Gas Tunnel Type Plasma Spraying Apparatus†

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Abstract

New type plasma spraying apparatus has been developed by applying the gas tunnel type plasma jet to the thermal spraying, and the characteristics of this type spraying apparatus and the properties of the coating obtained have been experimentally clarified. In this apparatus the supplying method of the spraying powder is different from the conventional type: the powder is supplied from the torch center electrode (hollow cathode) to the gas tunnel type plasma beam in the axial direction. For this reason, the quality of the spraying coating can be improved remarkably, namely the Vickers hardness of the alumina coatings obtained is much higher than that with the conventional type.

KEY WORDS: (Thermal Spraying) (Gas Tunnel) (Plasma Jet) (Coating) (Ceramics) (Alumina)

1. Introduction

Thermal spraying, especially, plasma spraying has been widely applied to many industrial fields, including mechanics, electronics, and chemistry and so on[1]. However, in the conventional plasma spraying apparatus, when the spraying powder is supplied from the cathode of the torch in the axial direction, the powder tends to choke inside the torch. Therefore the inlet of the powder is located at the exit of the torch[2] or the straight part of the anode nozzle of the torch[3,4]. But with these supplying methods, it's difficult to obtain the effective melting and acceleration of the spraying powder. As the results, there are many problems on the coating qualities of the thermal spraying, especially in the case of high melting point materials such as ceramics[5].

On the other hand, in the gas tunnel type plasma jet torch developed by the authors[6], it is easy to supply the spraying powder in the axial direction. Namely, the spraying powder supplyed from the center hole of hollow cathode can run through the gas tunnel type plasma jet without adhesion to the inside wall and/or electrodes of the torch. So, the effective heating and accelerating of the spraying powder can be carried out and as the result, high quality coatings can be obtained easily.

In this report, the fundamental characteristics of the gas tunnel type plasma spraying apparatus newly developed, and the ceramic coating quality obtained with this new apparatus are clarified.

2. Gas Tunnel Type Plasma Spraying Apparatus

2.1 Principle

This apparatus is based on the concept of the gas tunnel[7]. **Figure 1** shows the schematic diagram of gas tunnel type plasma jet torch and a gas tunnel generator and its pressure distribution in the vortex chamber. Figure 1 (b) shows the schematic diagram of a generating method of vortex flow and the formation of gas tunnel[8]. The vortex generator nozzle has plural holes through which the working gas flows in the tangential direction at the symmetrical four points of the inside wall of chamber. Due to the effect of gas divertor nozzle, a homogeneous vortex flow can be obtained in the vortex chamber. Then, the flow speed is increased as the gas flows into the center part, and can be achieved the speed of sound when the gas ejects outside the chamber from the gas divertor nozzle. So, as shown in Fig. 1 (c), the pressure distribution which has a sharp radial gradient in the vortex chamber can be obtained.

The characteristics of this gas tunnel (pressure, region and so on) are decided not only by the gas flow rate but also by the profile and size of gas divertor nozzle. As the result, this apparatus can be instantly correspond to various experimental conditions by means of exchanging simply the gas divertor nozzle. For the formation of gas tunnel, argon is used as the working gas in this study.

