Fusing of Sprayed Ni-base Coatings by Induction Heating†

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Abstract

In this research, the optimum temperature for induction fusing of Ni-base alloy coatings was studied, and the properties and microstructures of coatings were investigated. The properties were also compared with those of coatings that were fused with either an oxy-acetylene flame or in a furnace. A temperature range from 1323 K to 1343K was the optimum condition for induction fusing. Induction fusing at this temperature achieved the following properties ; a coating hardness of up to 800Hv, and coatings that were denser and with a smoother surface than those fused with flames or in a furnace.

KEY WORDS :(Flame spraying)(Ni base alloy coating)(Induction heating)(Fusing)

1. Introduction

Self-fluxing alloy coatings are used in various machine parts, such as in facilities for metal and petrochemical industries, because of their excellent corrosion resistance, heat resistance and abrasion resistance. The as-sprayed coatings are porous and mechanically adhere to the base metal. Fusion treatment enables removal of pores and the production of a metallurgical bond at the interface. [1)]

The fusing of self-fluxing alloy coatings is performed by flame heating, furnace heating or induction heating. Presently, flame heating (with oxy-acetylene flame) is most widely used.

However, in flame fusing, the properties of fused coatings, especially the uniformity and reliability of the quality of products, depend greatly on the worker's experience and skill. Further, in the case of large products such as rolls of large size, productivity as well as working environment may become a problem with the flame fusing process.

On the other hand, with fusing by induction heating, uniform and reliable treatment may be achieved by the establishment of standard optimum conditions. This is particularly the case for large products, where induction heating may be applied to greatly improve the properties of coatings.

In this research, the mutual relations among spraying conditions, fusing methods and coating properties were investigated to establish the optimum fusion conditions investigated to establish the optimum fusion conditions by an induction heating method.

2. Materials and Expermental procedures

Carbon steel rods of 600mm length and 22mm diameter were used as a base metal. They were alumina grit blasted and flame sprayed using nickel base self-fluxing alloy (METCO 16C). Individual specimens were 50mm in length. **Table 1** shows the chemical compositions of METCO 16C. **Table 2** shows the flame spraying conditions. Powder feed rate was changed in the spraying conditions.

Figure 1 shows a schematic diagram of the induction fusing process. A stationary induction heating was used for the fusing operation and the heating temperature was controlled by an on-off power regulation. The temperature was measured with a thermocouple buried into the substrate near its surface, as shown in **Fig. 1.**

Table 3 shows the conditions of induction heating, using a frequency of 2 kHz. The input power was varied between 15 kw and 50 kw to obtain the desired temperatures.

3. Results and Discussion

3-1. Optimum Conditions for Induction Fusing

Figure 2 is of the estimated curve of the temperature gradient from the coating surface to the center of the substrate. Since the coating has no iron content, and is partially porous, it is not directly heated by induction.[2)]

Rather, it is indirectly heated by the substrate, while natural radiant heat loss causes cooling of the coating surface. A temperature difference exists across the coating thickness, with the temperature gradually dropping towards the coating surface.

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Table 1 Typical compositions of METCO 16C

Ni	Cr	B	Si	Mo	Fe	C	Cu
Bal.	16.0	4.0	4.0	3.0	2.5	0.5	3.0

Table 2 Flame splaying conditions

Operation gas	O_2	0.22 MPa, 45 ℓ/min.
	C_2H_2	0.10 MPa, 28 ℓ/min.
Powder feed rate	38, 76, 153 g/min.	
Spraying distance	205 mm	
Coating thickness	1.5 mm	

