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Formation of High Hardness Ceramic Coating by Gas Tunnel Type Plasma Spraying†

Akira KOBAYASHI*, Naoto HASEGAWA** and Hirokazu NAMIKAWA***

Abstract

It can be possible to form high quality ceramic Sprayed coating by means of gas tunnel type plasma spraying. Moreover high hardness coating (in the case of alumina coating, more than H_V = 1300) at a short spraying distance. In this paper, the characteristic of the Vickers hardness of this high hardness coating was investigated, and the relation to the microstructure of the coating was discussed.

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

1. Introduction

In the formation process of the sprayed coating, indivisual spraying particle collides into the substrate and deposits to make the layer. At this time the pores which have various size and shape appear in the boundary of many deposit particles[1].

In the case of gas tunnel type plasma spraying, the sprayed particles are good melting state and the bonding between those particles is in good condition. Therefore the porosity is small, which leads the closeness of coating. And the mechanical properties such as Vickers hardness are improved better.

As the results, it has been obtained high quality ceramic coatings with a gas tunnel type plasma spraying, as compared to conventional ceramic coatings[2,3].

The mechanism of the formation of such ceramic coatings has 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[4).

Now, various methods on the surface processing such as PVD, CVD have been used for the formation of high function coating[5]. And they are applied to a lot of fields such as electronics.

In the above circumstances, plasma spraying method is recently noticed for using the excellent characteristics of ceramics such as corrosion resistance and thermal resistance and wear resistance and so on[6].

In this paper, the characteristics of high hardness ceramic coatings[7] formed by the gas tunnel type plasma spraying, 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 was examined.

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

2. Experimentals

The gas tunnel type plasma spraying apparatus used in this study is shown in **Fig. 1**. The experimental method in order to form high hardness ceramic coatings by means of the gas tunnel type plasma spraying has been described in

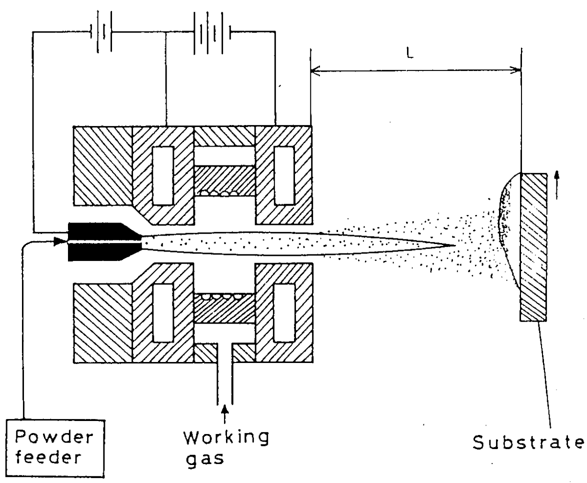

Fig. 1 Gas tunnel type plasma spraying apparatus, *L*: spraying distance.

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the previous papers[2,3,4,7].

As one of the factor of coating qualities, Vickers hardness has been investigated in this study. Especially, the experiment was carried out at short spraying distances (L = 20 ~ 50 mm). And the structure of the coating was observed by an optical microscope and so on.

The Vickers hardness measurement of the sprayed coatings is as follows. Here, we carried out this measurement at the non-pore region in the cross section of the coating, in the condition that the load weight was 100g and/ or 300g, its load time was more than 15s. The Vickers hardness was calculated as mean value of 10 point measurement.

3. Results and Discussion

3.1 Characteristics of Vickers hardness

Figure 2 shows the relations between the spraying distance L and the Vickers hardness on the cross sections of alumina sprayed coatings which were formed by the gas tunnel type plasma spraying.

As gas flow rate for gas tunnel type plasma spraying torch was Q = 200l/min, and the powder feed rate was 80g/min. And the power input was 20, 30kW, respectively.

As the power was low in these cases, the spalling between the sprayed coating and the substrate was suppressed even at the short spraying distance of L = 20 mm. However, in such case it was necessary to cool the surface of the substrate and/or to use a thick substrate.

As was described in the previous papers. Vickers hardness of the ceramic coating is increased with decreasing spraying distance[3]. Moreover it is found that a higher Vickers hardness can be obtained in the case of a shorter spraying distance ($L < 40$ mm), at each power input.

Here, L_p indicates the spraying distance at which the characteristics of the Vickers hardness of the coating change dramatically. The spraying distance is L_p = 37 mm when P = 20 kW, and is L_p = 44 mm when P = 30 kW. And we call such spraying at $L < L_p$ "short distance spraying".