As shown in Fig. 1 (a), the arc which is generated

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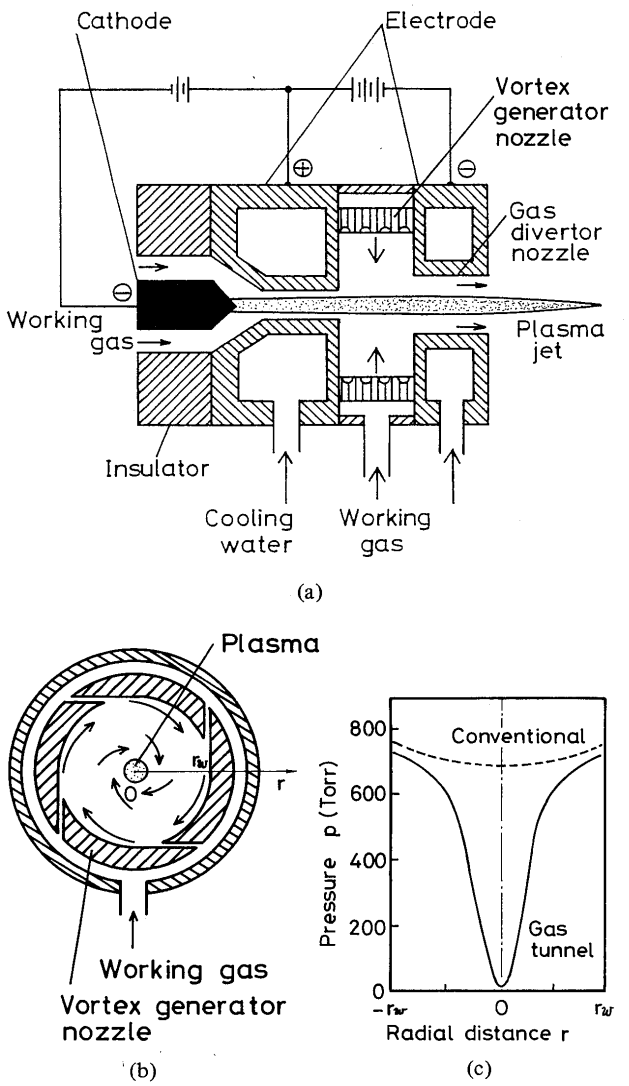

Fig. 1 Schematic diagram of gas tunnel type plasma jet torch (a), gas tunnel generator (b), and pressure distribution in the vortex chamber (c).

between torch center electrode (cathode) and anode of plasma jet gun is ejected from nozzle electrode (W) as a plasma jet. The jet is rapidly accelerated when it passes through the low-pressure gas tunnel, and the length of the jet is increased greatly[9]. And, moreover, the strong thermal pinch effect of high speed vortex flow due to the effect of the gas divertor nozzle decreases the diameter of plasma jet and generates the temperature increasing.

In addition to this effect of the gas divertor nozzle, by using this for the electrode, gas tunnel discharge is generated and the power of plasma jet is increased extremely[10]. Moreover the most extreme merit of this gas tunnel type plasma jet which differs from other conventional types is that the spraying materials (powder, solid rod, liquid and so on) can be supplied form the torch center in the axial direction. So, by applying this gas tunnel type plasma jet to the thermal spraying, the energy of the plasma jet effectively transfers to the spraying material, and it can be obtained much higher temperature and velocity of spraying powder than the conventional plasma spraying apparatuses. So, by using this spraying apparatus, we can obtain extremely high quality in spraying coating, moreover the thermal spraying of the ceramics which has a high melting point can be much easier than the conventional type.

2.2 Experimental method

The gas tunnel type plasma spraying apparatus is shown in **Fig. 2**. (A) is a plasma jet gun which is composed with a torch center electrode and a torch nozzle electrode, and each electrode is connected to the d.c. power source (PS1). (B) shows the gas tunnel type plasma jet generator which is composed with the torch nozzle electrode and the gas divertor nozzle electrode. Between these two electrodes, another d.c. power source (PS2) is connected and generates the gas tunnel type plasma jet. In this spraying experiment, the working gas used was argon and the torch was set on the side wall of experimental chamber and the plasma jet was ejected horizontally.

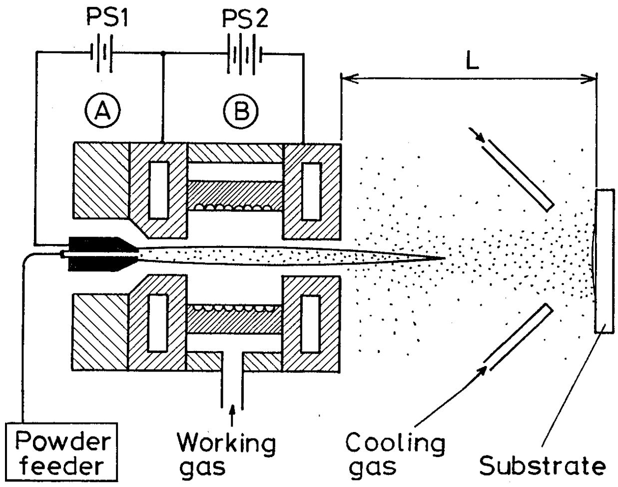

Fig. 2 Gas tunnel type plasma spraying apparatus.