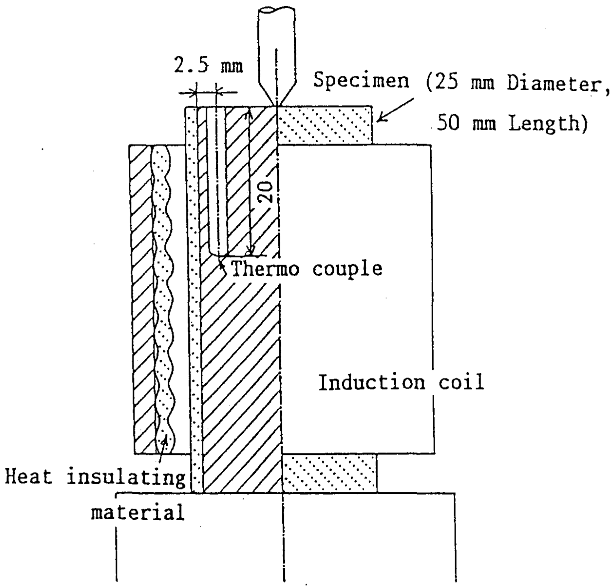

Fig. 1 Schematic diagram of the induction fusing process

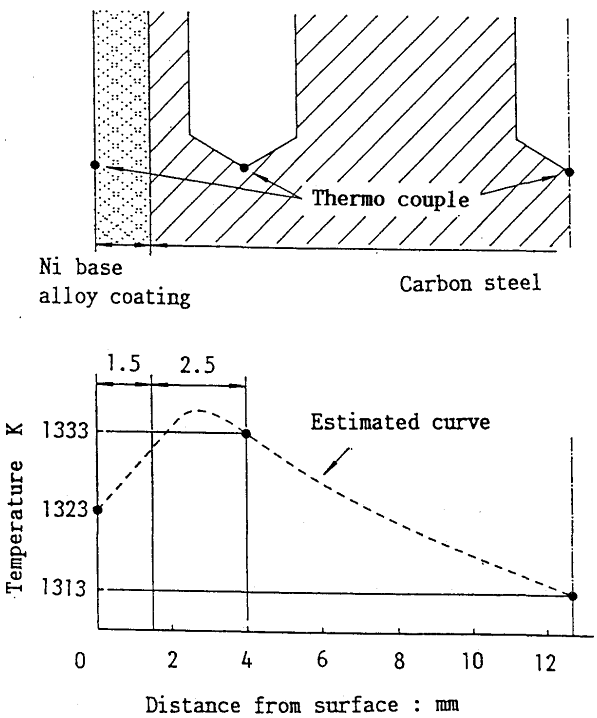

Fig. 2 Schematic diagram of the temperature gradient

Table 3 Induction fusing conditions

Frequency	2 kHz
Input Power	15 kW～50 kW
Temperature	1273 K～1413 K
Holding time	60 s

From this result, if the "wet shine"[3] appearance of the coating surface is relied on the optimum condition, as practiced in the flame fusing, the coating will be led to over fusing at the interface in the induction heating method. Therefore, an optimum temperature for induction fusing must be established to manufacture the optimum coating.

Figure 3 shows the relation between the fusion temperature and the coating properties .The coatings used for induction fusing were obtained by flame spraying at a powder feed rate of 76g/min. with the conditions shown in **Table 2.**

Figure 3 (a) shows the surface roughness (Ra) change with respect to the temperature. The Ra decreased with an increase of temperature, a minimum Ra of 5 μ m was achieved at 1333K. Above this temperature, the Ra gradually increased with increasing temperature. The coating began to melt at 1413K.

Figure 3 (b) shows a similar result for the hardness in cross section (H_V) . Coating hardness increased with increasing temperature until a maximum hardness of about 800H_V was obtained at 1353K. Above this

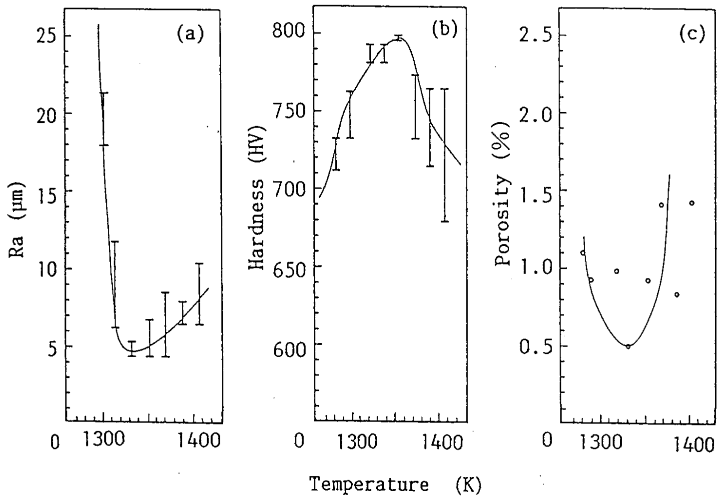

Fig. 3 Relation between the maximum temperature and coating properties

temperature, the hardness decreased with an increase of temperature. Generally, a hardness of above 750H_V can be maintained using temperatures from 1313K to 1353K.

Figure 3 (c) shows a similar result for the porosity of the coatings. Though the porosity varied widely, it was below 1.0% at temperatures between 1293K and 1353K. A minimum porosity of 0.5% was achieved at 1333K.

