Effect of Magnetic Steering of the Arc on Clad Quality in Submerged Arc Strip Cladding

Magnetic steering of the arc is demonstrated to improve corrosion resistance and microstructure while minimizing dilution

BY U. D. MALLYA AND H. S. SRINIVAS

ABSTRACT. Submerged arc strip cladding is often used when thickness of clad material is required. The productivity of this process has been improved by the use of higher welding currents and wider strips. The associated problems were arc blow, increased penetration and poor bead characteristics.

Dilution is the parameter that controls almost all qualities of cladding. Magnetic steering reduces penetration, and hence, dilution and arc blow control.

Stainless steel cladding on mild steel is often used to impart corrosion resistance. In such situations, the clad quality is specified by corrosion resistance, ferrite content and good fusion between clad metal and base metal.

This paper discusses results of an investigation on the effect of an oscillating magnetic field used to steer the arc in submerged arc strip cladding using 60 X 0.5-mm 309L stainless steel strips, with varying magnetizing flux intensity and dwell time. The resulting test pieces were evaluated for parameters that imparted the best clad quality and the results indicate the following:

1) Magnetic steering of the arc reduces dilution and corrosion rate.

2) Magnetic steering of the arc permits use of higher currents for a given dilution level, thus increasing productivity.

3) Clad metal microstructures of a desirable type are obtained when the arc is magnetically steered.

4) Use of 309L strips for single layer cladding appears to be satisfactory since ferrite content lies between 5 to 10% for a variety of welding conditions.

5) The corrosion rate (microns per 24 hours) is linearly related to the dilution percentage of the clad metal.

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Introduction

Among various cladding methods, submerged arc strip cladding is widely used where considerable thickness of clad material is required. This process offers high deposition rate and layering capacity with less sophisticated equipment. Even though higher current and wider strips have been used to increase productivity (Ref. 1), they are associated with arc blow, increased penetration and dilution and poor bead shape. Dilution is the parameter in cladding that controls almost all qualities. Magnetic steering of the arc not only reduces arc blow, but also reduces dilution. Stainless steel cladding on mild steel is often used to impart corrosion resistance. Clad qualities are specified by corrosion resistance, ferrite content and good fusion between clad metal and base metal. The present work reports the study of quality of cladding carried out under magnetic steered arc conditions.

KEY WORDS

Magnetic Steering
Clad Quality
Submerged Arc Strip
Ferrite Content
Bend Test
Corrosion Resistance
Dilution
Welding Current
Magnetic Flux Density
Oscillating Field

The welding arc, being a flexible conductor of electricity, can be deflected by applying an external magnetic field (Ref. 2). If an oscillating magnetic field is applied, the arc also oscillates accordingly. Out of various possibilities of arranging auxiliary magnetic fields with respect to the arc (Ref. 3), deflecting the arc forward and oscillating the arc across the joint width were reported to be beneficial (Ref. 2) in reducing penetration and hence the dilution. All the clad qualities are related to dilution directly or indirectly.

Clad qualities are evaluated by the following tests:

1) Corrosion test according to ASTM A262.

2) Side bend test (ASTM, E190) for the ductility of clad metal and for fusion between clad and base metal.

3) Ferrite content test to ensure resistance to hot cracking and microfissuring (Ref. 4).

4) Microprobe analysis to determine the distribution of Cr and Ni across the depth of cladding.

5) Microstructure examination.

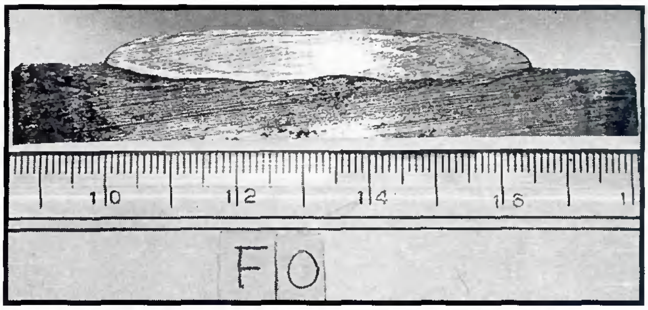


Fig. 1 — Cross-section of the bead. 1050 A, unsteered.