The cathode (torch center electrode of (A)) has a through hole "Powder Channel" at the center axis, from which the spraying powder can be supplied with a carrier gas, and the powder runs through the gas tunnel type plasma jet of (B) in the axial direction. The powder supply rate can be changed due to the adjustment of a powder carrier gas flow rate and/or a vibration strength of the powder feeder. The spraying powders applied in this study are shown in **Table 1**. Mainly, 99.5% Al_2O_3: the particle size of 10 – 40μm was used. The substrate was set at the place which distance is L from the torch. As the substrate, SUS 304, size of $2^t \times 25 \times 50$ was used, and the surface was shot blasted in order to obtain a rough surface. The traverse speed of the substrate was 2.8 m/min constantly for this spraying experiment. And as the cooling gas for the substrate argon was used and blown on the surface of

Table 1 Kinds of ceramic powder which is used in this study.

No.	Powder	Component	Particle size	Melting point
1	Alumina	Al_2O_3 99.5%	10 – 40μm	2050°C
2	Alumina	Al_2O_3 99.5%	5 – 20μm	2050°C
3	Alumina	Al_2O_3 99.5%	2μm	2050°C

the substrate in order to suppress the over heat of the substrate. The cooling gas flow rate was 25 l/min.

In order to examine the mechanical property of the spraying coatings obtained, the Vickers hardness of the coating was measured. In this case, the thickness of the sprayed coating was available value of more than 100μm, and the cross section was polished with buff using fine Al_2O_3 powder.

Then, the measured points of the hardness are more than 10 except the porosity, and in this case, the load weight is 300 gf and the load time is 15 sec.

3. Experimental Results

3.1 Deposit character of gas tunnel type plasma spraying

Figure 3 shows the photograph of gas tunnel type plasma spraying when the substrate was fixed at the same position. In this case the spraying distance L is 100 mm, the power input P was 20 kW and the spraying time t was 40 sec. On the right side of the figure is shown Al_2O_3 coating profile. The center of the coating is thick and the part around the center is thin and that the profile has a good symmetry against the center axis. This profile shows the distribution of the melted sprayed particles, and the particles which run through the plasma jet are many.

This is explained as follows. The vortex flow of high speed decreases the diameter of the plasma jet and on the contrary increases the temperature of the plasma jet (thermal pinch effect). Then, ceramic powder ejected from the gas tunnel type plasma jet torch, has high speed by accelerating and high temperature by heating in the gas tunnel type plasma jet on the axis. Therefore, the spraying powder in the center axis can adhere much effectively on the substrate. On the other hand, the spraying powder apart form the center axis is low speed, low temperature and non-melted, and is removed by means of centrifugal force of vortex flow.

As the result, as compared with the conventional plasma spraying apparatus, the width of the coating is decreased more than a few 10 percent, and the coating thickness is increased, about two times, in the case that the substrate is driven in the same direction under the same spraying conditions.

Figure 4 shows the time dependence of the thickness at the center part of the coating obtained in the same way as the above. The thickness is increased proportionally with the spraying time t. This shows that the spraying powder is supplied constantly. Next, when the spraying time is fixed at t = 60 sec and the supply rate of spraying powder is changed, the weight of the adhered powder was measured. The result is shown in **Fig. 5**. From this figure, although the deviation is observed a little, the weight is increased with increased supply rate; the maximum supply rate is 70 g/min in this experiment. In the range of this experimental condition, the adhesion rate of the spraying powder is a constant value, about 20%, being independent on the supplying rate.

