High Hardness Zirconia Coating by Means of Gas Tunnel Type Plasma Spraying†

Akira KOBAYASHI*, Nobuyori BESSHO and Masahiro HIGUCHI*****

Abstract

By means of gastunnel type plasma spraying, high hardness coatings (in the case of alumina coating, more than $H_V=1300$) can be formed at a short spraying distance. In this paper, the characteristic of the Vickers hardness of high hardness zirconia coating was investigated, and the characteristic of the coating was discussed as compared with conventional one.

KEY WORDS: (High Hardness Coating), (Zirconia Coating), (High Hardness Layer), (Gas Tunnel Type Plasma Spraying), (Short Distance Spraying)

1. Introduction

The sprayed particles can be melted efficiently and the bonding force between those particles is stronger by means of the gas tunnel type plasma spraying apparatus. Therefore the porosity is decreased, which leads the closeness of coating. And it has been obtained high quality ceramic coatings with a gas tunnel type plasma spraying, as compared to the sprayed ceramic coatings[1,2] with conventional type plasma spraying.

The characteristics of the quality of such ceramic coatings have been investigated. For example, characteristics of the Vickers hardness and porosity on the power input to plasma jet and spraying distance. And deposit characteristics of sprayed powder has been clarified at various spraying conditions[3,6].

Moreover, it was found that Vickers hardness of the alumina coating is increased with decreasing spraying distance, and the characteristics of the Vickers hardness change dramatically at the spraying distance L_p, in the gas tunnel type plasma spraying. A higher Vickers hardness can be obtained in the case of short distance spraying ($L<L_p$), at each power input[7].

For example, in the case of alumina coating, the value of L_p was about 40 mm, which related to the plasma jet length. The Vickers hardness of alumina coating was $H_V=1500$ at $L=30$ mm, when $P=30$ kW. According to the measurement of the distribution of the Vickers hardness, these high hardness coating has a hardaness layer near the surface. And it is found that the cell size is very fine compared with other parts of coating[8].

Now, various type of ceramic coating have been used for many industrial fields[4] due to its fanctionality, and they are applied to a lot of parts of industrial materials (goods) in the field of electronics. In such circumstances, zirconia coating by plasma spraying method is recently noticed in order to use the excellent characteristics of such as corossion resistance and thermal resistance and weare resistance and so on[5].

In this paper, the characteristics of high hardness zirconia coatings[7] formed by the gas tunnel type plasma spraying as one of the factor of coating qualities, has been investigated. Especially, the experiment was carried out at short spraying distances, and the effects of spraying distance etc. on the hardness of the sprayed coating.

And the characteristics of the hardness in the zirconia coatings by means of gas tunnel type plasma spraying was disscussed with the structure of the coating which was observed by an optical microscope.

2. Experimentals

Figure 1 shows the gas tunnel type plasma spraying apparatus used in this study. This apparatus is improved a little, for obtaining zirconia coating. The gas divertor nozzle diameter was broadened to 20 mm from 12 mm. And the polarity of electrode changed oposit of former one. But the structure and functionality is essencially the same as former case.

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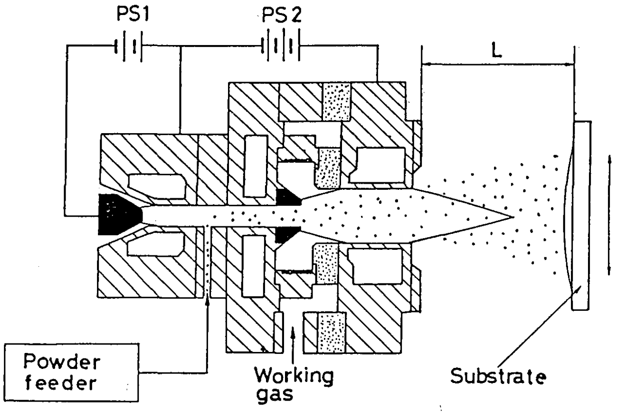


Fig. 1 Gas tunnel type plasma spraying apparatus; diameter of gas divertor nozzle is 20 mm, L: spraying distance.