In this way, by the short distance spraying at the spraying distance below L_p can be obtained very high hardness alumina coating. For example. Vickers hardness was H_V = 1500 at L = 30 mm, when P = 30 kW.

By the way, in the case of using fine alumina powder, the Vickers hardness of the sprayed coating became 20% or 30% higher than that with normal size of alumina powders.

Moreover, in the gas tunnel type plasma spraying with zirconia powder and/or titania powder can be obtained the same characteristics of Vickers hardness on the spray-

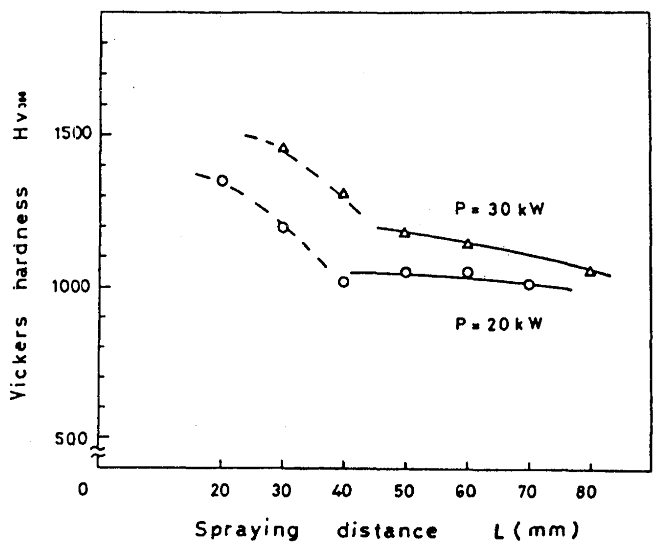
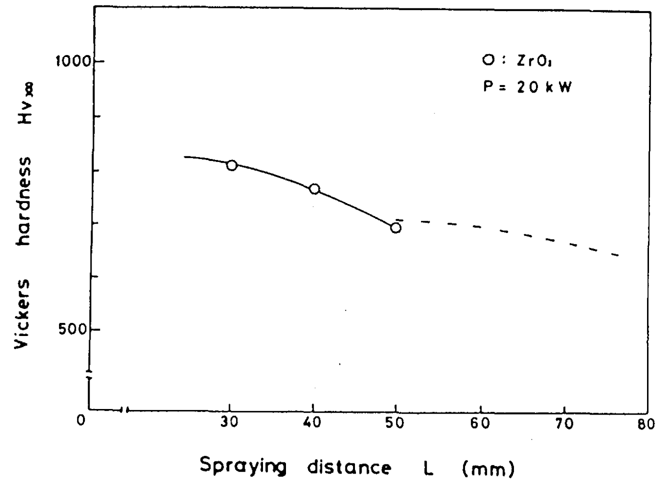
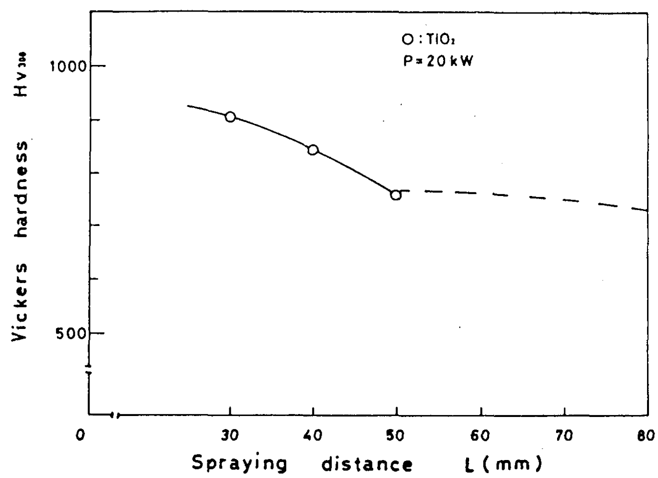


Fig. 2 Dependences of Vickers hardness of alumina coating on spraying distance at P = 20 kW and P = 30 kW.



(a)



(b)

Fig. 3 Dependences of Vickers hardness of various ceramic coatings on spraying distance at P = 20 kW, (a) zirconia coating, (b) titania coating

ing distance as that with the alumina powder. Those results are shown in **Fig. 3 (a), (b)** respectively. In these case, the L_p was about 50 mm.

In order to investigate the relation between the spraying distance L_p and the length of the plasma jet l_p, l_p was determined from the photograph of plasma jet. **Table 1** shows both l_p and L_p at each power input to plasma jet, 20 kW and 30 kW.

According to these results, it is found that L_p are about 10 mm longer than l_p at each power input. And the effect of plasma energy on the coating surface is very large.