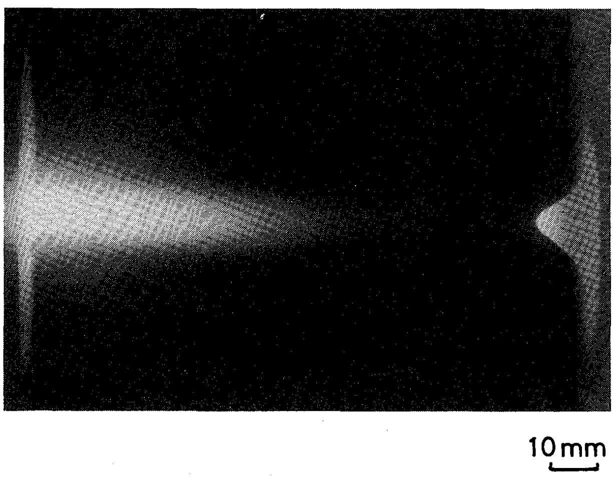

Fig. 3 Al_2O_3 coating profile; t = 40 sec.

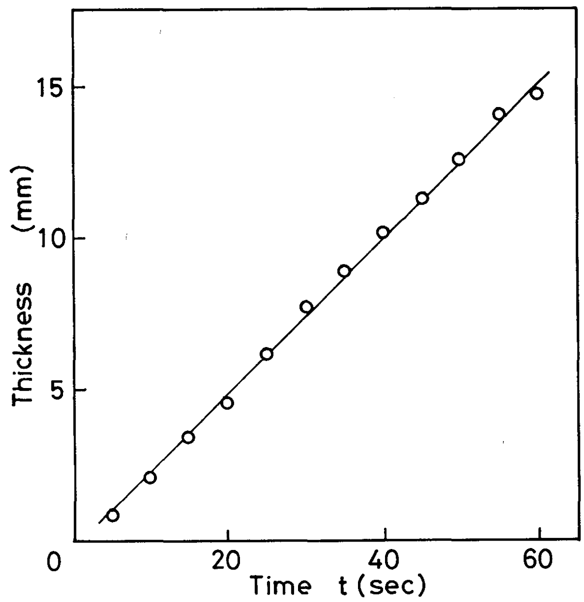

Fig. 4 Dependence of the thickness of the coating at the center on the spraying time t.

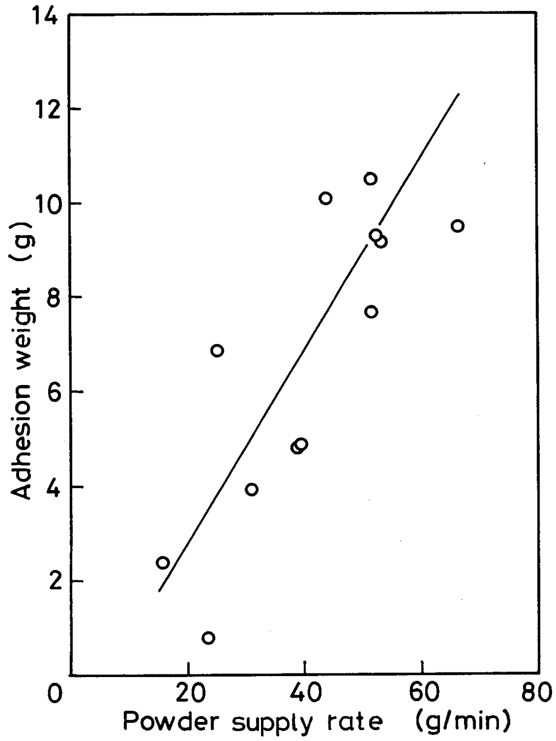

Fig. 5 Characteristics of adhesion; t = 60 sec.