The method in order to form high hardness zirconia coatings by means of the gas tunnel type plasma spraying is the same as that described in the previous papers [1,2,3,6]. The experimental conditions in this study are shown in **Table 1**. The power input to plasma jet and working gas flow rate were respectivery maintained constant values. And the effects of spraying distance on the quality of the sprayed coating were examined. Especially, the experiment was carried out at a short spraying distance (L=20–50 mm).

The powder used in this study is shown in **Table 2**. Among these, the K-90 which contains 8% Y_2O_3 was used, whose powder size was 10∼44 μm. As the substrate was used SUS304 of 5 mm thickness.

The Vickers hardness, one of the factor of coating qualities, has been investigated in this study, and the effects of spraying distance on the hardness of the sprayed coating was examined.

The Vickers hardness measurement of the sprayed coatings was carried out in the following conditions. The load weight was 100 g and its load time was 25 s. The Vickers hardness was caluculated as mean value of 10 point measurement.

The distributions of Vickers hardness of the sprayed coatings was measured in the thickness direction on the cross section. And the characteristics of the hardness in zirconia coatings by means of gas tunnel type plasma spraying was disscussed with the structure of the coating whose cross section of the coating was observed by optical microscope.

3. Results and Discussion

3.1 Cross section of ZrO_2 coating

The results obtained by means of the microscopic measurement of the cross section of zirconia coating formed by means of the gas tunnel type plasma spraying are as follows.

Figure 2 shows the photograph of the cross section of zirconia coating by an optical microscope. In this case, the power input to plasma jet was P=33 kW and the spraying distance was L=30 mm. Argon gas flow rate was Q=200 l/min, and the powder feed rate was w=40 g/min. The traverse speed of the substrate was v=120 cm/min. The coating thickness was about t_c=260 μm.

From the observation of the cross section of sprayed coating, it is found that the pore is very few on the cross section of this zirconia coating, in these case of short spraying distance. The part near the coating

Table 1 Plasma spraying conditions

	Gas tunnel type			Conventional type
	A	B	C	D
Power (kW)	33	33	33	35
Gas flow rate (l/min)	Ar 150	Ar 150	Ar 150	Ar/H_2=45/7
Powder feed rate (g/min)	40	60	40	40
Traverse speed (cm/min)	120	120	80	2000

Spraying distance: L=20∼70 mm

Table 2 Chemical composition and particle size of zirconia powders

	Chemical composition (wt%)					Size (μm)	
Type	ZrO_2	Y_2O_2	Al_2O_3	SiO_2	Fe_2O_3	Average	Range
202NS	80	20				50	10–100
204NS	92	8				56	10–106
K-90	90.78	8.15	0.38	0.20	0.11	26.3	10–44

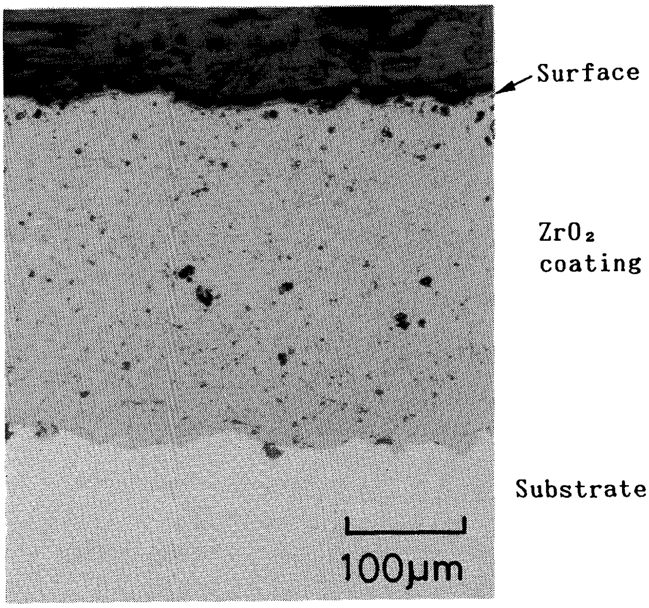


Fig. 2 Photograph of cross section of zirconia coating at spraying distance L=30 mm, when P=33 kW.

