Properties of metallic glass coatings sprayed by gas tunnel type plasma spraying†

KOBAYASHI Akira *, KURODA Toshio *, KIMURA Hisamichi **, and INOUE Akihisa ***

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1. Introduction

Metallic glass is one of the most attractive advanced materials because it has excellent physical and chemical functions such as high strength and corrosion resistance [1]. Therefore many researchers have engaged in various developmental research works. However, as the metallic glass material is expensive, the application for small size parts has been carried out only in some industrial fields. In order to widen the industrial application fields, a composite material is preferred for the cost performance. In the coating processes of metallic glass with the conventional deposition techniques such as plasma sputtering, there is a problem of the difficulty of obtaining thick coatings because of their low deposition rate. Thermal spraying is one of advantageous methods to produce metallic glass composites for easy operation.

The gas tunnel plasma spraying is the besk technology for high quality ceramic coatings [2-4]and synthesizing new functional materials [5], because the plasma jet has a high-speed and a high-energy density under a controlled operating condition [5]. By gas tunnel plasma spraying, metallic glass coatings can be formed on stainless steel substrates by using Fe-based or Zr-based metallic glass powder [7,8]. The proper conditions for high quality metallic glass coatings have been clarified from those experimental results.

In this study, a Ni-based metallic glass coating was also formed by the gas tunnel plasma spraying, and the microstructures and surface morphology of the different metallic glass coatings were observed by using a scanning electron microscope (SEM). Those results were compared to Fe-based and Zr-based metallic glass coatings.

2. Experimental

Ni-based metallic glass powder ($Ni_{60}Nb_{20}Zr_{20}$) was used in this study. This powder was atmospherically plasma sprayed (APS) on a flat 304 stainless-steel substrate by a gas tunnel type plasma spraying torch as shown in **Fig. 1**. Ni-based metallic glass powder was externally fed into the plasma flame from the exit of gas divertor nozzle, in order to melt the metallic glass powder effectively.

Experiments were carried out under the spraying conditions shown in **Table 1**. The plasma torch was operated at power levels up to P = 20kW and the arc current was changed I = 100-350 A. The plasma jet was generated with the aid of argon working gas supplied at Q = 200 l/m. The torch was maintained at a spray distance of L = 40 mm from the substrate surface. The powder feed rate was about 7 g/min. The stainless steel substrate was traversed at N =16 times during the spraying time of t =24 s.

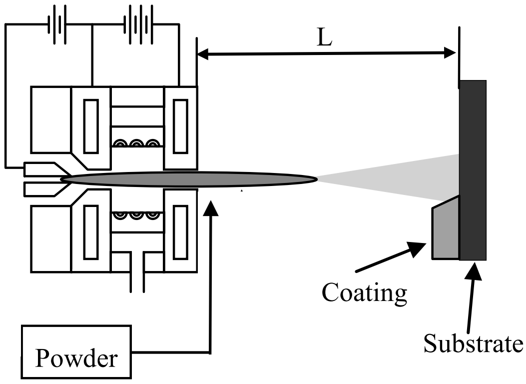

Fig. 1 Gas tunnel type plasma spraying used in this study. (L=spraying distance).

Microstructure of the Ni-based metallic glass coatings was observed by using a scanning electron microscope (SEM). The surface morphology of the feedstock powder and the metallic glass coating cross-section was also examined by a scanning electron microscope.

Table 1 Spraying conditions.

Arc current	100-350A
Voltage	40-50V
Spraying distance	40 mm
Working gas flow rate (Ar)	200 l/min
Powder feed gas flow rate(Ar)	10 l/min
Powder feed rate	7 g/min
Traverse number	16 times
Spraying time	24 s

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* JWRI, Osaka University, Ibaraki, Japan
** Welding Company, Rokko Steel, Ltd., Kobe, Japan
*** Tohoku University, Sendai,, Japan

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The phase constituents of metallic glass coating were identified by using a X-ray diffractmeter (XRD) system with CuKα radiation source at voltage of 40 kV and current of 40 mA. Obtained results were also discussed and compared to Fe-based and Zr-based metallic glass coatings.

Vickers microhardness measurement was made on the coating cross section by using a load of 100g. Indentation parameters were set as 20s loading time.

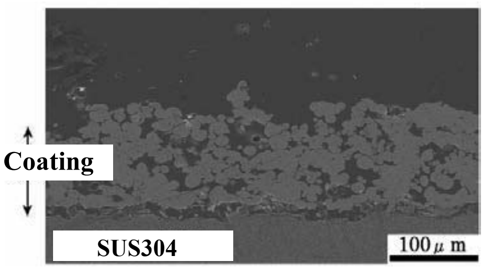
Regarding **t**he Ni-based metal glass powder used in this study, the size of powder was 10-25μm, and it was spherical type. (Average diameter is 18μm.)

3. Results

Microstructure of the metallic glass coating

Figure 2 shows the SEM micrographs of the cross-section of Ni-based metallic glass coatings sprayed at different plasma spraying current of *I*=100A and *I*=300A, at *L*=40mm.

There are some large pores in the Ni-based metallic glass coating at a low current of 100A in Fig. 2(a). The coating thickness increased with increase in the plasma current and it was more than 200 μm at 300A which is shown in Fig. 2(b). In this case, the coating was much denser on the cross section of surface side and it was rather lower porosity than that at 100A as shown in **Fig. 3**(a). The bonding condition between the coating and the substrate seemed good.