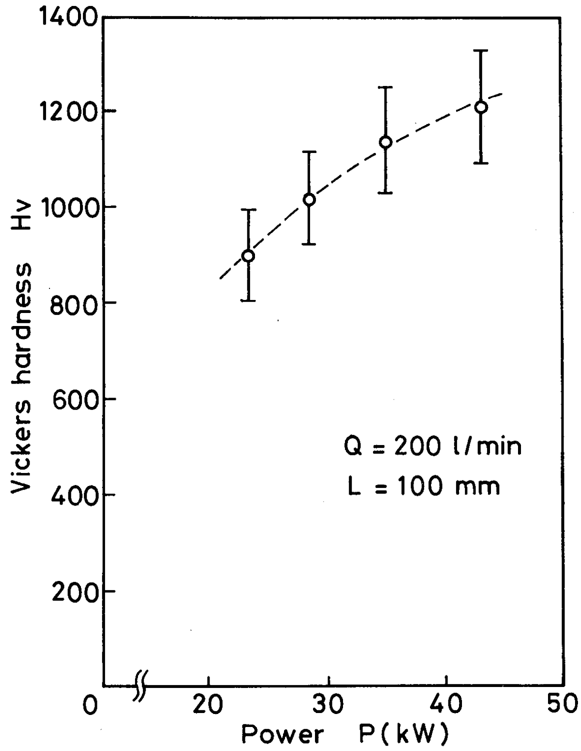

Fig. 6 Effect of the power on the Vickers hardness.

3.2 The formation of the Al_2O_3 coating

By the gas tunnel type plasma spraying apparatus, Al_2O_3 coating was produced and the character was investigated. The results are as follows.

Figure 6 shows the characteristic of the Vickers hardness H_v of the Al_2O_3 coating when the power of the plasma jet, P, is changed. The spraying distance L is 100 mm and the gas flow rate Q is 200 l/min. Changing the power of the plasma jet, from P = 22 kW up to P = 43 kW, the Vickers hardness of the coating is increased remarkably, and the average value is achieved to about 1200 at 43 kW.

In order to investigate the micro structure of these coatings, the micrograph was taken in the same spraying condition. **Figure 7** shows the cross section of Al_2O_3 coatings; (a): P = 22 kW, (b): P = 43 kW. The porosity is decreased with increased power and that the size becomes smaller.

A similar tendency is obtained by changing the spraying distance. **Figure 8** shows the effect of spraying distance on the Vickers hardness of Al_2O_3 coating, when the power is 22 kW and the thickness of the coatings is 180 – 200μm. The hardness is higher as the distance is shorter and the effect is the same as the case of larger power. In case L = 100 mm, H_v = 800, and contrarily L = 80 mm, H_v = 950. This result shows the energy of spraying powder is increased as the spraying distance decreases. According to the micrograph of spraying coatings, the porosity at the shorter distance didn't change so much, but the size is much smaller.

3.3 Discussion

Gas tunnel type plasma spraying apparatus is a new type plasma spraying system which is used the generating method of gas tunnel type plasma jet by the high speed vortex. It can be produced high power plasma jet applying an exchangeable gas divertor nozzle of various profiles. The characters of this new type apparatus clarified in this study are shown in **Table 2**, and especially as follows:

(1) It is possible to supply the spraying materials such a powder, solid rod and so on in the axial direction from the center axis of the torch.

(2) As the working gas, we can apply all the kinds of gases including chemical reactive gas, ..., and that we can easily change the atmosphere. Moreover, even pure argon can be used up to the inquired power of plasma jet.

These make it possible that the spraying powder has higher temperature and higher speed. In this new type spraying apparatus, as the melting of the powder is more effective, even at a low power level of 20 kW, high quality coating can be obtained easily. With the conventional type it is difficult to produce the ceramic coating at the power level of 20 kW, and much high power is necessary.

When the plasma jet has a higher energy by large input, the spraying powders melted sufficiently collide strongly to the surface of the substrate. For this reason, high power of the plasma jet leads to a few prosity and high

