Porosity Measurement of Ceramic Coating by Image Processing Method†

Akira KOBAYASHI*, Nobuyori BESSHO**, Setsu KURIHARA*** and Yoshiaki ARATA****

Abstract

For the porosity measurement of Ceramic coating, conventional method has rather complex procedure. On the contrary, the method by means of the image processing is easier to obtain the porosity and that it can offer a correcter value of the porosity.

The porosity of ceramic coating produced by gas tunnel type plasma spraying is rather small value: for example the porosity of alumia coating is less than 10%, and is increased as the power input is decreased.

KEY WORDS: (Porosity) (Image Processing) (Ceramic Coating) (Al_2O_3) (Gas Tunnel Type Plasma Spraying)

1. Introduction

It has been obtained high quality ceramic coatings with a gas tunnel type plasma spraying[1], as compared to conventional ceramic coatings[2]. For example, in the case of alumina coatings, high value of the Vickers hardness, $H_V = 1200$ has been achieved on their cross sections when power input to plasma jet is $P = 45$ kW[3].

The study on the mechanism of the formation of above ceramic coatings has been advanced. Then, the closeness of the coatings evaluated by means of the porosity in the coatings[4].

Then, the porosity in the cross section of the ceramic coatings, which is one of the factor of coating qualities, has been investigated in this paper. Especially, the measurement by means of an image processing was used instead of conventional method and the usefulness of this method is discussed.

And the characteristics of the porosity in the ceramic coatings, mainly alumina coating, with using gas tunnel type plasma spraying has been clarified.

2. Experimental Method

The gas tunnel type plasma spraying apparatus was developed by an application of high energy gas tunnel type plasma jet[5,6] to the thermal spraying. The detail and its properties have been already described in the previous papers[1,3,7].

Plasma spraying was carried out by this gas tunnel type plasma spraying apparatus in various spraying conditions, and was formed the ceramic sprayed coatings.

The porosity measurement of these sprayed coatings by means of an image processing was carried out by the method as follows. Here, we assumed that the black parts in the photograph of the cross section of coating were the pores. Then, the porosity was defined the percentage of the black parts for the total obserbing area of the coating.

The image processing system consists of the CCD camera, personal computer and image processor unit. This CCD camera is monochrome and high resolving power type, and divides the picture on its screen into 300 thousand pixels. The signals of all the pixels are respectively given the brightness of 226 stages (0–225). Then, if the proper threshold value is given, the binary image (black or white) is formed in the screen. As the results, the porosity is calculated by the ratio of black pixels against the total number of the pixels.

Figure 1 shows the photographs of the cross section of alumina coating formed by gas tunnel type plasma spraying respectively. This cross section is polished by the buff with alumina powder of 0.05μm size. The spraying condition is as follows, the power input is $P = 25$ kW, the spraying distance is $L = 100$ mm, the powder feed rate is 60 g/min. (a) is photograph by optical microscope and (b) is photograph by SEM (Scanning Electron Microscope).

Comparing both photos, it is found that the black parts of (a) shows good agreement with the pores in the photo of (b).

Here, (c) in Fig. 1 shows the figure which is after image processing of the microphotograph (a). And (d) shows 3 dimensional expression by this image processor. The

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* Associate Professor
** Graduate Student
*** Graduate Student (Present address: Sumitomo Heavy Industries, Ltd., Japan)
**** Professor, Kinki University

