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# Meet Our New Colleagues

This column presents selected currently graduating Ph.D. students in the thermal spray field from around the world. Students planning to graduate in the area of thermal spray within next 3-6 months are encouraged to submit a short description (1-2 pages, preferably as Word document) of the projects they performed during their studies to Jan Ilavsky, JTST Associate Editor, address: Argonne National Laboratory, Advanced Photon Source, 9700 S. Cass Ave., Argonne, IL, 60439; e-mail: JTST.Ilavsky@aps.anl.gov. After limited review and corrections and with agreement of the student's thesis advisor, selected submissions will be published in the upcoming issues of JTST.

## Arc Voltage Fluctuations: Comparison Between Argon and Nitrogen Plasma Jets

*Elise Noguès, Ph.D. student, SPCTS (Science of Ceramic Processes and Surface Treatment Laboratory), University of Limoges, France; e-mail: elise.nogues@bocedwards.com*

Elise Noguès

### Background and Motivation

In the plasma spray process, the particle thermal treatment is strongly linked to the arc root fluctuations. These fluctuations are due to the effect of two forces on the connecting arc column: the drag force issued from the gas flow in the cold boundary layer (CBL) and the electromagnetic self-induced forces, resulting in its continuous fluctuations along the anode wall. The connecting column lengthens and when the arc voltage, increasing with it, reaches the breakdown voltage, a new arc root is created with lower voltage drop (Ref 1). This movement, depending on the CBL thickness, induces a periodic variation in the arc voltage, modifying the enthalpy input to the gas, the plasma jet velocity and temperature, its length, and width. These arc fluctuations are function of the plasma torch geometry (anode shape and internal diameter), the plasma spray parameters (mass flow rate, secondary gas percentage, and arc current), and the nature of primary plasma gas (argon or nitrogen) (Ref 2-4).

During the process, the plasma momentum continuously varies following the voltage fluctuations, at a few kHz, but the momentum of particles injected remains constant. Therefore, the particle trajectories fluctuate and correlatively their temperatures and velocities (Ref 5). The measurements of Bisson and Moreau performed on alumina particles with a size distribution between 32 and 45 lm for an Ar-$H_2$ plasma (35 SLPM/10 SLPM), working at 550 A have shown that, due to the arc root fluctuations, at the same location, particle temperatures vary between 2400 and 2900 K, while their velocities range between 260 and 430 m/s (Ref 6, 7).

BOC Edwards Society uses nitrogen as primary gas to achieve zirconia coatings, although argon is usually employed. One of the objectives of this project is to compare the properties of the two different plasma jets (argon or nitrogen with hydrogen) in terms of arc voltage fluctuations and CBL thickness. The aim is to determine the effects on the particle thermal treatment and thus on the coating density.

### Experimental Setups to Measure the Arc Voltage and the CBL Thickness

A schematic representation of the experimental setup is depicted in Fig. 1. The arc voltage fluctuations are measured between the anode and cathode, and the values are recorded thanks to a LabVIEW interface. Using a fast Fourier transform (FFT) method, a frequency analysis is made. The recorded values are the main peak intensity and frequency, the mean voltage, the voltage fluctuations (standard deviation/mean voltage) and the CBL thickness (CBL measurement/plasma torch diameter).

To observe the cross section of the plasma jet inside the nozzle, end-zone imaging is used. Figure 1 shows a typical end-zone image, and the light intensity profile along the line, which crosses the arc column center. The edge of the CBL has been located at the point where the intensity is half of the highest intensity inside the nozzle channel.

**Table 1 Plasma spray parameters**

| Primary gas | Argon | Nitrogen |
|---|---|---|
| Mass flow rate, kg/h | 2.42-5.3 | 1.7-3.72 |
| Hydrogen, vol% | 2.8-19.5 | 2.8-15.9 |
| Current, A | 200-500 | 200-500 |

### Plasma Spray Parameters

For this study, a 3 MB plasma torch from Sulzer Metco was used. This torch allows using both argon or nitrogen as primary gas. The nozzles are 5.54 mm in internal diameter and their total lengths are identical, but the lengths of their cylindrical parts are different: 18 mm for the argon nozzle and 24 mm for the nitrogen nozzle. The plasma spray parameters are summarized in Table 1.

### Theoretical Approach

For an argon plasma jet, raising the mass flow rate:

- Slightly constricts the arc column, increasing the CBL thickness
- Strongly pushes the arc root downstream, increasing the value of frequency peak intensity and the mean voltage, thus the voltage fluctuations increase

However, due to its thickness increase, the CBL is heated less, and thus the time between two arc voltage breakdowns rises. Therefore the FFT peak frequency decreases.

