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TECHNICAL NOTE

Application of 500kV Ultra High Voltage E.B. to Surface Modification of Carbon Steel†

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KEY Words: (High Voltage Electron Beam)(Surface Modification)(Carbon Steel) (Ni-Cr Alloy)

1. Introduction

Recently, high accuracy, high efficiency and energy saving welding technology has been required, not only for large scale structures such as ships, aircraft and nuclear vessels but also for micro-structures such as IC and electronic parts. One of the solutions is to utilize electron beam heat sources. Electron beam heat sources can direct any required energy density and power into materials, enabling very narrow and deep penetration welding reducing heat distortion and welding defects such as cracking.

At the Research Center for Ultra High Energy Density Heat Sources, JWRI, the "500 kV Ultra High Voltage Electron Beam Heat Source" is being developed. 500 kV accerelated electrons can penetrate 0.2 mm into iron specimen, converting their kinetic energy to thermal energy along this distance. This thermal energy immediately heats and melts the specimen. This penetrating effect is a special characteristic of electrons accerelated to near light speed and the laser beam does not have such characteristics. In this report, surface modification of carbon steel is described following the application of this penetrating effect of 500 kV electrons. The alloy powder on SK4 carbon steel plates was melted immediately by penetrating electrons inside the powder. An alloy surface layer with reduced defects was obtained on carbon steel plates.

2. Experiments

500 kV electrons, accerelated by an 11 stage electromagnetic accerelating unit, were defocused by a 2 stage magnetic lens to a round beam shape of 4 - 7 mm in diameter at the surface of the specimen inside the vacuum working chamber. 80%Ni-20%Cr alloy power for thermal spraying was used to provide alloying elements. Its physical characteristics are shown in **Table 1**.

Table 1 Caracteristics of 80%Ni-20%Cr powder.

P.M.	Melting point (K)	Typical size range (μm)	Hardness (R_B)	Density (g/cm^3)
80%Ni -20%Cr	1673	40～70	90	7.5

The electron beam current, I_b, was 0.7 - 1.4 mA (beam power W_b was 350 - 700 W), beam scanning speed, v_b, was 0.75 - 1.0 mm/s, and gas pressure was 10^{-2} Pa. In order to homogenize the energy density profile, a special beam forming slit of tungsten was used. An illustration of beam irradiation and bead formation are shown in **Fig.1**. Bead shape was observed and hardness tests and EPMA examination were conducted on cross sections of the bead.

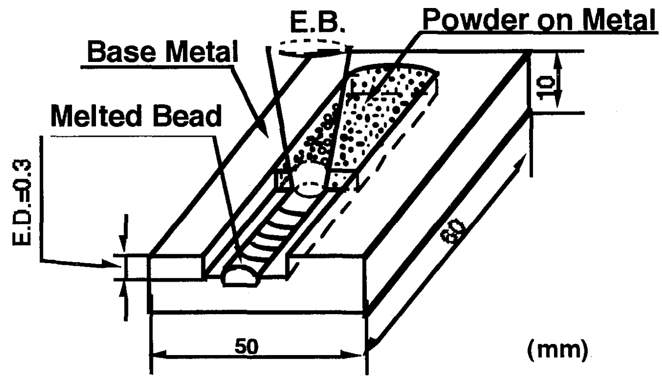

Fig.1 Illustration of melted bead formation.

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3. Results

An example of the cross section of a melted bead is shown in **Fig.2**. Beam current, I_b, was 1.2 mA, welding speed, v_b, was 1.0 mm/s and the thickness of the Ni-Cr alloy powder was 0.4 mm. The thickness of the melted part on the bead cross section is 0.5 mm and the bottom of the bead shape is flat. **Figure 3** shows Vickers hardness distributions along the bead center for melted beads of I_b=0.9 and 1.4 mA. The Vickers hardness is 200 at I_b=0.9 mA and 250 at I_b=1.4 mA. This is caused by the difference in the concentration of base material in the alloy layer, because the thickness of the melting bead h_p is 0.3 mm at I_b=0.9 mA and 0.6 mm at I_b=1.4 mA. Quantitative analysis by EPMA is shown in **Table 2**. Beam condition was I_b=0.9 mA, 1.2 mA and v_b=1.0 mm/s. Measurement positions are at 50mm depth from the surface, at the center and at 50mm depth from bottom. In the case of I_b=0.9 mA, there is little change in Ni and Cr concentration in the melted beads, however, in the case of I_b=1.2 mA the concentrations of Ni and Cr decrease and Fe concentration increases with depth. This is because the thickness of the melting bead increases from 0.3 mm at 0.9 mA to 0.5 mm at 1.2 mA.

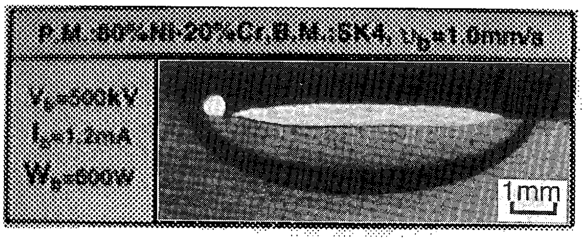

Fig.2 Cross section of melted bead.

4. Conclusions

An alloy surface layer with homogenized distribution of alloying elements was obtained by using a high voltage electron beam with energy density control together with Ni-Cr alloy powder for thermal spraying. There was little spattering of materials during electron beam irradiation and no porosity inside the melted layer. The feasibility of high quality surface modifications using the high voltage electron beam was demonstrated.

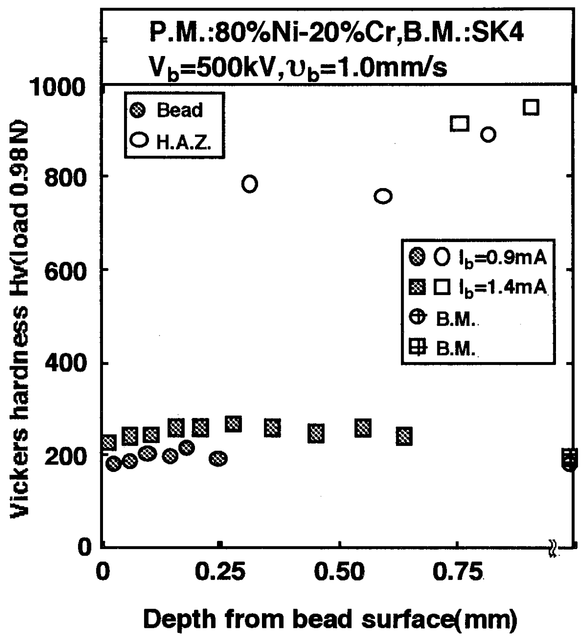

Fig.3 Hardness distribution of HAZ and bead section.

Table 2 Result of EPMA analysis for bead element.

P.M.:80%Cr-20%Ni,B.M.:SK4,P.T.=0.3mm											
$υ_b$=1.0mm/s I_b=0.9mA W_b=450W						$υ_b$=1.0mm/s I_b=1.2mA W_b=600W					
	Compositions of bead (mass%)						Compositions of bead (mass%)				
	Ni	Cr	Fe	C	Total		Ni	Cr	Fe	C	Total
●	49.8	12.1	33.8	0.8	96.5	●	43.8	9.5	44.0	1.1	98.4
◍	49.9	11.3	35.4	0.9	97.5	◍	42.5	9.1	46.9	1.2	99.7
⊘	47.6	12.0	37.1	1.0	97.7	⊘	35.5	7.7	55.2	0.9	99.3