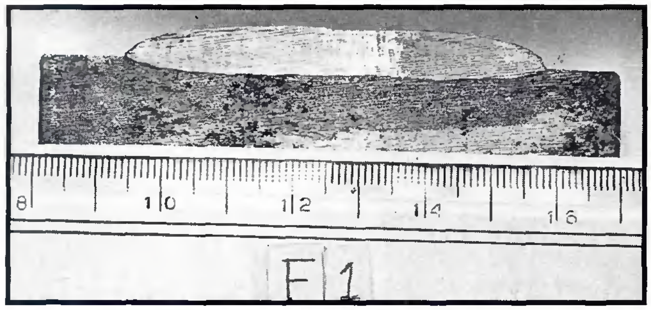


Fig. 2 — Cross-section of the bead. 1050 A, steered.

Experimental Details

Cladding was carried out by applying a magnetic field to oscillate the arc perpendicular to the welding direction using the following experimental parameters:

1) Arc Voltage: 28 V DC.
2) Electrode extension: 40 mm.
3) Travel speed: 150 mm/min.
4) Electrode polarity: positive.
5) Magnetizing function: trapezoidal.

The base plate was C14 grade steel (ISO 2004-1970) with the composition: 0.10–0.18C; 0.15–0.35Si; 0.4–0.7Mn; 0.05S (max); and 0.05P (max).

The electrode strip was AISI 309L stainless steel, 0.5mm thick, 60 and 30 mm wide with the composition: 0.02C; 0.27Si; 1.95Mn; 0.01P; 0.003S; 23.79Cr; and 12.78Ni.

The welding flux was the agglomerated type, and other variables were as follows:

1) Current levels: 25, 30 and 35 A/mm^2 area of cross-section of electrode strip.
2) Dwell time of peak magnetizing flux: 90, 120, 180 and 240 ms.
3) Peak magnetic flux density: 40, 60, 80 and 100 gauss.

The experiments were also conducted at the above three levels of current without applying the magnetic field. In all, 120 experiments were performed. Systematic variation of the variables was incorporated into the design of 102 of these experiments. The extra experiments included current levels without any magnetic steering, as well as some repeat experiments.

Dilution was evaluated at each condition by taking the cross-section of the bead (Figs. 1 and 2, for unsteered and steered conditions, respectively) and measuring cross-sectional areas of deposition and penetration. Representative specimens were chosen and they were subjected to the above-mentioned clad quality tests. Figure 3 shows the weld bead and location of various test specimens.

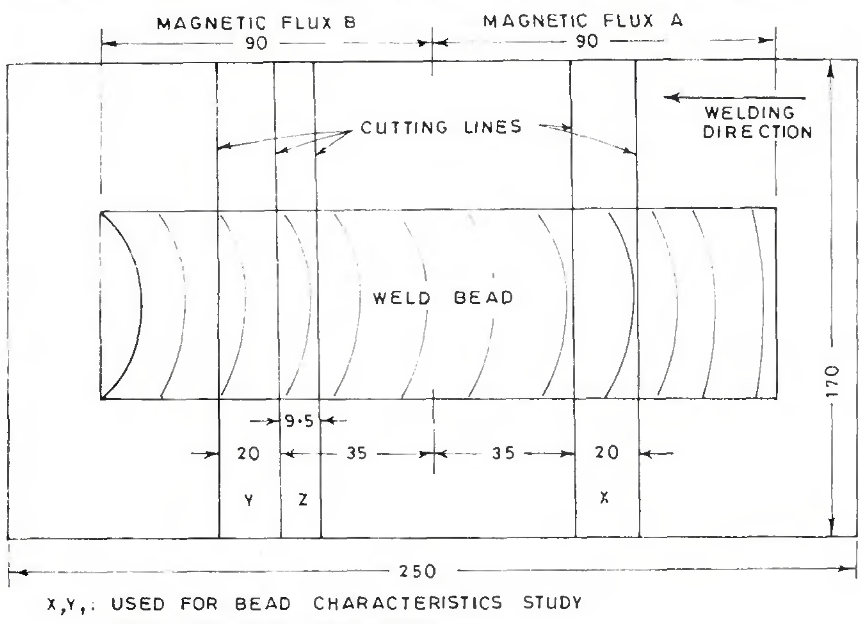


Fig. 3 — Specimen plate showing cutting lines and bead.