(a) 100A

(b) 300A

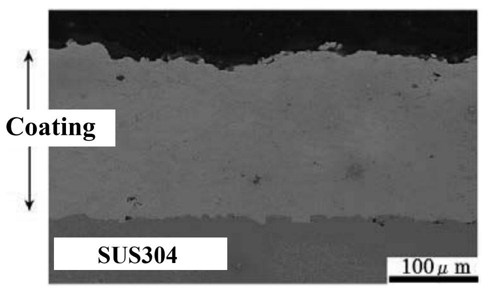
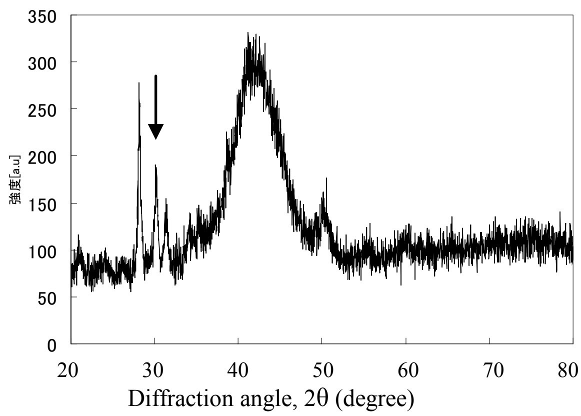


Fig. 2 SEM micrographs of the cross-section of the Ni based metallic glass coating sprayed at 100A and 300A, on the 16 times traversed substrate.

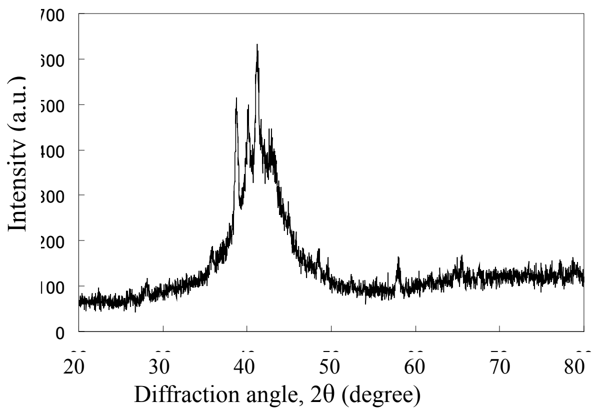
Crystallie structure of the metallic glass coating

The XRD pattern from the surface of the metallic glass coating at 300A which is shown in Fig. 2(b) is shown in Fig. 3(a). For comparison, the XRD pattern of Ni-based metallic glass powder used is shown in Fig. 3(b). The broad amorphous phase (Phase center is about 42 degree) was observed in this pattern. But the XRD pattern has some crystalline peaks corresponding to some other compounds of Ni, Nb, Zr, etc. shown in Fig. 3. Ni crystalline peak was recognized as shown in this figure. This means that the powder was not a perfectly amorphous phase and it contains some metal or oxidation phase.

These crystalline peaks near 40 degree were suppressed and disappeared on the metallic glass coating at 300A. The broad amorphous phase was clearly observed in the pattern which is shown in Fig. 3(a). There were some new peaks related to Ni, Nb, Zr, etc. at different diffraction angles of the XRD pattern. Two crystalline peaks near 30degree and 50degree were recognized as the peaks from Zr oxide phase. When the metallic glass powder is injected into the plasma jet, particles under high temperature conditions are heated and may be simultaneously decomposed. So, there is the large possibility of the crystalline peaks, and peaks of



(a) Coating at 300A



(b) Powder

Fig. 3 XRD patterns of the Ni-based metallic glass coating sprayed on stainless-steel substrate (a) and Ni-based metallic glass powder (b).

other oxidized materials, but there were no peaks from Ni, Nb, Zr detected in this XRD pattern.

4. Conclusions

The Ni based metallic glass sprayed coating in thickness of more than 200 μm with Hv_{100}= 700, was obtained at 300A by gas tunnel type plasma spraying. The coating thickness depends on the spraying parameters. Ni-based metallic glass particles had some decomposition of amorphous phase and/or oxidation (ZrO_2) during deposition at high plasma current above 350A.

References

[1] A. Inoue, B.L. Shen and H.M. Kimura: J. Metastable Nanocrys. Mater., 20-21 (2004), pp.3-12.
[2] Y. Arata, A. Kobayashi and Y.Habara: J. Appl. Phys., 62-12, (1987), pp.4884-4889.
[3] A. Kobayashi: Surface and Coating Technology, 90 (1990), pp.197-202.
[4] A. Kobayashi, T. Kitamura: Vacuum, 59 (2000), pp.194-202.
[5] A. Kobayashi: Weld.International, 4 (1990), pp.276-282.
[6] Y. Arata and A. Kobayashi: J. Appl. Phys., 59 (1986), pp.3038-3044.
[7] A. Kobayashi, S. Yano, H. Kimura and A. Inoue: Surface and Coating Technology, 202 (2008), pp.2513-2518.
[8] A. Kobayashi, S. Yano, H. Kimura and A. Inoue: Frontier of Applied Plasma Technology, 1 (2008), pp.47-50.