A New Highly Efficient High-Power DC Plasma Torch

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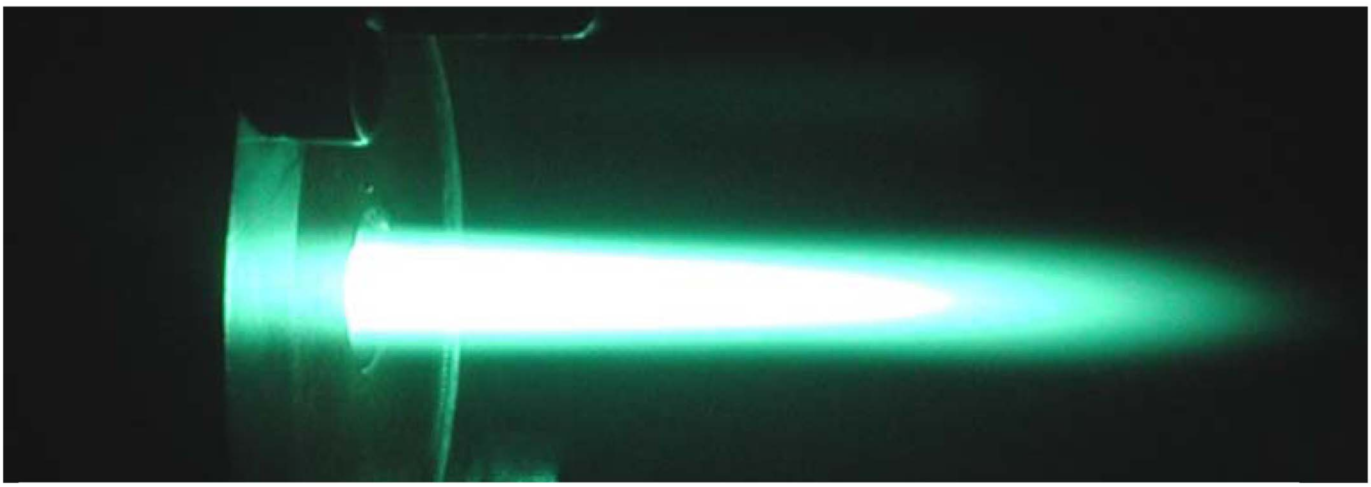

Fig. 1. Plasma torch in operation: $CO_2 + CH_4$ mixture. Current: 238 A. Arc voltage: 161 V.

***Abstract*—We have developed a new dc plasma torch which is operated with a mixture of carbon dioxide and hydrocarbons, e.g., methane. Erosion of the graphite cathode is continually compensated by the deposition of carbon ions. The torch is typically operated at low currents and, due to the nature of the gases, high voltage. Thermal efficiency of the torch is around 75%.**

***Index Terms*—Carbon dioxide plasma, DC plasma torch, high efficiency.**

DC PLASMA spray torches are normally operated with argon or argon-based mixtures. The use of argon is dictated by its inertness at high temperatures to tungsten, which is the main material for thermionic cathodes. However, the low thermal conductivity and low enthalpy of argon limit the thermal efficiency of the process.

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Molecular gases such as air and nitrogen are used extensively for plasma generation for metal cutting, melting scraps, and hazardous waste incineration. The use of gas mixtures containing hydrocarbons with graphite electrodes has also been reported. Carbon dioxide (CO_2) and hydrocarbon mixtures (such as CH_4) have a number of advantages over argon-based gas mixtures. The enthalpy and thermal conductivity of $CO_2 + CH_4$ plasma are considerably larger than argon plasma. This is due to the fact that molecular gases must dissociate before ionization. Thus, they require much higher input energy to become partially ionized. The larger energy input translates into higher enthalpy and higher thermal conductivity.

We have designed and built a water-cooled dc plasma torch which operates with a mixture of $CO_2 + CH_4$ (Fig. 1). The cathode is made of highly structured graphite. During the torch operation, carbon ions are produced in the arc region. The ions are attracted to the negatively charged cathode and are deposited. Sufficient ionic current can fully compensate the carbon loss due to sublimation resulting in a long cathode life. When appropriate process parameters are established, a dynamic equilibrium between carbon sublimation and precipitation is achieved. Figs. 2 shows the deposited carbon on the cathode surface. The deposits are in the form of carbon nanowires [Figs. 2(c)].

