EFFECTS OF SEVERAL ELEMENTS OF BARE ELECTRODE STEEL WIRE FOR GAS SHIELDED METAL ARC WELDING*

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1. Introduction

As the application of CO_2 (CO_2-O_2) arc welding spreads in the many industrial fields, some problems occur from a practical standpoint, which are, to further improve the impact value of as-welded metal, to prevent low nickel alloy steel weld metal from hot cracking and to make it possible to weld rusted plate or painted plate without porosity. This report refers to the effects of several elements of electrode wire on such problems.

2. Improvement of Notch Toughness

After some experiments[1) 2) 3)] to improve notch toughness of as-welded metal for mild steel and low nickel alloy steel, it was found that in weld metal, manganese, molybdenum, boron and aluminum were effective for such purpose, but nickel, chromium, niobium, titanium, vanadium and zirconium had little or no effect. Some of them were detrimental, if its amount increased.

These elements were added to weld metals by CO_2-O_2 arc welding and the specimens for V-notch Charpy impact test were taken from the weld metals. Some results obtained are shown in Fig. 1 and 2.

Figure 1 shows the effect of the alloying elements on the impact value of one-pass weld metal of low nickel alloy steel. Manganese, molybdenum and boron seem to be effective to improve the notch toughness, but titanium, vanadium, zirconium and niobium are not at all effective. Figure 2 shows the effect of nickel content on the notch toughness of weld metal with or without molybdenum. Molybdenum seems to be more effective to improve the notch toughness of as-welded metal than nickel, because the 0.3% of molybdenum increased by 3.5 kg-m/cm^2 of impact value; (compare two point near the ordinate of Fig. 2), though 1% of nickel increased only by 0.57 kg-m/cm^2. Moreover, molybdenum was more effective if a suitable amount of aluminum was added to weld metal. A microstructure of electro-gas as-welded metal containing aluminum and molybdenum is finer grain than that of as-welded metal containing only aluminum. And the impact value of the previous is higher than that of the latter. Photo. 1 shows this effect in the case of an electro-gas welding of a mild steel plate in 32 mm thickness.

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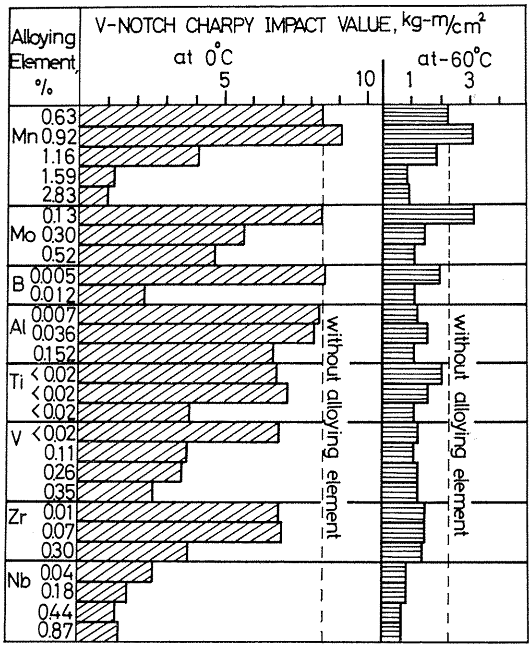


FIG. 1. Effect of alloying elements on notch toughness of weld metal of 2 1/2% nickel steel.