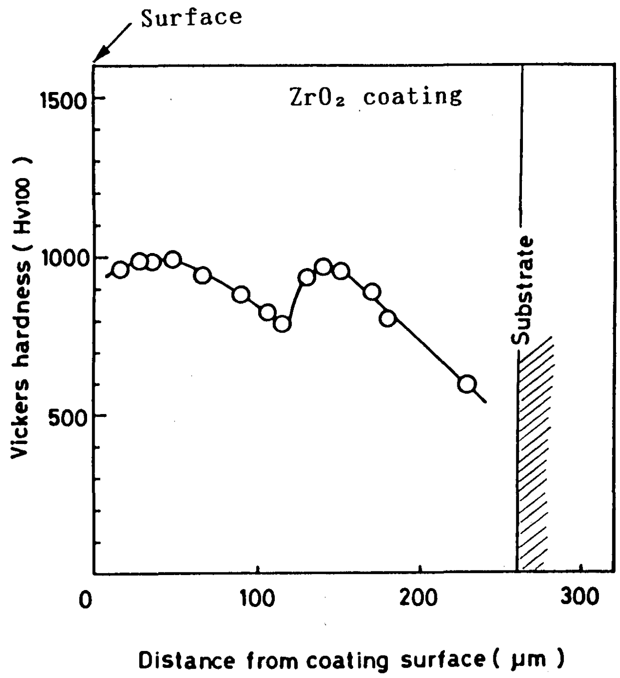


Fig. 3 Distribution of Vickers hardness on cross section of zirconia coating at spraying distance L=30 mm, when P=33 kW.

surface the pore size is fine compared with that in other parts. On the other hand, in the middle part of the coating the pore size becomes bigger, and this part forms a layer.

On the contrary, the zirconia coating which was formed at normal spraying distance such as L=70 mm have more pores on the cross section of the coating.

3.2 Distribution of Vickers hardness on the cross section of ZrO_2 coating

Figure 3 shows the distribution of Vickers hardness on the cross section of zirconia coating by means of the gas tunnel type plasma spraying. The measurement was carried out at each distance from the coating surface in the thickness direction.

In this case, the data was obtained the same zirconia coating which was shown in Fig. 2. Then the spraying condition is as follows; the power input to plasma jet was P=33 kW and the spraying distance was L=30 mm, Ar gas flow rate was Q=200 l/min, and the powder feed rate was w=40 g/min. The coating thickness was about t_c=260 μm.

The distribution curve of the Vickers hardness consists of two parabolic curve as shown in this figure. It was formed by two times traverse (two passes) spraying. It is found that the Vickers hardness near the coating surface (second pass) is higher than that near the substrate (first pass). The hardness is the highest at the distance from the coating surface of l = 40 μm, whose value is more than H_V=1000. This hard part in the coating formed "high hardness layer" which have the Vickers hardness of more than H_V=1000.

Thus we can obtained high hardness zirconia coating by means of gas tunnel type plasma spraying, as well as alumina coating. In the case of zirconia coating, there appears the part of lower hardness (H_V=800) between two passes, which corresponds to the middle part of the coating where the pore size becomes bigger as shown in Fig. 2. This did not appear in the case of alumina coating. This is due to higher melting point of zirconia: so that the melting condition is not better at the interface layer of those two passes.

3.3 Characteristics of Vickers hardness

Figure 4 shows the relations between the spraying distance L and the Vickers hardness on the cross sections of zirconia sprayed coatings which were formed by the gas tunnel type plasma spraying under various conditions. The Vickers hardness was measured respectively at the high hardness layer near the coating surface.

The spraying condition was as follows: Ar gas flow rate for gas tunnel type plasma spraying torch was constant value of Q=200 l/min, and the power input was also constant, P=33 kW.

In the case of Fig. 4(a), the powder feed rate was w=40 g/min and the traverse speed of the substrate was v=120 cm/min. This is condition A in Table 1.

