Proc. Jpn. Symp. Plasma Chem./Vol. 3, 1990

IN-FLIGHT MEASUREMENTS OF TEMPERATURE AND VELOCITY OF TUNGSTEN PARTICLE IN AN R.F. PLASMA

Hirofumi Takikawa* and Maher I. Boulos**
* Department of Electrical and Electronic Engineering, Toyohashi University of Technology, Toyohashi, Aichi, 441 Japan
** Department of Chemical Engineering, Université de Sherbrooke, Sherbrooke, Québec, Canada J1K 2R1

ABSTRACT

Simultaneous in-situ measurements of velocity and surface temperature of tungsten particles ($\overline{dp}$=69μm) have been carried out in a plasma generated with inductively coupled r.f. plasma torch, using Particle Emission Analysis (PEA) technique. The results show that the particle velocity and temperature are affected substantially by ambient pressure and by particle injection position, but not significantly by nature (He or Ar) and the flow rate of carrier gas. It is also found that the temperature drops quickly at downstream location under atmospheric pressure, when the sheath gas is composed by Ar/H_2 mixture. The particle velocity, on the other hand, is almost constant axially in the presence or absence of H_2 in the sheath gas.

1. INTRODUCTION

An inductively coupled r.f. plasma has become an interesting technology for particle treatment, such as plasma spray coating, particle spheroidization, sintering and chemical synthesis, since the first r.f. plasma torch had been performed by Reed in 1961 [1]. The spray coating of metal or ceramic particles with induction plasma torch has been expected as one of the potential applications, as the r.f. plasma is likely to have several advantages compared with d.c. plasma jet spray coating. Since r.f. plasma discharge can have a larger volume of high temperature zone and slower plasma gas velocity compared with d.c. plasma jets of the same power level, it is able to allow a longer residence time of particles in the high temperature zone. Therefore, much more particles can be treated in the r.f. plasma at once, and can be possible to obtain the higher temperature particle at the target location. Moreover, there is no contamination caused by vaporization of electrode material as seen in d.c. plasma jet [2].

The phenomena of in-flight heating or melting and acceleration of small particle under plasma stream by exchange of heat and momentum from the plasma to the particle, are expected to depend on many factors, such as particle trajectory, velocity, temperature, and plasma operation conditions, gas configuration, etc.. In order to accomplish a proper control of particle velocity and temperature prior to its impact on substrate, it is, therefore, very important to know how and how much degree such factors affect on the particle velocity and temperature. The understanding of basic phenomena of particle motion and heating process under the r.f. plasma has been progressed by great efforts of mathematical modeling work [3-5]. Unfortunately, it has been very difficult, however, to obtain intense available data to support the modeling work, due to lack of any appropriate measurement devices. Recently, the in-flight simultaneous particle parameters measurement system has been developed, using Particle Emission Analysis (PEA) technique [6-8].

In the present study, the experimental investigation has been devoted to heating and melting of tungsten particle under different plasma gas configurations as well as different ambient pressures, plasma powers particle injection levels, and probe designs, measuring particle velocity and surface temperature. The measurements are also carried out at different locations along the plasma torch axis in order to study particle parameters history in the plasma stream.

2. EXPERIMENTAL SETUP

The measurement principle of particle velocity and its surface temperature in-flight, using PEA technique is described in refs. 6, 7 and 8 in detail. In order to obtain essential valuables for evaluation of the particle parameters, the pulses, which are generated at two different wavelength ranges by particle own emission as it passes across the well-defined observation window, are analytically characterized. The particle velocity is evaluated from the flight time of the particle in the window corresponded to the widths of pulses, while the particle temperature is evaluated from the ratio of the pulses heights, based on two color pyrometric technique. The experimental setup of the devices is also shown in ref. 8. The optical devices are arranged together on a vertically movable optical bench to make replacement for the measurement at different locations easy.

A schematic design of the plasma torch used is shown in fig.1. The plasma produced in a plasma confining quartz tube of 50mm i.d., using a three-turn induction coil powered by 3MHz oscillator frequency, 25kW power supply. The sheath gas is introduced from annular space between the plasma confining tube and a smaller center tube of 38mm i.d. and 42mm o.d., which is concentrically located with the plasma confining tube. The tungsten particles (69μm mean diameter, 19μm standard deviation) are premixed with powder carrier gas by screw type powder feeder and injected into the plasma using water cooled stainless probe (feed rate 11g/min) which can be moved upward and downward. Quartz windows are fixed at intermediate position between an induction coil and deposition chamber, and at deposition chamber position in order to measure the particle parameters history. In this paper, center gas Q2 is a constant of 43L/min (Ar).

