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Deposit Characteristics of Sprayed Powder by Gas Tunnel Type Plasma Spraying Apparatus†

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Abstract

The deposit characteristics of alumina powder which was sprayed on the substrate by the gas tunnel type plasma spraying apparatus were studied. The shape, the weight and the state of deposit powder on the substrate were observed. The relations between these deposit characteristics and the torch condition, such as the input to the torch and the spraying distance, were clarified. The alumina coating on stainless steel was examined on the hardness, porosity, and as the result, it was proved that the quality of the coating was influenced by these conditions. To examine the deposit characteristics was very effective in order to decide the proper spraying condition. This method is useful to apply other spraying methods to decide the best spraying conditions.

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

1. Introduction

This type of plasma jet is generated in the gas tunnel which is produced inside the plasma jet torch by the special vortex nozzle. This torch is the high voltage type in volt-ampere characteristics. Therefore the damage of electrode is so less and a high power can be easily obtained¹⁾. This plasma jet was stable and had a high temperature and high energy density^{2,3)}, being applied to the ceramic coating. As the result, at a lower power compared with the conventional plasma spraying apparatus, the coating was very hard and less porosity⁴⁾. This gas tunnel type plasma spraying apparatus is able to feed the powder to the plasma through the center electrode of spraying torch. Supplied powder is enough melted through the long plasma jet and sprayed at a high speed.

In this work, the deposit characteristics of the powder sprayed by the gas tunnel type plasma spraying apparatus were clarified. The study of deposit by the thermal sprayings was rare^{5,6)} and the relation between the sprayed coating and the deposit particle has not been reported. And the spraying conditions, such as the power input to the torch, the spraying distance, the working gas flow rate and the kind of working gases have been examined only experimentally. In this work, for the decision of proper coating conditions, the shape, the weight and the state of deposited alumina powder on a substrate are observed and the deposit characteristics are clarified. Some characteristics of alumina coating is examined in the relation to the powder deposit characteristics.

2. Experimental Method

Gas tunnel type plasma spraying torch used in this experiment is the same one in the previous report⁴⁾. Experimental conditions are shown in Table 1. The plasma spraying was carried out at various input to the torch and spraying distance. Experimental arrangement is illustrated in Fig. 1 (a). Powder was sprayed on the aluminium substrate ($1.0^t \times 100 \times 100$) at a spraying distance L . The substrate was vertically set to the torch axis. The copper slit set between the spraying torch and the plate is movable, and was moved after the stable spraying began. The sprayed powder passed through the slit was deposited on the aluminium plate. The slit speed was adjusted so as to spray only for about 0.1 sec, in order that the individual deposits were observed with ease.

Another method is shown in Fig. 1 (b). The substrate aluminium plate ($1.0^t \times 50 \times 250$) was tilted $\theta = 26^\circ$ from the torch center axis. On spraying the tilted plate traversed a plasma jet. This method has a good advantage of observing the effect of spraying distance on a coating at one time. Then the plate was divided into the width 10 mm and set side by side. The powder was sprayed on each plate. The increase of the sprayed plate weight was measured at each distance.

The deposit powder on the plate was observed by the optical microscope. The coating thickness in a radial distance was measured at the cross section.

In this experiment, the composition of coating powder is 99.5% Al_2O_3 and the size 10–40 μ m. The micrograph of this powder is shown in Fig. 2. The powder was spray-

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ed on blasted SUS 304 stainless steel ($2.0^t \times 25 \times 50$) at each distance. The coating was examined in the Vickers hardness and the porosity of the cross section. The load weight of the hardness measurement is 300g. The porosity rate was measured from the picture of the coating cross-

Table 1 Spraying conditions

Gas divertor nozzle diameter	12 ϕ mm
Current	200 – 300 A
Working gas (Ar)	200 l/min
Powder carrier gas (Ar)	10 l/min