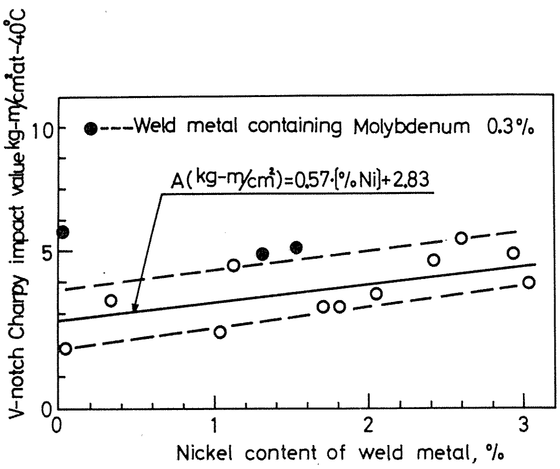
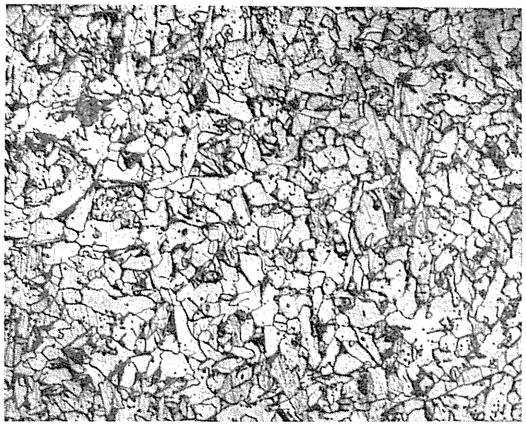


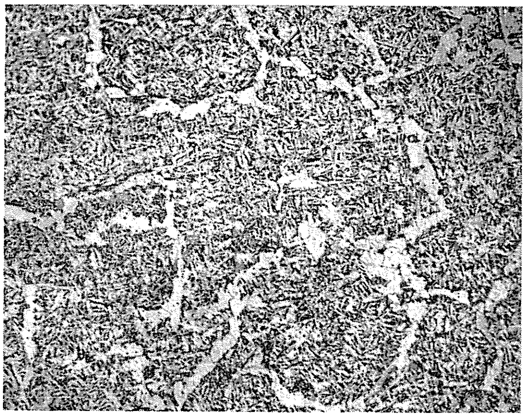
FIG. 2. Effect of nickel content on notch toughness of weld metal.

An electrode wire modified with these elements gives higher impact value to mild steel weld metal also by high current CO_2-O_2 arc welding than impact value of weld metal by usual electrode wire. An experimental result is illustrated in Fig. 3[4)]

0.12% C, 0.28% Si, 0.96% Mn,
0.012% Al,
Impact value, 2.8 kg-m/cm^2



0.11% C, 0.35% Si, 1.08% Mn,
0.103% Al,
Impact value, 0.9 kg-m/cm^2



0.12% C, 0.40% Si, 1.28% Mn,
0.022% Al, 0.27% Mo,
Impact value, 4.3 kg-m/cm^2

PHOTO. 1. Effect of molybdenum and aluminum on microstructure and impact value at 0°C of electro-gas weld metal.

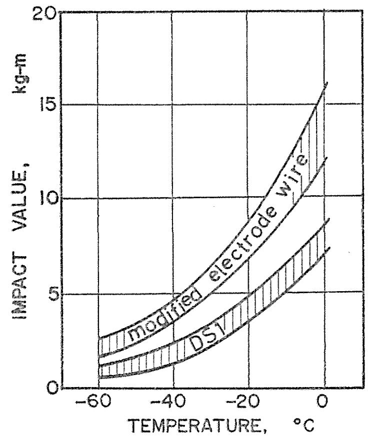


FIG. 3. Effect of modified electrode on the impact value of multi-layer weld metals by high current CO_2-O_2 arc welding; welding current: 380 A, arc voltage: 36 V, welding rate: 40 cm/min, extention: 20 mm, diameter of electrode wire: 1.6 mm, supplied gas: $CO_2+10\%O_2$.

3. Prevention of Hot Cracking

It is generally recognized that nickel alloy steel weld metal is susceptible to hot cracking. It was found by experiments that the contents of nickel and sulphur of weld metal are most responsible for such hot cracking as shown in Fig. 4. And there is a relation between nickel and sulphur contents of weld metal, in which hot cracking will occur.