3. RESULTS AND DISCUSSIONS

3.1 Effect of particle injection probe and carrier gas

Two different shaped particle injection probes as shown in fig.2 have been prepared to investigate the effect of particle injection velocity and of carrier gas velocity. Normal probe (fig.2(a)) is of standard design with a straight hole of 3.2mmϕ. Special probe (fig.2(b)) is designed with wide exit hole of 5.72mmϕ, connecting to original tube of 2.3mmϕ. In the case of using normal probe, the particle injection velocity is supposed to be equal to carrier gas velocity. On the other hand, in the case of using special probe, the particle injection velocity is supposed to be around one sixth faster than the carrier gas velocity. The particle injection velocity with special probe is supposed to be twice faster than that with normal probe.

Figure 4 shows the experiment results of mean particle velocity and surface temperature under different carrier gas mass flow rate, measured at z=370mm in the case of the plate power Po=15kW, ambient pressure Pa=170torr, probe position zp=0mm. The measurement has repeated with normal probe and with special probe, as well as with different nature of particle carrier gas, such as He and Ar. It is found that mean particle velocity and surface temperature are 44m/s and 3100K respectively in any cases over this investigation, and there is no particular effect of carrier gas flow rate and type of particle injection probe. It can be suggested that particles are dominantly accelerated or decelerated by the drag force of plasma gas, and thus the initial injection velocity and carrier gas velocity do not affect significantly the particle velocity at plasma plume. This result is basically consistent with the result of particle velocity by LDA reported under similar conditions (Pa=150torr, Po=16kW, z=380mm) with nickel arroy powder using 5.8mm i.d. probe [10].

It was expected that the particle temperature could be higher using He as carrier gas than that using Ar, since the thermal conductivity of He at high temperature is larger than that of Ar [11]. The result, however, shows no substantial difference on particle temperature between using He and Ar as carrier gas. A few mixture of He into Ar/H_2 plasma is guessed to be insufficient to increase the particle temperature.

3.2 Effect of ambient pressure

The effect of ambient pressure on particle velocity and surface temperature at Po=15kW, measured at z=370mm, is shown in fig.4. The particle velocity increases parabolically with the decrease of ambient pressure. For instance, the velocities at atmospheric pressure and 100torr are 7.5m/s and 59m/s, respectively, with normal probe using He as carrier gas and the ratio between these values is 7.9, which is very close to the reciprocal ratio of the pressures. This result consists essentially with the previous reports using alumina and nickel particle measured by LDA [10] and PEA [9]. It can be said, therefore, that the particle velocity is dominated mainly by ambient pressure at constant plasma power.

On the other hand, the particle temperature doesn't vary constantly against ambient pressure. In the range of 100～300torr, the particle temperature increases with the increase of ambient pressure, while the temperature measured at atmospheric pressure is much lower than that measured at 100torr. It can be guessed that in the case of high ambient pressure, the particle is significantly cooled down by its emission loss at downstream location, since the particle residence time is relatively long, while in the case of low ambient pressure, the rate of particle emission loss is small since particle residence time is fairly short.

3.3 Effect of particle injection position

The existence of the recirculation zone of plasma gas flow at around induction coil position is expected as one of unique characteristics of r.f.

plasma torch, because of magnetic pinch effect [6]. Therefore, it is interesting to know the effect of particle injection position, such as roughly upstream or downstream of the recirculation zone, on the particle parameters. Figure 6 shows the measurement result of particle velocity and temperature in the cases of particle injection position (probe tip position) zp=0 and zp=30mm. These positions are supposed to correspond approximately to the upstream and downstream of recirculation zone, respectively. The measurement are carried out, at z=140, 290 and 370mm.

From fig.6, it is found that the particle velocity in the case of zp=30mm is slightly slower than in the case of zp=0mm and the particle surface temperature is almost same in both case at zp=140mm, but decreases more quickly at downstream location in the case of zp=30mm than in the case of zp=0mm. It is guessed that these results come from the decrease of plasma gas velocity and temperature caused by insert of cold particle injection probe into the hot plasma region.

3.4 Effect of hydrogen gas mixture

The small amount of H_2 gas is sometimes mixed with sheath gas in order to increase the efficiency of avoiding the contact of plasma to the plasma confining tube. However, this H_2 gas can not only play so but also enter the plasma and thus the particle parameters could be varied, according to the variation of plasma characteristics.