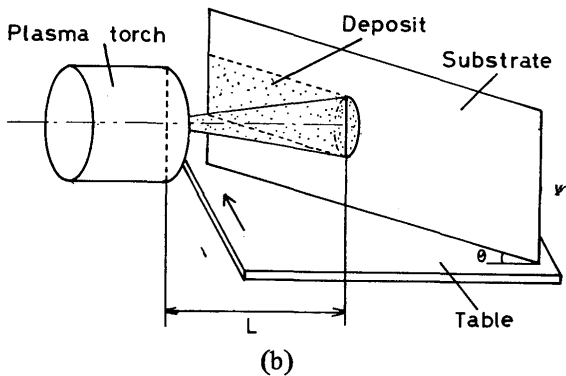
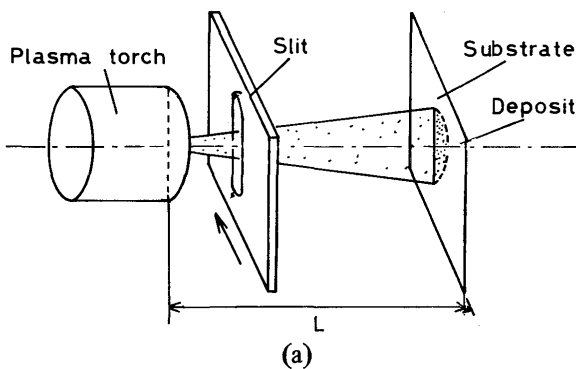


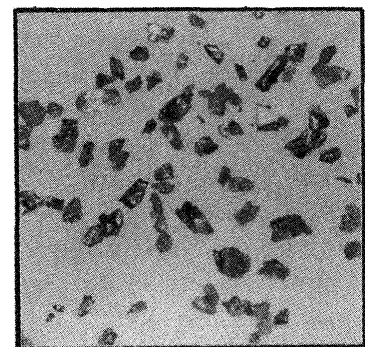
Fig. 1 Experimental arrangement for observing the sprayed deposit on the substrate. (a) vertical plate type, (b) tilted plate type

section by means of the point counting method.

3. Experimental Results and Discussion

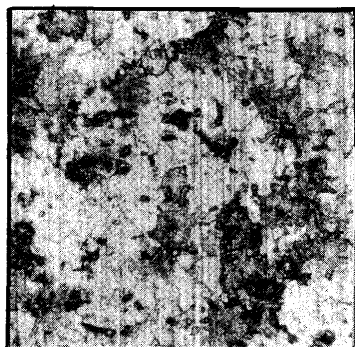
3.1 Sprayed deposit on vertical plate

The alumina deposits sprayed vertically on the aluminium plate are shown in Fig. 3 (a)–(c) at a spraying distance $L = 100, 150$ and 200 mm respectively. Then, the power input to the torch was $P = 20$ kW and the powder feed rate 50 g/min. Sprayed powders seen in Fig. 3 (a) are hardly damaged on the plate at a spraying distance $L = 100$ mm. Some of them are spattered. In Fig. 3 (b) at $L = 150$ mm, three typical types of deposits are observed. These are classified into a severely damaged particle, a flat round particle and a spattered small particle. The flat round particle is considered to be formed because of the temperature decrease on flying. In Fig. 3 (c) at $L = 200$ mm, the severely damaged deposits are not observed, while the flat round particles are increased, compared with the case of $L = 150$ mm. In the case of $L = 150$ and 200 mm, the deposits like sphere are also observed on the aluminium substrate. It seems that this deposit had been

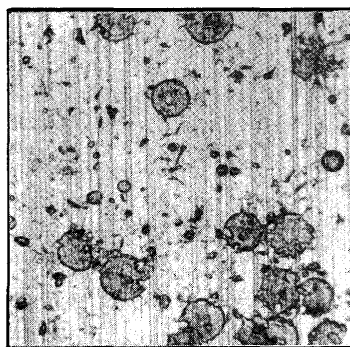


100 μ m

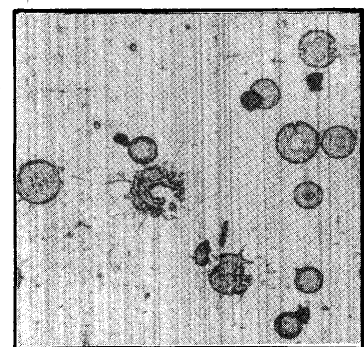
Fig. 2 Micrograph of alumina powders



(a)



(b)



(c)

100 μ m

Fig. 3 Alumina deposits sprayed on vertical plate at $P = 20$ kW. (a) $L = 100$ mm, (b) $L = 150$ mm, (c) $L = 200$ mm

solidified on flying. As the spraying distance is increased, the temperature of the deposits is decreased and its shape becomes flat round.

The spraying distance is one of the important spraying conditions which influences the solidification of sprayed powder. The coatings are made from these deposits, therefore the coating properties will be affected by the spraying distance.