Fig. 4 shows that sulphur content must be less than 0.01% to prevent a weld metal from hot cracking, if a weld metal contains more than 2.5% of nickel. Phosphor in weld metal may also be responsible for hot cracking.

Fig. 5 shows a relation between nickel and sulphur plus phosphor content of weld metal. From this figure it is deduced that the content of sulphur plus phosphor must be lowered to less than 0.02%. Weld metal containing less than

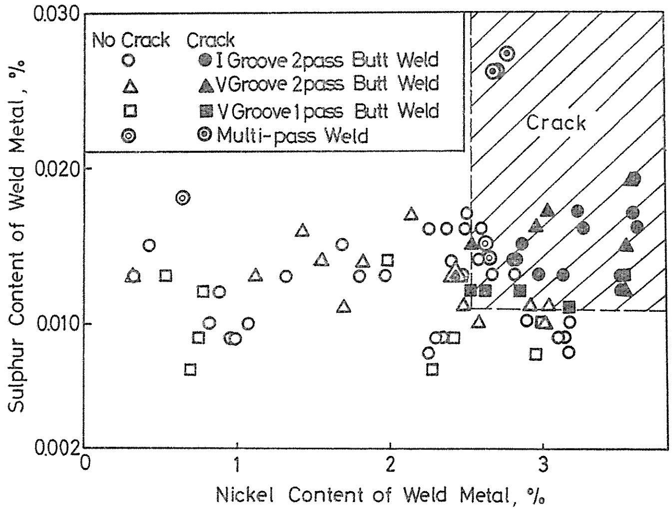


FIG. 4. Effect of nickel and sulphur contents on the hot crack in weld metal.

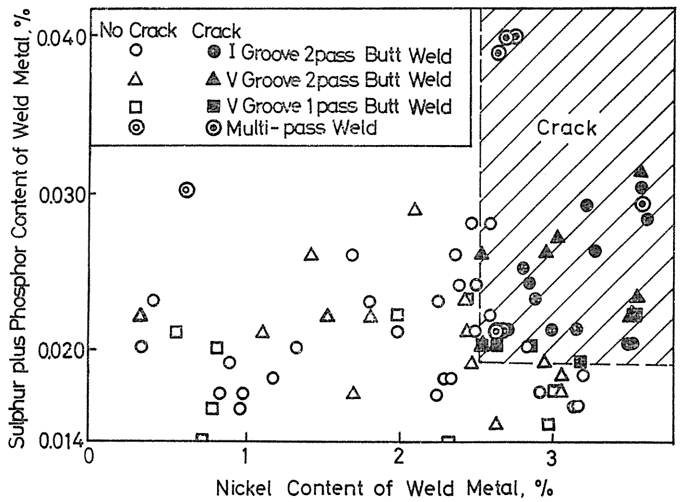


FIG. 5. Effect of sulphur, phosphor and nickel contents on the hot crack in weld metal.

2.5% nickel seems to be unsusceptible to hot cracking.

According to the result determined by an electron probe microanalyser of hot cracking of low nickel alloy steel weld metal the sulphur concentration on the fracture surface was 16 to 60 times higher than its average concentration, the nickel concentration was about two third lower than its average concentration and the phosphor concentration was almost the same as its average concentration.

4. Welding of Low Nickel Alloy Steel with Austenitic Steel Electrode Wire

It is very difficult to get a weld metal of which impact value is comparable to that of low nickel alloy steel base metal, if the low nickel alloy ferritic electrode wire of which composition is similar to base metal is used. Impact value of such weld metal can be slightly improved by annealing or normalizing, but it is not enough to compare with the value of rolled and heat-treated base metal. An austenitic steel electrode wire is recommended to increase the productivity by using a high current gas shielded metal arc welding and also to secure the notch toughness of weld metal, comparable to that of the base metal.