From these results it can be established that the optimum temperature to obtain the smoothest, hardest and densest coating is from 1333K to 1353K.

As was stated previously, the temperature was measured near the surface of the substrate, Fig. 1. Generally, however, the temperature of the coating surface is measured with a pyrometer, and the surface temperature is about 10K lower than that of the substrate sub-surface, as shown in Fig.2. Therefore, the optimum temperature of the coating surface is determined as being from 1323K to 1343K.

Figure 4 shows etching microstructures. A diffusion zone was formed at the interface during fusing. This diffusion zone became thicker with an increase of temperature. In the case of an over fused coating, the diffusion zone was excessively thick. Also a carbon rich layer in the substeate became thicker with increasing temperature.

Figure 5 shows the SEM micrographs of the interface between the induction fused coating and substrate. In the diffusion zone, an absence of chromium was observed.

Next, the effects of spray conditions on coating properties were investigated. Here, the powder feed rate was varied using of 38, 76 and 153 g/min..

Figure 6 shows the relation between the powder feed rates and coating properties after induction fusing. The surface roughness increased with an increase of the powder feed rate. The hardness was not greatly affected

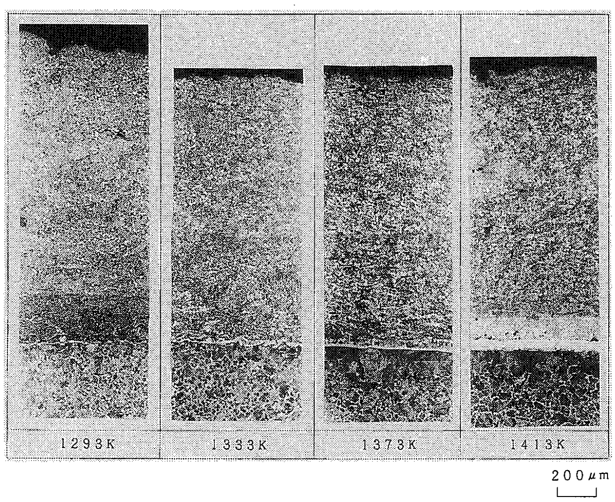

Fig. 4 Microstructures of induction fused coatings(micro etching)

by the powder feed rate. The average hardness was about 750H_V. An increase of powder feed rate led to an increase of porosity. Coating properties were improved with decreased powder feed rate.

Figure 7 shows the coating properties of the three types of fusing methods. The three fusing methods that were investigated were induction, oxy-acetylene flame and furnace fusing. Induction fusing was done under optimum conditions (1333K × 60s). The flame fusing was performed by observing the change of the coating surface with respect to the "wet shine[3]". An electric furnace at 1333K was used. (250mm diameter, 200mm height) The Ni-base coatings used for such fusing were flame sprayed under constant parameters.