3.2 Sprayed deposit on tilted plate

The sprayed alumina powder on the tilted aluminium plate is shown in Fig. 4. The black part in the photograph is aluminium plate and the white is sprayed powder. The horizontal direction shows the distance from torch and its vertical direction shows the radial distance of plasma jet. In this case the powder feed rate is 50 g/min. Fig. 4 (a) is the case of $P = 21$ kW and (b) is the case of $P = 35$ kW. The sprayed powders flew straightly to the torch axial direction, and didn't spread in the radial direction. The increase of the input to the torch elongated the adhered distance.

The shapes of sprayed powder were observed by the optical microscope at some distances. This result is shown in Fig. 5 (a)–(c), when the input is $P = 21$ kW, the observed position is the radial distance $r = 0$ mm. At a spraying distance $L = 50$ mm, the shapes of sprayed deposits can't be distinguished, but at $L = 100$ mm each deposit can be seen. These deposits have the tail where the alumina has flown on the plate. At $L = 150$ mm, the number of the elliptic particle is increased more than that with a tail. This elliptic deposit without a tail can be considered to correspond to the flat round deposit seen in Fig. 3 (b) at $L = 150$ mm.

The deposit with a tail is formed by the powder at a high temperature and high speed. The elliptic particle is deposited at a low temperature and has been solidified on flying. In the case of a higher power $P = 36$ kW, even at a spraying distance $L = 200$ mm, the deposits with a tail are

many. But, as the increase of spraying distance, those deposits become less.

At a distance, the deposit powder weight on aluminium plate ($1.0^t \times 10 \times 50$) was measured, and the relation of spraying distance and the deposit weight are shown in Fig. 6. The plate was moved at a traverse speed of 280 cm/min. In order to increase the deposit weight on a plate, the spraying was carried out three times, and the weight of the deposit powder was measured in the case of $P = 24$ kW and 36 kW. In each input, as the increase of spraying distance, the deposit powder weight is decreased, but the decrease rate of deposit weight is a little, up to a certain distance. The spraying efficiency is high in this region. At $P = 24$ kW, $L > 130$ mm or $P = 36$ kW, $L > 170$ mm, the weight are greatly decreased. At more longer distance of $L > 210$ mm at $P = 24$ kW, the deposit weight is very little. This tendency of deposit weight is related to the shapes of deposit powder in Fig. 3 or Fig. 5. As decreasing of the alumina deposit with a tail, the flat round particles, which adhere on the substrate at a low temperature, are recognized.

At $L = 100$ mm, the radial distribution of the thickness of alumina coatings was measured at the input to the torch $P = 24$ kW or $P = 36$ kW. These results are shown in