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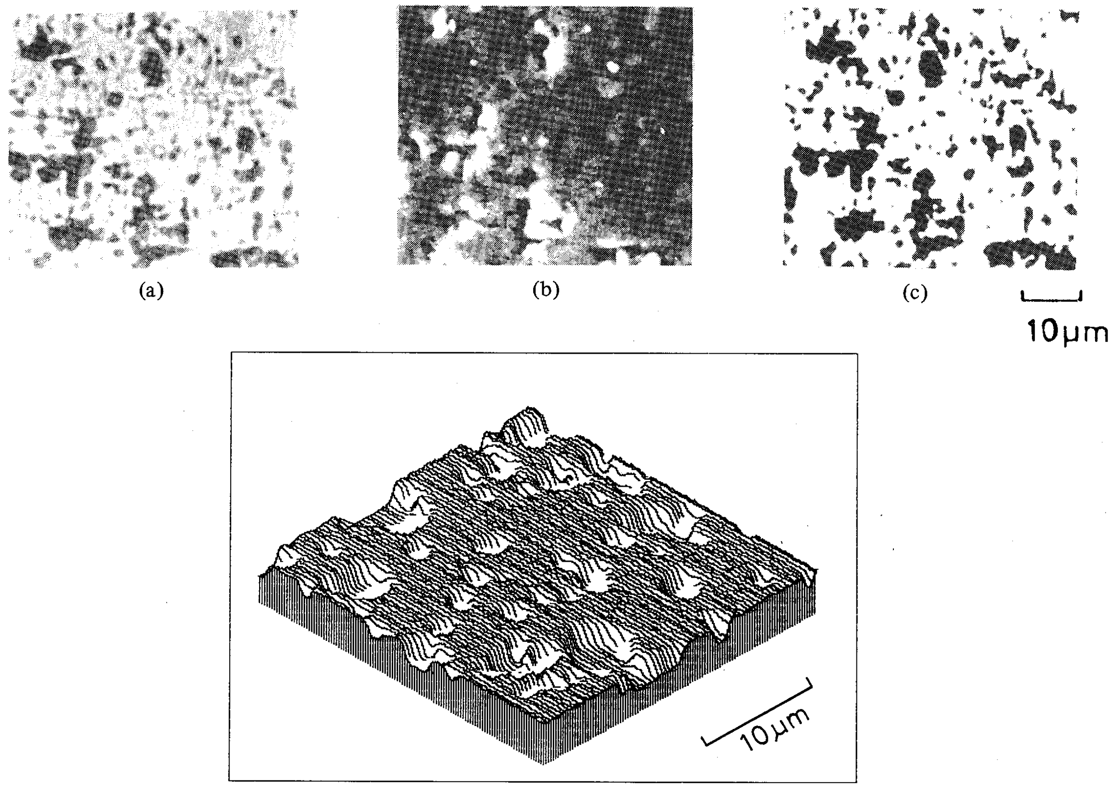


Fig. 1 Photographs of cross section of alumina coating.
(a) micrograph, (b) SEM, (c) after image processing, (d) 3 dimensional expression on the cross section

boundary of the pores can be clearly observed by such image processing. Then, the porosity can be easily calculated and decided.

For the conventional method such as water-saturation method and so on, the measurement of the porosity is carried out by means of virtual porosity. These pores almost pass through out to the surface of the coating, which are named the "open pores".

On the other hand, the porosity by means of an image processing shows the ratio of total pores including "close pores" in addition to the "open pores". As the result, with this method it can be possible to evaluate the pore of the coating, namely the closeness of the stracture, more accurately.

3. Results and Discussion

Figure 2 shows the cross sections of alumina sprayed coatings by the gas tunnel type plasma spraying, when the power input is 20, 30, 40 kW, on (a), (b) and (c) respectively. And (a′), (b′) and (c′) are after image processing of each microphotographs of (a), (b) and (c) respectively. In this case, the spraying distance was L = 100mm, and powder feed rate was 70g/min.

In the case of a large power input, it is found that the number of the pore is not only large, but also the size of the pore is small. The thickness of the coating is increased as the power input is increased.

Figure 3 shows the dependense of the porosity of alumina coating on the power input to plasma jet torch in the gas tunnel type plasma spraying. As the spraying condition, the spraying distance was L = 100mm. Ar gas flow rate was Q = 200l/min, and the powder feed rate was 80g/min.

The curve **a** in this figure shows the porosity obtained by means of the image processing. From this result, it is found that the porosity is decreased largely as the increasing power input.

Now, in order to compare with this method, the result of the porosity measurement by means of the conventional method is shown as the curve **b** in the same figure. As is found easily, both of the porosities **a**, **b** indicate a similar tendency (dependence on the power input). But, the porosity by the image processing method shows a little large values than the porosity by means of the conventional method, because of the reason mentioned above.