Figure 6 shows an experimental result of welding 3 1/2% nickel steel with 25 Cr-20 Ni and 18 Cr-12 Ni-2 Mo austenitic electrode wires. V-notch impact value of austenitic V-butt 2 pass weld metal is high enough as 3 1/2% nickel steel base metal under −60°C. But weld metals by 18 Cr-12 Ni-2 Mo electrode wires and I-butt 2 pass weld metal by 25 Cr-20 Ni electrode wire show very low impact values at all range of temperature compared with base metal.

This is explained from the Schaeffler's diagram as shown in Fig. 7, that is, the structure of a V-butt 2 pass weld metal by 25 Cr-20 Ni electrode wire is completely austenitic, but the others are austenitic and martensitic. It is therefore

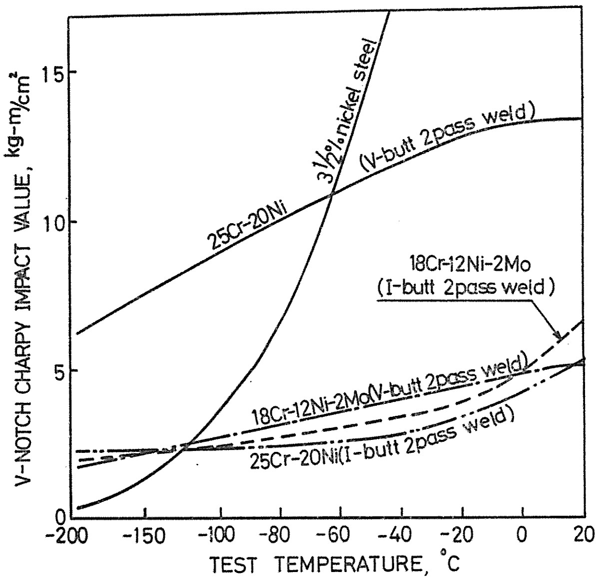


FIG. 6. Transition curves of austenitic weld metal of 3 1/2% nickel steel.

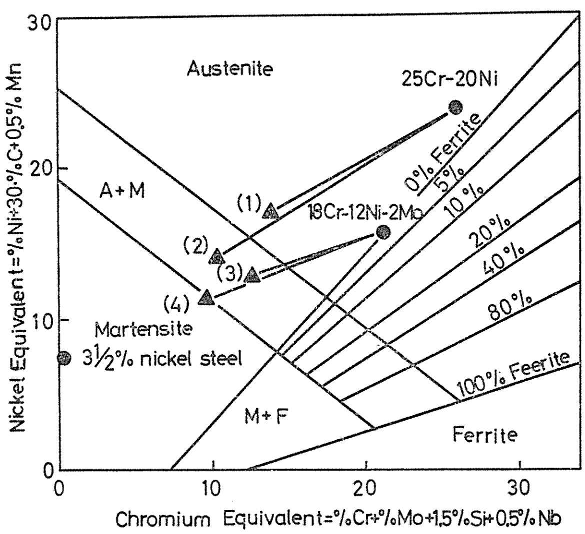


FIG. 7. Constitution diagram for stainless steel weld metal.

Remarks: Base metal; 3 1/2% nickel steel

25 Cr-20 Ni electrode wire	18 Cr-12 Ni-2 Mo electrode wire
(1) V-butt 2 pass weld	(3) V-butt 2 pass weld
(2) I-butt 2 pass weld	(4) I-butt 2 pass weld.

deduced that an electrode wire, which gives completely austenitic weld metal, considering dilution of base metal, must be used.

5. Welding Painted or Rusted Plate

It is known that we must completely remove rust, oil, lacquer or paint from joint groove before welding, otherwise porous weld will be produced, however it is not always possible to remove them; furthermere, it would not be economical. Sometimes it is necessary to weld steel plate with some rust, oil, lacquer or paint.