Corrosion Test

Corrosion test was conducted according to ASTM A262 (Huey test) to study the variation of corrosion rate with dilution. Since magnetic steering reduces dilution, any reduction in corrosion rate with reduction in dilution can be related to effects of magnetic steering. Four specimens with dilution values ranging from 15.8 to 23.6% were selected. The clad stainless steel specimens were machined so that they were free from the mild steel base metal. Their surface area and weight were measured accurately. They were then boiled continuously for 24 hours in 65% nitric acid. The weight loss of the specimens was determined after boiling. The corrosion rate was then calculated taking specific gravity of stainless steel as 7.9.

$$\text{Corrosion rate in microns / 24h} = \frac{\text{weight loss in g / 24h} \times 10^6}{\text{surface area, mm}^2 \times 7.9} \quad (1)$$

Side Bend Test

To study the ductility of the clad metal and the fusion between clad and base metal, side bend tests were conducted (ASTM E190). Four specimens were selected with penetration values ranging from 1.02 mm to 2.3 mm (max). Guided side bend tests were conducted according to the standard for a 180-deg bend. Figure 4 shows the specimen for the side bend test.

Ferrite Content Test

To avoid hot cracking and microfissuring in the clad layer, it has been suggested (Ref. 4) that the clad metal should have ferrite content in the range of 5 to 10%. Five clad test pieces, totally free from mild steel base metal, were selected at various welding conditions, and the ferrite content was measured using a ferrite meter. The ferrite content for each of the ten specimens was measured at ten different places, and the average was taken.

Electron Microprobe Analysis

To study the chromium and nickel distribution from the interface across the thickness of the cladding, electron microprobe analysis was conducted. This examination determined at what distance from the interface the chromium and nickel percentages attained stable values under steered and unsteered conditions. Two test pieces were subjected to this analysis.

Microstructure

For qualitative metallurgical analysis of the clad metal, microstructures of the clad specimens subjected to electron microprobe analysis were observed.

Results and Discussion

Table 1 shows the results of the corrosion test and Fig. 5 shows the relationship between the dilution and corrosion rate. From the figure, it is observed that the corrosion rate is linearly related to dilution. As dilution is reduced from 23.6 to 15.8%, the corrosion rate is reduced by 22%. That means a relative reduction of 33% in dilution results in a reduction of the corrosion rate by 22%.

Magnetic steering of the arc reduces the dilution by 23% (relative) compared to unsteered conditions (Ref. 5). From the corrosion test conducted, reduction of 23% dilution amounts to about 15% reduction in the corrosion rate. Hence, it may be concluded that by magnetic steering of the arc, a 15% reduction in corrosion rate could be achieved.

Table 2 gives sample readings of the side bend tests. In all the cases, good fusion between clad and base metal was observed. By using 309L grade strips, good ductility of clad metal was achieved even at a high dilution of 30.6%. Base metal cracking in the fourth case may be due to a base metal defect since the crack was located far away from the HAZ.

Table 3 shows the ferritic content in the clad metal of a representative sample under various welding conditions. It is seen from the table that over a range of varied welding conditions, the ferrite content lies from 5 to 10%. This ferrite range is normally preferred in strip cladding (Ref. 4).