In the formation process of the sprayed coating, indivisual spraying particle collides into the substrate and deposits flatly to make the layer. Then the pore which has a different size and shape appears in the boundary of deposit particles.

In the case of large power input, the spraying particles maintain a good melting state during the flight, and the bonding among those particles is in good condition. Therefore, the pores are difficult to appear: the porosity in the coating is decreased with the increasing power input.

As the above result, the decrease in the porosity leads the closeness of the alumina coating which has a large bonding force. And consequently the mechanical property is improved better: the ceramic coating which has high Vickers hardness and good wear resistance can be obtained.

The porosity of alumina sprayed coating formed by the gas tunnel type plasma spraying was compared with the porosity of alumina sprayed coating formed by the conventional plasma spraying method, for the power input of P = 45 kW. For both cross sections of the coatings were carried out the image processing, and those photographs are shown in **Fig. 4**.

In this case, the spraying condition of gas tunnel type plasma spraying is the same as Fig. 3. The spraying condi-

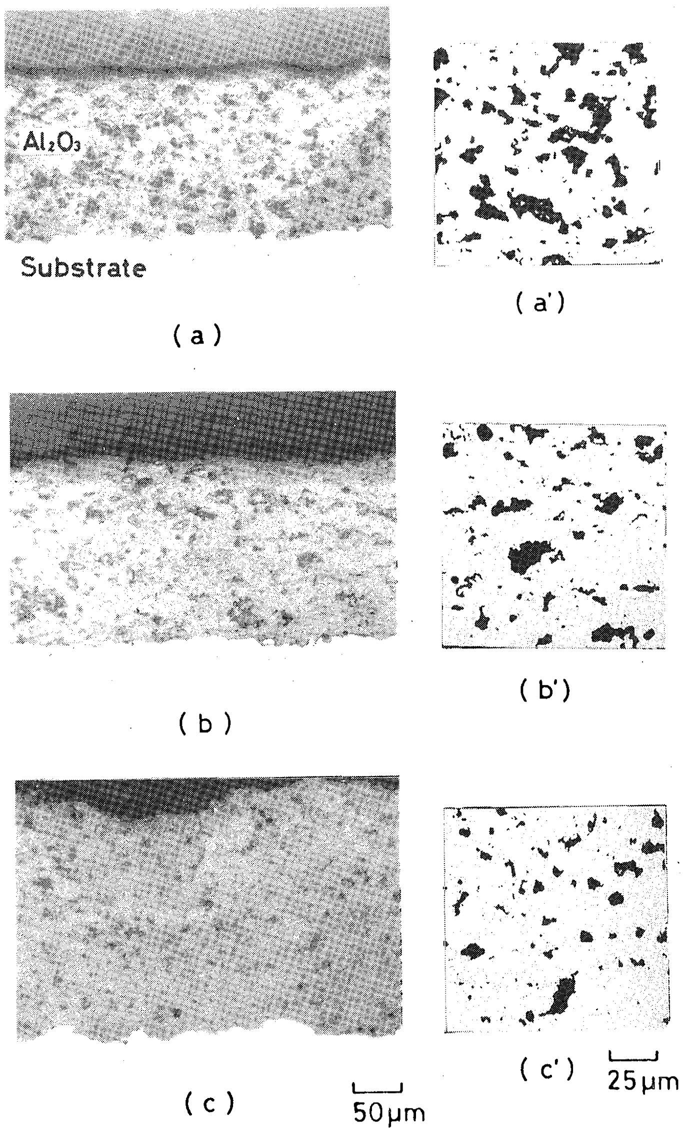


Fig. 2 Cross sections of alumina coatings.
(a) P = 20 kW, (b) P = 30 kW, (c) P = 40 kW,
(a'), (b'), (c') after image processing of (a), (b), (c) respectively.