As is shown in this figure, by means of the gas tunnel type plasma spraying with zirconia powder can be obtained the same characteristics of Vickers hardness on the spraying distance as that with the alumina

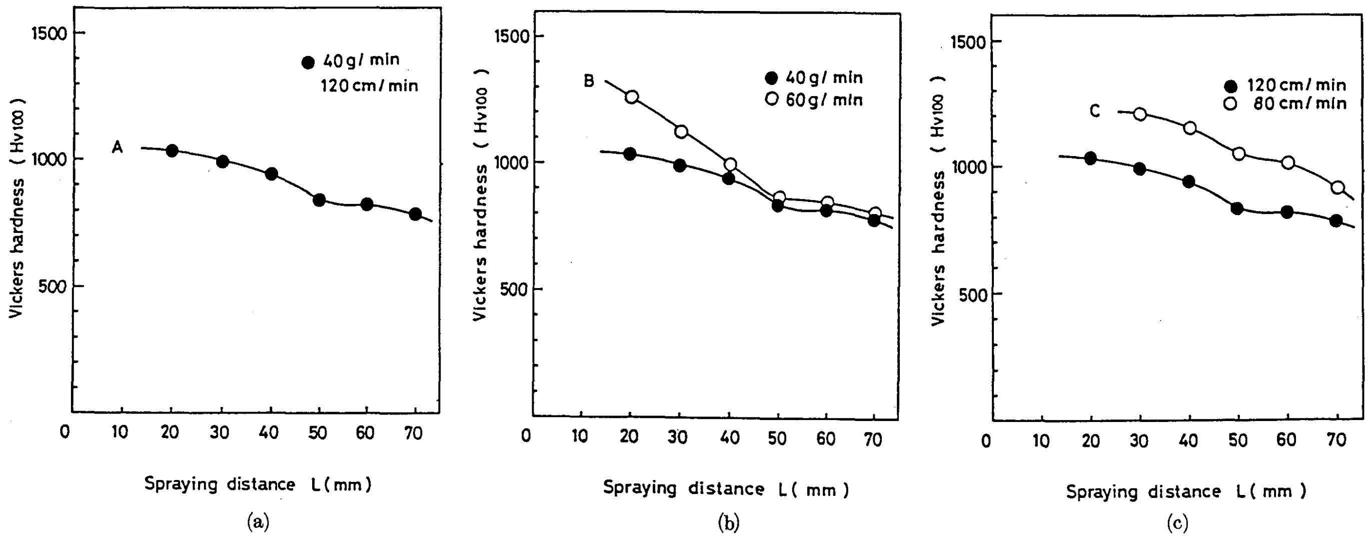


Fig. 4 Dependences of Vickers hardness of zirconia coating on the spraying distance at $P=33$ kW in various spraying conditions.
(a) condition A: powder feed rate: $w=40$ g/min,traverse speed $v=120$ cm/min.
(b) condition B: powder feed rate: $w=60$ g/min, traverse speed $v=120$ cm/min.
(c) condition C: powder feed rate: $w=40$ g/min, traverse speed $v=80$ cm/min.

powder.

In the case of the short distance spraying at the spraying distance below L_p ($=50$ mm) can be obtained very high hardness zirconia coating. For example, Vickers hardness was more than $H_V=1000$ at $L=30$ mm, when $P=33$ kW.

By the way, in the case of changing the powder feed rate is shown in Fig. 4(b). When the powder feed rate w is increased to 60 g/min from 40 g/min, the characteristic curve is shown B in Fig. 4(b). Increasing the powder feed rate from 40 g/min to 60 g/min, the Vickers hardness of the zirconia sprayed coating became 20% or 30% higher than that in the case of $w=40$ g/min, at short spraying distance of $L=20$ mm: the Vickers hardness of the sprayed coating is near $H_V=1300$. On the other hand, at large spraying distance the hardness was not change greatly, when the poweder feed rate was increased.

Moreover, in the gas tunnel type plasma spraying with zirconia powder the data when the traverse speed v was changed were measured. The obtained characteristic curve is shown C in Fig. 4(c).

When the traverse speed was $v=80$ cm/min could be obtained the same characteristics of Vickers hardness on the spraying distance as that with the fast traverse speed of $v=120$ cm/min. But the Vickers hardness of the sprayed coating at $v=80$ cm/min became 20% higher than that with fast traverse speed at any spraying distance. At $L=30$ mm the Vickers hardness is more than $H_V=1200$.

In this way, by the short distance spraying at the spraying distance below L_p can be obtained very high hardness zirconia coating, whose results are shown in Fig. 4 (a), (b), (c) respectively. In these case, the value of L_p was all about 50 mm in the case of zirconia coating.