The result of the particle temperature and velocity of tungsten particle when the sheath gas composed by Ar (72L/min) and H_2 (5.6L/min) at atmospheric pressure operation is shown in fig.7, comparing the result when the sheath gas composed by pure Ar (72L/min). It can be noted that the particle surface temperature is higher at the upstream location (z=140mm) in any cases and drops more rapidly at the downstream location in the case of the sheath gas composed by Ar/H_2 mixture than in the case of sheath gas composed by pure Ar. The particle velocity, on the other hand, is almost constant axially and there is no significant difference between the particle velocities in the presence or absence of H_2 in sheath gas. It may be suggested that the mixture of H_2 in sheath cause the decrease of field temperature especially at downstream location since the H_2 may be mixed well at downstream, while gas velocity may not change as much to decrease the particle velocity by the presence of H_2 in plasma.

ACKNOWLEDGMENT

The financial supports of the Ministry of Education of the Province of Québec and the National Science and Engineering Research Council of Canada are gratefully acknowledged.

REFERENCES

1. T.B.Reed, J.Appl.Phys., 32, 821(1961)
2. J.Jurwicz, R.Kaczmarek, and M.I.Boulos, ISPC-7, 4, 1131(1985)
3. M.I.Boulos, IEEE PS-6, 96(1978)
4. P.Proulx, J.Mostaghimi, and M.I.Boulos, Int.J.H.M.T., 28, 1327(1985)
5. Ibid, Plasma Chem. Plasma Proces., 7, 29(1987)

6. T.Sakuta, and M.I.Boulos, ISPC-8, 1, 371(1987)
7. Ibid, Rev.Sci.Instrum., 59, 285 (1988)
8. H.Takikawa, T.Sakuta, and M.I.Boulos, ISPC-9, 371(1989)
9. H.Takikawa, and M.I.Boulos, IEEJ, ED-90-31 (1990)
10. M.S.Bronet, and M.I.Boulos, Plasma Chem. Plasma Proces., 9, 343(1989)
11. I.Amdur, and E.A.Mason, Phys.Fluids, 1, 370(1958)

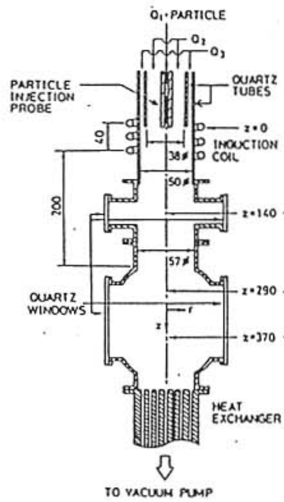


Fig. 1. RF plasma torch and deposition chamber (in mm)