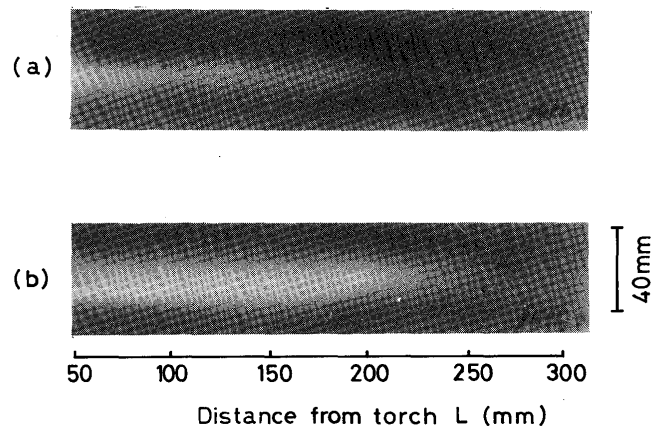


Fig. 4 Sprayed alumina powder on tilted plate. (a) $P = 21$ kW, (b) $P = 35$ kW

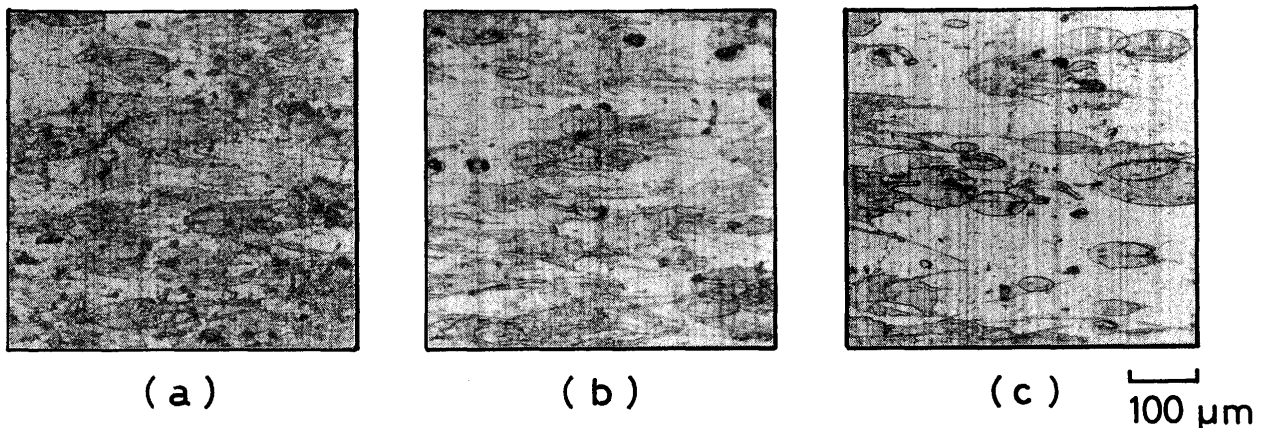


Fig. 5 Alumina deposits sprayed on tilted plate at $P = 21$ kW. (a) $L = 50$ mm, (b) $L = 100$ mm, (c) $L = 150$ mm

Fig. 7. This distribution of the coating thickness t_c seems to be proportional to the radial distribution of adhesion weight. In the gas tunnel type plasma spraying, the powder is sprayed through the long-length plasma jet, so well melted powder near the torch center axis adheres effectively on the plate. These radial distributions are symmetrical to the center axis.

The radial distributions of the coating thickness at each spraying distance are shown in Fig. 8. The input is $P = 24$ kW. As the spraying distance is increased, the coating thickness t_c at the center axis is decreased largely. On the contrary, the width of the deposit is nearly constant, about 30 mm.

3.3 Characteristics of alumina coating

The cross section of alumina coatings sprayed on the stainless steel is shown in Fig. 9, where the input is $P = 21$ kW or 35 kW. Under the same condition of the torch, the thickness of coating is decreased with the spraying distance. At $P = 21$ kW, $L = 160$ mm, the interface of the coating and the substrate is separated. The porosity size is greater as increasing the spraying distance. If the spraying conditions under which the deposit powder is well melted and crashed on the plate are selected, the less porosity coating can be obtained, and the joining of the coating and substrate becomes stronger.