As was described in the previous papers, it is found that a higher Vickers hardness of the ceramic coating can be obtained by a short distance spraying ($L<L_p$). In the case of alumina coating, this critical spraying distance is $L_p=44$ mm when $P=30$ kW.

In the case of zirconia coating, the value of L_p is 50 mm, which is 6 mm larger than that of alumina coating at power input of $P=30$ kW. It is considered that this L_p relates to the melting point of the ceramics and/ or plasma jet energy.

3.4 Comparison of ZrO_2 sprayed coating to the conventional one

Figure 5 shows the relations between the spraying distance L and the Vickers hardness on the cross sections of zirconia sprayed coatings which were formed both by the gas tunnel type plasma spraying and by conventional plasma spraying.

As the spraying condition. In the case of the gas tunnel type plasma spraying. Ar gas flow rate for plasma spraying torch was $Q=200$ l/min, and the power input was $P=33$ kW. The powder feed rate was $w=40$ g/min and the traverse speed of the substrate was $v=80$ cm/min, as the same condition of the case of Fig. 4(c).

In the case of conventional type plasma spraying. Ar gas flow rate for plasma spraying torch was $Q=45$ l/min, hydrogen gas flow rate was $Q=7$ l/min, and the power input is $P=35$ kW. In the case of Fig. 4(a), the powder feed rate is $w=40$ g/min and the traverse speed of the substrate was $v=2000$ cm/min as was shown in Table 1. Then, this coating was formed by of 18 passes scanning.

The Vickers hardness of the sprayed coating by the gas tunnel type plasma spraying became 20% higher than that of conventional one, at any spraying distance. At $L=30$ mm the Vickers hardness is about 1200 and 1000 respectively.

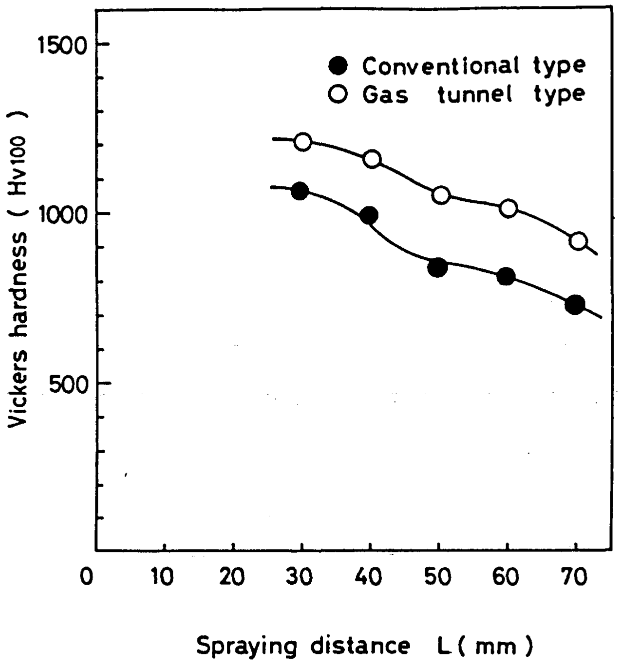


Fig. 5 Dependences of Vickers hardness of zirconia coating on spraying distance both by gas tunnel type plasma spraying and conventional type plasma spraying.

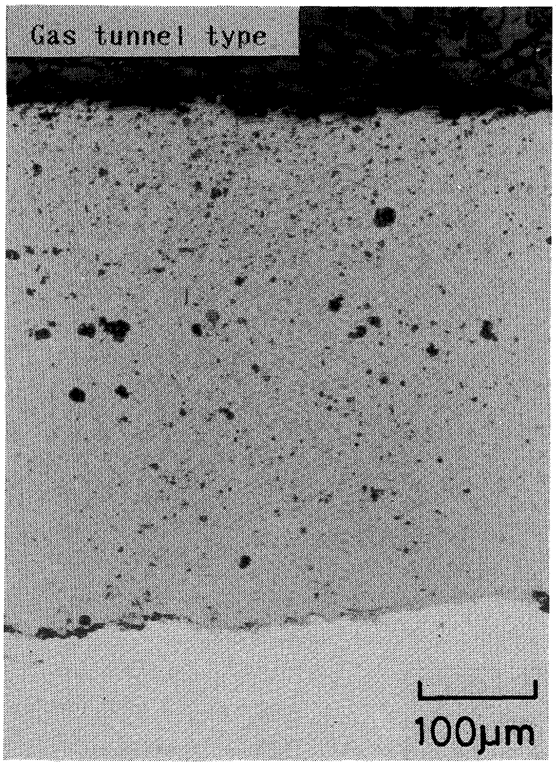
The results obtained by means of the microscopic measurement of the cross section of zirconia coating formed at $L=30$ mm both by the gas tunnel type plasma spraying and by conventional plasma spraying are shown in **Fig. 6**. Other spraying conditions are same as those in Fig. 5.