The Ra of induction fusing and flame fusing were

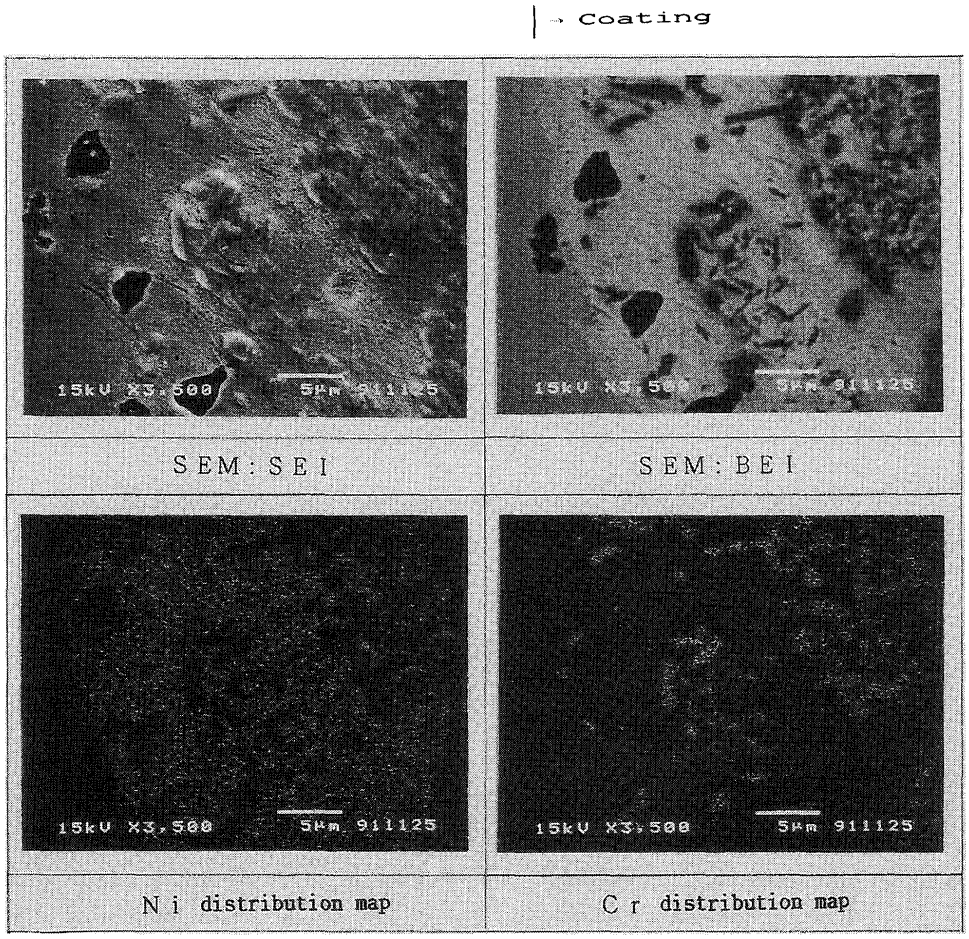

Fig. 5 SEM micrographs and scanning images of induction fused coatings (1333K)

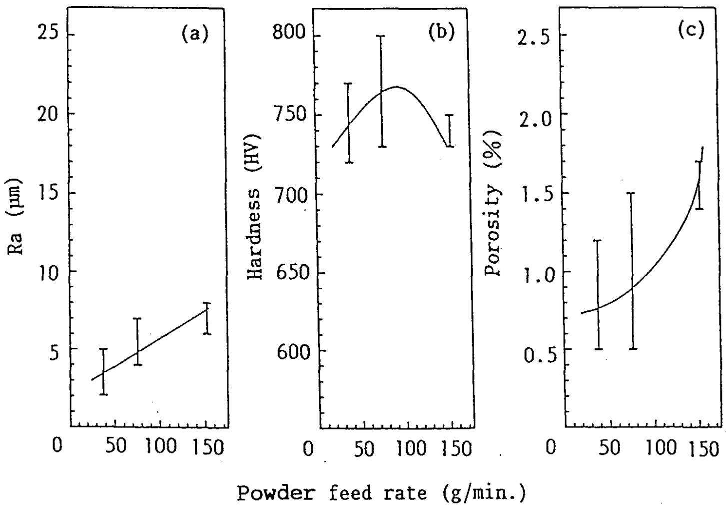

Fig. 6 Relations between powder feed rates and coating properties

about 5 μm, while that of furnace fusing was above 10 m. The hardness of induction fusing was about $750H_V$, when that of flame fusing was $700H_V$, and that of furnace fusing was only $650H_V$. The porosity of induction fusing was a little better than other methods.

From these results the coatings obtained by induction fusing were smoother and denser than those produced by flame and furnace fusing.

With induction fusing, carbides appeared finely and uniformity distributed. This can be attributed to the shorter period of heating required in the induction process. For this reason, it can be concluded that induction fused coatings are harder than those of the other methods.

3-2. Application of Induction Fusing

A roll of 1400 mm length, 250 mm diameter and 70 mm wall thickness was flame sprayed with a Ni-base alloy. After flame spraying, the roll was treated by induction fusing with a dynamic method. Figure 8 shows the appearance during induction fusing. In this dynamic treatment method, the coil moved along the roll. The surface temperature during induction fusing was measured with a pyrometer, and was maintained between 1323K and 1343K. The process time was reduced, and the working environment was improved by induction fusing. Also, uniform coating properties were obtained using the optimum temperature. Figure 9 shows the appearance of the roll after induction fusing.

It can be concluded that induction fusing is particularly effective in treating large or long items.

4. Conclusions

The optimum conditions for induction fusing were investigated to produce the smoothest, hardest and densest coatings of Ni-base alloy. Then, the coating properties for induction fusing were compared with those of flame fusing or furnace fusing.

The results obtained are as follows;

1. The optimum surface temperature for induction fusing is from 1323K to 1343K.
2. On induction fusing with the optimum conditions, the coating becomes denser and smoother than those of flame fusion or furnace fusing, and the coating hardness is up to $800H_V$.
3. The application of induction fusing to large and long products enables shorter processing times and a more favorable working environment.