Figures 6 and 7 show the results of electron microprobe analysis. It is seen from Fig. 6 (unsteered condition) that Cr and Ni attain stable values at a distance of 109 microns from the interface. Under magnetically steered conditions (Fig. 7), the transition zone is substantially reduced to 45 microns. The reduction in transition zone under magnetically steered conditions may be attributed to

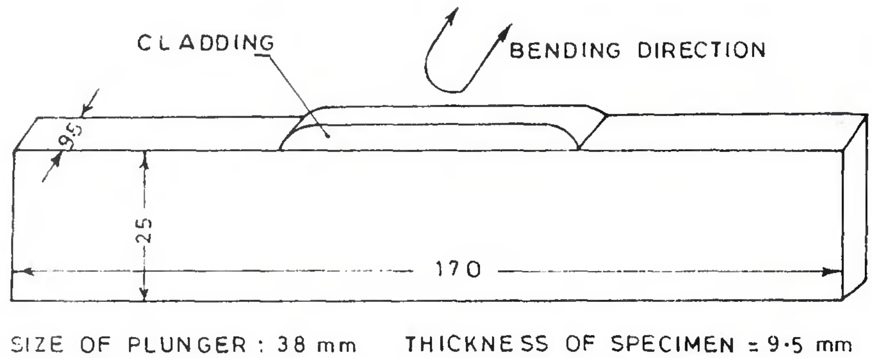


Fig. 4 — Specimen for bend test.

Table 1—Results of Corrosion Test (30-mm strip)

S1	Welding Conditions	Dilution %	Surface Area, mm^2	Wt before Test, g	Wt after Test, g	Wt. Loss g	Corrosion μ/24 h
1	375 A 90 ms 60 Gauss	15.8	1262.83	12.7313	12.7200	0.0113	1.133
2	450 A 90 ms 60 Gauss	19.0	1456.57	14.2725	14.2575	0.0150	1.304
3	375 A 120 ms 40 Gauss	22.5	1305.25	13.4234	13.4091	0.01431	1.387
4	525 A 90 ms 60 Gauss	23.6	1876.86	28.4642	28.4426	0.0216	1.455
5	525 A No steering	27.5					
6	450 A No steering	24.8					
7	375 A	24.7					

Table 2—Results of Side Bend Test (60-mm strip)

Sl No.	Welding Conditions	Penetration mm	Dilution %	Remarks
1	750 Amps 120 ms 60 Gauss	1.02	20.0	No cracking
2	750 Amps 180 ms 80 Gauss	1.07	19.8	No cracking
3	900 Amps 90 ms 60 Gauss	1.75	27.1	No cracking
4	1050 Amps 90 ms 60 Gauss	2.3 (max)	30.6	No cracking in clad metal. Base metal cracked away from the interface.

Table 3—Results of Ferrite Content Test

Sr No.	Welding Conditions	Dilution %	Ferrite content %
1	750 Amps 180 ms 80 Gauss	19.8	9.32
2	750 Amps 240 ms 80 Gauss	21.4	7.1
3	900 Amps 90 ms 40 Gauss	18.9	5.7
4	900 Amps 120 ms 60 Gauss	18.5	7.78
5	900 Amps 180 ms 40 Gauss	19.4	8.18

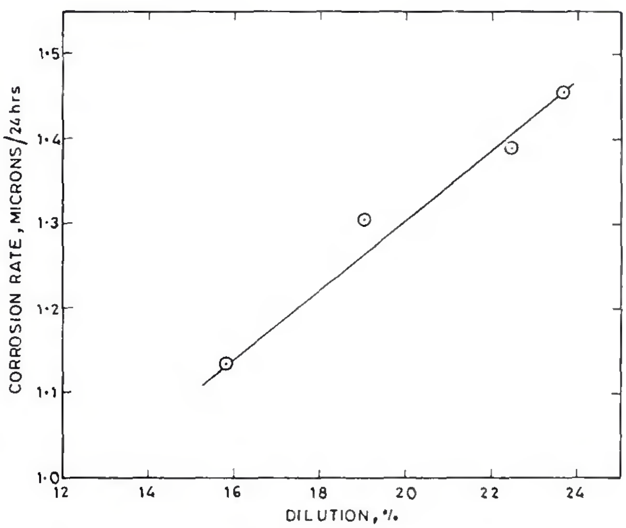


Fig. 5 — Relationship between dilution and corrosion rate.