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

Figure 4 shows the distribution of Vickers hardness on the cross section of alumina coating in 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 power input to plasma jet was 20 kW and the spraying distance was L = 30mm. Ar gas flow rate was Q = 2001/min, and the powder feed rate was 80g/min. The coating thickness was about 450 μm.

The distribution of the Vickers hardness shows a parabolic curve as shown in this figure. It is found that the Vickers hardness near the coating surface (Y-axis) is higher than that near the substrate. The hardness is the highest at the distance from the coating surface of l = 200 μm, whose value is more than H_V = 1300.

Here, we have called this hard part in the coating a "high hardness layer" because the hard part which have the Vickers hardness of more than H_V = 1300 appears like a layer. And the coating which had a high hardness layer has been also called a "high hardness coating".

Figure 5 shows the distribution of Vickers hardness on the cross section of alumina coating in the gas tunnel type plasma spraying, when the power input to plasma torch is 30 kW.

In this case, other spraying conditions were the same as Fig. 4: the spraying distance was L = 30min. Ar gas flow rate was Q = 200 1/min, and the powder feed rate was 80g/min. The coating thickness is 450 μm.

The distribution of Vickers hardness is also parabolic curve. However, the Vickers hardness near the coating surface is more higher than that at P = 20 kW. Because the hardness of alumina coating is increased largely as the increasing power input, as shown in Fig. 2. The Vickers hardness is the highest at the distance from the coating surface of l = 150 μm, whose value is very high: H_V = 1600. And the width of the high hardness layer is more wider than that at P = 20 kW.

The ceramic coating which was formed at normal spraying distance such as L = 80mm had a flat distribution of Vickers hardness on the cross section in the thickness direction. And a high hardness layer did not exist in the alumina coating at P = 20 kW; the highest Vickers hardness was about 1000.

3.3 Structure of alumina sprayed coating

The results obtained by means of the microscopic

Table 1 Plasma length l_p and spraying distance L_p at P = 20 kW and 30 kW

Power input	Plasma length	Spraying distance
P = 20 kW	l_p = 28 mm	L_p = 37 mm
P = 30 kW	l_p = 32 mm	L_p = 44 mm

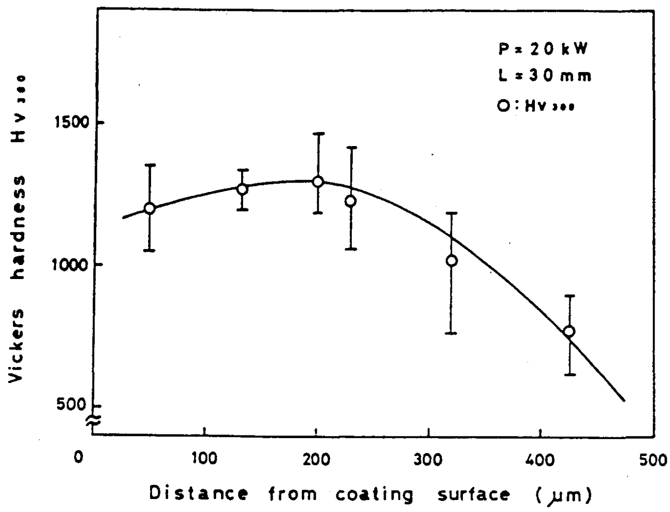


Fig. 4 Distribution of Vickers hardness on cross section of alumina coating at spraying distance L = 30mm, when P = 20 kW.

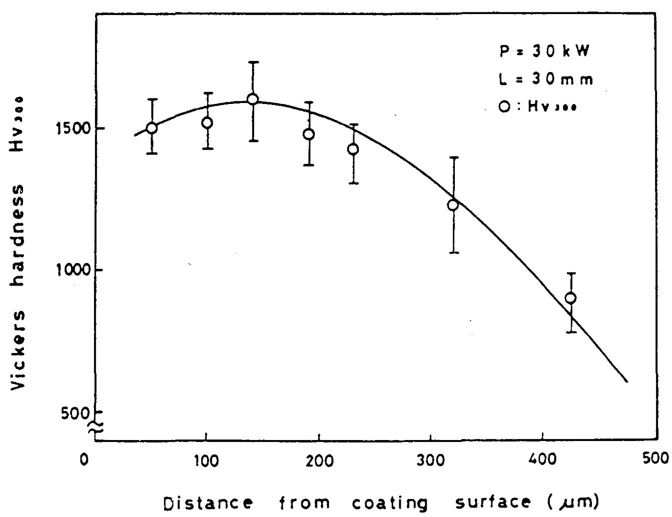


Fig. 5 Distribution of Vickers hardness on cross section of alumina coating at spraying distance L = 30mm, when P = 30 kW.

measurement of the cross section of alumina coating formed by the gas tunnel type plasma spraying are as follows.

