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Formation of stainless steel layer on mild steel by welding arc cladding

T. ISHIDA
Advanced Materials Division, KRI International Inc., Kyoto Research Park, 17 Minamimachi, Chudoji, Shimogyoku, Kyoto 600, Japan

The discrete microstructural characterization and the formation of stainless steel layer on mild steel where produced in cladding deposits, and fusion boundary region were investigated using tungsten inert gas (TIG) arc, high current pulsed arc and constricted plasma arc. The experimental procedure involved making bead-on-plate method for controlled travel speed, employing filler metal by using tungsten inert gas arc, pulsed current gas tungsten arc and transferred plasma arc, with subsequent sectioning and examination of the reaction interface. For TIG arc cladding, using filler metal of small diameter the deposit does not become stainless steel, but on using 3.2 mm diameter filler metal it becomes stainless steel with less than 50% dilution. For pulsed arc cladding, the complete stainless steel is not obtained on account of the existence of an incomplete mixture, particularly at the fusion boundary region. However, on using a large diameter filler metal at a pulse frequency of 500 Hz, the complete stainless steel microstructure has been accomplished. The plasma arc cladding can be achieved in such a way that the conversion into stainless steel on the mild steel surface – which is the microstructures of cellular austenite in cladding deposit and cellular dendritic austenite containing δ or σ-phase in fusion boundary region – is possible irrespective of the melt penetration and the dilution. The following conditions were found to be beneficial for the formation of stainless steel microstructure layer on the mild steel: using large diameter filler metal, below 50% dilution, and further rendering arc localized and constricted.

1. Introduction

A great deal of attention has recently been drawn to selectively modifing the mechanical properties of the metals surfaces (particularly wear properties) by laser or arc cladding [1], surface alloying [2] and glazing technique [3]. The performance required for surface-hardening cladding metal has been extended broadly over the years. In machinable instruments having heat-, wear-, and corrosion-resistances, cobalt-based hardfacing alloys, nickel-based alloys and composite alloys are used, in which the cladding is required to be an economical method and of high-quality. Recently, the cladding technique on composite alloys, including carbide, was developed where fine-grain structure and minute microstructure are obtained in high-quality joint.

In the present paper, the discrete microstructural characterization of cladding deposit and fusion boundary region (FBR) and the formation of stainless steel layer on mild steel are determined quantitatively to clarify the possibility of completely converting to stainless steel microstructure in the mild steel surface-melting portion [4] by using TIG, high current pulsed arc, and constricted plasma arc. In turn this can lead to the selective refinements of the superior microstructure of a particular metal surface to produce a material more resistance to a specific chemical attack.

2. Experimental procedure

The base metal used was a mild steel plate with the dimension of 4.6 mm × 30 mm × 70 mm. The composition of the base plate is indicated in Table I. The experiments have been carried out by bead-on-plate method under a constant travel speed, using a TIG arc, a high current pulsed TIG arc and constricted transferred plasma arc welders. Sumitomo bare wire (309) of different diameters, 2.0, 2.4 and 3.2 mm was employed as filler metal. The composition of the filler metal is given in Table I. The filler metal was centrally placed on the base metal specimen and then surface cladding was carried out using TIG, pulsed and plasma arcs. Table II shows welding arc parameters used in the present investigation. The deposit cladding was done using a 2% thoriated tungsten electrode, 20 and 31.5 V d.c. (electrode negative, straight polarity), and a torch location vertical to the work piece. Metallographic specimens, both cross-sections normal and longitudinal to the cladding direction for pulsed arc cladding were polished and finished, and then etched using an *aqua-regia* of 75 ml hydrochloric acid and 50 ml nitric acid. The bead geometry, the microstructural observation, the dilution and Vickers microhardness of the cladding regions were measured by optical microscope and fittings.

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TABLE I Compositions of base plate and filler metal used (wt %)

Elements	C	Si	Mn	P	S	Ni	Cr	Al	Fe
Base plate mild steel (SS34)	0.13	0.16	0.58	0.024	0.021	0.020	0.043	0.027	balance
Filler metal Sumitomo (309)	0.015	0.38	1.76	0.023	0.006	13.6	23.3	–	balance