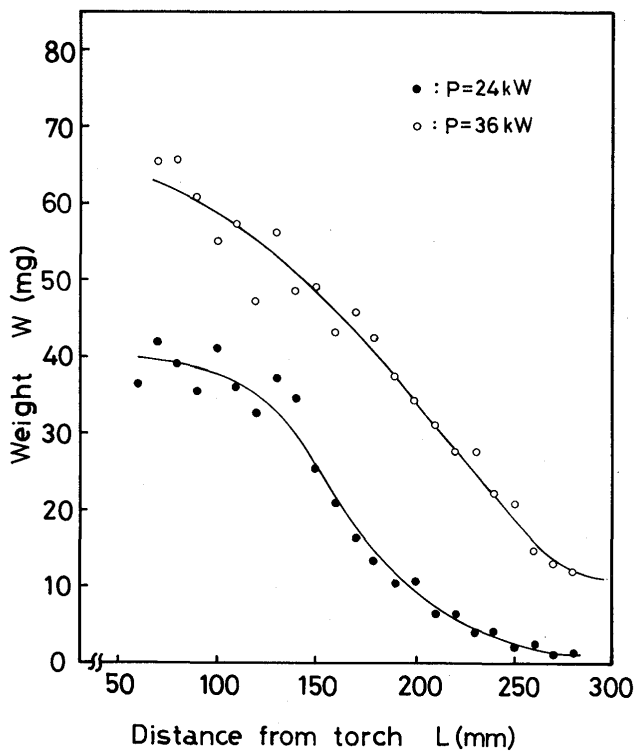


Fig. 6 Relation between deposit weight and distance from torch

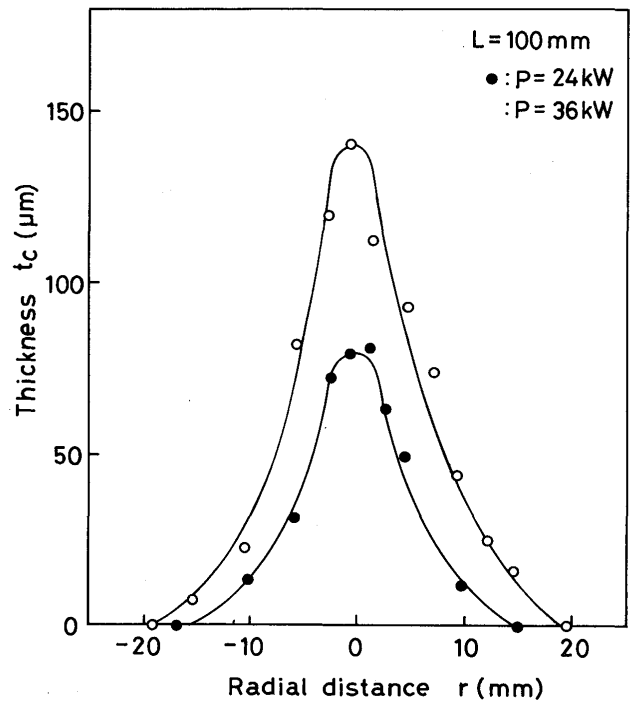


Fig. 7 Radial distributions of coating thickness at $L = 100$ mm

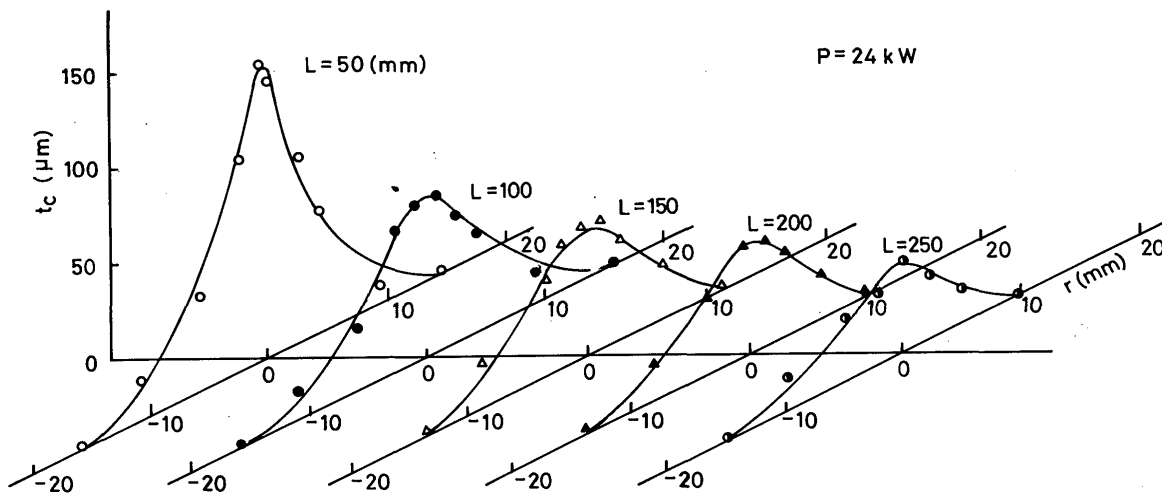


Fig. 8 Dependence of radial distributions of coating thickness on distance from torch

becomes good condition.

The coating at the condition of $L = 100$ mm, $P = 35$ kW has less porosity than that of $P = 21$ kW. In the case of $P = 35$ kW at even spraying distance $L = 160$ mm, the porosity is as little as that of $P = 21$ kW, $L = 100$ mm. The results of the Vickers hardness measurement of coating are shown in Fig. 10. As the increase of spraying distance, the hardness is decreased. The joining of each sprayed deposit seems to be weakened as the increase of spraying distance.

The porosity rate was measured from the picture of the cross section. The porosity rate was increased with the increase of spraying distance as shown in Fig. 11. As the round deposit is observed, the porosity rate is increased. It is considered that the state of melting and the shape of deposit are strongly influenced to the coating quality.

4. Conclusion

Alumina powder was sprayed using the gas tunnel type plasma spraying apparatus. The deposit powder on the substrate was observed and its relation to the Vickers hardness and the porosity was clarified.

- (1) The deposit powders consist of severely damaged particles, flat round particles and spattered small particles.
- (2) If the flat round particles are observed, the porosity of coating is increased and the hardness is decreased. Thus, the ratio of these deposits affects strongly to the properties of coatings.
- (3) The method of examining the shape and the weight of deposit is convenient to decide the proper spraying conditions.