Figure 6 shows the photograph of the cross section of high hardness alumina coating by an optical microscope, which is the same coating as that shown in Fig. 4. In this case, the power input is P = 20 kW and the spraying distance is L = 30 mm.

From the observation of sprayed coating, the part (c) near the substrate is the same coating structure as that formed at the usual spraying distance. On the other hand, in the part (a) near the coating surface the cell size becomes bigger. Moreover, in the part (b) the sell size is very fine as compared with that in other parts, and this part forms a layer whose width is about 60 μm.

This layer (b) just corresponds to a high hardness layer of $H_V \geqslant 1300$, that was described above, in Fig. 4.

In the case of a large power input, as mentioned above the Vickers hardness becomes higher and the hardness layer becomes wider. **Figure 7** shows the photograph of optical microscope of the cross section of high hardness alumina coating, which is the same coating as that shown in Fig. 5.

In this case, the power input is P = 30 kW and the spraying distance is L = 30 mm.

From the observation of this sprayed coating, the part (c) near the substrate is the same coating structure as the part (c) in Fig. 6. On the other hand, in the part (b) from the coating surface to $2/3t_c$ (t_c: coating thickness), the cell size becomes finer, forming a wider layer.

This layer (b) corresponds to the high hardness layer, which is shown in Fig. 5.

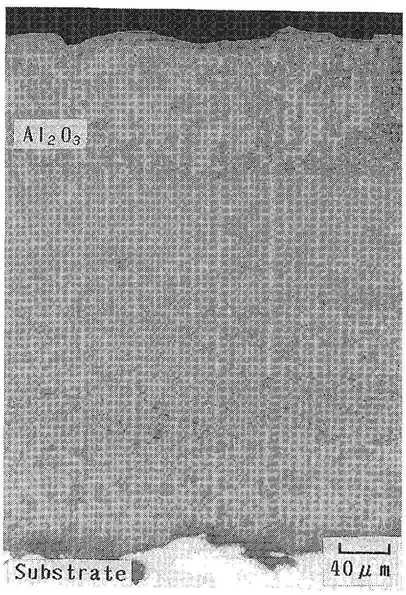


Fig. 6 Photograph of cross section of alumina coating at spraying distance L = 30 mm, when P = 20 kW.

In this case, however, the part (a) where the cell size is big which appears near the coating surface does not exist.

4. Conclusion

Vickers hardness of the ceramic coating is increased with zirconia and/or titania as the alumina powder. In these cases, the value of L_p was from 40mm to 50mm, which related to the plasma jet length.

Thus a higher Vickers hardness can be obtained in the case of "short distance spraying" ($L < L_p$), at each power input.

For example, Vickers hardness of alumina coating was H_V = 1500 at L = 30 mm, when P = 30 kW. Moreover, can be obtained the same characteristics of Vickers hardness with zirconia and/or titania as the alumina powder. In these cases, the value of L_p was from 40mm to 50mm, which related to the plasma jet length.

According to the measurement of the distribution of the Vickers hardness, these high hardness coating has a hardness layer near the surface. This high hardness layer is increased in the width and has a higher value of Vickers hardness in the case of large power input.

Observing the microstructure of alumina coating in this high hardness layer, it is found that the cell size is very fine compared with other parts of coating.

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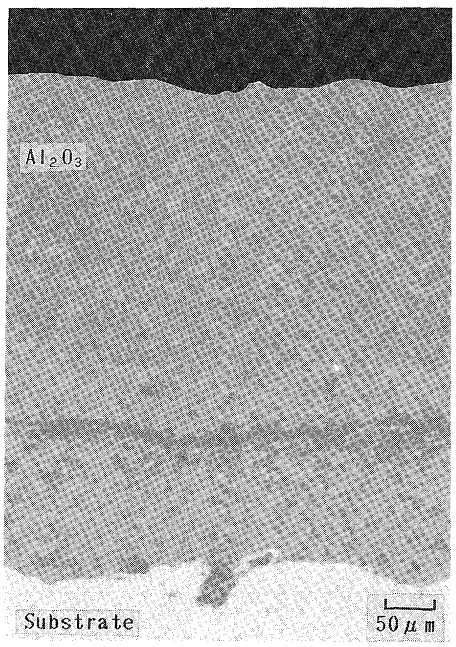

Fig. 7 Photograph of cross section of alumina coating at spraying distance L = 30 mm, when P = 30 kW.

Ministry of Education, Science and Culture.

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