TABLE II Welding arc parameters used in present investigation

Parameters \ Welding arcs	TIG arc	Pulsed arc	Plasma arc
Welding current, A	200	Peak current = 250 Base current = 60 Pulse frequency = 1, 5, 50, 100 and 500 Hz Pulse amplitude = 50%	100
Welding voltage, V	20.0	20	31.5
Plasma gas, $l\ min^{-1}$	–	–	Argon = 1.0
Shield gas, $l\ min^{-1}$	Argon = 8.0	Argon = 8.0	Argon + 10%H_2 = 5.0
Nozzle diameter, mm	9.0	9.0	3.0
W-electrode diameter, mm	2.0	2.0	6.0
Travel speed, $cm\ min^{-1}$	16.0	16.0	16.0
Nozzle-workpiece distance, mm	8.0	8.0	12.0
Nominal heat input, $kJ\ cm^{-1}$	15.0	10.9	11.8

3. Results and discussion

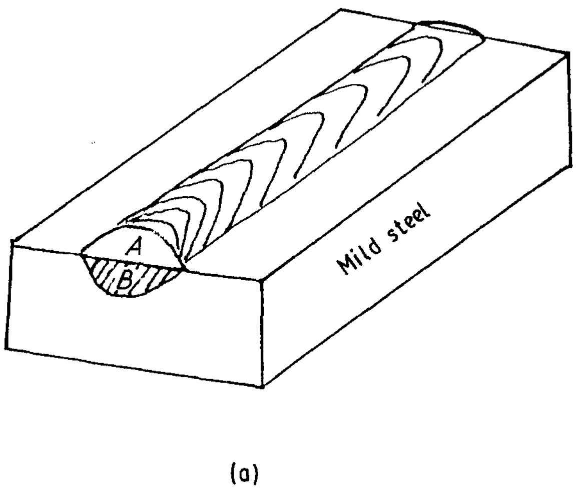
3.1. Dilution

Dilution is the reduction in alloy content of a weld deposit by the mixing of the deposited metal with that part of the base metal which is molten during the welding. Dilution varies with the welding parameters of arc current, travel speed, electrode diameter and so on. Dilution is commonly expressed as the percentage of base metal that has entered the weld metal [5]. Dilution is calculated as follows

$$\text{Dilution} = \frac{B}{A + B} \times 100\ (\%)$$

where A is the bead zone area and B is the fusion zone area.

Composition of weld deposit varies by dilution of the base metal. Fig. 1 shows bead form and geometry produced on a mild steel plate under a welding arc. Fig. 1a indicates weld deposit bead on the plate and Fig. 1b indicates a cross-section perpendicular to the direction of weld deposit, in which M_W is melt width and M_D is melt depth. The dilution has a major influence on the structure of deposited weld metal and fusion boundary. The amount of dilution and the depth of penetration primarily depends upon the welding conditions. Moreover, dilution will be affected by welding technique and sequence. Dilution data obtained in the present experiment are shown in the following sections.



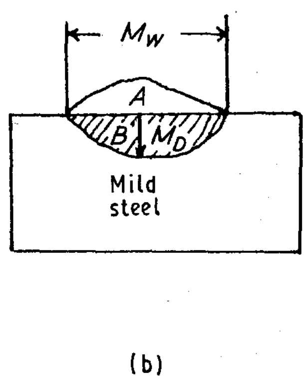


Figure 1 Schematic illustration showing the bead form produced on mild steel by bead-on-plate method using filler metal: (a) surface appearance produced on mild steel; (b) Cross-section configuration.

3.2. TIG arc cladding

Table III shows observed data on bead geometry, dilution and discrete microstructures produced by

TABLE III Observed data on bead geometry, dilution and microstructure of discrete region produced on mild steel for TIG arc cladding with an arc current of 200 A using filler metals

Filler metal	M_W (mm)	M_D (mm)	A (%)	B (%)	Dilution (%)	Microstructures of discrete region produced on mild steel		
						Fusion region	Fusion boundary region	Heat affected zone
Cr granule and Ni wire (2 mm ϕ)	10.0	1.30	70	30	30	Stainless steel	Fine ferrite and pearlite	Coarse ferrite
2.0 mm ϕ (Sumitomo, 309)	10.2	2.30	10	90	90	Low alloyed steel	Fine martensite	Coarse ferrite
2.4 mm ϕ (309)	10.9	2.10	15	85	85	Low alloyed steel	Fine Martensite	Coarse ferrite and pearlite
3.2 mm ϕ	10.35	1.00	80	20	20	Stainless steel	Fine ferrite	Coarse
(309)	10.7	1.35	55	45	45			ferrite and pearlite