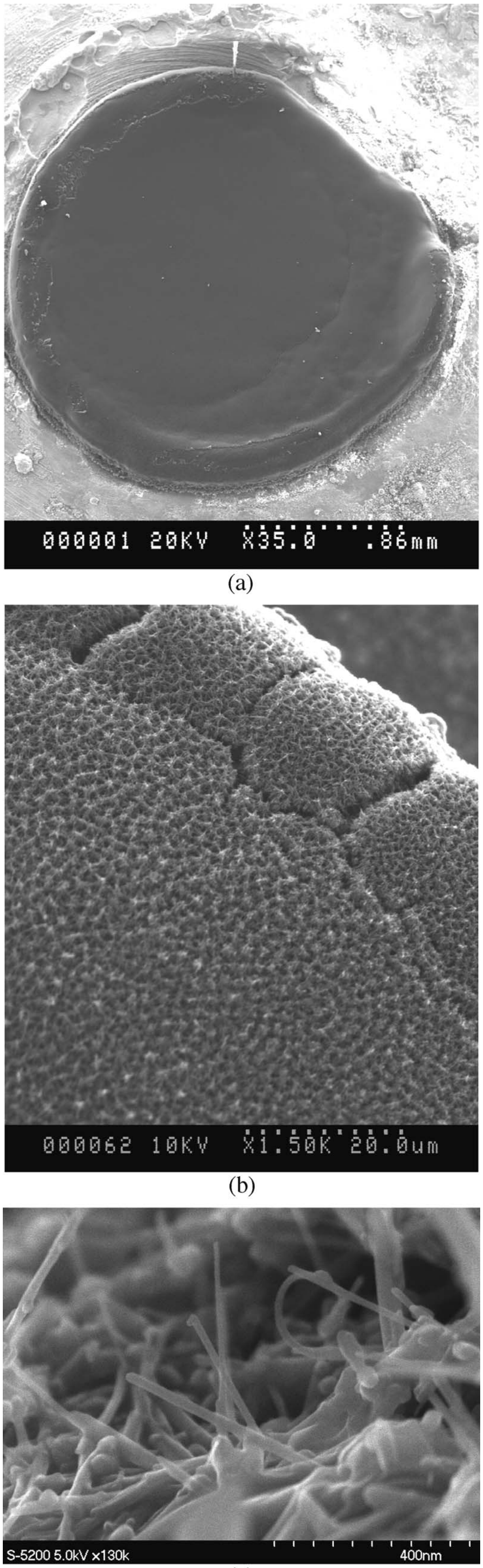

Fig. 2. Deposited carbon on the graphite cathode, (a) cathode attachment areas surface structure (b) at x1.5K and the nanowire deposits (c) at x100K.

The torch has a 7-mm nozzle diameter with a vortex injection of the plasma gas mixture and a button-type water-cooled highly structured graphite cathode.

Two materials were used for cathodes, i.e., tungsten and graphite with highly ordered structure. The experiments were carried out with the same torch and the same anode; only the cathodes and gases were changed. The thermal efficiency of the new torch operated with CO_2-CH_4 mixture is more than 75%, while for the torch operated with argon–hydrogen mixture the efficiency is only 32%. Thermal efficiency is defined as the ratio of the net power of the plasma jet, i.e., input power minus heat losses to the cooling water, to the input power.

The arc voltage for the torch varies between 130 and 220 V. In contrast, for argon–hydrogen mixture, the voltage was in the range of 45–60 V. The high arc voltage is beneficial since, for a given plasma power, it allows the torch to be operated at much lower arc currents. The lower current reduces the thermal load on the electrodes and extends their lives. The torch may be operated at wide CO_2/hydrocarbon ratios; for most applications it is 3/1 with total gas flow rate in the range of 30–50 L/min.

The torch was employed to spray zirconia on steel substrates. The sprayed YSZ powder was Amperit 825-0 from H.C. Starck, Inc. with average particle size of 20 μm. Powder injection was external at the feed rate of 0.5 lb/h. Measurements of in-flight particle conditions were made by a DPV-2000 monitoring system (Tecnar Automation Ltee, St-Bruno, Canada). We increased the plasma power from 23.5 to 40.6 kW. This led to the particles temperature rise from 2784 K to 3041 K and the velocity from 146 to 205 m/s [2]. This means that majority of the particles were molten, which is a crucial factor in producing dense high-quality coatings. Deposition efficiency was measured, and it was found between 59% to 63%.

The high thermal efficiency, low operating cost, and high power of this torch makes it an ideal candidate for applications in hazardous waste treatment processes. This is currently under consideration.

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