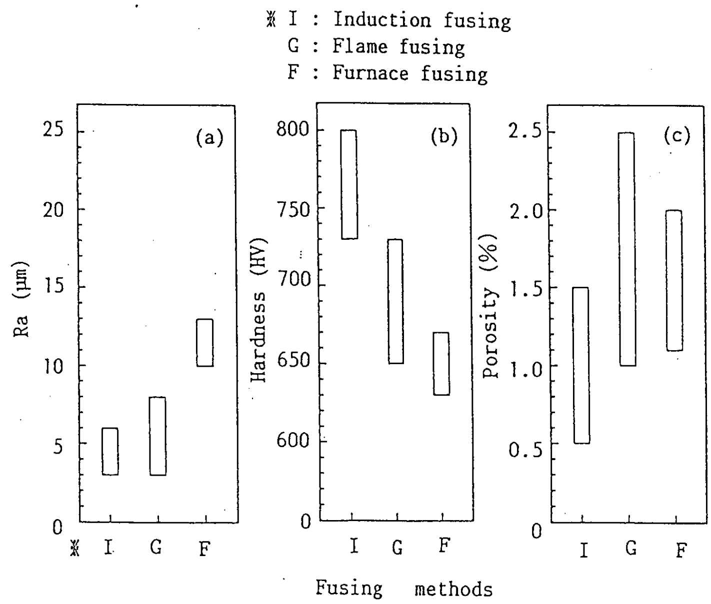

Fig. 7 Relations between fusing methods and coating properties

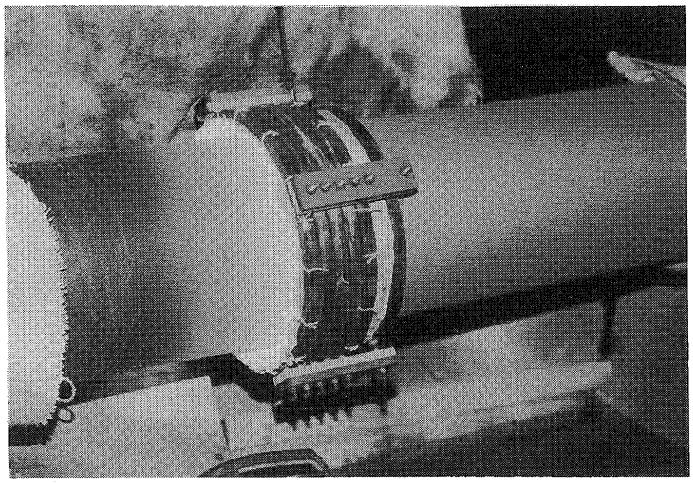

Fig. 8 Appearance of the induction fusing

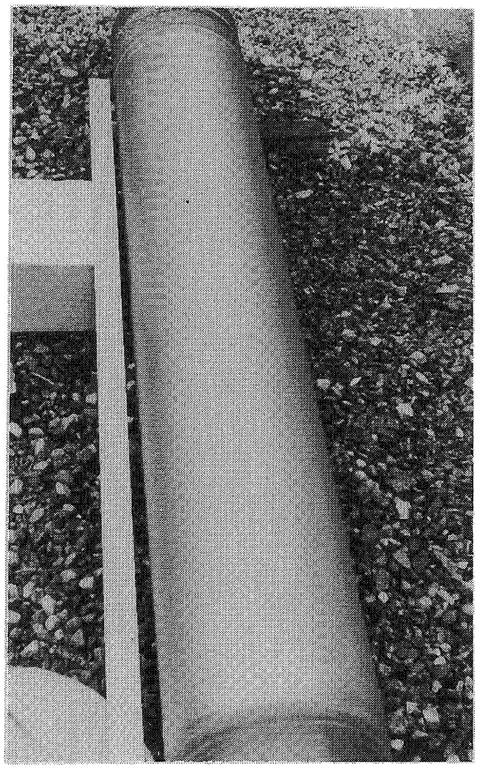

Fig. 9 Appearance of the roll after induction fusing

References

1) H. G. Schafstall and P. Szelogouski, "Flame Sprayed Surface for Corrosion Protection of Offshore Structures", Proc. ITSC'80, (1980) 171, Essen
2) M. G. Lozinskii, "Industrial Applications of Induction Heating", Copyright; Pergamon Press Ltd., 1969
3) G. Welwich and A. Wilwerding, "Economical Hard Surfacing by Flame Spraying and Flame Fusing of Metal Powders", Proc. ITSC'80 (1980) 129, Essen