Figure 6(a) shows the photograph of the cross section of high hardness zirconia coating by gas tunnel type plasma spraying. In this case, the power input is $P=33$ kW and the spraying distance is $L=30$ mm.

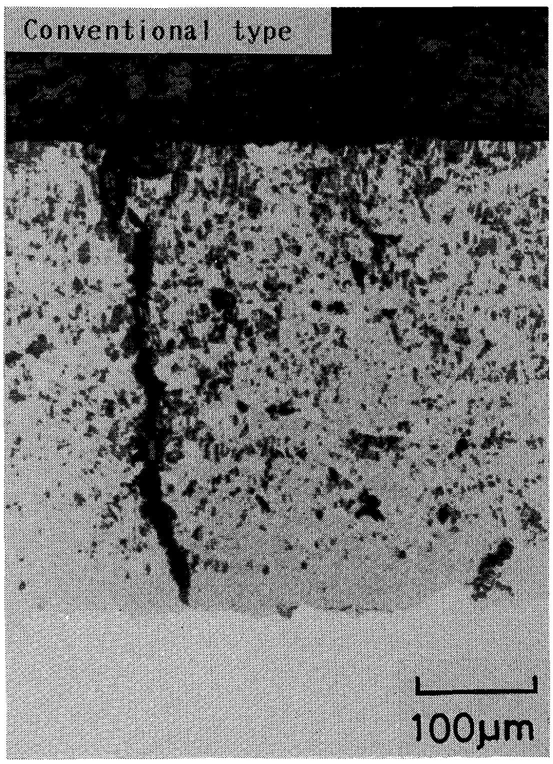
This sprayed coating has also a high hardness layer of low porosity near the coating surface as described above, where the Vickers hardness H_V is about 1200.

On the other hand, Figure 6(b) shows the photograph of the cross section of zirconia coating, which was formed at $L=30$ mm by the conventional plasma spraying under the condition that shown in Fig. 5. In this case, the power input was $P=35$ kW and the spraying distance was $L=30$ mm.

From the observation of this sprayed coating, there appear many large pores in its cross section and a large crack. This coating being formed many layers (18 passes), the pores are spreadened all over the cross section. It is found that all the zirconia coating by conventional type plasma spraying is the same coating structure like this.



(a)



(b)

Fig. 6 Photograph of cross section of zirconia coating at spraying distance $L=30$ mm.
(a) Gas tunnel type plasma spraying.
(b) Conventional type plasma spraying.

4. Conclusion

Vickers hardness of ZrO_2 coating is increased with decreasing spraying distance, and the characteristics of the Vickers hardness change dramatically at the spraying distance L_p, in the gas tunnel type plasma spraying, which is the same characteristics of Vickers hardness as that of the alumina coating.

1) In the case of zirconia coating, the value of the critical spraying distance L_p was about 50 mm at power input of 33 kW.

   Higher Vickers hardness can be obtained by means of short distance spraying ($L<L_p$). The Vickers hardness of zirconia coating was more than $H_V=1200$ at $L=30$ mm, when $P=33$ kW.

2) According to the measurement of the distribution of the Vickers hardness, these high hardness coating has a high hardness layer near the surface corresponds to the last pass, the hardness of the part between each pass is lower value than the center value of the last pass.

3) Observing the microstructure of zirconia coating in this high hardness layer, it is found that the coating is very fine compared with the conventional coating.

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