It was experimentally found that an electrode wire containing some amount of aluminum was effective in such a case. The experiment was carried out by a bead-on plate test with CO_2-O_2 arc welding, in which a vee groove was cut and filled with various material, as shown in Fig. 8. All deposited beads were examined by radiography. Compositions of electrode wires used are shown in Table 1. Some results are graphically illustrated in Fig. 9, 10 and 11. These figures show that aluminum over 0.3% content of electrode wire is very effective in preventing weld metal from porosity. In this figure the relative porosity means the number of blowholes of bead in unit length of a radiograph. Futhermore, the joint faces of 9 mm thickness plates which had been rusted, lacquered, painted or oiled, were welded by CO_2-O_2 arc welding with some electrodes of various contents of aluminum. A result of mechanical test of welded joints is shown in Table 2.

Photo 2 illustrates some examples of radiographs which show the effects of aluminum in electrode wire on the prevention of porosity of weld metal.

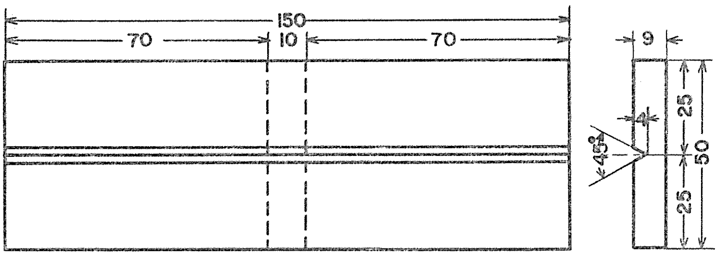


FIG. 8. Bead-on-plate test pieces with grove, unit mm.

TABLE 1. Composition of electrode wires

Mark	Elements, %					
	C	Si	Mn	P	S	Al
I	0.05	0.53	1.80	0.012	0.020	0.006
II	0.05	0.55	1.81	0.012	0.016	0.2
III	0.06	0.64	1.80	0.012	0.020	0.35
IV	0.06	0.64	1.74	0.011	0.013	0.71
V	0.07	0.58	1.73	0.011	0.018	1.03
VI	0.06	0.57	1.66	0.012	0.018	1.83

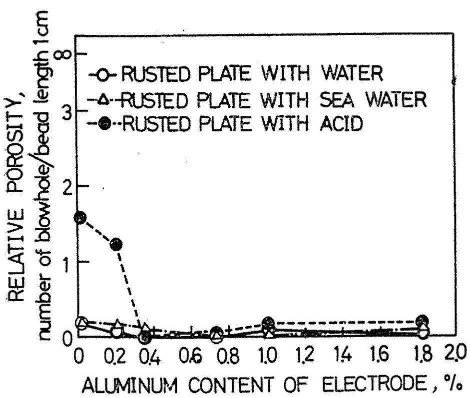


FIG. 9. Effect of aluminum content of electrode wire on the porosity of weld metal of rusted steel plates.

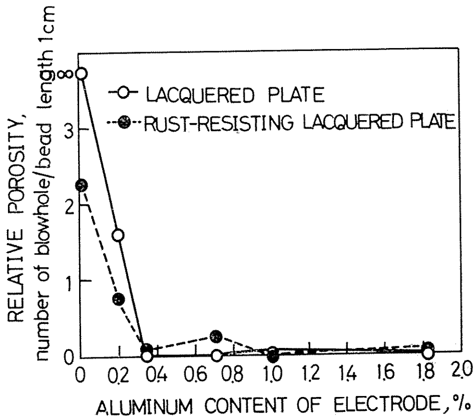


FIG. 10. Effect of aluminum content of electrode wire on the porosity of weld metal of lacquered steel plates.