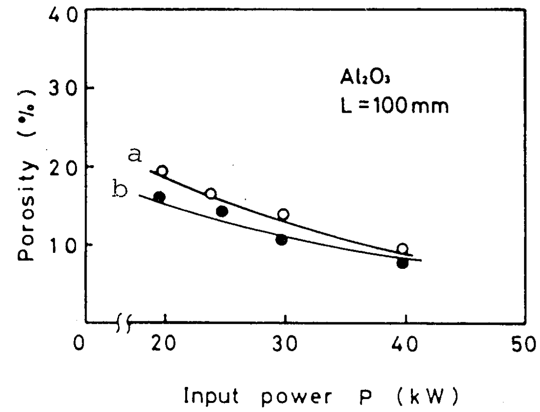


Fig. 3 Dependence of porosity of alumina coating on power input at L = 100 mm
a: image processing method
b: conventional method

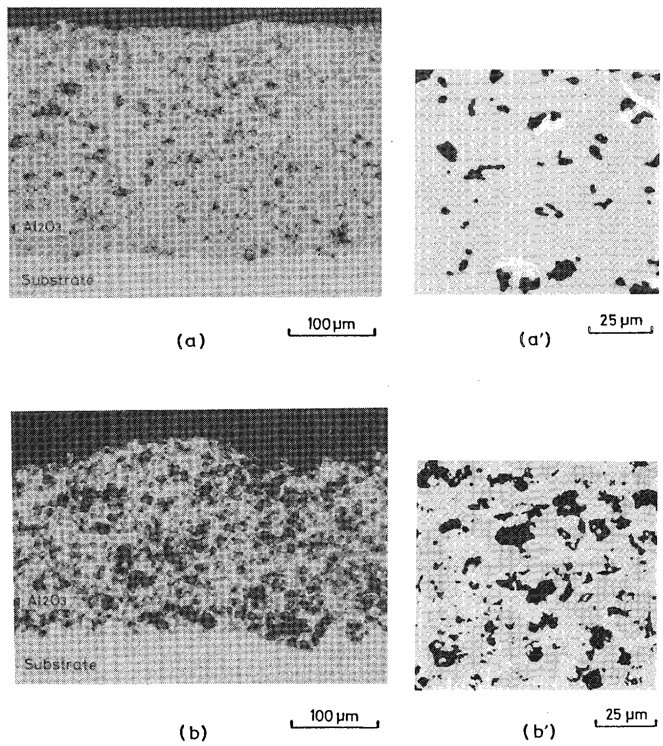


Fig. 4 Comparison of alumina coatings at P = 45 kW.
(a) gas tunnel type, L = 100 mm
(b) conventional type, L = 65 mm
(a') (b') after image processing

tions of conventional type was that the spraying distance was L = 65mm, working gas ($Ar:H_2$ = 9 : 1) flow rate was Q = 60 l/min, the powder feed rate was 6g/min.

Observing from the photographs of the cross sections of the alumina sprayed coatings in Fig. 4, the pore of the conventional sprayed coating has larger size and larger number than that of gas tunnel type sprayed coating.

For example, the mean area of the pore in the cross section of alumina coating is about 20μm^2 in the case of gas tunnel type and almost of the pore size is smaller than 100μm^2, on the other hand, the mean area of the pore is 80 ~ 100μm^2 in the case of conventional type plasma spraying, and exist the pore which is bigger size of 600μm^2.

Therefore, the porosity of the conventional sprayed coating is more than 20%, that is bigger than the porosity in gas tunnel type plasma spraying at each power input as shown in **Fig. 5**. And, this porosity of the conventional

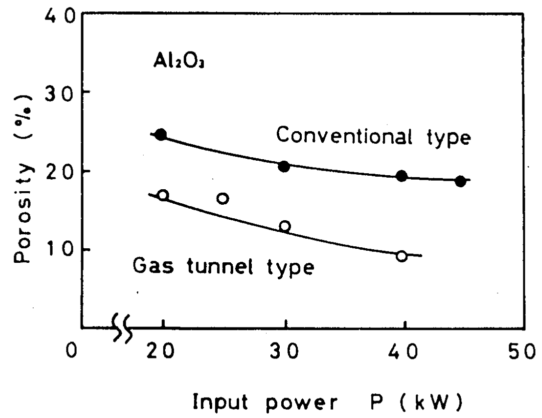


Fig. 5 Comparison of porosity of alumina coating between gas tunnel type and conventional type