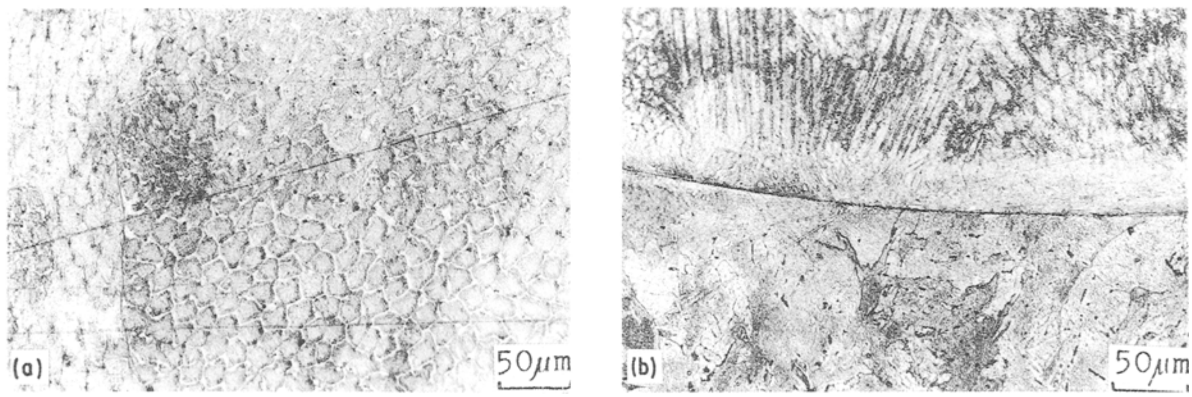


Figure 2 Stainless steel layer on mild steel by TIG arc cladding (Filler metal = Fe–23.3 wt % Cr–13.6 wt % Ni, 3.2 mm ϕ, arc current = 200 A, travel speed = 2.67 mm s^{-1}, etchant = aqua-regia): (a) cellular austenite in the deposit region of stainless steel on mild steel; (b) cellular dendritic austenite containing δ-ferrite at the fusion boundary region.

TABLE IV Observed data on bead geometry, dilution and microstructure of discrete region produced on mild steel for high current pulsed TIG arc cladding using filler metal

Filler metal	Pulse frequence (Hz)	M_W (mm)	M_D (mm)	A (%)	B (%)	Dilution (%)	Microstructures of discrete regions		
							Deposit region	Fusion boundary region	Heat affected zone
	1	11.7	1.60	20	80	80	Non-stainless	Fine ferrite and martensite	Ferrite and pearlite
	5	10.8	1.65	20	80	80	Non-stainless	Fine ferrite and martensite	Ferrite and pearlite
2.4 mm ϕ	50	10.4	2.05	15	85	85	Non-stainless	Fine ferrite and martensite	Ferrite and pearlite
(309)	100	9.15	1.60	15	85	85	Non-stainless	Fine ferrite and martensite	Ferrite and pearlite
	500	8.90	1.25	30	70	70	Stainless steel, partly non-stainless	Fine ferrite and martensite	Ferrite and pearlite
2.0 mm ϕ (309)	500	9.30	1.80	15	85	85	Stainless steel, partly non-stainless	Fine ferrite and pearlite	Ferrite and pearlite
2.4 mm ϕ (309)	500	8.90	1.25	30	70	70	Stainless steel, partly non-stainless	Fine ferrite and pearlite	Ferrite and pearlite
3.2 mm ϕ (309)	500	8.40	1.20	60	40	40	Stainless steel	Fine pearlite	Ferrite and pearlite

conventional TIG arc cladding using filler metals. On using filler metal with smaller diameter, the cladding deposit does not beccome stainless steel. This is probably due to greater penetration and higher dilution. However, when filler metal of larger diameter is used, it becomes stainless steel on weld deposit with smaller penetration and lower dilution. The deposit metal is liable to become sensitive to stainless steel is not more than 50% dilution with low penetration, and employing filler metal of large diameter, 3.2 mm. Micrographs in Fig. 2 show the formation of stainless steel layer on the mild steel by TIG arc cladding with 3.2 mm ϕ Fe–Cr–Ni filler metal. Fig. 2a indicates cellular austenitic matrix in deposit region and Fig. 2b indicates cellular dendritic austenite containing δ-ferrite precipitation in fusion boundary region. These micrographs are representative of austenitic type in stainless steel microstructure [6, 7]. This stainless steel microstructure is obtained over the entire range of fusion zone and on the fusion line refined structure is visible. The weld interface may be expected to be strong in strength. Thus, on using 3.2 mm diameter filler metal the cladding deposit becomes stainless steel with less than 50% dilution for TIG arc cladding.