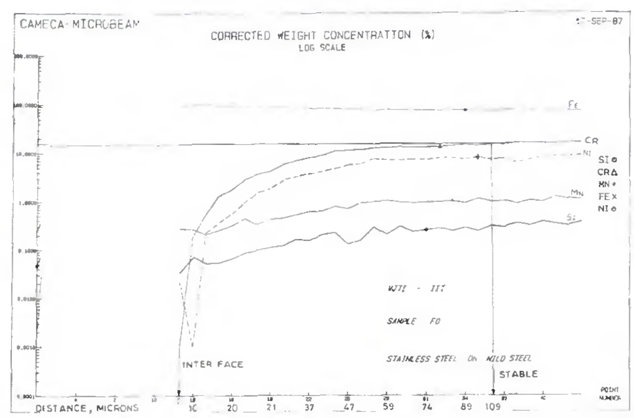
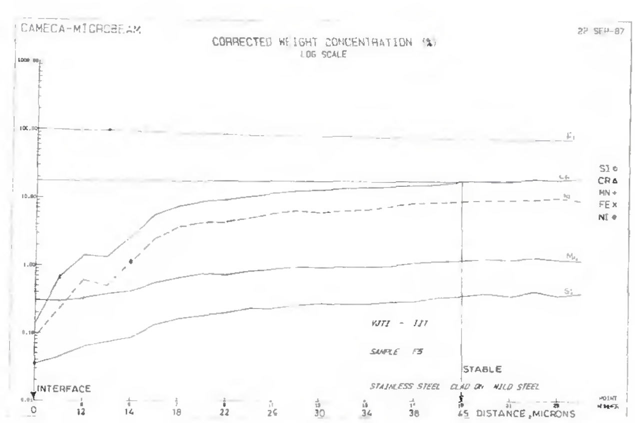


Fig. 6 — Electron microprobe analysis. Unsteered.

Fig. 7 — Electron microprobe analysis. Steered.



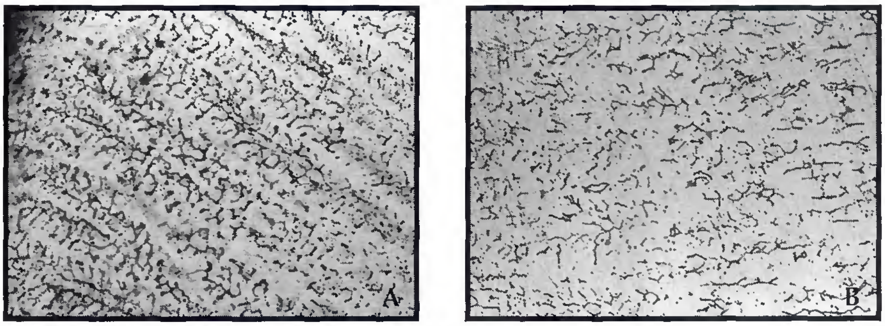


Fig. 8 — A — Microstructure of clad metal, unsteered, 1050 A, 100X; B — microstructure of clad metal, steered, 1050 A, 100X.

the electromagnetic stirring of the weld pool by the applied auxiliary magnetic field.

Figure 8A and B shows the typical microstructures of austenitic stainless steel deposited by the submerged arc process. In Fig. 8A, under unsteered conditions, a predominantly dendritic structure is present. The ferrite content is slightly higher than normal. From Fig. 8B, it is seen that with magnetic steering, the dendritic structure disappears and the ferrite network is broken. The ferrite content is considerably less than in Fig. 8A. Thus, it may be inferred that magnetic steering results in a favorable microstructure and a desirable type of ferrite distribution.

Conclusions

1) Magnetic steering of the arc reduced dilution, which in turn reduced the corrosion rate of the clad metal. Corrosion rate is linearly related to dilution. Any reduction in dilution consequently reduces the corrosion rate.

2) Desirable microstructures of the clad metal are achieved with magnetic steering of the arc.

3) The transition zone is reduced under magnetically steered conditions before the clad composition reaches stable values.

4) Magnetic steering enhanced the ductility of the clad metal. The fusion of clad metal to base metal is satisfactory, and the interface is free from undesirable characteristics even when a high current of 1050 A is used for 60 X 0.5-mm strip.

5) Use of 309L (24/13 L) strips for single layer cladding appears to be satisfactory since ferrite content lies between 5 to 10% over a range of varied welding conditions.

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