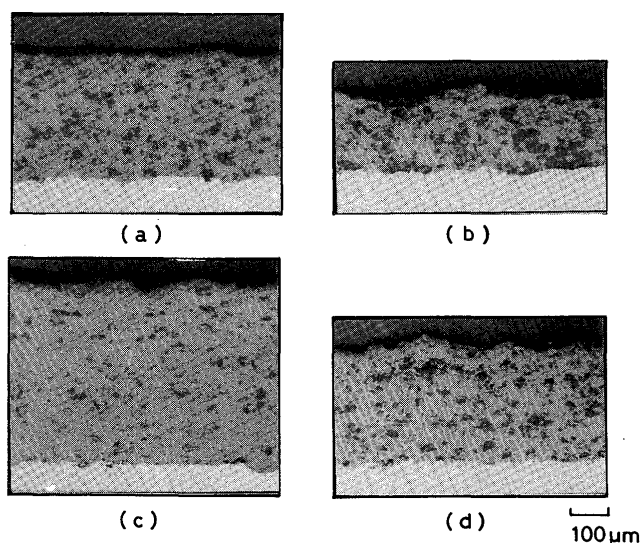


Fig. 9 Cross section of alumina coating
 (a) $P = 21$ kW, $L = 100$ mm
 (b) $P = 21$ kW, $L = 160$ mm
 (c) $P = 35$ kW, $L = 100$ mm
 (d) $P = 35$ kW, $L = 160$ mm

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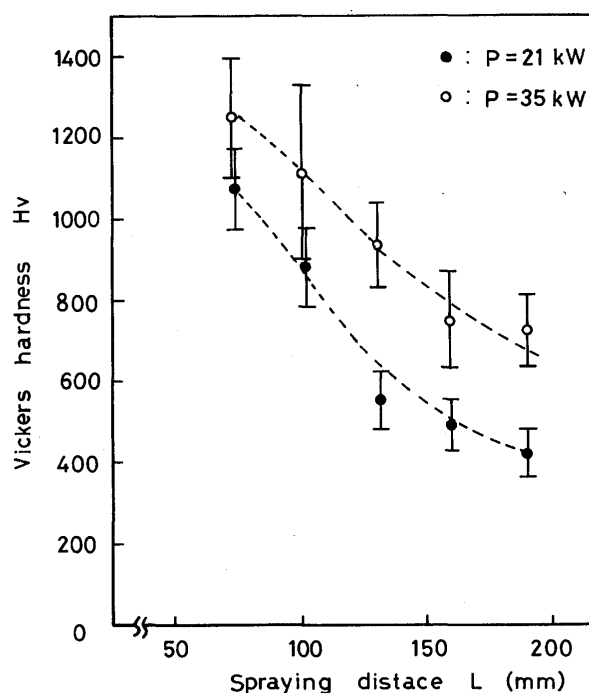


Fig. 10 Dependence of Vickers hardness of alumina coating on spraying distance.

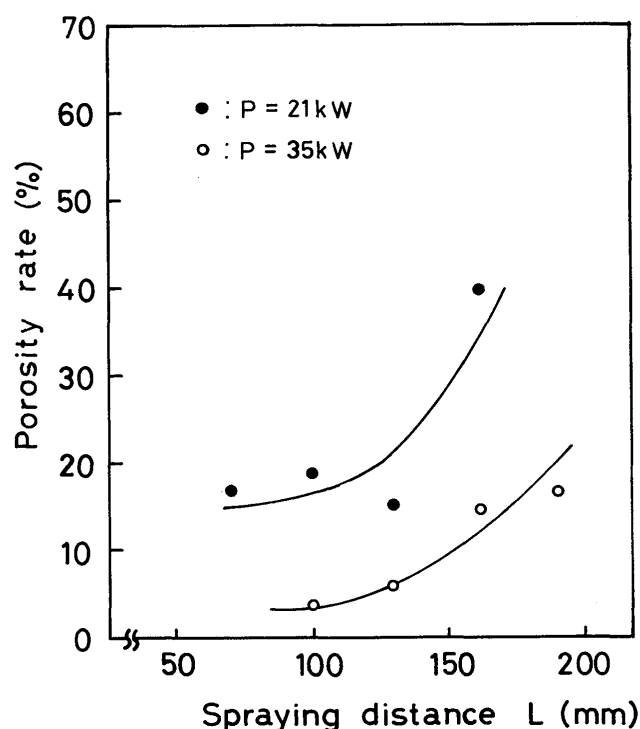


Fig. 11 Dependence of porosity rate of alumina coating on spraying distance.

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