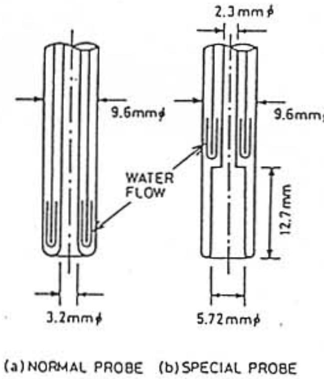


Fig. 2. Designs of different particle injection probes

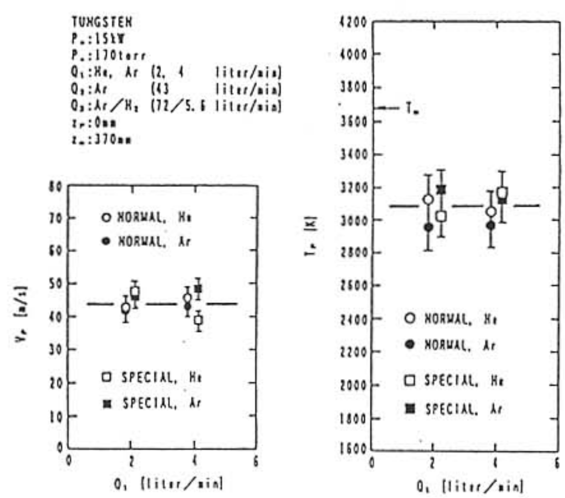


Fig. 3. Effect of carrier gas

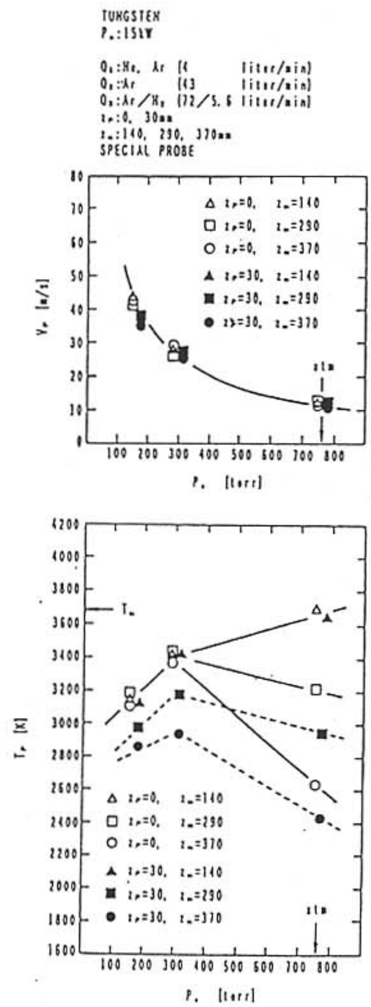
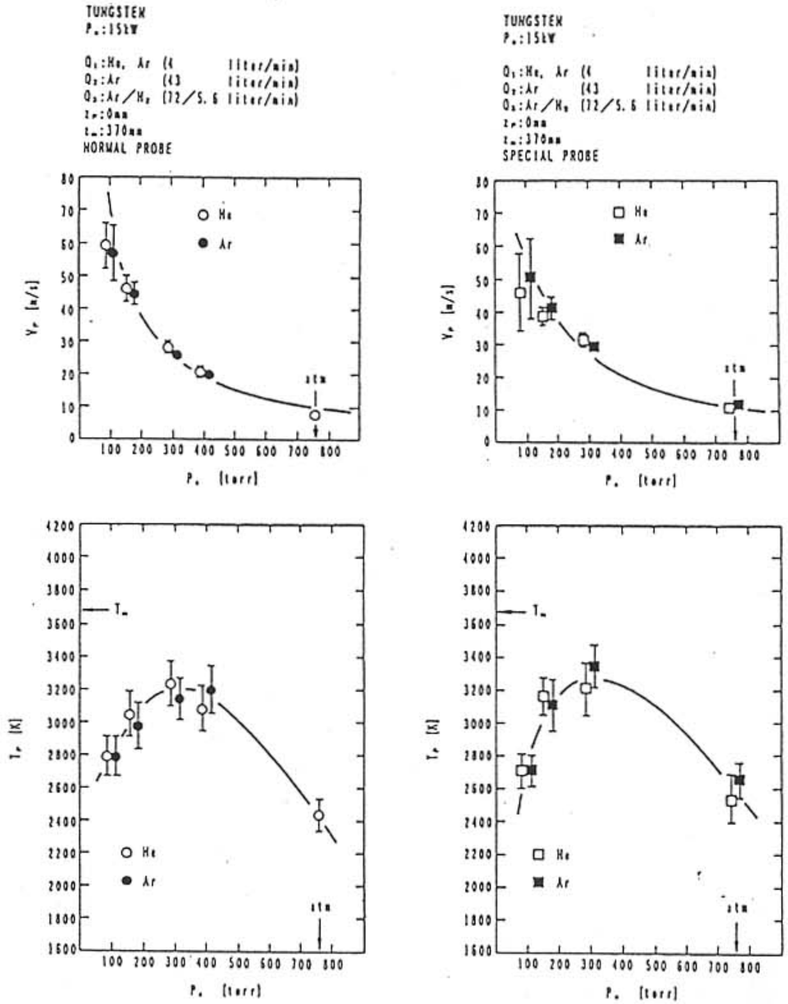


Fig. 5. Effect of position of particle injection probe tip



(a) Normal probe

(b) Special probe

Fig. 4. Effect of ambient pressure

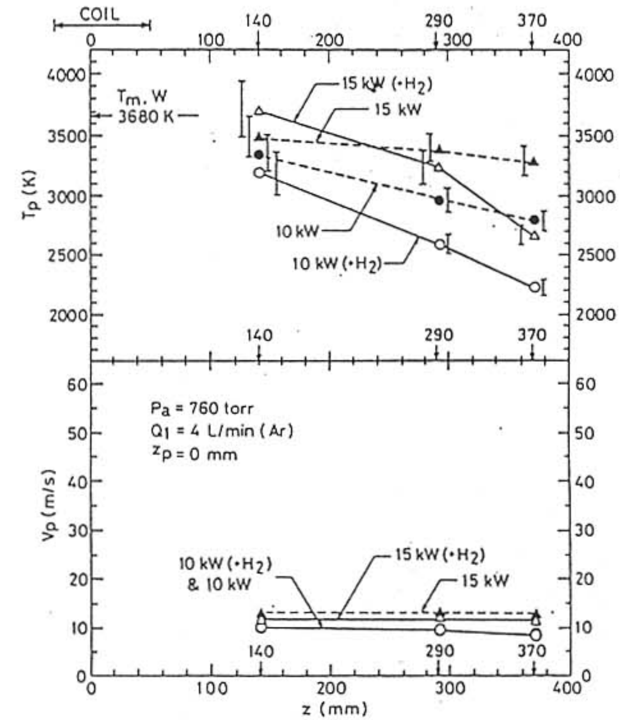


Fig. 6. Effect of hydrogen gas mixture