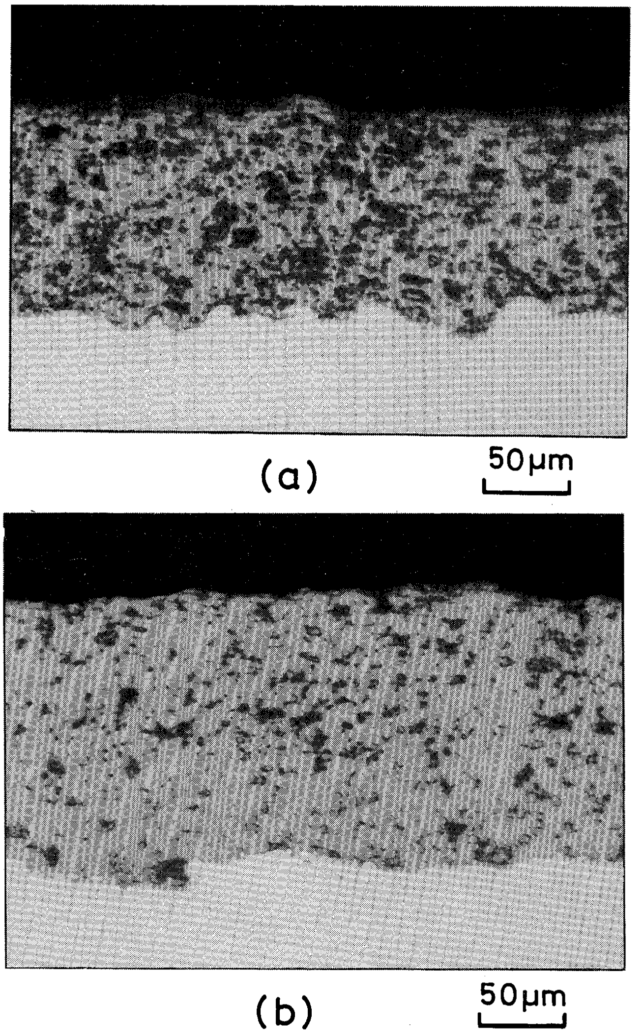

Fig. 7 Cross section of Al_2O_3 coatings.
(a): P = 22 kW, (b): P = 43 kW.

hardness coatings. As mentioned above, by using the gas tunnel type plasma spraying apparatus, the Vickers hardness of the Al_2O_3 coating is achieved H_v = 1200, which is much higher value than that of the conventional type (H_v = 700 – 900).

4. Conclusions

A new type plasma spraying apparatus has been developed and the fundamental characteristic has been clarified. The results are as follows.

(1) This type is very effective to melt the spraying powder. Therefore, it can be possible to obtain high quality coatings at a low power level of 20 kW.

(2) The Vickers hardness obtained is much higher value of H_v = 1200 than that of the conventional type in the case of Al_2O_3 coating.

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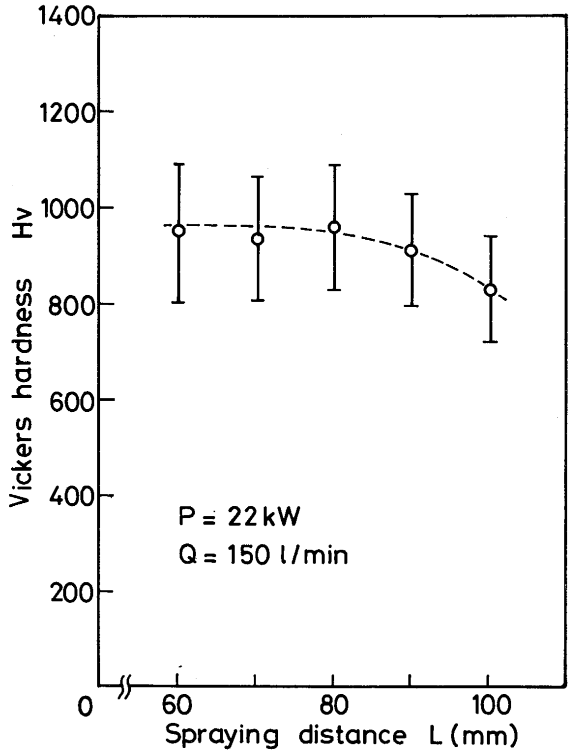

Fig. 8 Effect of the spraying distance on the Vickers hardness.

Table 2 Comparison between gas tunnel type and the conventional type in the optimum spraying conditions.

Parameter	Gas tunnel type	Conventional type
Working gas	Argon	Argon + Hydrogen
Gas flow rate	200 l/min	50 l/min
Current	200 – 400 A	500 – 800 A
Voltage	100 – 150 V	50 – 60 V
Power	20 – 60 kW	30 – 50 kW
Powder supply rate	20 – 80 g/min	0 – 50 g/min

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