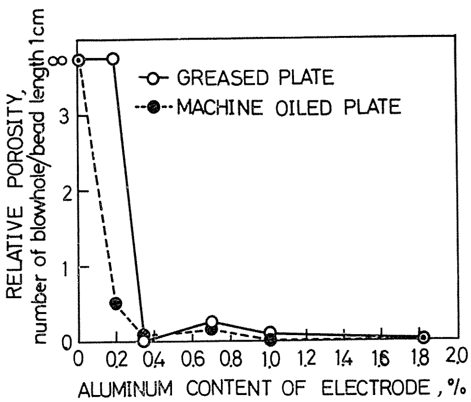
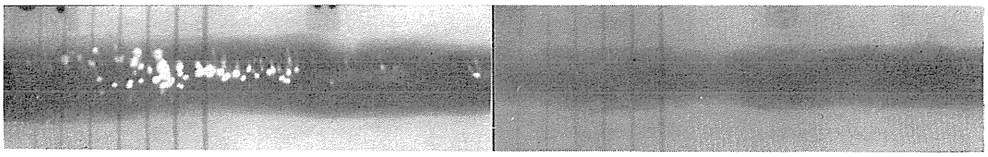


FIG. 11. Effect of aluminum content of electrode wire on the porosity of weld metal of greased and oiled steel plates.

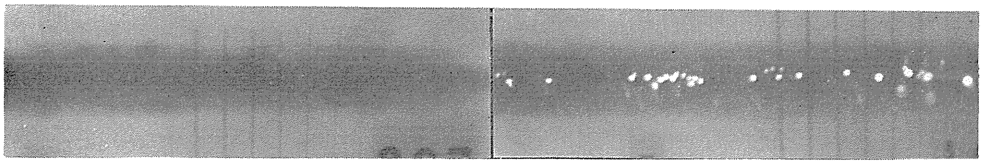
TABLE 2. Mechanical properties of welded joints of greased or lacquered steel plate

Materials	Electrode	Al Content, %	Yield Point, kg/mm²	Tensile Strength, kg/mm²	Elongation, %	Broke at
Grease	usual	0.11	34.9 37.4	46.6 37.3	22.9 17.7	base metal weld metal
	III	0.35	35.0 34.9	47.2 47.6	25.6 27.6	base metal base metal
Lacquer	usual	0.11	35.9 34.3	46.6 48.3	24.0 17.4	weld metal weld metal
	IV	0.71	34.6 34.7	48.1 47.4	30.0 26.6	base metal base metal



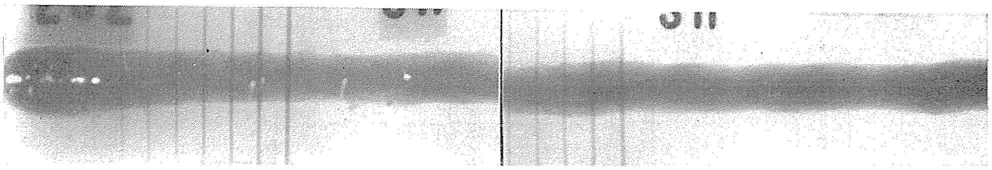
i) usual electrode DS 1 ii) electrode III (0.35% Al)

a) cutting oiled plate



iii) usual electrode DS 1 iv) electrode III (0.35% Al)

b) rust-resisting lacquered plate



v) usual electrode DS 1 vi) electrode III (0.35% Al)

c) rusted plate with acid

PHOTO 2. Effect of aluminum content on the porosity of weld metal of oiled a), lacquered b) and rusted c) steel plate.

6. Conclusions

1) Impact value of as welded metal is increased by addition of aluminum, boron, manganese and molybdenum into bare electrode wire.

2) If low nickel alloy steel is welded by austenitic electrode wire to secure notch toughness of weld metal comparable to the base metal, the composition of the electrode wire must be selected to give a completely austenitic structure in weld metal, considering a dilution of base metal.

3) Sulphur and phosphor content of low nickel alloy steel weld metal must be lowered to less than 0.02 per cent to prevent the weld metal from hot cracking.

4) Aluminum content over 0.3 per cent of electrode wire for CO_2-O_2 arc welding is effective in preventing rusted, painted or oiled steel plate weld metal from porosity.

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