these differences in the arc jet width could be explained theoretically by differences in the plasma environment composition, the experimental evidence to support this hypothesis is still poor.

Even though experimental information about the chemical composition of ablation-dominated arcs in air is scanty, it has been shown that hydrogen is the major plasma component introduced by polymers [5]. Unfortunately, other elements (e.g. carbon, oxygen, nitrogen) are difficult to detect due to the dominance of copper emission in the spectra.

In order to gather additional chemical information of the released ablated vapours, the optical emission of the observation point (Fig. 1.a) at the interface between the surface of the polymers and the arc environment, has been measured for POM and PMMA. An example of the spectra recorded is shown in Fig. 4. It is found that the spectrum is dominated by H, H_2 and Cu peaks. The emission from H and H_2 species is expected considering their concentration in pure POM and PMMA vapours at several thousand kelvins [7]. The significant Cu emission is surprising considering the large separation between the observation point and the arc jets if polymers are used (as seen in Fig. 3). However, the copper emission recorded can be explained by a significant diffusion of metallic species from the arc column. This could be expected considering the large gradients in densities, pressure and external forces [8] present in this experiment.

Two additional diatomic species are also detected in the spectrum. A well-defined CN violet band ($B^2\Sigma^+ – X^2\Sigma^+$) is found for both polymers during the complete current cycle. Also, a clear C_2 Swan band ($d^3\Pi_g \rightarrow a^3\Pi_u$, $\Delta\upsilon=0$) is observed, although it is only present in the case of PMMA walls. Even though CO has also been reported to be a major product of arc-induced polymer ablation in nitrogen [7], neither the Angstrom system in the visible nor the 3rd positive bands of CO in the UV [9] could be detected.

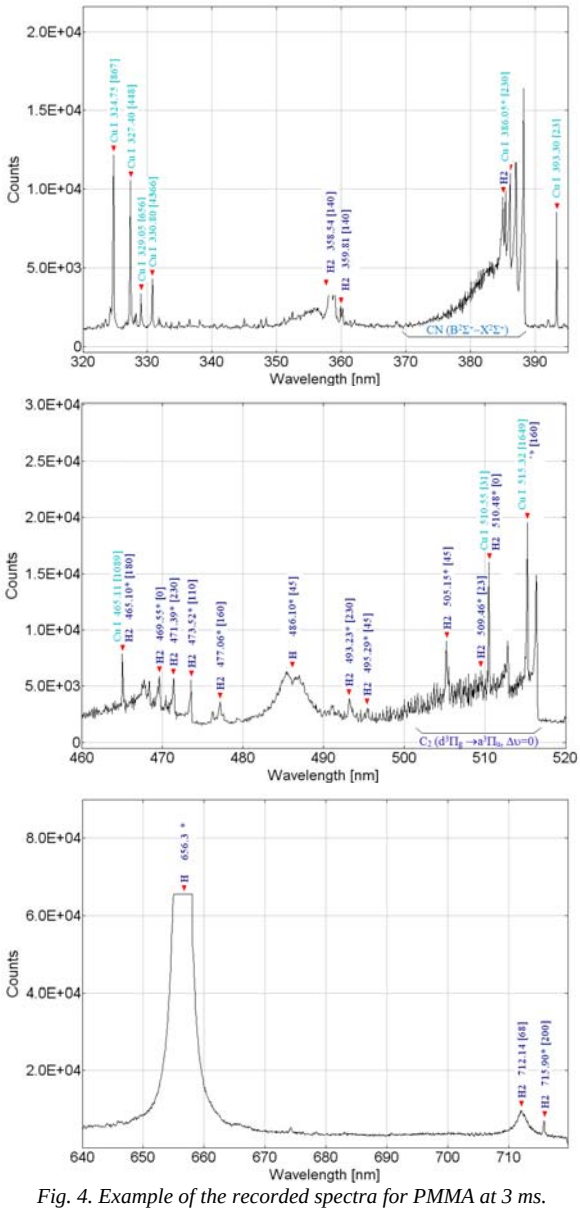

Fig. 4. Example of the recorded spectra for PMMA at 3 ms. Observe that the H peak at 656.3 is truncated since it saturated the spectrometer.

In order to estimate the maximum temperature in the observed point in the close proximity of the polymer surface, the measured CN band is compared with the spectra simulated with the software LIFBASE [10] assuming thermal equilibrium. Figure 5 shows the comparison

between measured and simulated spectra for a gas temperature of 9000 ±1000 K. Further analysis of the CN band for both polymers as a function of time show no significant change in the temperature at the observation point.

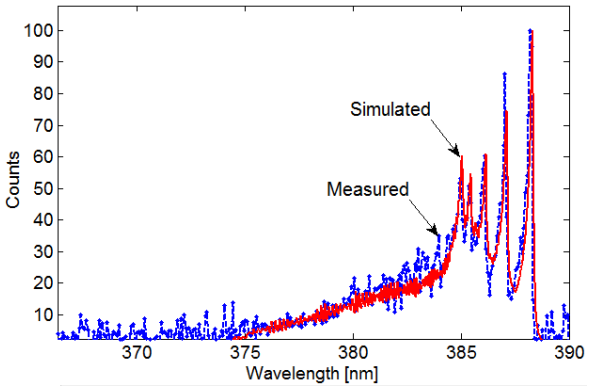

Fig. 5. Comparison of the measured and simulated CN band for PMMA at 3 ms.

4. CONCLUDING REMARKS

The presented results show that the transversal blowing (due to pressure increase) caused by the release of ablation products does not have a significant effect in the arc voltage build-up in this experiment. Instead, the chemistry of the plasma environment due to the injected organic vapours appears to be the main mechanism leading to the change of the arc cross section and therefore influencing the arc voltage.

Contrary to measurements of optical emission from the arc column [5], the recorded spectra show clear differences in the chemical composition of the gas in front of the polymer surface for POM and PMMA. Further analysis of these differences can be used to better understand the effect of the chemistry of the plasma environment in the arc voltage.

One surprising finding is that the maximum temperature in the close proximity of the polymer surface is maintained in time at about 9000 K, regardless of the used polymer. However, this result is difficult to explain without the analysis of the complex interaction of the injected ablation vapours and the magnetohydrodynamic flows involved. Further research in this direction is ongoing.

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