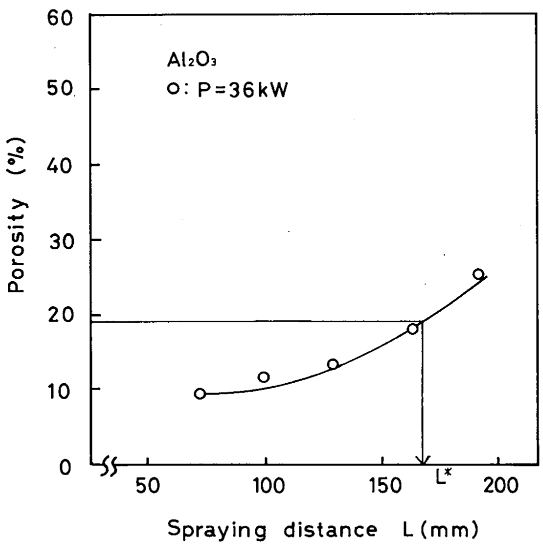


Fig. 6 Dependence of porosity of alumina coating on the spraying distance at P = 36 kW

ones is decrease as the power input is increased, but the decreasing rate is very small.

On the other hand, in the sprayed coating by the gas tunnel type plasma spraying the porosity is smaller than 20% at a lower level of power input. And the porosity is decreased with the increasing power input, and becomes very small value of 9% at P = 40 kW.

Figure 6 shows the dependence of the porosity of alumina sprayed coating on the spraying distance L, when the power input to the torch is P = 40 kW. This characteristic has been already described in the previous papers: as the spraying distance is increased, the porosity is increased. At this time the critical distance L^* is defined for the distance at which the porosity is a value of about 20%. In the region $L > L^*$, the porosity is more than 20%: this corresponds to the spraying distance where the circle deposit particles appear on the deposit characteristics of sprayed particles.

For the other ceramic coating except alumina coating, zirconia coating is formed by the gas tunnel type plasma spraying. **Figure 7** shows the photographs of cross section of zirconia coatings, (a) is formed by the gas tunnel type at P = 25kW, and (b) is formed by the conventional type at P = 28kW. The spraying distance is both 80mm.

From the photograph of the cross section of zirconia coating, similarly as the case of alumina sprayed coating,

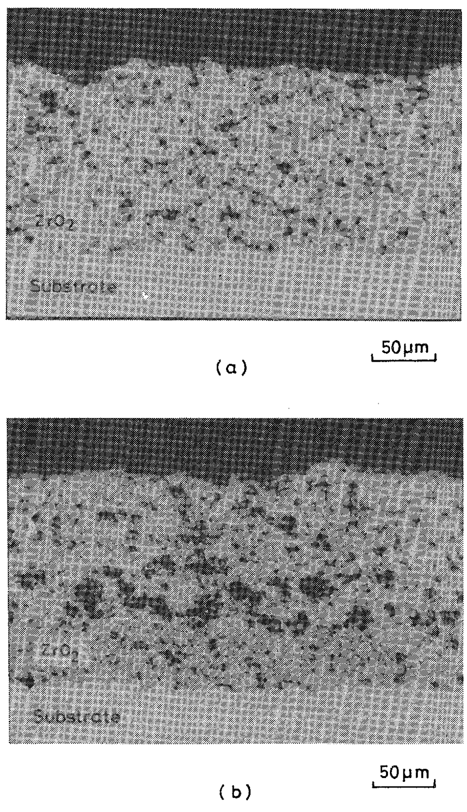
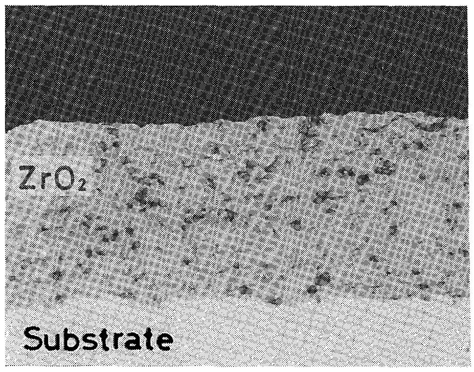
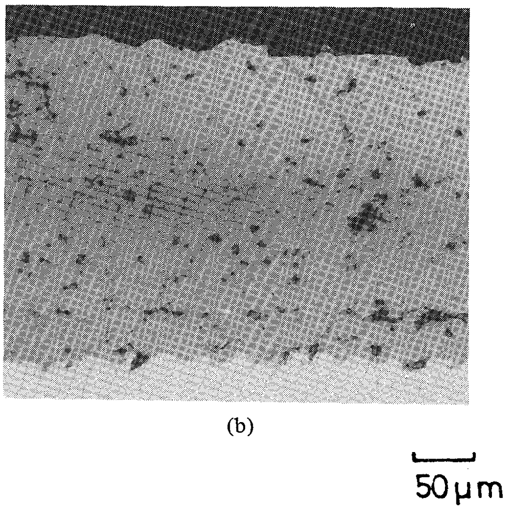