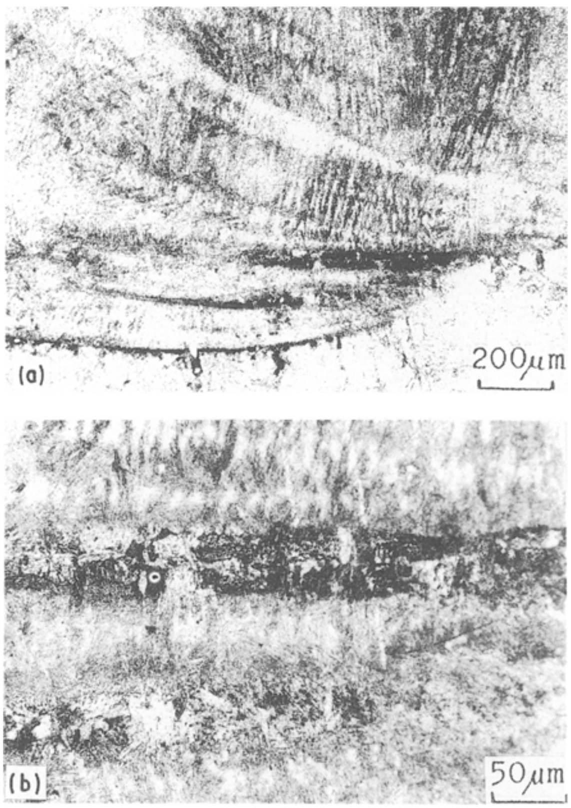


Figure 3 Stainless steel layer on mild steel by pulsed TIG arc cladding (Filler metal = 2.4 mm ϕ Fe–23.3 wt % Cr–13.6 wt % Ni, peak current = 300 A, base current = 60 A, pulse frequency = 100 Hz, travel speed = 2.67 mm s^{-1}, etchant = aqua-regia): (a) low alloyed steel stretching linearly to the deposit side in the neighbourhood of fusion boundary region; (b) low alloyed steel in the fusion boundary region.

3.3. Pulsed TIG arc cladding

Observed results on bead geometry, dilution and discrete microstructures produced by high current pulsed TIG arc cladding using filler metals are given in Table IV for different diameters of filler metal.

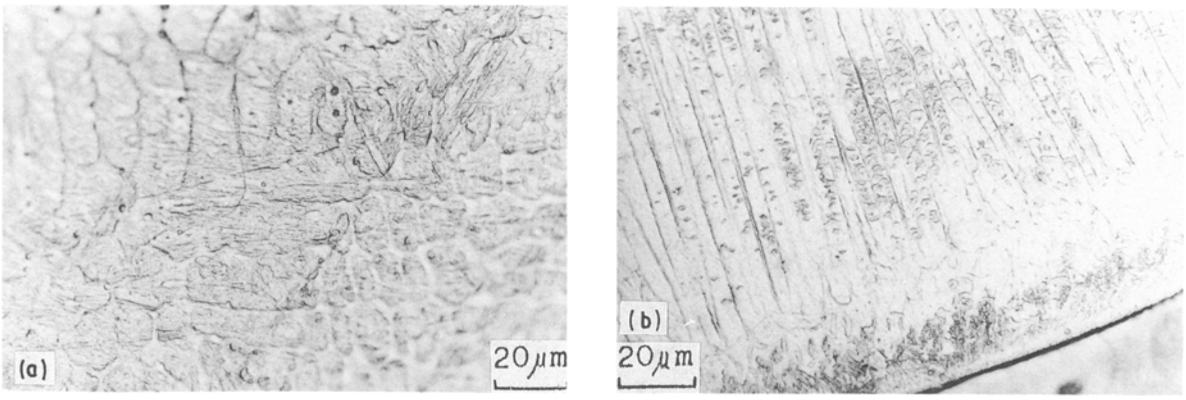
In the low frequency (1–5 Hz) region, the whole weld deposit does not become stainless steel. This non-stainless steel is observed to be low alloyed steel in the deposit metal and fusion boundary region. In the middle frequency region (50–500 Hz), weld deposit appears in part as stainless steel, but with increasing pulse frequency the weld deposit becomes stainless steel as shown in Fig. 3. However, the stainless steel status is not satisfactory in the neighbourhood of fusion boundary region. The state of this non-stainless steel is recognized to be linearly stretched as low alloyed steel in the direction of the deposit metal side in the fusion boundary region (Fig. 3). This is caused by a high dilution of 70–80%, due to a great amount of molten base metal and incomplete mixing with filler metal, particularly in the fusion boundary region at lower frequency [8]. However, when filler metal of large diameter (3.2 mm ϕ) is used at a pulse frequency of 500 Hz, complete conversion to stainless steel microstructure is accomplished at a dilution of 40%, in which the microstructure of fusion boundary region is refined pearlite. The implication is that the stainless steel constituent can be achieved until the fusion line.

