Seminar

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Institute for Plasma Research

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Title: Investigation of Thermal Plasma Jet for Low - Pressure Plasma Spraying

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Time: 03.30 PM

Venue: Seminar Hall, IPR

Online link: https://meet.google.com/ogb-xvkw-fae

Abstract

Thermal plasma spraying is a well established technology that is acclaimed for its versatility in enhancing surface properties across diverse applications in the energy, aerospace, and automotive sectors. In recent years, new techniques have emerged to keep pace with the rapid advancement in these industrially demanding sectors. The Very Low-Pressure Plasma Spraying (VLPPS) technique is one that operates under controlled environment to generate high-density coatings at a rapid pace. This technique finds its primary application in gas turbine engine components, particularly in the formation of protective thermal barrier coatings (TBCs). These coatings can protect turbine blades and high-temperature components from extreme heat, augmenting performance and extending operational lifespan. The technique primarily involves a high power thermal plasma torch under low and very low-pressure conditions (1 – 30 mbar), besides other sub-systems and accessories.

The primary objective of this study is the investigation of the behaviour of the plasma jet emanating out of a high power thermal plasma torch through rigorous experimental analysis by characterizing the plasma jet properties in detail. This study involves a multi-dimensional approach, employing various diagnostics encompassing electrical, visual, spectroscopic, and electrostatic probe techniques. To facilitate these investigations, a high power (~50 kW) DC plasma torch has been designed and developed specifically for operating under very low-pressure plasma spraying applications.

This first key investigation is the analysis of Current-Voltage Characteristics (CVC), thermal efficiency, and arc voltage fluctuations under diverse controllable input parameters. The CVC and thermal efficiency yield insights into the operational capability of the plasma torch, while spectral analysis of arc voltage fluctuations highlights the oscillation modes that serve as indicators of the transition from subsonic to supersonic plasma jet regimes. Furthermore, a semi-empirical relationship is formulated based on the theory of dynamic similarity, enabling the scaling up of the laboratory-scale plasma torch to suit large-scale industrial applications. An evaluation of influence of ambient pressure is conducted through a comparative analysis with dimensionless parameters at atmospheric pressure, highlighting the roles of Euler's number and acceleration number in low-pressure operations. These parameters profoundly impact arc voltage and thermal efficiency.

Along with the electrical characteristics, this research also explores the plasma jet's phenomenology, shock structure, and their variations with chamber pressure. High-speed camera observations explain the transition of the under-expanded plasma jet from a continuum regime to a frozen state, along with implications for energy transfer during spraying. Optical Emission Spectroscopy (OES) and Mach probe measurements provide insight into excitation temperature and velocity profiles along the central axis's longitudinal direction. Notably, this investigation highlights the impact of chamber pressure on temperature, electron density, and velocity profiles, offering conducive conditions for effective plasma spraying.

As a test case, the feasibility of the developed plasma torch device and the accompanying full laboratory-scale VLPPS system has been demonstrated by the successful development of Yttria Stabilized Zirconia (YSZ) TBC coatings on an SS304 substrate at a chamber pressure of 1 mbar. This serves as a testament to the capabilities and potential of the indigenously designed and developed plasma torch. In summary, this work provides valuable insights to the advancement of thermal spray technology, optimizing plasma spraying processes, and their potential applications.