Fig. 7 Comparison of zirconia coatings at L = 80 mm
(a) gas tunnel type, P = 25 kW
(b) conventional type, P = 28 kW



(a)



(b)

Fig.8 Cross sections of zirconia coatings at L = 60 mm
(a) P = 20 kW, (b) P = 32 kW

the pore of the conventional sprayed coating has large size and large number as compared to gas tunnel type prasma sprayed coating.

Figure 8 shows the microphotographs of the cross sections of zirconia sprayed coatings by the gas tunnel type plasma spraying, when the power input is 20, 32 kW, on (a) and (b) respectively. In this case, the spraying distance was L = 60mm, and powder feed rate was 80g/min.

In the case of a large power input, it is found that the number of the pore is not only small, but also the size of the pore is small, as well as the case of alumina sprayed coating.

Figure 9 shows the dependence of the porosity of zirconia sprayed coating on the spraying distance L, when the power input to the torch is P = 32 kW. As the spraying distance is increased, the porosity is increased. In this case the critical distance L^* is about 94 mm, at which the porosity is a value of 13%. In the region $L > L^*$, the porosity is increased extreme with the increasing spraying distance.

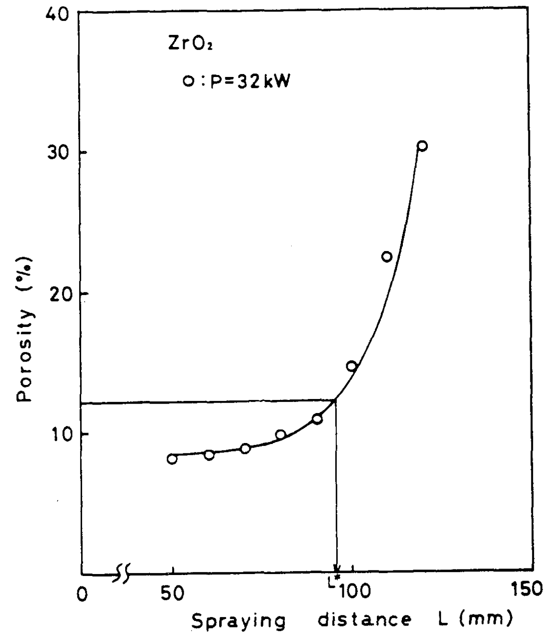


Fig. 9 Dependence of porosity of zirconia coating on the spraying distance at P = 32 kW

4. Conclusion

According to the measurement of the porosity by the image processing emthod, the property of the sprayed coating formed by the gas tunnel type plasma spraying has been clarified in detail.

The porosity of alumina sprayed coating is lower than 20% and is decreased as the increasing power input. At P = 40 kW, the porosity becomes less than 10%. This value of gas tunnel type sprayed coating is smaller than that of the conventional one. In zirconia sprayed coating, the similar results as alumina coating can be obtained.

The porosity measurement by the image processing is easier than the conventional method and it can be obtained correcter value. As the result, this method may be one of the useful methods of the porosity measurement of the ceramic coating.

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