3.4. Plasma arc cladding

Table V shows the results on bead geometry, dilution and microstructures produced on the mild steel by employing filler metal for different diameters, using the constricted plasma arc. In these plasma arcs the conversion into stainless steel is completely recognized in the fusion zone and boundary region. Fig. 4 shows the representative microstructures of stainless steel in the deposit metal and fusion boundary region, in which cellular austenitic matrix (Fig. 4a) and cellular dendritic austenite containing σ-phase (Fig. 4b, c) are observed. By employing filler metals having any diameter, the microstructure in the fusion zone becomes stainless steel and that in the fusion boundary region becomes refined at the dilution of 30–80%. This is probably due to high constriction even in low current and more enriched reaction of plasma arc characterization. Therefore, plasma arc utilization appears to

TABLE V Observed data on bead geometry, dilution and microstructure of discrete region produced on mild steel for plasma arc cladding with an arc current of 100 A using filler metals

Filler metal	M_W (mm)	M_D (mm)	A (%)	B (%)	Dilution (%)	Microstructures of discrete region		
						Deposit region	Fusion boundary region	Heat affected zone
2.0 mm ϕ (309)	9.2	1.55	20	80	80	Stainless steel	Fine ferrite and pearlite	Coarse ferrite
2.4 mm ϕ (309)	9.0	0.80	30	70	70	Stainless steel	Fine ferrite and pearlite	Ferrtie
3.2 mm ϕ (309)	8.40	0.75	70	30	30	Stainless steel	Fine ferrite and pearlite	Ferrtie



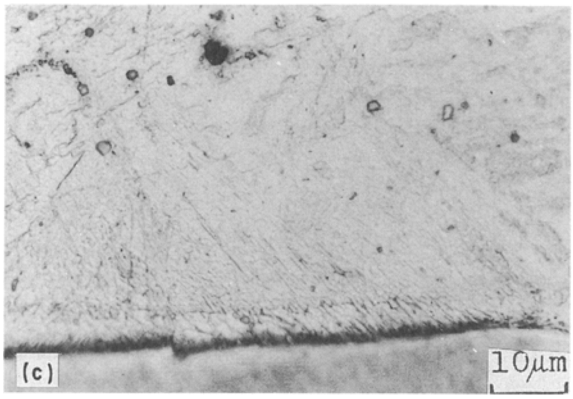


Figure 4 Stainless steel layer on mild steel by plasma arc cladding (Filler metal = 3.2 mm ϕ Fe–23.3 wt % Cr–13.6 wt % Ni, arc current = 100 A, travel speed = 2.67 mm s^{-1}, etchant = aqua-regia): (a) cellular austenite structure in the deposit region; (b) cellular dendritic austenite in the fusion boundary region; (c) austenitic matrix precipitating σ-phase in the fusion boundary region.

be a very suitable method for conversion into stainless steel.

4. Conclusions

The discrete microstructural characterization and the formation of stainless steel layer on mild steel were produced in cladding deposit, and were investigated using TIG arc, high current pulsed arc and constricted plasma arc and the following results were obtained.

1. For TIG arc cladding, using filler metal of small diameter it does not become stainless steel. Whereas when filler metal of large diameter (3.2 mm ϕ) are used, it become stainless steel on the deposit metal and fusion boundary region with dilution of less than 50%, where the microstructure is cellular austenite in the deposit region and cellular dendritic austenite with δ-ferrite precipitation in the fusion boundary region.
2. For pulsed arc cladding, complete stainless steel is not obtained due to the existence of incomplete mixing at the fusion boundary region. However, at higher pulse frequency (500 Hz) and on using filler metal of larger diameter (3.2 mm ϕ), the complete stainless steel microstructure is accomplished.
3. For plasma arc cladding, stainless steel microstructure that is cellular austenitic structure in the deposit metal and cellular dendritic austenite with σ-phase in the fusion boundary region, can be completely achieved.
4. From these experimental results, it can be appreciated that to form complete stainless steel layer on the mild steel with less than 50% dilution and with localized and concentrated arc on welding arc cladding.

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