The increase in the hydrogen percentage slightly constricts the arc column and allows better heating of the CBL, reducing the time between two voltage breakdowns. Therefore, the FFT peak frequency increases.

The arc current increase allows the arc column growth, implying a CBL thickness reduction. If the arc column diameter increases, then the arc strikes upstream, decreasing the mean voltage and voltage fluctuations also decrease. Another consequence is the FFT peak intensity decrease due to a shorter arc root movement. Therefore, the time between two voltage breakdowns decreases and so the FFT frequency increases.

The difference between argon and nitrogen is that the nitrogen dissociation occurs around 7000-8000 K. With

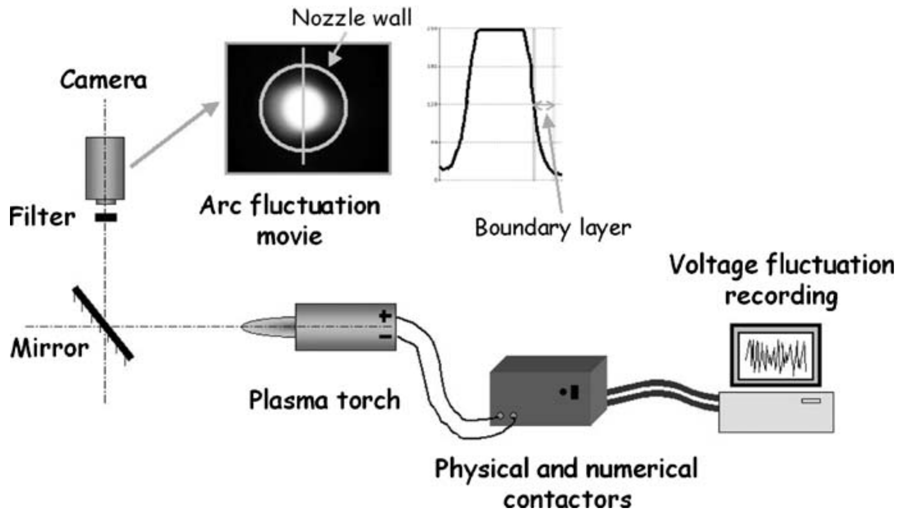


**Fig. 1** Experimental setup

**Table 2 Experimental results obtained for an increase of mass flow hydrogen percentage and current**

| | | FFT peak intensity | FFT peak frequency | Mean voltage | Voltage fluctuations | CBL thickness |
|---|---|---|---|---|---|---|
| Argon | ↗ mass flow | ↗ | ↘ | ↗ | ↗ | ↗ |
| | ↗ $H_2$ % | ↗ | ↗ | ↗ | ↗ | ↗ |
| | ↗ Current | ↘ | ↗ | ↘ | ↘ | ↘ |
| Nitrogen | ↗ mass flow | ↗ | ↗ | ↗ | ↗ | ↗ |
| | ↗ $H_2$ % | ↗ | ↗ | ↗ | ↗ | ↗ |
| | ↗ Current | ↘ | ↗ | ↘ | ↘ | ↘ |

nitrogen, this temperature corresponds both to the temperature over which the mean thermal conductivity increases drastically due to nitrogen dissociation, and the electrical conductivity is sufficient to generate the arc column. Thus the plasma column is almost "self-constricted," and its radius does not depend very much on the hydrogen percentage. The increase of $H_2$ percentage will increase the losses toward the torch wall and slightly the voltage.

For argon, the arc column constriction depends on the mass flow rate and on the hydrogen percentage, whereas for the nitrogen, the arc column is "self-constricted." Therefore, unlike with argon, with nitrogen the time between two voltage breakdowns decreases with the mass flow rate raise, and thus the FFT frequency increases. For the other parameters, argon and nitrogen have the same evolution.

### Experimental Results

The experimental results obtained for the argon and nitrogen nozzles are summarized in Table 2. The evolution of the characteristic parameters corresponds to the theoretical approach both for argon and nitrogen plasma gas mixtures. Concerning the CBL thickness measurement, with the nitrogen plasma jet few variations can be observed, thus confirming the plasma jet "self-constriction."

### Conclusion and Prospects

These results show the influence of the plasma gas composition (mass flow rate, hydrogen percentage, current, and plasma gas composition) on the plasma torch stability. Other studies, in progress, are related to the influence of the anode-nozzle shape and diameter as well as the effect of the voltage fluctuations on the particle thermal treatment and, correspondingly, on the coating density.

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